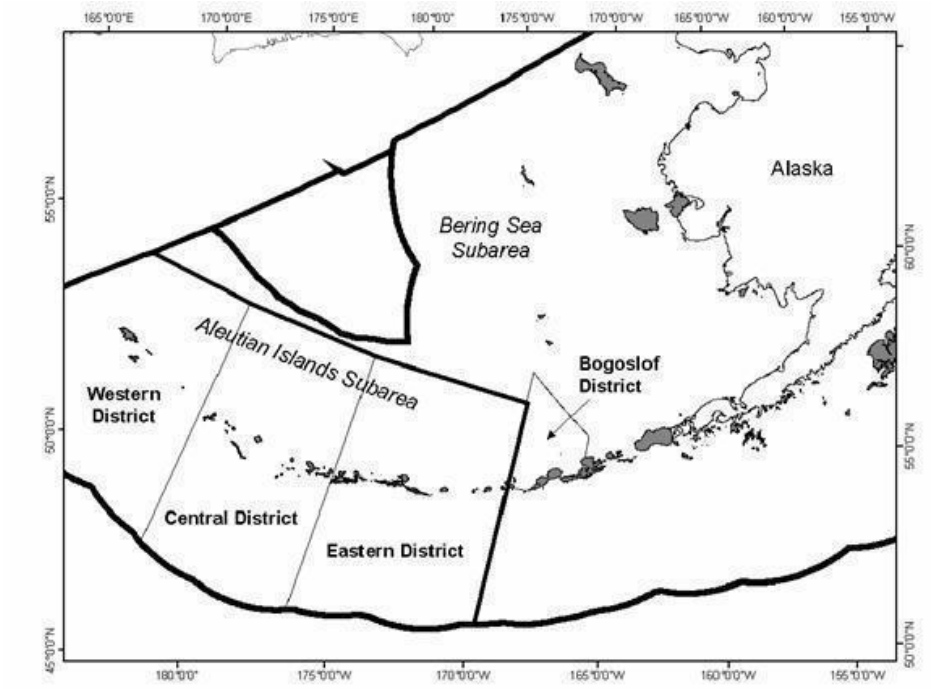
STOCK ASSESSMENT AND FISHERY EVALUATION REPORT

FOR THE GROUNDFISH RESOURCES

OF THE BERING SEA/ALEUTIAN ISLANDS REGIONS

Compiled by:

The Plan Team for the Groundfish Fisheries
of the Bering Sea and Aleutian Islands



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Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Region

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Summary

By

The Plan Team for the Groundfish Fisheries of the Bering Sea and Aleutian Islands

Introduction

The *National Standard Guidelines for Fishery Management Plans* published by the National Marine Fisheries Service (NMFS) require that a stock assessment and fishery evaluation (SAFE) report be prepared and reviewed annually for each fishery management plan (FMP). The SAFE report summarizes the best available scientific information concerning the past, present, and possible future condition of the stocks, marine ecosystems, and fisheries that are managed under Federal regulation. It provides information to the Councils for determining annual harvest levels from each stock, documenting significant trends or changes in the resource, marine ecosystems, and fishery over time, and assessing the relative success of existing state and Federal fishery management programs. For the FMP for the Groundfish Fishery of the Bering Sea and Aleutian Islands (BSAI) Area, the SAFE report is published in three sections: a "Stock Assessment" section, which comprises the bulk of this document, and "Economic Status of Groundfish Fisheries off Alaska" and "Ecosystem Considerations" sections, which are bound separately.

The BSAI Groundfish FMP requires that a draft of the SAFE Report be produced each year in time for the December meeting of the North Pacific Fishery Management Council. Each stock or stock complex is represented in the SAFE Report by a chapter containing the latest stock assessment. New or revised stock assessment models are usually previewed at the September Plan Team meeting, and considered again by the Team at its November meeting for recommending final specifications for the following two fishing years. This process is repeated annually.

Normally, full stock assessments are required for walleye pollock, Pacific cod, Atka mackerel, sablefish, and some flatfish stocks every year; while all rockfishes, some flatfishes, sharks, skates, octopus, squid, and sculpins require full stock assessment only during years in which the Aleutian Island bottom trawl survey is conducted (typically even-numbered years).

This Stock Assessment section of the SAFE report for the BSAI groundfish fisheries is compiled by the BSAI Groundfish Plan Team from chapters contributed by scientists at NMFS Alaska Fisheries Science Center (AFSC). These chapters include a recommendation by the author(s) for overfishing level (OFL) and acceptable biological catch (ABC) for each stock and stock complex managed under the FMP for the next two fishing years. This introductory section includes the recommendations of the Team (Table 1), along with a summary of each chapter, including the Ecosystems Considerations chapter and the Economic SAFE Report.

The OFL and ABC recommendations by the Plan Team are reviewed by the Scientific and Statistical Committee (SSC), which may confirm the Team recommendations or develop its own. The Team and SSC recommendations, together with social and economic factors, are considered by the Council in determining total allowable catches (TACs) and other measures used to manage the fisheries. Neither the author(s), Team, nor SSC typically recommends TACs.

Members of the BSAI Groundfish Plan Team who compiled this SAFE report were: Mike Sigler (co-chair), Grant Thompson (co- chair), Diana Stram (BSAI Groundfish FMP coordinator), Kerim Aydin, David Barnard, Liz Chilton, Bill Clark, Lowell Fritz, Mary Furuness, Dana Hanselman, Alan Haynie, Brenda Norcross, and Chris Siddon.

Background Information

The BSAI management area lies within the 200-mile U.S. Exclusive Economic Zone (EEZ) of the US (Figure 1). International North Pacific Fisheries Commission (INPFC) statistical areas 1 and 2 comprise the EBS. The Aleutian Islands (AI) region is INPFC Area 5.

Amendment 95 to the BSAI Groundfish FMP, which was implemented in 2010 for the start of the 2011 fishing year, defined three categories of species or species groups that are likely to be taken in the groundfish fishery. Species may be split or combined within the "target species" category according to procedures set forth in the FMP. The three categories of finfishes and invertebrates that have been designated for management purposes under two management classifications are listed below.

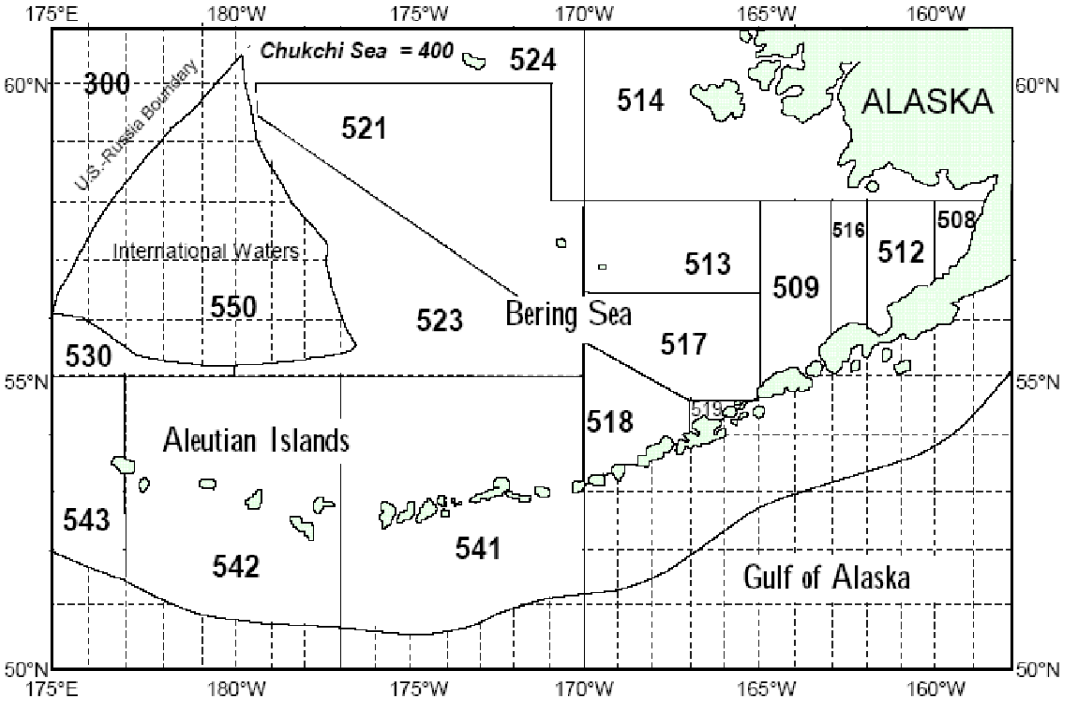

Figure 1 Bering Sea/Aleutian Islands statistical and reporting areas.

In the Fishery:

Target species–are those species that support either a single species or mixed species target fishery, are commercially important, and for which a sufficient data base exists that allows each to be managed on its own biological merits. Accordingly, a specific TAC is established annually for each target species or species assemblage. Catch of each species must be recorded and reported. Stocks/assemblages in the target category are listed below.

Ecosystem Component:

Prohibited Species–are those species and species groups the catch of which must be avoided while fishing for groundfish, and which must be immediately returned to sea with a minimum of injury except when their retention is authorized by other applicable law. Groundfish species and species groups under the FMP for which the ABCs have been achieved shall be treated in the same manner as prohibited species.

Forage fish species–are those species listed below, which are a critical food source for many marine mammal, seabird and fish species. The forage fish species category is established to allow for the

management of these species in a manner that prevents the development of a commercial directed fishery for forage fish. Management measures for this species category will be specified in regulations and may include such measures as prohibitions on directed fishing, limitations on allowable bycatch retention amounts, or limitations on the sale, barter, trade or any other commercial exchange, as well as the processing of forage fish in a commercial processing facility.

In the fishery	**Ecosystem component**	
Target species[1]	**Prohibited species**[2]	**Forage fish species**[3]
Walleye Pollock	Pacific halibut	Osmeridae family (eulachon, capelin,and other smelts)
Pacific cod	Pacific herring	Myctophidae family (laternfishes)
Sablefish	Pacific salmon	Bathylagidae (deep-sea smelts)
Yellowfin sole	Steelhead trout	Ammodytidae family (Pacific sandlance)
Greenland turbot	King crab	Trichodontidae family (Pacific sand fish)
Arrowtooth flounder	Tanner crab	Pholidae family (gunnels)
Kamchatka flounder		Stichaeidae family (pricklebacks warbonnets, eelblennys, cockscombs, shannys)
Northern rock sole		Gonostomatidae family (bristlemouths, lightfishes and anglemouths)
Flathead sole		Other euphausiacea (krill)
Alaska plaice		
Other flatfish		
Pacific Ocean perch		
Northern rockfish		
Blackspotted/Rougheye		
Shortraker rockfish		
Other rockfish*		
Atka mackerel		
Skates		
Sculpins		
Sharks		
Squids		
Octopus		

[1] TAC for each listing. Species and species groups may or may not be targets of directed fisheries.
[2] Must be immediately returned to the sea, except when retention is required or authorized.
[3] Management measures for forage fish are established in regulations implementing the FMP.

Historical Catch Statistics

Catch statistics since 1954 are shown for the Eastern Bering Sea (EBS) subarea in Table 2. The initial target species in the BSAI commercial fisheries was yellowfin sole. During this period, total catches of groundfish peaked at 674,000 t in 1961. Following a decline in abundance of yellowfin sole, other species (principally walleye pollock) were targeted, and total catches peaked at 2.2 million t in 1972. Pollock is now the principal fishery, with catches peaking at approximately 1.4-1.5 million t due to years of high recruitment. After the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) was adopted in 1976, catch restrictions and other management measures were placed on the fishery and total groundfish catches have since varied from one to two million t. In 2005, Congress implemented a statutory cap on TACs for BSAI groundfish of 2 million t, which had previously been a policy adopted by the Council. Total groundfish catches generally are well below the 2 million t optimal yield (OY) cap. Total groundfish catches in the EBS in 2013 totaled 1,829,931 t; catches through November 8, 2014 totaled 1,794,998 t. Pollock catches in the EBS totaled 1,270,723 t in 2013; catches through November 8, 2014 totaled 1,294,703 t.

Catches in the Aleutian Islands (AI) subarea always are much less than in the EBS (Table 3). Total AI catches peaked at 190,750 t in 1996. Total AI catches were 144,684 t in 2010, and dropped to 98,601 t in 2012 and to 84,616 in 2013. Total catch of 7,629 t through November 8, 2014 is the lowest since 1988.

The predominance of target species in the AI has changed over the years. Pacific ocean perch (POP) was the initial target species. As POP abundance declined, the fishery diversified to target different species. POP was the second largest fishery at 18,554 t in 2012 and 26,342 t in 2013; catch totaled 29,944 t through November 8, 2014. Pacific ocean perch displaced Pacific cod as the second largest fishery beginning in 2011, as Pacific cod catch dropped from 29,001 t in 2010 to 13,572 t in 2013 as a result of Steller sea lion protection measures; catch is 6,145 t through November 8, 2014. Atka mackerel was the largest fishery in the AI at 50,600 t in 2011 and 46,859 t in 2012 (down from 68,496 t in 2010); catch was 23,034 t in 2013 and catch in 2014 was 30,812 t as of November 8, 2014. Atka mackerel harvest also dropped as a result of Steller sea lion protection measures and a shift in its biomass distribution; the 2013 catch of 23,034 t was less than 50% of 2012 catch of 46,859 t.

Total catches since 1954 for the BSAI, combined, are shown in Table 4. Total BSAI catches were 1,351,354 t in 2010 (81 percent of the total TAC and 68 percent of the OY). Combined BSAI catches rose to 1,817,947 t in 2011 (91 percent of total TACs (which equaled the OY)) and 1,829,931 t (91 percent of OY) in 2013. BSAI catches through November 8, 2014 totaled 1,794,998 t, which equaled 90% of OY. The relationship of the various biological reference points (biomass, OFL, ABC, TAC, and catch) is depicted in Figure 2.

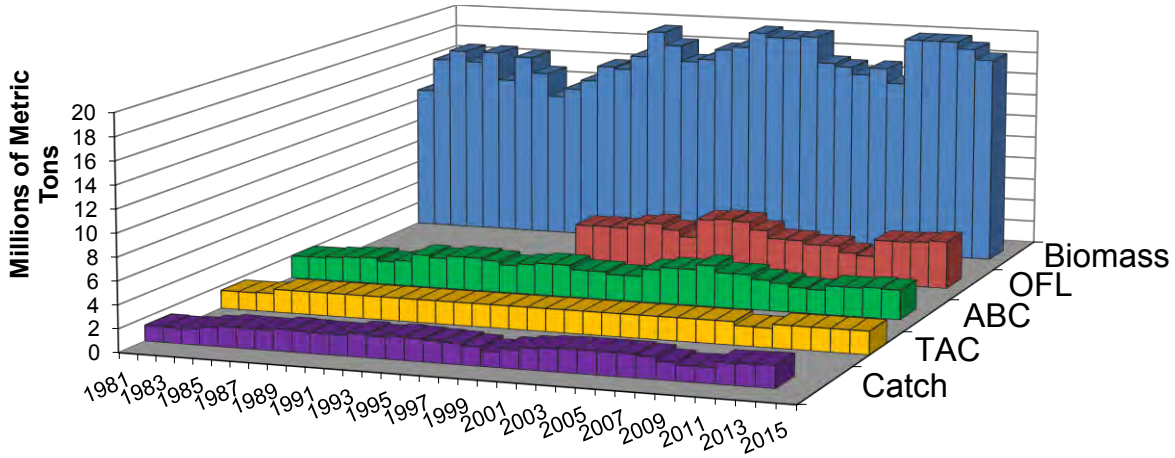

Figure 2 Biomass, Overfishing Level, Acceptable Biological Catch, and Total Allowable Catch for 1981-2015* and Catch, 1981-2014.
*2015, Biomass, ABC and OFLs as recommended by the Plan Team and assuming total TACs = OY

Recent Total Allowable Catches

Amendment 1 to the BSAI Groundfish FMP provided the framework to manage the groundfish resources as a complex. Maximum sustainable yield (MSY) for the BSAI groundfish complex was estimated at 1.8 to 2.4 million t. The OY range was set at 85 percent of the MSY range, or 1.4 to 2.0 million t. The sum of the TACs equals OY for the groundfish complex, which is constrained by the 2.0 million t cap on OY. Recent total TACs have been set equal to the OY cap.

Establishment of the Western Alaska Community Development Quota (CDQ) Program annual groundfish reserves is concurrent with the annual BSAI groundfish harvest specifications. Once annual BSAI groundfish TACs are established, the CDQ Program is allocated set portions of the TACs for certain species and species assemblages. This includes 10 percent of the BS and AI pollock TACs, 20 percent of the fixed gear sablefish TAC, and 7.5 percent of the sablefish trawl gear allocation. It also receives 10.7 percent of the TACs for Pacific cod, yellowfin sole, rock sole, flathead sole, Atka mackerel, AI Pacific

ocean perch, arrowtooth flounder, and BS Greenland turbot. The program also receives allocations of PSC limits.

The TAC specifications for the primary allocated species, and PSC limit specifications, are recommended by the Council at its December meetings. The State of Alaska (State) manages separate Pacific cod guideline harvest level (GHL) fisheries in the Bering Sea subarea (starting in 2006) and Aleutian Islands subarea (starting in 2014). The State's Pacific cod GHL fisheries are conducted independently of the Federal groundfish fisheries under direct regulation of the State. The GHL amounts for each subarea are derived as 3 percent of the combined Pacific cod Bering Sea subarea ABC and Aleutian Islands subarea ABC. The Council is expected to set the TAC for each subarea to account for the two State GHL fisheries. This is necessary to prevent harvest levels, GHL plus TAC, from exceeding the ABCs.

For the BSAI reserves, 15 percent of the TAC for each target species, except for pollock, the hook-and-line and pot gear allocation of sablefish, and the Amendment 80 species (Pacific cod, Atka mackerel, flathead sole, rock sole, yellowfin sole, and Aleutian Islands Pacific ocean perch), are automatically apportioned to a non-specified reserve. Apportionments to the non-specified reserve range from 4.3 to 15 percent of each species or species group's TAC. The non-specified reserve is used to (1) correct operational problems in the fishing fleets, (2) promote full and efficient use of groundfish resources, (3) adjust species TACs according to changing conditions of stocks during the fishing year, and (4) make apportionments and Community Development Quota allocations. The initial TAC (ITAC) for each species is the remainder of the TAC after the subtraction of the reserve.

Definition of Acceptable Biological Catch and the Overfishing Level

Amendment 56 to the BSAI Groundfish FMP, which was implemented in 1999, defines ABC and OFL for the BSAI groundfish fisheries. The definitions are shown below, where the fishing mortality rate is denoted F, stock biomass (or spawning stock biomass, as appropriate) is denoted B, and the F and B levels corresponding to MSY are denoted F_{MSY} and B_{MSY} respectively.

Acceptable Biological Catch is a preliminary description of the acceptable harvest (or range of harvests) for a given stock or complex. Its derivation focuses on the status and dynamics of the stock, environmental conditions, other ecological factors, and prevailing technological characteristics of the fishery. The fishing mortality rate used to calculate ABC is capped as described as shown in the text box below.

Overfishing is defined as any amount of fishing in excess of a prescribed maximum allowable rate. This maximum allowable rate is prescribed through a set of six tiers which are listed below in descending order of preference, corresponding to descending order of information availability. The SSC will have final authority for determining whether a given item of information is reliable for the purpose of this definition, and may use either objective or subjective criteria in making such determinations. For Tier (1), a pdf refers to a probability density function. For Tiers (1-2), if a reliable pdf of B_{MSY} is available, the preferred point estimate of B_{MSY} is the geometric mean of its pdf. For Tiers (1-5), if a reliable pdf of B is available, the preferred point estimate is the geometric mean of its pdf. For Tiers (1-3), the coefficient 'α' is set at a default value of 0.05, with the understanding that the SSC may establish a different value for a specific stock or stock complex as merited by the best available scientific information. For Tiers (2-4), a designation of the form "$F_{X\%}$" refers to the F associated with an equilibrium level of spawning per recruit (SPR) equal to X percent of the equilibrium level of spawning per recruit in the absence of any fishing. If reliable information sufficient to characterize the entire maturity schedule of a species is not available, the SSC may choose to view SPR calculations based on a knife-edge maturity assumption as reliable. For Tier (3), the term $B_{40\%}$ refers to the long-term average biomass that would be expected under average recruitment and $F=F_{40\%}$.

Overfished or approaching an overfished condition is determined for all age-structured stock assessments by comparison of the stock level in relation to its MSY level according to harvest scenarios 6 and 7

described in the next section (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$). For stocks in Tiers 4-6, no determination can be made of overfished status or approaching an overfished condition as information is insufficient to estimate the MSY stock level.

Standard Harvest and Recruitment Scenarios and Projection Methodology

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the MSFCMA.

For each scenario, the projections begin with an estimated vector of 2014 or 2015 numbers at age. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years, except that in the first two years of the projection, a lower catch may be specified for stocks where catch is typically below ABC. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios are designed to provide a range of harvest alternatives that are likely to bracket the final TACs for 2015 and 2016, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2015 recommended in the assessment to the *max* F_{ABC} for 2015. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to the 2009-2013 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 4: In all future years, the upper bound on F_{ABC} is set at $F_{60\%}$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is 1) above its MSY level in 2014 or 2) above 1/2 of its MSY level in 2014 and expected to be above its MSY level in 2024 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its MSY level in 2016 or 2) above 1/2 of its MSY level in 2016

and expected to be above its MSY level in 2026 under this scenario, then the stock is not approaching an overfished condition.)

Overview of "Stock Assessment" Section

The current status of individual groundfish stocks managed under the FMP is summarized in this section. Plan Team recommendations for 2014 and 2015 ABCs and OFLs are summarized in Tables 1, 5, and 6.

The sum of the recommended ABCs for 2015 and 2016 are 2,842,543 t and 2,728,127 t, respectively. These compare with the sums of the 2014 ABCs (2,572,819 t) and 2013 ABCS (2,639,317 t), indicating relative stability. The Team recommended maximum permissible ABCs for all stocks, except for EBS pollock, EBS Pacific cod, and BSAI skates (Table 6).

Overall, the status of the stocks continues to appear favorable. Nearly all stocks are above B_{MSY} or the B_{MSY} proxy of $B_{35\%}$. The abundances of EBS pollock, EBS Pacific cod, all rockfishes managed under Tier 3, and all flatfishes except Greenland turbot managed under Tiers 1 or 3 are projected to be above B_{MSY} or the B_{MSY} proxy of $B_{35\%}$ in 2015. The abundances of three stocks are projected to be below $B_{35\%}$ for 2015: AI pollock by about 1 percent, sablefish by about 0.2%, and Greenland turbot by about 11 percent.

The sum of the biomasses for 2015 listed in Table 5 represents a 7% increase from 2014. The 2014 value, in turn, was nearly the same as reported for 2013, following declines of 5 percent from 2012 to 2013 and 6 percent from 2011 to 2012.

Summary and Use of Terms

Stock status is summarized and OFL and ABC recommendations are presented on a stock-by-stock basis in the remainder of this section, with the following conventions observed:

"Fishing mortality rate" refers to the full-selection F (i.e., the rate that applies to fish of fully selected sizes or ages), except in the cases of stocks managed under Tier 1 (EBS pollock, yellowfin sole, and northern rock sole). For these stocks, the fishing mortality rate consists of the ratio between catch (in biomass) and biomass at the start of the year. EBS pollock uses "fishable biomass" whereas yellowfin sole and northern rock sole use age 6+ biomass for this calculation.

"Projected age+ biomass" refers to the total biomass of all cohorts of ages greater than or equal to some minimum age, as projected for January 1 of the coming year. The minimum age varies from species to species. When possible, the minimum age corresponds to the age of recruitment listed in the respective stock assessment. Otherwise, the minimum age corresponds to the minimum age included in the assessment model, or to some other early age traditionally used for a particular species. When a biomass estimate from the trawl survey is used as a proxy for projected age+ biomass, the minimum age is assumed to correspond with the age of recruitment, even though the survey may not select that age fully and undoubtedly selects fish of younger ages to some extent.

The reported ABCs and OFLs for past years correspond to the values approved by the Council. Projected ABCs and OFLs listed for the next two years are the Team's recommendations.

Reported catches are as of November 8, 2014.

Two-Year OFL and ABC Projections

Proposed and final harvest specifications are adopted annually for a two year period. This requires the Team to provide OFLs and ABCs for the next two years in this cycle (Table 1). The 2015 harvest specifications (from Council recommendations in December 2013) are in place to start the fishery on January 1, 2015, but these will be replaced by final harvest specifications that will be recommended by the Council in December 2014. The final 2015 and 2016 harvest specifications will become effective when final rulemaking occurs in February or March 2015.This process allows the Council to use the most

current survey and fishery data in stock assessment models for setting quotas for the next two years, while having no gap in harvest specifications.

The 2016 ABC and OFL values recommended in next year's SAFE report are likely to differ from this year's projections for 2016 because of new (e.g., survey) information that is incorporated into the assessments. In the case of stocks managed under Tier 3, ABC and OFL projections for the second year in the cycle are typically based on the output for Scenarios 1 or 2 from the standard projection model using assumed (best estimates) of actual catch levels. For stocks managed under Tiers 4-6, projections for the second year in the cycle are set equal to the Plan Team's recommended values for the first year in the cycle.

Tier

1) Information available: *Reliable point estimates of B and B_{MSY} and reliable pdf of F_{MSY}.*
   - 1a) Stock status: $B/B_{MSY} > 1$
     $F_{OFL} = \mu_A$, *the arithmetic mean of the pdf*
     $F_{ABC} \le \mu_H$, *the harmonic mean of the pdf*
   - 1b) Stock status: $\alpha < B/B_{MSY} \le 1$
     $F_{OFL} = \mu_A \times (B/B_{MSY} - \alpha)/(1 - \alpha)$
     $F_{ABC} \le \mu_H \times (B/B_{MSY} - \alpha)/(1 - \alpha)$
   - 1c) Stock status: $B/B_{MSY} \le \alpha$
     $F_{OFL} = 0$
     $F_{ABC} = 0$

2) Information available: *Reliable point estimates of B, B_{MSY}, F_{MSY}, $F_{35\%}$, and $F_{40\%}$.*
   - 2a) Stock status: $B/B_{MSY} > 1$
     $F_{OFL} = F_{MSY}$
     $F_{ABC} \le F_{MSY} \times (F_{40\%}/F_{35\%})$
   - 2b) Stock status: $\alpha < B/B_{MSY} \le 1$
     $F_{OFL} = F_{MSY} \times (B/B_{MSY} - \alpha)/(1 - \alpha)$
     $F_{ABC} \le F_{MSY} \times (F_{40\%}/F_{35\%}) \times (B/B_{MSY} - \alpha)/(1 - \alpha)$
   - 2c) Stock status: $B/B_{MSY} \le \alpha$
     $F_{OFL} = 0$
     $F_{ABC} = 0$

3) Information available: *Reliable point estimates of B, $B_{40\%}$, $F_{35\%}$, and $F_{40\%}$.*
   - *3a) Stock status:* $B/B_{40\%} > 1$
     $F_{OFL} = F_{35\%}$
     $F_{ABC} \le F_{40\%}$
   - *3b) Stock status:* $\alpha < B/B_{40\%} \le 1$
     $F_{OFL} = F_{35\%} \times (B/B_{40\%} - \alpha)/(1 - \alpha)$
     $F_{ABC} \le F_{40\%} \times (B/B_{40\%} - \alpha)/(1 - \alpha)$
   - *3c) Stock status:* $B/B_{40\%} \le \alpha$
     $F_{OFL} = 0$
     $F_{ABC} = 0$

4) Information available: *Reliable point estimates of B, $F_{35\%}$, and $F_{40\%}$.*
   $F_{OFL} = F_{35\%}$
   $F_{ABC} \le F_{40\%}$

5) Information available: *Reliable point estimates of B and natural mortality rate M.*
   $F_{OFL} = M$
   $F_{ABC} \le 0.75 \times M$

6) Information available: *Reliable catch history from 1978 through 1995.*
   OFL = the average catch from 1978 through 1995, unless an alternative value is established by the SSC on the basis of the best available scientific information
   $ABC \le 0.75 \times OFL$

Ecosystem Considerations

The Ecosystem Assessment provided streamlined Report Cards for both the Bering Sea and Aleutian Islands. Overall, 50 indices were updated, and 6 new indices were presented.

Eastern Bering Sea

Recap/update of data on 2013 conditions: Overall, there were mixed ecosystem signals in 2013. Some indicators suggest increased productivity, some lower. The environment remained cold, similar to 2007. Jellyfish were abundant, and groundfish length-weight residuals were positive, indicating that foraging conditions and ecosystem productivity were positive for groundfish. There was below-median recruitment of age-1 pollock, influenced by the extreme cold of 2012. Coho and some chum runs were above average; chinook and sockeye were below. Seabirds bred earlier, but kittiwakes did poorly in terms of reproduction.

Data on 2014 conditions: Conditions were changed in 2014, with warm temperatures, a small cold pool, and high apparent productivity. Guild trends (benthic foragers, motile epifauna, benthic foragers, pelagic foragers, and apex predators) were all stable or increasing. The mutivariate seabird index was above its long-term mean, indicating favorable conditions for piscivorous seabirds.

2015 forecast: Last year, the authors presented a 2013 9-month prediction for 2014 based on Regional Oceanographic Modeling forced by NCEP climate predictions. The predicted warming of the Bering Sea was confirmed by field data. For 2015, the model predicts similar levels of warmth, although it should be emphasized that the model has undergone only limited testing.

Aleutian Islands

The Aleutians Islands survey showed that 2014 had the warmest water temperatures on record, whereas 2012 was the coldest year. Report Card indicators showed a mix of effects. In the eastern Aleutians, conditions were good for seabirds. Guild biomass tracking showed increases in all regions and guilds except for Apex Predators in the western Aleutians. Fish condition was better in the eastern Aleutians/SE Bering Sea and worst in the western Aleutians.

Economic Summary of the BSAI commercial groundfish fisheries in 2012-13

The real ex-vessel value of all Alaska domestic fish and shellfish catch, including the estimated value of fish caught almost exclusively by catcher/processors, decreased from $2150.5 million in 2012 to $1924.2 million in 2013. The first wholesale value of 2013 groundfish catch was $2169.9 million. The 2013 total groundfish catch increased by 2.3% while the total first-wholesale value decreased by 14.6% relative to 2012.

In terms of ex-vessel value, the groundfish fisheries accounted for the largest share (45.7%) of the ex-vessel value of all commercial fisheries off Alaska, while the Pacific salmon (*Oncorhynchus spp*.) fishery was second with $679.5 million or 35.3% of the total Alaska ex-vessel value. The value of the shellfish fishery amounted to $238.4 million or 12.4% of the total for Alaska and exceeded the value of Pacific halibut (*Hippoglossus stenolepis*) with $111.5 million or 5.8% of the total for Alaska.

The Economic SAFE report (bound separately) contains detailed information about economic aspects of the groundfish fisheries, including figures and tables, catch share fishery indicators, product price forecasts, a summary of the Alaskan community participation in fisheries, an Amendment 80 fishery economic data report (EDR) summary, market profiles for the most commercially valuable species, a summary of the relevant research being undertaken by the Economic and Social Sciences Research Program (ESSRP) at the Alaska Fisheries Science Center (AFSC) and a list of recent publications by ESSRP analysts. The figures and tables in the report provide estimates of total groundfish catch, groundfish discards and discard rates, prohibited species catch (PSC) and PSC rates, the ex-vessel value of the groundfish catch, the ex-vessel value of the catch in other Alaska fisheries, the gross product value of the resulting groundfish seafood products, the number and sizes of vessels that participated in the

groundfish fisheries off Alaska, vessel activity, and employment on at-sea processors. Generally, the data presented in this report cover the years 2009 through 2013, but limited catch and ex-vessel value data are reported for earlier years in order to illustrate the rapid development of the domestic groundfish fishery in the 1980s and to provide a more complete historical perspective on catch. Several series have been discontinued and new price/revenue tables from an alternative source are presented in Appendix A: Ex-vessel Economic Data Tables: alternative pricing based on CFEC fish tickets.

The Economic SAFE report updates the data associated with the market profiles for pollock, Pacific cod, sablefish, and yellowfin sole that display the markets for these species in terms of pricing, volume, supply and demand, and trade. In addition, the Economic SAFE contains links to data on some of the external factors that impact the economic status of the fisheries. Such factors include foreign exchange rates, the prices and price indices of products that compete with products from these fisheries, domestic per capita consumption of seafood products, and fishery imports.

The Economic SAFE report also updates a section that analyzes economic performance of the groundfish fisheries using indices. These indices are created for different sectors of the North Pacific, and relate changes in value, price, and quantity across species, product and gear types to aggregate changes in the market.

The data behind the tables from this and past Economic SAFE reports are available online at

http://www.afsc.noaa.gov/refm/Socioeconomics/SAFE/default.php

Decomposition of the change in first-wholesale revenues from 2012-13 in the BSAI

The following brief analysis summarizes the overall changes that occurred between 2012-13 in the quantity produced and revenue generated from BSAI groundfish. According to data reported in the 2014 Economic SAFE report, the ex-vessel value of BSAI groundfish dropped from $814.0 million in 2012 to $690.9 million in 2013 (Figure 3), and first-wholesale revenues from the processing and production of groundfish in the BSAI fell from $2168.7 million in 2012 to $1840.9 million in 2013, a decrease of 15.1% (Figure 4).

The total quantity of groundfish products from the BSAI increased from 802.7 thousand metric tons in 2012 to 818.2 thousand metric tons in 2013, a difference of 15.5 thousand metric tons. These changes in the BSAI account for part of the change in first-wholesale revenues from Alaska groundfish fisheries overall which decreased by $372.8 million, a relative difference of -14.7% in 2013 compared to 2012 levels.

By species group, a negative price effect of $226.8 million for pollock was the largest change in first-wholesale revenues from the BSAI for 2012-13 (Figure 5). This enormous price effect was partially offset by a positive quantity effect of $82.6 million for pollock. A negative price effect of $88.8 million for cod was also important. By product group, a positive quantity effect occurred for fillets, and negative price effects were concentrated in the surimi and whole head & gut categories in the BSAI first-wholesale revenue decomposition for 2012-13.

In summary, first-wholesale revenues from the BSAI groundfish fisheries decreased by $327.8 million from 2012-13. A major driver was an enormous negative price effect for pollock concentrated in the surimi and whole head & gut product groups. In comparison, first-wholesale revenues decreased by $44.9 million from 2012-13 in the GOA, due to a strong negative quantity effect for cod, and negative price effects for rockfish and sablefish.

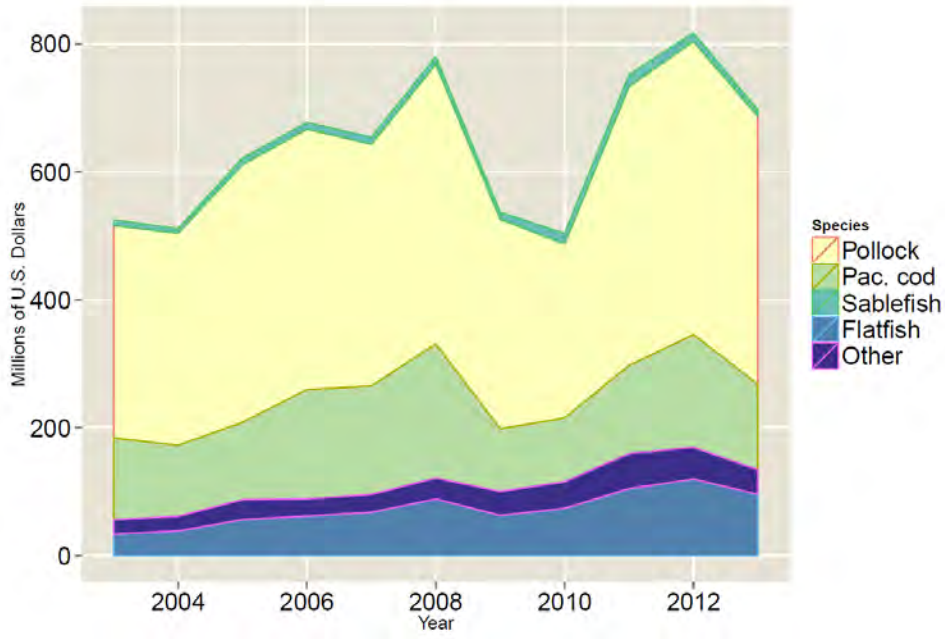

Figure 3 Real ex-vessel value of the groundfish catch in the domestic commercial fisheries in the BSAI area by species, 2003-2013 (base year = 2013).

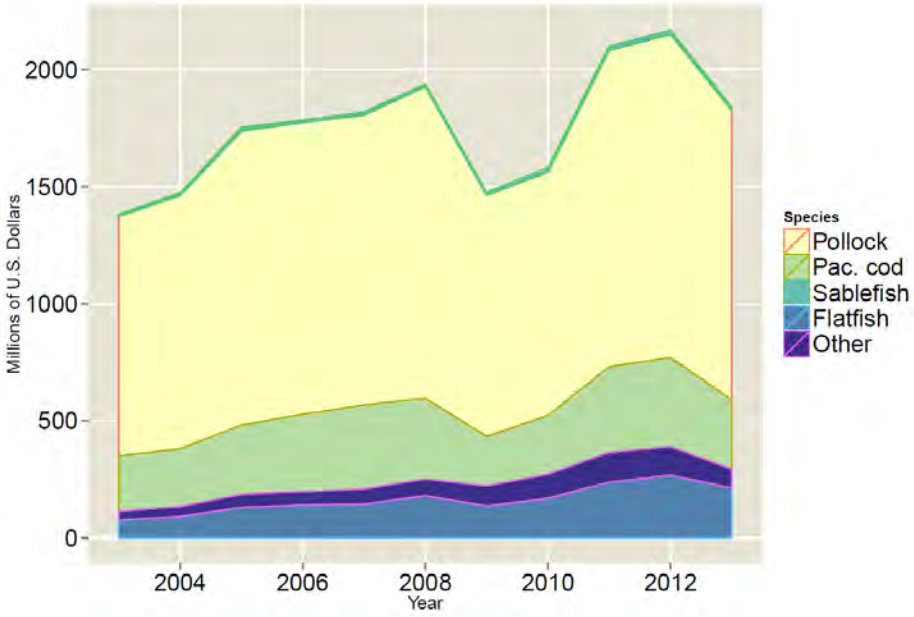

Figure 4 Real gross product value of the groundfish catch in the BSAI area by species, 2003-2013 (base year = 2013).

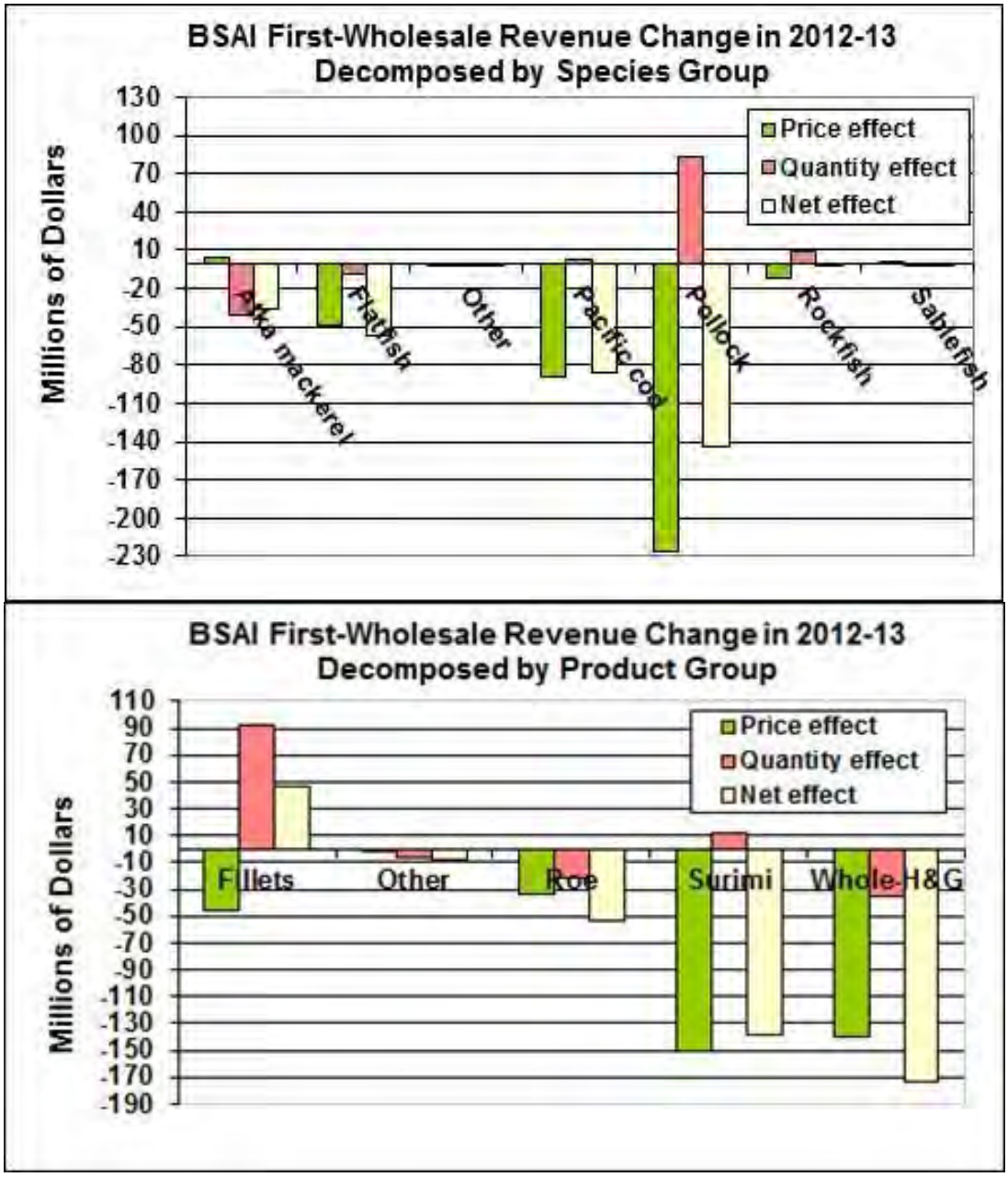

Figure 5 Decomposition of the change in first-wholesale revenues from 2012-13 in the BSAI area. The first decomposition is by the species groups used in the Economic SAFE report, and the second decomposition is by product group. The price effect refers to the change in revenues due to the change in the first-wholesale price index (current dollars per metric ton) for each group. The quantity effect refers to the change in revenues due to the change in production (in metric tons) for each group. The net effect is the sum of price and quantity effects. Year to year changes in the total quantity of first-wholesale groundfish products include changes in total catch and the mix of product types (e.g., fillet vs. surimi).

Stock Status Summaries

Except as otherwise noted, the Team's recommended ABCs are set at the maximum permissible levels under their respective tiers.

1. Walleye Pollock

Status and catch specifications (t) of walleye pollock in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The age grouping is 3+ for eastern Bering Sea, 2+ for the Aleutian Islands and the survey biomass for Bogoslof, as reported in the respective assessments. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Biomass	OFL	ABC	TAC	Catch
Eastern Bering Sea	2013	8,140,000	2,550,000	1,375,000	1,247,000	1,270,723
	2014	8,045,000	2,795,000	1,369,000	1,267,000	1,294,703
	2015	9,203,000	3,330,000	1,637,000	n/a	n/a
	2016	9,063,000	3,319,000	1,554,000	n/a	n/a
Aleutian Islands	2013	266,000	45,600	37,300	19,000	2,964
	2014	259,525	42,811	35,048	19,000	2,375
	2015	228,102	36,005	29,659	n/a	n/a
	2016	249,523	38,699	31,900	n/a	n/a
Bogoslof	2013	67,100	13,400	10,100	100	57
	2014	67,063	13,413	10,059	75	427
	2015	106,000	21,200	15,900	n/a	n/a
	2016	106,000	21,200	15,900	n/a	n/a

*In 2013, NMFS reallocated 14,900 t of pollock TAC from the Aleutian Islands to the Bering Sea which increased the Bering Sea TAC to 1,212,400 t and decreased the Aleutian Islands TAC to 4,100 t. In 2014, NMFS reallocated 13,650 t of pollock TAC from the Aleutian Islands to the Bering Sea, which increased the Bering Sea TAC to 1,280,650 t and decreased the Aleutian Islands TAC to 5,350 t.

Eastern Bering Sea pollock

Changes from previous assessment

New data in this year's assessment include the following:

- 2014 summer bottom trawl survey abundance at age
- 2014 summer acoustic-trawl survey abundance at age
- updated 2013 summer acoustic-trawl survey abundance at age (data using an age-length key from that survey replaced those in last year's assessment that were based on an age-length key from the bottom trawl survey)
- updated catch at age and average weight at age from the 2013 fishery
- updated total catch, including a preliminary value for 2014.

There were no changes in the authors' recommended assessment model.

Spawning biomass and stock trends

Spawning biomass in 2008 was at the lowest level since 1980, but has increased by 75% since then, with a 3% decrease projected for next year. The 2008 low was the result of extremely poor recruitments from the 2002-2005 year classes. Recent and projected increases are fueled by above average recruitment from the 2006 year class and very strong recruitment from the 2008 year class, along with reductions in average fishing mortality (ages 3-8) from 2009-2010. Spawning biomass is projected to be 39% and 32% above B_{MSY} in 2015 and 2016, respectively.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The SSC has determined that EBS pollock qualifies for management under Tier 1 because there are reliable estimates of B_{MSY} and the probability density function for F_{MSY}. The Team concurred with the SSC's conclusion that the Tier 1 reference points continue to be reliably estimated.

The updated estimate of B_{MSY} from the present assessment is 1.948 million t, down 8% from last year's estimate of 2.122 million t. Projected spawning biomass for 2015 is 2.714 million t, placing EBS walleye pollock in sub-tier "a" of Tier 1. As in recent assessments, the maximum permissible ABC harvest rate was based on the ratio between MSY and the equilibrium biomass corresponding to MSY. The harmonic mean of this ratio from the present assessment is 0.512, up 9% from last year's value of 0.469. The harvest ratio of 0.512 is multiplied by the geometric mean of the projected fishable biomass for 2015 (5.669 million t) to obtain the maximum permissible ABC for 2015, which is 2.9 million t, up 15% and 19% from the maximum permissible ABCs for 2014 and 2015 projected in last year's assessment.

However, as with other recent EBS pollock assessments, the authors recommend setting ABCs well below the maximum permissible levels. They list three reasons for doing so in the SAFE chapter:

- A single year class (2008) accounts for more than half of the spawning biomass
- In 2014, the fleet achieved good catch rates and low salmon bycatch with an ABC far below the maximum permissible level
- Current low roe recovery rates may be indicative of reduced reproductive potential.

During the period 2010-2013, the Team and SSC based ABC recommendations on the most recent 5-year average fishing mortality rate. This year, the authors instead based their 2015 and 2016 ABC recommendations on a "replacement yield" strategy, giving a value of 1.35 million t for both years. The Team agrees that an ABC well below the maximum permissible value continues to be appropriate, but felt that stock conditions had improved sufficiently that an increase in the ABC harvest rate was appropriate. Specifically, the Team recommends basing the 2015 and 2016 ABCs on the harvest rate associated with Tier 3, the stock's Tier 1 classification notwithstanding, giving values of 1.637 million t and 1.554 million t, respectively.

The OFL harvest ratio under Tier 1a is 0.587, the arithmetic mean of the ratio between MSY and the equilibrium fishable biomass corresponding to MSY. The product of this ratio and the geometric mean of the projected fishable biomass for 2015 determines the OFL for 2015, which is 3.33 million t. The current projection for OFL in 2016 given a 2015 catch equal to the Team's recommended ABC is 3.319 million t.

Status determination

The walleye pollock stock in the EBS is not being subjected to overfishing, is not overfished, and is not approaching an overfished condition.

Aleutian Islands pollock

Changes from previous assessment

The new data in the model consist of updated catch information and the addition of 2014 Aleutian Islands survey data. There was one minor change in the assessment methodology, the inclusion of age one pollock in the model.

Spawning biomass and stock trends

This year's assessment estimates that spawning biomass reached a minimum level of about $B_{29\%}$ in 1999 and then has generally increased, with a projected value of $B_{34\%}$ for 2015. The increase in spawning biomass since 1999 has resulted more from a dramatic decrease in harvest than from good recruitment, as there have been no above-average year classes spawned since 1989. Spawning biomass for 2015 is projected to be 70,012 t.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The SSC has determined that this stock qualifies for management under Tier 3. The Team concurred and supported continued use of last year's model for evaluating stock status and recommending ABC. The model estimates $B_{40\%}$ at a value of 83,042 t, placing the AI pollock stock in sub-tier "b" of Tier 3. The model estimates the values of $F_{35\%}$ as 0.40 and $F_{40\%}$ as 0.31. Under Tier 3b, with the adjusted value of $F_{40\%}$=0.25, the maximum permissible ABC is 29,659 t for 2015. The Team recommends setting the 2015 ABC at this level. Following the Tier 3b formula with the adjusted value of $F_{35\%}$=0.32, OFL for 2015 is 36,005 t. If the 2015 catch is 1,237 t (i.e., equal to the five year average for 2009-2013), the 2016 maximum permissible ABC would be 31,900 t and the 2016 OFL would be 38,699 t. The Team recommends setting 2016 the ABC and OFL at the latter levels.

Status determination

The walleye pollock stock in the Aleutian Islands is not being subjected to overfishing, is not overfished, and is not approaching an overfished condition.

Bogoslof pollock

Changes from previous assessment

A Bogoslof pollock acoustic-trawl survey was conducted in 2014. The 2014 Bogoslof pollock acoustic-trawl survey resulted in a biomass estimate of 112,070 t, which was an increase from the 2012 estimate of 67,100 t. The 2012 estimate was the lowest since the survey began in 1988.

Spawning biomass and stock trends

Survey biomass estimates since 2000 have all been lower than estimates prior to 2000, ranging from a low of 67,063 t in 2012 to a high of 301,000 t in 2000.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The SSC has determined that this stock qualifies for management under Tier 5. The maximum permissible ABC value for 2014 would be 15,900 t (assuming M = 0.2 and F_{ABC} = 0.75 x M = 0.15): ABC = B_{2014} x M x 0.75 = 106,000 x 0.2 x 0.75 = 15,900 t. The projected ABC for 2016 is the same.

Following the Tier 5 formula with M=0.20, OFL for 2015 is 21,200 t. The OFL for 2016 is the same.

Status determination

The walleye pollock stock in the Bogoslof district is not being subjected to overfishing. It is not possible to determine whether this stock is overfished or whether it is approaching an overfished condition because it is managed under Tier 5.

2. Pacific cod

This is the second year in which separate assessments and OFL/ABC specifications have been made for the EBS and Aleutians

Status and catch specifications (t) of Pacific cod in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Age 0+ biomass	OFL	ABC	TAC*	Catch
Eastern Bering Sea	2014	1,570,000	299,000	255,000	246,897	208,053
	2015	1,680,000	346,000	255,000	n/a	n/a
	2016	1,770,000	389,000	255,000	n/a	n/a
Aleutian Islands	2014	59,000**	20,100	15,100	6,997	6,145
	2015	68,900**	23,400	17,600	n/a	n/a
	2016	68,900**	23,400	17,600	n/a	n/a

*The Council sets the Federal TAC to account for the State of Alaska Aleutian Islands Guideline Harvest Level fishery that is set equal to 3 percent of the BSAI ABC. Catch includes only that which accrues to the Federal TAC.

**Biomass shown for AI cod is survey biomass (Tier 5) not Age 0+ biomass.

Eastern Bering Sea Pacific cod

Changes from previous assessment

All survey and commercial data series on CPUE, catch at age, and catch at length were updated. The 2015 specifications were based on the same model used in 2011-2013, but the Team expressed serious reservations about this model's poor retrospective performance and continued reliance on a fixed value of survey catchability that is no longer very credible. A different model was requested for next year.

Spawning biomass and stock trends

Survey biomass was higher again in 2014, continuing an upward trend that began around 2006 and has been sustained by several good year classes. Spawning stock biomass is now estimated to be in the vicinity of $B_{40\%}$.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

$B_{40\%}$ for this stock is estimated to be 330,000 t and projected spawning biomass in 2015 is 409,000 t, so this stock is assigned to Tier 3a. The maximum 2015 ABC in this tier is 295,000 t, but the author and Team recommend that ABC be held at the 2014 level of 255,000 t to compensate for the poor retrospective behavior of the standard model. The Team recommends the same value for the preliminary 2016 ABC. The corresponding OFLs are 346,000 t and 389,000 t.

Status determination

EBS Pacific cod is not being subjected to overfishing, is not overfished, and is not approaching an overfished condition.

Aleutian Islands Pacific cod

Changes from previous assessment

For some years there has been concern that a disproportionate share of the BSAI TAC was being taken from the Aleutians. The separate specification of EBS and AI OFL/ABC for the AI region, begun last year, is a response to that concern. Both age-structured (Tier 3) and survey-based (Tier 5) assessments have been considered for this area, but the working assessment was and is Tier 5.

Spawning biomass and stock trends

The survey biomass index has been flat and below the long-term average for the last ten years.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The Team reviewed the present Tier 5 assessment and two age-structured alternatives, both of which displayed poor retrospective performance and estimated biomass on the order of three times the trawl survey swept-area values, which is very high. The author and Team recommend using the Tier 5 assessment again for 2015 (ABC=17,600 t, OFL=23,400 t) while continuing work on the age-structured models with the aim of moving this assessment up to Tier 3.

Status determination

This stock is not being subjected to overfishing.

3. Sablefish

Status and catch specifications (t) of sablefish in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Age 4+ Biomass	OFL	ABC	TAC	Catch
Being Sea	2013	19,000	1,870	1,580	1,580	634
	2014	21,000	1,584	1,339	1,339	315
	2015	34,000	1,575	1,333	n/a	n/a
	2016	33,000	1,431	1,211	n/a	n/a
Aleutian Islands	2013	28,000	2,530	2,140	2,140	1,062
	2014	28,000	2,141	1,811	1,811	817
	2015	24,000	2,128	1,802	n/a	n/a
	2016	23,000	1,934	1,637	n/a	n/a

Changes from previous assessment

The assessment model incorporates the following new data into the model:

- relative abundance and length data from the 2014 longline survey
- relative abundance and length data from the 2014 longline fisheries
- length data from the 2013 trawl fisheries
- age data from the 2013 longline survey and 2013 fixed gear fishery
- updated historical catches from 2006-2013 and projected 2014-2016 catches.

There were no model changes.

Spawning biomass and stock trends

The longline survey abundance index increased 15% from 2013 to 2014 following a 25% decrease from 2011 to 2013. The fishery abundance index has been trending down since 2007 and reached its lowest value in 2013 (2014 data are not available yet). The 2013 IPHC GOA sablefish index was not used in the model, but also declined 21% from 2012. The 2008 year class showed potential to be above average in previous assessments based on patterns in the age and length compositions. However, the estimate in this year's assessment is only average because it is heavily influenced by the recent large overall decrease in the longline survey and trawl indices. The 1997 year class has been an important contributor to the population; however, it has been reduced and is predicted to comprise less than 7% of the 2015 spawning biomass. The 2000 year class is still the largest contributor, with 16% of the spawning biomass in 2015. The 2008 year class is average and will comprise 10% of spawning biomass in 2015 even though it is

only 60% mature. Spawning biomass has increased from a low of 32% of unfished biomass in 2002 to 35% of unfished biomass projected for 2015, but is trending downward in projections for the near future.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

Sablefish are managed under Tier 3 of the NPFMC harvest rules. Reference points are calculated using recruitments from 1979-2012. The updated point estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ from this assessment are 104,908 t (combined across the EBS, AI, and GOA), 0.095, and 0.112, respectively. Projected female spawning biomass (combined areas) for 2015 is 91,183 t (88% of $B_{40\%}$), placing sablefish in sub-tier "b" of Tier 3. The maximum permissible value of F_{ABC} under Tier 3b is 0.082, which translates into a 2015 ABC (combined areas) of 13,657 t. This value is very similar to the 2014 ABC of 13,722 t. In contrast, the 2013 assessment had projected a 10% decrease in ABC for 2015 from 2014. The more optimistic outlook from this year's assessment is supported by the increase in this year's domestic longline survey index noted above. ABCs are projected to decrease in 2016 to 12,406 t and 12,292 t in 2017. The OFL fishing mortality rate is 0.098 which translates into a 2015 OFL (combined areas) of 16,128 t.

Area apportionment

In December 1999, the Council apportioned the 2000 ABC and OFL based on a 5-year exponential weighting of the survey and fishery abundance indices. The same algorithm was used to apportion the ABC and OFL from 2000 specifications to 2013 specifications. Starting with the 2014 ABC and OFL, the Teams' recommended apportionments have been fixed at the2013 values. As described in last year's SAFE, the objective to reduce variability in apportionment was not being achieved under the previous formula. A Ph.D. student with the University of Alaska-Fairbanks began a project in 2012 with the objectives of re-examining the apportionment strategy and conducting management strategy evaluations. A spatial sablefish model has been developed, but management strategy evaluations have not begun yet. Meanwhile, it seems imprudent to move to an interim apportionment or return to the former scheme until more satisfactory methods have been identified and evaluated. Therefore, for 2015, the Teams recommend keeping the apportionment fixed at the proportions used in 2013 and 2014.

Status determination

Sablefish is not being subjected to overfishing, is not overfished, and is not approaching an overfished condition.

4. Yellowfin sole

Status and catch specifications (t) of yellowfin sole in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2014 and 2015 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Age 6+ Biomass	OFL	ABC	TAC	Catch
BSAI	2013	1,960,000	220,000	206,000	198,000	164,943
	2014	2,113,000	259,700	239,800	184,000	143,805
	2015	2,127,800	266,400	248,800	n/a	n/a
	2016	2,100,000	262,900	245,500	n/a	n/a

Changes from previous assessment

There were no changes to the assessment methodology. Changes to the input data include:

- 2013 fishery age composition
- 2013 survey age composition
- 2014 trawl survey biomass point estimate and standard error
- estimate of the discarded and retained portions of the 2013 catch
- estimate of total catch made through the end of 2014.

Spawning biomass and stock trends

The projected female spawning biomass estimate for 2015 is 644,200 t, which is an 8% increase from the 2014 estimate (594,800 t). The increase in projected spawning biomass for 2015 and beyond suggests a transition from the generally monotonic decline in spawning biomass that has prevailed since 1994. The total stock biomass has been quite stable throughout the 2000s.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The SSC has determined that reliable estimates of B_{MSY} and the probability density function for F_{MSY} exist for this stock. The estimate of B_{MSY} from the present assessment is 391,000 t, and projected spawning biomass for 2015 is 644,200 t, meaning that yellowfin sole qualify for management under Tier 1a. Corresponding to the approach used in recent years, the 1978-2006 stock-recruitment data were used this year to determine the Tier 1 harvest recommendation. This provided a maximum permissible ABC harvest ratio (the harmonic mean of the F_{MSY} harvest ratio) of 0.117. The current value of the OFL harvest ratio (the arithmetic mean of the F_{MSY} ratio) is 0.125. The product of the maximum permissible ABC harvest ratio and the geometric mean of the 2015 biomass estimate produced the 2015 ABC of 248,800 t recommended by the author and Team, and the corresponding product using the OFL harvest ratio produces the 2015 OFL of 266,400 t. For 2016, the corresponding quantities are 245,500 t and 262,900 t, respectively.

Status determination

Yellowfin sole is not being subjected to overfishing, is not overfished, and is not approaching an overfished condition.

Ecosystem considerations

As in previous years, this assessment contains an ecosystem feature that represents catchability of the EBS shelf trawl survey as an exponential function of average annual bottom temperature.

5. Greenland turbot

Status and catch specifications (t) of Greenland turbot in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Age 1+ Biomass	OFL	ABC	TAC	Catch
BSAI	2013	81,000	2,540	2,060	2,060	1,746
	2014	84,546	2,647	2,124	2,124	1,653
	2015	122,298	3,903	3,172	n/a	n/a
	2016	132,666	6,453	5,248	n/a	n/a
Eastern Bering Sea	2013			1,610	1,610	1,450
	2014			1,659	1,659	1,476
	2015			2,448	n/a	n/a
	2016			4,050	n/a	n/a
Aleutian Islands	2013			450	450	296
	2014			465	465	177
	2015			724	n/a	n/a
	2016			1,198	n/a	n/a

Changes from previous assessment

This year's Greenland turbot assessment model included:

- updated 2014 catch data, including a 433t decrease in the catch estimate for 2003 from last year
- 2014 EBS shelf survey biomass
- 2014 ABL longline survey RPN
- 2014 EBS shelf survey and ABL longline age and length composition estimates
- Shelf survey age and length composition data now include the expanded northern strata from 1987 onward
- Updated fishery catch-at-length data for longline and trawl gear from 2014
- For Model 2 (see below), the 2006 and 2007 trawl fishery length composition data were removed; the sample sizes were deemed too small
- Updated fishery catch-at-length data for longline and trawl gear from 2014.
- Length of females at 50% mature was changed from 55 to 60 cm per D'yakov (1982).

Two models (Models 1 and 2) were presented for review and Model 2 was accepted for use by the Team. Model 1 was identical to Model 1 from 2013 except for the addition of new female maturity parameters. Model 2 differed from Model 1 (from 2014) by the addition of a recruitment autocorrelation parameter; fixing of catchability for shelf and slope surveys at 0.62 and 0.57, respectively; and inclusion of an additional selectivity bin (2010 - 2014) for the longline fishery length composition data.

Spawning biomass and stock trends

The projected 2015 female spawning biomass is 30,853 t. This is a 12% increase from the 2015 spawning biomass of 27,624 t projected in last year's assessment. Spawning biomass is projected to increase to 38,848 t in 2016. While spawning biomass continues to be near historic lows, increases have been estimated or are projected for the years following 2013, and large 2008 and 2009 year classes are being observed in both the survey and fishery size composition data. These year classes are both estimated to be stronger than any other year class spawned since the 1970s.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The SSC has determined that reliable estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist for this stock. Greenland turbot therefore qualifies for management under Tier 3. Updated point estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ from the present assessment are 52,049 t, 0.176, and 0.218, respectively. The stock remains in Tier 3b. The maximum permissible value of F_{ABC} under this tier translates into a maximum permissible ABC of 3,172 t for 2015 and 5,248 t for 2016, and an OFL of 3,903 t for 2015 and 6,453 t for 2016. These are the authors' and Team's ABC and OFL recommendations.

Area apportionment

The authors' and Team's recommended 2015 and 2016 ABCs in the EBS are 2,448 t and 4,050 t, respectively. The authors' and Team's recommended 2015 and 2016 ABCs in the AI are 724 t and 1,198 t, respectively. Area apportionment of OFL is not recommended.

Status determination

Greenland turbot is not being subjected to overfishing, is not overfished, and is not approaching an overfished condition.

6. Arrowtooth flounder

Status and catch specifications (t) of arrowtooth flounder in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year, except that the 2013 value was held constant at the 2012 value. The OFL and ABC for 2015 and 2016 are those recommended

by the Plan Team and are taken from the 2011 assessment. Catch data are current through November 8, 2014.

Area	Year	Age 1+ Bio	OFL	ABC	TAC	Catch
BSAI	2013	1,130,000	186,000	152,000	25,000	20,507
	2014	1,023,440	125,642	106,599	25,000	18,697
	2015	908,379	93,856	80,547	n/a	n/a
	2016	911,652	91,663	78,661	n/a	n/a

Changes from previous assessment

The following new data was included in the model:

- Survey size compositions from the 2013 and 2014 Eastern Bering Sea shelf surveys and the 2014 Aleutian Islands survey
- Biomass point estimates and standard errors from the 2013 and 2014 Eastern Bering Sea shelf surveys and the 2014 Aleutian Islands survey
- Fishery size compositions for 2012, 2013, and 2014. Fishery size composition data were also added for 1992-1999, which were not previously included
- Estimates of catch through October 10, 2014
- Age data from the 2010 Bering Sea shelf and 2010 Aleutian Islands surveys, as well as the 2004 shelf survey, which was not previously included

Summary of changes to the assessment model methodology:

The age-structured assessment model is similar to the model used for the 2012 and 2013 assessments. The 2014 model implemented the following changes based on Plan Team and SSC comments:

- Fishery selectivity is estimated non-parametrically rather than using a 2-parameter logistic function
- An additional likelihood component was added to incorporate theAleutian Islands age data.

Spawning biomass and stock trends

The projected age 1+ total biomass for 2015 is 908,379 t, a decrease from the value of 995,494 t projected for 2015 in last year's assessment. The projected female spawning biomass for 2015 is 533,731 t which is also a decrease from the previous estimate of 632,319 t. The recommended 2015 ABC is 80,547 t based on a $F_{40\%}$=0.153 harvest rate and the 2015 overfishing level is 93,856 t based on a F_{OFL}=0.180 harvest rate.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The SSC has determined that reliable estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist for this stock. Arrowtooth flounder therefore qualifies for management under Tier 3. The point estimates of $B_{40\%}$ and $F_{40\%}$, from last year's assessment were 231,015 t and 0.156, respectively; from this year's assessment, they are 222,019 t, 0.153, respectively. The projected 2015 spawning biomass is far above $B_{40\%}$ in both last year's and this year's assessments, so ABC and OFL recommendations for 2015 were calculated under sub-tier "a" of Tier 3. The authors and Team recommend setting F_{ABC} at the $F_{40\%}$ level, which is the maximum permissible level under Tier 3a, which results in 2015 and 2016 ABCs of 80,547 t and 78,661 t, respectively, and 2015 and 2016 OFLs of 93,856 t and 91,663 t.

Status determination

Arrowtooth flounder is a largely unexploited stock in the BSAI. Arrowtooth flounder is not being subjected to overfishing, is not overfished, and is not approaching an overfished condition.

Ecosystem Considerations

In contrast to the Gulf of Alaska, arrowtooth flounder is not at the top of the food chain on the EBS shelf. Arrowtooth flounder in the EBS is an occasional prey in the diets of groundfish, being eaten by Pacific cod, walleye pollock, Alaska skates, and sleeper sharks. However, given the large biomass of most of the predator species in the EBS, these occasionally recorded events translate into considerable total mortality for the arrowtooth flounder population in the EBS ecosystem.

7. Kamchatka flounder

Status and catch specifications (t) of Kamchatka flounder in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014

Area	Year	Age 1+ Bio	OFL	ABC	TAC	Catch
BSAI	2013	125,000	16,300	12,200	10,000	7,766
	2014	136,600	8,270	7,100	7,100	6,395
	2015	174,500	10,500	9,000	n/a	n/a
	2016	181,000	11,000	9,500	n/a	n/a

Changes from previous assessment

This assessment is a full update of the 2012 stock assessment. The 2013 assessment was an off-cycle assessment that did not re-run an updated assessment model, but instead the projection model was run with updated catch information only to provide estimates of 2014 and 2015 ABC and OFL without re-estimating the stock assessment model parameters and biological reference points.

Summary of changes in assessment input:

- Estimate of catch for 2012-2014
- 2012 and 2013 fishery length composition
- 2013 and 2014 shelf survey length composition
- 2013 and 2014 shelf survey biomass and standard error estimates
- 2014 Aleutian Islands survey biomass and standard error
- 2014 Aleutian Islands survey length composition
- 2012 slope survey age composition.

No changes were made to the assessment methodology.

Spawning biomass and stock trends

Kamchatka flounder has a widespread distribution along the deeper waters of the BSAI region. Spawning biomass increased continuously, at an average rate of about 5% per year, from the start of the model time series in 1991 to a peak of 62,963 t in 2009. Spawning biomasses from 2006 through 2014 have all been within 10% of the peak value. The 2000-2002, 2008-2010, and 2012 year classes are all estimated to be well above average, with the 2002, 2008, and 2010 year classes estimated to be at least twice average. Projected 2015 female spawning biomass is estimated at 60,100 t, above the $B_{40\%}$ level of 53,000 t, and is projected to remain above $B_{40\%}$.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

This stock was managed under Tier 3 for the first time in 2014. As noted above, projected spawning biomass for 2015 is above $B_{40\%}$, placing Kamchatka flounder in sub-tier "a" of Tier 3. For the 2015 fishery, the authors and Team recommend setting 2015 ABC at the maximum permissible value of 9,000 t from the projection model. This value is an increase of 1,900 t over the 2014 ABC (7,100 t). The 2015 OFL from the projection model is 10,500 t, up from 8,270 t for 2014.

Status Determination

Kamchatka flounder is not being subjected to overfishing, is not overfished, and is not approaching an overfished condition.

8. Northern rock sole

Status and catch specifications (t) of northern rock sole in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2014 and 2015 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Age 6+ Biomass	OFL	ABC	TAC	Catch
BSAI	2013	1,470,000	241,000	214,000	92,380	59,806
	2014	1,393,200	228,700	203,800	85,000	51,549
	2015	1,233,400	187,600	181,700	n/a	n/a
	2016	1,118,700	170,100	164,800	n/a	n/a

***C**hanges from previous assessment*

The last full assessment was in November 2012, therefore changes to input data in this analysis include:

- 2012 and 2013 fishery age composition
- 2012 and 2013 survey age composition
- 2013 and 2014 trawl survey biomass point estimates and standard errors
- Estimate of catch and discards for 2013 and 2014
- Estimate of retained and discarded portions of the 2013 catch

The assessment methodology was unchanged.

Spawning biomass and stock trends

Spawning biomass increased almost continuously from a low of 54,981 t at the beginning of the model time series in 1975 to a peak of 758,648 t in 2001. Spawning biomass then declined to 491,611 t in 2009, but has increased continuously since then, reaching 632,502 t in 2014. The 1996-2001 year classes are all estimated to be above average, with the 1998 year class estimated to be at least twice average. The stock assessment model projects a 2015 spawning biomass of 622,300 t. This was slightly less than the 2015 value projected in last year's assessment. The projected spawning biomass for 2016 is 589,800 t.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The SSC has determined that northern rock sole qualifies for management under Tier 1. Spawning biomass for 2015 is projected to be well above the B_{MSY} estimate of 260,000, placing northern rock sole in sub-tier "a" of Tier 1. The Tier 1 2015 ABC harvest recommendation is 181,700 t (F_{ABC} = 0.143) and the 2015 OFL is 187,600 t (F_{OFL} = 0.152). The 2016 ABC and OFL values are 164,800 t and 170,100 t, respectively. Recommended ABCs correspond to the maximum permissible levels.

This is a stable fishery that lightly exploits the stock because it is constrained by PSC limits and the BSAI optimum yield cap. Usually the average catch/biomass ratio is about 3.5 percent of the northern rock sole stock.

Status determination

Northern rock sole is not being subjected to overfishing, is not overfished, and is not approaching an overfished condition.

9. Flathead sole

Status and catch specifications (t) of flathead sole in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Age 3+ Biomass	OFL	ABC	TAC	Catch
BSAI	2013	748,454	81,500	67,900	22,699	17,358
	2014	745,237	79,633	66,293	24,500	16,102
	2015	736,947	79,419	66,130	n/a	n/a
	2016	741,446	76,504	63,711	n/a	n/a

Changes from previous assessment

- 2014 catch biomass was added to the model
- 2013 catch biomass was updated to reflect October – December 2013 catches
- 2012 fishery age composition data were added and 2011 fishery age composition data were updated to reflect changes made to the observer database
- 2013-2014 fishery length composition data were added to the model
- 2013-2014 Eastern Bering Sea (EBS) shelf survey biomass and 2014 Aleutian Islands (AI) survey biomass were added to the linear regression used to determine estimates of AI survey biomass in years when no AI survey occurred, which resulted in updating the entire time series;
- 2013-2014 survey bottom temperatures were added to the model
- 2013 survey age composition data were added to the model
- 2014 survey length composition data were added to the model
- Minor changes in the historical survey catch were made to the eastern Bering Sea shelf bottom trawl survey database, as a result of Pacific halibut data reconciliation between RACE and the IPHC. The most common error was an incorrect application of an expansion factor to the Pacific halibut catch sample. In hauls where the catch was subsampled, this change in expansion for halibut affected the catch proportion of the other species in the catch to a minor degree.

No changes were made to the assessment methodology.

Spawning biomass and stock trends

Spawning biomass increased continuously from a low of 17,654 t in 1979 to a high of 319,400 t in 1997, and has been quite stable since 2005, with biomasses ranging between 234,130 t and 252,320 t. The 1998, 2001-2003, and 2011 year classes are all estimated to be well above average. The projected spawning stock biomass for 2015 is 233,736 t. Flathead sole are abundant and only lightly exploited.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The SSC has determined that reliable estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist for this stock, thereby qualifying flathead sole for management under Tier 3. The current values of these reference points are $B_{40\%}$=127,682 t, $F_{40\%}$=0.28, and $F_{35\%}$=0.35. Because projected spawning biomass for 2015 (233,736 t) is above $B_{40\%}$, flathead sole is in sub-tier "a" of Tier 3. The authors and Team recommend setting ABCs for 2015 and 2016 at the maximum permissible values under Tier 3a, which are 66,130 t and 63,711 t, respectively. The 2015 and 2016 OFLs under Tier 3a are 79,419 t and 76,504 t, respectively.

Status determination

Flathead sole is not being subjected to overfishing, is not overfished, and is not approaching an overfished condition.

10. Alaska plaice

Status and catch specifications (t) of Alaska plaice in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Age 3 + Bio	OFL	ABC	TAC	Catch
BSAI	2013	589,000	67,000	55,200	20,000	23,523
	2014	576,300	66,800	55,100	24,500	18,808
	2015	471,500	54,000	44,900	n/a	n/a
	2016	462,600	51,600	42,900	n/a	n/a

Changes from previous assessment

The last full assessment was in November 2012, therefore changes to input data in this analysis include:

- Estimated 2014 fishery catch and updated 2013 fishery catch
- 2013 and 2014 trawl survey biomass estimate and standard error
- 2014 survey length composition
- 2012 and 2013 survey age composition
- 2013 fishery length composition
- 1975 and 1979-1981 survey biomass data were excluded
- New maturity schedule estimated from histological analysis of samples collected in 2012.

The assessment methodology was unchanged.

Spawning biomass and stock trends

The stock assessment model estimates a 2015 spawning biomass of 215,300. This was slightly less than the 2015 value of 246,300 projected in last year's assessment. The projected spawning biomass for 2016 is 201,300. Above average recruitment strength in 1998 and exceptionally strong recruitment in 2001 and 2002 have contributed to recent highs level of female spawning biomass.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

Reliable estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist for this stock, therefore qualifying it for management under Tier 3. The updated point estimates are $B_{40\%}$ = 142,100 t, $F_{40\%}$ = 0.143, and $F_{35\%}$ = 0.175. Given that the projected 2015 spawning biomass of 215,300 t exceeds $B_{40\%}$, the ABC and OFL recommendations for 2015 were calculated under sub-tier "a" of Tier 3. Projected harvesting at the $F_{40\%}$

level gives a 2015 ABC of 44,900 t and a 2016 ABC of 42,900 t. The OFL was determined from the Tier 3a formula, which gives a 2015 value of 54,000 t and a 2016 value of 51,600 t.

Status determination

Alaska plaice is not being subjected to overfishing, is not overfished, and is not approaching an overfished condition.

11. Other Flatfish complex

Status and catch specifications (t) of other flatfish in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Total Bio.	OFL	ABC	TAC	Catch
BSAI	2013	114,000	17,800	13,300	3,500	1,535
	2014	107,500	16,700	12,400	2,650	4,388
	2015	143,000	17,700	13,250	n/a	n/a
	2016	143,000	17,700	13,250	n/a	n/a

In 2014, the other flatfish TAC increased to 4,500 t after a reallocation of 1,850 t from the non-specified reserves.

Changes from previous assessment

The assessment incorporates 2014 total and discarded catch and 2014 EBS shelf and slope and Aleutian Islands trawl survey biomass. The assessment methodology was changed such that biomass values that are the basis for recommending ABC and OFL were computed by a random effects model.

Spawning biomass and stock trends

EBS survey biomass estimates for this complex were all below 100,000 t from 1983-2005, and reached a high of 133,502 t in 2007. The 2014 EBS estimate for 2014 (129,025 t) is within 3% of the time series high. The 2014 AI survey biomass estimate (13,936 t) is in the vicinity of the estimates from 2004-2012. All of the AI survey estimates since 2004 are higher than any of the estimates prior to 2004. Starry flounder, rex sole, and butter sole comprise the majority of the fishery catch with a negligible amount of other species caught in recent years. Starry flounder continues to dominate the shelf survey biomass in the EBS, while rex sole is the most abundant "other" flatfish in the Aleutian Islands.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The SSC has classified "other flatfish" as a Tier 5 species complex with harvest recommendations calculated from estimates of biomass and natural mortality. Natural mortality rates for rex (0.17) and Dover sole (0.085) in the GOA SAFE document are used, along with a value of 0.15 for all other species in the complex. Projected harvesting at the 0.75 M level (average F_{ABC} = 0.093) gives a 2015 ABC of 13,250 t for the "other flatfish" complex. The corresponding 2015 OFL (average F_{OFL} = 0.124) is 17,700 t.

Status determination

This assemblage is not being subjected to overfishing. It is not possible to determine whether this assemblage is overfished or whether it is approaching an overfished condition because it is managed under Tier 5.

12. Pacific ocean perch

Status and catch specifications (t) of Pacific ocean perch in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Team. Catch data are current through November 8, 2014.

Area	Year	Age 3+ Bio	OFL	ABC	TAC	Catch
BSAI	2013	663,000	41,900	35,100	35,100	28,049
	2014	639,505	39,585	33,122	33,122	32,373
	2015	577,967	42,558	34,988	n/a	n/a
	2016	561,090	40,809	33,550	n/a	n/a
Eastern Bering Sea	2013	n/a	n/a	8,130	8,130	5,050
	2014	n/a	n/a	7,684	7,684	7,429
	2015	n/a	n/a	8,771	n/a	n/a
	2016	n/a	n/a	8,441	n/a	n/a
Eastern Aleutian Islands	2013	n/a	n/a	9,790	9,790	9,530
	2014	n/a	n/a	9,246	9,246	9,021
	2015	n/a	n/a	8,312	n/a	n/a
	2016	n/a	n/a	7,970	n/a	n/a
Central Aleutian Islands	2013			6,980	6,980	6,747
	2014			6,594	6,594	6,439
	2015			7,723	n/a	n/a
	2016			7,406	n/a	n/a
Western Aleutian Islands	2013			10,200	10,200	10,065
	2014			9,598	9,598	9,485
	2015			10,182	n/a	n/a
	2016			9,763	n/a	n/a

Changes from previous assessment

The 2014 BSAI POP assessment was a full assessment. The survey biomass estimates and age composition data from the U.S.-Japan cooperative survey in 1980, 1983, and 1986 were removed from the assessment. The 2014 AI survey biomass estimate and length composition was included in the assessment. The 2012 AI survey and 2013 fishery age compositions were included in the assessment. The 2012 fishery length composition was included in the assessment. The length-at-age, weights-at-age, and age-to-length conversion matrix were updated based on data from the NMFS AI trawl survey beginning in 1991.

A bicubic spline model was used to estimate fishery selectivity as a function of year and age. The multinomial input sample sizes for the age and length composition data were changed using an iterative reweighting procedure that ensures that the standard deviation of the normalized residuals for each composition data type is 1.

Spawning biomass and stock trends

The 2014 AI survey biomass is large and consistent with the survey biomass estimates in 2010 and 2012, and the size composition data continue to show relatively strong cohorts from 1994 to 2000. Spawning biomass is well above the $B_{40\%}$ reference point and projected to be 234,426 t in 2015 and to decline to 223,744 t in 2016. Large recruitments in the late 1990s have driven up recent estimates of stock abundance.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The Plan Team accepted the author's recommended changes to the model. The SSC has determined that reliable estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist for this stock, thereby qualifying Pacific ocean perch for management under Tier 3. The current estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ are 169,203 t, 0.089, and 0.0109 respectively. Spawning biomass for 2015 (234,426 t) is projected to exceed $B_{40\%}$, thereby placing POP in sub-tier "a" of Tier 3. The 2015 and 2016 catches associated with the $F_{40\%}$ level of 0.089 are 34,988 t and 33,550 t, respectively, and are the authors' and Team's recommended ABCs. The 2015 and 2016 OFLs are 42,558 t and 40,809 t.

Area apportionment

The Team agreed with the author's recommendation for adopting the random effects model so that ABCs would be set regionally based on the proportions of model-based estimates of ending year survey biomass which for 2015 are: BS = 8,771 t, Eastern Aleutians (Area 541) =8,312 t, Central Aleutians (Area 542) = 7,723 t, and Western Aleutians (Area 543) = 10,182 t. The recommended OFL for 2015 and 2016 is not regionally apportioned.

Status determination

Pacific ocean perch is not being subjected to overfishing, is not overfished, and is not approaching an overfished condition.

13. Northern rockfish

Status and catch specifications (t) of northern rockfish in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Age 3+ Biomass	OFL	ABC	TAC	Catch
BSAI	2013	195,000	12,200	9,850	3,000	2,038
	2014	197,541	12,077	9,761	2,594	2,339
	2015	218,901	15,337	12,488	n/a	n/a
	2016	218,898	15,100	12,295	n/a	n/a

Changes from previous assessment

Catch was updated through October 11, 2014. The survey biomass estimates and age composition data from the U.S.-Japan cooperative surveys in 1980, 1983, and 1986 were removed from the assessment. The 2014 AI survey biomass estimate and length composition were included in the assessment. The 2012 AI survey age composition was included in the assessment. The 2012 and 2013 fishery length compositions were included in the assessment. The length-at-age, weights-at-age, and age-to-length conversion matrix were updated based on data from the NMFS AI trawl survey beginning in 1991.

The multinomial input sample sizes for the age and length composition data were obtained by an iterative reweighting procedure that ensures that the standard deviation of the normalized residuals for each composition data type is 1.

Spawning biomass and stock trends

The 1980s cooperative surveys had low biomass estimates relative to the remainder of the time series, and removal of these data increased the estimated population size. Spawning biomass has been increasing slowly and almost continuously since 1977 until recent years, where it appears to be leveling off. Female spawning biomass is projected to be 94,873 t and 93,540 t in 2015 and 2016 which are well above $B_{40\%}$. Recent recruitment has generally been below average.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The Plan Team agreed with the author's recommended changes to the model. The SSC has determined that this stock qualifies for management under Tier 3 due to the availability of reliable estimates for $B_{40\%}$ (57,768 t), $F_{40\%}$ (0.070), and $F_{35\%}$ (0.088). Because the projected female spawning biomass of 94,873 t is greater than $B_{40\%}$, sub-tier "a" is applicable, with maximum permissible $F_{ABC} = F_{40\%}$ and $F_{OFL} = F_{35\%}$. Under Tier 3a, the maximum permissible ABC for 2015 is 12,488 t, which is the authors' and Team's recommendation for the 2015 ABC. Under Tier 3a, the 2014 OFL is 15,337 t for the Bering Sea/Aleutian Islands combined. The Team continues to recommend setting a combined BSAI OFL and ABC. The Team recommendation for 2016 ABC is 12,295 t and the 2016 OFL is 15,100 t.

Status determination

Northern rockfish is not being subjected to overfishing, is not overfished, and is not approaching an overfished condition.

14. Blackspotted and rougheye rockfish

Area/subarea	Year	Total Biomass (t)	OFL	ABC	TAC	Catch
BSAI	2013	29,800	462	378	378	341
	2014	30,400	505	416	416	196
	2015	41,666	799	648	n/a	n/a
	2016	43,633	865	702	n/a	n/a
Western/Central Aleutian Islands	2013			209	209	146
	2014			239	239	98
	2015			445	n/a	n/a
	2016			484	n/a	n/a
Eastern AI/ Eastern Bering Sea	2013			169	169	177
	2014			177	177	98
	2015			203	n/a	n/a
	2016			218	n/a	n/a

[1] Total biomass from AI age-structured projection model and survey biomass estimates from EBS.

Changes from previous assessment

This year was a full assessment, the first full assessment since 2012. New data in this assessment included:

- updated catch for 2013 and catch for 2014 through October 11, 2014
- fishery length composition data were included for 2012 and 2013
- the 2014 AI survey biomass estimate and length composition was included
- the 2012 AI survey age composition was included

The survey biomass estimates and age composition data from the U.S.-Japan cooperative survey in 1980, 1983, and 1986 were removed from the assessment.

The length-at-age, weights-at-age, and age-to-length conversion matrices were updated based on data from the NMFS AI trawl survey beginning in 1991.

Two major changes were made in the age-structured model for the AI component of this stock complex:

- After evaluating several alternative methods of parameterizing selectivity, the recommended model uses a double logistic curve to model fishery selectivity.

- Multinomial input sample sizes for the age and length composition data were obtained by an iterative reweighting procedure that ensures that the standard deviation of the normalized residuals for each composition data type is 1.

A simple random effects model was used to estimate current biomass for the EBS component of this stock complex.

Spawning biomass and stock trends

Total biomass for the AI component of the stock in 2015 is projected to be 40,327 t which is an increase from last year's projected 2014 value of 29,087 t. For the period 1977-2014, the current (2014) estimate of female spawning biomass is the all-time high. Female spawning biomass is projected to increase further to 7,921 t in 2015 and 8,993 t in 2016. These projected increases are fueled by extremely large year classes spawned in 1998, 2002, and 2006.

Application of the random effects model produces an estimated biomass for the SBS area of 1,339 t for 2015, a small decrease from last year's estimate of 1,389 t.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

As was the case with the two most recent full assessments in 2010 and 2012, the authors and the Team both expressed concerns about the appropriate range of year classes from which to estimate average recruitment. This year, the authors recommended using year classes up through 1998, but the Team recommends using year classes up through 1996 only, as this would correspond to the result of the formula recommended by the recruitment working group. The difference in the recommended range of year classes causes the Team's $B_{40\%}$ estimate to differ from that of the authors, which in turn affects the recommended ABCs. The values listed in this summary correspond to the Team's estimate of $B_{40\%}$.

For the Aleutian Islands, this stock qualifies for management under Tier 3 due to the availability of reliable estimates for $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$. Because the projected female spawning biomass for 2015 of 7,921 t is greater than $B_{40\%}$, (5,535 t) the stock qualifies as Tier 3a and the adjusted $F_{ABC} = F_{40\%}$values for 2015 and 2016 are 0.047 and 0.058, respectively. The maximum permissible ABC for the Aleutian Islands is 615 t, which is the authors' and Team's recommendation for the AI portion of the 2015 ABC. Under Tier 3a, the 2015 OFL is 799 t for the combined BSAI region. The apportionment of 2015 ABC to subareas is 445 t for the Western and Central Aleutian Islands and 203 t for the Eastern Aleutian Islands and Eastern Bering Sea. The Team recommends an overall 2016 ABC of 702 t and a 2016 OFL of 865 t.

Area apportionment

Given on-going concerns about fishing pressure relative to biomass in the Western Aleutians, the SSC requested that the potential apportionment by sub-area be calculated and presented. The maximum area-specific catch levels within the WAI/CAI, based on the random effects (RE) model, are as follows:

	WAI	**CAI**	**WAI-CAI**
ABC (2015, RE model)	68	377	455
ABC (2016, RE model)	74	410	484

Status determination

The blackspotted and rougheye rockfish complex is not being subjected to overfishing, is not overfished, and is not approaching an overfished condition.

15. Shortraker rockfish

Area	Year	Survey Biomass	OFL	ABC	TAC	Catch
BSAI	2013	16,450	493	370	370	372
	2014	16,447	493	370	370	194
	2015	23,009	690	518	n/a	n/a
	2016	23,009	690	518	n/a	n/a

Changes from previous assessment

The 2014 biomass estimate is based on the Aleutian Island survey data through 2014 as well as the 2002-2012 eastern Bering Sea slope survey data. The EBS slope survey data had not been included in previous biomass estimates for this species. Catch data have been revised and updated through October 31, 2014.

For estimation of biomass, the assessment methodology was changed from a Kalman filter version of the Gompertz-Fox surplus production model to a simple random effects model.

Spawning biomass and stock trends

The 2015 estimated shortraker rockfish biomass is 23,009 t, increasing from the previous estimate of 16,447 t primarily due to the inclusion of the 2002-2012 EBS slope survey biomass estimates.

The modern EBS slope survey time series began in 2002. For the period 2002-2014, EBS slope survey biomass estimates ranged from a low of 2,570 t in 2004 to a high of 9,299 in 2012 (which was the year of the most recent EBS slope survey). For the period 1991-2014, the AI survey biomass estimates ranged from a low of 12,961 t in 2006 to a high of 38,497 t in 1997. According to the random effects model, total biomass (AI and EBS slope combined) from 2002-2014 has been very stable, ranging from a low of 20,896 t in 2006 to a high of 23,938 t in 2002. The time series from the random effects model is much smoother than the time series for the raw data, due to large standard errors associated with the data.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The SSC has previously determined that reliable estimates of only biomass and natural mortality exist for shortraker rockfish, qualifying the species for management under Tier 5. The Team recommends basing the biomass estimate on the random effects model. The Team recommended setting F_{ABC} at the maximum permissible level under Tier 5, which is 75 percent of M. The accepted value of M for this stock is 0.03 for shortraker rockfish, resulting in a $maxF_{ABC}$ value of 0.0225. The ABC is 518 t for 2015 and 2016 and the OFL is 690 t for 2015 and 2016.

Status determination

Shortraker rockfish is not being subjected to overfishing. It is not possible to determine whether this stock is overfished or whether it is approaching an overfished condition because it is managed under Tier 5.

16. Other Rockfish complex

Status and catch specifications (t) of other rockfish in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Survey Biomass	OFL	ABC	TAC	Catch
BSAI	2013	47,700	1,540	1,159	873	814
	2014	47,767	1,550	1,163	773	931
	2015	49,630	1,667	1,251	n/a	n/a
	2016	49,630	1,667	1,251	n/a	n/a
Eastern Bering Sea	2013	29,800	n/a	686	400	191
	2014	29,885	n/a	690	300	316
	2015	n/a	n/a	695	n/a	n/a
	2016	n/a	n/a	695	n/a	n/a
Aleutian Islands	2013	17,900	n/a	473	473	623
	2014	17,878	n/a	473	473	615
	2015	n/a	n/a	555	n/a	n/a
	2016	n/a	n/a	555	n/a	n/a

For 2014, NMFS increased the Bering Sea TAC to 400 t with a reallocation of 100 t from the non-specified reserves,

Changes from previous assessment

New data in the 2014 assessment included updated catch and fishery lengths for 2014. Biomass estimates, CPUE, and length frequency compositions were also included from the 2014 Aleutian Island trawl survey, and the 2013 and 2014 eastern Bering Sea shelf survey. There was no Bering Sea slope survey in 2014. Of the new data, only the survey biomass estimate is used in computing recommended ABCs and OFLs.

In previous assessments, a 4-6-9 weighted average of three most recent surveys for each region (Aleutian Islands, Bering Sea shelf, and Bering Sea slope) had been used to calculate the BSAI other rockfish biomass estimate. To remain consistent with other Tier 5 assessments, the Team recommends using a random effects model for each region to calculate the biomass estimate for the entire BSAI area.

Spawning biomass and stock trends

Trends in spawning biomass are unknown. The 2014 assessment reported that biomass of other rockfish was at an all-time high in both the most recent EBS slope survey (2012) and this year's AI survey.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The Team agrees with the approach recommended by the author of setting F_{ABC} at the maximum allowable under Tier 5 ($F_{ABC} = 0.75M$). The accepted values of M for species in this complex are 0.03 for shortspine thornyheads and 0.09 for all other species. Multiplying these rates by the best biomass estimates of shortspine thornyhead and other rockfish species in the "other rockfish" complex yields 2015 and 2016 ABCs of 695 t in the EBS and 555 t in the AI. The Team recommends that OFL be set for the entire BSAI area, which under Tier 5 is calculated by multiplying the best estimates of total biomass for the area by the separate natural mortality values and adding the results, which yields an OFL of 1,667 t for 2015 and 2016.

Status determination

The "other rockfish" complex is not being subjected to overfishing. It is not possible to determine whether this complex is overfished or whether it is approaching an overfished condition because it is managed under Tier 5.

17. Atka mackerel

Status and catch specifications (t) of Atka mackerel in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Age 1+ Biomass	OFL	ABC	TAC	Catch
BSAI	2013	447,189	57,700	50,000	25,920	23,180
	2014	456,620	74,492	64,131	32,322	30,947
	2015	694,421	125,297	106,000	n/a	n/a
	2016	673,327	115,908	98,137	n/a	n/a
E Aleutian Islands / EBS	2013	n/a	n/a	16,900	16,900	15,776
	2014	n/a	n/a	21,652	21,652	21,185
	2015	n/a	n/a	38,493	n/a	n/a
	2016	n/a	n/a	35,637	n/a	n/a
Central Aleutian Islands	2013	n/a	n/a	16,000	7,520	7,284
	2014	n/a	n/a	20,574	9,670	9,520
	2015	n/a	n/a	33,108	n/a	n/a
	2016	n/a	n/a	30,652	n/a	n/a
Western Aleutian Islands	2013	n/a	n/a	17,100	1,500	120
	2014	n/a	n/a	21,905	1,000	242
	2015	n/a	n/a	34,400	n/a	n/a
	2016	n/a	n/a	31,848	n/a	n/a

Changes from previous assessment

The following new data were included in this year's assessment:

- Fishery catch data were updated.
- The 2013 fishery age composition data were added.
- Total 2014 year end catch was estimated at 31,670 t based on the observation that an average of 25% of the catch has occurred after Oct. 1 in recent years.
- The 2014 survey biomass estimates were included.
- The estimated average selectivity for 2010-2014 was used for projections.
- It was assumed that 80% of the BSAI-wide ABC is likely to be taken under the revised Steller Sea Lion Reasonable and Prudent Alternatives (SSL RPAs) to be implemented in 2015. This percentage was applied to the 2015 maximum permissible ABC, and that amount was assumed to be caught in order to estimate the 2016 ABCs and OFL values.

There were no changes to the assessment methodology.

Spawning biomass and stock trends

Spawning biomass reached an all-time high in 2005, then decreased by 56% from 2005-2013, and now appears to have stabilized. The only above-average year class since 2001 is the 2006 cohort, which is 23% above average. The projected female spawning biomass for 2015 is 167,136 t, which is above $B_{40\%}$ (133,295 t). The stock is projected to remain above $B_{40\%}$ through 2016 at the recommended harvest levels.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The projected female spawning biomass under the recommended harvest strategy is estimated to be above $B_{40\%}$, thereby placing BSAI Atka mackerel in Tier 3a**.** The projected 2015 yield (ABC) at $F_{40\%}$= 0.403 is 106,000 t, up 65% from the 2014 ABC. The projected 2015 overfishing level at $F_{35\%}$ = 0.489 is 125,297 t, up 68% from last year's estimate for 2014. The increase in yield is due primarily to a large increase in survey biomass in 2014 and the addition of the 2013 fishery age composition, which increased the estimated magnitudes of the 1999-2001 year classes by 12-15% and the magnitude of the 2006 year class by 17% relative to last year's assessment.

Area apportionment

A 4-survey weighted average is used to apportion the ABC among areas. The last 4 surveys were conducted in 2006, 2010, 2012, and 2014. The recommended ABC apportionments by subarea for 2015 are 38,493 t for Area 541 and the southern Bering Sea region, 33,108 t for Area 542, and 34,400 t for Area 543.

Status determination

Atka mackerel is not being subjected to overfishing, is not overfished, and is not approaching an overfished condition.

Ecosystem Considerations

Atka mackerel is the most common prey item of the endangered western Steller sea lion throughout the year in the Aleutian Islands. Analysis of historic fishery CPUE revealed that the fishery may create temporary localized depletions of Atka mackerel, and fishery harvest rates in localized areas may have been high enough to affect prey availability for Steller sea lions. The objectives of having areas closed to Atka mackerel fishing around Steller sea lion haulouts and rookeries, and time-area ABC/TAC allocations, are to maintain sufficient prey for the recovery of Steller sea lions in the Aleutian Islands while also providing opportunities to harvest Atka mackerel. Steller sea lion surveys indicate that counts of adults, juveniles, and pups continue to decline in the Aleutian Islands, particularly in the western Aleutians (area 543) where counts of pups and non-pups declined 9%/year and 7%/year, respectively, between 2000 and 2013. This contrasts with Steller sea lion counts in the eastern Aleutian Islands and southern Bering Sea (between Samalga and False Passes), which are increasing. New regulations proposed for 2015 remove the closure of area 543 to directed fishing for Atka mackerel (but with a maximum TAC of 65% of the area ABC), remove the TAC reduction in area 542, and re-open areas in 541 and 542 that were previously closed to directed Atka mackerel fishing.

18. Skates

Status and catch specifications (t) of skates in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Age 0+ Biomass	OFL	ABC	TAC	Catch
BSAI	2013	745,000	45,800	38,800	24,000	27,038
	2014	726,561	41,849	35,383	26,000	24,695
	2015	625,314	49,575	35,551	n/a	n/a
	2016	595,880	47,035	35,551	n/a	n/a

For 2013, NMFS increased the TAC to 25,500 t with a reallocation of 1,500 t from the non-specified reserves, For 2014, NMFS increased the TAC to 26,600 t with a reallocation of 600 t from the non-specified reserves,

Changes from previous assessment

This chapter was a full assessment. The following new data were included in this year's assessment:

- updated 2013 and preliminary 2014 catch
- 2014 EBS shelf and Aleutian Islands survey data
- 1982-1991 EBS shelf survey biomass estimates
- Reconstructed historical catch data back to 1954
- Length-at-age data from 2003, 2007, 2008, and 2009
- Weight-at-length data from the 2008-2010 EBS shelf surveys

Four assessment models for Alaska skate were presented, including last year's model. The Team recommended the author's preferred Model 2. All of the new models included the following changes:

- For all Alaska skate models, growth parameters are estimated within the model.
- The "embryonic stage" (ages 0-3 in previous models) was eliminated from the model, so that in the model age-0 skates are free-swimming individuals in their first year outside of the eggcase.
- The recruitment function was returned to the original formulation, a Beverton-Holt curve with steepness fixed at 1.0; this effectively defines an average level of recruitment at all stock sizes.
- The maximum age was returned to its original value of 25 (from 30 in the 2012 model).
- Age selectivity was removed from the model the model.

For the "other skates" assessment, the author recommended a random effects model to replace the model based on the 3-survey average.

Spawning biomass and stock trends

The 2014 biomass estimates from the shelf survey increased slightly from 2013. In the case of Alaska skates, survey biomass estimates, though variable, are basically trendless since species identification began in 1999. Model estimates of spawning biomass are also basically trendless over the 1992-2013 period covered by the model. As would be expected from the lack of trend in spawning biomass, estimated recruitments have also been fairly constant, with a CV of 31% for the post-1976 portion of the time series.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

Since 2011, the Alaska skate portions of the ABC and OFL have been specified under Tier 3, while the "other skates" portions have been specified under Tier 5.

Because projected spawning biomass for 2015 (115,490 t) exceeds $B_{40\%}$ (74,769 t), Alaska skates are managed in sub-tier "a" of Tier 3. Other reference points are $maxF_{ABC} = F_{40\%} = 0.077$ and $F_{OFL} = F_{35\%} = 0.090$. The Team accepted the author's preferred model. The maximum permissible ABCs for 2015 and 2016 are 34,389 t and 32,199 t, respectively; up 30% and 22% from the current 2015 specification. In contrast, projected spawning biomasses for 2015 and 2016 are down 35% and 37% from last year's projected value for 2015. The Team felt it was unwise to be recommending such large increases in ABC in the face of commensurately large decreases in spawning biomass, and instead recommended holding 2015 and 2016 ABC constant at the 2014 level. The Alaska skate portions of the 2015 and 2016 ABCs are 28,282 t for both years, and the Alaska skate portions of the 2014 and 2015 OFLs are 39,883 t and 37,343 t. The "other skates" component is assessed under Tier 5, based on a natural mortality rate of 0.10 and a biomass estimated using the random effects model. The "other skates" portion of the 2015 and 2016 ABCs is 7,269 t for both years and the "other skates" portion of the 2015 and 2016 OFLs is 9,692 t for both years.

For the skate complex as a whole, OFLs for 2015 and 2016 total 49,575 t and 47,035 t, respectively, and ABCs for 2015 and 2016 total 35,551 t for both years.

Status determination

Alaska skate, which may be viewed as an indicator stock for the complex, is not overfished and is not approaching an overfished condition. The skate complex was not subjected to overfishing. It is not possible to determine whether the other skates complex is overfished or approaching an overfished condition because it is managed under Tier 5.

19. Sculpins

Status and catch specifications (t) of sculpins in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Biomass	OFL	ABC	TAC	Catch
BSAI	2013	215,713	56,400	42,300	5,600	5,829
	2014	215,713	56,424	42,318	5,750	4,570
	2015	180,570	52,365	39,725	n/a	n/a
	2016	180,570	52,365	39,725	n/a	n/a

In 2013, the sculpins TAC increased to 5,900 t after a reallocation of 300 t from the non-specified reserves.

Changes from previous assessment

Biomass estimates and length compositions were included from the 2014 Aleutian Island trawl survey, and the 2013 and 2014 eastern Bering Sea shelf survey. Of these, only the survey biomass estimates have an impact on ABC and OFL.

In previous assessments, the average of the three most recent survey estimates for each region (Aleutian Islands, Bering Sea shelf and Bering Sea slope) had been used to calculate the BSAI sculpin complex biomass estimate. To remain consistent with other Tier 5 assessments, the Team recommends using the random effects model for each region to calculate the biomass estimate for the entire BSAI area.

Spawning biomass and stock trends

Biomass estimates for 6 of the most abundant sculpin species on the EBS shelf seem to be relatively stable and comprise 95% of the total sculpin biomass. EBS slope trawl surveys, conducted since 2002, show a different sculpin community than seen on the EBS shelf and AI.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The Plan team supported the authors' recommendation to use an average *M* rate using a biomass-weighted average of the instantaneous natural mortality rates for the six most abundant sculpin species in the BSAI. The complex mortality rate may change as new survey data become available. The Team recommended using the random effects model to estimate the biomass for the entire BSAI area. The total (Tier 5) sculpin recommended ABCs and OFLs for 2015 and 2016 are 39,725 t and 52,365 t, respectively.

Status determination

The sculpin complex is not being subjected to overfishing. It is not possible to determine whether the sculpin complex is overfished or whether it is approaching an overfished condition because it is managed under Tier 5.

20. Sharks

Status and catch specifications (t) of sharks in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Biomass	OFL	ABC	TAC	Catch
BSAI	2013	n/a	1,360	1,020	100	116
	2014	n/a	1,363	1,022	125	122
	2015	n/a	1,363	1,022	n/a	n/a
	2016	n/a	1,363	1,022	n/a	n/a

For 2014, NMFS increased the BSAI TAC to 225 t with a reallocation of 100 t from the non-specified reserves,

Changes from previous assessment

OFL and ABC are based on historical catches, so there are no new data that would impact ABC or OFL. The authors recommended changing the formula for computing ABC and OFL to one based on average rather than maximum catch over the 1997-2007 period, but the Team recommends retaining the existing formula.

Spawning biomass and stock trends

The main species taken in the BSAI fisheries (mainly pollock and cod) are Pacific sleeper sharks and salmon sharks. Beginning around 2000, catch rates of sleeper sharks in both the IPHC longline survey and the bycatch fisheries declined steeply for several years, causing possible concern about depletion. On the other hand, all sleeper sharks taken in the survey and fisheries are juveniles, so it is impossible to know what effect those catches have on spawning stock biomass. Recent catch levels have been well below ABC.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The SSC has placed sharks in Tier 6, where OFL and ABC are typically based on historical catches. Consistent with past policy, the Team recommended setting OFL at the maximum catch during the period 1997-2007 (1,363 t, taken in 2002), and ABC at 75 percent of OFL, which continues to be 1,022 t. (The small changes in the above table between 2013 and 2014-2016 result from different rounding practices.)

Status determination

The shark complex is not being subjected to overfishing. It is not possible to determine whether this species complex is overfished or whether it is approaching an overfished condition because it is managed under Tier 6.

21. Squids

Status and catch specifications (t) of squid in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Biomass	OFL	ABC	TAC	Catch
BSAI	2013	n/a	2,620	1,970	700	300
	2014	n/a	2,624	1,970	310	1,678
	2015	n/a	2,624	1,970	n/a	n/a
	2016	n/a	2,624	1,970	n/a	n/a

In 2014, the squids TAC increased to 1,764 t after a reallocation of 1,454 t from the non-specified reserves.

Changes from previous assessment

While no methodological changes were made to this assessment, the authors provided new information on length distribution on fisheries catch which suggests that, in some years, fishing occurred on two cohorts, while in other years, only one cohort was evident. This information does not impact ABC or OFL.

Spawning biomass and stock trends

Survey biomass is not considered a reliable indicator of stock trends for squid.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

Squids are managed under Tier 6 because the groundfish bottom trawl surveys do not provide reliable biomass estimates. The Team concurred with the author's ABC and OFL recommendations for 2015 and 2016, which are unchanged from last year. The recommended ABCs for 2015 and 2016 are the maximum permissible level, calculated as 0.75 times the average catch from the reference period of 1978-1995, or 1,970 t. The recommended OFLs in 2015 and 2016 are calculated as the average catch from 1978-1995, or 2,624 t. (The small change in the above table between 2013 and 2014-2016 result from different rounding practices.)

Status determination

The squid complex is not being subjected to overfishing. It is not possible to determine whether this species complex is overfished or whether it is approaching an overfished condition because it is managed under Tier 6.

22. Octopus

Status and catch specifications (t) of octopus in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2015 and 2016 are those recommended by the Plan Team. Catch data are current through November 8, 2014.

Area	Year	Biomass	OFL	ABC	TAC	Catch
BSAI	2013	n/a	3,450	2,590	500	224
	2014	n/a	3,450	2,590	225	351
	2015	n/a	3,452	2,589	n/a	n/a
	2016	n/a	3,452	2,589	n/a	n/a

For 2014, NMFS increased the TAC to 425 t with a reallocation of 200 t from the non-specified reserves,

Changes from previous assessment

This chapter was presented as a full assessment. No changes were made in the methodology for assessing octopus based on consumption of octopus by Pacific cod. The consumption estimate using Pacific cod predation of octopus as an estimator of biomass lost due to natural mortality first was accepted in 2011; the authors recommended that this calculation be revisited once every five years.

The following new data were included in this year's assessment:

- updated 2013 and preliminary 2014 catch
- 2014 EBS shelf and Aleutian Islands survey data

These data do not impact ABC or OFL.

Spawning biomass and stock trends

Estimated survey biomass was higher in 2014 than in the survey in 2013 for the Bering Sea shelf and in 2012 for the Aleutian Islands. Species composition and size frequencies from the surveys were similar to previous years.

On the EBS shelf and in the commercial catch, giant Pacific octopus is the most abundant of at least seven octopus species found in the BSAI. Octopuses are commonly caught in pot and trawl fisheries, especially in the Pacific cod pot fishery. Trawl surveys sample octopus poorly, and biomass estimates from trawl surveys are not considered reliable.

Tier determination/Plan Team discussion and resulting ABCs and OFLs

The ABC and OFL values were determined under Tier 6. Usually, Tier 6 specifications are based on average catch, but starting in 2012, the assessment authors recommended setting harvest specifications using an alternative mortality estimate based on species composition of Bering Sea Pacific cod diet from 1984-2008 survey data and weight-at-age data. This method is also recommended for 2015 and 2016. The recommended ABCs and OFLs for 2015 and 2016 are unchanged from the 2014 values.

Status determination

The octopus complex is not being subjected to overfishing. It is not possible to determine whether the octopus complex is overfished or whether it is approaching an overfished condition because it is managed under Tier 6.

Appendix 1: Grenadiers

An abbreviated grenadier assessment is provided in Appendix 1; while not required, it is provided to assist the Council in tracking abundance of the assemblage in the groundfish FMPs.

The Secretary of Commerce approved Amendments 100/91 on August 6, 2014, which added the grenadier complex into both FMPs as Ecosystem Components. Under this rule, they are not allowed to be targeted but there is an 8% Maximum Retainable Allowance (MRA) (Federal Register, Proposed Rules, Vol. 79, No. 93). The final rule will publish before the end of the year and so it may be effective for the start of the 2015 fishing year.

As an Ecosystem Component, a stock assessment is not required and there is no ABC or OFL.

Seven species of grenadiers are known to occur in Alaska. The giant grenadier is the most abundant and has the shallowest depth distribution on the continental slope. The assessment focused on the giant grenadier as it is the most common grenadier caught in both the commercial fishery and longline and trawl surveys. Pacific grenadiers and popeye grenadiers are occasionally caught.

Overall, the estimate of total catch of grenadier in 2013 (15,504 mt) was almost the same as in 2012 (15,119 t) (Table 1). Catch in 2013 was up 13% from the 2003-2012 average. Even though the great majority of grenadier catch occurs by Oct. 1, the catch estimate in 2014 is only 7,863 t. For example, by Oct. of 2013 95% of the catch was taken. Thus, the assessment authors expect that the final catch estimate for 2014 will be much lower than average. It is possible that this is related to observer restructuring. Highest catches have consistently been in the GOA. By region, annual catches have ranged between 5,400-14,700 t in the GOA, 1,600-5,000 t in the EBS, and 1,300-4,600 t in the AI. Most of the catch occurs in longline and pot fisheries.

Changes in the input data

New data inputs include: 1) updated catch data for 2003-2014; 2) updated 2000-2014 Aleutian Island (AI) biomass from 1-1,000 m using the estimation method presented in the 2012 SAFE; 3) NMFS longline survey results for 2013 and 2014; 4) updated GOA biomass using a random effects model. There was no EBS slope trawl survey in 2014.

Changes in assessment methodology

This year the authors used a random effects model (a similar method, a Kalman filter, was presented in the 2012 SAFE report (Rodgveller et al. 2012)), that utilizes trawl survey data from 1984-2013 to estimate the exploitable biomass in 2013. Since there was no trawl survey in the GOA in 2014, the estimate for 2013 is used as the most recent value of exploitable biomass.

If the complex had been included in the fishery under the FMPs in 2014, Tier 5 determinations would have resulted in the following OFLs and ABCs. For 2015, the maximum allowable ABC for the BSAI is 75,274 t and for the GOA is 30,691 t. This ABC is a 12% increase for the BSAI and a 12% decrease for the GOA. The corresponding reference values for grenadier are summarized in the following tables, with the recommended ABC and OFL values in bold. Overfishing is not occurring in either the BSAI or GOA.

Table 1. BSAI Groundfish Plan Team Recommended OFLs, and ABCs for 2015 and 2016; OFL, ABC, TAC and catch through November 8, 2014

		2014			2014 Catch	2015		2016	
Species	**Area**	**OFL**	**ABC**	**TAC**	**as of 11/8/14**	**OFL**	**ABC**	**OFL**	**ABC**
Pollock	EBS	2,795,000	1,369,000	1,267,000	1,294,703	3,330,000	1,637,000	3,319,000	1,554,000
	AI	42,811	35,048	19,000	2,375	36,005	29,659	38,699	31,900
	Bogoslof	13,413	10,059	75	427	21,200	15,900	21,200	15,900
Pacific cod	BS	299,000	255,000	246,897	208,053	346,000	255,000	389,000	255,000
	AI	20,100	15,100	6,997	6,145	23,400	17,600	23,400	17,600
Sablefish	BS	1,584	1,339	1,339	315	1,575	1,333	1,431	1,211
	AI	2,141	1,811	1,811	817	2,128	1,802	1,934	1,637
Yellowfin sole	BSAI	259,700	239,800	184,000	143,805	266,400	248,800	262,900	245,500
Greenland turbot	BSAI	2,647	2,124	2,124	1,653	3,903	3,172	6,453	5,284
	BS	n/a	1,659	1,659	1,476	n/a	2,448	n/a	4,050
	AI	n/a	465	465	177	n/a	724	n/a	1,198
Arrowtooth flounder	BSAI	125,642	106,599	25,000	18,697	93,856	80,547	91,663	78,661
Kamchatka flounder	BSAI	8,270	7,100	7,100	6,395	10,500	9,000	11,000	9,500
Northern rock sole	BSAI	228,700	203,800	85,000	51,549	187,600	181,700	170,100	164,800
Flathead sole	BSAI	79,633	66,293	24,500	16,102	79,419	66,130	76,504	63,711
Alaska plaice	BSAI	66,800	55,100	24,500	18,808	54,000	44,900	51,600	42,900
Other flatfish	BSAI	16,700	12,400	2,650	4,388	17,700	13,250	17,700	13,250
Pacific Ocean perch	BSAI	39,585	33,122	33,122	32,373	42,558	34,988	40,809	33,550
	BS	n/a	7,684	7,684	7,429	n/a	8,771	n/a	8,411
	EAI	n/a	9,246	9,246	9,021	n/a	8,312	n/a	7,970
	CAI	n/a	6,594	6,594	6,439	n/a	7,723	n/a	7,406
	WAI	n/a	9,598	9,598	9,485	n/a	10,182	n/a	9,763
Northern rockfish	BSAI	12,077	9,761	2,594	2,339	15,337	12,488	15,100	12,295
Blackspotted/Rougheye	BSAI	505	416	416	196	799	648	865	702
Rockfish	EBS/EAI	n/a	177	177	98	n/a	203	n/a	218
	CAI/WAI	n/a	239	239	98	n/a	445	n/a	484
Shortraker rockfish	BSAI	493	370	370	194	690	518	690	518
Other rockfish	BSAI	1,550	1,163	773	931	1,667	1,251	1,667	1,251
	BS	n/a	690	300	316	n/a	695	n/a	695
	AI	n/a	473	473	615	n/a	555	n/a	555
Atka mackerel	BSAI	74,492	64,131	32,322	30,947	125,297	106,000	115,908	98,137
	EAI/BS	n/a	21,652	21,652	21,185	n/a	38,493	n/a	35,637
	CAI	n/a	20,574	9,670	9,520	n/a	33,108	n/a	30,652
	WAI	n/a	21,905	1,000	242	n/a	34,400	n/a	31,848
Skates	BSAI	41,849	35,383	26,000	24,695	49,575	35,551	47,035	35,551
Sculpins	BSAI	56,424	42,318	5,750	4,570	52,365	39,725	52,365	39,725
Sharks	BSAI	1,363	1,022	125	122	1,363	1,022	1,363	1,022
Squids	BSAI	2,624	1,970	310	1,678	2,624	1,970	2,624	1,970
Octopuses	BSAI	3,450	2,590	225	351	3,452	2,589	3,452	2,589
Total	BSAI	4,196,553	2,572,819	2,000,000	1,872,627	4,769,413	2,842,543	4,764,462	2,728,127

Table 2. Groundfish catches (metric tons) in the eastern Bering Sea, 1954-2014.

Year	Pollock	Pacific Cod	Sable Fish	Yellowfin Sole	Greenland Turbot	Arrowtooth Flounder/a	Kamchatka Flounder/d	Rock Sole/c	Flathead sole	Alaska Plaice	Other Flatfish
1954				12,562							
1955				14,690							
1956				24,697							
1957				24,145							
1958	6,924	171	6	44,153							
1959	32,793	2,864	289	185,321							
1960			1,861	456,103	36,843						
1961			15,627	553,742	57,348						
1962			25,989	420,703	58,226						
1963			13,706	85,810	31,565						35,643
1964	174,792	13,408	3,545	111,177	33,729						30,604
1965	230,551	14,719	4,838	53,810	9,747						11,686
1966	261,678	18,200	9,505	102,353	13,042						24,864
1967	550,362	32,064	11,698	162,228	23,869						32,109
1968	702,181	57,902	4,374	84,189	35,232						29,647
1969	862,789	50,351	16,009	167,134	36,029						34,749
1970	1,256,565	70,094	11,737	133,079	19,691	12,598					64,690
1971	1,743,763	43,054	15,106	160,399	40,464	18,792					92,452
1972	1,874,534	42,905	12,758	47,856	64,510	13,123					76,813
1973	1,758,919	53,386	5,957	78,240	55,280	9,217					43,919
1974	1,588,390	62,462	4,258	42,235	69,654	21,473					37,357
1975	1,356,736	51,551	2,766	64,690	64,819	20,832					20,393
1976	1,177,822	50,481	2,923	56,221	60,523	17,806					21,746
1977	978,370	33,335	2,718	58,373	27,708	9,454					14,393
1978	979,431	42,543	1,192	138,433	37,423	8,358					21,040
1979	913,881	33,761	1,376	99,017	34,998	7,921					19,724
1980	958,279	45,861	2,206	87,391	48,856	13,761					20,406
1981	973,505	51,996	2,604	97,301	52,921	13,473					23,428
1982	955,964	55,040	3,184	95,712	45,805	9,103					23,809
1983	982,363	83,212	2,695	108,385	43,443	10,216					30,454
1984	1,098,783	110,944	2,329	159,526	21,317	7,980					44,286
1985	1,179,759	132,736	2,348	227,107	14,698	7,288					71,179
1986	1,188,449	130,555	3,518	208,597	7,710	6,761					76,328
1987	1,237,597	144,539	4,178	181,429	6,533	4,380					50,372
1988	1,228,000	192,726	3,193	223,156	6,064	5,477					137,418
1989	1,230,000	164,800	1,252	153,165	4,061	3,024					63,452
1990	1,353,000	162,927	2,329	80,584	7,267	2,773					22,568
1991	1,268,360	165,444	1,128	94,755	3,704	12,748		46,681			30,401
1992	1,384,376	163,240	558	146,942	1,875	11,080		51,720			34,757
1993	1,301,574	133,156	669	105,809	6,330	7,950		63,942			28,812
1994	1,362,694	174,151	699	144,544	7,211	13,043		60,276			29,720
1995	1,264,578	228,496	929	124,746	5,855	8,282		54,672	14,699		20,165
1996	1,189,296	209,201	629	129,509	4,699	13,280		46,775	17,334		18,529
1997	1,115,268	209,475	547	166,681	6,589	8,580		67,249	20,656		22,957
1998	1,101,428	160,681	586	101,310	8,303	14,985		33,221	24,550		15,355
1999	988,703	146,738	678	69,275	5,401	10,585		40,505	18,534		15,515
2000	1,132,736	151,372	742	84,057	5,888	12,071		49,186	20,342		16,453
2001	1,387,452	142,452	863	63,563	4,252	12,836		28,949	17,757		9,930
2002	1,481,815	166,552	1,143	74,956	3,150	10,821		40,700	15,464		2,588
2003	1,492,039	174,687	1,039	81,050	2,565	13,667		36,375	14,132	10,118	2,922
2004	1,480,552	183,745	1,041	75,502	1,825	17,367		47,862	17,361	7,888	4,755
2005	1,483,022	182,936	1,070	94,383	2,140	13,409		36,814	16,074	11,194	4,566
2006	1,488,031	168,814	1,079	99,156	1,453	11,966		35,878	17,942	17,318	3,123
2007	1,354,502	140,129	1,182	120,962	1,481	11,082		36,364	18,929	19,522	5,699
2008	990,587	139,802	1,141	148,893	2,089	18,897		50,934	24,521	17,377	3,578
2009	810,857	147,174	916	107,512	2,252	19,212		48,145	19,535	13,944	2,133
2010	810,392	142,875	755	118,625	2,273	14,784		52,645	20,097	16,165	2,158
2011	1,199,242	209,250	705	151,166	3,120	16,927	4,478	60,353	13,548	23,656	3,122
2012	1,205,276	232,676	743	147,186	3,062	18,979	2,511	75,776	11,355	16,612	3,501
2013	1,270,802	236,702	634	164,943	1,449	14,022	2,109	59,596	17,348	23,523	1,501
2014/e	*1,295,130*	*208,053*	*315*	*143,805*	*1,476*	*14,517*	*3,205*	*51,394*	*16,093*	*18,808*	*4,337*

a/ Arrowtooth flounder included in Greenland turbot catch statistics, 1960-69.
b/ Includes POP shortraker, rougheye, northern, and sharpchin.
c/ Rock sole prior to 1991 and flathead sole prior to 1995 are included in other flatfish catch statistics.

Table 2. (continued) Groundfish catches (metric tons) in the eastern Bering Sea, 1954-2014.

Year	POP Complx/b	POP	N Rockfish	BS/RE Rockfish	Shortrkr Rockfish	Other Rockfish	Atka Mackerel	Other	Skates	Sculpins	Sharks	Squids	Octopus	Total (All Species)
1954														12,562
1955														14,690
1956														24,697
1957														24,145
1958								147						51,401
1959								380						221,647
1960	6,100													500,907
1961	47,000													673,717
1962	19,900													524,818
1963	24,500													191,224
1964	25,900							736						393,891
1965	16,800							2,218						344,369
1966	20,200							2,239						452,081
1967	19,600							4,378						836,308
1968	31,500							22,058						967,083
1969	14,500							10,459						1,192,020
1970	9,900							15,295						1,593,649
1971	9,800							13,496						2,137,326
1972	5,700							10,893						2,149,092
1973	3,700							55,826						2,064,444
1974	14,000							60,263						1,900,092
1975	8,600							54,845						1,645,232
1976	14,900							26,143						1,428,565
1977	2,654					311		35,902				4,926		1,168,144
1978	2,221					2,614	831	61,537				6,886		1,302,509
1979	1,723					2,108	1,985	38,767				4,286		1,159,547
1980	1,097					459	4,955	34,633				4,040		1,221,944
1981	1,222					356	3,027	35,651				4,182		1,259,666
1982	224					276	328	18,200				3,838		1,211,483
1983	221					220	141	15,465				3,470		1,280,285
1984	1,569					176	57	8,508				2,824		1,458,299
1985	784					92	4	11,503				1,611		1,649,109
1986	560					102	12	10,471				848		1,633,911
1987	930					474	12	8,569				108		1,639,121
1988	1,047					341	428	12,206				414		1,810,470
1989	2,017					192	3,126	4,993				300		1,630,382
1990	5,639					384	480	5,698				460		1,644,109
1991	4,744					396	2,265	16,285				544		1,647,455
1992	3,309					675	2,610	29,993				819		1,831,954
1993	3,763					190	201	21,413				597		1,674,406
1994	1,907					261	190	23,430				502		1,818,628
1995	1,210					629	340	20,928				364		1,745,893
1996	2,635					364	780	19,717				1,080		1,653,828
1997	1,060					161	171	20,997				1,438		1,641,829
1998	1,134					203	901	23,156				891		1,486,704
1999	654					141	2,267	18,916				392		1,318,304
2000	704					239	239	23,098				375		1,497,502
2001	1,148					296	264	23,148				1,761		1,694,671
2002	858					401	572	26,639				1,334		1,826,993
2003	1,391					336	6,362	26,986				1,246		1,864,915
2004		731	116	24	119	318	7,159	27,588				1,000		1,874,953
2005		879	112	12	108	178	3,540	28,066				1,170		1,879,673
2006		1,041	246	7	47	157	3,176	25,077				1,403		1,875,914
2007		870	70	10	114	220	3,005	24,746				1,175		1,740,061
2008		513	22	22	41	222	392	27,152				1,494		1,427,678
2009		623	48	13	69	208	244	25,369				269		1,198,523
2010		3,547	299	30	161	268	150	20,700				305		1,206,229
2011		5,601	198	36	106	328	1,210		22,429	4,874	103	237	576	1,721,266
2012		5,589	91	17	117	211	966		23,746	4,991	94	560	127	1,754,186
2013		5,050	137	27	105	191	147		25,980	5,222	98	158	185	1,829,931
2014/e		*7,429*	*137*	*23*	*93*	*316*	*135*		*23,516*	*4,197*	*119*	*1,568*	*333*	*1,794,998*

d/ Kamchatka flounder included in Arrowtooth flounder prior to 2011.
e/ Data through November 8, 2014.
f/ Octopus, sculpin, sharks, skates included in Other species prior to 2011.
Note: Numbers don't include fish taken for research.

Table 3. Groundfish catches (metric tons) in the Aleutian Islands, 1954-2014.

Year	Pollock	Pacific Cod	Sable Fish	Yellowfin Sole	Greenland Turbot	Arrowtooth Flounder/a	Kamchatka Flounder/d	Rock Sole/c	Flathead sole	Alaska Plaice	Other Flatfish
1954											
1955											
1956											
1957											
1958											
1959											
1960											
1961											
1962											
1963			664		7						
1964		241	1,541		504						
1965		451	1,249		300						
1966		154	1,341		63						
1967		293	1,652		394						
1968		289	1,673		213						
1969		220	1,673		228						
1970		283	1,248		285	274					
1971		2,078	2,936		1,750	581					
1972		435	3,531		12,874	1,323					
1973		977	2,902		8,666	3,705					
1974		1,379	2,477		8,788	3,195					
1975		2,838	1,747		2,970	784					
1976		4,190	1,659		2,067	1,370					
1977	7,625	3,262	1,897		2,453	2,035					
1978	6,282	3,295	821		4,766	1,782					
1979	9,504	5,593	782		6,411	6,436					
1980	58,156	5,788	274		3,697	4,603					
1981	55,516	10,462	533		4,400	3,640					
1982	57,978	1,526	955		6,317	2,415					
1983	59,026	9,955	673		4,115	3,753					
1984	81,834	22,216	999		1,803	1,472					
1985	58,730	12,690	1,448		33	87					
1986	46,641	10,332	3,028		2,154	142					
1987	28,720	13,207	3,834		3,066	159					
1988	43,000	5,165	3,415		1,044	406					
1989	156,000	4,118	3,248		4,761	198					
1990	73,000	8,081	2,116		2,353	1,459					
1991	78,104	6,714	2,071	1,380	3,174	938					88
1992	54,036	42,889	1546	4	895	900		236			68
1993	57,184	34,234	2078		2,138	1,348		318			59
1994	58,708	22,421	1771		3,168	1,334		308			55
1995	64,925	16,534	1119	6	2,338	1,001		356	16		31
1996	28,933	31,389	720	654	1,677	1,330		371	10		51
1997	26,872	25,166	779	234	1,077	1,071		271	32		7
1998	23,821	34,964	595	5	821	694		446	19		35
1999	981	28,117	671	13	460	774		580	34		20
2000	1,244	39,684	1070	13	1,086	1,157		480	80		32
2001	824	34,207	1074	15	1,060	1,220		526	54		43
2002	1,177	30,801	1,118	29	485	1,032		1,165	111		39
2003	1,653	32,459	1,009	0	965	913		964	49		32
2004	1,158	28,873	955	9	434	818		818	38	0	33
2005	1,621	22,699	1,481	2	468	834		549	34	0	26
2006	1,745	24,211	1,151	4	537	1,476		578	39	0	36
2007	2,519	34,356	1,168	2	523	834		762	29	0	25
2008	1,278	31,229	899	0	822	2,473		342	18	0	46
2009	1,662	28,582	1099.775	1	2,263	10,688		570	23	0	45
2010	1,285	29,001	1093.969	0	1,872	24,098		577	29		41
2011	1,208	10,858	1024.415	1	532	3,269	5,493	279	7		56
2012	975	18,223	1204.958	1	1,658	3,400	6,995	322	12	0	42
2013	2,964	13,572	1062.27	0	296	6,484	5,657	210	10	0	35
2014/e	*2,375*	*6,145*	*816.996*	*0*	*177*	*4,180*	*3,190*	*155*	*9*	*0*	*51*

a/ Arrowtooth flounder included in Greenland turbot catch statistics, 1960-69.
b/ Includes POP shortraker, rougheye, northern, and sharpchin.
c/ Rock sole prior to 1991 and flathead sole prior to 1995 are included in other flatfish catch statistics.

Table 3. (continued) Groundfish catches (metric tons) in the Aleutian Islands, 1954-2014.

Year	POP Complx/b	POP	N Rockfish	BS/RE Rockfish	Shortrkr Rockfish	Other Rockfish	Atka Mackerel	Other	Skates	Sculpins	Sharks	Squids	Octopus	Total (All Species)
1954														
1955														
1956														
1957														
1958														
1959														
1960														
1961														
1962	200													200
1963	20,800													21,471
1964	90,300							66						92,652
1965	109,100							768						111,868
1966	85,900							131						87,589
1967	55,900							8,542						66,781
1968	44,900							8,948						56,023
1969	38,800							3,088						44,009
1970	66,900						949	10,671						80,610
1971	21,800							2,973						32,118
1972	33,200						5,907	22,447						79,717
1973	11,800						1,712	4,244						34,006
1974	22,400						1,377	9,724						49,340
1975	16,600						13,326	8,288						46,553
1976	14,000						13,126	7,053						43,465
1977	8,080					3,043	20,975	16,170				1,808		67,348
1978	5,286					921	23,418	12,436				2,085		61,092
1979	5,487					4,517	21,279	12,934				2,252		75,195
1980	4,700					420	15,533	13,028				2,332		108,531
1981	3,622					328	16,661	7,274				1,763		104,199
1982	1,014					2,114	19,546	5,167				1,201		98,233
1983	280					1,045	11,585	3,675				510		94,617
1984	631					56	35,998	1,670				343		147,022
1985	308					99	37,856	2,050				9		113,310
1986	286					169	31,978	1,509				20		96,259
1987	1,004					147	30,049	1,155				23		81,364
1988	1,979					278	21,656	437				3		77,383
1989	2,706					481	14,868	108				6		186,494
1990	14,650					864	21,725	627				11		124,886
1991	2,545					549	22,258	91				30		117,942
1992	10,277					3,689	46,831	3,081				61		164,513
1993	13,375					495	65,805	2,540				85		179,659
1994	16,959					301	69,401	1,102				86		175,614
1995	14,734					220	81,214	1,273				95		183,862
1996	20,443					278	103,087	1,720				87		190,750
1997	15,687					307	65,668	1,555				323		139,049
1998	13,729					385	56,195	2,448				25		134,182
1999	18,501					657	53,966	1,670				9		106,453
2000	14,893					601	46,990	3,010				8		110,348
2001	15,587					610	61,296	4,029				5		120,550
2002	14,996					551	44,722	1,980				10		98,216
2003	18,765					401	52,988	1,326				36		111,560
2004		11,165	4,567	185	123	337	53,405	1,866				14		104,798
2005		9,548	3,852	78	62	286	58,474	1,417				17		101,446
2006		11,826	3,582	196	165	426	58,719	1,943				15		106,650
2007		17,581	3,946	157	210	435	55,742	2,053				13		120,357
2008		16,923	3,265	171	91	390	57,690	2,322				49		118,010
2009		14,725	3,064	184	116	403	72,563	2,514				91		138,594
2010		14,304	4,033	202	139	503	68,496	2,713				105		148,493
2011		18,403	2,566	129	227	616	50,600		732	502	4	99	11	96,616
2012		18,554	2,388	174	227	736	46,859		1,084	808	2	128	11	103,805
2013		26,342	1,900	296	268	623	23,034		1,058	607	17	141	39	84,616
2014/e		*24,944*	*2,202*	*173*	*101*	*615*	*30,812*		*1,179*	*373*	*3*	*110*	*18*	*77,629*

d/ Kamchatka flounder included in Arrowtooth flounder prior to 2011.
e/ Data through November 8, 2014.
f/ Octopus, sculpin, sharks, skates included in Other species prior to 2011.
Note: Numbers don't include fish taken for research.

Table 4. Groundfish catches (metric tons) in the Bering Sea and Aleutian Islands, 1954-2014.

Year	Pollock	Pacific Cod	Sable Fish	Yellowfin Sole	Greenland Turbot	Arrowtooth Flounder/a	Kamchatka Flounder/d	Rock Sole/c	Flathead sole	Alaska Plaice	Other Flatfish
1954				12,562							
1955				14,690							
1956				24,697							
1957				24,145							
1958	6,924	171	6	44,153							
1959	32,793	2,864	289	185,321							
1960			1,861	456,103	36,843						
1961			15,627	553,742	57,348						
1962			25,989	420,703	58,226						
1963			14,370	85,810	31,572						35,643
1964	174,792	13,649	5,086	111,177	34,233						30,604
1965	230,551	15,170	6,087	53,810	10,047						11,686
1966	261,678	18,354	10,846	102,353	13,105						24,864
1967	550,362	32,357	13,350	162,228	24,263						32,109
1968	702,181	58,191	6,047	84,189	35,445						29,647
1969	862,789	50,571	17,682	167,134	36,257						34,749
1970	1,256,565	70,377	12,985	133,079	19,976	12,872					64,690
1971	1,743,763	45,132	18,042	160,399	42,214	19,373					92,452
1972	1,874,534	43,340	16,289	47,856	77,384	14,446					76,813
1973	1,758,919	54,363	8,859	78,240	63,946	12,922					43,919
1974	1,588,390	63,841	6,735	42,235	78,442	24,668					37,357
1975	1,356,736	54,389	4,513	64,690	67,789	21,616					20,393
1976	1,177,822	54,671	4,582	56,221	62,590	19,176					21,746
1977	985,995	36,597	4,615	58,373	30,161	11,489					14,393
1978	985,713	45,838	2,013	138,433	42,189	10,140					21,040
1979	923,385	39,354	2,158	99,017	41,409	14,357					19,724
1980	1,016,435	51,649	2,480	87,391	52,553	18,364					20,406
1981	1,029,021	62,458	3,137	97,301	57,321	17,113					23,428
1982	1,013,942	56,566	4,139	95,712	52,122	11,518					23,809
1983	1,041,389	93,167	3,368	108,385	47,558	13,969					30,454
1984	1,180,617	133,160	3,328	159,526	23,120	9,452					44,286
1985	1,238,489	145,426	3,796	227,107	14,731	7,375					71,179
1986	1,235,090	140,887	6,546	208,597	9,864	6,903					76,328
1987	1,266,317	157,746	8,012	181,429	9,599	4,539					50,372
1988	1,271,000	197,891	6,608	223,156	7,108	5,883					137,418
1989	1,386,000	168,918	4,500	153,165	8,822	3,222					63,452
1990	1,426,000	171,008	4,445	80,584	9,620	4,232					22,568
1991	1,346,464	172,158	3,199	96,135	6,878	13,686		46,681			30,489
1992	1,438,412	206,129	2104	146,946	2,770	11,980		51,956			34,825
1993	1,358,758	167,390	2747	105,809	8,468	9,298		64,260			28,871
1994	1,421,402	196,572	2470	144,544	10,379	14,377		60,584			29,775
1995	1,329,503	245,030	2048	124,752	8,193	9,283		55,028	14,715		20,196
1996	1,218,229	240,590	1349	130,163	6,376	14,610		47,146	17,344		18,580
1997	1,142,140	234,641	1326	166,915	7,666	9,651		67,520	20,688		22,964
1998	1,125,249	195,645	1181	101,315	9,124	15,679		33,667	24,569		15,390
1999	989,684	174,855	1349	69,288	5,861	11,359		41,085	18,568		15,535
2000	1,133,980	191,056	1812	84,070	6,974	13,228		49,666	20,422		16,485
2001	1,388,276	176,659	1937	63,578	5,312	14,056		29,475	17,811		9,973
2002	1,482,992	197,353	2,261	74,985	3,635	11,853		41,865	15,575		2,627
2003	1,493,692	207,146	2,048	81,050	3,530	14,580		37,339	14,181	10,118	2,954
2004	1,481,710	212,618	1,996	75,511	2,259	18,185		48,681	17,398	7,888	4,788
2005	1,484,643	205,635	2,551	94,385	2,608	14,243		37,362	16,108	11,194	4,592
2006	1,489,776	193,025	2,229	99,160	1,989	13,442		36,456	17,981	17,318	3,160
2007	1,357,021	174,485	2,350	120,964	2,004	11,916		37,126	18,958	19,522	5,724
2008	991,865	171,030	2,040	148,894	2,911	21,370		51,276	24,540	17,377	3,624
2009	812,520	175,756	2015.793	107,513	4,515	29,900		48,716	19,558	13,944	2,178
2010	811,677	171,875	1849.357	118,625	4,145	38,881		53,221	20,127	16,165	2,199
2011	1,200,450	220,109	1729.516	151,168	3,652	20,195	9,971	60,632	13,555	23,656	3,178
2012	1,206,252	250,899	1947.999	147,187	4,720	22,379	9,506	76,098	11,366	16,612	3,543
2013	1,273,766	250,274	1696.713	164,944	1,745	20,507	7,766	59,807	17,358	23,523	1,535
2014/e	*1,297,505*	*214,198*	*1131.552*	*143,805*	*1,653*	*18,697*	*6,395*	*51,549*	*16,102*	*18,808*	*4,388*

a/ Arrowtooth flounder included in Greenland turbot catch statistics, 1960-69.
b/ Includes POP shortraker, rougheye, northern, and sharpchin.
c/ Rock sole prior to 1991 and flathead sole prior to 1995 are included in other flatfish catch statistics.

Table 4. (continued) Groundfish catches in the Bering Sea and Aleutian Islands, 1954-2014.

Year	POP Complx/b	POP	N Rockfish	BS/RE Rockfish	Shortrkr Rockfish	Other Rockfish	Atka Mackerel	Other	Skates	Sculpins	Sharks	Squids	Octopus	Total (All Species)
1954														12,562
1955														14,690
1956														24,697
1957														24,145
1958								147						51,401
1959								380						221,647
1960	6,100													500,907
1961	47,000													673,717
1962	20,100													525,018
1963	45,300													212,695
1964	116,200							802						486,543
1965	125,900							2,986						456,237
1966	106,100							2,370						539,670
1967	75,500							12,920						903,089
1968	76,400							31,006						1,023,106
1969	53,300							13,547						1,236,029
1970	76,800						949	25,966						1,674,259
1971	31,600							16,469						2,169,444
1972	38,900						5,907	33,340						2,228,809
1973	15,500						1,712	60,070						2,098,450
1974	36,400						1,377	69,987						1,949,432
1975	25,200						13,326	63,133						1,691,785
1976	28,900						13,126	33,196						1,472,030
1977	10,734					3,354	20,975	52,072				6,734		1,235,492
1978	7,507					3,535	24,249	73,973				8,971		1,363,601
1979	7,210					6,625	23,264	51,701				6,538		1,234,742
1980	5,797					879	20,488	47,661				6,372		1,330,475
1981	4,844					684	19,688	42,925				5,945		1,363,865
1982	1,238					2,390	19,874	23,367				5,039		1,309,716
1983	501					1,265	11,726	19,140				3,980		1,374,902
1984	2,200					232	36,055	10,178				3,167		1,605,321
1985	1,092					191	37,860	13,553				1,620		1,762,419
1986	846					271	31,990	11,980				868		1,730,170
1987	1,934					621	30,061	9,724				131		1,720,485
1988	3,026					619	22,084	12,643				417		1,887,853
1989	4,723					673	17,994	5,101				306		1,816,876
1990	20,289					1,248	22,205	6,325				471		1,768,995
1991	7,289					945	24,523	16,376				574		1,765,397
1992	13,586					4,364	49,441	33,074				880		1,996,467
1993	17,138					685	66,006	23,953				682		1,854,065
1994	18,866					562	69,591	24,532				588		1,994,242
1995	15,944					849	81,554	22,201				459		1,929,755
1996	23,078					642	103,867	21,437				1,167		1,844,578
1997	16,747					468	65,839	22,552				1,761		1,780,878
1998	14,863					588	57,096	25,604				916		1,620,886
1999	19,155					798	56,233	20,586				401		1,424,757
2000	15,597					840	47,229	26,108				383		1,607,850
2001	16,735					906	61,560	27,177				1,766		1,815,221
2002	15,854					952	45,294	28,619				1,344		1,925,209
2003	20,156					737	59,350	28,312				1,282		1,976,475
2004		11,896	4,684	209	242	656	60,564	29,454				1,014		1,979,752
2005		10,427	3,964	90	170	465	62,014	29,482				1,186		1,981,119
2006		12,867	3,828	203	212	583	61,895	27,021				1,418		1,982,564
2007		18,451	4,016	168	323	655	58,747	26,799				1,188		1,860,418
2008		17,436	3,287	193	133	612	58,082	29,474				1,542		1,545,687
2009		15,347	3,111	197	184	611	72,807	27,883				360		1,337,116
2010		17,852	4,332	232	300	771	68,647	23,413				410		1,354,721
2011		24,004	2,764	165	333	944	51,810		23,161	5,375	107	336	587	1,817,882
2012		24,143	2,479	191	344	947	47,825		24,830	5,799	96	688	138	1,857,991
2013		31,393	2,038	323	372	815	23,181		27,038	5,829	116	300	224	1,914,548
2014/e		32,373	2,339	196	194	931	30,946		24,695	4,570	122	1,678	351	1,872,627

d/ Kamchatka flounder included in Arrowtooth flounder prior to 2011.
e/ Data through November 8, 2014.
f/ Octopus, sculpin, sharks, skates included in Other species prior to 2011.
Note: Numbers don't include fish taken for research.

Table 5. Summary of stock abundance (biomass), overfishing level (OFL), acceptable biological catch (ABC), the fishing mortality rate corresponding to ABC (FABC), and the fishing mortality rate corresponding to OFL (FOFL) for the eastern Bering Sea (EBS), Aleutian Islands (AI), and Bogoslof district as projected for 2015 and 2016. "Biomass" corresponds to projected January abundance for the age+ range reported in the summary. Stock-specific biomass, OFL, and ABC are in metric tons.

Species or Complex	Tier	Area	2015					2016			
			Biomass	OFL	ABC	FOFL	FABC	OFL	ABC	FOFL	FABC
Pollock	1a	EBS	9,203,000	3,330,000	1,637,000		0.392	3,319,000	1,554,000	0.587	0.392
	3b	Aleutian Islands	228,102	36,005	29,659	0.32	0.25	38,699	31,900	0.33	0.27
	5	Bogoslof District	106,000	21,200	15,900	0.2	0.15	21,200	15,900	0.2	0.15
Pacific cod	3a	BS	1,680,000	346,000	255,000	0.35	0.21	389,000	255,000	0.35	0.21
	5	AI	68,900	23,400	17,900	0.34	0.26	23,400	17,900	0.34	0.26
Sablefish	3b	BS	34,000	1,575	1,333	0.098	0.082	1,431	1,211	0.091	0.078
	3b	AI	24,000	2,128	1,802	0.098	0.082	1,934	1,637	0.091	0.078
Yellowfin sole	1a	BSAI	2,127,800	266,400	248,800	0.125	0.117	262,900	245,500	0.125	0.117
Greenland turbot	3b	Total	122,298	3,903	3,172	0.12	0.1	6,453	5,248	0.18	0.15
Arrowtooth flounder	3a	BSAI	908,379	93,856	80,547	0.18	0.153	91,663	78,661	0.18	0.153
Kamchatka flounder	3a	BSAI	174,500	10,500	9,000	0.076	0.065	11,000	9,500	0.076	0.065
Northern rock sole	1a	BSAI	1,233,400	187,600	181,700	0.152	0.143	171,100	164,800	0.152	0.143
Flathead sole	3a	BSAI	736,947	79,419	66,130	0.35	0.28	79,419	66,130	0.35	0.28
Alaska plaice	3a	BSAI	471,500	54,000	44,900	0.175	0.143	51,600	42,900	0.175	0.143
Other flatfish	5	BSAI	143,000	17,700	13,250	0.17/.085/.15	.113/.064/.113	17,700	13,250	0.17/.085/.15	.113/.064/.113
Pacific ocean perch	3a	BSAI	577,967	42,558	34,988	0.109	0.089	40,809	33,550	0.109	0.089
Northern rockfish	3a	BSAI	218,901	15,337	12,488	0.088	0.07	15,100	12,295	0.088	0.07
Shortraker rockfish	5	BSAI	23,009	690	518	0.03	0.0225	690	518	0.03	0.0225
Blackspotted /Rougheye	3a	BSAI	40,327	799	648	0.058	0.047	865	702	0.058	0.047
Other rockfish	5	BSAI	49,630	1,667	1,251	.03/.09	0.0225/.0675	1,667	1,251	.03/.09	0.0225/.0675
Atka mackerel	3a	Total	694,421	125,297	106,000	0.489	0.403	115,908	98,137	0.489	0.403
Skate	3a/5	BSAI	625,314	49,575	35,551	0.09/.100	0.077/.075	47,035	35,551	0.09/.100	0.077/.075
Sculpin	5	BSAI	194,783	52,365	39,725	0.29	0.22	52,365	39,725	0.29	0.22
Shark	6	BSAI	n/a	1,363	1,022	n/a	n/a	1,363	1,022	n/a	n/a
Squid	6	BSAI	n/a	2,624	1,970	n/a	n/a	2,624	1,970	n/a	n/a
Octopus	6	BSAI	n/a	3,452	2,589	n/a	n/a	3,452	2,589	n/a	n/a
Total		BSAI	18,294,178	4,769,433	2,842,843			4,768,377	2,730,847		

Table 6. Summary of groundfish tier designations under Amendment 56, maximum permissible ABC fishing mortality rate (max FABC), the Plan Team's recommended tier designation, ABC fishing mortality rate (FABC), the maximum permissible value of ABC (max ABC), the Plan Team's recommended ABC, and the percentage reduction (% Red.) between max ABC and the Plan Team's recommended ABC for 2015-2016. Stock-specific max ABC and ABC are in metric tons, reported to three significant digits. Fishing mortality rates are reported to two significant digits.

		2014					
Species or Complex	**Area**	**Tier**	**max F_{ABC}**	**F_{ABC}**	**max ABC**	**ABC**	**% Red.**
Pollock	EBS	1a	0.512	0.392	2,900,000	1,637,000	44%
Pacific cod	EBS	3a	0.29	0.21	295,000	255,000	14%
Skates	BSAI	3a/5	0.077/0.075	0.063	41,658	35,551	15%

		2015					
Species or Complex	**Area**	**Tier**	**max F_{ABC}**	**F_{ABC}**	**max ABC**	**ABC**	**% Red.**
Pollock	EBS	1a	0.512	0.392	3,040,000	1,554,000	49%
Pacific cod	EBS	3a	0.29	0.18	316,000	255,000	19%
Skates	BSAI	3a/5	0.077/0.075	0.068	41,658	35,551	15%

Table 7. Species included in assessments for the 2014 BSAI SAFE Report (extends over several pages).

Chapter	Common name	Scientific name	Count
1	**Walleye Pollock**	*Gadus chalcogrammus*	1
2	**Pacific cod**	*Gadus macrocephalus*	1
3	**Sablefish**	*Anoplopoma fimbria*	1
4	**Yellowfin sole**	*Limanda aspera*	1
5	**Greenland turbot**	*Reinhardtius hippoglossoides*	1
6	**Arrowtooth flounder**	*Atherestes stomias*	2
7	**Kamchatka flounder**	*Atherestes evermanni*	
8	**Northern rock sole**	*Lepidopsetta polyxystra n. sp.*	2
	Southern rock sole	*Lepidopsetta bilineata*	
9	**Flathead sole**	*Hippoglossoides classodon*	2
	Bering flounder	*Hippoglossoides robustus*	
10	**Alaska plaice**	*Pleuronectes quadrituberculatus*	1
11	**Other flatfish**		15
	Arctic flounder	*Liopsetta glacialis*	
	butter sole	*Isopsetta isolepis*	
	curlfin sole	*Pleuronectes decurrens*	
	deepsea sole	*Embassichths bathybius*	
	Dover sole	*Microstomus pacificus*	
	English sole	*Parophrys vetulus*	
	longhead dab	*Limanda proboscidea*	
	Pacific sanddab	*Citharichthys sordidus*	
	petrale sole	*Eopsetta jordani*	
	rex sole	*Glyptocephalus zachirus*	
	roughscale sole	*Clidodoerma asperrimum*	
	sand sole	*Psettichthys melanostictus*	
	slender sole	*Lyopsetta exilis*	
	starry flounder	*Platichthys stellatus*	
	Sakhalin sole	*Pleuronectes sakhalinensis*	
12	**Pacific Ocean perch**	*Sebastes alutus*	1
13	**Northern rockfish**	*Sebastes polyspinus*	1
14	**Blackspotted/Rougheye**		2
	Blackspotted rockfish	*Sebastes melanostictus*	
	Rougheye rockfish	*Sebastes aleutianus*	

Table 7. Species included in assessments for the 2014 BSAI SAFE Report (extends over several pages).

Chapter	Common name	Scientific name	Count
15	**Shortraker rockfish**	*Sebastes borealis*	1
16	**Other rockfish***		
	Shortspine thornyhead	*Sebastolobus alascanus*	7
	Dusky rockfish	*Sebastes variabilis*	
	Red banded rockfish	*Sebastes babcocki*	
	Redstripe rockfish	*Sebastes proriger*	
	Harlequin rockfish	*Sebastes variegatus*	
	Sharpchin rockfish	*Sebastes zacentrus*	
	Yelloweye rockfish	*Sebastes ruberrimus*	
17	**Atka mackerel**	*Pleurogrammus monopterygius*	1
18	**Skates**		15
	deepsea skate	*Bathyraja abyssicola*	
	Aleutian skate	*Bathyraja aleutica*	
	Bering skate (complex?)	*Bathyraja interrupta*	
	Commander skate	*Bathyraja lindbergi*	
	whiteblotched skate	*Bathyraja maculata*	
	butterfly skate	*Bathyraja mariposa*	
	whitebrow skate	*Bathyraja minispinosa*	
	Alaska skate	*Bathyraja parmifera*	
	"Leopard" parmifera	*Bathyraja sp. cf. parmifera*	
	mud skate	*Bathyraja taranetzi*	
	roughtail skate	*Bathyraja trachura*	
	Okhotsk skate	*Bathyraja violacea*	
	big skate	*Raja binoculata*	
	roughshoulder skate	*Amblyraja badia*	
	longnose skate	*Raja rhina*	
19	**Sculpins**		48
	Scaled sculpin	*Archistes biseriatus*	
	Bride sculpin	*Artediellus miacanthus*	
	Pacific hookear sculpin	*Artediellus pacificus*	
	Broadfin sculpin	*Bolinia euryptera*	
	Antlered sculpin	*Enophrys diceraus*	
	Leister sculpin	*Enophrys lucasi*	
	Purplegray sculpin	*Gymnocanthus detrisus*	
	Armorhead sculpin	*Gymnocanthus galeatus*	
	threaded sculpin	*Gymnocanthus pistilliger*	
	Arctic staghorn sculpin	*Gymnocanthus tricuspis*	
	Banded Irish lord	*Hemilepidotus gilberti*	
	Red Irish Lord	*Hemilepidotus hemilepidotus*	
	Yellow Irish Lord	*Hemilepidotus jordani*	
	Butterfly sculpin	*Hemilepidotus papilio*	
	Longfin Irish lord	*Hemilepidotus zapus*	
	Northern sculpin	*Icelinus borealis*	
	Blacknose sculpin	*Icelus canaliculatus*	
	Wide-eye sculpin	*Icelus euryops*	
	Spatulate sculpin	*Icelus spatula*	
	thorny sculpin	*Icelus spiniger*	
	Uncinate sculpin	*Icelus uncinalis*	
	Longfin sculpin	*Jordania zonope*	
	Pacific staghorn sculpin	*Leptocottus armatus*	
	Plain sculpin	*Myoxocephalus jaok*	
	Great sculpin	*Myoxocephalus polyacanthocephalus*	
	Fourhorn sculpin	*Myoxocephalus quadricornis*	
	Warty sculpin	*Myoxocephalus verrucocus*	
	Slim sculpin	*Radulinus asprellus*	
	Roughskin sculpin	*Rastrinus scutiger*	
	Sponge sculpin	*thyriscus anoplus*	
	Scissortail sculpin	*Triglops forficatus*	
	Roughspine sculpin	*Triglops macellus*	

Table 7. Species included in assessments for the 2014 BSAI SAFE Report (extends over several pages).

Chapter	Common name	Scientific name	Count
	Crescent-tail sculpin	*Triglops metopias*	
	Ribbed sculpin	*Triglops pingelii*	
	Spectacled sculpin	*Triglops septicus*	
	Scalybreasted sculpin	*Triglops xenostethus*	
	Flabby sculpin	*Zesticelus profundorum*	
	Crested sculpin	*Blepsias bilobus*	
	Bigmouth sculpin	*Hemitripterus bolini*	
	Sailfin sculpin	*Nautichthys oculofasciatus*	
	Eyeshade sculpin	*Nautichthys pribilovius*	
	Spinyhead sculpin	*Dasycottus setiger*	
	Smoothcheek sculpin	*Eurymen gyrinus*	
	Darkfin sculpin	*Malacoccottus zonurus*	
	Blackfin sculpin	*Malacocottus kincaidi*	
	Tadpole sculpin	*Psychrolutes paradoxus*	
	Blob sculpin	*Psychrolutes phrictus*	
	Grunt sculpin	*Rhamphocottus richardsoni*	
20	**Sharks**		8
	brown cat shark	*Apristurus brunneus*	
	White shark	*Carcharodon carcharias*	
	basking shark	*Cetorhinus maximus*	
	sixgill shark	*Hexanchus griseus*	
	salmon shark	*Lamna ditropis*	
	blue shark	*Prionace glauca*	
	Pacific sleeper shark	*Somniosus pacificus*	
	Spiny dogfish	*Squalus acanthias*	
21	**Squids**		14
		Chiroteuthis calyx	
	"glass squids"	*Belonella borealis*	
		Galiteuthis phyllura	
	minimal armhook squid	*Berryteuthis anonychus*	
	magistrate armhook squid	*Berryteuthis magister*	
		Eogonatus tinro	
	boreopacific armhook squid	*Gonatopsis borealis*	
	Berry armhook squid	*Gonatus berryi*	
		Gonatus madokai	
		Gonatus middendorffi	
	clawed armhook squid	*Gonatus onyx*	
	robust clubhook squid	*Moroteuthis robusta*	
	boreal clubhook squid	*Onychoteuthis borealijaponicus*	
	North Pacific bobtail squid	*Rossia pacifica*	
22	**Octopus**		8
	flapjack devilfish	*Opisthoteuthis cf californiana*	
	pelagic octopus	*Japetella diaphana*	
	smooth octopus	*Benthoctopus leioderma*	
		Benthoctopus oregonensis	
		Benthoctopus salebrosus	
	giant octopus	*Enteroctopus dofleini*	
		Granelodone boreopacifica	
	stubby octopus	*Sasakiopus salebrosus*	
Total number of species			**133**

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1. Assessment of the walleye pollock stock in the Eastern Bering Sea

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Executive Summary

This chapter covers the Eastern Bering Sea (EBS) region—the Aleutian Islands region (Chapter 1A) and the Bogoslof Island area (Chapter 1B) are presented separately.

Summary of changes in assessment inputs
The primary changes include:

- The 2014 NMFS summer bottom-trawl survey (BTS) abundance at age estimates are included.
- The 2014 NMFS summer acoustic-trawl (AT) survey estimated abundance-at-age estimates were added.
- Observer data for catch-at-age and average weight-at-age from the 2013 fishery were finalized and included.
- Total catch as reported by NMFS Alaska Regional office was updated and included through 2014.

Changes in the assessment methods
The general modeling approach remained the same. As introduced in 2012, work on developing a density-dependence correction for the bottom-trawl survey data has progressed. This index is included as an alternative model run in which the age compositions and time series of the bottom trawl data are adjusted to account for gear efficiency for the entire time series. The time series of mean estimated population numbers is provided along with an externally estimated covariance matrix. These data are modeled following a multivariate lognormal distribution. The extent that selectivity should vary for the AT survey was re-evaluated. Given that selectivity estimates were exhibiting minor differences over time and, based on an Akaike's information criterion (AIC), the number of parameters was reduced.

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Summary of results

EBS pollock results

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2016
M (natural mortality rate, ages 3+)	0.3	0.3	0.3	0.3
Tier	1a	1a	1a	1a
Projected total (age 3+) biomass (t)	8,045,000 t	7,778,000 t	9,203,000 t	9,420,000 t
Projected female spawning biomass (t)	**2,606,000 t**	**2,467,000 t**	2,850**,000 t**	2,950**,000 t**
B_0	5,334,000 t	5,334,000 t	5,162,000 t	5,162,000 t
B_{MSY}	2,122,000 t	2,122,000 t	1,948,000 t	1,948,000 t
F_{OFL}	0.518	0.518	0.587	0.587
$maxF_{ABC}$	0.469	0.469	0.512	0.512
F_{ABC}	0.25	0.22	0.24	0.25
OFL (t)	2,795,000 t	2,693,000 t	3,330,000 t	3,490,000 t
maxABC (t)	2,528,000 t	2,436,000 t	2,900,000 t	3,040,000 t
ABC (t)	1,369,000 t	1,258,000 t	1,350,000 t	1,350,000 t
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

*Projections are based on estimated catches assuming 1,350,000 t used in place of maximum permissible ABC for 2015 and 2016.

The survey and fishery data continue to confirm that the 2008 year class is well above average. These age 6 pollock in 2014 were estimated to represent 56% of the female spawning stock biomass (following years when that same class comprised 48% and 56% of the spawning biomass in 2012 and 2013 at ages 4 and 5, respectively. Projections indicate that catches in 2015 of 1.35 million t will result in a stable spawning biomass trend through 2016. The maximum permissible Tier 1a ABC remains high. After examining a other population indicators and some alternative model configurations, an ABC is recommended (1,350,000 t) which is well below the maximum permissible (Tier 1a) value of 2,900,000 t. The Tier 1a overfishing level (OFL) is estimated to be 3,330,000 t.

Response to SSC and Plan Team comments

General comments:

The SSC asks assessment authors to project the reference points for the future two years (e.g., 2015 and 2016) on the phase diagrams (December 2013 minutes).

This has been added to the diagram.

The Team also recommended that the authors consider the recommendations of the Recruitment Working Group, once the Teams and SSC have accepted final recommendations

A number of the provisional recommendations from the working group have been included in the approach used for projections and stock-recruit variability specifications. However, in this assessment the approach is the same as used for the 2013 assessment.

Comments specific to this assessment

The Team recommended that the authors explore the use of a matrix of cohort-specific weights at age for making projections.

Future expected body mass-at-age was developed, which account for two-year projections. Adding uncertainty and future expectations of mean body mass at age is an area of planned future research.

The SSC requests that the authors include survey weight-at-age in the assessment to assure that the decreases in weight-at-age are not an artifact of changes in the distribution of the fishery.

Survey weights at age are included in Table 1.14 and results presented in Fig. 1.19 suggests that the 2008 year class is lighter than average. The weights-at-age used in the projections are adjusted accordingly.

The SSC also requests that the study of survey efficiency by Kotwicki be presented to the SSC next September.

This was been included in the September and December 2013 assessments and is included here again as an optional model configuration (identified as mod2.0).

Introduction

Walleye pollock (*Gadus chalcogrammus;* hereafter referred to as pollock) are broadly distributed throughout the North Pacific with the largest concentrations found in the Eastern Bering Sea. Also marketed under the name Alaska pollock, this species continues to represent over 40% of the global whitefish production, with the market disposition split fairly evenly between fillets, whole (headed and gutted), and surimi (Fissel et al. 2013). An important component of the commercial production is the sale of roe from pre-spawning pollock. Pollock are considered to be a relatively fast growing and short-lived species. They play an important role in the Bering Sea ecosystem.

Stock structure

In the U.S. portion of the Bering Sea three stocks of pollock are identified for management purposes. These are: Eastern Bering Sea which consists of pollock occurring on the Eastern Bering Sea shelf from Unimak Pass to the U.S.-Russia Convention line; the Aleutian Islands Region, encompassing the Aleutian Islands shelf region from 170°W to the U.S.-Russia Convention line; and the Central Bering Sea—Bogoslof Island pollock. These three management stocks undoubtedly have some degree of exchange. The Bogoslof stock forms a distinct spawning aggregation that has some connection with the deep-water region of the Aleutian Basin (Hinckley 1987). In the Russian EEZ, pollock are considered to form two stocks, a western Bering Sea stock centered in the Gulf of Olyutorski, and a northern stock located along the Navarin shelf from 171°E to the U.S.- Russia Convention line (Kotenev and Glubokov 2007). There is some indication (based on NMFS surveys) that the fish in the northern region may be a mixture of eastern and western Bering Sea pollock with the former predominant. Bailey et al. (1999) present a thorough

review of population structure of pollock throughout the north Pacific region. Genetic differentiation using microsatellite methods suggest that populations from across the North Pacific Ocean and Bering Sea were similar. However, weak differences were significant on large geographical scales and conform to an isolation-by-distance pattern (O'Reilly et al. 2004; Canino et al. 2005; Grant et al. 2010). Bacheler et al. (2010) analyzed 19 years of egg and larval distribution data for the eastern Bering Sea. Their results suggested that pollock spawn in two pulses spanning 4-6 weeks: first in late February, then again in mid-late April. Their data also suggest three unique areas of egg concentrations, with the region north of Unimak Island and the Alaska Peninsula being the most concentrated. Such syntheses of egg and larval distribution data provide a useful baseline for comparing trends in the distribution of pre-spawning pollock. Recent studies on movement of pollock within the region data are presented in Hulson et al. (2011). This work was extended to evaluate environmental effects on spatial stock structure and the potential impact on management advice (Hulson et al. 2013).

Fishery

EBS pollock catches were low until directed foreign fisheries began in 1964. Catches increased rapidly during the late 1960s and reached a peak in 1970-75 when they ranged from 1.3 to 1.9 million t annually (Fig. 1.1). Following the peak catch in 1972, bilateral agreements with Japan and the USSR resulted in reductions. Since 1977 (when the U.S. EEZ was declared) the annual average EBS pollock catch has been about 1.2 million t, ranging from 0.815 million t in 2009 to nearly 1.5 million t during 2003-2006 (Fig. 1.1). United States vessels began fishing for pollock in 1980 and by 1987 they were able to take 99% of the quota. Since 1988, only U.S. vessels have been operating in this fishery. Observers collected data aboard the foreign vessels since the late 1970s. The current observer program for the domestic fishery formally began in 1991 and has been continually refined and improved. Since 2011, regulations require that all vessels participating in the pollock fishery carry at least one observer. Prior to this time about 70-80% of the catch was observed either at sea or during dockside offloading. During a 10-year period, catches by foreign vessels operating in the "Donut Hole" region of the Aleutian Basin were substantial totaling nearly 7 million t (Table 1.1). A fishing moratorium was enacted in 1993 and only trace amounts of pollock have been harvested from the Aleutian Basin region since then.

Management measures/units

The EBS pollock stock is managed by NMFS regulations that provide limits on seasonal catch. The NMFS observer program data provide near real-time statistics during the season and vessels operate within well-defined limits.

Due to concerns over possible impacts groundfish fisheries may have on rebuilding populations of Steller sea lions, a number of management measures have been implemented. Some measures were designed to reduce the possibility of competitive interactions between fisheries and Steller sea lions. For the pollock fisheries, seasonal fishery catch and pollock biomass distributions (from surveys) indicated that the apparent disproportionately high seasonal harvest rates within Steller sea lion critical habitat *could* lead to reduced sea lion prey densities. Consequently, management measures redistributed the fishery both temporally and spatially according to pollock biomass distributions. This was intended to disperse fishing so that localized harvest rates were more consistent with annual exploitation rates. The measures include establishing: 1) pollock fishery exclusion zones around sea lion rookery or haulout sites; 2) phased-in reductions in the seasonal proportions of TAC that can be taken from critical habitat; and 3) additional seasonal TAC releases to disperse the fishery in time.

Prior to adoption the above management measures, the pollock fishery occurred in each of the three major NMFS management regions of the North Pacific Ocean: the Aleutian Islands (1,001,780 km^2 inside the EEZ), the Eastern Bering Sea (968,600 km^2), and the Gulf of Alaska (1,156,100 km^2). The marine portion of Steller sea lion critical habitat in Alaska west of 150°W encompasses 386,770 km^2 of ocean surface, or 12% of the fishery management regions.

Prior to 1999, 84,100 km^2, or 22% of critical habitat was closed to the pollock fishery. Most of this closure consisted of the 10- and 20-nm radius all-trawl fishery exclusion zones around sea lion rookeries (48,920 km^2, or 13% of critical habitat). The remainder was largely management area 518 (35,180 km^2, or 9% of critical habitat) that was closed pursuant to an international agreement to protect spawning stocks of central Bering Sea pollock.

In 1999, an additional 83,080 km^2 (21%) of critical habitat in the Aleutian Islands was closed to pollock fishing along with 43,170 km^2 (11%) around sea lion haulouts in the GOA and Eastern Bering Sea. In 1998, over 22,000 t of pollock were caught in the Aleutian Island region, with over 17,000 t taken within critical habitat region. Between 1998 and 2004 a directed fishery for pollock was prohibited. Consequently, 210,350 km^2 (54%) of critical habitat was closed to the pollock fishery. The portion of critical habitat that remained open to the pollock fishery consisted primarily of the area between 10- and 20-nm from rookeries and haulouts in the GOA and parts of the southeastern Bering Sea foraging area. In 2000, phased-in reductions in the proportions of seasonal TAC that could be caught within the BSAI Steller sea lion Conservation Area (SCA) were implemented. Since 2005, a limited pollock fishery has been prosecuted in the Aleutian Islands but with less than 2,000 t of annual catch.

On the EBS shelf, an estimate (based on observer at-sea data) of the proportion of pollock caught in the SCA has averaged about 38% annually. During the A-season, the average is about 49% (since pre-spawning pollock are more concentrated in this area during this period). The proportion of pollock caught within the SCA varies considerably, presumably due to temperature regimes and population age structure. Since 2005 the annual proportion of catch within the SCA has dropped considerably (on average) with about 30% of the catch taken in this area. However, the proportion taken in the A-season reached 57% in 2007, the highest level since 1998, but in 2013 only 22% of the A-season catch occurred within the SCA (Table 1.2). In 2014 it increased to 38% during the A season and 37% during B season.

The 1998 American Fisheries Act (AFA) reduced the capacity of the catcher/processor fleet and permitted the formation of cooperatives in each industry sector by the year 2000. Because of some of its provisions, the AFA gave the industry the ability to respond efficiently to changes mandated for sea lion conservation and salmon bycatch measures. Without such a catch-share program, these additional measures would likely have been less effective and less economical.

An additional strategy to minimize potential adverse effects on sea lion populations is to disperse the fishery throughout more of the pollock range on the Eastern Bering Sea shelf. While the distribution of fishing during the A season is limited due to ice and weather conditions, there appears to be some dispersion to the northwest area (Fig. 1.2).

The majority (~56%) of Chinook salmon caught as bycatch in the pollock fishery originate from western Alaskan rivers. An Environmental Impact Statement (EIS) was completed in 2009 in conjunction with the Council's recommended management approach. This EIS evaluated the relative impacts of different bycatch management approaches as well as estimated the impact of bycatch levels on adult equivalent salmon (AEQ) returning to river systems (NMFS/NPFMC 2009). As a result, salmon bycatch management measures went into effect in 2011 (Amendment 91 to the Groundfish FMP resulting from the NPFMC's 2009 action). The program imposes a dual cap system which is divided by sector and season. Annual bycatch is intended to remain below the lower cap to avoid penalty. In order to fish under the dual cap system (as opposed to solely the lower cap) sectors must participate in incentive program agreements (IPAs) that are approved by NMFS and are designed for further bycatch reduction and individual vessel accountability. The fishery has been operating under rules to implement this program since January 2011. During 2008 - 2013, bycatch levels for Chinook salmon have been well below average following record high levels in 2007. This is likely due to industry-based restrictions on areas where pollock fishing may occur, environmental conditions, Amendment 91 measures, and perhaps salmon abundance.

Measures to reduce salmon bycatch in the pollock fishery continue to be considered. This follows from a draft Environmental Assessment presented to the Council in 2012 that examined the impact of the chum salmon bycatch on western Alaska systems. The analysis indicated that the impact rates to some runs returning to Alaskan rivers (specifically western Alaska) appeared to be below 2% in the worst year (with caveats that genetic data failed to discern small regions which could potentially have been more heavily impacted than adjacent larger systems). Chum salmon bycatch remains a concern and the NPFMC is presently evaluating trade-offs of management measures. Due to differences in seasonal and spatial bycatch patterns between chum and Chinook salmon, measures that may reduce the bycatch of one species may increase the bycatch of the other. Consequently, a suite of management options is being evaluated and will be presented at the December 2014 meetings for initial review. Salmon bycatch statistics and further discussion are presented along with other bycatch estimates in the Ecosystem Considerations section below. A summary of some key management measures is provided in Table 1.3.

Fishery characteristics

Pre-spawning aggregations of pollock are the focus of the first so-called A-season that opens on January 20th and extends into early-mid April. During this season, the fishery is characterized as producing highly valued roe that can comprise over 4% of the catch in weight. The second, or B-season, presently opens on June 10th and extends through noon on November 1st. Since the closure of the Bogoslof management district (INPFC area 518) to directed pollock fishing in 1992, the A-season pollock fishery on the EBS shelf has been concentrated primarily north and west of Unimak Island (e.g., Ianelli *et al.* 2013). Depending on ice conditions and fish distribution, there has also been effort along the 100 m contour (and deeper) between Unimak Island and the Pribilof Islands but since 2011, regulations and industry-based measures to reduce salmon bycatch have affected the spatial distribution of the fishery and to some degree, the way individual vessel operators fish (Stram and Ianelli, 2014). The 2014 spatial pattern had relatively high concentrations of fishing on the shelf north of Unimak Island, especially compared to the pattern observed in 2012 and 2013 when most fishing activity occurred farther north (Fig. 1.2). The catch estimates by sex for the A-season compared to estimates for the entire season indicate that over time, the number of males and females has been fairly equal (Fig. 1.3).

Fishing conditions during the A-season have in recent years appear to be characterized by lower production of roe relative to total pollock caught in that season but some improvement in 2014 (Fig. 1.4). This might be due in part to colder conditions, slower maturing pollock given their age/size (which may also be related to colder condtions), and changes in the fishery distribution (e.g., in areas outside of the industry's Chinook salmon hot-spot closure areas; farther to the north than has been typical).

The 2014 summer and fall (B-season) fishing was also characterized as having catches distributed closer to Unimak Island than in recent years (Fig. 1.5). Fishing conditions, as measured by computing nominal catch per hour from NMFS observer data, were similar to the 2013 pattern with reasonably good rates compared with the previous two years (Fig. 1.6). For each tow in the pollock fishery, a NMFS observer records the estimated number of fish and the total weight. These data can be used to compute the average weight of pollock in each tow and when binned by 50-gram categories, fine-scale weekly size frequency patterns can be evaluated by sector (e.g., Fig. 1.7). Presently these data have only been used for visualization. Their value as a fishery indicator for the asssessment model (relative to the normal length frequency data collected by observers) is an area of research that might be worth pursuing.

From 1977-2014 the catch of EBS pollock has averaged 1.174 million t (Table 1.4). Since 2001, the average has been above 1.268 million t. However, the 2009 and 2010 catch dropped to 0.81 million t due to stock declines and concomitant reductions in allowable harvest rates. Since 2011 the TAC (and catch) has averaged 1.24 million t.

Pollock catch in the Eastern Bering Sea and Aleutian Islands by area from observer estimates of retained and discarded catch for 1991-2014 are shown in Table 1.5. Since 1991, estimates of discarded pollock have ranged from a high of 9.1% of total pollock catch in 1992 to recent lows of around 0.6%. These low

values reflect the implementation of the Council's Improved Retention /Improved Utilization program. Prior to the implementation of the AFA in 1999, higher discards may have occurred under the "race for fish" and incidental catch of pollock that were below marketable sizes. Since implementation of the AFA, the vessel operators have more time to pursue optimal sizes of pollock for market since the quota is allocated to vessels (via cooperative arrangements). In addition, several vessels have made gear modifications to avoid retention of smaller pollock. In all cases, the magnitude of discards counts as part of the total catch for management (to ensure the TAC is not exceeded) and within the assessment. Bycatch of other non-target, target, and prohibited species is presented in the section titled Ecosystem Considerations below. In that section it is noted that the bycatch of pollock in other target fisheries is more than double the bycatch of other target species (e.g., Pacific cod) in the pollock fishery.

Data

The following data were used in the assessment

Source	Type	Years
Fishery	Catch biomass	1964-2014
Fishery	Catch age composition	1964-2013
Fishery	Japanese trawl CPUE	1965-1976
EBS bottom trawl	Area-swept abundance (numbers) index	1982-2014
EBS bottom trawl	Proportions at age	1982-2014
Acoustic trawl survey	Population abundance (numbers) index	1979, 1982, 1985, 1988, 1991, 1994, 1996, 1997, 1999, 2000, 2002, 2004, 2006-2010, 2012, 2014
Acoustic trawl survey	Proportions at age	1979, 1982, 1985, 1988, 1991, 1994, 1996, 1997, 1999, 2000, 2002, 2004, 2006-2010, 2012, 2014
Acoustic vessels of opportunity (AVO)	Population abundance (numbers) index	2006-2013 (same as in 2013)

Fishery

The catch-at-age composition was estimated using the methods described by Kimura (1989) and modified by Dorn (1992). Length-stratified age data are used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates are then weighted by the catch within each stratum to arrive at an overall age composition for each year. Data were collected through shore-side sampling and at-sea observers. The three strata for the EBS were: *i*) January–June (all areas, but mainly east of 170°W); *ii*) INPFC area 51 (east of 170°W) from July–December; and *iii*) INPFC area 52 (west of 170°W) from July–December. This method was used to derive the age compositions from 1991-2013 (the period for which all the necessary information is readily available). Prior to 1991, we used the same catch-at-age composition estimates as presented in Wespestad *et al.* (1996).

The catch-at-age estimation method uses a two-stage bootstrap re-sampling of the data. Observed tows were first selected with replacement, followed by re-sampling actual lengths and age specimens given those set of tows. This method allows an objective way to specify the effective sample size for fitting fishery age composition data within the assessment model. In addition, estimates of stratum-specific fishery mean weights-at-age (and variances) are provided which are useful for evaluating general patterns in growth and growth variability. For example, Ianelli et al. (2007) showed that seasonal aspects of pollock condition factor could affect estimates of mean weight-at-age. They showed that within a year, the condition factor for pollock varies by more than 15%, with the heaviest pollock caught late in the year from October-December (although most fishing occurs during other times of the year) and the thinnest fish at length tending to occur in late winter. They also showed that spatial patterns in the fishery affect

mean weights, particularly when the fishery is shifted more towards the northwest where pollock tend to be smaller at age. In 2011 the winter fishery catch consisted primarily of age 5 pollock (the 2006 year class) and later in that year age 3 pollock (the 2008 year class) were present. In 2012 and 2013 the 2008 year class became prominent as 4- and 5-year olds in the catches (Fig. 1.8; Table 1.6).

Since 1999 the observer program adopted a new sampling strategy for lengths and age-determination studies (Barbeaux et al. 2005). Under this scheme, more observers collect otoliths from a greater number of hauls (but far fewer specimens per haul). This has improved the geographic coverage but lowered the total number of otoliths collected. Previously, large numbers were collected but most were not aged. The sampling effort for lengths has decreased since 1999 but the number of otoliths processed for age-determinations increased (Tables 1.7 and 1.8). Sampling for pollock lengths and ages by area has been shown to be relatively proportional to catches (e.g., Fig. 1.8 *in* Ianelli et al. 2004). For total pollock catch biomass, Miller (2005) estimated the CV to be on the order of 1%

Surveys

Scientific research catches are reported to fulfill requirements of the Magnuson-Stevens Fisheries Conservation and Management Act. The annual estimated research catches (1963 - 2014) from NMFS surveys in the Bering Sea and Aleutian Islands Region are given in Table 1.9. Since these values represent extremely small fractions of the total removals (~0.02%) they are ignored as a contributor to the catches as modeled for assessment purposes.

Bottom trawl surveys (BTS)

Trawl surveys have been conducted annually by the AFSC to assess the abundance of crab and groundfish in the Eastern Bering Sea since 1979 and since 1982 using consistent areas and gears. For pollock, this survey has been instrumental in providing an abundance index and information on the population age structure. This survey is complemented by the acoustic trawl (AT) surveys that sample mid-water abundance levels. Between 1991 and 2014 the BTS biomass estimates ranged from 2.28 to 8.39 million t (Table 1.10; Fig. 1.9). In the mid-1980s and early 1990s several years resulted in above-average biomass estimates. The stock appeared to be at lower levels during 1996-1999 then increased moderately until about 2003 and since then has averaged about 3.7 million t—excluding the jump in biomass observed in 2014 (which brings the 2004-2014 average to just over 4 million t). These surveys are multi-purpose and serve as a consistent measure of environmental conditions such as temperature characterizations that reflect the cold conditions experienced during 2006-2013. Large-scale zoogeographic shifts in the EBS shelf due to temperature changes have been documented during a warming trend (e.g., Mueter and Litzow 2008). However, after a period of relatively warm conditions ending in 2005, seven years were below average, indicating that the zoogeographic responses may be less temperature dependent than initially appeared (Kotwicki and Lauth 2013). Bottom temperatures increased in 2011 to about average from the low value in 2010 but declined again in 2012-2013 and in 2014 increased dramatically along with surface temperatures (Fig. 1.10).

Beginning in 1987 NMFS expanded the standard survey area farther to the northwest. The pollock biomass levels found in these “non-standard” strata were highly variable, ranging from 1% to 22% of the total biomass; the 2014 estimate is 12% compared to the overall average of 6% overall (Table 1.11). In some years (e.g., 1997 and 1998) some stations had high catches of pollock in that region and this resulted in high (CVs of 95% and 65% for 1997 and 1998 respectively). This region is contiguous with the Russian border and these strata improve coverage over the range of the exploited pollock stock. The use of the additional strata was evaluated in 2006 and accepted as appropriate by the Council’s SSC.

The 2014 biomass estimate was 7.43 million t, about 55% more than the average for this survey (4.8 million t). This survey estimate ranks 2nd out of the 27 estimates since 1987 and is the largest estimate since 2003. The distribution of pollock was spread throughout the shelf region, with the biggest concentrations in the middle and outer domain of the shelf and relatively unconstrained by the warmer

bottom temperatures (Fig. 1.11). Comparing the past several years shows that pollock appear to occur at higher densities in most stations in 2014 (Fig. 1.12).

In general, much of the interannual variability of survey estimates is due to the effect of year class variability. Survey abundance-at-age estimates reflect the impact of this variability (Fig. 1.13). The BTS operations generally catch pollock above 40 cm in length, and in some years include many 1-year olds (with modal lengths around 10-19 cm) but rarely age 2 pollock (lengths around 20-29 cm). Other sources of variability may be unaccounted-for variability in natural mortality, survey catchability, and migration. For example, some strong year classes appear in the surveys over several ages (e.g., the 1989 year class) while others appear only at older ages (e.g., the 1992 year class). Sometimes initially strong year classes appear to wane in successive assessments (e.g., the 1996 year class estimate dropped from 43 billion in 2003 to 32 billion in 2007 (Ianelli et al. 2007). Retrospective analyses (e.g., Parma 1993) have also highlighted these patterns, as presented in Ianelli et al. (2006, 2011). Kotwicki et al. (2013) also found that that the catchability of either BTS or AT survey for pollock is variable in space and time because it depends on environmental variables, and is density-dependent in the case of the BTS survey. Model 2.0 in this assessment accounts for this variability.

The 2014 survey age compositions were developed from age-structures collected during the survey (June-July) and processed at the AFSC labs within a few weeks after the survey was completed. The level of sampling for lengths and ages in the BTS is shown in Table 1.12. The estimated numbers-at-age from the BTS for the standard strata (1-6) and for the northern strata included are presented in Table 1.13 and the corresponding mean body mass at ages are given in Table 1.14.

As in previous assessments, a descriptive evaluation the BTS data alone was conducted to evaluate mortality patterns. Cotter et al. (2004) promoted this type of analysis as having a simple and intuitive appeal which is independent of population scale. In this approach, log-abundance of age 6 and older pollock is regressed against age by cohort. The negative values estimated for the slope are estimates of total annual mortality. Age-6 was selected because younger pollock are still recruiting to the bottom trawl survey gear. A key assumption of this analysis is that all ages are equally available to the gear. Total mortality by cohort seems to be variable (unlike the example in Cotter et al., 2004). Cohorts from the early 1990s appear to have lower total mortality than cohorts since the mid-1990s, which average around 0.4 (Fig. 1.14). Total mortality estimates by cohort represent lifetime averages since harvest rates (and actual natural mortality) vary from year to year. The low values estimated for some year classes (e.g., the 1992 cohort) could be because these age groups only become available to the survey at a later age (i.e., that the availability/selectivity to the survey gear changed for these cohorts). Alternatively, it may suggest some net immigration into the survey area or a period of lower natural mortality. In general, these values are consistent with the types of values obtained from within the assessment models. The low values for the most recent cohorts are due to the increased abundances observed in 2013 and 2014. This can be observed in an output diagnostic using the software "YCC" (Cotter et al. 2007) which fit both age and year coefficients to examine trends in cohorts (Fig. 1.15).

New studies on the efficiency of bottom-trawl gear for estimating pollock densities have been completed (Kotwicki et al. 2014). They found that bottom-trawl efficiency decreased with increasing bottom trawl catches, resulting in hyper-stability (under-estimates during high abundance levels) of the index of abundance derived from bottom trawl survey. They developed a method for correcting these density-dependent effects to avoid potential issues associated with hyper-stability. Since these factors can span years in the way they are modeled, the assessment model was modified to accept an estimated covariance matrix so that the BTS abundance data could be modeled following a multivariate normal distribution (see Model Details section below). This index (normalized to have the same mean) shows a slight departure from the current BTS values and the estimated uncertainty is greater (Fig. 1.16). The input covariance matrix ($\boldsymbol{\Sigma}$) can be provided from the authors upon request.

Other time series used in the assessment

Acoustic trawl (AT) surveys
The AT surveys are conducted biennially and are designed to estimate the off-bottom component of the pollock stock (compared to the BTS which are conducted annually and provide an abundance index of the near-bottom pollock; Table 1.10). The number of trawl hauls, lengths, and ages sampled from the AT survey are presented in Table 1.15. Relative estimation errors for the total biomass (presented as CVs) were derived from a one-dimensional (1D) geostatistical method (Petitgas 1993, Walline 2007, Williamson and Traynor 1996). This method accounts for observed spatial structure for sampling along transects. As done in previous assessments, the other sources of error (e.g., target strength, trawl sampling) were accounted for by inflating the annual error estimates to have an overall average CV of 20% for application within the assessment model.

The 2014 summer AT survey was characterized by the predominance of 2-year old pollock—in fact the highest level observed since 1982 (Fig. 1.17; Table 1.16). The survey results also indicated relatively high numbers of 1-year-old pollock, and a relatively abundant 6-year old age group. The latter is consistent with the 2012 observations of 4-year olds (and consistent with other survey and fishery data on the 2008 year class).

Spatially, the 2014 mid-water pollock distribution differed from recent years. The biomass estimated east of 170º W was 41% compared to an average of 26% (since 1994; Table 1.17). Also, the distribution of pollock within the SCA rose to 12% compared to the 2007-2012 average of 7l% (and 1994-2014 average of 16%). Overall, the mid-water pollock densities from the AT survey were consistent with the findings from the bottom trawl survey in that pollock were wide-spread throughout the shelf but with lower concentrations in the mid-water zone compared to the bottom zone (Fig. 1.18).

Biomass index from Acoustic-Vessels-of-Opportunity (AVO)
In 2014 acoustic data were collected from commercial fishing vessels used for the eastern Bering Sea bottom trawl (BT) survey as before (e.g.,Von Szalay et al., 2007, Kotwicki et al., 2009, Honkalehto et al. 2011). These data link integrated 38 kHz backscatter from an index area since 2006 and became formally included in the assessment in 2013 (Ianelli et al. 2013). The index remains the same as last year, with the time series covering the period 2006-2013 (Table 1.18). In 2015 we anticipate updating the index with the 2014 and 2015 estimates. This will provide some information on mid-water pollock abundance because the next AT survey in the region is planned for 2016.

Analytic approach

Model structure

A statistical age-structured assessment model conceptually outlined in Fournier and Archibald (1982) and similar to Methot's (1990) stock synthesis model was applied over the period 1964-2014. A technical description is presented in the Model Details section. The analysis was first introduced in the 1996 SAFE report and compared to the cohort analyses that had been used previously. The current model also was documented in an Academy of Sciences National Research Council report (Ianelli and Fournier 1998). The model was implemented using automatic differentiation software developed as a set of libraries under the C++ language ("ADMB," Fournier et al. 2012).

The main changes from last year's analyses include:

- The 2014 EBS bottom trawl survey estimate of population numbers-at-age was added
- The 2014 EBS AT survey estimate of population numbers-at-age was added (the age-length key was adopted from the BTS with supplemental juvenile pollock otolith samples from the AT survey)

- The 2013 final fishery age composition data was updated.

Parameters estimated outside of the assessment model

Natural mortality and maturity at age
For Model 1, fixed natural mortality rates at age were assumed (M=0.9, 0.45, and 0.3 for ages 1, 2, and 3+ respectively; Wespestad and Terry 1984). These values have been applied to catch-age models and forecasts since 1982 and appear reasonable for pollock. In the 2009 assessment, based on a workshop on natural mortality hosted by the AFSC, alternative age-specific patterns of natural mortality were investigated. This approach combined Lorenzen's (2000) observation that natural mortality is inversely proportional to length for young fish with Lehodey et al.'s (2008) logistic model for older fish scaled to maturation. Applying this relationship with pollock life history characteristics indicated a vector of age-specific natural mortality for the youngest and oldest ages similar to that used here.

Estimates of natural mortality are also higher when predation is explicitly considered (Livingston and Methot 1998; Hollowed et al. 2000). However, Model 1 values were selected because Clark (1999) found that specifying a conservative (lower) natural mortality rate is advised when natural mortality rates are uncertain. For sensitivity, alternative estimates are included based on the Lorenzen approach and that of Gislason et al (2010) were compiled (see appendix on Model Details). Pollock natural mortality-at-age (by model) and maturity-at-age (for all models; Smith 1981) values used were:

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Model 1.0 M	0.900	0.450	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Model 1.1 M	2.791	1.047	0.621	0.444	0.351	0.294	0.258	0.232	0.214	0.200	0.190	0.182	0.176	0.171	0.166
Model 1.2 M	0.990	0.754	0.601	0.554	0.521	0.490	0.468	0.451	0.439	0.424	0.416	0.402	0.396	0.349	0.990
Prop. Mature	0.000	0.008	0.290	0.642	0.842	0.902	0.948	0.964	0.970	1.000	1.000	1.000	1.000	1.000	1.000

Maturity-at-age values were reevaluated based on the studies of Stahl (2004; subsequently Stahl and Kruse 2008a). Ianelli et al. (2005) investigated the inter-annual variability found by Stahl (2004). This involved using the fixed maturity-at-age levels presented above (for Model 1) to estimate total mature and immature numbers at age and then converting those to values at length using female mean-lengths at age (with an assumed natural variability about these means). Expected proportion mature-at-length for 2002 matched Stahl's data whereas for 2003, the model's expected values for maturity-at-length were shifted towards larger pollock. This result suggests that younger-than-currently-assumed pollock may contribute to the spawning stock. This minor change may be due to time varying effects on maturity and since this result was consistent, the maturity-at-age schedule was left at the same values used in all recent assessments (Smith 1981).

Length and Weight at Age
Age determination methods have been validated for pollock (Kimura et al. 1992; Kimura et al. 2006, and Kastelle and Kimura 2006). Regular age-determination methods coupled with extensive length and weight data collections show that growth may differ by sex, area, and year class. Pollock in the northwest area typically are smaller at age than pollock in the southeast area. The differences in average weight-at-age are taken into account by stratifying estimates of catch-at-age by year, area, season and weighting estimates proportional to catch.

Stock assessment models for groundfish in Alaska typically track numbers of individuals in the population. Management recommendations are based on allowable catch levels expressed as tons of fish. While estimates of pollock catch-at-age are based on large data sets, these are typically only available up until the most recent completed calendar year of fishing (i.e., 2013 for the assessment conducted in 2014). Consequently, estimates of weight-at-age in the current year are required to map total catch biomass (typically equal to the quota) to numbers of fish caught (in the current year since age-composition data are unavailable).

The mean weight at age in the fishery can vary due to environmental conditions in addition to spatial and temporal patterns of the fishery. For estimation errors due to sampling, bootstrap distributions of the variability (within-year) indicate that this source is relatively small compared to the between-year variability in mean weights-at-age implying that processes determining mean weights in the fishery cause more variability than sampling (Table 1.19). The coefficients of variation between years are on the order of 6% to 9% (for the ages that are targeted) whereas the sampling variability is generally around 1% or 2%.

Alternative estimators for mean weight at age were developed in Ianelli et al. (2009). This year, due to the apparently below-average mean weight of the 2008 year-class (as apparent in the fishery and modestly so in the survey; Fig. 1.19), an approach to account for this was developed as follows. For a given age *a* greater than age 2, three values were computed:

w_1 The mean body mass at age *a* from 1991-2013,

w_2 The percentile body mass of age *a* pollock 1991-2013 observations based on the rank of the age *a-1* body mass in 2013 (so if the age *a-1* pollock was about average in mass in 2013, then w_2 would be assigned a median value),

w_3 The percentile body mass of age *a* pollock from the 1991-2013 observations based on the rank of the age *a-2* body mass in 2013,

w_a^* the body mass assumed for 2014 and in future years set to the minimum of w_1,w_2, and w_3.

This method accounts for the cohort effect observed but will be biased low for the two-year projections. For example, the revised 2013 mean weights-at-age are slightly heavier than assumed in Ianelli et al. (2013) for the older pollock but nearly identical to that used for pollock younger than age 6 (Fig. 1.20).

Parameters estimated inside the assessment model

For the selected model, 758 parameters were estimated conditioned on data and model assumptions. Initial age composition, subsequent recruitment, and stock-recruitment parameters account for 74 parameters. This includes vectors describing the initial age composition (and deviation from the equilibrium expectation) in the first year (as ages 2-15 in 1964) and the recruitment mean and deviations (at age 1) from 1964-2014 and projected recruitment variability (using the variance of past recruitments) for five years (2015-2019). The two-parameter stock-recruitment curve is included in addition to a term that allows the average recruitment before 1964 (that comprises the initial age composition in that year) to have a mean value different from subsequent years.

Fishing mortality is parameterized to be semi-separable with year and age (selectivity) components. The age component is allowed to vary over time; changes are allowed in each year. The mean value of the age component is constrained to equal one and the last 5 age groups (ages 11-15) are specified to be equal. The annual components of fishing mortality result in 52 parameters and the age-time selectivity schedule forms a 10x50 matrix of 500 parameters bringing the total fishing mortality parameters to 552.

Selectivity-at-age estimates for the bottom trawl survey are specified with age and year specific deviations in the average selectivity-at-age. For the AT survey, which began in 1979, parameters are used to specify age-time specific availability. Time-varying survey selectivity is estimated to account for the changes in availability of pollock to the survey gear and is constrained by pre-specified variance terms. Four catchability coefficients were estimated: one each for the early fishery catch-per-unit effort (CPUE) data (from Low and Ikeda, 1980), the early bottom trawl survey data (where only 6 strata were surveyed), the main bottom trawl survey data, and the AT survey data. The selectivity parameters for the 2 main indices total 116 and there are 5 scale parameters (q): 2 for the BTS index, and one each for the AT, CPUE, and AVO indices.

Based on the work of Von Szalay et al. (2007) prior distributions on the sum of the AT and BTS catchability coefficients were introduced in Ianelli et al. (2007). This simply allows an evaluation of the extent that the BTS covers the bottom-dwelling pollock (up to ~3 m above the bottom) and the AT survey covers the remainder of the water column. Conceptually, the catchabilities from both surveys could sum to unity (assuming fish lack behavioral responses to survey gear—e.g., herding or diving). Values of this sum that are less than one could imply that there are spatial aspects of the pollock stock that are missed whereas values greater than one could imply that there are pollock on the shelf during the summer that could be considered as visitors perhaps originating (and returning to) other areas such as the Russian zone.

Additional fishing mortality rates used for recommending harvest levels are estimated conditionally on other outputs from the model. For example, the values corresponding to the $F_{40\%}$, $F_{35\%}$ and F_{MSY} harvest rates are found by satisfying the constraint that, given age-specific population parameters (e.g., selectivity, maturity, mortality, weight-at-age), unique values exist that correspond to these fishing mortality rates. The likelihood components that are used to fit the model can be categorized as:

- Total catch biomass (log-normal, σ=0.05)
- Log-normal indices of abundance (numbers of fish; bottom trawl surveys assume annual estimates of sampling error, as represented in Fig. 1.9; for the AT index the annual errors were specified to have a mean of 0.20; while for the AVO data, a relative value was assumed which gave a mean of about 0.32).
- Fishery and survey proportions-at-age estimates (robust quasi-multinomial with effective sample sizes presented in Table 1.20).
- Age 1 index from the AT survey (CV set equal to 30% as in prior assessments)
- Selectivity constraints: penalties/priors on age-age variability, time changes, and decreasing (with age) patterns
- Stock-recruitment: penalties/priors involved with fitting a stochastic stock-recruitment relationship within the integrated model.

Results

Model evaluation

A preliminary sequence of models was developed that evaluated sensitivities to new data which included updating the catch biomass for 2013 and estimated levels for 2014 along with the 2013 fishery mean weights-at-age. As in past years, a set of models showing the impact of new data was constructed along with a few sensitivity analyses:

Name	Updated catch to 2014	2013 Catch age	2014 Bottom trawl data	2014 Acoustic Trawl data
Data considerations				
Model 0.0	X			
Model 0.1	X	X		
Model 0.2	X	X	X	
Model 0.3	X	X	X	X
Evaluate alternative natural mortality estimates				
Model 1.0	Status quo (Mod0.3)			
Model 1.1	Set to Lorenzen vector			
Model 1.2	Set to estimate based on Gislason approach			
Kotwicki index: efficiency correction for bottom trawl survey data				
Model 2.0	Uses multivariate lognormal (over time) instead of univariate			

The sequential addition of new data to the model indicated that the BTS survey had a large impact on the fit to the data, especially when the 2014 bottom trawl survey information was added (Mod0.2; Fig. 1.21). Adding in the 2014 AT survey data had a relatively minor impact (but indicated an above average 2012 year class Fig. 1.21).

In Ianelli et al. (2013) an iterative approach to estimating the stock recruitment variability (σ_R) parameter was conducted following methods proposed under the Plan Teams' recruitment working group report. The result for this indicated a value of about 0.674. This approach was tested again this year in place of the previously assumed value, 0.9. As before, the results of past biomass and recruitments were nearly identical but the fitted Ricker stock recruitment relationship changes significantly. The value for steepness (or slope at the origin) again increased due to two relative high year-classes that occurred at relatively low stock sizes (the 1978 and the more recent 2008 values) given the lower value assumed for variability about the stock recruitment curve. Based on this, and given the critical role that the bio-physical environmental conditions, more detailed study on the stock-recruit estimation relative to random effects should be undertaken before estimates of σ_R are adopted. Conseuquently, for consistency with past analyses, the fixed value of 0.9 was retained.

Model 2.0 was the same as Model 1.0 except that it used an alternative index and age composition for the BTS data. This index also included a covariance matrix that was used in model fitting. Results showed that adding the efficiency-corrected index resulted in generally better fits to other data components and also led to a slightly higher degree of uncertainty associated with the 2014 spawning biomass estimate (Fig. 1.22). For contrast, this figure also includes a sensitivity in which the BTS data are down-weighted and shows that the current stock size estimates are affected by the survey index.

Sensitivity runs for different natural mortality-at-age vectors suggested that the Lorenzen approach (Model 1.1) came close to fitting the data and model assumptions as well as the status quo model (Model 1.0), whereas Model 1.2 (the Gislason et al. derived natural mortality-at-age) performed poorly and resulted in unrealistically high biomass estimates (Table 1.21). Model 2.0 was included for reference (but note that the likelihood function differs for the BTS).

For the purposes of management, Model 1.0 performed similarly or out-performed the others evaluated and was carried forward for the remaining figures and considerations. The estimated parameters and standard errors are provided in Table 1.22.

The estimated selectivity pattern changes over time and reflects to some degree the extent to which the fishery is focused on particularly prominent year-classes (Fig. 1.23). The model fits the fishery age-composition data quite well under this form of selectivity (Fig. 1.24). The fit to the early Japanese fishery CPUE data (Low and Ikeda 1980) is consistent with the population trends for this period (Fig. 1.25). The fit to the fishery-independent index from the 2006-2013 AVO data was reasonable, especially for 2011-2013 (Fig. 1.26).

Bottom-trawl survey selectivity and fits to the numbers of age 2 and older pollock indicate that the model predicts fewer pollock than observed in the 2014 survey but slightly more than observed in the 2012 and 2013 surveys (Fig. 1.27). The pattern of bottom trawl survey age composition data in recent years shows a decline in the abundance of older pollock since 2011. The 2006 year class observations are below model expectations in 2012 and 2013, partly due to the fact that in 2010 the survey estimates are greater than the model predictions (Fig. 1.28).

The AT survey selectivity estimates were allowed to differ in the 1979 survey; (Fig. 1.29; top panel). The fit to the numbers of age 2 and older pollock in the AT survey generally falls within the confidence bounds of the survey sampling distributions (here assumed to have an average CV of 20%) with a fairly reasonable pattern of residuals (Fig. 1.29, bottom panel). The AT age compositions consistently track large year classes through the population and the model fits these patterns reasonably well (Fig. 1.30).

The AT age-1 index is generally fit poorly but with residuals that appear to be reasonably random (Fig. 1.30, bottom panel).

Time series results

The estimate of B_{MSY} is 1,948,000 t (with a CV of 20%) which is less than the projected 2015 spawning biomass of 2,850,000 t; Table 1.23). For 2014, the Tier 1 levels of yield are 2,900,000 t from a fishable biomass estimated at around 5,669,000 t (Table 1.24). Estimated numbers-at-age are presented in Table 1.25 and estimated catch-at-age is presented in Table 1.26. Estimated summary biomass (age 3+), female spawning biomass, and age-1 recruitment are given in Table 1.27.

Model 1.0 results indicate that spawning biomass will be above $B_{40\%}$ (2,491,000 t) in 2015 and about 146% of the B_{MSY} level. The probability that the current stock size is below 20% of B_0 (based on estimation uncertainty alone) is <0.1% for 2014 and 2015 (Fig. 1.31).

Another diagnostic (see Eq. 14 in appendix) on the impact of fishing shows that the 2014 spawning stock size is about 61% of the predicted value had no fishing occurred since 1978 (Table 1.23). This compares with the 47% of $B_{100\%}$ (based on the SPR expansion using mean recruitment from 1978-2012) and 57% of B_0 (based on the estimated stock-recruitment curve). The latter two values are based on expected recruitment either from the mean value since 1978 or from the estimated stock recruitment relationship.

The time series of begin-year biomass estimates (ages 3 and older) derived from Model 1.0 suggest that the abundance of Eastern Bering Sea pollock remained at a fairly high level from 1981-88, with estimates ranging from 8 to 12 million t (Table 1.28). Historically, biomass levels increased from 1979 to the mid-1980s due to the strong 1978 and relatively strong 1982 and 1984 year classes recruiting to the fishable population. The stock is characterized by peaks in the mid-1980s, the mid-1990s and again appears to be above 8 million t in 2013 and 2014, following a low in 2008 at 4.7 million t.

The level of fishing relative to biomass estimates show that the spawning exploitation rate (SER, defined as the percent removal of egg production in a given spawning year) has been mostly below 20% since 1980 (Fig. 1.32). During 2006-2008 the rate averaged more than 20% and the average fishing mortality for ages 3-8 increased during the period of stock decline The estimate for 2009 through 2014 is below 20% due to the reductions in TACs relative to the maximum permissible ABC values and increases in the spawning biomass. The average F (ages 3-8) increased in 2011 to nearly 0.3 when the TAC increased but has dropped since then and in 2014 was estimated at about 0.2. Age specific fishing mortality rates reflect these patterns and show some increases in the oldest ages from 2011-2013 but a decline in 2014 (Fig. 1.33). The estimates of age 3+ pollock biomass are mostly higher than the estimates from previous years, especially the past 4 assessments (Fig. 1.34, Table 1.28).

One way to evaluate past management and assessment performance is to plot estimated fishing mortality relative to some reference values. For EBS pollock, we computed the reference fishing mortality from Tier 1 (unadjusted) and calculated the historical values for F_{MSY} (since selectivity has changed over time). Since 1977 the current estimates of fishing mortality suggest that during the early period, harvest rates were above F_{MSY} until about 1980. Since that time, the levels of fishing mortality have averaged about 35% of the F_{MSY} level (Fig. 1.35).

Recruitment

Model estimates indicate that the 2006 year class is only 12% above the average level (Fig. 1.36, top panel). This compares with the 2008 year class that appears to be about twice the mean value. The stock-recruitment curve as fit within the integrated model shows a fair amount of variability both in the estimated recruitments and in the uncertainty of the curve (Fig. 1.36; bottom panel). Note that the 2012 and 2013 year classes (as age 1 recruits in 2013 and 2014) are excluded from estimating the stock-recruitment curve.

Environmental factors affecting recruitment
Previous studies linked strong Bering Sea pollock recruitment to years with warm sea temperatures and northward transport of pollock eggs and larvae (Wespestad et al. 2000; Mueter et al. 2006). As part of the Bering-Aleutian Salmon International Survey (BASIS) project research has also been directed toward the relative density and quality (in terms of condition for survival) of young-of-year pollock. For example, Moss et al. (2009) found age-0 pollock were very abundant and widely distributed to the north and east on the Bering Sea shelf during 2004 and 2005 (warm sea temperature; high water column stratification) indicating high northern transport of pollock eggs and larvae during those years. More recently, Mueter et al. (2011) found that warmer conditions tended to result in lower pollock recruitment in the EBS. This is consistent with the hypothesis that when sea temperatures on the eastern Bering Sea shelf are warm and the water column is highly stratified during summer, age-0 pollock appear to allocate more energy to growth than to lipid storage, leading to low energy density prior to winter. This then may result in increased over-winter mortality (Swartzman et al. 2005, Winter et al. 2005). Ianelli et al. (2011) evaluate the consequences of current harvest policies in the face of warmer conditions and potentially lower pollock recruitment and noted that the current management system is likely to face higher chances of ABCs below the average.

Retrospective analysis
As requested by the SSC and Plan Team, retrospective analyses were again conducted with results that differed considerably from previous years. The model 1.0 runs indicate that the impact of new data in 2014 increases the overall historical biomass trajectory (Fig. 1.37). Previous results indicated a slight tendency for over-estimation of spawning biomass when it is declining and a slight tendency for underestimation during increases. The increase based on new data this year has made the retrospective pattern (for the 10-year period) appear as mainly underestimates with Mohn's rho equal to -0.11. However, the retrospective estimates still fall well within the bounds of uncertainty (Figs. 1.37).

Harvest recommendations

Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines overfishing level (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. Estimates of reference points related to maximum sustainable yield (MSY) are currently available. However, their reliability is questionable. We therefore present both reference points for pollock in the BSAI to retain the option for classification in either Tier 1 or Tier 3 of Amendment 56. These Tiers require reference point estimates for biomass level determinations. Consistent with other groundfish stocks, the following values are based on recruitment estimates from post-1976 spawning events:

B_{MSY} = 1,948 thousand t female spawning biomass

B_{0} = 5,162 thousand t female spawning biomass

$B_{100\%}$ = 6,227 thousand t female spawning biomass

$B_{40\%}$ = 2,491 thousand t female spawning biomass

$B_{35\%}$ = 2,179 thousand t female spawning biomass

Specification of OFL and Maximum Permissible ABC

The 2015 spawning biomass is estimated to be 2,850,000 t (at the time of spawning, assuming the stock is fished at recommended ABC level). This is above the B_{MSY} value of 1,948,000 t. Under Amendment 56, this stock has qualified under Tier 1 and the harmonic mean value is considered a risk-averse policy since

reliable estimates of F_{MSY} and its pdf are available (Thompson 1996). The exploitation-rate type value that corresponds to the F_{MSY} level was applied to the fishable biomass for computing ABC levels. For a future year, the fishable biomass is defined as the sum over ages of predicted begin-year numbers multiplied by age specific fishery selectivity (normalized to the value at age 6) and mean body mass.

Since the 2015 female spawning biomass is estimated to be above the B_{MSY} level (1,948,000 t) and the $B_{40\%}$ value (2,491,000 t) in 2015 and assuming that the 2015 catch equals 1.35 million t, the OFL and maximum permissible ABC values by the different Tiers would be:

Tier	Year	MaxABC	OFL
1a	2015	2,900,000 t	3,330,000 t
1a	2016	3,040,000 t	3,040,000 t

Tier	Year	MaxABC	OFL
3a	2015	1,637,000 t	2,022,000 t
3a	2016	1,642,000 t	2,026,000 t

Standard Harvest Scenarios and Projection Methodology

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). While EBS pollock is generally considered to fall within Tier 1, the standard projection model requires knowledge of future uncertainty in F_{MSY}. Since this would require a number of additional assumptions that presume future knowledge about stock-recruit uncertainty, the projections in this subsection are based on Tier 3.

For each scenario, the projections begin with the vector of 2014 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2015 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch assumed for 2014. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. Annual recruitments are simulated from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times to obtain distributions of possible future stock sizes and catches under alternative fishing mortality rate scenarios.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2015 and 2016, are as follows (*max* F_{ABC} refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs).

Scenario 2: In 2015 and 2016 the catch is set equal to 1.35 million t and in future years F is set equal to the Tier 3 estimate (Rationale: this was estimated to be the level of catch where the spawning biomass is in 2016 would equal the 2014 estimate).

Scenario 3: In all future years, F is set equal to the 2010-2014 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 4: In all future years, F is set equal to $F_{60\%}$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels. This was requested by public comment for the DSEIS developed in 2006)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2014 or 2) above ½ of its MSY level in 2015 and above its MSY level in 2026 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2026 under this scenario, then the stock is not approaching an overfished condition).

Projections and status determination

For the purposes of these projections, we present results based on selecting the $F_{40\%}$ harvest rate as the max F_{ABC} value and use $F_{35\%}$ as a proxy for F_{MSY}. Scenarios 1 through 7 were projected 14 years from 2014 (Table 1.29). Under the maximum permissible catch level in Tier 3, the expected spawning biomass will decline (and be below the target by 2015) through 2016 and eventually begin to increase and stabilize around $B_{40\%}$ (in expectation) by about 2020 years (Fig. 1.38).

Any stock that is below its minimum stock size threshold (MSST) is defined to be overfished. Any stock that is expected to fall below its MSST in the next two years is defined to be approaching an overfished condition. Harvest scenarios 6 and 7 are used in these determinations as follows:

Is the stock overfished? This depends on the stock's estimated spawning biomass in 2014:

If spawning biomass for 2014 is estimated to be below ½ $B_{35\%}$ the stock is below its MSST.

If spawning biomass for 2014 is estimated to be above $B_{35\%}$, the stock is above its MSST.

If spawning biomass for 2014 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest scenario 6 (Table 1.29). If the mean spawning biomass for 2024 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario 7:

If the mean spawning biomass for 2016 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

If the mean spawning biomass for 2016 is above $B_{35\%}$, the stock is not approaching an overfished condition.

If the mean spawning biomass for 2016 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2026. If the mean spawning biomass for 2026 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

For scenarios 6 and 7, we conclude that pollock is not below MSST for the year 2014, nor is it expected to be approaching an overfished condition based on Scenario 7 (the mean spawning biomass in 2014 is above the $B_{35\%}$ level; Table 1.29). Tier 1 calculations for ABC and OFL values in 2015 and 2016 (assuming catch is 1,350,000 t in 2015 are given in Table 1.30. Based on this, the EBS pollock stock is not being subjected to overfishing.

ABC Recommendation

ABC levels are affected by estimates of F_{MSY} (which depends principally on the stock-recruitment relationship and demographic schedules such as selectivity-at-age, maturity, growth), the B_{MSY} level, and current stock size (both spawning and fishable). Updated data and analysis result in an estimate of 2014 spawning biomass (2,945 kt) that is about 146% of B_{MSY} (1,948 kt). The spawning stock appears to have recovered well above the low point estimated in 2008. The replacement yield—defined as the catch next year that is expected to achieve a 2016 spawning biomass estimate equal to that from 2014—is estimated to be about 1,350,000 t.

Even though the EBS pollock stock has appeared to recover from its 2008 low, there are some reasons to remain conservative in specifying ABCs to be less than the maximum permissible Tier 1 values:

- The 2008 year class has represented the majority of the spawning biomass since 2012 when it was 48%. In 2013 and 2014 it was estimated to be 56% of the female spawning stock biomass in both years. This represents the 3rd highest proportion of spawning biomass consisting of a single cohort (over the period 1964-2014). Reliance on a single year class comprising such a large portion of the reproductive output may affect the robustness of the spawning stock.
- The fleet was able to operate with reasonably good catch rates and maintain salmon bycatch at relatively low levels. Relative to 2014, a catch of 1,350,000 t would require about 13% more effort (based on the ratio of fishing mortality rates).
- Roe recovery rates are still below average. This may be indicative of reduced reproductive potential.

Given these factors, a 2015 ABC of 1,350,000 t is recommended to provide an even chance that the current spawning stock will be achieved in 2016. The alternative maximum permissible Tier 1a ABC seems risky since the change in the stock size would be dramatic (i.e., large reductions in ABC would be needed due to normal recruitment variability). Adopting a Tier 3 approach for specifying ABC would also provide greater near-term yield but with less spawning stock and future catch variability than expected under Tier 1.

Ecosystem considerations

In general, a number of key issues for ecosystem conservation and management can be highlighted. These include:

- Preventing overfishing;
- Avoiding habitat degradation;
- Minimizing incidental bycatch;
- Monitoring bycatch and the level of discards; and
- Considering multi-species trophic interactions relative to harvest policies.

For the case of pollock in the Eastern Bering Sea, the NPFMC and NMFS continue to manage the fishery on the basis of these issues in addition to the single-species harvest approach (Hollowed et al. 2011). The prevention of overfishing is clearly set out as the main guideline for management. Habitat degradation has been minimized in the pollock fishery by converting the industry to pelagic-gear only. Bycatch in the

pollock fleet is closely monitored by the NMFS observer program and managed on that basis. Discard rates of many species have been reduced in this fishery and efforts to minimize bycatch continue.

In comparisons of the Western Bering Sea (WBS) with the Eastern Bering Sea using mass-balance food-web models based on 1980-85 summer diet data, Aydin et al. (2002) found that the production in these two systems is quite different. On a per-unit-area measure, the western Bering Sea has higher productivity than the EBS. Also, the pathways of this productivity are different with much of the energy flowing through epifaunal species (e.g., sea urchins and brittlestars) in the WBS whereas for the EBS, crab and flatfish species play a similar role. In both regions, the keystone species in 1980-85 were pollock and Pacific cod. This study showed that the food web estimated for the EBS ecosystem appears to be relatively mature due to the large number of interconnections among species. In a more recent study based on 1990-93 diet data (see Appendix 1 of the Ecosystem Considerations chapter for methods), pollock remain in a central role in the ecosystem. The diet of pollock is similar between adults and juveniles with the exception that adults become more piscivorous (with consumption of pollock by adult pollock representing their third largest prey item). In terms of magnitude, pollock cannibalism may account for 2.5 million t to nearly 5 million t of pollock consumed (based on uncertainties in diet percentage and total consumption rate; Jurado-Molina et al. 2005).

Regarding specific small-scale ecosystems of the EBS, Ciannelli et al. (2004a, 2004b) presented an application of an ecosystem model scaled to data available around the Pribilof Islands region. They applied bioenergetics and foraging theory to characterize the spatial extent of this ecosystem. They compared energy balance, from a food web model relevant to the foraging range of northern fur seals and found that a range of 100 nautical mile radius encloses the area of highest energy balance representing about 50% of the observed foraging range for lactating fur seals. This has led to a hypothesis that fur seals depend on areas outside the energetic balance region. This study develops a method for evaluating the shape and extent of a key ecosystem in the EBS (i.e., the Pribilof Islands). Furthermore, the overlap of the pollock fishery and northern fur seal foraging habitat (see Sterling and Ream 2004, Zeppelin and Ream 2006) will require careful monitoring and evaluation.

A brief summary of these two perspectives (ecosystem effects on pollock stock and pollock fishery effects on ecosystem) is given in Table 1.31. Unlike the food-web models discussed above, examining predators and prey in isolation may overly simplify relationships. This table serves to highlight the main connections and the status of our understanding or lack thereof.

Ecosystem effects on the EBS pollock stock

The pollock stock condition appears to have benefitted substantially from the recent conditions in the EBS. The conditions on the shelf during 2008 apparently affected conditions for age-0 northern rock sole due to cold conditions and apparently unfavorable currents that retain them into the over-summer nursery areas (Cooper et al. 2014). It may be that such conditions favor pollock recruitment. Hollowed et al. (2012) provided an extensive review of habitat and density for age-0 and age-1 pollock based on extensive survey data. They noted that during cold years, age-0 pollock were distributed primarily in the outer domain in waters greater than 1ºC and during warm years, age-0 pollock were distributed mostly in the middle domain. This temperature relationship, along with interactions with available food in early-life stages, appears to have important implications for pollock recruitment success (Coyle et al. 2011).

Euphausiids, principally *Thysanoessa inermis* and *T. raschii*, are among the most important prey items for pollock in the Bering Sea (Livingston, 1991; Lang et al., 2000; Brodeur et al., 2002; Cianelli et al., 2004; Lang et al., 2005). In the 2009 SAFE report, an analysis of MACE AT survey backscatter as an index of euphausiid abundance on the Bering Sea shelf was presented. In 2010 and this year the index was updated and spatial distributions and trends were evaluated using methods described in De Robertis et al. (2010) and Ressler et al. (2012). This information is presented in the Ecosystem Consideration chapter and indicates declines observed in both the 2012 and 2014 surveys relative to the 2009 peak. It is noteworthy

that this index shows a peak abundance in 2009 which may have contributed to the survival of the 2008 year class of EBS pollock.

EBS pollock fishery effects on the ecosystem.

Since the pollock fishery is primarily pelagic in nature, the bycatch of non-target species is small relative to the magnitude of the fishery (Table 1.32). Jellyfish represent the largest component of the bycatch of non-target species and had averaged around 5-6 thousand tons per year but more than doubled this year with catches exceeding 13 thousand t. The data on non-target species shows a high degree of inter-annual variability, which reflects the spatial variability of the fishery and high observation error. This variability may reduce the ability to detect significant trends for bycatch species.

The catch of other target species in the pollock fishery represent less than 1% of the total pollock catch. Incidental catch of Pacific cod has increased since 1999 but remains below the 1997 levels (Table 1.33). The incidental catch of flatfish was variable over time and has increased, particularly for yellowfin sole. Proportionately, the incidental catch has decreased since the overall levels of pollock catch have increased. In fact, the bycatch of pollock in *other* target fisheries is more than double the bycatch of target species in the pollock fishery (Table 1.34).

A high number of non-Chinook salmon (nearly all made up of chum salmon) was observed in 2014 (about 13% above the 2003-2013 average) after the low level observed in 2012 (Table 1.35). Chinook salmon bycatch in 2014 was low (36% of the 2003-2014 mean value) and consistent with the magnitude of bycatch since the implementation of Amendment 91 in 2011 (2014 was 92% of the 2011-2014 mean). Ianelli and Stram (2014) provide estimates of the bycatch impact on Chinook salmon runs to the coastal west Alaska region and found that the peak bycatch levels exceeded 7% of the total run return. Since 2011, the impact has been estimated to be below 2%.

Data gaps and research priorities

The available data for EBS pollock are extensive yet many processes behind the observed patterns are poorly understood. For example, the bottom trawl survey in 2014 found abundance levels for the 2008 year class to be at record levels—and this after record levels of age 5 pollock from the 2013 estimates. Research on developing and testing plausible hypotheses about the underlying processes that cause such observations is needed. More studies on spatial dynamics, including the relationship between climate and recruitment and trophic interactions of pollock within the ecosystem would be useful for improving ways to evaluate the current and alternative fishery management system.

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Tables

Table 1.1 Catch from the Eastern Bering Sea by area, the Aleutian Islands, the Donut Hole, and the Bogoslof Island area, 1979-2014 (2014 values through October 25th 2014). The southeast area refers to the EBS region east of 170W; the Northwest is west of 170W.

	Eastern Bering Sea			Aleutians	Donut Hole	Bogoslof I.
Year	Southeast	Northwest	Total			
1979	368,848	566,866	935,714	9,446		
1980	437,253	521,027	958,280	58,157		
1981	714,584	258,918	973,502	55,517		
1982	713,912	242,052	955,964	57,753		
1983	687,504	293,946	981,450	59,021		
1984	442,733	649,322	1,092,055	77,595	181,200	
1985	604,465	535,211	1,139,676	58,147	363,400	
1986	594,997	546,996	1,141,993	45,439	1,039,800	
1987	529,461	329,955	859,416	28,471	1,326,300	377,436
1988	931,812	296,909	1,228,721	41,203	1,395,900	87,813
1989	904,201	325,399	1,229,600	10,569	1,447,600	36,073
1990	640,511	814,682	1,455,193	79,025	917,400	151,672
1991	653,555	542,109	1,195,664	98,604	293,400	316,038
1992	830,559	559,741	1,390,299	52,352	10,000	241
1993	1,094,429	232,173	1,326,602	57,132	1,957	886
1994	1,152,575	176,777	1,329,352	58,659		556
1995	1,172,306	91,941	1,264,247	64,925		334
1996	1,086,843	105,939	1,192,781	29,062		499
1997	819,889	304,544	1,124,433	25,940		163
1998	886,567	132,515	1,019,082	22,054		136
1999	782,983	206,698	989,680	1,010		29
2000	839,177	293,532	1,132,710	1,244		29
2001	961,977	425,220	1,387,197	825		258
2002	1,160,334	320,442	1,480,776	1,177		1,042
2003	933,191	557,588	1,490,779	1,649		24
2004	1,090,008	390,544	1,480,552	1,158		0
2005	802,154	680,868	1,483,022	1,621		
2006	827,207	660,823	1,488,031	1,745		
2007	728,249	626,253	1,354,502	2,519		
2008	482,748	507,880	990,629	1,278		9
2009	358,252	452,532	810,784	1,662		73
2010	255,023	555,192	810,215	1,285		176
2011	747,594	451,475	1,199,069	1,208		173
2012	618,854	586,343	1,205,197	975		79
2013	695,648	575,097	1,270,745	2,964		57
2014	852,399	438,175	1,290,574	2,348		428
Average since 1991	826,355	411,433	1,237,788			
1979	368,848	566,866	935,714	9,446		

1979-1989 data are from Pacfin.
1990-2014 data are from NMFS Alaska Regional Office, and include discards.
The 2014 EBS catch estimates are preliminary

Table 1.2. Total catch recorded by observers (rounded to nearest 1,000 t) by year and season with percentages indicating the proportion of the catch that came from within the Steller sea lion conservation area (SCA), 1998-2014. Note that the 2014 data are preliminary and observer coverage for shore-based catcher vessels increased in 2011.

	A season	B-season	Total
1998	385,000 t (82%)	403,000 t (38%)	788,000 t (60%)
1999	339,000 t (54%)	468,000 t (23%)	807,000 t (36%)
2000	375,000 t (36%)	572,000 t (4%)	947,000 t (16%)
2001	490,000 t (27%)	674,000 t (46%)	1,164,000 t (38%)
2002	566,000 t (54%)	690,000 t (49%)	1,256,000 t (51%)
2003	616,000 t (45%)	680,000 t (42%)	1,296,000 t (43%)
2004	531,000 t (45%)	711,000 t (34%)	1,242,000 t (38%)
2005	529,000 t (45%)	673,000 t (17%)	1,203,000 t (29%)
2006	533,000 t (51%)	764,000 t (14%)	1,298,000 t (29%)
2007	480,000 t (57%)	663,000 t (11%)	1,143,000 t (30%)
2008	342,000 t (46%)	490,000 t (12%)	832,000 t (26%)
2009	283,000 t (26%)	389,000 t (13%)	671,000 t (24%)
2010	281,000 t (17%)	412,000 t (9%)	693,000 t (12%)
2011	490,000 t (54%)	531,000 t (28%)	1,020,000 t (40%)
2012	457,000 t (52%)	687,000 t (17%)	1,145,000 t (31%)
2013	472,000 t (22%)	708,000 t (19%)	1,180,000 t (20%)
2014	483,000 t (38%)	741,000 t (37%)	1,224,000 t (37%)

Table 1.3. Time series of 1964-1976 catch (left) and ABC, TAC, and catch for EBS pollock, 1977-2014 in t. Source: compiled from NMFS Regional office web site and various NPFMC reports. Note that the 2014 value is based on catch reported to October 25th 2014 plus an added estimated of 8.019 thousand t due to bycatch of pollock in other fisheries.

Year	Catch	Year	ABC	TAC	Catch
1964	174,792	1977	950,000	950,000	978,370
1965	230,551	1978	950,000	950,000	979,431
1966	261,678	1979	1,100,000	950,000	935,714
1967	550,362	1980	1,300,000	1,000,000	958,280
1968	702,181	1981	1,300,000	1,000,000	973,502
1969	862,789	1982	1,300,000	1,000,000	955,964
1970	1,256,565	1983	1,300,000	1,000,000	981,450
1971	1,743,763	1984	1,300,000	1,200,000	1,092,055
1972	1,874,534	1985	1,300,000	1,200,000	1,139,676
1973	1,758,919	1986	1,300,000	1,200,000	1,141,993
1974	1,588,390	1987	1,300,000	1,200,000	859,416
1975	1,356,736	1988	1,500,000	1,300,000	1,228,721
1976	1,177,822	1989	1,340,000	1,340,000	1,229,600
		1990	1,450,000	1,280,000	1,455,193
		1991	1,676,000	1,300,000	1,195,664
		1992	1,490,000	1,300,000	1,390,299
		1993	1,340,000	1,300,000	1,326,602
		1994	1,330,000	1,330,000	1,329,352
		1995	1,250,000	1,250,000	1,264,247
		1996	1,190,000	1,190,000	1,192,781
		1997	1,130,000	1,130,000	1,124,433
		1998	1,110,000	1,110,000	1,019,082
		1999	992,000	992,000	989,680
		2000	1,139,000	1,139,000	1,132,710
		2001	1,842,000	1,400,000	1,387,197
		2002	2,110,000	1,485,000	1,480,776
		2003	2,330,000	1,491,760	1,490,779
		2004	2,560,000	1,492,000	1,480,552
		2005	1,960,000	1,478,500	1,483,022
		2006	1,930,000	1,485,000	1,488,031
		2007	1,394,000	1,394,000	1,354,502
		2008	1,000,000	1,000,000	990,629
		2009	815,000	815,000	810,784
		2010	813,000	813,000	810,215
		2011	1,270,000	1,252,000	1,199,069
		2012	1,220,000	1,200,000	1,205,197
		2013	1,375,000	1,247,000	1,270,745
		2014	1,369,000	1,267,000	1,298,593
	1977-2014 average		1,376,974	1,195,559	1,174,324

Table 1.4. Highlights of some management measures affecting the pollock fishery (DRAFT).

Year	Management
1977	Preliminary BSAI FMP implemented with several closure areas
1982	FMP implement for the BSAI
1982	Chinook salmon bycatch limits established for foreign trawlers
1984	2 million t groundfish OY limit established
1984	Limits on Chinook salmon bycatch reduced,
1990	New observer program established along with data reporting
1992	Pollock CDQ program commences
1994	NMFS adopts minimum mesh size requirements for trawl codends
1994	Voluntary retention of salmon for foodbank donations
1994	NMFS publishes individual vessel bycatch rates on internet
1995	Trawl closures areas established for chum and Chinook salmon
1998	Improved utilization and retention in effect (reduced discarded pollock)
1998	American Fisheries Act passed
1999	American Fisheries Act implemented
1999	Additional critical habitat areas around sea lion haulouts in the GOA and Eastern Bering Sea are closed.
2000	AFA implemented for all sectors
2005	Rolling hotspot program accepted
2011	Amendment 91 enacted, Chinook salmon regulations enhanced

Table 1.5. Estimates of discarded pollock (t), percent of total (in parentheses) and total catch for the Aleutians, Bogoslof, Northwest and Southeastern Bering Sea, 1991-2014. SE represents the EBS east of 170° W, NW is the EBS west of 170° W, source: NMFS Blend and catch-accounting system database. 2014 data are preliminary. Note that the higher discard rates in the Aleutian Islands and Bogoslof region reflect the lack of directed pollock fishing.

	Discarded pollock					**Total (retained plus discard)**				
	Aleutian Is.	Bogoslof	NW	SE	Total	Aleutian Is.	Bogoslof	NW	SE	Total
1991	5,231 (5%)	20,327 (6%)	48,257 (9%)	66,792 (10%)	140,607 (9%)	98,604	316,038	542,109	653,555	1,610,306
1992	2,986 (6%)	240 (100%)	57,609 (10%)	71,194 (9%)	131,998 (9%)	52,362	241	559,741	830,559	1,442,902
1993	1,740 (3%)	308 (35%)	26,100 (11%)	83,986 (8%)	112,135 (8%)	57,138	886	232,173	1,094,429	1,384,627
1994	1,373 (2%)	11 (2%)	16,083 (9%)	88,098 (8%)	105,566 (8%)	58,659	556	176,777	1,152,575	1,388,567
1995	1,380 (2%)	267 (80%)	9,715 (11%)	87,492 (7%)	98,855 (7%)	64,925	334	91,941	1,172,306	1,329,506
1996	994 (3%)	7 (1%)	4,838 (5%)	71,368 (7%)	77,208 (6%)	29,062	499	105,939	1,086,843	1,222,342
1997	618 (2%)	13 (8%)	22,557 (7%)	71,032 (9%)	94,219 (8%)	25,940	163	304,544	819,889	1,150,536
1998	162 (1%)	3 (39%)	1,581 (1%)	14,291 (2%)	16,037 (2%)	22,054	8	132,515	886,567	1,041,144
1999	480 (48%)	11 (39%)	1,912 (0.9%)	26,912 (3%)	29,315 (3%)	1,010	29	206,698	782,983	990,719
2000	790 (63%)	20 (67%)	1,942 (0.7%)	19,678 (2%)	22,429 (2%)	1,244	29	293,532	839,177	1,133,984
2001	380 (46%)	28 (11%)	2,450 (0.6%)	14,874 (2%)	17,732 (1%)	825	258	425,220	961,977	1,388,280
2002	779 (66%)	12 (1%)	1,441 (0.4%)	19,430 (2%)	21,661 (1%)	1,177	1,042	320,442	1,160,334	1,482,995
2003	468 (28%)	19 (79%)	2,959 (0.5%)	13,795 (1%)	17,242 (1%)	1,649	24	557,588	933,191	1,492,453
2004	287 (25%)		2,781 (0.7%)	20,380 (2%)	23,448 (2%)	1,158	0	390,544	1,090,008	1,481,710
2005	324 (20%)		2,586 (0.4%)	14,838 (2%)	17,747 (1%)	1,621	0	680,868	802,154	1,484,643
2006	311 (18%)		3,677 (0.6%)	11,877 (1%)	15,865 (1%)	1,745	0	660,823	827,207	1,489,776
2007	425 (17%)		3,769 (0.6%)	12,334 (2%)	16,529 (1%)	2,519	0	626,253	728,249	1,357,021
2008	81 (6%)		1,643 (0.3%)	5,968 (1%)	7,692 (1%)	1,278	9	507,880	482,748	991,916
2009	395 (24%)	6 (8%)	1,936 (0.4%)	4,014 (1%)	6,351 (1%)	1,662	73	452,532	358,252	812,520
2010	142 (11%)	53 (30%)	1,201 (0.2%)	2,510 (1%)	3,907 (0%)	1,285	176	555,192	255,023	811,677
2011	75 (6%)	23 (13%)	1,335 (0.3%)	3,444 (0%)	4,876 (0%)	1,208	173	451,475	747,594	1,200,450
2012	95 (10%)	5.0 (6%)	1,187 (0.2%)	4,177 (1%)	5,464 (0%)	975	79	586,343	618,854	1,206,252
2013	107 (4%)	0.4 (1%)	1,227 (0.2%)	4,145 (1%)	5,480 (0%)	2,964	57	575,097	695,648	1,273,766
2014	110 (5%)	54 (13%)	1,681 (0.4%)	12,058 (1%)	13,902 (1%)	2,348	428	438,175	852,399	1,293,350

Table 1.6. Eastern Bering Sea pollock catch at age estimates based on observer data, 1979-2013. Units are in millions of fish.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14+	Total
1979	101.4	543	719.8	420.1	392.5	215.5	56.3	25.7	35.9	27.5	17.6	7.9	3	1.1	2,567
1980	9.8	462.2	822.9	443.3	252.1	210.9	83.7	37.6	21.7	23.9	25.4	15.9	7.7	3.7	2,421
1981	0.6	72.2	1012.7	637.9	227.0	102.9	51.7	29.6	16.1	9.3	7.5	4.6	1.5	1.0	2,175
1982	4.7	25.3	161.4	1172.2	422.3	103.7	36.0	36.0	21.5	9.1	5.4	3.2	1.9	1.0	2,004
1983	5.1	118.6	157.8	312.9	816.8	218.2	41.4	24.7	19.8	11.1	7.6	4.9	3.5	2.1	1,745
1984	2.1	45.8	88.6	430.4	491.4	653.6	133.7	35.5	25.1	15.6	7.1	2.5	2.9	3.7	1,938
1985	2.6	55.2	381.2	121.7	365.7	321.5	443.2	112.5	36.6	25.8	24.8	10.7	9.4	9.1	1,920
1986	3.1	86.0	92.3	748.6	214.1	378.1	221.9	214.3	59.7	15.2	3.3	2.6	0.3	1.2	2,041
1987	0.0	19.8	111.5	77.6	413.4	138.8	122.4	90.6	247.2	54.1	38.7	21.4	28.9	14.1	1,379
1988	0.0	10.7	454.0	421.6	252.1	544.3	224.8	104.9	39.2	96.8	18.2	10.2	3.8	11.7	2,192
1989	0.0	4.8	55.1	149.0	451.1	166.7	572.2	96.3	103.8	32.4	129.0	10.9	4.0	8.5	1,784
1990	1.3	33.0	57.0	219.5	200.7	477.7	129.2	368.4	65.7	101.9	9.0	60.1	8.5	13.9	1,746
1991	0.7	111.8	39.9	86.5	139.2	152.8	386.2	51.9	218.4	21.8	115.0	13.8	72.6	59.0	1,469
1992	0.0	93.5	674.9	132.8	79.5	114.2	134.3	252.2	100.1	155.1	54.3	43.1	12.5	74.2	1,921
1993	0.2	8.1	262.7	1146.2	102.1	65.8	63.7	53.3	91.2	20.5	32.3	11.7	12.5	23.2	1,893
1994	1.6	36.0	56.8	359.6	1066.7	175.8	54.5	20.2	13.4	20.7	8.6	9.4	7.0	11.3	1,842
1995	0.0	0.5	81.3	151.7	397.5	761.2	130.6	32.2	11.1	8.5	18.2	5.5	6.3	10.6	1,615
1996	0.0	23.2	56.2	81.8	166.4	368.5	475.1	185.6	31.4	13.4	8.8	8.6	4.8	11.0	1,435
1997	2.4	83.6	37.8	111.7	478.6	288.3	251.3	196.7	61.6	13.6	6.4	5.0	3.5	15.9	1,556
1998	0.6	51.1	89.8	72.0	156.9	686.9	199.0	128.3	108.7	29.5	6.3	5.8	2.9	8.7	1,547
1999	0.4	11.6	295.0	227.7	105.3	155.7	473.7	132.7	57.5	32.9	3.5	2.2	0.7	2.3	1,501
2000	0.0	17.4	80.2	423.2	343.0	105.4	169.1	359.5	86.0	29.6	24.4	5.7	1.6	2.3	1,647
2001	0.0	3.7	56.8	162.0	574.8	405.8	136.1	129.2	158.3	57.5	35.1	16.0	5.9	5.1	1,746
2002	0.9	56.7	111.1	214.8	284.1	602.2	267.2	99.3	87.4	95.6	34.9	14.5	12.6	4.4	1,886
2003	0.0	17.3	402.2	320.8	366.8	305.2	332.1	157.3	53.0	40.2	36.5	23.7	7.0	7.0	2,069
2004	0.0	1.1	90.0	829.6	479.7	238.2	168.7	156.9	64.0	16.9	18.9	26.1	10.6	13.6	2,114
2005	0.0	3.1	53.7	391.2	861.8	489.1	156.4	67.5	67.1	33.7	11.2	10.2	3.4	5.5	2,154
2006	0.0	12.2	84.2	290.1	622.8	592.2	279.9	108.9	49.6	38.4	16.4	9.6	9.5	13.1	2,127
2007	1.8	19.5	57.2	124.2	374.0	514.7	306.3	139.0	50.2	28.0	23.3	9.4	6.5	16.3	1,671
2008	0.0	26.9	58.6	78.6	147.7	307.4	242.3	149.1	83.3	22.3	19.1	14.5	8.6	15.4	1,174
2009	0.8	3.4	151.8	188.8	73.4	102.0	126.9	106.9	85.7	40.7	26.4	10.5	9.0	19.7	946
2010	2.3	31.4	31.8	560.1	222.3	53.7	44.3	55.8	49.3	34.7	13.9	9.1	5.7	13.3	1,128
2011	0.9	14.7	191.6	117.7	807.6	283.8	64.1	39.4	38.3	40.1	25.3	13.3	1.7	10.4	1,649
2012	0.0	28.3	120.5	942.7	173.0	432.8	138.3	37.9	17.8	13.4	15.9	16.0	8.3	11.5	1,956
2013	3.4	1.7	70.2	342.2	944.4	187.9	154.7	68.5	20.6	17.7	13.6	12.4	9.0	13.2	1,860
Average	4.2	61.0	207.7	357.4	384.8	312.0	196.3	111.6	65.6	35.6	24.6	12.9	8.5	12.5	1,795

Table 1.7. Numbers of pollock fishery samples measured for lengths and for length-weight by sex and strata, 1977-2013, as sampled by the NMFS observer program.

Length	A Season		B Season SE		B Season NW		
Frequency	Males	Females	Males	Females	Males	Females	Total
1977	26,411	25,923	4,301	4,511	29,075	31,219	121,440
1978	25,110	31,653	9,829	9,524	46,349	46,072	168,537
1979	59,782	62,512	3,461	3,113	62,298	61,402	252,568
1980	42,726	42,577	3,380	3,464	47,030	49,037	188,214
1981	64,718	57,936	2,401	2,147	53,161	53,570	233,933
1982	74,172	70,073	16,265	14,885	181,606	163,272	520,273
1983	94,118	90,778	16,604	16,826	193,031	174,589	585,946
1984	158,329	161,876	106,654	105,234	243,877	217,362	993,332
1985	119,384	109,230	96,684	97,841	284,850	256,091	964,080
1986	186,505	189,497	135,444	123,413	164,546	131,322	930,727
1987	373,163	399,072	14,170	21,162	24,038	22,117	853,722
1991	160,491	148,236	166,117	150,261	141,085	139,852	906,042
1992	158,405	153,866	163,045	164,227	101,036	102,667	843,244
1993	143,296	133,711	148,299	140,402	27,262	28,522	621,490
1994	139,332	147,204	159,341	153,526	28,015	27,953	655,370
1995	131,287	128,389	179,312	154,520	16,170	16,356	626,032
1996	149,111	140,981	200,482	156,804	18,165	18,348	683,890
1997	124,953	104,115	116,448	107,630	60,192	53,191	566,527
1998	136,605	110,620	208,659	178,012	32,819	40,307	707,019
1999	36,258	32,630	38,840	35,695	16,282	18,339	178,044
2000	64,575	58,162	63,832	41,120	40,868	39,134	307,689
2001	79,333	75,633	54,119	51,268	44,295	45,836	350,483
2002	71,776	69,743	65,432	64,373	37,701	39,322	348,347
2003	74,995	77,612	49,469	53,053	51,799	53,463	360,390
2004	75,426	76,018	63,204	62,005	47,289	44,246	368,188
2005	76,627	69,543	43,205	33,886	68,878	63,088	355,225
2006	72,353	63,108	28,799	22,363	75,180	65,209	327,010
2007	62,827	60,522	32,945	25,518	75,128	69,116	326,054
2008	46,125	51,027	20,493	23,503	61,149	64,598	266,894
2009	45,958	43,987	19,869	18,571	50,309	53,202	231,896
2010	39,495	41,054	40,449	41,323	19,194	20,591	202,106
2011	58,822	62,617	51,137	48,084	60,254	65,057	345,971
2012	53,641	57,966	50,167	53,224	45,044	46,940	306,982
2013	52,303	62,336	49,484	49,903	37,434	44,709	296,168

Table 1.7. (continued) Numbers of pollock fishery samples measured for lengths and for length-weight by sex and strata, 1977-2013, as sampled by the NMFS observer program.

Length – weight samples

	A Season		B Season SE		B Season NW		
	Males	Females	Males	Females	Males	Females	Total
1977	1,222	1,338	137	166	1,461	1,664	5,988
1978	1,991	2,686	409	516	2,200	2,623	10,425
1979	2,709	3,151	152	209	1,469	1,566	9,256
1980	1,849	2,156	99	144	612	681	5,541
1981	1,821	2,045	51	52	1,623	1,810	7,402
1982	2,030	2,208	181	176	2,852	3,043	10,490
1983	1,199	1,200	144	122	3,268	3,447	9,380
1984	980	1,046	117	136	1,273	1,378	4,930
1985	520	499	46	55	426	488	2,034
1986	689	794	518	501	286	286	3,074
1987	1,351	1,466	25	33	72	63	3,010
1991	2,712	2,781	2,339	2,496	1,065	1,169	12,562
1992	1,517	1,582	1,911	1,970	588	566	8,134
1993	1,201	1,270	1,448	1,406	435	450	6,210
1994	1,552	1,630	1,569	1,577	162	171	6,661
1995	1,215	1,259	1,320	1,343	223	232	5,592
1996	2,094	2,135	1,409	1,384	1	1	7,024
1997	628	627	616	665	511	523	3,570
1998	1,852	1,946	959	923	327	350	6,357
1999	5,318	4,798	7,797	7,054	3,532	3,768	32,267
2000	12,421	11,318	12,374	7,809	7,977	7,738	59,637
2001	14,882	14,369	10,778	10,378	8,777	9,079	68,263
2002	14,004	13,541	12,883	12,942	7,202	7,648	68,220
2003	14,780	15,495	9,401	10,092	9,994	10,261	70,023
2004	7,690	7,890	6,819	6,847	4,603	4,321	38,170
2005	7,390	7,033	5,109	4,115	6,927	6,424	36,998
2006	7,324	6,989	5,085	4,068	6,842	6,356	36,664
2007	6,681	6,635	4,278	3,203	7,745	7,094	35,636
2008	4,256	4,787	2,056	2,563	5,950	6,316	25,928
2009	3,890	4,461	1,839	2,370	4,179	5,318	22,057
2010	4,536	5,272	4,125	4,618	2,261	2,749	23,561
2011	6,772	6,388	5,809	4,634	6,906	6,455	36,964
2012	5,500	5,981	4,928	5,348	4,508	4,774	31,039
2013	6,525	5,690	4,920	4,849	4,313	3,613	29,910

Table 1.8. Numbers of pollock fishery samples used for age determination estimates by sex and strata, 1977-2013, as sampled by the NMFS observer program.

	Aged						
	A Season		B Season SE		B Season NW		
	Males	Females	Males	Females	Males	Females	Total
1977	1,229	1,344	137	166	1,415	1,613	5,904
1978	1,992	2,686	407	514	2,188	2,611	10,398
1979	2,647	3,088	152	209	1,464	1,561	9,121
1980	1,854	2,158	93	138	606	675	5,524
1981	1,819	2,042	51	52	1,620	1,807	7,391
1982	2,030	2,210	181	176	2,865	3,062	10,524
1983	1,200	1,200	144	122	3,249	3,420	9,335
1984	980	1,046	117	136	1,272	1,379	4,930
1985	520	499	46	55	426	488	2,034
1986	689	794	518	501	286	286	3,074
1987	1,351	1,466	25	33	72	63	3,010
1991	420	423	272	265	320	341	2,041
1992	392	392	371	386	178	177	1,896
1993	444	473	503	493	124	122	2,159
1994	201	202	570	573	131	141	1,818
1995	298	316	436	417	123	131	1,721
1996	468	449	442	433	1	1	1,794
1997	433	436	284	311	326	326	2,116
1998	592	659	307	307	216	232	2,313
1999	540	500	730	727	306	298	3,100
2000	666	626	843	584	253	293	3,265
2001	598	560	724	688	178	205	2,951
2002	651	670	834	886	201	247	3,489
2003	583	644	652	680	260	274	3,092
2004	560	547	599	697	244	221	2,867
2005	611	597	613	489	419	421	3,149
2006	608	599	590	457	397	398	3,048
2007	639	627	586	482	583	570	3,485
2008	492	491	313	356	541	647	2,838
2009	483	404	298	238	431	440	2,294
2010	624	545	465	414	504	419	2,971
2011	581	808	404	396	579	659	3,427
2012	517	571	485	579	480	533	3,165
2013	703	666	568	526	517	402	3,381

Table 1.9. NMFS total pollock research catch by year in t, 1964-2014.

Year	Aleutian Is.	Bering Sea	Year	Aleutian Is.	Bering Sea
1964	0	0	1989	0	393
1965	0	18	1990	0	369
1966	0	17	1991	51	465
1967	0	21	1992	0	156
1968	0	7	1993	0	221
1969	0	14	1994	48	267
1970	0	9	1995	0	249
1971	0	16	1996	0	206
1972	0	11	1997	36	262
1973	0	69	1998	0	121
1974	0	83	1999	0	299
1975	0	197	2000	40	313
1976	0	122	2001	0	241
1977	0	35	2002	79	440
1978	0	94	2003	0	285
1979	0	458	2004	51	363
1980	193	139	2005	0	87
1981	0	466	2006	21	251
1982	40	682	2007	0	333
1983	454	508	2008	0	168
1984	0	208	2009	0	156
1985	0	435	2010	62	226
1986	292	163	2011	0	124
1987	0	174	2012		
1988	0	467	2013	0	
			2014		

Table 1.10. Biomass (age 1+) of Eastern Bering Sea pollock as estimated by surveys 1979-2014 (**millions** of tons). Note that the bottom-trawl survey data only represent biomass from the standard survey strata (1-6) areas in 1982-1984, and 1986. For all other years the estimates include strata 8-9. Also, the 1979 - 1981 bottom trawl survey data were omitted from the model since the survey gear differed.

Year	Bottom trawl Survey	AT Survey	AT % age 3+	Total*	Near bottom biomass
1979		7.458	22%		
1980					
1981					
1982	2.856	4.901	95%	7.757	37%
1983	6.258				
1984	4.894				
1985	5.955	4.799	97%	10.754	55%
1986	4.897				
1987	5.498				
1988	7.289	4.675	97%	11.964	61%
1989	6.550				
1990	7.316				
1991	5.130	1.454	46%	6.584	78%
1992	4.583				
1993	5.631				
1994	5.027	2.886	85%	7.913	64%
1995	5.478				
1996	3.415	2.311	97%	5.726	60%
1997	3.800	2.591	70%	6.391	59%
1998	2.781				
1999	3.798	3.285	95%	7.083	54%
2000	5.281	3.049	95%	8.330	63%
2001	4.197				
2002	5.033	3.622	82%	8.655	58%
2003	8.392				
2004	3.863	3.307	99%	7.170	54%
2005	5.321				
2006	3.045	1.560	98%	4.605	66%
2007	4.338	1.769	89%	6.107	71%
2008	3.023	0.997	76%	4.020	75%
2009	2.282	0.924	78%	3.206	71%
2010	3.738	2.323	65%	6.061	62%
2011	3.112				
2012	3.487	1.843	71%	5.330	65%
2013	4.575				
2014	7.430	3.439	na	10.869	68%
Average	4.796	2.763	84%	7.140	62%

* Although the two survey estimates are added in this table, the stock assessment model treats them as separate, independent indices (survey *q*'s are estimated).

Table 1.11. Survey biomass estimates (age 1+, t) of Eastern Bering Sea pollock based on area-swept expansion methods from NMFS bottom trawl surveys 1982-2014.

Year	Survey biomass estimates in strata 1-6	Survey biomass estimates in strata 8 and 9	All area Total	NW %Total
1982	2,855,539			
1983	6,257,632			
1984	4,893,536			
1985	4,630,149	1,325,102	5,955,251	22%
1986	4,899,245			
1987	5,111,645	386,788	5,498,433	7%
1988	7,106,818	181,839	7,288,657	2%
1989	5,906,477	643,938	6,550,415	10%
1990	7,126,088	190,218	7,316,306	3%
1991	5,067,092	62,446	5,129,538	1%
1992	4,367,962	214,557	4,582,518	5%
1993	5,524,830	105,707	5,630,538	2%
1994	4,977,639	49,686	5,027,325	1%
1995	5,409,297	68,541	5,477,838	1%
1996	3,258,806	155,861	3,414,667	5%
1997	3,036,898	762,954	3,799,852	20%
1998	2,213,697	567,569	2,781,266	20%
1999	3,598,688	199,786	3,798,474	5%
2000	5,152,594	128,846	5,281,439	2%
2001	4,145,746	51,108	4,196,854	1%
2002	4,832,508	200,337	5,032,845	4%
2003	8,106,358	285,902	8,392,261	3%
2004	3,744,501	118,473	3,862,974	3%
2005	5,168,300	152,300	5,320,600	3%
2006	2,845,129	199,885	3,045,015	7%
2007	4,158,176	179,986	4,338,162	4%
2008	2,834,093	189,174	3,023,267	6%
2009	2,231,225	51,185	2,282,410	2%
2010	3,550,981	186,898	3,737,878	5%
2011	2,945,641	166,672	3,112,312	5%
2012	3,281,223	206,005	3,487,229	6%
2013	4,297,970	277,433	4,575,403	6%
2014	6,552,849	877,104	7,429,952	12%
Avg.	4,548,395	282,286	4,805,851	6%

Table 1.12. Sampling effort for pollock in the EBS from the NMFS bottom trawl survey 1982-2014. Years where only strata 1-6 were surveyed are shown in italics.

Year	Number of Hauls	Lengths	Aged	Year	Number of Hauls	Lengths	Aged
1982	*329*	*40,001*	*1,611*	1998	375	37,673	1,261
1983	*354*	*78,033*	*1,931*	1999	373	32,532	1,385
1984	*355*	*40,530*	*1,806*	2000	372	41,762	1,545
1985	434	48,642	1,913	2001	375	47,335	1,641
1986	*354*	*41,101*	*1,344*	2002	375	43,361	1,695
1987	356	40,144	1,607	2003	376	46,480	1,638
1988	373	40,408	1,173	2004	375	44,102	1,660
1989	373	38,926	1,227	2005	373	35,976	1,676
1990	371	34,814	1,257	2006	376	39,211	1,573
1991	371	43,406	1,083	2007	376	29,679	1,484
1992	356	34,024	1,263	2008	375	24,635	1,251
1993	375	43,278	1,385	2009	375	24,819	1,342
1994	375	38,901	1,141	2010	376	23,142	1,385
1995	376	25,673	1,156	2011	376	36,227	1,734
1996	375	40,789	1,387	2012	376	35,782	1,785
1997	376	35,536	1,193	2013	376	35,908	1,847
				2014	376	43,042	2,099

Table 1.13. Bottom-trawl survey estimated numbers (millions) at age used for the stock assessment model, 1982-2014 based on strata 1-9. Shaded cells represent years where only strata 1-6 were surveyed. Standard errors and CVs are based on design-based sampling errors.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total	StdErr	CV
1982	948	2,271	2,433	3,115	1,061	144	100	48	30	19	12	7	3	1	1	10,192	1,273	12%
1983	3,918	576	1,278	2,267	5,055	1,554	286	157	71	61	46	16	7	5	2	15,300	1,192	8%
1984	367	281	399	1,152	1,458	3,426	652	145	68	24	16	6	4	5	2	8,005	791	10%
1985	4,785	677	2,563	833	2,876	1,835	1,272	252	65	53	19	6	7	1	0	15,244	1,949	13%
1986	2,188	497	362	1,338	816	1,383	1,220	1,123	358	56	26	11	1	3	1	9,381	837	9%
1987	345	559	723	538	3,246	913	918	370	1,197	189	57	23	4	2	2	9,088	1,126	12%
1988	1,070	512	1,198	2,286	1,012	3,319	1,002	786	462	1,117	107	64	13	17	9	12,976	1,466	11%
1989	762	225	428	1,411	3,198	645	2,486	379	471	182	581	101	89	45	64	11,067	1,136	10%
1990	1,721	241	86	552	1,110	3,754	759	1,906	198	373	58	544	47	36	48	11,432	1,373	12%
1991	2,419	660	234	76	461	429	1,421	534	1,158	304	419	87	265	38	35	8,539	827	10%
1992	1,338	324	1,703	285	319	536	478	689	310	595	212	268	117	92	73	7,340	808	11%
1993	2,347	333	709	2,972	647	521	275	384	527	325	286	208	165	91	110	9,900	920	9%
1994	1,249	521	395	1,115	3,026	530	141	124	143	268	166	233	89	86	145	8,232	973	12%
1995	1,443	138	270	1,224	1,604	2,566	1,086	288	179	116	219	91	167	68	101	9,561	1,809	19%
1996	1,434	346	155	308	806	1,125	1,027	349	87	94	65	123	40	74	100	6,134	508	8%
1997	2,239	339	147	180	2,166	1,008	626	782	137	70	53	59	96	32	111	8,042	1,082	13%
1998	625	549	281	185	354	2,024	529	342	269	68	31	11	24	28	65	5,385	592	11%
1999	817	704	646	701	401	726	1,846	514	260	243	91	39	16	24	82	7,110	834	12%
2000	921	292	353	1,189	1,223	648	571	1,874	737	394	172	116	36	17	76	8,618	1,017	12%
2001	1,465	841	441	407	1,034	1,093	475	239	718	518	201	163	66	23	65	7,750	696	9%
2002	644	300	621	894	928	1,205	627	307	421	792	396	179	107	33	37	7,491	769	10%
2003	376	124	723	1,178	1,377	1,244	1,651	915	411	536	1,081	469	179	89	69	10,421	1,863	18%
2004	320	225	140	1,036	1,005	762	448	486	242	151	152	275	118	29	23	5,413	499	9%
2005	345	124	185	799	2,319	1,578	838	387	297	230	60	127	207	81	84	7,662	743	10%
2006	715	62	96	317	791	1,006	647	312	179	155	75	47	67	91	90	4,649	427	9%
2007	2,023	48	116	337	1,057	1,245	905	656	278	125	116	101	47	58	113	7,225	669	9%
2008	442	99	82	148	421	852	673	471	300	118	100	76	35	19	120	3,955	431	11%
2009	674	165	342	372	219	319	433	342	250	123	82	27	28	14	59	3,449	415	12%
2010	408	115	204	2,055	930	295	261	278	295	203	175	64	39	23	51	5,396	707	13%
2011	982	100	208	285	1,433	707	210	121	189	189	157	120	51	24	64	4,841	453	9%
2012	964	188	344	2,472	572	915	313	125	94	130	106	94	79	28	51	6,474	611	9%
2013	973	99	189	744	3,702	865	547	194	66	60	79	60	56	31	41	7,706	625	8%
2014	1,701	438	203	268	1,233	4,494	2,346	508	281	103	40	56	58	27	70	11,827	792	7%
Avg	1,302	393	553	1,001	1,450	1,323	820	497	326	242	165	117	70	37	60	8,358	915	11%

Table 1.14. Mean EBS pollock body mass (kg) at age as observed in the summer NMFS bottom trawl survey, 1982- 2014.

	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Age 14	Age 15
1982	0.033	0.067	0.167	0.350	0.429	0.669	1.004	1.128	1.202	1.420	1.597	1.624	1.786	2.140	2.673
1983	0.016	0.105	0.170	0.360	0.494	0.577	0.742	1.070	1.146	1.015	1.100	1.148	1.902	1.108	2.723
1984	0.017	0.064	0.193	0.361	0.487	0.616	0.752	1.013	1.220	1.368	1.678	1.655	1.404	1.470	2.506
1985	0.022	0.084	0.171	0.398	0.493	0.630	0.960	1.009	1.367	1.065	1.378	1.764	1.581	2.189	2.753
1986	0.017	0.084	0.145	0.358	0.462	0.642	0.720	0.844	0.996	1.355	1.473	1.471	2.558	2.128	2.833
1987	0.024	0.088	0.188	0.353	0.434	0.530	0.703	0.795	0.888	0.986	1.194	1.367	1.724	2.057	2.699
1988	0.021	0.080	0.210	0.356	0.460	0.521	0.602	0.760	0.851	0.992	1.201	1.209	1.532	1.051	2.441
1989	0.021	0.071	0.174	0.370	0.441	0.534	0.628	0.683	0.935	0.928	1.048	1.066	1.108	1.138	2.163
1990	0.019	0.086	0.155	0.377	0.503	0.573	0.619	0.722	0.796	1.051	1.106	1.128	1.108	1.294	2.295
1991	0.018	0.085	0.151	0.364	0.486	0.580	0.696	0.744	0.877	0.918	1.095	1.201	1.241	1.398	2.522
1992	0.029	0.093	0.205	0.373	0.522	0.623	0.777	0.844	0.898	0.988	1.123	1.241	1.391	1.360	2.484
1993	0.017	0.076	0.253	0.453	0.503	0.563	0.665	0.807	0.978	1.026	1.147	1.263	1.391	1.536	2.504
1994	0.021	0.081	0.190	0.474	0.576	0.638	0.713	0.969	1.170	1.126	1.226	1.326	1.432	1.491	2.278
1995	0.019	0.064	0.114	0.377	0.485	0.629	0.655	0.840	0.966	1.181	1.163	1.330	1.398	1.479	2.234
1996	0.020	0.066	0.117	0.313	0.497	0.597	0.734	0.815	0.972	1.062	1.306	1.395	1.469	1.548	2.148
1997	0.017	0.068	0.209	0.322	0.499	0.597	0.789	0.935	0.966	1.035	1.169	1.295	1.275	1.495	2.080
1998	0.021	0.060	0.134	0.341	0.477	0.520	0.679	0.830	0.911	1.010	1.072	1.331	1.396	1.770	2.176
1999	0.018	0.062	0.157	0.357	0.425	0.561	0.634	0.780	0.981	1.011	1.101	1.200	1.627	1.768	2.232
2000	0.016	0.059	0.168	0.377	0.459	0.532	0.660	0.709	0.784	0.957	1.184	1.214	1.355	1.494	2.212
2001	0.020	0.062	0.129	0.374	0.535	0.618	0.774	0.821	0.855	0.948	1.103	1.201	1.411	1.417	1.917
2002	0.019	0.076	0.223	0.392	0.533	0.646	0.810	0.943	0.897	0.963	1.047	1.094	1.209	1.389	1.955
2003	0.024	0.083	0.237	0.435	0.567	0.672	0.734	0.832	0.884	0.961	0.991	1.029	1.040	1.142	2.218
2004	0.026	0.079	0.210	0.476	0.555	0.680	0.765	0.793	0.941	0.963	1.058	1.052	1.120	1.426	2.426
2005	0.023	0.069	0.213	0.405	0.517	0.610	0.704	0.816	0.888	0.925	1.072	1.112	1.123	1.195	2.000
2006	0.023	0.073	0.177	0.363	0.517	0.607	0.721	0.807	0.908	1.046	1.273	1.206	1.272	1.246	2.095
2007	0.021	0.079	0.279	0.421	0.547	0.672	0.782	0.844	0.925	1.098	1.131	1.112	1.341	1.305	2.071
2008	0.024	0.054	0.185	0.416	0.523	0.642	0.756	0.860	0.924	1.076	1.217	1.206	1.386	1.586	2.064
2009	0.020	0.078	0.165	0.408	0.571	0.669	0.884	1.009	0.955	1.119	1.192	1.440	1.437	1.540	1.928
2010	0.025	0.070	0.237	0.402	0.549	0.679	0.894	0.982	1.033	1.123	1.168	1.258	1.447	1.535	2.202
2011	0.024	0.086	0.169	0.425	0.539	0.647	0.933	1.006	1.108	1.114	1.243	1.304	1.436	1.463	2.114
2012	0.021	0.069	0.204	0.358	0.533	0.671	0.807	0.948	1.212	1.237	1.322	1.360	1.417	1.640	2.071
2013	0.023	0.063	0.167	0.420	0.492	0.623	0.834	0.976	1.079	1.235	1.319	1.366	1.466	1.608	2.128
2014	0.023	0.081	0.162	0.353	0.474	0.604	0.657	0.895	0.987	1.115	1.401	1.350	1.386	1.505	2.043

Table 1.15. Number of (age 1+) hauls and sample sizes for EBS pollock collected by the AT surveys. Sub-headings E and W represent collections east and west of 170°W (within the US EEZ) and US represents the US sub-total and RU represents the collections from the Russian side of the surveyed region.

	Hauls				Lengths				Otoliths				Number aged			
Year	E	W	US	RU	E	W	US	RU	E	W	US	RU	E	W	US	RU
1979			25				7,722				0				2,610	
1982	13	31	48		1,725	6,689	8,687		840	2,324	3,164		783	1,958	2,741	
1985			73				19,872				2,739				2,739	
1988			25				6,619				1,471				1,471	
1991			62				16,343				2,062				1,663	
1994	25	51	76	19	4,553	21,011	25,564	8,930	1,560	3,694	4,966	1,270	612	932	1,770	455
1996	15	42	57		3,551	13,273	16,824		669	1,280	1,949		815	1,111	1,926	
1997	25	61	86		6,493	23,043	29,536		966	2,669	3,635		936	1,349	2,285	
1999	41	77	118		13,841	28,521	42,362		1,945	3,001	4,946		946	1,500	2,446	
2000	29	95	124		7,721	36,008	43,729		850	2,609	3,459		850	1,403	2,253	
2002	47	79	126		14,601	25,633	40,234		1,424	1,883	3,307		1,000	1,200	2,200	
2004	33	57	90	15	8,896	18,262	27,158	5,893	1,167	2,002	3,169	461	798	1,192	2,351	461
2006	27	56	83		4,939	19,326	24,265		822	1,871	2,693		822	1,870	2,692	
2007	23	46	69	4	5,492	14,863	20,355	1,407	871	1,961	2,832	319	823	1,737	2,560	315
2008	9	53	62	6	2,394	15,354	17,748	1,754	341	1,698	2,039	177	338	1,381	1,719	176
2009	13	33	46	3	1,576	9,257	10,833	282	308	1,210	1,518	54	306	1,205	1,511	54
2010	11	48	59	9	2,432	20,263	22,695	3,502	653	1,868	2,521	381	652	1,598	2,250	379
2012	17	60	77	14	4,422	23,929	28,351	5,620	650	2,045	2,695	418	646	1,483	2,129	416
2014	52	87	139	3	28,857	8,645	37,502	747	1739	849	2,588	72	NA	NA	NA	NA

Table 1.16. AT survey estimates of EBS pollock abundance-at-age (millions), 1979-2014. Age 2+ totals and age-1s are modeled as separate indices. CV's are based on relative error estimates and assumed to average 20% (since 1982).

	Age												
Year	1	2	3	4	5	6	7	8	9	10+	Age 2+	CV	Total
1979	69,110	41,132	3,884	413	534	128	30	4	28	161	46,314	250%	115,424
1982	108	3,401	4,108	7,637	1,790	283	141	178	90	177	17,805	20%	17,913
1985	2,076	929	8,149	898	2,186	1,510	1,127	130	21	15	14,965	20%	17,041
1988	11	1,112	3,586	3,864	739	1,882	403	151	130	414	12,280	20%	12,292
1991	639	5,942	967	215	224	133	120	39	37	53	7,730	20%	8,369
1994	453	3,906	1,127	1,670	1,908	293	69	67	30	59	9,130	19%	9,582
1996	972	446	520	2,686	821	509	434	85	17	34	5,553	16%	6,524
1997	12,384	2,743	385	491	1,918	384	205	143	33	18	6,319	15%	18,704
1999	112	1,588	3,597	1,684	583	274	1,169	400	105	90	9,489	23%	9,602
2000	258	1,272	1,185	2,480	900	244	234	725	190	141	7,372	13%	7,629
2002	561	4,188	3,841	1,295	685	593	288	100	132	439	11,561	13%	12,122
2004	16	275	1,189	2,929	1,444	417	202	193	68	101	6,819	15%	6,834
2006	456	209	282	610	695	552	320	110	53	110	2,940	16%	3,396
2007	5,589	1,026	320	430	669	589	306	166	60	52	3,618	18%	9,207
2008	36	2,905	1,032	144	107	170	132	71	58	48	4,668	31%	4,704
2009	5,128	797	1,674	199	31	34	51	38	21	25	2,870	36%	7,997
2010	2,526	6,395	973	2,183	384	46	6	7	7	21	10,023	25%	12,549
2012	67	1,963	1,641	2,444	203	246	64	13	8	19	6,600	25%	6,667
2014	4,473	8,294	1,329	533	857	1,192	545	81	40	39	13,073	4,473	17,105
Avg.*	1,968	2,635	1,995	1,800	899	522	324	150	61	103	8,490	1,968	10,458
Median*	508	1,776	1,187	1,483	717	339	220	105	47	53	7,551	20%	9,394

*Average and median values exclude 1979 values.

Table 1.17. Mid-water pollock abundance (near surface down to 3 m from the bottom) by area as estimated from summer acoustic-trawl surveys on the U.S. EEZ portion of the Bering Sea shelf, 1994-2014 (as described in Honkalehto et al. 2010).

Date		**Area**	**Biomass in millions of t** (percent of total)						**Total Biomass**
		$(nmi)^2$	**SCA**		**E170-SCA**		**W170**		**(millions t)**
1994	9 Jul - 19 Aug	78,251	0.312	(11%)	0.399	(14%)	2.176	(75%)	2.886
1996	20 Jul - 30 Aug	93,810	0.215	(9%)	0.269	(12%)	1.826	(79%)	2.311
1997	17 Jul - 4 Sept	102,770	0.246	(10%)	0.527	(20%)	1.818	(70%)	2.591
1999	7 Jun - 5 Aug	103,670	0.299	(9%)	0.579	(18%)	2.408	(73%)	3.285
2000	7 Jun - 2 Aug	106,140	0.393	(13%)	0.498	(16%)	2.158	(71%)	3.049
2002	4 Jun - 30 Jul	99,526	0.647	(18%)	0.797	(22%)	2.178	(60%)	3.622
2004	4 Jun - 29 Jul	99,659	0.498	(15%)	0.516	(16%)	2.293	(69%)	3.307
2006	3 Jun - 25 Jul	89,550	0.131	(8%)	0.254	(16%)	1.175	(75%)	1.560
2007	2 Jun - 30 Jul	92,944	0.084	(5%)	0.168	(10%)	1.517	(86%)	1.769
2008	2 Jun - 31 Jul	95,374	0.085	(9%)	0.029	(3%)	0.883	(89%)	0.997
2009	9 Jun - 7 Aug	91,414	0.070	(8%)	0.018	(2%)	0.835	(90%)	0.924
2010	5 Jun - 7 Aug	92,849	0.067	(3%)	0.113	(5%)	2.143	(92%)	2.323
2012	7 Jun - 10 Aug	96,852	0.142	(8%)	0.138	(7%)	1.563	(85%)	1.843
2014	12 Jun - 13 Aug	94,361	0.426	(12%)	1.000	(29%)	2.014	(59%)	3.439

Key: SCA = Sea lion Conservation Area
E170 - SCA = East of 170 W minus SCA
W170 = West of 170 W

Table 1.18. An abundance index derived from acoustic data collected opportunistically aboard bottom-trawl survey vessels (AVO index; Honkalehto et al. 2014). Note values in parentheses are the coefficients of variation from using 1-D geostatistical estimates of sampling variability (Petitgas, 1993). See Honkalehto et al. (2011) for the derivation of these estimates. CV_{AVO}, was assumed to have a mean value of 0.32 for model fitting purposes (scaling relative to the AT and BTS indices). *Note that data were collected in the 2014 bottom-trawl survey and will be developed and included for the 2015 assessment.*

	AT scaled biomass index	AVO index	CV_{AVO},
2006	0.470 (3.9%)	0.555 (5.1%)	23%
2007	0.534 (4.5%)	0.638 (8.7%)	39%
2008	0.301 (7.6%)	0.316 (6.4%)	29%
2009	0.279 (8.8%)	0.285 (12.0%)	54%
2010	0.701 (6.0%)	0.679 (8.6%)	39%
2011	*-no survey-*	0.543 (5.7%)	26%
2012	0.556 (4.2%)	0.661 (6.3%)	28%
2013	*-no survey-*	0.696 (3.9%)	18%

Table 1.19. Mean weight-at-age (kg) estimates from the fishery (1991-2014) showing the between-year variability (middle row) and sampling error (bottom panel) based on bootstrap resampling of observer data. Italicized values for 2014 are preliminary (see text for how they were estimated). The bold values represent the 1992 year-class to show that it was below-average at most ages.

Mean body mass at age (kg) in fishery **Age**

	3	4	5	6	7	8	9	10	11	12	13	14	15
1964-1990	0.303	0.447	0.589	0.722	0.840	0.942	1.029	1.102	1.163	1.212	1.253	1.286	1.312
1991	0.287	0.479	0.608	0.727	0.848	0.887	1.006	1.127	1.125	1.237	1.242	1.279	1.244
1992	0.398	0.468	0.645	0.712	0.814	0.983	1.028	1.224	1.234	1.270	1.175	1.353	1.441
1993	0.495	0.613	0.656	0.772	0.930	1.043	1.196	1.230	1.407	1.548	1.650	1.688	1.635
1994	0.394	0.649	0.730	0.746	0.706	1.010	1.392	1.320	1.339	1.417	1.374	1.310	1.386
1995	0.375	0.502	0.730	0.843	0.856	0.973	1.224	1.338	1.413	1.497	1.395	1.212	1.363
1996	0.322	**0.428**	0.680	0.790	0.946	0.949	1.021	1.090	1.403	1.497	1.539	1.750	1.536
1997	0.323	0.466	**0.554**	0.742	0.888	1.071	1.088	1.240	1.410	1.473	1.724	1.458	1.423
1998	0.372	0.588	0.627	**0.623**	0.779	1.034	1.177	1.243	1.294	1.417	1.559	1.556	1.720
1999	0.400	0.502	0.638	0.701	**0.727**	0.901	1.039	1.272	1.207	1.415	1.164	1.141	1.319
2000	0.351	0.524	0.630	0.732	0.782	**0.805**	0.972	1.018	1.268	1.317	1.320	1.665	1.738
2001	0.324	0.497	0.669	0.787	0.963	0.995	**1.062**	1.137	1.327	1.451	1.585	1.466	1.665
2002	0.380	0.508	0.669	0.795	0.908	1.024	1.117	**1.096**	1.300	1.430	1.611	1.319	1.636
2003	0.484	0.550	0.650	0.768	0.862	0.954	1.085	1.224	**1.213**	1.227	1.445	1.340	1.721
2004	0.404	0.580	0.640	0.770	0.890	0.928	1.026	1.207	1.159	**1.179**	1.351	1.292	1.232
2005	0.353	0.507	0.639	0.739	0.880	0.948	1.063	1.094	1.267	1.312	**1.313**	1.164	1.419
2006	0.305	0.448	0.604	0.754	0.855	0.958	1.055	1.126	1.219	1.283	1.306	**1.399**	1.453
2007	0.338	0.509	0.642	0.782	0.960	1.104	1.196	1.276	1.328	1.516	1.416	1.768	**1.532**
2008	0.329	0.521	0.652	0.772	0.899	1.042	1.114	1.204	1.309	1.404	1.513	1.599	1.506
2009	0.345	0.548	0.687	0.892	1.020	1.153	1.407	1.486	1.636	1.637	1.817	2.176	2.292
2010	0.379	0.489	0.665	0.916	1.107	1.255	1.342	1.595	1.613	1.844	1.945	2.049	2.197
2011	0.290	0.508	0.666	0.807	0.973	1.222	1.337	1.507	1.578	1.614	2.114	1.731	2.260
2012	0.271	0.410	0.641	0.824	0.973	1.173	1.307	1.523	1.614	1.648	1.721	2.020	2.105
2013	0.290	0.443	0.566	0.783	1.117	1.275	1.429	1.702	1.850	1.819	1.935	2.115	2.071
2014	*0.290*	*0.447*	*0.600*	*0.698*	*0.726*	*1.030*	*1.160*	*1.273*	*1.370*	*1.454*	*1.531*	*1.559*	*1.648*
Stdev	0.057	0.058	0.041	0.061	0.104	0.121	0.144	0.178	0.179	0.176	0.256	0.312	0.325
CV	16%	11%	6%	8%	12%	12%	12%	14%	13%	12%	17%	20%	20%
Mean	0.357	0.510	0.647	0.773	0.899	1.030	1.160	1.273	1.370	1.454	1.531	1.559	1.648
Sampling error (from bootstrap)													
1991	8%	4%	3%	2%	2%	4%	2%	6%	3%	6%	4%	6%	4%
1992	2%	4%	5%	3%	3%	2%	3%	3%	4%	4%	11%	6%	6%
1993	2%	1%	3%	4%	4%	4%	3%	4%	4%	6%	7%	10%	8%
1994	8%	2%	1%	3%	8%	12%	5%	5%	4%	5%	6%	11%	6%
1995	5%	3%	2%	1%	3%	4%	6%	6%	5%	10%	6%	48%	6%
1996	7%	10%	3%	2%	1%	2%	4%	6%	13%	7%	6%	7%	9%
1997	9%	2%	1%	2%	2%	2%	3%	6%	10%	9%	14%	6%	7%
1998	5%	5%	3%	1%	3%	3%	2%	4%	8%	9%	13%	16%	14%
1999	1%	1%	2%	2%	1%	2%	3%	4%	12%	19%	42%	102%	22%
2000	4%	1%	1%	2%	2%	1%	3%	6%	5%	10%	47%	63%	48%
2001	5%	3%	1%	2%	3%	3%	2%	4%	5%	6%	8%	10%	33%
2002	4%	2%	2%	1%	1%	2%	3%	3%	5%	5%	7%	25%	22%
2003	1%	2%	1%	2%	1%	2%	3%	5%	5%	6%	10%	28%	13%
2004	4%	1%	1%	2%	2%	2%	3%	7%	6%	5%	10%	14%	9%
2005	4%	1%	1%	1%	2%	3%	3%	4%	7%	6%	20%	35%	20%
2006	4%	1%	1%	1%	1%	3%	4%	4%	7%	11%	9%	14%	7%
2007	3%	2%	1%	1%	1%	2%	3%	4%	5%	9%	9%	7%	6%
2008	3%	2%	2%	1%	1%	2%	2%	5%	5%	5%	5%	14%	6%
2009	3%	2%	4%	2%	2%	3%	3%	4%	6%	7%	5%	14%	7%
2010	6%	1%	1%	4%	3%	3%	3%	3%	4%	5%	8%	6%	5%
2011	2%	3%	1%	1%	3%	4%	3%	4%	4%	5%	15%	10%	9%
2012	3%	1%	2%	1%	2%	4%	7%	7%	6%	6%	8%	10%	21%
2013	3%	1%	1%	2%	2%	3%	5%	5%	6%	7%	7%	9%	6%

Table 1.20. Pollock sample sizes assumed for the age-composition data likelihoods from the fishery, bottom-trawl survey, and AT surveys, 1964-2014. *Note that the sample size for 2014 is set to a lower value for the AT data because the age-length key is derived from the bottom-trawl survey.*

Year	Fishery	Year	BTS	AT
1964-1977	10	1979	-	6
1978-1990	50			
1991	174			
1992	200	1982-2013	100	50
1993	273	2014	100	20
1994	108			
1995	138			
1996	149			
1997	256			
1998	270			
1999	456			
2000	452			
2001	292			
2002	435			
2003	389			
2004	332			
2005	399			
2006	328			
2007	408			
2008	341			
2009	360			
2010	350			
2011	350			
2012	350			
2013	350			

Table 1.21 Negative-log likelihood (NLL) components for EBS pollock model alternatives along with the contribution by prior distributions assumed for the model. Note that the values for Model 2.0 are not strictly comparable because a different likelihood function was selected for the BTS abundance.

	Model 1.0	Model 1.1	Model 1.2	Model 2.0
Fishery Catch	0.9	1.2	0.3	0.9
CPUE NLL	1.1	1.1	0.7	1.1
BTS abundance NLL	9.6	10.6	11.8	17.3
AT abundance (age-2 and older) NLL	39.5	42.0	33.9	39.0
AT age-1 abundance NLL	29.1	29.3	28.9	29.4
AVO NLL	1.2	1.6	1.7	1.2
Fishery age composition NLL	-1,110.3	-1,112.5	-1,110.5	-1,111.0
BTS age composition NLL	-541.9	-555.1	-538.8	-553.2
AT age composition NLL	1,469.7	1,473.7	1,475.9	1,469.6
Priors	120.6	128.3	135.7	111.3
Data	-101.1	-108.1	-96.1	-99.3
Total	19.5	20.3	39.6	12.0
Number of parameters	758	758	758	758
AIC	1,555	1,557	1,595	1,540
2014 SSB	2,945	2,685	7,416	2,941
Age 5 M	0.30	0.35	0.55	0.30
Age 15 M	0.30	0.17	0.35	0.30

Table 1.22. Parameter estimates and their standard errors for Model 1.0.

index	name	value	std.dev	index	name	value	std.dev	index	name	value	std.dev
1	log_avgrec	9.9506	0.10124	76	repl_F	0.31037	0.17221	151	sel_devs_fsh	-0.21183	0.36585
2	log_avginit	4.5657	0.68142	77	log_F_devs	-0.40693	0.29725	152	sel_devs_fsh	-0.17266	0.33058
3	log_avg_F	-1.4835	0.083067	78	log_F_devs	-0.57276	0.21714	153	sel_devs_fsh	-0.13256	0.32006
4	log_q_bts	0.36751	0.077401	79	log_F_devs	-0.67495	0.20598	154	sel_devs_fsh	-0.086029	0.31908
5	log_q_std_area	-0.26477	0.16321	80	log_F_devs	-0.16183	0.20206	155	sel_devs_fsh	-0.048173	0.3198
6	log_q_eit	-1.081	0.11029	81	log_F_devs	-0.16529	0.19438	156	sel_devs_fsh	-0.02131	0.32795
7	log_Rzero	9.9104	0.15429	82	log_F_devs	-0.21144	0.21423	157	sel_devs_fsh	0.005489	0.35472
8	steepness	0.67425	0.068245	83	log_F_devs	0.22358	0.21563	158	sel_devs_fsh	0.07716	0.68206
9	log_q_cpue	0.03455	0.18969	84	log_F_devs	0.61362	0.21633	159	sel_devs_fsh	0.1124	0.57673
10	log_q_avo	-9.6805	0.13323	85	log_F_devs	0.67361	0.21472	160	sel_devs_fsh	-0.24342	0.5037
11	log_initdevs	3.6258	0.72802	86	log_F_devs	0.82005	0.21457	161	sel_devs_fsh	0.1007	0.36478
12	log_initdevs	3.1676	0.71995	87	log_F_devs	0.80444	0.21429	162	sel_devs_fsh	0.044156	0.33354
13	log_initdevs	1.5929	0.86039	88	log_F_devs	0.65878	0.20728	163	sel_devs_fsh	0.013824	0.32024
14	log_initdevs	0.79808	0.96937	89	log_F_devs	0.51301	0.19648	164	sel_devs_fsh	-0.0096289	0.31908
15	log_initdevs	1.2544	0.84361	90	log_F_devs	0.31071	0.23466	165	sel_devs_fsh	-0.023736	0.31981
16	log_initdevs	0.34742	1.1	91	log_F_devs	0.34085	0.25898	166	sel_devs_fsh	-0.029494	0.32665
17	log_initdevs	-0.65403	1.2784	92	log_F_devs	0.37618	0.25804	167	sel_devs_fsh	-0.041955	0.35219
18	log_initdevs	-1.4441	1.2288	93	log_F_devs	0.33072	0.22478	168	sel_devs_fsh	0.033706	0.68231
19	log_initdevs	-1.4187	1.2342	94	log_F_devs	0.10278	0.3161	169	sel_devs_fsh	0.065075	0.55762
20	log_initdevs	-1.4209	1.2346	95	log_F_devs	-0.17849	0.36258	170	sel_devs_fsh	0.38297	0.50054
21	log_initdevs	-1.4274	1.2361	96	log_F_devs	-0.18909	0.37507	171	sel_devs_fsh	-0.13128	0.3621
22	log_initdevs	-1.4473	1.2406	97	log_F_devs	-0.1653	0.36925	172	sel_devs_fsh	-0.11964	0.3305
23	log_initdevs	-1.4866	1.2509	98	log_F_devs	-0.13142	0.37741	173	sel_devs_fsh	-0.10676	0.32101
24	log_initdevs	-1.4872	1.251	99	log_F_devs	-0.27317	0.33285	174	sel_devs_fsh	-0.080806	0.32605
25	log_rec_devs	-1.3588	0.34236	100	log_F_devs	-0.58214	0.30094	175	sel_devs_fsh	-0.056941	0.34152
26	log_rec_devs	-0.016911	0.22889	101	log_F_devs	-0.51159	0.14743	176	sel_devs_fsh	-0.037639	0.37622
27	log_rec_devs	-0.36454	0.32415	102	log_F_devs	-0.45839	0.13491	177	sel_devs_fsh	0.05131	0.46112
28	log_rec_devs	0.31704	0.25609	103	log_F_devs	-0.13873	0.12239	178	sel_devs_fsh	0.0239	0.69131
29	log_rec_devs	0.24305	0.26587	104	log_F_devs	-0.0041678	0.11372	179	sel_devs_fsh	0.40237	0.56134
30	log_rec_devs	0.3316	0.25352	105	log_F_devs	0.32364	0.1181	180	sel_devs_fsh	0.02548	0.45111
31	log_rec_devs	-0.039685	0.2874	106	log_F_devs	-0.1908	0.13094	181	sel_devs_fsh	-0.25049	0.3702
32	log_rec_devs	-0.75705	0.34216	107	log_F_devs	-0.36102	0.14835	182	sel_devs_fsh	-0.22816	0.34555
33	log_rec_devs	-0.66337	0.31421	108	log_F_devs	-0.28304	0.1476	183	sel_devs_fsh	-0.20993	0.36244
34	log_rec_devs	0.31702	0.18913	109	log_F_devs	-0.041354	0.14972	184	sel_devs_fsh	-0.047292	0.38884
35	log_rec_devs	0.02138	0.1961	110	log_F_devs	-0.050507	0.18087	185	sel_devs_fsh	-0.041767	0.37829
36	log_rec_devs	-0.14226	0.18173	111	log_F_devs	-0.14079	0.16066	186	sel_devs_fsh	-0.038269	0.41007
37	log_rec_devs	-0.40402	0.18127	112	log_F_devs	-0.50303	0.12603	187	sel_devs_fsh	0.36416	0.46627
38	log_rec_devs	-0.40472	0.1625	113	log_F_devs	-0.35584	0.1186	188	sel_devs_fsh	-0.043721	0.68372
39	log_rec_devs	0.25839	0.13287	114	log_F_devs	-0.19475	0.11815	189	sel_devs_fsh	-0.1789	0.5649
40	log_rec_devs	1.1657	0.11881	115	log_F_devs	-0.05369	0.10817	190	sel_devs_fsh	-0.13546	0.45514
41	log_rec_devs	0.24815	0.12601	116	log_F_devs	-0.051961	0.11375	191	sel_devs_fsh	0.011679	0.45391
42	log_rec_devs	0.38361	0.12574	117	log_F_devs	-0.11694	0.12634	192	sel_devs_fsh	0.12974	0.37973
43	log_rec_devs	-0.2762	0.14658	118	log_F_devs	-0.22205	0.12141	193	sel_devs_fsh	0.1271	0.38096
44	log_rec_devs	0.94035	0.11339	119	log_F_devs	-0.0044829	0.11898	194	sel_devs_fsh	-0.035367	0.4538
45	log_rec_devs	-0.45405	0.14735	120	log_F_devs	0.05235	0.11324	195	sel_devs_fsh	-0.025636	0.55835
46	log_rec_devs	0.52313	0.11604	121	log_F_devs	0.12955	0.11071	196	sel_devs_fsh	-0.018603	0.59418
47	log_rec_devs	-0.36519	0.13145	122	log_F_devs	0.11872	0.12589	197	sel_devs_fsh	0.16917	0.42943
48	log_rec_devs	-0.9022	0.14858	123	log_F_devs	-0.073078	0.12548	198	sel_devs_fsh	-0.081469	0.68663
49	log_rec_devs	-1.3452	0.1641	124	log_F_devs	0.2788	0.13841	199	sel_devs_fsh	0.3864	0.59201
50	log_rec_devs	-0.705	0.1424	125	log_F_devs	0.28154	0.17304	200	sel_devs_fsh	0.1349	0.50119
51	log_rec_devs	0.87403	0.10664	126	log_F_devs	0.34692	0.26974	201	sel_devs_fsh	0.036245	0.46629
52	log_rec_devs	0.19887	0.11425	127	log_F_devs	0.16919	0.36348	202	sel_devs_fsh	-0.074586	0.37313
53	log_rec_devs	0.049038	0.11829	128	sel_devs_fsh	-0.069523	0.70628	203	sel_devs_fsh	-0.058674	0.35338
54	log_rec_devs	0.82024	0.10791	129	sel_devs_fsh	-0.00064539	0.61175	204	sel_devs_fsh	-0.051574	0.37635
55	log_rec_devs	-0.35973	0.12366	130	sel_devs_fsh	0.3165	0.57131	205	sel_devs_fsh	-0.063988	0.55971
56	log_rec_devs	-0.67305	0.12688	131	sel_devs_fsh	0.10657	0.5858	206	sel_devs_fsh	-0.011472	0.60261
57	log_rec_devs	0.099289	0.11107	132	sel_devs_fsh	0.0024275	0.38173	207	sel_devs_fsh	-0.21578	0.42894
58	log_rec_devs	0.40722	0.108	133	sel_devs_fsh	-0.05998	0.34705	208	sel_devs_fsh	-0.10761	0.69093
59	log_rec_devs	-0.28801	0.11588	134	sel_devs_fsh	-0.077108	0.3342	209	sel_devs_fsh	0.012384	0.59803
60	log_rec_devs	-0.1967	0.11431	135	sel_devs_fsh	-0.07546	0.33451	210	sel_devs_fsh	-0.077571	0.52304
61	log_rec_devs	0.23655	0.10913	136	sel_devs_fsh	-0.071755	0.34726	211	sel_devs_fsh	0.056583	0.36349
62	log_rec_devs	0.54022	0.10594	137	sel_devs_fsh	-0.071027	0.38193	212	sel_devs_fsh	0.067519	0.32974
63	log_rec_devs	0.10345	0.10884	138	sel_devs_fsh	0.016027	0.66644	213	sel_devs_fsh	0.076426	0.32589
64	log_rec_devs	-0.40563	0.11284	139	sel_devs_fsh	0.25988	0.5847	214	sel_devs_fsh	0.06857	0.34058
65	log_rec_devs	-1.2084	0.12702	140	sel_devs_fsh	0.14194	0.55022	215	sel_devs_fsh	0.068139	0.38031
66	log_rec_devs	-1.5946	0.13893	141	sel_devs_fsh	-0.077024	0.36014	216	sel_devs_fsh	0.0093996	0.59873
67	log_rec_devs	-0.65135	0.11867	142	sel_devs_fsh	-0.061146	0.33067	217	sel_devs_fsh	-0.17384	0.43747
68	log_rec_devs	0.19966	0.11421	143	sel_devs_fsh	-0.066137	0.32281	218	sel_devs_fsh	-0.066961	0.67282
69	log_rec_devs	-0.72387	0.15035	144	sel_devs_fsh	-0.061829	0.32002	219	sel_devs_fsh	0.24727	0.53103
70	log_rec_devs	0.98532	0.1314	145	sel_devs_fsh	-0.059735	0.32174	220	sel_devs_fsh	0.15394	0.47906
71	log_rec_devs	-0.020358	0.17908	146	sel_devs_fsh	-0.051322	0.33175	221	sel_devs_fsh	-0.015801	0.35417
72	log_rec_devs	0.14507	0.21178	147	sel_devs_fsh	-0.040654	0.36016	222	sel_devs_fsh	-0.024076	0.32863
73	log_rec_devs	-0.14627	0.17367	148	sel_devs_fsh	-0.021022	0.66637	223	sel_devs_fsh	-0.030178	0.332
74	log_rec_devs	0.39127	0.17671	149	sel_devs_fsh	0.16081	0.57829	224	sel_devs_fsh	-0.023924	0.36316
75	log_rec_devs	0.12385	0.18873	150	sel_devs_fsh	0.52728	0.5207	225	sel_devs_fsh	-0.010594	0.52866

Table 1.22. (continued) Parameter estimates and their standard errors for Model 1.0.

index	name	value	std.dev	index	name	value	std.dev	index	name	value	std.dev
226	sel_devs_fsh	-0.0052364	0.54689	301	sel_devs_fsh	-0.055062	0.39169	376	sel_devs_fsh	0.082959	0.36242
227	sel_devs_fsh	-0.22444	0.45768	302	sel_devs_fsh	0.034414	0.40298	377	sel_devs_fsh	0.10838	0.37316
228	sel_devs_fsh	-0.094434	0.67287	303	sel_devs_fsh	0.099795	0.39794	378	sel_devs_fsh	-0.11567	0.6837
229	sel_devs_fsh	-0.53145	0.49814	304	sel_devs_fsh	0.10143	0.40167	379	sel_devs_fsh	0.076295	0.61033
230	sel_devs_fsh	0.16723	0.35869	305	sel_devs_fsh	0.14209	0.58335	380	sel_devs_fsh	-0.26049	0.54215
231	sel_devs_fsh	0.10127	0.32847	306	sel_devs_fsh	0.16161	0.61777	381	sel_devs_fsh	0.29137	0.45992
232	sel_devs_fsh	0.067506	0.32194	307	sel_devs_fsh	0.30661	0.59283	382	sel_devs_fsh	0.27646	0.39466
233	sel_devs_fsh	0.057397	0.33045	308	sel_devs_fsh	-0.12525	0.67054	383	sel_devs_fsh	0.070393	0.4351
234	sel_devs_fsh	0.048266	0.36135	309	sel_devs_fsh	0.13557	0.62072	384	sel_devs_fsh	-0.13833	0.41044
235	sel_devs_fsh	0.035233	0.52831	310	sel_devs_fsh	-0.044724	0.46974	385	sel_devs_fsh	-0.041661	0.33764
236	sel_devs_fsh	0.029607	0.54624	311	sel_devs_fsh	-0.16011	0.40171	386	sel_devs_fsh	-0.037335	0.33616
237	sel_devs_fsh	0.11938	0.47158	312	sel_devs_fsh	-0.22926	0.40791	387	sel_devs_fsh	-0.12103	0.35836
238	sel_devs_fsh	-0.089841	0.66958	313	sel_devs_fsh	0.032043	0.40629	388	sel_devs_fsh	-0.10306	0.68116
239	sel_devs_fsh	-0.032922	0.51887	314	sel_devs_fsh	0.036604	0.41559	389	sel_devs_fsh	-0.017713	0.58843
240	sel_devs_fsh	-0.19902	0.40417	315	sel_devs_fsh	0.03101	0.60087	390	sel_devs_fsh	-0.42876	0.53193
241	sel_devs_fsh	0.0797	0.34528	316	sel_devs_fsh	0.10331	0.62837	391	sel_devs_fsh	-0.28336	0.4509
242	sel_devs_fsh	0.073996	0.32572	317	sel_devs_fsh	0.22081	0.59529	392	sel_devs_fsh	-0.043708	0.39169
243	sel_devs_fsh	0.065877	0.32139	318	sel_devs_fsh	-0.11466	0.68078	393	sel_devs_fsh	0.044536	0.36033
244	sel_devs_fsh	0.057411	0.32624	319	sel_devs_fsh	-0.15619	0.62101	394	sel_devs_fsh	0.2566	0.40219
245	sel_devs_fsh	0.050331	0.34518	320	sel_devs_fsh	0.032434	0.49531	395	sel_devs_fsh	0.032444	0.34288
246	sel_devs_fsh	0.046234	0.3887	321	sel_devs_fsh	-0.039605	0.42101	396	sel_devs_fsh	0.25383	0.32564
247	sel_devs_fsh	-0.051769	0.47659	322	sel_devs_fsh	0.22274	0.37267	397	sel_devs_fsh	0.28919	0.3427
248	sel_devs_fsh	-0.037657	0.66222	323	sel_devs_fsh	-0.12861	0.38468	398	sel_devs_fsh	-0.097085	0.67981
249	sel_devs_fsh	0.32547	0.54459	324	sel_devs_fsh	0.014256	0.45737	399	sel_devs_fsh	-0.050434	0.43186
250	sel_devs_fsh	-0.12622	0.47362	325	sel_devs_fsh	0.027797	0.60239	400	sel_devs_fsh	0.62914	0.36328
251	sel_devs_fsh	-0.10995	0.45284	326	sel_devs_fsh	0.040872	0.63342	401	sel_devs_fsh	-0.40636	0.38968
252	sel_devs_fsh	-0.014288	0.35909	327	sel_devs_fsh	0.10096	0.58704	402	sel_devs_fsh	-0.41126	0.39344
253	sel_devs_fsh	-0.0033752	0.33454	328	sel_devs_fsh	-0.11601	0.68113	403	sel_devs_fsh	-0.050878	0.36846
254	sel_devs_fsh	0.0035683	0.33065	329	sel_devs_fsh	0.30206	0.61589	404	sel_devs_fsh	-0.10383	0.33445
255	sel_devs_fsh	0.0055679	0.343	330	sel_devs_fsh	0.1545	0.48216	405	sel_devs_fsh	0.23117	0.32758
256	sel_devs_fsh	0.0038965	0.37911	331	sel_devs_fsh	-0.29807	0.44149	406	sel_devs_fsh	0.10847	0.33136
257	sel_devs_fsh	-0.047009	0.5219	332	sel_devs_fsh	-0.3273	0.39217	407	sel_devs_fsh	0.15107	0.32024
258	sel_devs_fsh	-0.065504	0.66468	333	sel_devs_fsh	0.19079	0.36588	408	sel_devs_fsh	-0.078551	0.67915
259	sel_devs_fsh	-0.10695	0.52816	334	sel_devs_fsh	-0.0034513	0.44231	409	sel_devs_fsh	-0.86661	0.46832
260	sel_devs_fsh	0.075969	0.45577	335	sel_devs_fsh	0.03885	0.58338	410	sel_devs_fsh	0.068588	0.31026
261	sel_devs_fsh	0.0079622	0.47198	336	sel_devs_fsh	0.016034	0.63094	411	sel_devs_fsh	0.88425	0.32405
262	sel_devs_fsh	-0.02114	0.38405	337	sel_devs_fsh	0.042599	0.58794	412	sel_devs_fsh	0.13232	0.37484
263	sel_devs_fsh	-0.02878	0.37654	338	sel_devs_fsh	-0.11259	0.68386	413	sel_devs_fsh	0.084585	0.41212
264	sel_devs_fsh	0.017008	0.5217	339	sel_devs_fsh	0.1366	0.61338	414	sel_devs_fsh	0.10239	0.34915
265	sel_devs_fsh	0.038649	0.39123	340	sel_devs_fsh	-0.03154	0.49139	415	sel_devs_fsh	-0.058462	0.32141
266	sel_devs_fsh	0.041967	0.37507	341	sel_devs_fsh	0.31109	0.42492	416	sel_devs_fsh	-0.10347	0.32984
267	sel_devs_fsh	0.040822	0.40159	342	sel_devs_fsh	-0.044756	0.44405	417	sel_devs_fsh	-0.16503	0.31296
268	sel_devs_fsh	-0.067319	0.64016	343	sel_devs_fsh	-0.029352	0.3933	418	sel_devs_fsh	-0.029877	0.68737
269	sel_devs_fsh	-0.50449	0.43753	344	sel_devs_fsh	0.042935	0.3803	419	sel_devs_fsh	0.078781	0.51805
270	sel_devs_fsh	-0.11238	0.4102	345	sel_devs_fsh	-0.14959	0.50491	420	sel_devs_fsh	-0.89941	0.40706
271	sel_devs_fsh	-0.072173	0.43226	346	sel_devs_fsh	-0.021539	0.61826	421	sel_devs_fsh	-0.33894	0.32329
272	sel_devs_fsh	0.1399	0.3732	347	sel_devs_fsh	-0.10126	0.57326	422	sel_devs_fsh	0.86309	0.30542
273	sel_devs_fsh	0.15898	0.36811	348	sel_devs_fsh	-0.11576	0.68378	423	sel_devs_fsh	0.31328	0.38292
274	sel_devs_fsh	0.098158	0.52516	349	sel_devs_fsh	-0.001352	0.60845	424	sel_devs_fsh	0.035768	0.32622
275	sel_devs_fsh	0.11936	0.40701	350	sel_devs_fsh	-0.024493	0.49005	425	sel_devs_fsh	0.0054817	0.31068
276	sel_devs_fsh	0.11997	0.38168	351	sel_devs_fsh	-0.22016	0.43234	426	sel_devs_fsh	-0.031417	0.31163
277	sel_devs_fsh	0.12	0.40387	352	sel_devs_fsh	-0.023977	0.43238	427	sel_devs_fsh	0.003254	0.33195
278	sel_devs_fsh	-0.28566	0.63591	353	sel_devs_fsh	-0.093509	0.39769	428	sel_devs_fsh	-0.032181	0.68718
279	sel_devs_fsh	-0.71526	0.4199	354	sel_devs_fsh	-0.11885	0.38359	429	sel_devs_fsh	0.059467	0.5349
280	sel_devs_fsh	-0.33501	0.39649	355	sel_devs_fsh	0.39467	0.3892	430	sel_devs_fsh	-0.36101	0.43151
281	sel_devs_fsh	0.205	0.43436	356	sel_devs_fsh	0.18187	0.5185	431	sel_devs_fsh	-0.71536	0.3833
282	sel_devs_fsh	0.15794	0.43009	357	sel_devs_fsh	0.021556	0.56821	432	sel_devs_fsh	-0.33822	0.31129
283	sel_devs_fsh	0.22286	0.36542	358	sel_devs_fsh	-0.11594	0.68381	433	sel_devs_fsh	0.41807	0.29701
284	sel_devs_fsh	0.22475	0.36906	359	sel_devs_fsh	-0.047009	0.61528	434	sel_devs_fsh	0.29663	0.30793
285	sel_devs_fsh	0.17582	0.39305	360	sel_devs_fsh	1.009	0.40894	435	sel_devs_fsh	0.25095	0.31295
286	sel_devs_fsh	0.17287	0.37788	361	sel_devs_fsh	0.13024	0.42326	436	sel_devs_fsh	0.21548	0.31857
287	sel_devs_fsh	0.17669	0.40494	362	sel_devs_fsh	0.2399	0.37074	437	sel_devs_fsh	0.20619	0.33802
288	sel_devs_fsh	-0.23151	0.6437	363	sel_devs_fsh	-0.18728	0.3653	438	sel_devs_fsh	-0.03155	0.68733
289	sel_devs_fsh	-0.40889	0.49522	364	sel_devs_fsh	0.14997	0.38983	439	sel_devs_fsh	0.74969	0.55651
290	sel_devs_fsh	-0.31695	0.38147	365	sel_devs_fsh	-0.32644	0.38864	440	sel_devs_fsh	0.40791	0.38787
291	sel_devs_fsh	-0.054074	0.41389	366	sel_devs_fsh	-0.30609	0.39984	441	sel_devs_fsh	-1.0636	0.37375
292	sel_devs_fsh	0.19318	0.42546	367	sel_devs_fsh	-0.54633	0.52653	442	sel_devs_fsh	-0.80834	0.34131
293	sel_devs_fsh	0.1259	0.34941	368	sel_devs_fsh	-0.11633	0.68381	443	sel_devs_fsh	-0.27417	0.30407
294	sel_devs_fsh	0.13884	0.33006	369	sel_devs_fsh	0.01478	0.61673	444	sel_devs_fsh	0.27703	0.29656
295	sel_devs_fsh	0.148	0.34157	370	sel_devs_fsh	-0.63312	0.46343	445	sel_devs_fsh	0.27875	0.31825
296	sel_devs_fsh	0.15176	0.38068	371	sel_devs_fsh	0.19135	0.40792	446	sel_devs_fsh	0.2537	0.32283
297	sel_devs_fsh	0.25375	0.56615	372	sel_devs_fsh	-0.12012	0.37557	447	sel_devs_fsh	0.21057	0.3361
298	sel_devs_fsh	-0.11909	0.67016	373	sel_devs_fsh	0.16837	0.42997	448	sel_devs_fsh	-0.02909	0.688
299	sel_devs_fsh	-0.27929	0.53929	374	sel_devs_fsh	0.143	0.36539	449	sel_devs_fsh	0.48032	0.5458
300	sel_devs_fsh	-0.39251	0.43214	375	sel_devs_fsh	0.16074	0.35304	450	sel_devs_fsh	-0.01356	0.40694

Table 1.22. (continued) Parameter estimates and their standard errors for Model 1.0.

index	name	value	std.dev
451	sel_devs_fsh	0.90312	0.36185
452	sel_devs_fsh	-0.012047	0.3251
453	sel_devs_fsh	-0.51026	0.31542
454	sel_devs_fsh	-0.41442	0.30629
455	sel_devs_fsh	-0.27847	0.32344
456	sel_devs_fsh	-0.075958	0.35619
457	sel_devs_fsh	-0.049631	0.34475
458	sel_devs_fsh	-0.045719	0.68793
459	sel_devs_fsh	-0.49296	0.42968
460	sel_devs_fsh	0.23461	0.40271
461	sel_devs_fsh	0.15331	0.38472
462	sel_devs_fsh	0.19894	0.31807
463	sel_devs_fsh	0.19872	0.29353
464	sel_devs_fsh	-0.29266	0.32083
465	sel_devs_fsh	-0.036694	0.33881
466	sel_devs_fsh	0.013238	0.35742
467	sel_devs_fsh	0.06922	0.3575
468	sel_devs_fsh	-0.046732	0.68795
469	sel_devs_fsh	-0.49947	0.45674
470	sel_devs_fsh	0.8822	0.32377
471	sel_devs_fsh	0.45864	0.34469
472	sel_devs_fsh	0.063601	0.33641
473	sel_devs_fsh	-0.20091	0.29586
474	sel_devs_fsh	0.21	0.29757
475	sel_devs_fsh	-0.13857	0.32042
476	sel_devs_fsh	-0.33264	0.31035
477	sel_devs_fsh	-0.39612	0.33055
478	sel_devs_fsh	-0.045844	0.68779
479	sel_devs_fsh	-0.18104	0.51345
480	sel_devs_fsh	-0.64715	0.31692
481	sel_devs_fsh	0.26904	0.28263
482	sel_devs_fsh	0.37657	0.30376
483	sel_devs_fsh	-0.097962	0.31009
484	sel_devs_fsh	0.02835	0.29821
485	sel_devs_fsh	0.20328	0.27809
486	sel_devs_fsh	0.067179	0.29184
487	sel_devs_fsh	0.02758	0.31088
488	sel_devs_fsh	-0.032333	0.68753
489	sel_devs_fsh	-0.47051	0.50926
490	sel_devs_fsh	-0.38786	0.37346
491	sel_devs_fsh	-0.27985	0.30612
492	sel_devs_fsh	0.29439	0.2777
493	sel_devs_fsh	0.6806	0.29084
494	sel_devs_fsh	0.088341	0.30706
495	sel_devs_fsh	-0.065734	0.28592
496	sel_devs_fsh	0.043723	0.28834
497	sel_devs_fsh	0.12924	0.31727
498	sel_devs_fsh	-0.020233	0.68838
499	sel_devs_fsh	0.64028	0.46453
500	sel_devs_fsh	-0.018872	0.36529
501	sel_devs_fsh	-0.075704	0.31706
502	sel_devs_fsh	-0.31342	0.28569
503	sel_devs_fsh	-0.01531	0.27363
504	sel_devs_fsh	-0.010693	0.28159
505	sel_devs_fsh	-0.023498	0.29279
506	sel_devs_fsh	-0.02998	0.29046
507	sel_devs_fsh	-0.13257	0.30425
508	sel_devs_fsh	-0.022938	0.68871
509	sel_devs_fsh	-0.4452	0.48414
510	sel_devs_fsh	0.8226	0.30686
511	sel_devs_fsh	-0.071614	0.29603
512	sel_devs_fsh	0.10119	0.29161
513	sel_devs_fsh	-0.14583	0.28494
514	sel_devs_fsh	0.0039444	0.27651
515	sel_devs_fsh	-0.02036	0.28879
516	sel_devs_fsh	-0.085489	0.30041
517	sel_devs_fsh	-0.1363	0.2953
518	sel_devs_fsh	-0.019968	0.68889
519	sel_devs_fsh	-0.26136	0.53121
520	sel_devs_fsh	-0.77619	0.33057
521	sel_devs_fsh	0.85631	0.28312
522	sel_devs_fsh	0.023926	0.28992
523	sel_devs_fsh	-0.1301	0.30929
524	sel_devs_fsh	0.019218	0.29548
525	sel_devs_fsh	0.046281	0.28962
526	sel_devs_fsh	0.081277	0.30336
527	sel_devs_fsh	0.16061	0.31478
528	sel_devs_fsh	-0.019692	0.68889
529	sel_devs_fsh	0.21346	0.60377
530	sel_devs_fsh	0.02979	0.37995
531	sel_devs_fsh	-0.36336	0.28685
532	sel_devs_fsh	0.46179	0.28373
533	sel_devs_fsh	0.28382	0.30128
534	sel_devs_fsh	-0.11121	0.29982
535	sel_devs_fsh	-0.18348	0.29523
536	sel_devs_fsh	-0.14557	0.30479
537	sel_devs_fsh	-0.16554	0.32279
538	sel_devs_fsh	-0.019674	0.68888
539	sel_devs_fsh	0.24795	0.62131
540	sel_devs_fsh	0.69708	0.41067
541	sel_devs_fsh	-0.13688	0.30499
542	sel_devs_fsh	-0.35791	0.28159
543	sel_devs_fsh	-0.14762	0.28105
544	sel_devs_fsh	-0.085405	0.28641
545	sel_devs_fsh	-0.053819	0.29718
546	sel_devs_fsh	-0.086304	0.30688
547	sel_devs_fsh	-0.05742	0.32424
548	sel_devs_fsh	-0.018135	0.68863
549	sel_devs_fsh	0.097247	0.62457
550	sel_devs_fsh	-0.031535	0.41969
551	sel_devs_fsh	-0.02873	0.32448
552	sel_devs_fsh	-0.050908	0.28703
553	sel_devs_fsh	0.066375	0.27831
554	sel_devs_fsh	0.0053419	0.2804
555	sel_devs_fsh	-0.040635	0.2904
556	sel_devs_fsh	-0.014557	0.30379
557	sel_devs_fsh	0.015536	0.31862
558	sel_devs_fsh	-0.031872	0.68824
559	sel_devs_fsh	-0.22628	0.53522
560	sel_devs_fsh	-0.64686	0.38683
561	sel_devs_fsh	0.029151	0.34294
562	sel_devs_fsh	0.036131	0.30304
563	sel_devs_fsh	0.11912	0.2763
564	sel_devs_fsh	0.17418	0.27529
565	sel_devs_fsh	0.16729	0.28048
566	sel_devs_fsh	0.20804	0.294
567	sel_devs_fsh	0.1711	0.31239
568	sel_devs_fsh	-0.027268	0.68703
569	sel_devs_fsh	-0.38483	0.48143
570	sel_devs_fsh	0.12901	0.32696
571	sel_devs_fsh	0.022023	0.32524
572	sel_devs_fsh	-0.19943	0.33198
573	sel_devs_fsh	-0.15215	0.30997
574	sel_devs_fsh	0.019436	0.28397
575	sel_devs_fsh	0.11947	0.2908
576	sel_devs_fsh	0.17963	0.31625
577	sel_devs_fsh	0.29411	0.32267
578	sel_devs_fsh	0.047371	0.71166
579	sel_devs_fsh	0.093769	0.4728
580	sel_devs_fsh	-0.3993	0.36456
581	sel_devs_fsh	0.42917	0.28506
582	sel_devs_fsh	0.27436	0.32617
583	sel_devs_fsh	-0.17502	0.36137
584	sel_devs_fsh	-0.12511	0.35957
585	sel_devs_fsh	-0.0013831	0.31189
586	sel_devs_fsh	-0.048295	0.32476
587	sel_devs_fsh	-0.095564	0.32892
588	sel_devs_fsh	0.021717	0.70507
589	sel_devs_fsh	0.012152	0.49724
590	sel_devs_fsh	-0.2027	0.37356
591	sel_devs_fsh	-0.86252	0.31654
592	sel_devs_fsh	0.30872	0.29578
593	sel_devs_fsh	0.41444	0.34378
594	sel_devs_fsh	0.2011	0.3561
595	sel_devs_fsh	0.052635	0.3179
596	sel_devs_fsh	0.031675	0.30834
597	sel_devs_fsh	0.022779	0.32041
598	sel_devs_fsh	0.019492	0.70856
599	sel_devs_fsh	0.017885	0.56779
600	sel_devs_fsh	0.41671	0.36053
601	sel_devs_fsh	0.26598	0.32581
602	sel_devs_fsh	-0.78178	0.32184
603	sel_devs_fsh	-0.13654	0.31477
604	sel_devs_fsh	0.039662	0.31287
605	sel_devs_fsh	0.062545	0.31255
606	sel_devs_fsh	0.051969	0.31516
607	sel_devs_fsh	0.044081	0.33247
608	sel_devs_fsh	0.024735	0.71315
609	sel_devs_fsh	-0.46681	0.58333
610	sel_devs_fsh	-0.38633	0.42068
611	sel_devs_fsh	0.20519	0.3297
612	sel_devs_fsh	0.15449	0.33589
613	sel_devs_fsh	-0.13037	0.32437
614	sel_devs_fsh	-0.28052	0.35843
615	sel_devs_fsh	0.24994	0.36506
616	sel_devs_fsh	0.2891	0.38538
617	sel_devs_fsh	0.34058	0.45304
618	sel_devs_fsh	-0.000027996	0.7071
619	sel_devs_fsh	-0.0014311	0.7066
620	sel_devs_fsh	0.018978	0.71372
621	sel_devs_fsh	0.047741	0.71325
622	sel_devs_fsh	0.43554	0.4926
623	sel_devs_fsh	-0.13163	0.48374
624	sel_devs_fsh	-0.093252	0.68103
625	sel_devs_fsh	-0.097228	0.44193
626	sel_devs_fsh	-0.086043	0.43661
627	sel_devs_fsh	-0.092656	0.50798
628	sel_devs_eit	-1.2525	1.5589
629	sel_devs_eit	0.34102	1.9268
630	sel_devs_eit	1.2025	2.0296
631	sel_devs_eit	1.1481	2.0361
632	sel_devs_eit	1.1762	2.6242
633	sel_devs_eit	1.1245	1.6905
634	sel_devs_eit	0.97542	1.5784
635	sel_coffs_fsh	-4.8082	1.3119
636	sel_coffs_fsh	-2.3707	0.75659
637	sel_coffs_fsh	-1.2378	0.58912
638	sel_coffs_fsh	0.35011	0.58779
639	sel_coffs_fsh	0.39725	0.32218
640	sel_coffs_fsh	0.39236	0.2913
641	sel_coffs_fsh	0.34728	0.28078
642	sel_coffs_fsh	0.28964	0.28507
643	sel_coffs_fsh	0.23277	0.30264
644	sel_coffs_fsh	0.18876	0.33415
645	sel_coffs_eit	1.3804	0.45957
646	sel_coffs_eit	-0.016874	1.2005
647	sel_coffs_eit	-0.81875	1.3837
648	sel_coffs_eit	-0.81109	1.3923
649	sel_coffs_eit	-0.88835	2.1659
650	sel_coffs_eit	-0.89167	1.085
651	sel_coffs_eit	-0.89011	0.93434
652	sel_slp_bts	1.0864	0.049025
653	sel_a50_bts	5.2992	0.14597
654	sel_age_one	-2.7416	0.084063
655	sel_slp_bts_dev	-0.54031	0.18224
656	sel_slp_bts_dev	-0.13308	0.15478
657	sel_slp_bts_dev	0.092908	0.10918
658	sel_slp_bts_dev	-0.13166	0.16076
659	sel_slp_bts_dev	-0.18287	0.14261
660	sel_slp_bts_dev	-0.26303	0.14856
661	sel_slp_bts_dev	-0.35073	0.15689
662	sel_slp_bts_dev	-0.23095	0.16469
663	sel_slp_bts_dev	-0.021598	0.13916
664	sel_slp_bts_dev	-0.093511	0.11258
665	sel_slp_bts_dev	-0.058958	0.12281
666	sel_slp_bts_dev	0.039214	0.12507
667	sel_slp_bts_dev	0.064257	0.1068
668	sel_slp_bts_dev	-0.03139	0.1201
669	sel_slp_bts_dev	-0.14351	0.1345
670	sel_slp_bts_dev	-0.24576	0.12809
671	sel_slp_bts_dev	-0.3747	0.1142
672	sel_slp_bts_dev	-0.39178	0.12179
673	sel_slp_bts_dev	-0.28079	0.11832
674	sel_slp_bts_dev	-0.32248	0.12795
675	sel_slp_bts_dev	-0.10104	0.10363
676	sel_slp_bts_dev	0.089221	0.10876
677	sel_slp_bts_dev	0.091142	0.11448
678	sel_slp_bts_dev	0.14573	0.12853
679	sel_slp_bts_dev	0.047259	0.14026
680	sel_slp_bts_dev	0.22193	0.13373
681	sel_slp_bts_dev	0.38544	0.12158
682	sel_slp_bts_dev	0.41198	0.12978
683	sel_slp_bts_dev	0.64206	0.095692
684	sel_slp_bts_dev	0.58967	0.097536
685	sel_slp_bts_dev	0.31627	0.13634
686	sel_slp_bts_dev	0.38863	0.13183
687	sel_slp_bts_dev	0.37243	0.17168
688	sel_a50_bts_dev	-0.17571	0.13076
689	sel_a50_bts_dev	-0.2005	0.084012
690	sel_a50_bts_dev	-0.045063	0.061397
691	sel_a50_bts_dev	-0.072282	0.075985
692	sel_a50_bts_dev	0.069866	0.070584
693	sel_a50_bts_dev	0.052023	0.059326
694	sel_a50_bts_dev	-0.061278	0.071895
695	sel_a50_bts_dev	-0.13426	0.068366
696	sel_a50_bts_dev	-0.1097	0.061862
697	sel_a50_bts_dev	0.082089	0.067167
698	sel_a50_bts_dev	-0.014826	0.063555
699	sel_a50_bts_dev	-0.088196	0.051741
700	sel_a50_bts_dev	-0.023806	0.047736
701	sel_a50_bts_dev	0.058836	0.06854
702	sel_a50_bts_dev	0.1896	0.045923
703	sel_a50_bts_dev	0.19753	0.06256
704	sel_a50_bts_dev	0.25373	0.051407
705	sel_a50_bts_dev	0.17557	0.060621
706	sel_a50_bts_dev	0.11493	0.061351
707	sel_a50_bts_dev	0.13053	0.054837
708	sel_a50_bts_dev	0.055798	0.05761
709	sel_a50_bts_dev	0.065664	0.065339
710	sel_a50_bts_dev	0.079614	0.041117
711	sel_a50_bts_dev	-0.019642	0.041844
712	sel_a50_bts_dev	0.12381	0.039915
713	sel_a50_bts_dev	-0.063997	0.05823
714	sel_a50_bts_dev	-0.052431	0.05067
715	sel_a50_bts_dev	-0.080322	0.047577
716	sel_a50_bts_dev	-0.20117	0.040656
717	sel_a50_bts_dev	-0.040788	0.038812
718	sel_a50_bts_dev	-0.071159	0.046226
719	sel_a50_bts_dev	-0.053041	0.03954
720	sel_a50_bts_dev	-0.1414	0.059429
721	sel_one_bts_dev	-0.18148	0.14732
722	sel_one_bts_dev	-0.13819	0.10289
723	sel_one_bts_dev	0.025307	0.11167
724	sel_one_bts_dev	-0.35137	0.1264
725	sel_one_bts_dev	-0.46079	0.1229
726	sel_one_bts_dev	-0.10963	0.11675
727	sel_one_bts_dev	-0.26384	0.16922
728	sel_one_bts_dev	-0.10256	0.1287
729	sel_one_bts_dev	0.14978	0.072159
730	sel_one_bts_dev	-0.12744	0.087061
731	sel_one_bts_dev	-0.020798	0.086685
732	sel_one_bts_dev	0.049415	0.077229
733	sel_one_bts_dev	-0.12932	0.10366
734	sel_one_bts_dev	-0.16809	0.11946
735	sel_one_bts_dev	-0.0189	0.083804
736	sel_one_bts_dev	-0.042054	0.087888
737	sel_one_bts_dev	0.078628	0.089571
738	sel_one_bts_dev	0.070574	0.094991
739	sel_one_bts_dev	0.18646	0.084832
740	sel_one_bts_dev	0.10952	0.076603
741	sel_one_bts_dev	0.22624	0.08764
742	sel_one_bts_dev	0.32296	0.094949
743	sel_one_bts_dev	0.063876	0.12363
744	sel_one_bts_dev	-0.057408	0.14255
745	sel_one_bts_dev	-0.093885	0.095091
746	sel_one_bts_dev	-0.10133	0.081802
747	sel_one_bts_dev	0.097745	0.096376
748	sel_one_bts_dev	0.40343	0.061223
749	sel_one_bts_dev	0.31715	0.091293
750	sel_one_bts_dev	0.14584	0.089138
751	sel_one_bts_dev	0.032079	0.10106
752	sel_one_bts_dev	0.15227	0.092875
753	sel_one_bts_dev	-0.06418	0.11955
754	rec_dev_future	0	0.65971
755	rec_dev_future	0	0.65971
756	rec_dev_future	0	0.65971
757	rec_dev_future	0	0.65971
758	rec_dev_future	0	0.65971
759	q_all	1.4592	0.09204

Table 1.23. Summary model results showing the stock condition for EBS pollock. Values in parentheses are coefficients of variation (CV's) of values immediately above.

	2014 **Assessment**
Biomass	
Year 2015 spawning biomass*	2,850,000 t
(CV)	(14%)
2014 spawning biomass	2,945,000 t
B_{MSY}	1,948,000 t
(CV)	(20%)
$SPR\|\ B_{MSY}$	27.4%
$B_{40\%}$	2,491,000 t
$B_{35\%}$	2,179,000 t
B_0 (stock-recruitment curve)	5,162,000 t
2014 Percent of B_{MSY} spawning biomass	151%
2015 Percent of B_{MSY} spawning biomass	146%
Ratio of B_{2014} over B_{2014} under no fishing since 1978	0.61
Recruitment (millions of pollock at age 1)	
Steepness parameter (h)	0.671
Average recruitment (all yrs)	22,759
2000 year class	35,982
2006 year class	25,597
2008 year class	56,155
Natural Mortality (age 3 and older)	0.3

Table 1.24. Summary results of Tier 1 2015 yield projections for EBS pollock.

Description	Value
Tier 1 maximum permissible ABC	
2015 fishable biomass (GM)	5,669,000 t
MSYR (HM)	0.512
Adjustment factor	1.0
Adjusted ABC rate	0.512
2015 MSYR yield (Tier 1 ABC)	2,900,000 t
OFL	
MSYR (AM)	0.587
2015 MSYR OFL	3,330,000 t
Recommended F_{ABC}	0.24
Recommended ABC	1,350,000 t
Fishable biomass at *MSY*	3,495,000 t

Notes: MSYR = exploitation rate relative to begin-year age fishable biomass corresponding to F_{MSY}. F_{MSY} yields calculated within the model (i.e., including uncertainty in both the estimate of F_{MSY} and in projected stock size). HM = Harmonic mean, GM = Geometric mean, AM = Arithmetic mean

*Assuming 2015 catch will be 1,350,00 t

Table 1.25 Estimates millions of EBS pollock at age from the 2014 Model 1.0.

	1	2	3	4	5	6	7	8	9	10+	Total
1964	5,387	3,610	2,283	473	214	337	136	50	23	136	12,648
1965	20,612	2,188	2,272	1,623	287	128	203	83	31	99	27,524
1966	14,560	8,372	1,379	1,602	988	176	80	128	52	83	27,421
1967	28,785	5,914	5,263	968	999	621	112	51	82	88	42,884
1968	26,732	11,685	3,664	3,331	564	583	365	66	30	101	47,121
1969	29,207	10,850	7,210	2,394	1,884	324	340	215	39	79	52,542
1970	20,148	11,855	6,691	4,481	1,416	1,126	196	206	130	71	46,319
1971	9,833	8,173	7,072	3,897	2,626	834	668	112	118	109	33,441
1972	10,799	3,986	4,838	3,959	2,104	1,375	442	355	59	104	28,022
1973	28,784	4,376	2,227	2,434	1,974	1,056	695	224	180	70	42,020
1974	21,417	11,660	2,361	1,054	1,067	869	467	309	100	107	39,410
1975	18,184	8,675	5,888	989	445	454	373	201	132	87	35,429
1976	13,996	7,373	4,959	2,551	447	206	212	175	95	100	30,114
1977	13,986	5,678	4,286	2,501	1,182	212	99	103	86	94	28,227
1978	27,145	5,677	3,250	2,385	1,299	605	109	51	54	94	40,669
1979	67,256	11,018	3,283	1,766	1,234	669	315	56	26	76	85,699
1980	26,869	27,305	6,643	1,869	952	614	334	159	28	51	64,823
1981	30,766	10,914	17,025	4,219	1,006	482	304	167	80	40	65,003
1982	15,905	12,503	6,890	11,702	2,554	548	263	167	92	65	50,689
1983	53,686	6,465	7,935	4,948	7,706	1,554	330	159	100	92	82,974
1984	13,313	21,823	4,103	5,728	3,359	4,983	956	203	97	111	54,676
1985	35,373	5,412	13,863	2,963	3,918	2,117	3,159	593	125	118	67,641
1986	14,550	14,379	3,433	9,966	2,068	2,580	1,296	1,956	361	138	50,727
1987	8,505	5,915	9,119	2,475	6,842	1,379	1,609	806	1,239	298	38,185
1988	5,461	3,457	3,757	6,630	1,756	4,714	914	1,068	507	959	29,222
1989	10,359	2,220	2,192	2,576	4,561	1,133	3,041	559	662	909	28,212
1990	50,241	4,211	1,408	1,561	1,751	3,001	716	1,820	338	962	66,009
1991	25,577	20,424	2,662	998	978	1,034	1,739	406	1,018	752	55,588
1992	22,018	10,398	12,920	1,919	656	590	600	926	228	954	51,207
1993	47,610	8,951	6,566	8,962	1,283	408	324	303	439	552	75,398
1994	14,630	19,355	5,693	4,652	5,676	838	246	184	172	569	52,015
1995	10,695	5,948	12,314	4,157	3,155	3,317	497	146	110	451	40,791
1996	23,152	4,348	3,784	9,040	2,961	2,004	1,810	282	85	333	47,801
1997	31,501	9,413	2,759	2,761	6,597	2,032	1,146	904	145	228	57,485
1998	15,718	12,807	5,947	2,009	1,961	4,486	1,262	631	489	198	45,507
1999	17,221	6,390	8,126	4,323	1,425	1,325	2,749	770	359	374	43,060
2000	26,559	7,001	4,064	5,778	3,011	967	854	1,643	464	448	50,789
2001	35,982	10,798	4,453	2,941	3,920	1,940	624	497	923	542	62,621
2002	23,249	14,629	6,874	3,245	2,034	2,395	1,087	353	282	848	54,996
2003	13,974	9,452	9,292	4,990	2,219	1,261	1,252	573	188	634	43,833
2004	6,261	5,681	6,011	6,546	3,408	1,326	673	640	299	467	31,313
2005	4,255	2,546	3,616	4,367	4,129	2,099	772	363	348	436	22,930
2006	10,929	1,730	1,620	2,627	2,903	2,302	1,139	434	210	467	24,361
2007	25,597	4,443	1,099	1,138	1,710	1,639	1,182	597	233	381	38,019
2008	10,165	10,406	2,821	771	738	966	804	607	319	339	27,936
2009	56,155	4,132	6,615	2,035	503	420	463	396	313	350	71,383
2010	20,542	22,830	2,630	4,777	1,351	311	227	242	208	344	53,461
2011	24,237	8,351	14,532	1,920	3,056	813	183	129	133	307	53,660
2012	18,111	9,853	5,313	10,593	1,310	1,554	379	88	63	221	47,486
2013	31,003	7,363	6,268	3,839	7,039	815	765	177	41	139	57,449
2014	23,728	12,604	4,689	4,577	2,539	4,383	445	421	80	82	53,548
Median	20,577	8,262	4,764	2,851	1,820	1,001	482	262	131	198	47,121
Average	22,759	9,128	5,568	3,726	2,348	1,410	764	427	236	307	46,672

Table 1.26. Assessment model-estimated catch-at-age of EBS pollock (millions; 1964-2014).

	1	2	3	4	5	6	7	8	9	10+	Total
1964	4.1	38.1	79.2	74.5	35.1	55.2	21.4	7.5	3.2	18.5	336.9
1965	12.9	20.3	94.8	251.2	42.1	17.7	26.4	10.2	3.6	11.2	490.4
1966	8.7	95.2	62.6	219.2	130.2	21.7	9.3	14.2	5.6	8.6	575.3
1967	29.1	135.4	665.1	179.3	184.8	111.5	19.9	9.0	14.2	15.2	1,363.4
1968	29.7	304.0	374.8	684.7	110.2	107.6	65.3	11.5	5.2	17.0	1,710.0
1969	32.0	287.1	1,007.7	419.8	316.8	52.1	54.2	34.0	6.2	13.2	2,223.3
1970	30.2	617.2	1,243.9	813.8	251.5	194.5	38.8	40.7	25.7	20.9	3,277.1
1971	18.8	472.5	1,502.9	919.6	671.1	207.1	164.7	27.8	29.4	45.9	4,059.8
1972	23.0	399.0	1,354.8	1,129.3	591.7	380.8	122.2	97.9	17.2	43.0	4,159.1
1973	68.8	546.2	703.0	869.0	701.4	372.7	243.4	78.0	62.8	30.1	3,675.4
1974	52.2	1,970.9	898.0	396.9	397.5	319.8	171.5	114.2	37.0	41.3	4,399.3
1975	32.1	726.2	2,140.2	338.2	146.4	146.5	119.1	64.0	42.1	30.9	3,785.5
1976	19.8	526.4	1,381.0	835.4	140.1	62.8	63.8	52.2	28.1	30.9	3,140.3
1977	16.1	470.3	927.7	651.2	318.6	56.1	25.9	26.8	22.1	24.3	2,539.0
1978	29.3	426.5	754.4	627.9	345.5	156.8	29.1	13.8	14.4	25.1	2,422.9
1979	64.6	484.3	661.1	418.7	353.3	189.8	87.2	16.0	7.5	21.5	2,304.0
1980	15.9	487.3	822.6	444.5	263.0	177.3	94.4	44.4	7.8	14.2	2,371.4
1981	9.6	86.9	1,063.1	669.0	232.5	110.0	68.6	37.6	18.0	9.8	2,305.1
1982	2.7	46.5	183.0	1,126.3	396.4	89.1	42.3	27.7	15.5	13.7	1,943.2
1983	7.0	23.9	175.5	357.6	849.6	229.0	48.2	23.9	16.3	20.6	1,751.7
1984	1.5	65.8	89.2	379.9	435.0	622.8	135.3	29.9	15.8	26.0	1,801.2
1985	3.5	22.3	355.0	148.9	377.7	318.8	450.7	91.4	20.7	29.2	1,818.3
1986	1.2	63.3	79.5	632.2	178.6	354.5	180.3	246.3	55.1	29.3	1,820.3
1987	0.4	18.4	146.3	90.5	414.5	125.6	144.8	106.2	162.6	47.3	1,256.7
1988	0.4	15.4	241.6	408.9	197.0	527.9	138.3	151.5	73.0	134.1	1,888.1
1989	0.6	9.7	73.6	184.9	442.5	143.8	507.7	89.1	99.6	136.1	1,687.6
1990	3.9	28.7	52.6	208.7	308.0	567.6	146.8	387.7	68.6	180.1	1,952.6
1991	1.7	130.2	62.1	97.8	158.3	194.8	426.6	85.2	246.4	173.6	1,576.7
1992	1.7	80.7	712.1	161.9	91.5	132.1	166.2	291.1	74.1	307.1	2,018.5
1993	2.2	18.5	247.4	1,127.9	132.1	65.5	66.2	61.6	88.9	104.8	1,915.1
1994	0.5	34.3	70.0	340.8	1,041.3	144.6	42.1	30.5	27.5	87.8	1,819.5
1995	0.3	10.2	96.2	138.4	389.5	760.5	101.7	27.9	19.6	76.8	1,621.1
1996	0.8	17.5	49.5	117.3	188.5	398.2	515.1	75.0	20.7	75.4	1,458.0
1997	1.2	69.4	40.3	99.0	468.7	285.6	255.4	211.4	37.0	55.1	1,523.1
1998	0.5	50.9	96.6	73.9	149.1	672.7	193.5	128.0	113.3	45.5	1,524.0
1999	0.5	13.8	282.4	223.1	103.5	148.8	461.0	124.9	56.0	54.7	1,468.7
2000	0.7	13.8	81.5	421.2	340.2	107.7	159.1	345.8	83.3	72.9	1,626.2
2001	1.0	13.7	62.5	168.2	596.6	411.5	128.9	101.3	176.8	101.5	1,762.1
2002	0.8	44.5	119.9	217.0	288.8	614.7	272.9	86.5	64.8	174.2	1,884.1
2003	0.5	20.0	394.4	336.7	371.8	306.2	337.6	147.9	43.0	124.0	2,081.9
2004	0.2	7.8	100.3	844.1	499.4	247.6	159.6	148.5	63.2	90.4	2,161.2
2005	0.1	4.2	60.2	388.6	888.8	488.6	161.6	69.7	62.9	70.8	2,195.6
2006	0.4	5.0	72.9	275.9	600.4	616.2	290.0	104.4	46.2	95.1	2,106.6
2007	1.0	14.8	50.4	122.1	354.1	483.9	315.7	145.1	53.0	82.3	1,622.6
2008	0.4	25.9	64.2	79.8	148.7	297.3	234.5	160.5	82.0	80.2	1,173.5
2009	1.6	5.9	144.5	183.2	72.7	98.9	119.2	100.4	81.2	91.8	899.4
2010	0.5	31.2	33.7	564.9	220.7	55.5	46.6	54.3	45.9	73.9	1,127.4
2011	0.9	15.3	201.4	130.9	835.3	262.4	56.4	38.3	38.2	85.5	1,664.6
2012	0.7	18.7	113.1	945.6	182.4	455.4	122.4	27.8	19.1	64.6	1,949.7
2013	1.0	7.5	77.5	357.2	973.7	186.8	170.6	60.3	13.9	47.0	1,895.5
2014	0.7	11.4	52.9	400.9	471.0	811.6	82.9	121.2	23.1	23.5	1,999.1
Median	1.6	32.8	132.2	349.0	317.7	194.6	125.7	66.8	33.2	47.0	1,884.1
Average	10.6	177.5	400.4	417.6	360.8	273.8	158.9	90.2	48.2	64.6	2,002.6

Table 1.27. Estimated EBS pollock age 3+ biomass, female spawning biomass, and age 1 recruitment for 1964-2014. Biomass units are thousands of t, age-1 recruitment is in millions of pollock.

Year	Age 3+ biomass	Spawning biomass	Age 1 Rec.	Year	Age 3+ biomass	Spawning biomass	Age 1 Rec.
1964	1,602	448	5,387	1990	7,891	3,085	50,241
1965	2,051	571	20,612	1991	6,171	2,318	25,577
1966	2,150	683	14,560	1992	9,562	2,410	22,018
1967	3,344	866	28,785	1993	11,712	3,281	47,610
1968	3,800	1,071	26,732	1994	11,306	3,560	14,630
1969	5,145	1,355	29,207	1995	13,074	3,750	10,695
1970	6,179	1,694	20,148	1996	11,198	3,740	23,152
1971	6,884	1,906	9,833	1997	9,801	3,526	31,501
1972	6,299	1,829	10,799	1998	9,903	3,279	15,718
1973	4,692	1,460	28,784	1999	10,791	3,289	17,221
1974	3,291	1,006	21,417	2000	10,020	3,330	26,559
1975	3,516	837	18,184	2001	9,803	3,369	35,982
1976	3,578	861	13,996	2002	10,182	3,203	23,249
1977	3,613	931	13,986	2003	12,211	3,397	13,974
1978	3,524	980	27,145	2004	11,416	3,490	6,261
1979	3,387	963	67,256	2005	9,522	3,187	4,255
1980	4,307	1,082	26,869	2006	7,262	2,612	10,929
1981	8,321	1,792	30,766	2007	5,840	2,173	25,597
1982	9,497	2,744	15,905	2008	4,607	1,589	10,165
1983	10,560	3,398	53,686	2009	5,880	1,708	56,155
1984	10,239	3,630	13,313	2010	5,622	1,862	20,542
1985	12,409	3,900	35,373	2011	7,928	2,239	24,237
1986	11,621	4,133	14,550	2012	7,853	2,623	18,111
1987	12,243	4,250	8,505	2013	8,261	3,043	31,003
1988	11,583	4,232	5,461	2014	8,045	2,945	23,728
1989	9,861	3,814	10,359	2015	7,778		

Table 1.28. Estimates of begin-year age 3 and older biomass (thousands of tons) and coefficients of variation (CV) for the current assessment compared to 2007-2013 assessments for EBS pollock.

	Current		2013		2012		2011		2010		2009		2008		2007	
	Assess.	CV	Assess.	CV	Assess.	CV	Assess.	CV	Assess.	CV	Assess.	CV	Assess.	CV	Assess.	CV
1964	1,622	21%	1,602	21%	1,608	21%	1,602	21%	1,589	21%	1,564	22%	1,600	22%	1,717	23%
1965	2,077	20%	2,051	20%	2,059	20%	2,050	20%	2,008	19%	2,008	20%	2,050	20%	2,141	21%
1966	2,186	20%	2,150	20%	2,157	20%	2,159	20%	1,944	21%	1,947	22%	2,007	21%	2,037	22%
1967	3,397	16%	3,344	16%	3,353	16%	3,365	16%	3,140	17%	3,149	17%	3,245	17%	3,206	18%
1968	3,871	17%	3,800	17%	3,809	17%	3,838	17%	3,486	18%	3,510	19%	3,592	18%	3,558	19%
1969	5,220	16%	5,145	16%	5,154	16%	5,187	16%	4,879	17%	5,007	17%	5,020	17%	5,118	17%
1970	6,253	15%	6,179	15%	6,188	15%	6,221	15%	5,974	16%	6,159	15%	6,005	16%	6,368	15%
1971	6,946	14%	6,884	14%	6,894	14%	6,918	14%	6,785	13%	6,949	13%	6,727	14%	7,164	13%
1972	6,353	14%	6,299	14%	6,308	14%	6,329	14%	6,277	13%	6,444	13%	6,289	14%	6,666	13%
1973	4,749	16%	4,692	16%	4,700	16%	4,728	16%	4,547	16%	4,696	16%	4,556	17%	4,942	16%
1974	3,348	20%	3,291	20%	3,298	20%	3,329	20%	3,085	20%	3,196	20%	3,064	22%	3,475	20%
1975	3,554	14%	3,516	14%	3,523	14%	3,533	14%	3,366	13%	3,384	13%	3,276	14%	3,604	14%
1976	3,609	11%	3,578	11%	3,587	11%	3,580	11%	3,460	10%	3,431	11%	3,339	11%	3,584	11%
1977	3,643	10%	3,613	9%	3,624	10%	3,598	9%	3,500	9%	3,457	9%	3,340	10%	3,602	10%
1978	3,557	9%	3,524	9%	3,537	9%	3,497	9%	3,390	9%	3,340	9%	3,202	9%	3,476	9%
1979	3,426	9%	3,387	9%	3,403	9%	3,343	9%	3,267	9%	3,212	9%	3,090	9%	3,363	9%
1980	4,372	7%	4,307	7%	4,333	7%	4,230	7%	4,203	7%	4,124	8%	4,044	7%	4,384	8%
1981	8,528	6%	8,321	6%	8,364	6%	8,160	6%	8,190	6%	8,031	6%	7,704	6%	8,307	6%
1982	9,767	5%	9,497	6%	9,549	6%	9,313	6%	9,349	6%	9,165	6%	8,783	6%	9,439	6%
1983	10,911	5%	10,560	5%	10,621	5%	10,340	5%	10,376	5%	10,168	5%	9,804	5%	10,493	6%
1984	10,601	5%	10,239	5%	10,300	5%	10,031	5%	10,060	5%	9,857	5%	9,518	5%	10,200	6%
1985	12,838	4%	12,409	4%	12,478	4%	12,186	4%	12,246	4%	12,027	4%	11,802	4%	12,531	5%
1986	12,036	4%	11,621	4%	11,685	4%	11,426	4%	11,471	4%	11,269	4%	11,075	4%	11,773	5%
1987	12,615	4%	12,243	4%	12,308	4%	12,063	4%	12,111	4%	11,915	4%	11,732	4%	12,401	4%
1988	11,906	3%	11,583	4%	11,642	4%	11,424	4%	11,402	4%	11,227	4%	11,004	4%	11,617	4%
1989	10,128	4%	9,861	4%	9,913	4%	9,724	4%	9,671	4%	9,521	4%	9,320	4%	9,875	4%
1990	8,102	4%	7,891	4%	7,936	4%	7,764	4%	7,681	4%	7,558	4%	7,345	4%	7,847	5%
1991	6,331	4%	6,171	5%	6,209	5%	6,049	5%	5,911	5%	5,811	5%	5,590	5%	6,097	5%
1992	9,705	3%	9,562	3%	9,602	3%	9,411	3%	9,316	3%	9,211	4%	8,966	4%	9,557	4%
1993	11,840	3%	11,712	3%	11,754	3%	11,543	3%	11,493	3%	11,388	3%	11,175	3%	11,832	4%
1994	11,402	3%	11,306	3%	11,341	3%	11,146	3%	11,077	3%	10,990	4%	10,782	4%	11,485	4%
1995	13,135	3%	13,074	3%	13,109	3%	12,883	3%	12,779	3%	12,699	3%	12,704	3%	13,615	4%
1996	11,235	3%	11,198	3%	11,229	3%	11,019	3%	10,903	4%	10,843	4%	10,829	4%	11,537	4%
1997	9,816	4%	9,801	4%	9,828	4%	9,627	4%	9,485	4%	9,440	4%	9,403	4%	10,104	5%
1998	9,907	3%	9,903	4%	9,929	3%	9,722	4%	9,584	4%	9,538	4%	9,467	4%	10,178	5%
1999	10,799	3%	10,791	3%	10,819	3%	10,607	3%	10,509	3%	10,421	3%	10,379	4%	11,081	4%
2000	10,031	3%	10,020	3%	10,044	3%	9,841	3%	9,747	3%	9,632	3%	9,503	4%	10,201	4%
2001	9,819	3%	9,803	3%	9,830	3%	9,616	3%	9,506	3%	9,341	4%	9,175	4%	9,898	5%
2002	10,221	3%	10,182	3%	10,230	3%	9,988	3%	9,842	3%	9,595	4%	9,554	4%	10,224	5%
2003	12,278	3%	12,211	3%	12,269	3%	11,974	3%	11,805	3%	11,453	3%	11,182	4%	12,865	6%
2004	11,493	3%	11,416	3%	11,491	3%	11,178	3%	10,974	3%	10,606	4%	10,274	4%	11,784	7%
2005	9,602	3%	9,522	3%	9,608	3%	9,299	3%	9,079	4%	8,736	4%	8,423	5%	9,598	8%
2006	7,343	3%	7,262	4%	7,349	4%	7,060	4%	6,839	4%	6,543	5%	6,340	6%	7,178	10%
2007	5,933	4%	5,840	4%	5,954	4%	5,633	5%	5,386	5%	5,090	6%	5,015	8%	5,363	14%
2008	4,722	5%	4,607	5%	4,724	5%	4,393	6%	4,146	7%	3,809	8%	4,222	12%	4,357	20%
2009	6,069	5%	5,880	5%	6,069	6%	6,172	8%	6,225	10%	4,762	11%	6,240	20%		
2010	5,937	5%	5,622	6%	5,769	7%	6,095	10%	6,582	12%	4,616	13%				
2011	8,895	6%	7,928	8%	7,781	9%	7,823	11%	9,620	15%						
2012	8,823	8%	7,853	10%	7,867	10%	8,341	12%								
2013	9,541	8%	8,261	11%	8,138	12%										
2014	8,960	9%	8,045	12%												
2015	9,203	10%														

Table 1.29 Tier 3 projections of catch, fishing mortality, and spawning biomass (thousands of tons) for EBS pollock for the 7 scenarios. Note that the values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 6,227, 2,491 and 2,179 thousand t, respectively.

Catch	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2014	1,298	1,298	1,298	1,298	1,298	1,298	1,298
2015	1,637	1,350	1,409	732	0	2,023	1,637
2016	1,554	1,642	1,399	825	0	1,703	1,554
2017	1,394	1,466	1,321	849	0	1,450	1,707
2018	1,349	1,382	1,322	895	0	1,425	1,515
2019	1,345	1,358	1,325	926	0	1,433	1,464
2020	1,373	1,378	1,341	956	0	1,463	1,473
2021	1,395	1,397	1,353	979	0	1,484	1,486
2022	1,411	1,411	1,367	998	0	1,494	1,494
2023	1,410	1,410	1,369	1,009	0	1,487	1,487
2024	1,404	1,404	1,363	1,012	0	1,478	1,478
2025	1,395	1,395	1,356	1,012	0	1,466	1,466
2026	1,389	1,389	1,352	1,012	0	1,461	1,461
2027	1,387	1,387	1,349	1,010	0	1,459	1,459
Fishing M.	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2014	0.277	0.277	0.277	0.277	0.277	0.277	0.277
2015	0.392	0.313	0.329	0.160	0.000	0.507	0.392
2016	0.392	0.392	0.329	0.160	0.000	0.482	0.392
2017	0.381	0.387	0.329	0.160	0.000	0.453	0.485
2018	0.367	0.370	0.329	0.160	0.000	0.444	0.453
2019	0.359	0.360	0.329	0.160	0.000	0.437	0.440
2020	0.359	0.359	0.329	0.160	0.000	0.438	0.438
2021	0.360	0.360	0.329	0.160	0.000	0.440	0.440
2022	0.359	0.359	0.329	0.160	0.000	0.439	0.439
2023	0.359	0.358	0.329	0.160	0.000	0.436	0.436
2024	0.358	0.358	0.329	0.160	0.000	0.436	0.436
2025	0.358	0.358	0.329	0.160	0.000	0.435	0.435
2026	0.358	0.358	0.329	0.160	0.000	0.435	0.435
2027	0.357	0.357	0.329	0.160	0.000	0.433	0.433
Spawning Biomass	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2014	2,941	2,941	2,941	2,941	2,941	2,941	2,941
2015	2,714	2,755	2,747	2,839	2,929	2,654	2,714
2016	2,570	2,686	2,695	3,080	3,517	2,374	2,570
2017	2,478	2,543	2,644	3,224	3,982	2,255	2,431
2018	2,501	2,532	2,674	3,392	4,455	2,278	2,344
2019	2,532	2,546	2,692	3,497	4,816	2,304	2,327
2020	2,567	2,572	2,716	3,587	5,136	2,328	2,336
2021	2,597	2,599	2,741	3,661	5,407	2,349	2,351
2022	2,612	2,613	2,755	3,711	5,623	2,357	2,357
2023	2,605	2,605	2,749	3,732	5,787	2,346	2,346
2024	2,591	2,592	2,734	3,734	5,897	2,332	2,332
2025	2,579	2,579	2,721	3,730	5,978	2,320	2,320
2026	2,576	2,576	2,716	3,731	6,045	2,319	2,319
2027	2,582	2,582	2,720	3,735	6,094	2,327	2,327

Table 1.30 Maximum permissible Tier 1a EBS pollock ABC and OFL projections for 2015 and for 2016.

Year	Catch	ABC	OFL
2015	1,350,000 t	2,900,000 t	3,330,000 t
2016	1,350,000 t	3,040,000 t	3,490,000 t

Table 1.31. Analysis of ecosystem considerations for BSAI pollock and the pollock fishery.

Indicator	Observation	Interpretation	Evaluation
Ecosystem effects on EBS pollock			
Prey availability or abundance trends			
Zooplankton	Stomach contents, AT and ichthyoplankton surveys, changes mean wt-at-age	Data improving, indication of increases from 2004-2009 and subsequent decreasees (for euphausiids in 2012 and 2014)	Variable abundance—indicates important recruitment (for prey)
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	Possibly lower mortality on pollock	Probably no concern
Birds	Stable, some increasing some decreasing	Affects young-of-year mortality	Probably no concern
Fish (Pollock, Pacific cod, halibut)	Stable to increasing	Possible increases to pollock mortality	
Changes in habitat quality			
Temperature regime	Cold years pollock distribution towards NW on average	Likely to affect surveyed stock	Some concern, the distribution of pollock availability to different surveys may change systematically
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability
Production	Fairly stable nutrient flow from upwelled BS Basin	Inter-annual variability low	No concern
Fishery effects on ecosystem			
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Likely to be safe	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	Likely to be safe	No concern
HAPC biota	Likely minor impact	Likely to be safe	No concern
Marine mammals and birds	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Generally more diffuse	Mixed potential impact (fur seals vs Steller sea lions)	Possible concern
Fishery effects on amount of large size target fish	Depends on highly variable year-class strength	Natural fluctuation	Probably no concern
Fishery contribution to discards and offal production	Decreasing	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	Maturity study (gonad collection) underway	NA	Possible concern

Table 1.32 Bycatch estimates (t) of non-target species caught in the BSAI directed pollock fishery, 1997-2002 based on observer data, 2003-2014 based on observer data as processed through the catch accounting system (NMFS Regional Office, Juneau, Alaska).

Group	1997	1998	1999	2000	2001	2002
Jellyfish	6,632	6,129	6,176	9,361	3,095	1,530
Squid	1,487	1,210	474	379	1,776	1,708
Skates	348	406	376	598	628	870
Misc Fish	207	134	156	236	156	134
Sculpins	109	188	67	185	199	199
Sleeper shark	105	74	77	104	206	149
Smelts	19.5	30.2	38.7	48.7	72.5	15.3
Grenadiers	19.7	34.9	79.4	33.2	11.6	6.5
Salmon shark	6.6	15.2	24.7	19.5	22.5	27.5
Starfish	6.5	57.7	6.8	6.2	12.8	17.4
Shark	15.6	45.4	10.3	0.1	2.3	2.3
Benthic inverts.	2.5	26.3	7.4	1.7	0.6	2.1
Sponges	0.8	21	2.4	0.2	2.1	0.3
Octopus	1	4.7	0.4	0.8	4.8	8.1
Crabs	1	8.2	0.8	0.5	1.8	1.5
Anemone	2.6	1.8	0.3	5.8	0.1	0.6
Tunicate	0.1	1.5	1.5	0.4	3.7	3.8
Unident. inverts	0.2	2.9	0.1	4.4	0.1	0.2
Echinoderms	0.8	2.6	0.1	0	0.2	0.1
Seapen/whip	0.1	0.2	0.5	0.9	1.5	2.1
Other	0.8	2.9	1.1	0.8	1.2	3.7

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Scypho jellies	5,644	6,590	5,196	2,716	2,398	4,183	8,115	2,661	8,893	3,878	6,117	13,886
Misc fish	101.3	89.8	157.9	154.1	202.9	120.2	135.1	173.0	325.8	163.0	151.0	50.1
Sea star	89.4	7.2	9.5	11.3	5.3	18.7	9.8	13.2	37.5	8.1	14.8	30.1
Eulachon	2.5	19.3	9.2	93.6	100.8	2.4	5.3	0.7	3.3	1.7	0.8	2.4
Eelpouts	7.0	0.7	1.3	21.0	118.7	8.9	4.3	2.1	1.3	1.3	1.8	8.1
osmerids	7.5	2.0	3.4	5.8	37.5	2.0	0.1	0.1	0.3	0.2	0.2	0.5
Sea pens	0.6	1.0	1.7	2.0	4.0	1.1	2.6	3.1	2.9	3.9	2.3	4.0
Sponge	0.1	0.0	0.0	0.0	1.4	0.2	0.5	4.9	3.9	0.5	6.6	2.5
Snails	1.3	1.0	6.9	0.2	0.5	1.9	1.5	1.4	1.4	1.5	1.1	1.7
Lanternfishes	0.3	0.1	0.6	9.6	5.8	1.5	0.4	0.0	0.0	0.1	0.0	0.0
Sea anemone	0.4	0.4	0.3	0.6	0.3	0.9	1.3	2.4	2.0	1.7	2.4	2.0
Brittle star	0.3	0.0	0.0	2.6	0.2	3.6	0.1	0.3	0.2	0.1	0.1	2.3
urochordata	0.0	0.0	0.5	0.0	0.0	0.8	0.7	3.1	0.9	0.1	1.9	1.1
Invertebrate	0.0	0.1	0.1	0.2	0.8	0.3	0.3	1.0	0.7	2.2	0.2	0.6
Misc crabs	0.7	0.0	0.3	0.1	1.3	0.6	0.2	0.1	0.3	0.2	0.6	0.4
All other	0.3	0.7	3.5	3.9	5.1	2.1	1.9	2.0	1.8	0.6	0.8	1.7

Table 1.33 Bycatch estimates (t) of other **target species** caught in the BSAI directed pollock fishery, 1997-2012 based on then NMFS Alaska Regional Office reports from observers (*2014 data are preliminary*).

	Pacific Cod	Flathead Sole	Rock Sole	Yellowfin Sole	Arrowtooth Flounder	Pacific Ocean Perch	Atka Mackerel	Sablefish	Greenland Turbot	Alaska Plaice	Skates	Squid	Sharks	Sculpin	All other	Total
1997	8,262	2,350	1,522	606	985	428	83	2	123	1					879	15,241
1998	6,559	2,118	779	1,762	1,762	682	91	2	178	14					805	14,751
1999	3,220	1,885	1,058	350	273	121	161	7	30	3					249	7,357
2000	3,432	2,510	2,688	1,466	979	22	2	12	52	147					306	11,615
2001	3,878	2,199	1,673	594	529	574	41	21	68	14					505	10,098
2002	5,925	1,843	1,885	768	606	544	221	34	70	50					267	12,214
2003	5,968	1,706	1,419	210	618	935	762	48	40	7	571	1,226	294	81	327	14,213
2004	6,437	2,009	2,554	841	557	394	1,053	17	18	8	841	977	187	150	436	16,477
2005	7,413	2,319	1,125	63	651	653	678	11	31	45	732	1,150	169	131	490	15,661
2006	7,291	2,837	1,361	256	1,089	736	789	9	65	11	1,308	1,399	512	169	620	18,450
2007	5,630	4,203	510	86	2,795	625	315	12	107	3	1,287	1,169	245	190	726	17,902
2008	6,965	4,288	2,123	516	1,711	336	15	5	85	49	2,756	1,452	144	281	438	21,164
2009	7,878	4,602	7,602	271	2,203	114	25	3	44	176	3,856	209	100	292	305	27,682
2010	6,987	4,309	2,330	1,057	1,502	231	57	2	26	126	1,886	277	26	258	375	19,448
2011	9,998	4,846	8,463	1,095	1,599	660	894	1	29	74	2,342	178	65	315	590	31,150
2012	10,047	3,957	6,819	1,452	735	713	263	1	53	129	2,017	495	55	286	512	27,534
2013	8,944	3,142	6,360	2,072	958	611	70	0	21	147	1,756	117	43	221	242	24,703
2014	5,193	2,537	4,380	1,927	756	1,295	117	1	41	322	811	1,478	75	189	495	19,617

Table 1.34 Bycatch estimates (t) of **pollock** caught in the other non-pollock EBS directed fisheries, 2003-2011 based on then NMFS Alaska Regional Office reports from observers.

	Fishery						
	Pacific cod	Yellowfin sole	Rock sole	Flathead sole	Other flatfish	Others	**Total**
2003	15,922	11,570	4,925	2,989	691	265	36,362
2004	18,619	10,479	8,964	5,112	1,231	196	44,600
2005	14,105	10,312	7,240	3,664	1,394	202	36,917
2006	15,147	5,967	7,040	2,641	1,153	143	32,090
2007	20,306	4,042	3,220	3,448	932	268	32,215
2008	9,584	9,867	4,995	4,098	714	17	29,275
2009	7,879	6,998	6,150	3,166	347	14	24,553
2010	6,416	5,207	5,913	3,072	322	91	21,022
2011	8,965	8,695	7,090	1,491	831	301	27,373
2012	8,386	11,226	6,779	903	841	413	28,547
2013	9,044	20,246	7,372	2,021	2,026	252	40,961
2014	9,556	20,190	11,105	4,138	2,295	70	47,352
Average	11,994	10,400	6,733	3,062	1,065	186	33,439

Table 1.35 Bycatch estimates of prohibited species caught in the BSAI directed pollock fishery, 1997-2012 based on then AKFIN (NMFS Regional Office) reports from observers. Herring and halibut units are in t, all others represent numbers of individuals caught. Data for 2014 are preliminary.

Year	Bairdi Crab	Blue King Crab	Chinook Salmon	Golden King Crab	Halibut catch	Halibut Mort	Herring	Non-Chinook Salmon	Opilio Crab	Other King Crab	Red King Crab
1991	1,398,112		40,906		2,159,774		3,159,252	28,951	4,380,025	33,431	17,777
1992	1,501,801		35,950		2,221,417		647,013	40,274	4,570,741	20,387	43,874
1993	1,649,104		38,516		1,326,119		527,497	242,191	738,260	1,926	58,140
1994	371,238		33,136		963,417	689	1,626,561	92,672	811,758	514	42,361
1995	153,995		14,984		492,283	398	904,899	19,264	206,654	941	4,646
1996	89,416		55,623		382,071	321	1,241,853	77,236	63,398	215	5,934
1997	17,248		44,909		260,761	203	1,134,544	65,988	216,152	393	137
1998	57,042		51,322		353,210	278	800,753	64,042	123,405	5,093	14,287
1999	2,397		10,381		153,970	125	799,550	44,610	15,830	7	91
2000	1,485		4,242		110,456	91	482,751	56,867	6,481	121	0
2001	5,061		30,937		265,907	200	225,277	53,904	5,653	5,139	106
2002	2,113		32,402		199,299	168	108,584	77,178	2,698	194	17
2003	733	9	43,021		113,493	96	909,216	180,782	609		52
2004	1,189	4	51,700	2	108,623	93	1,104,136	440,475	743		27
2005	659	0	67,362	1	146,727	113	610,123	704,587	2,300		0
2006	1,657	0	82,750	3	156,510	122	435,558	306,047	2,909		203
2007	1,522	0	122,255	3	360,261	292	353,518	93,201	3,220		8
2008	8,839	8	21,398	33	424,351	334	127,805	15,555	9,428		576
2009	6,120	20	12,743	0	588,227	458	64,952	46,893	7,428		1,137
2010	13,589	29	9,831	0	356,652	274	351,378	13,797	9,431		1,009
2011	10,319	20	25,499	0	508,606	382	377,220	193,555	6,332		577
2012	5,413	0	11,344	0	474,800	386	2,352,551	22,390	6,106		344
2013	12,149	34	13,108	147	347,403	268	958,969	125,525	8,549		316
2014			15,020		191,011	160		219,092			

Figures

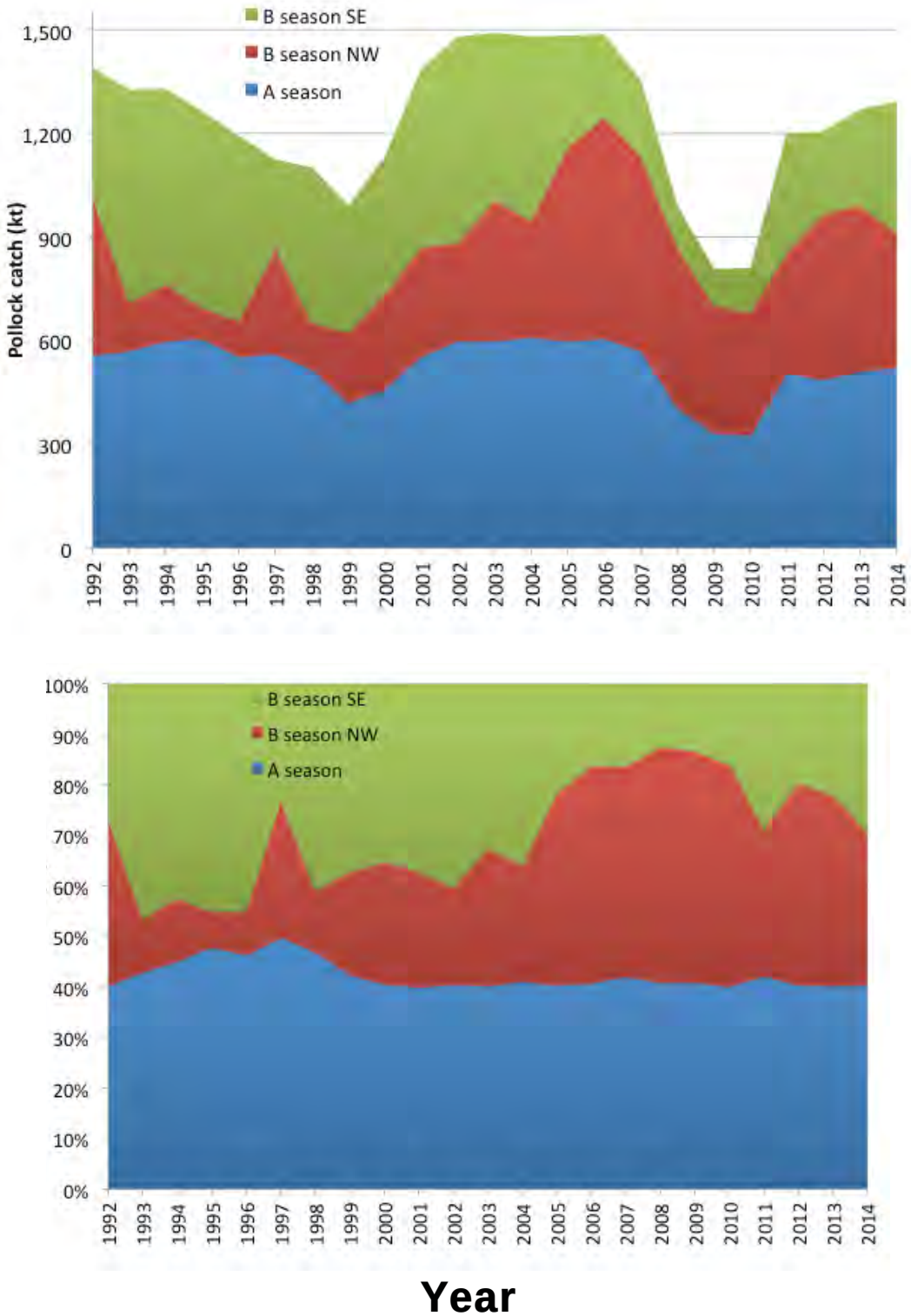

Figure 1.1. Pollock catch estimates from the Eastern Bering Sea by season and region in kt (top) and proportion (bottom). The A-season is defined as from Jan-May and B-season from June-October, 1992-2014.

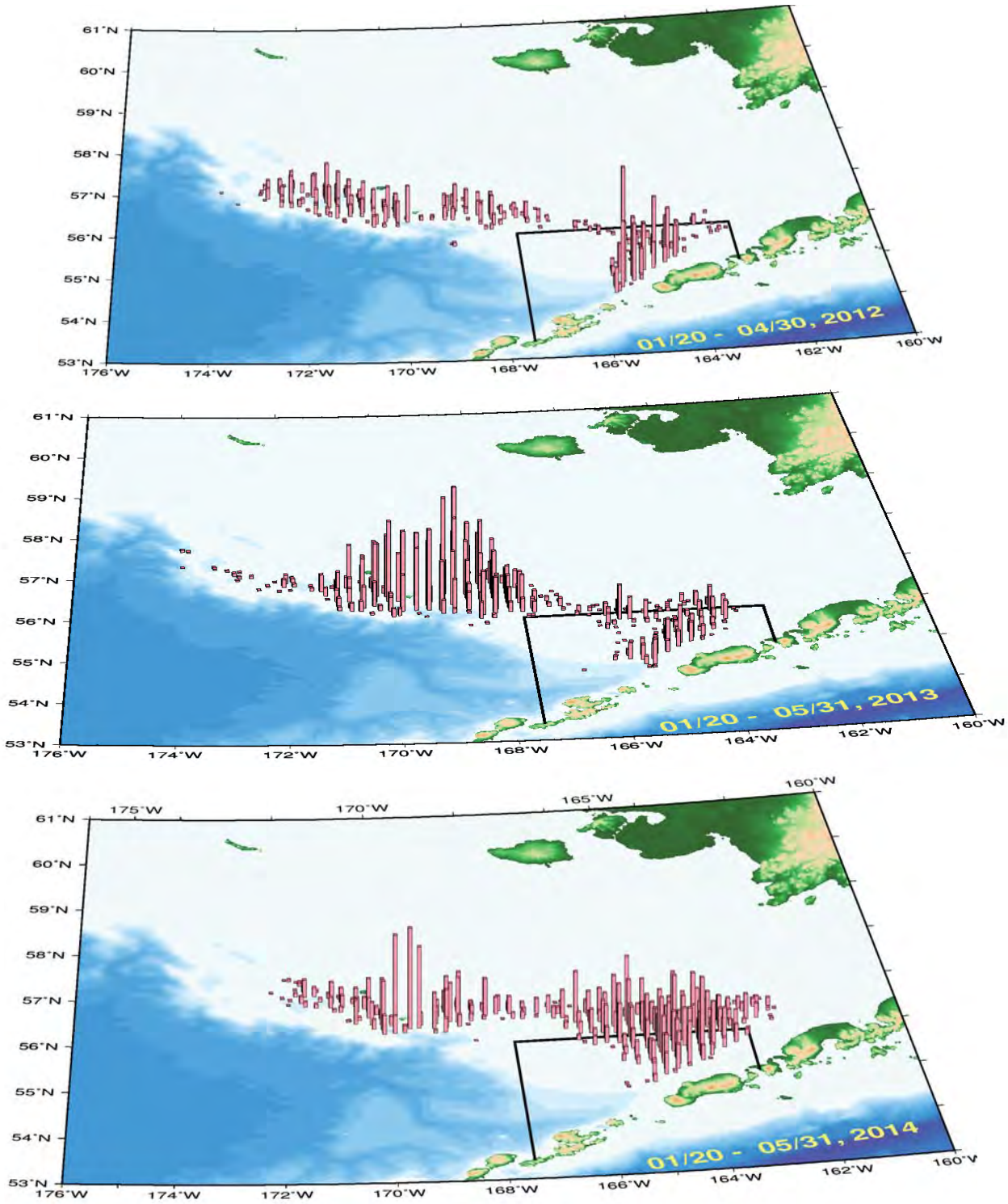

Figure 1.2. Pollock catch distribution 2012-2014, for the A-season on the EBS shelf. Line delineates catcher-vessel operational area (CVOA). The column height represents relative removal on the same scale in all years.

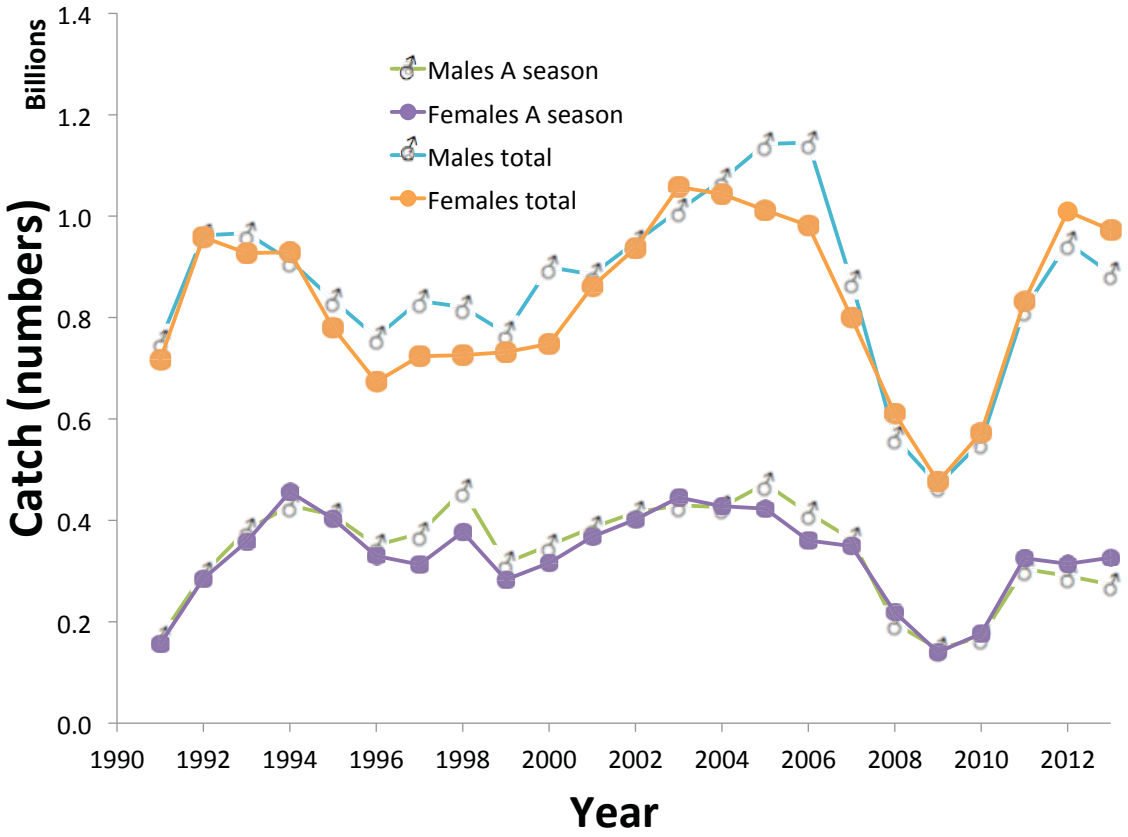

Figure 1.3. Estimate of EBS pollock catch numbers by sex for the A season (January-May) and for the entire annual fishery, 1991-2013.

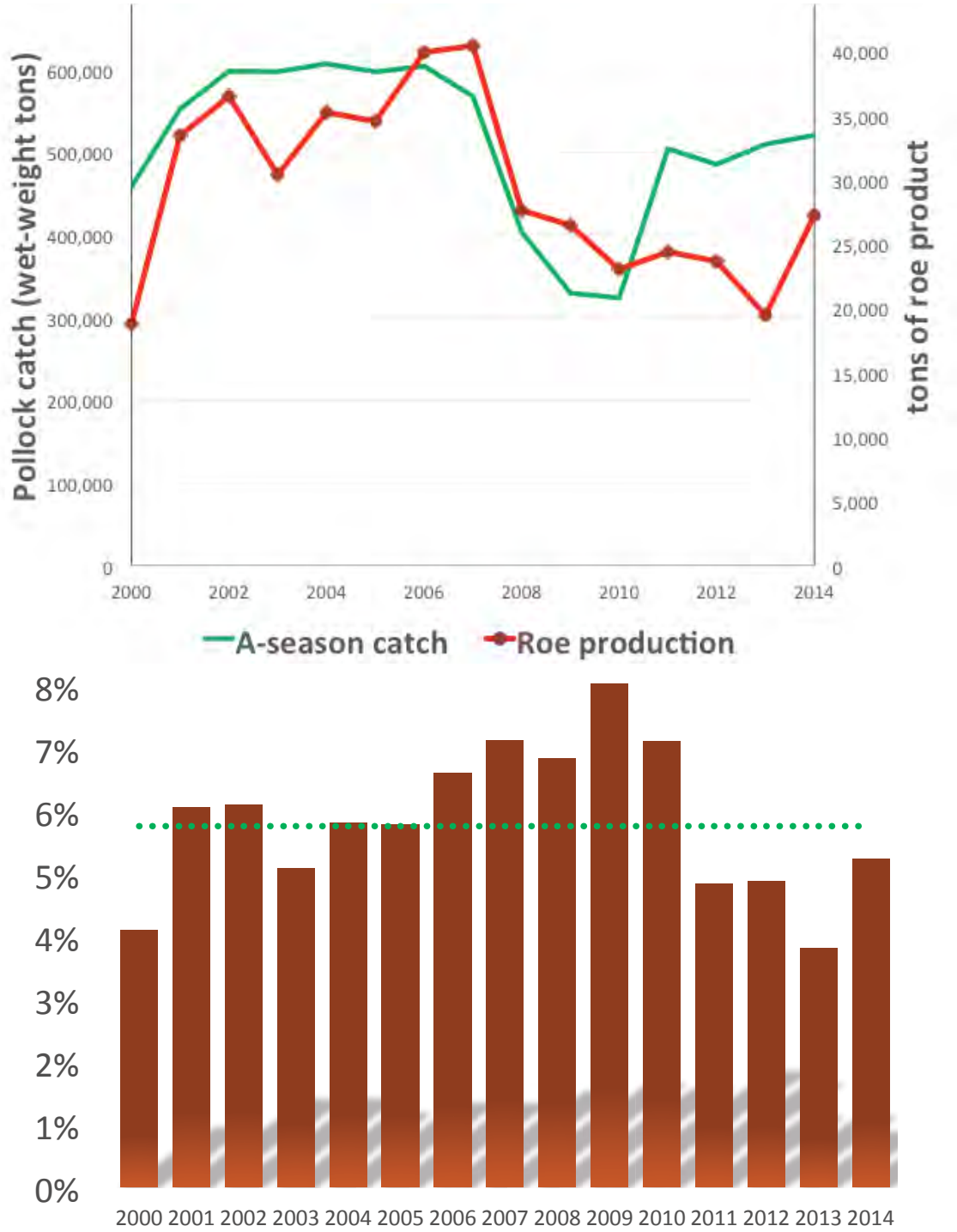

Figure 1.4. EBS pollock fishery catch in the A-season compared to tons of roe produced (top) and ratio of roe recovery relative to the mean value for 2000-2014 (bottom). Note that pollock catch for the A-season is from NMFS catch-accounting system and roe production data is derived from NMFS REFM-Division socio-economic database.

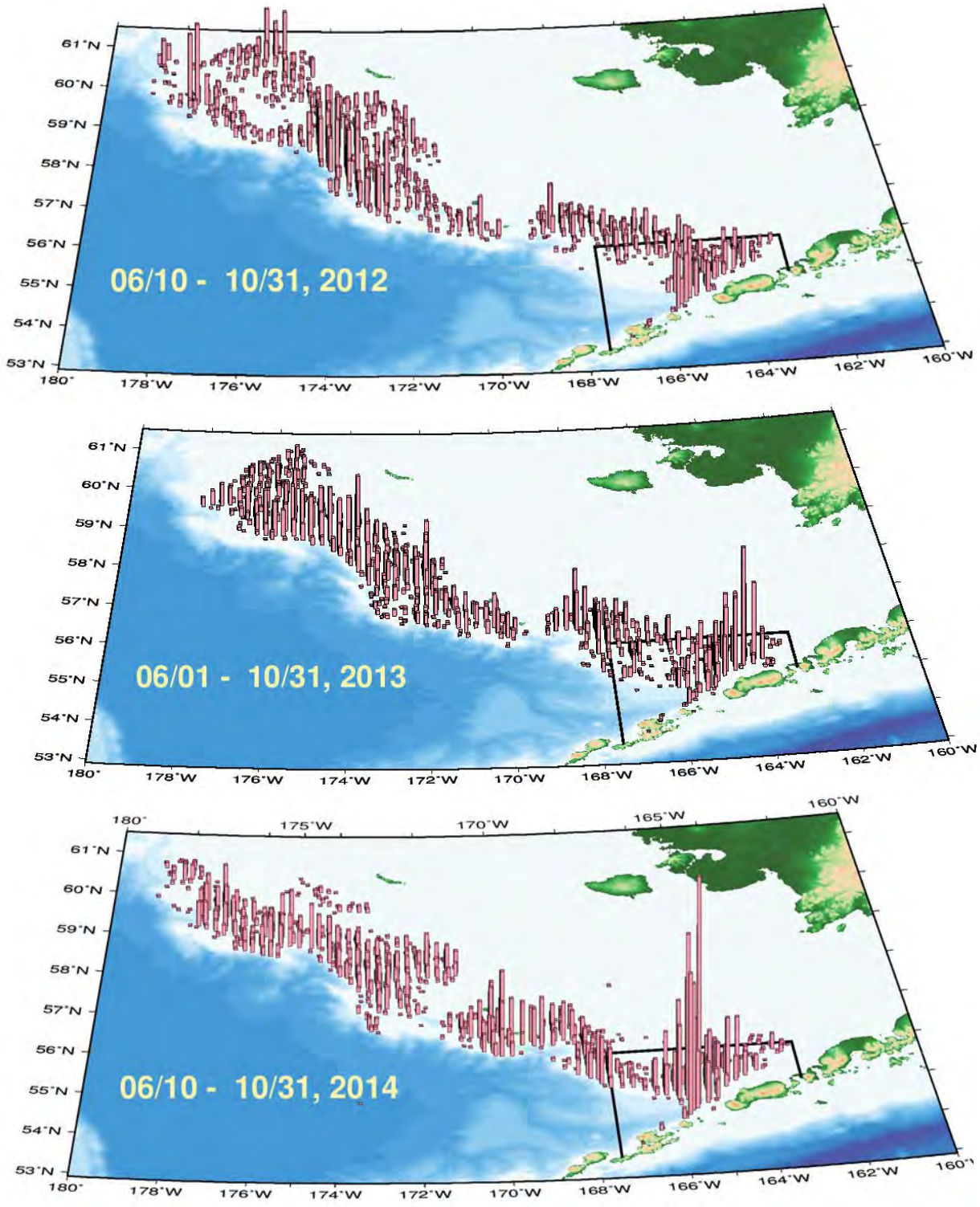

Figure 1.5. Pollock catch distribution during June – October, 2012-2014. The line delineates the catcher-vessel operational area (CVOA) and the height of the bars represents relative removal on the same scale between years.

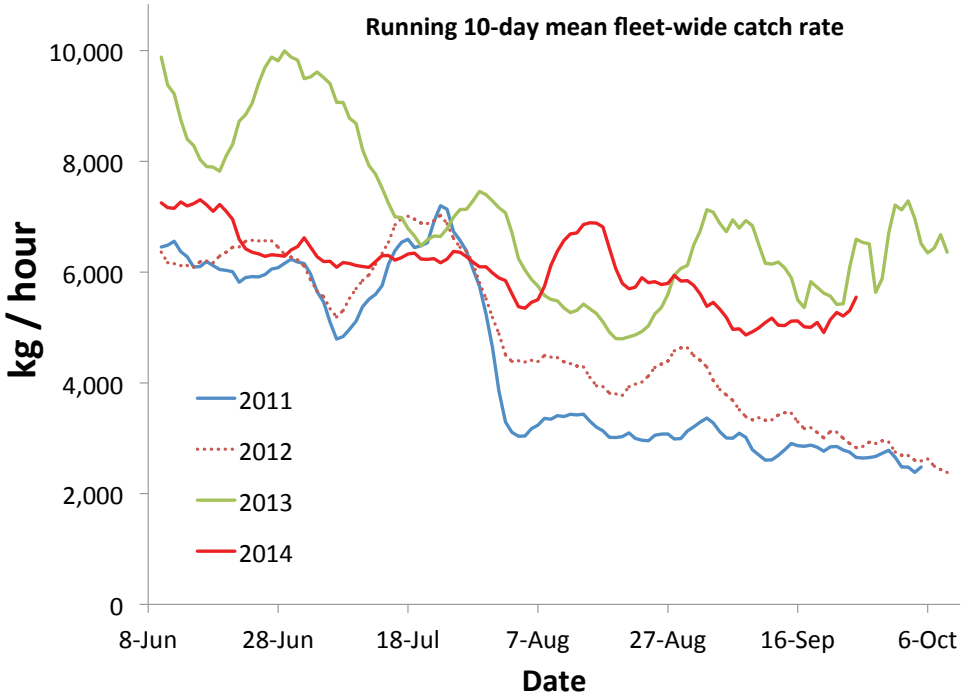

Figure 1.6. Moving average (10-day) pollock catch (kg) per hour towed for the EBS pollock fishery comparing 2011-2014.

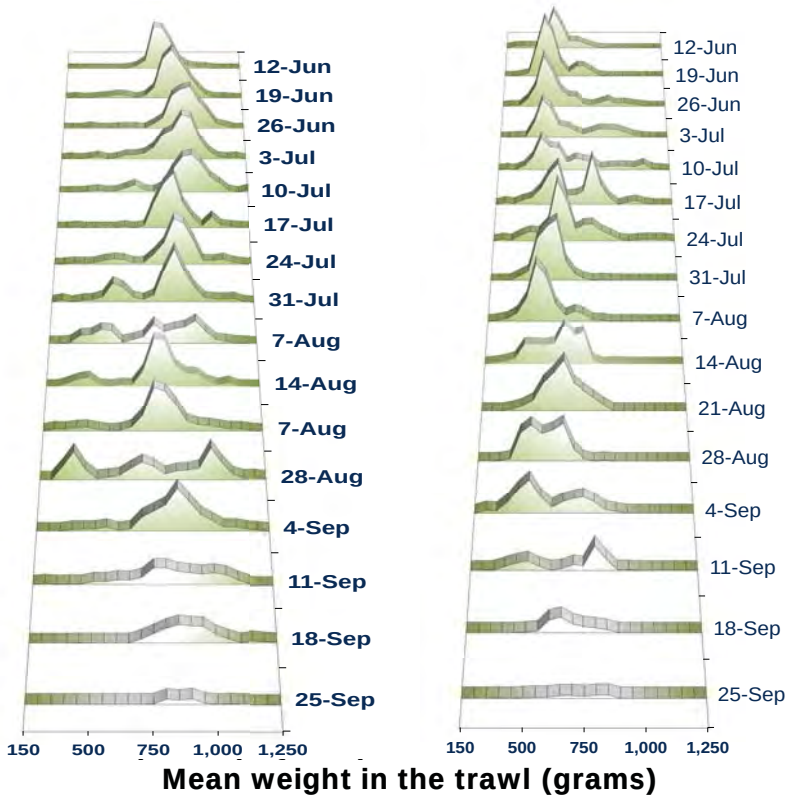

Figure 1.7. Weekly NMFS observer data on the frequency distribution of mean weight (by 50-gram categories) per tow for the summer 2014 EBS pollock fishery with shore-based fleet represented on the left and offshore fleet on the right.

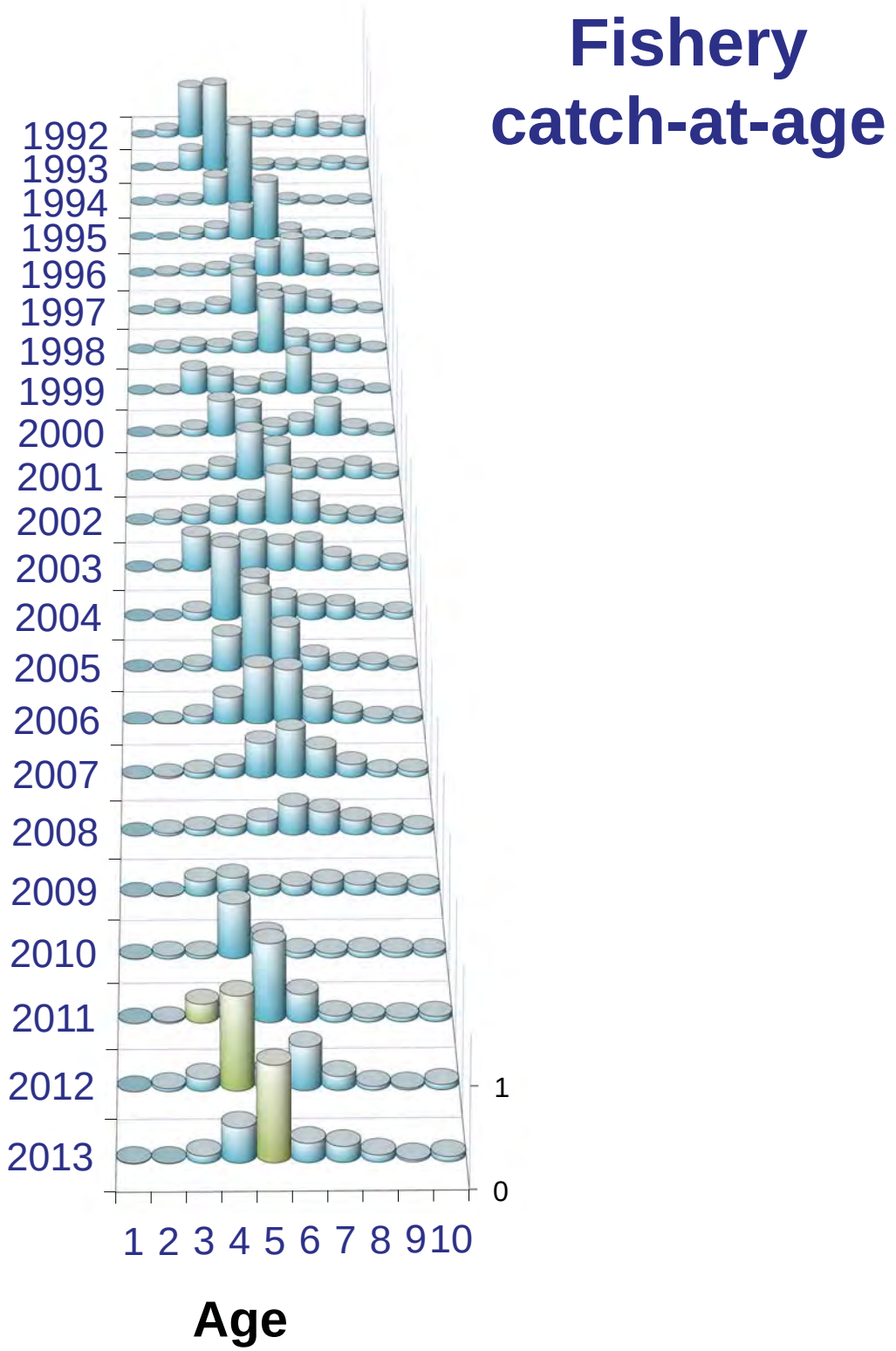

Figure 1.8. EBS pollock fishery estimated catch-at-age data (in number) for 1991-2013. Age 10 represents pollock age 10 and older. The 2008 year-class is shaded in green.

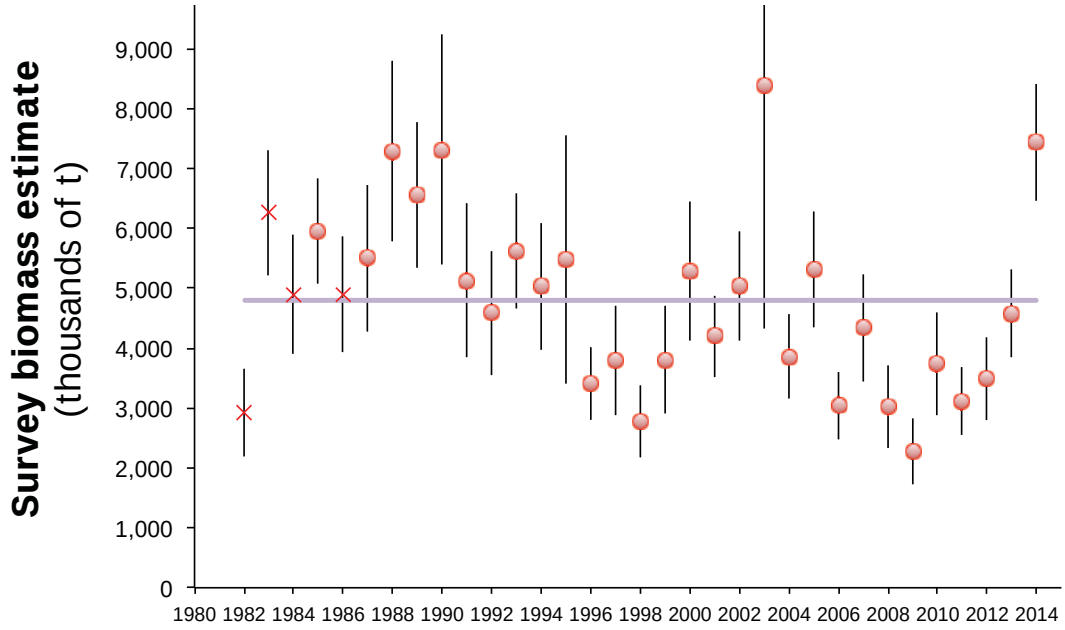

Figure 1.9. Bottom-trawl survey biomass estimates with approximate 95% confidence bounds (based on sampling error) for EBS pollock, 1982-2014. These estimates **include** the northern strata except for 1982-84, and 1986. Horizontal line represents the long-term mean.

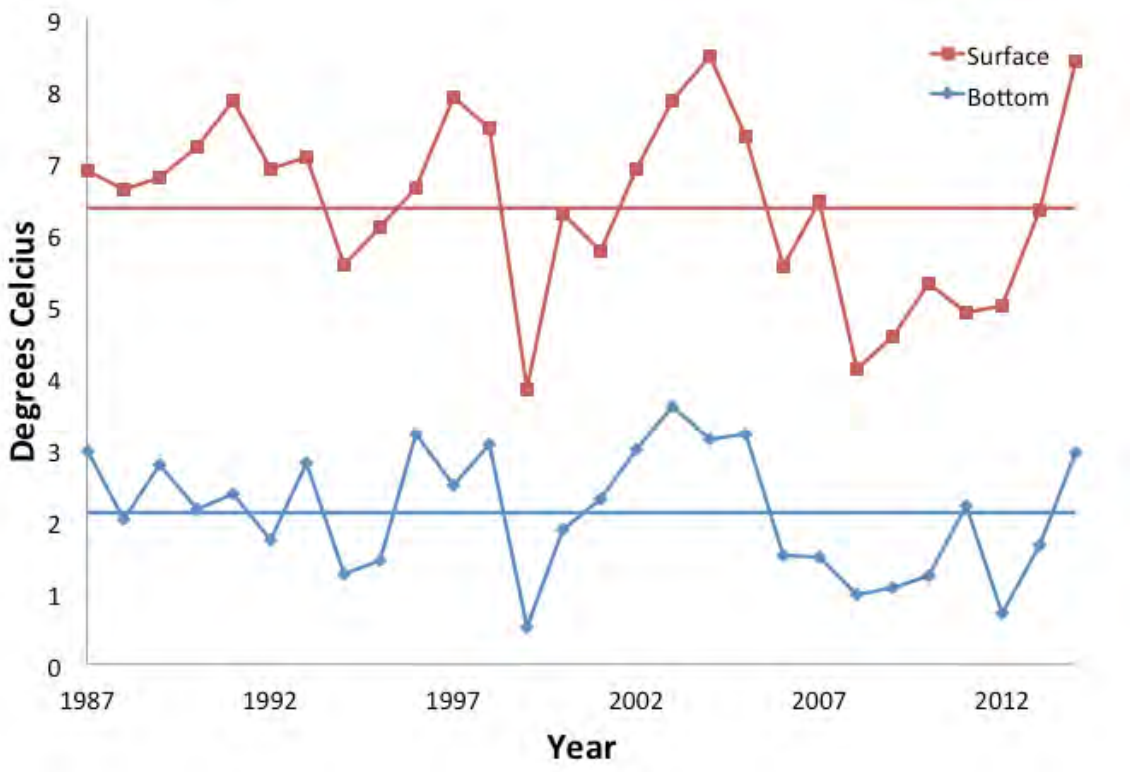

Figure 1.10. Area-weighted bottom (lower lines) and surface (upper lines) temperatures for the Bering Sea and mean values from the NMFS summer bottom-trawl surveys (1987-2014).

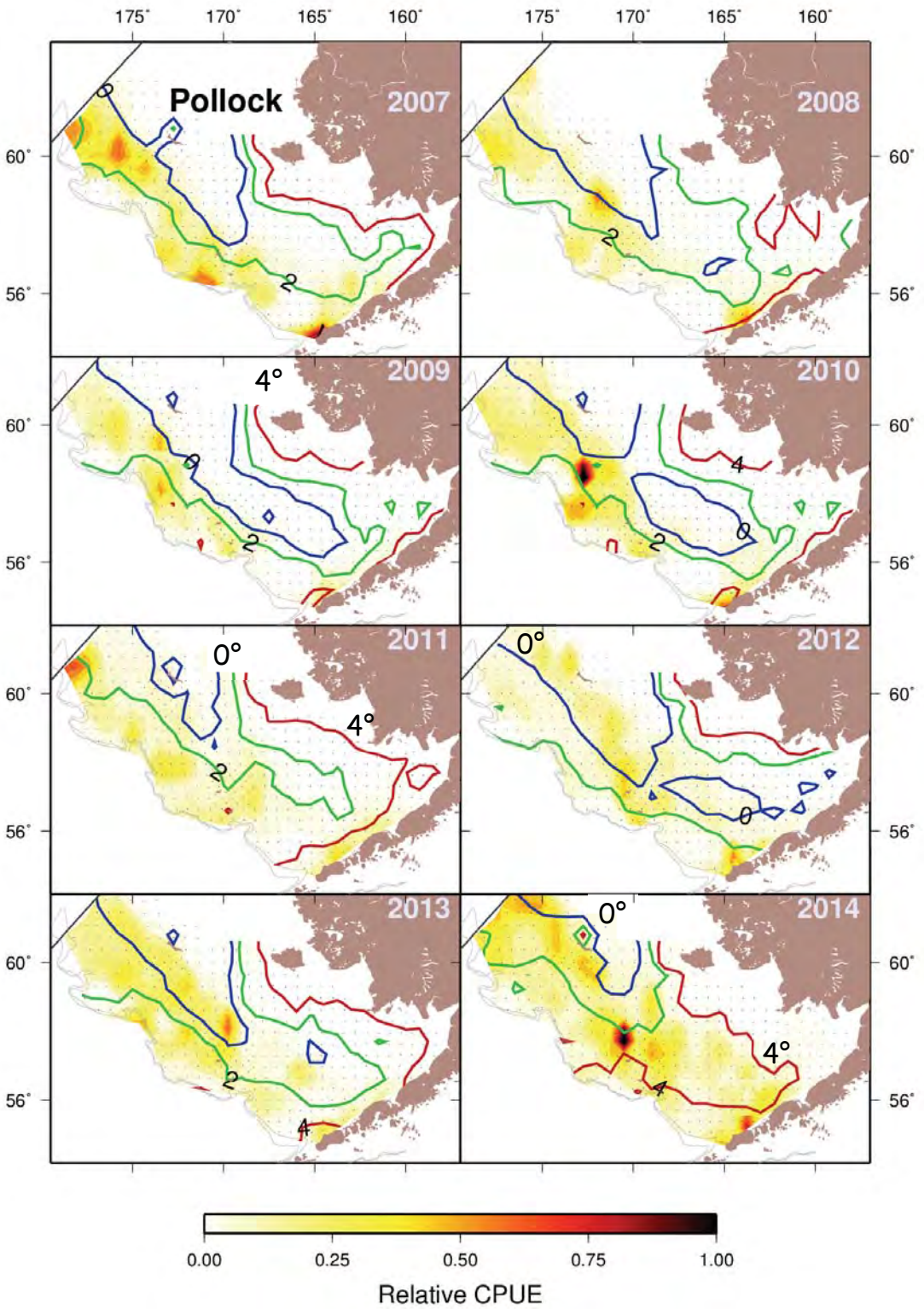

Figure 1.11. EBS pollock CPUE (shades = relative kg/hectare) and bottom temperature isotherms of 0º, 2º, and 4º Celsius from summer bottom-trawl surveys, 2007-2014.

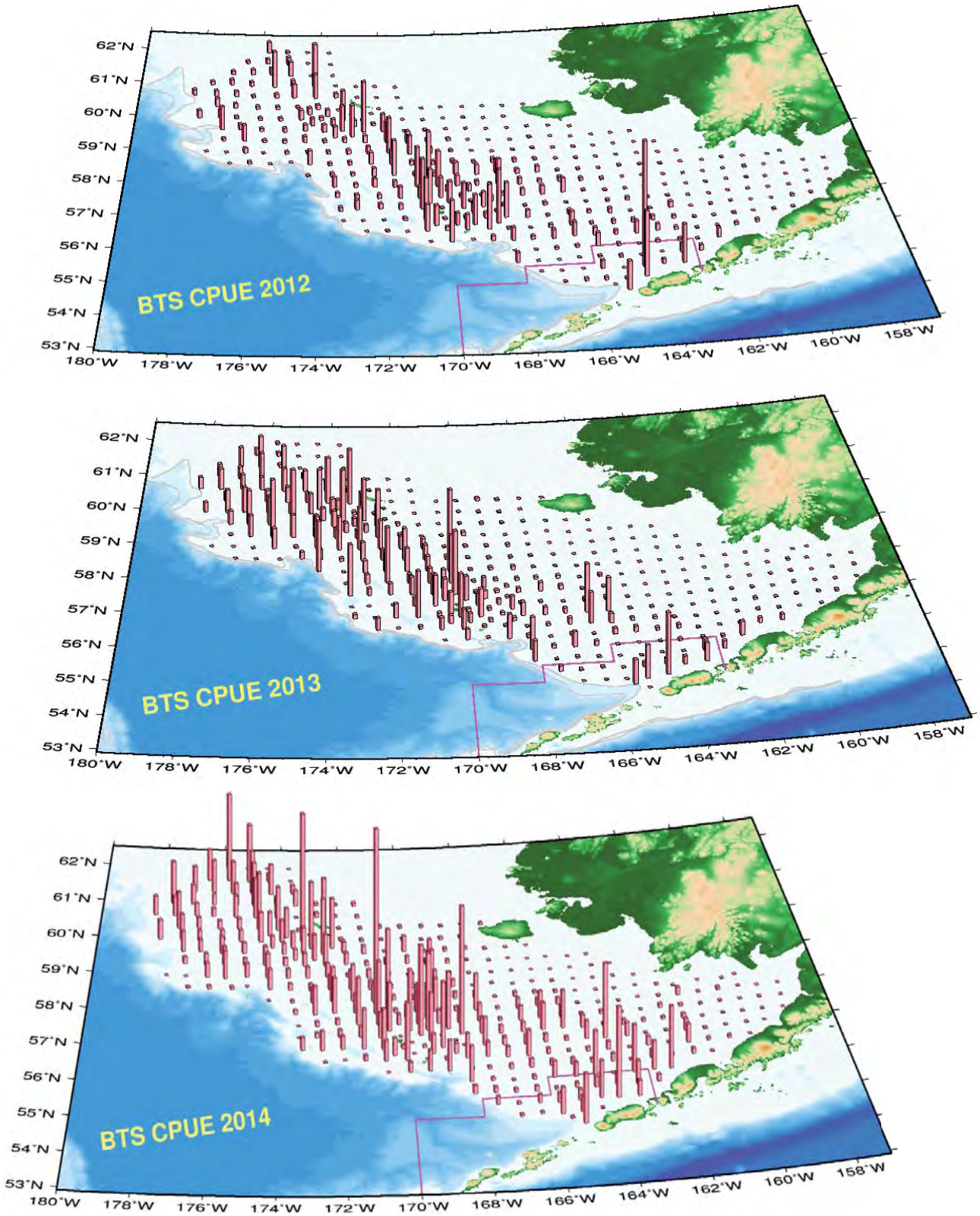

Figure 1.12. Bottom trawl survey pollock catch in kg per hectare for 2012 - 2014. Vertical lines represent station-specific pollock densities.

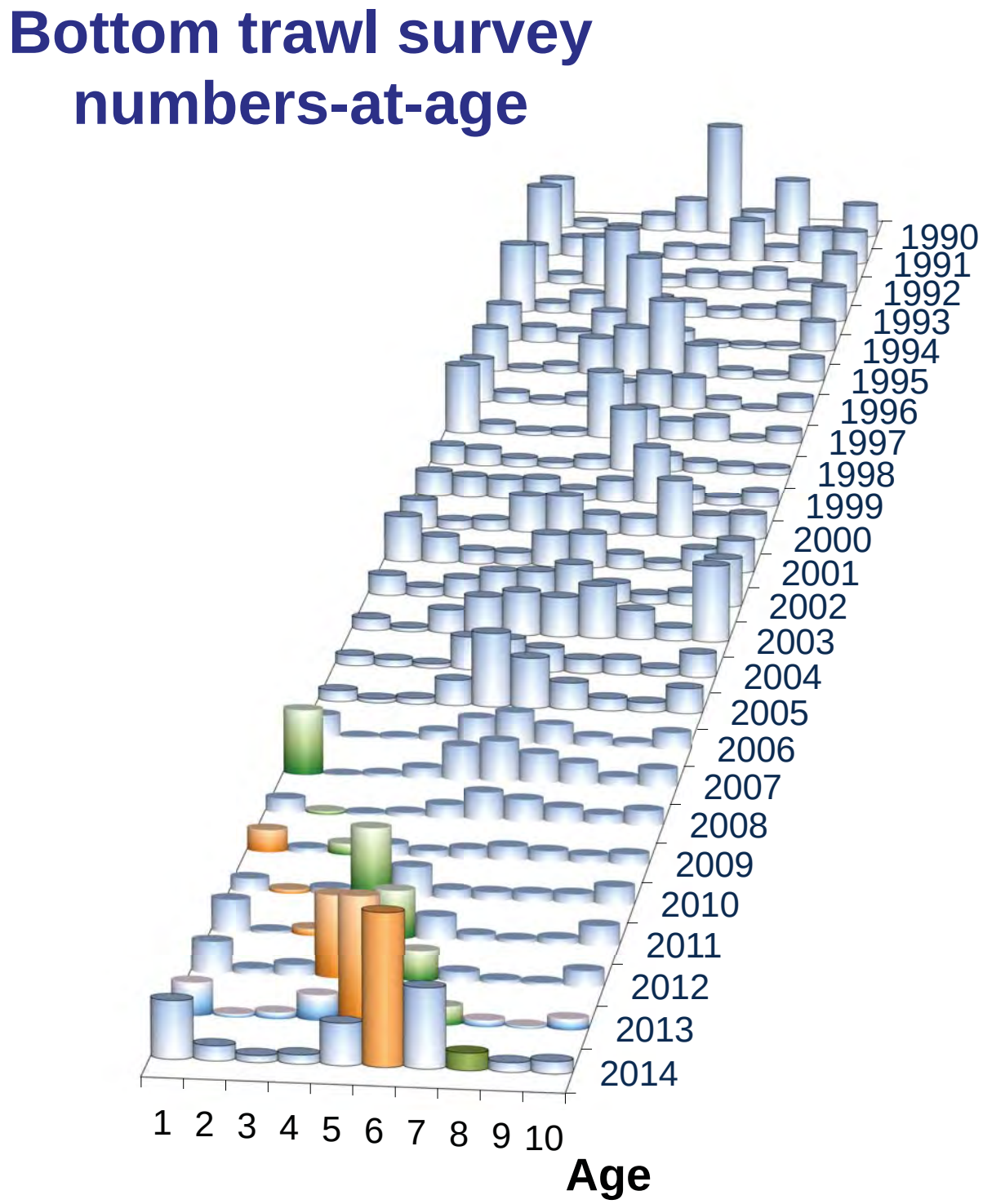

Figure 1.13. Pollock abundance levels by age and year as estimated directly from the NMFS bottom-trawl surveys (1989-2014). The 2006 and 2008 year-classes are shaded differently.

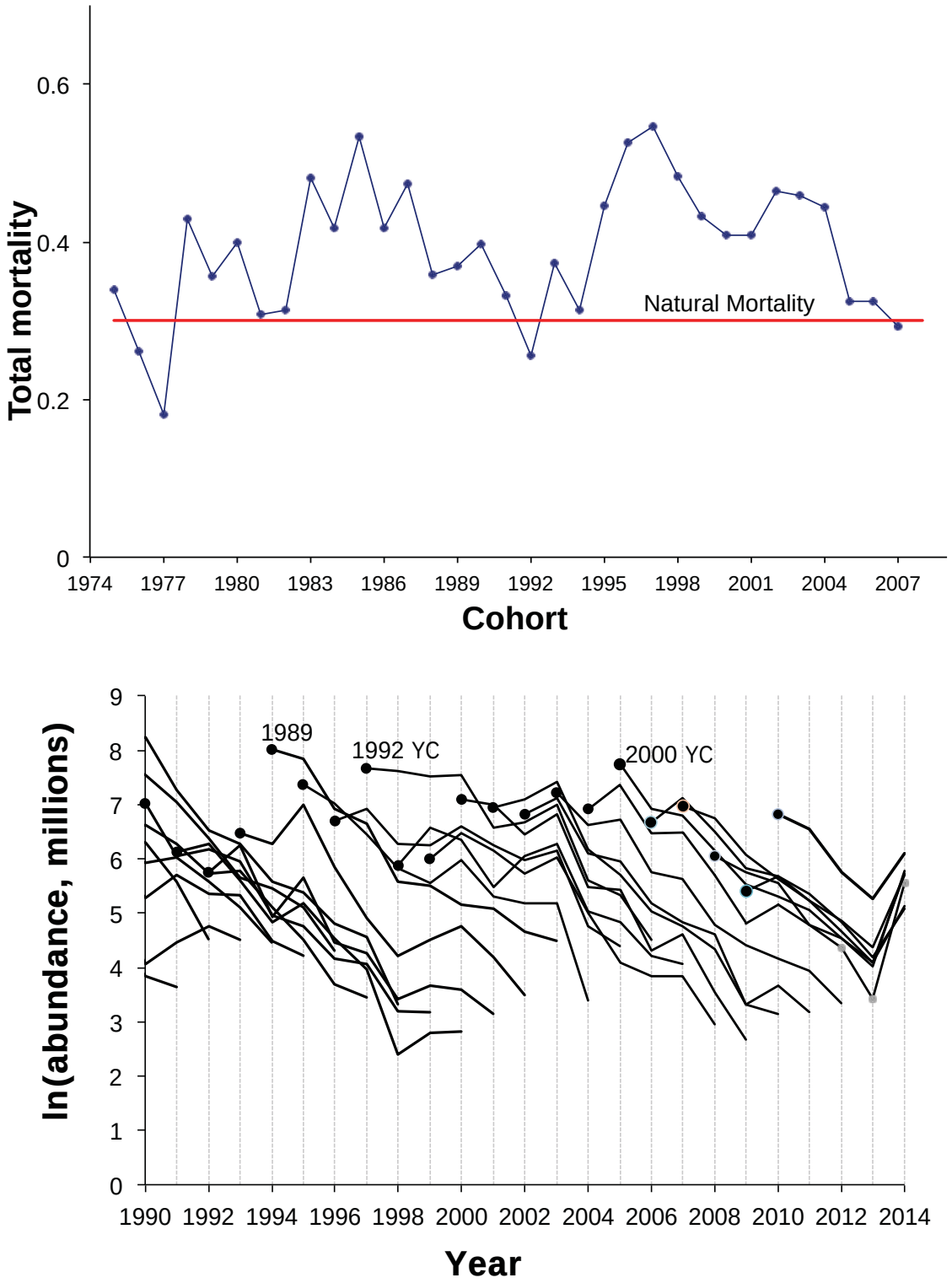

Figure 1.14. Evaluation of EBS pollock cohort abundances as observed for age 5 and older in the NMFS summer bottom trawl surveys, 1982-2014. The bottom panel shows the raw log-abundances at age while the top panel shows the estimates of total mortality by cohort.

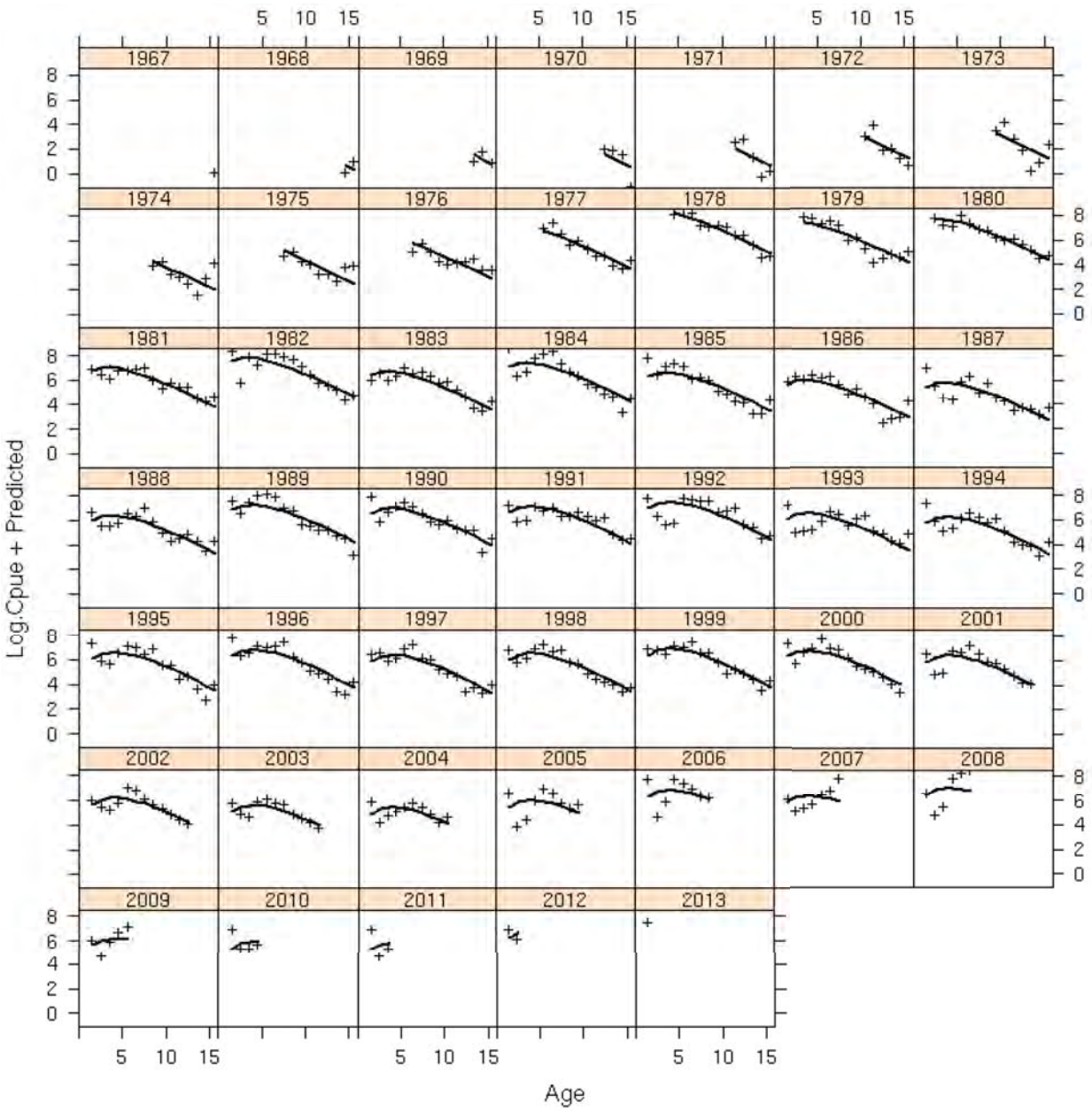

Figure 1.15. Representation of EBS pollock bottom-trawl survey log-cohort abundances modeled using the software of Cotter et al. (2007) YCC (meaning Year-Class Curves). Model configuration included cohort and age effects and each panel shows the data (+) and the model fit for each cohort.

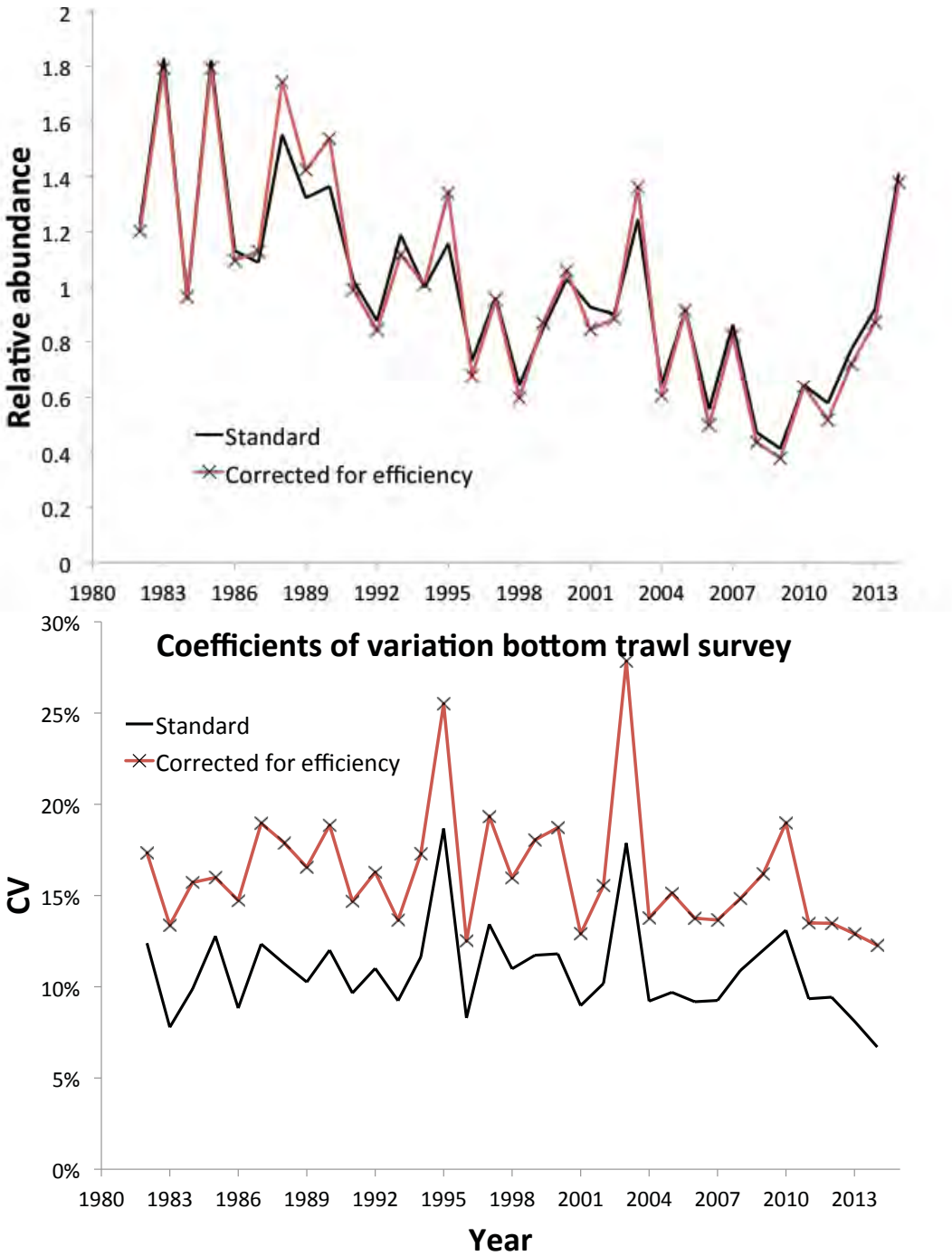

Figure 1.16. Relative abundance trends as estimated using the Kotwicki index compared to the standard survey abundance estimate (top panel) and the estimated coefficients of variation (CVs; bottom) for EBS pollock.

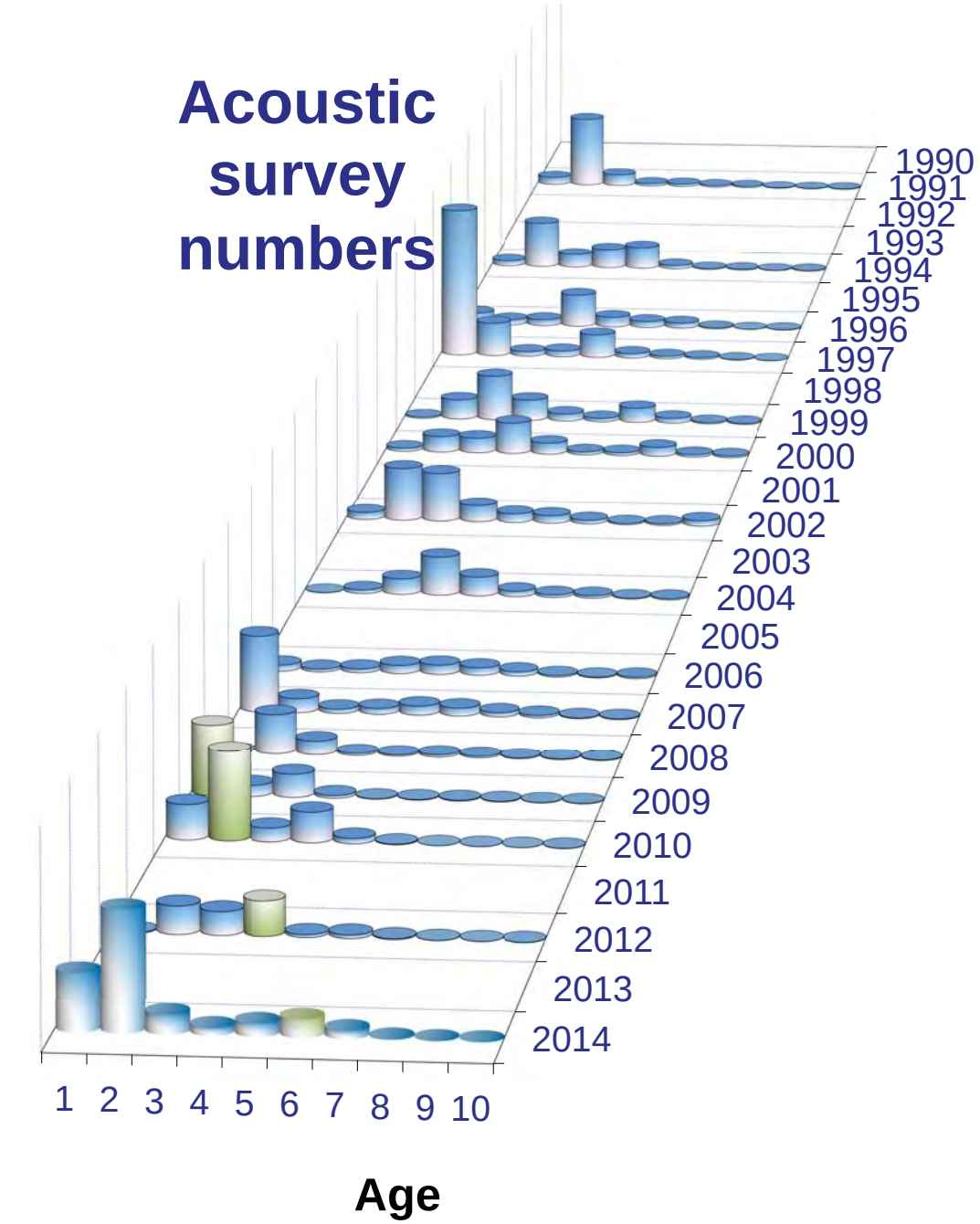

Figure 1.17. Time series of estimated numbers at age (millions) for EBS pollock from the AT surveys, 1991-2014. The differently shaded columns represent the 2008 cohort.

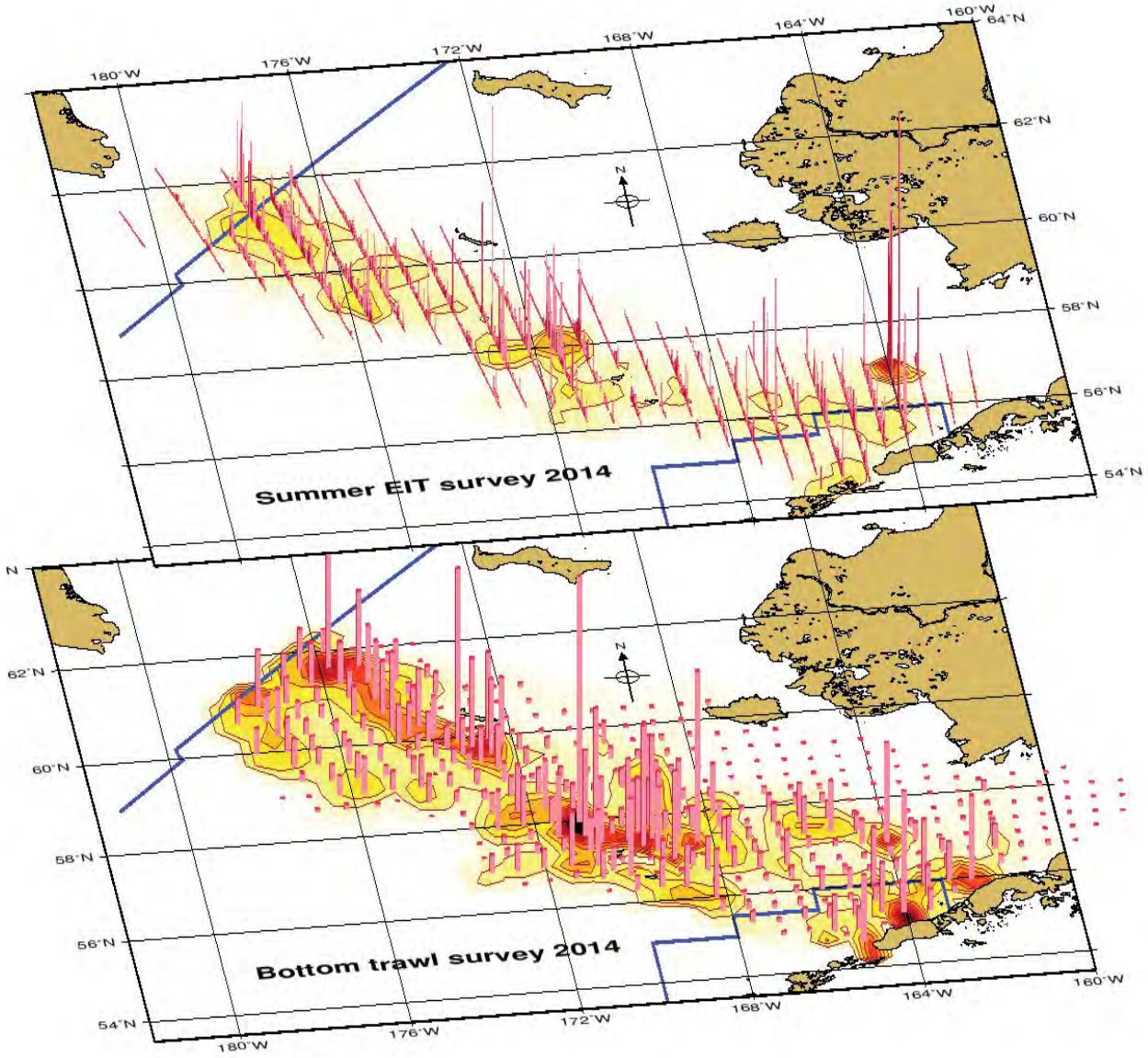

Figure 1.18. Comparison of the mid-water EBS pollock density from the AT survey (top layer) and that of the BTS (bottom layer). The blue line in the SE corner of the region delineates the Steller sea lion conservation area (SCA).

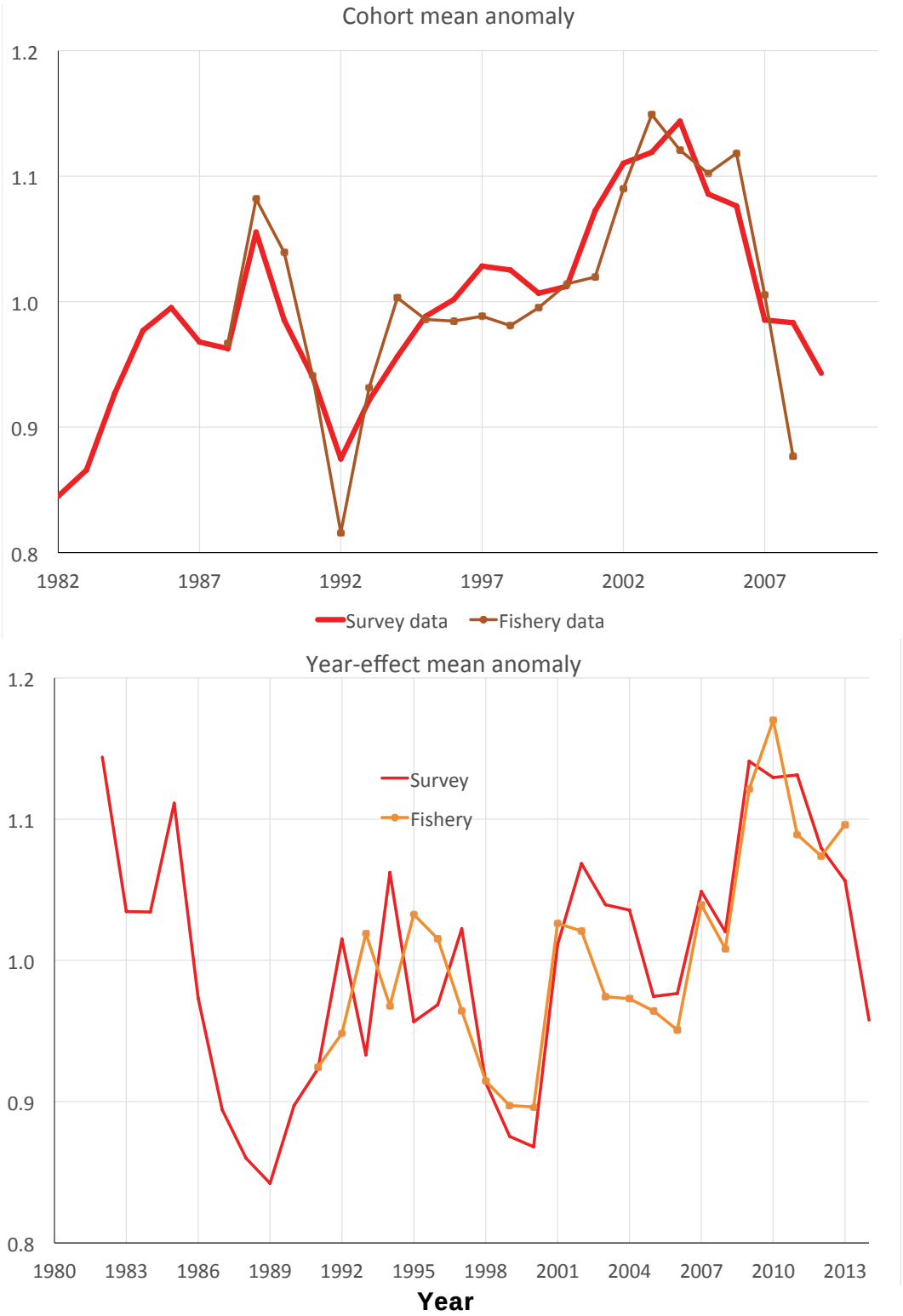

Figure 1.19. Mean fishery and bottom-trawl survey body weight anomaly (relative to their mean values) for EBS pollock by cohort (top) and by year (bottom).

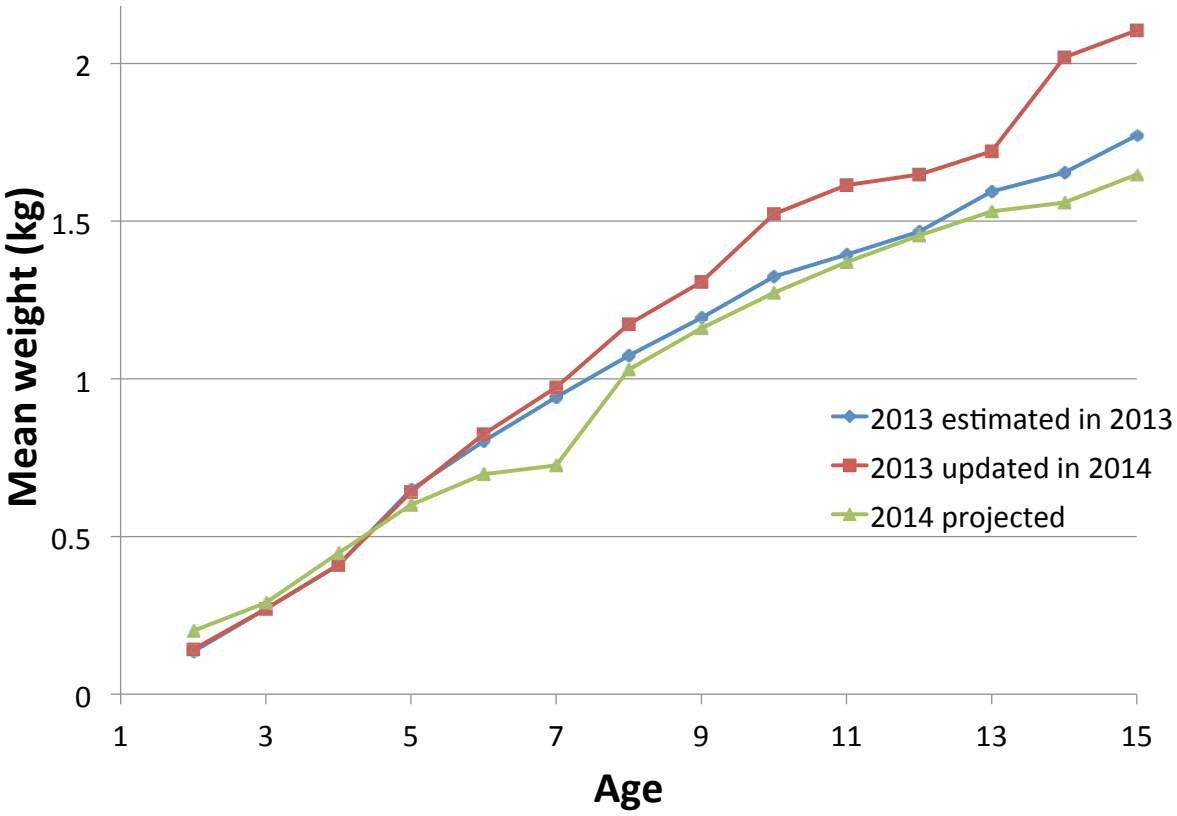

Figure 1.20. Mean fishery body mass (kg) for EBS pollock assumed for the 2013 assessment and as revised using observer data. The 2014 values are estimated as described in the text.

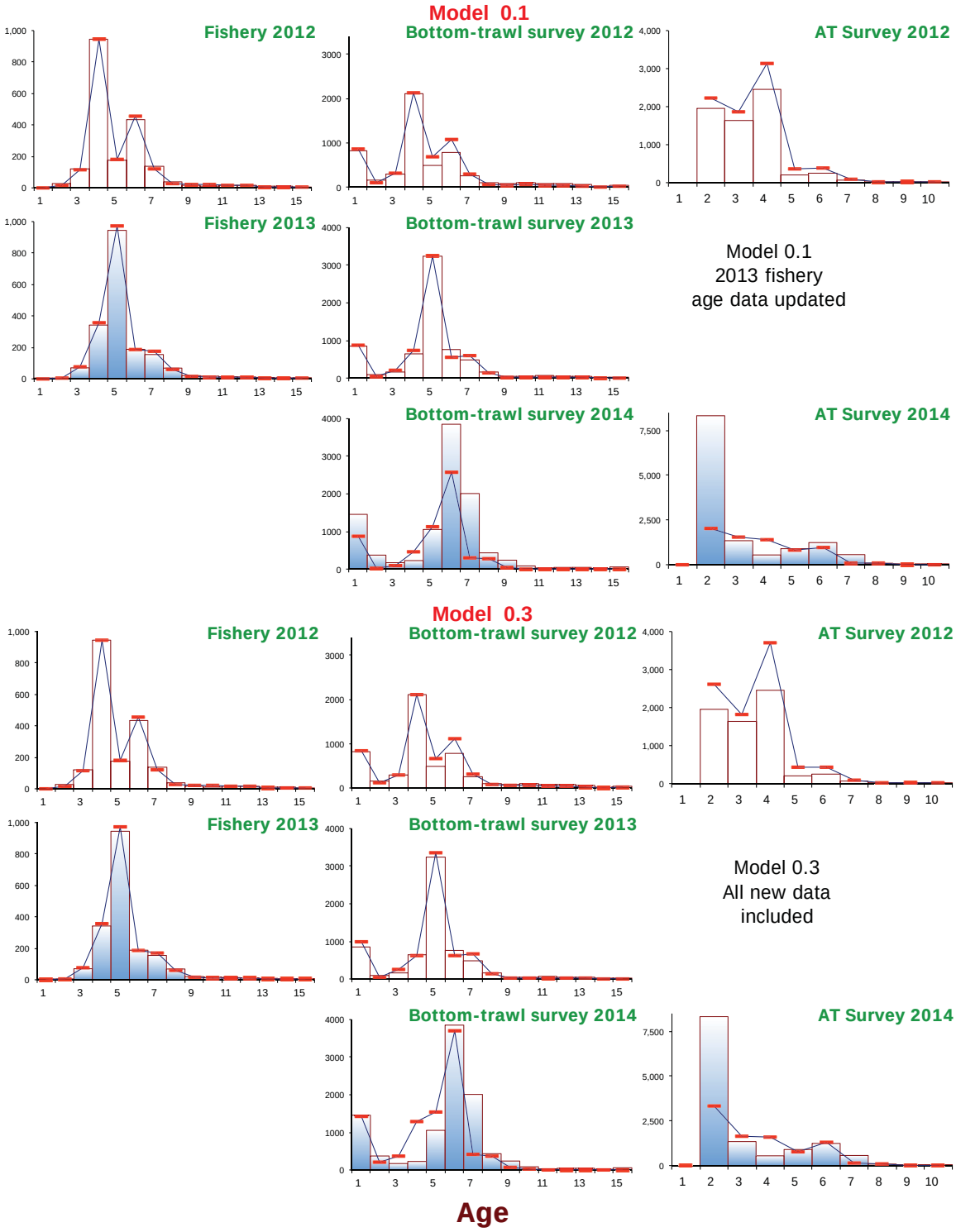

Figure 1.21. Three model configuration results of predicted EBS pollock numbers-at-age for catch and surveys as new data were added. Columns represent the data, horizontal red lines represent model predictions.

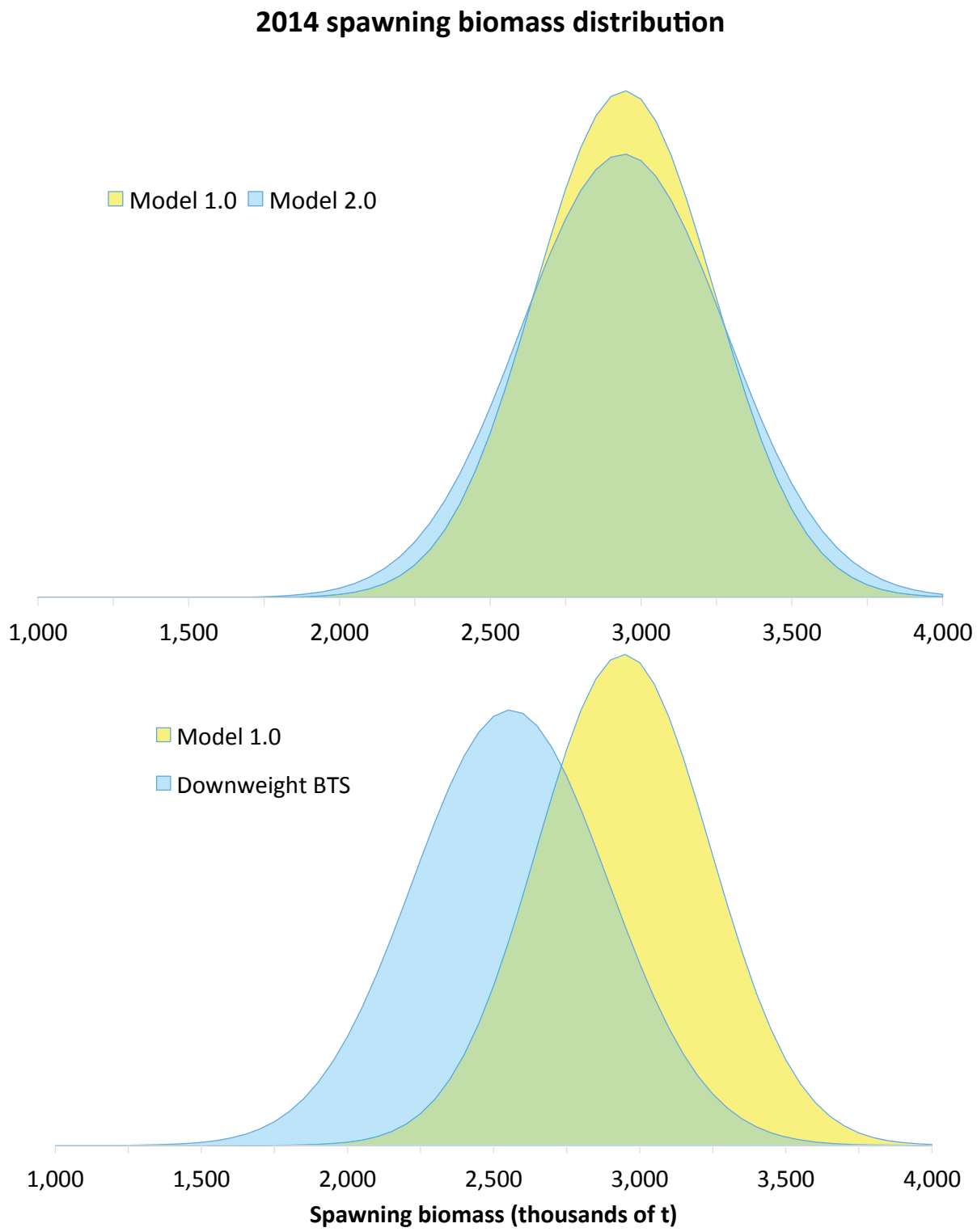

Figure 1.22. Approximate probability distributions for EBS 2014 pollock spawning biomass comparing model 1.0 (reference model) with 2.0 (model with efficiency adjusted data for the bottom trawl survey) and with a run where the BTS data area all downweighted (standard errors inflated by a factor of 100).

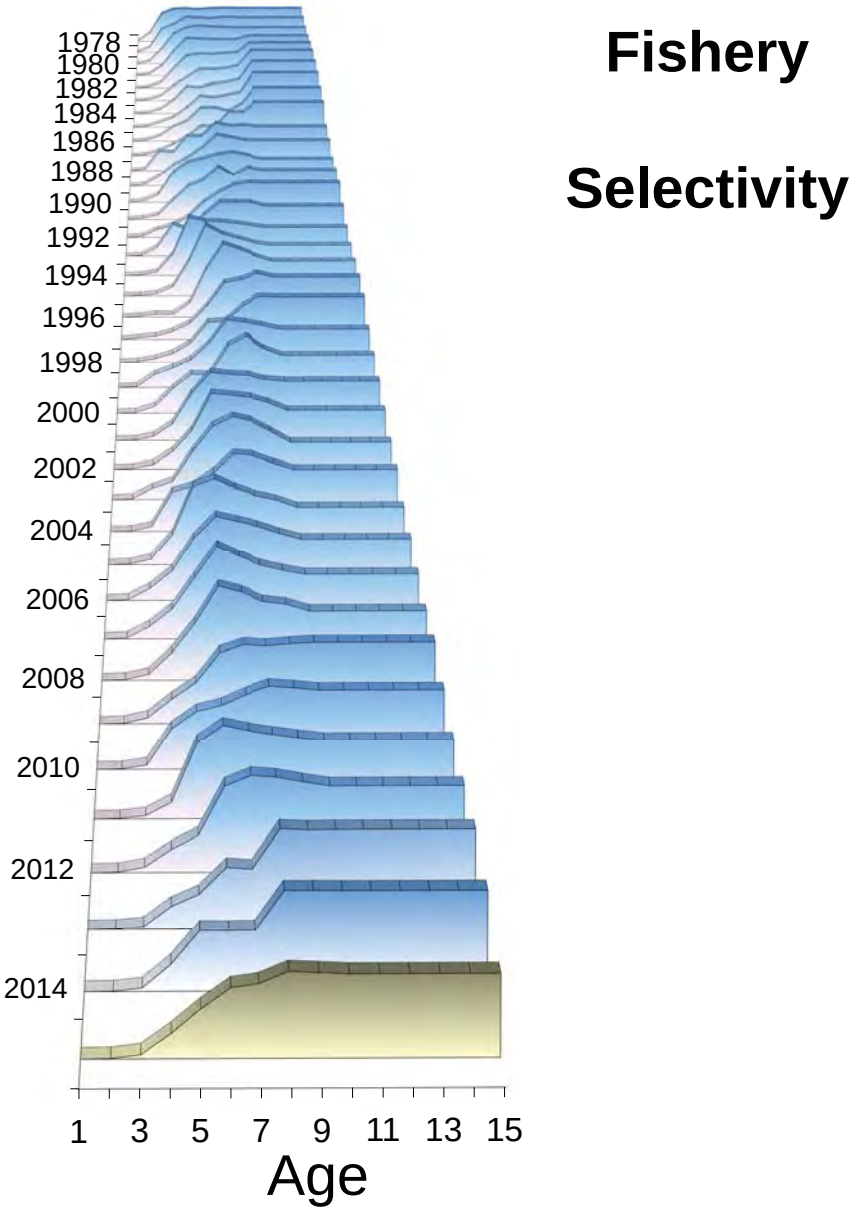

Figure 1.23. Selectivity at age estimates for the EBS pollock fishery, 1978-2014 including the estimates (front-most panel) used for the future yield considerations.

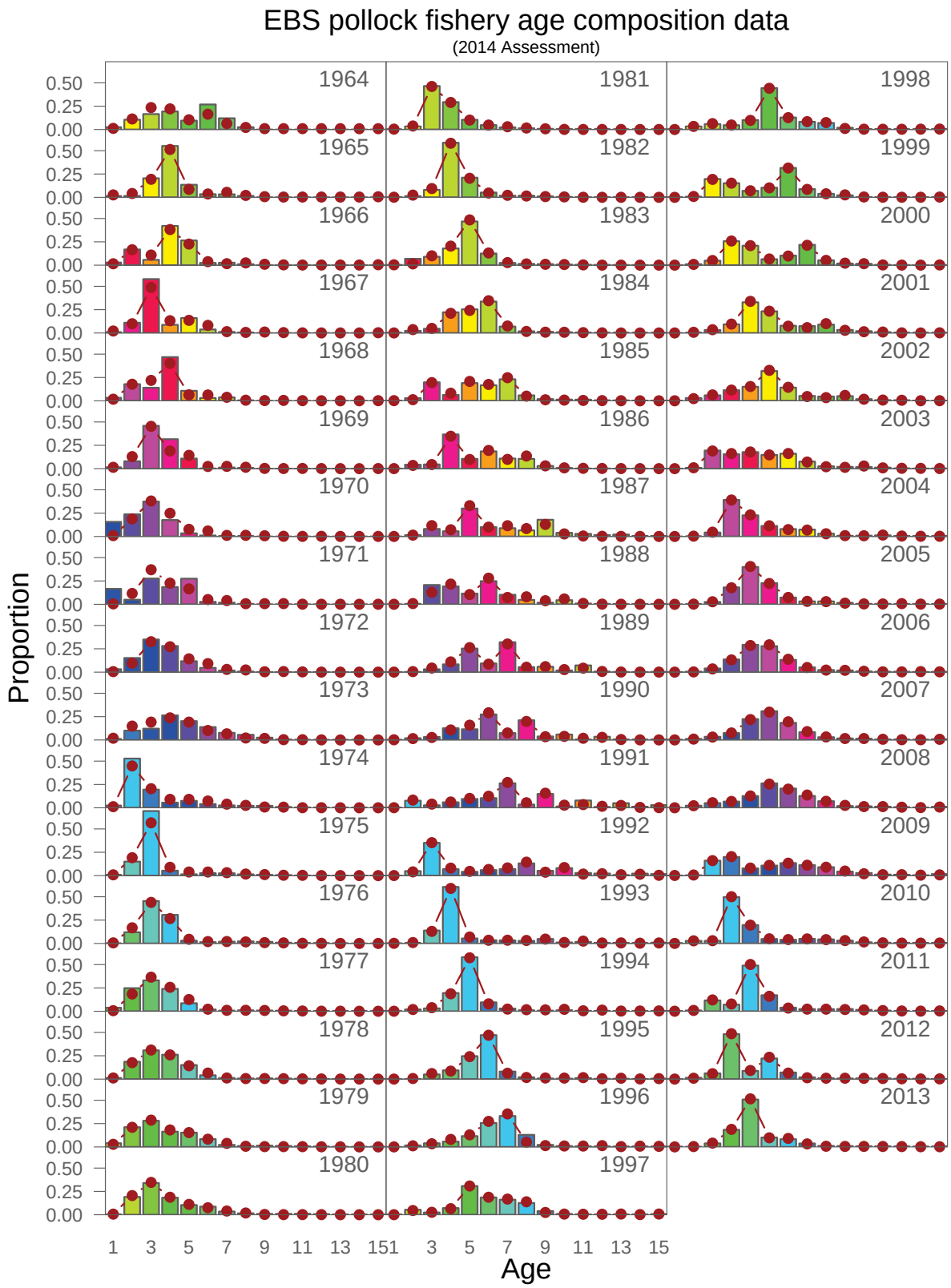

Figure 1.24. Model fit (dots) to the EBS pollock fishery proportion-at-age data (columns; 1964-2013). The 2013 data are new to this year's assessment. Colors coincide with cohorts progressing through time.

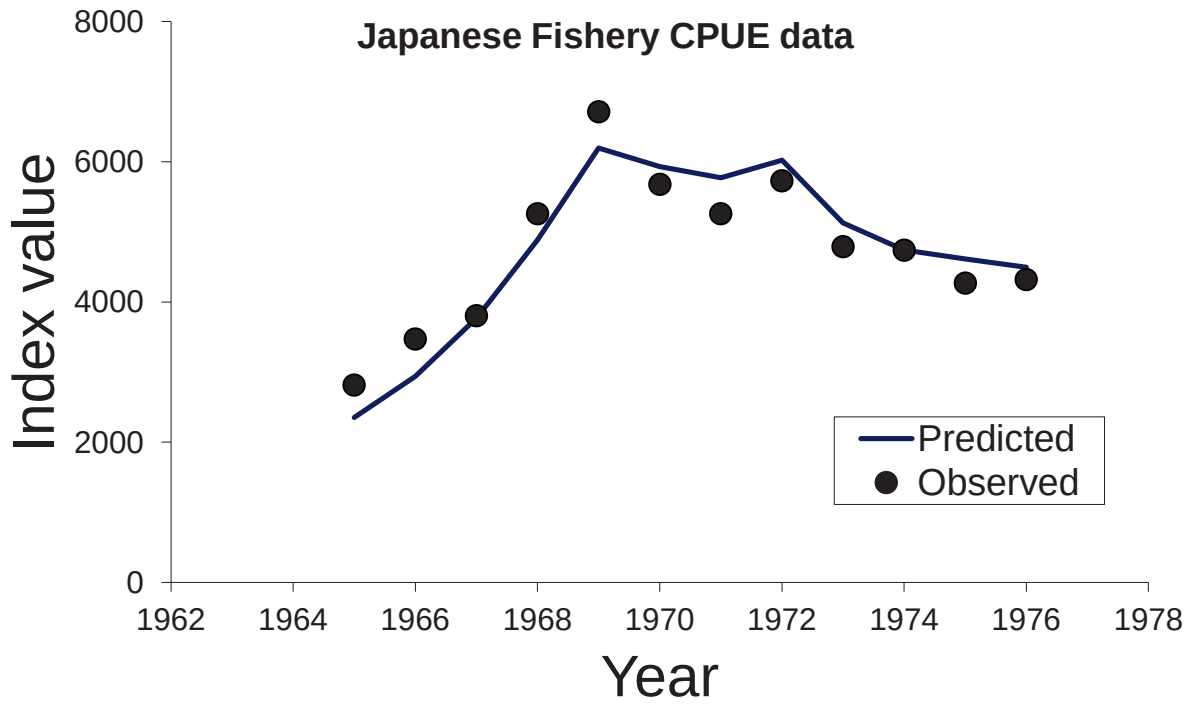

Figure 1.25. Japanese fishery CPUE (Low and Ikeda, 1980) model fits for EBS pollock, 1965-1976.

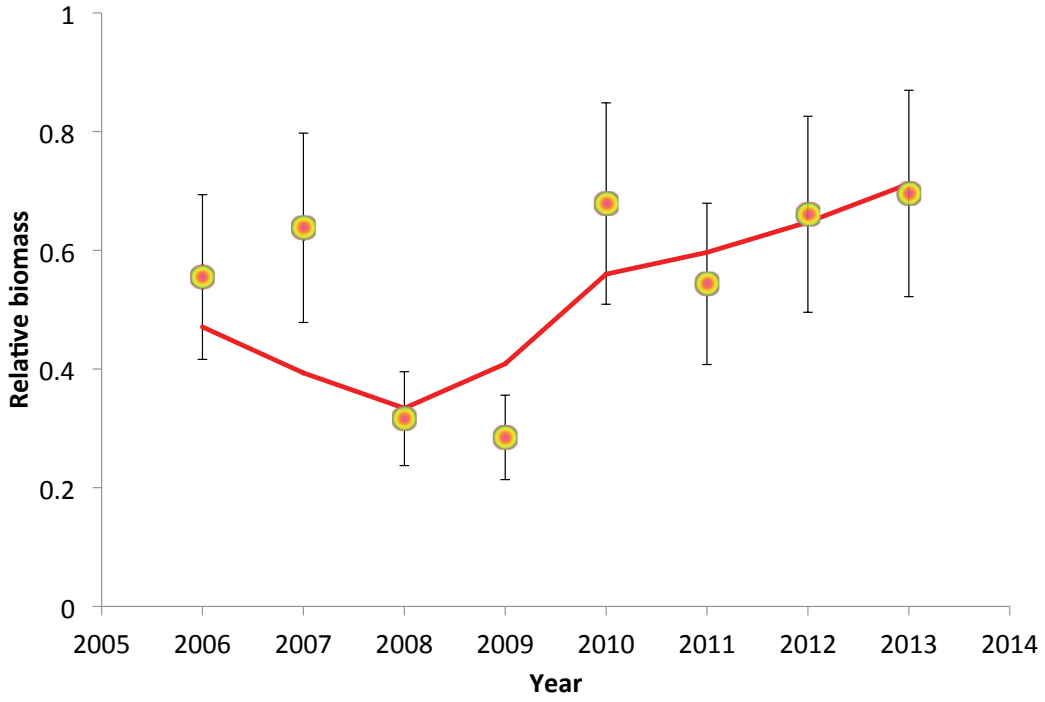

Figure 1.26. Model results of predicted EBS pollock biomass following the AVO index (under model 1.0). Error bars represent assumed 95% confidence bounds.

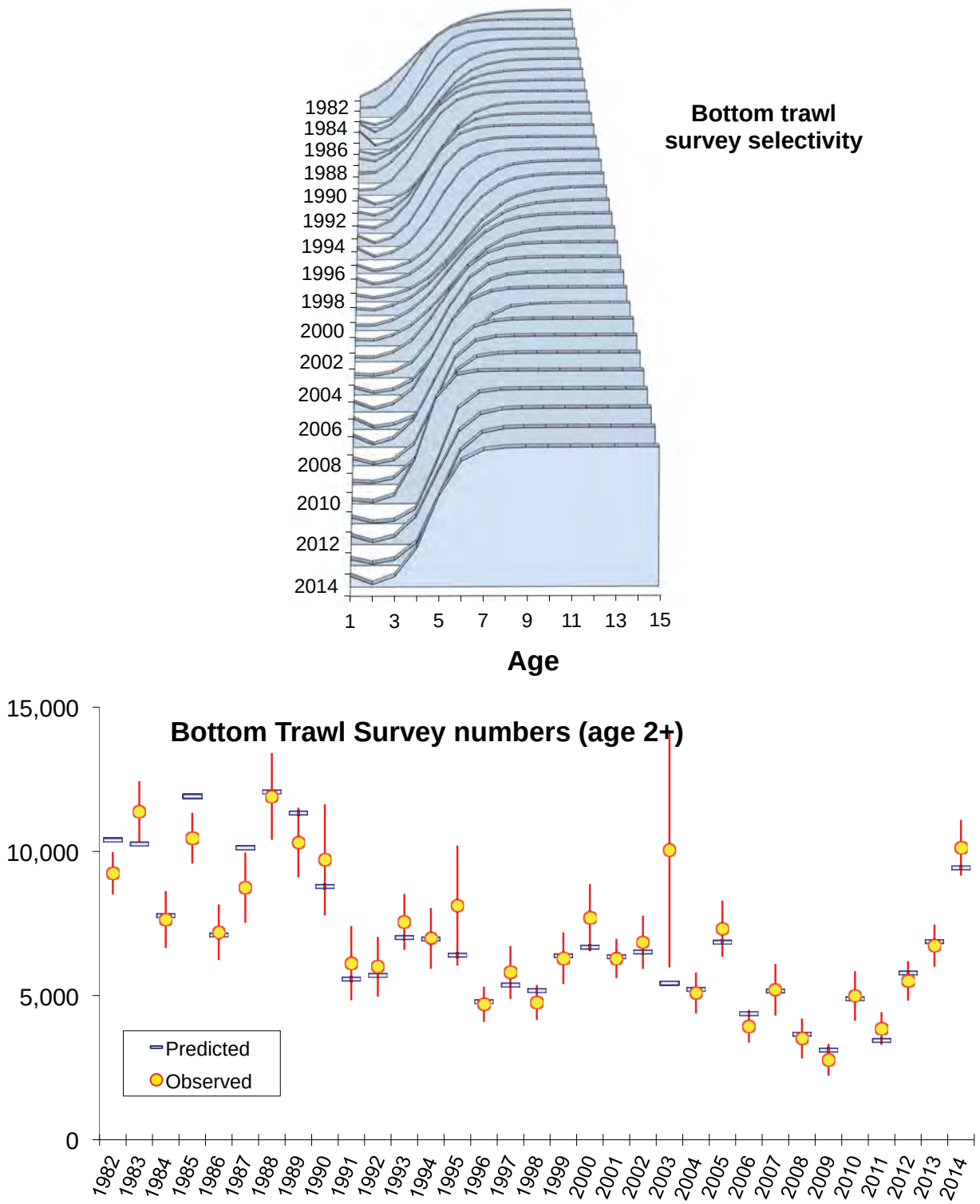

Figure 1.27. Estimates of bottom-trawl survey numbers (millions age 2 and older, lower panel) and selectivity-at-age (with maximum value equal to 1.0) over time (upper panel) for EBS pollock, 1982-2014.

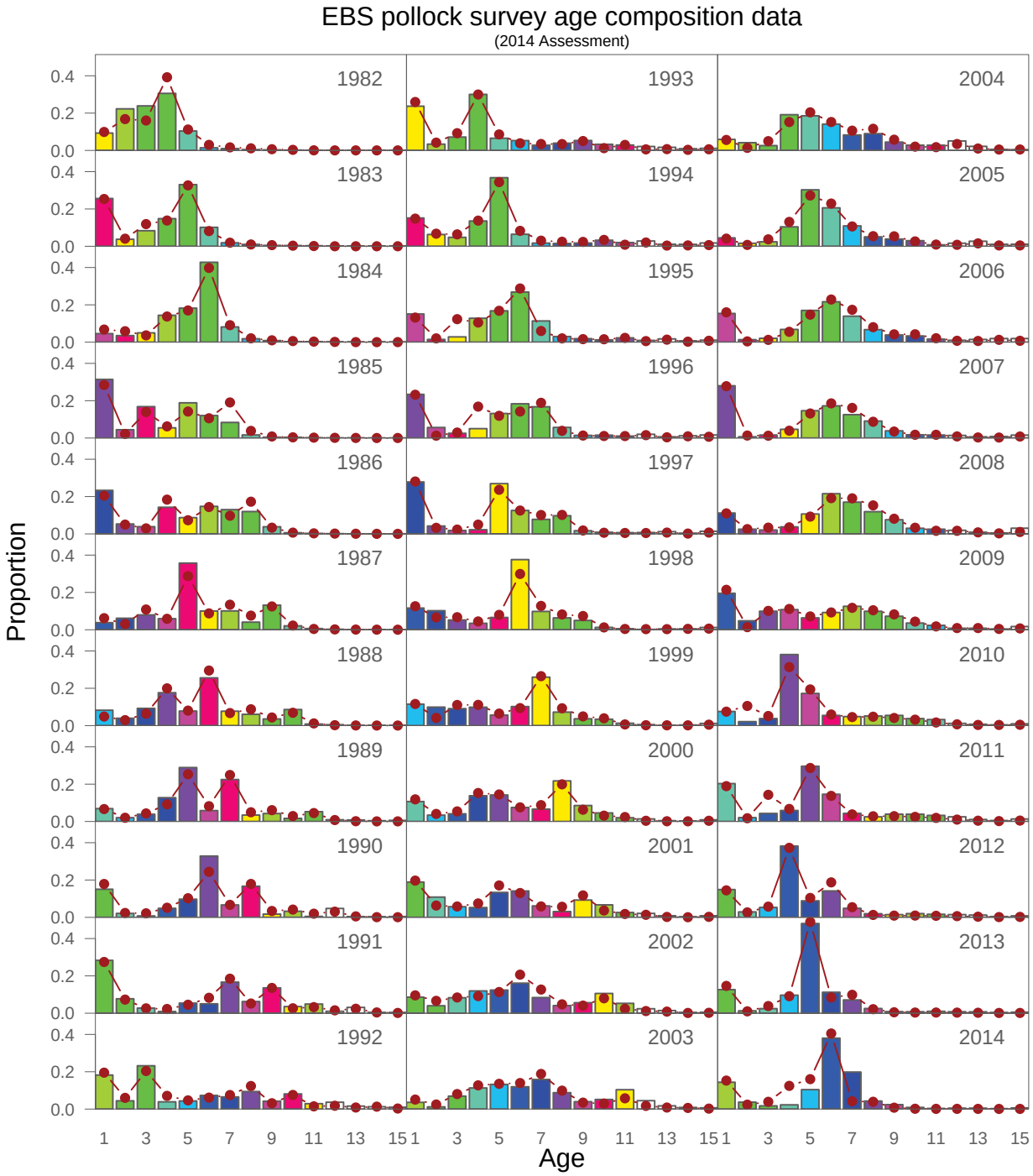

Figure 1.28. Model fit (dots) to the bottom trawl survey proportion-at-age composition data (columns) for EBS pollock. Colors correspond to cohorts over time. Data new to this assessment are from 2014.

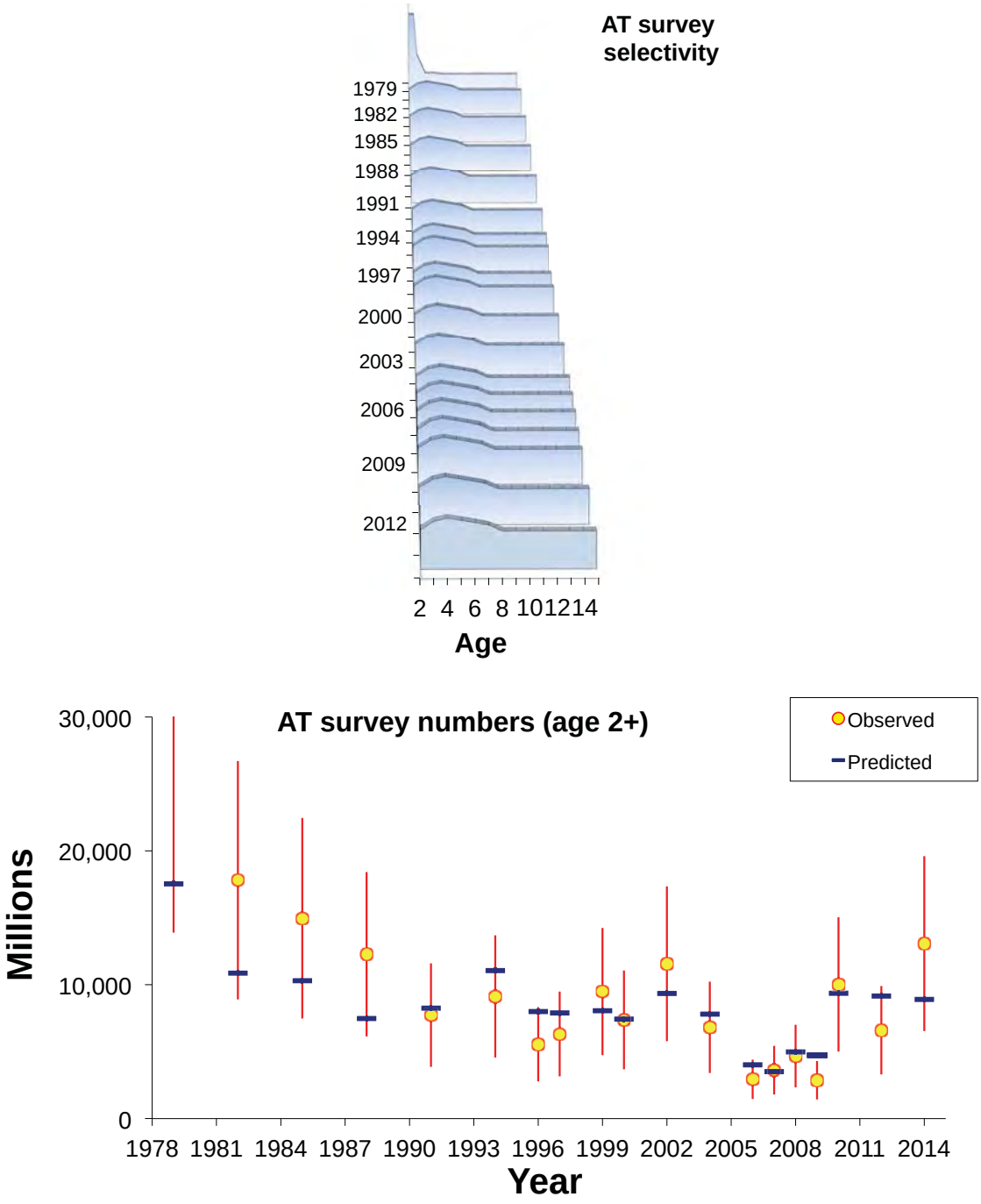

Figure 1.29. Estimates of AT survey numbers (lower panel) and selectivity-at-age (with mean value equal to 1.0) over time (upper panel) for EBS pollock age 2 and older, 1979-2014. Note that the 1979 observed value (=46,314) is off the scale of the figure.

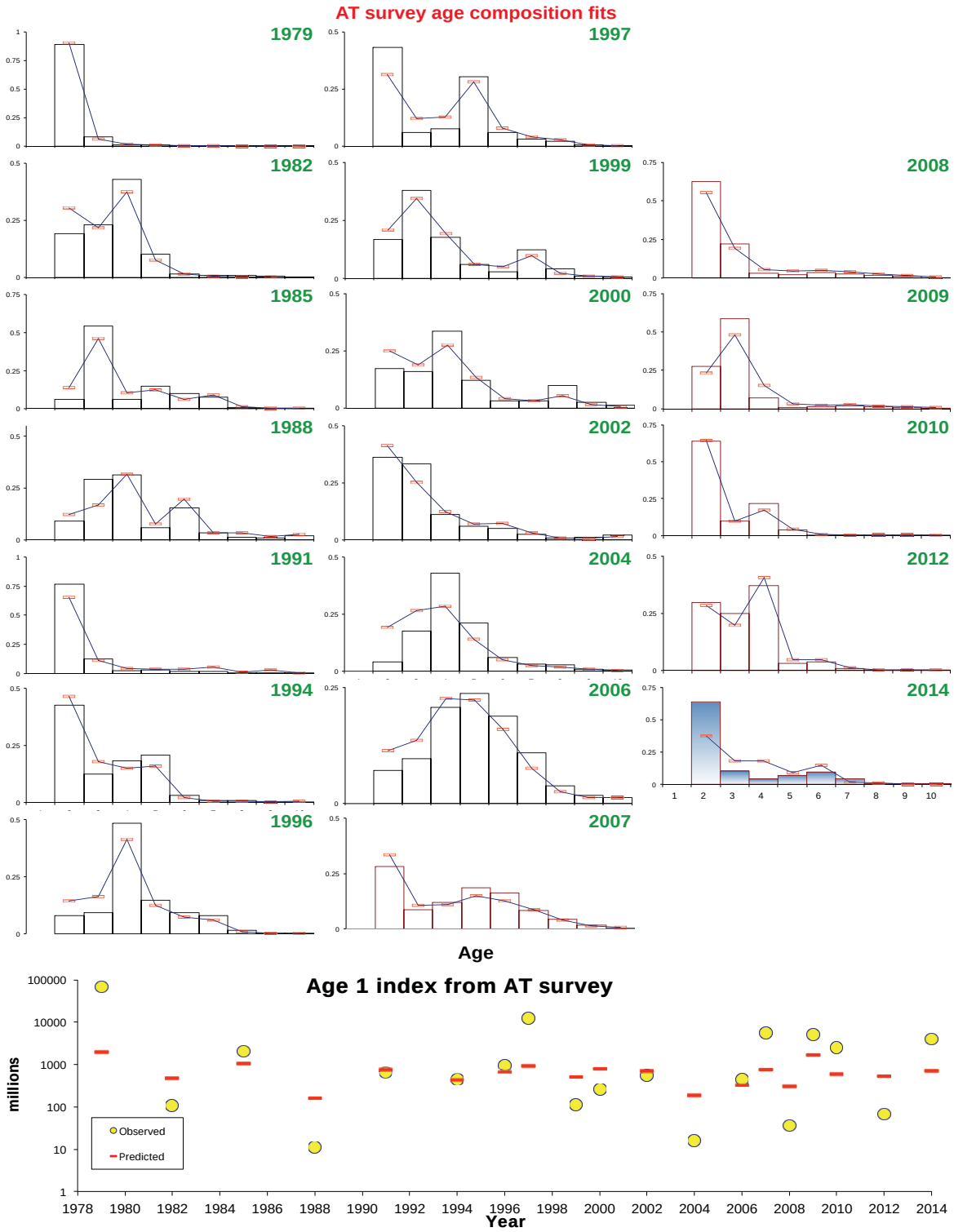

Figure 1.30. Fit to the AT survey EBS pollock age composition data (proportion of numbers) and age 1 index (bottom panel; log-scale). Lines represent model predictions while the vertical columns and dots represent data. The 2014 age composition data were based on using a bottom trawl survey age-length key, with some supplemental samples (juveniles) from the AT survey.

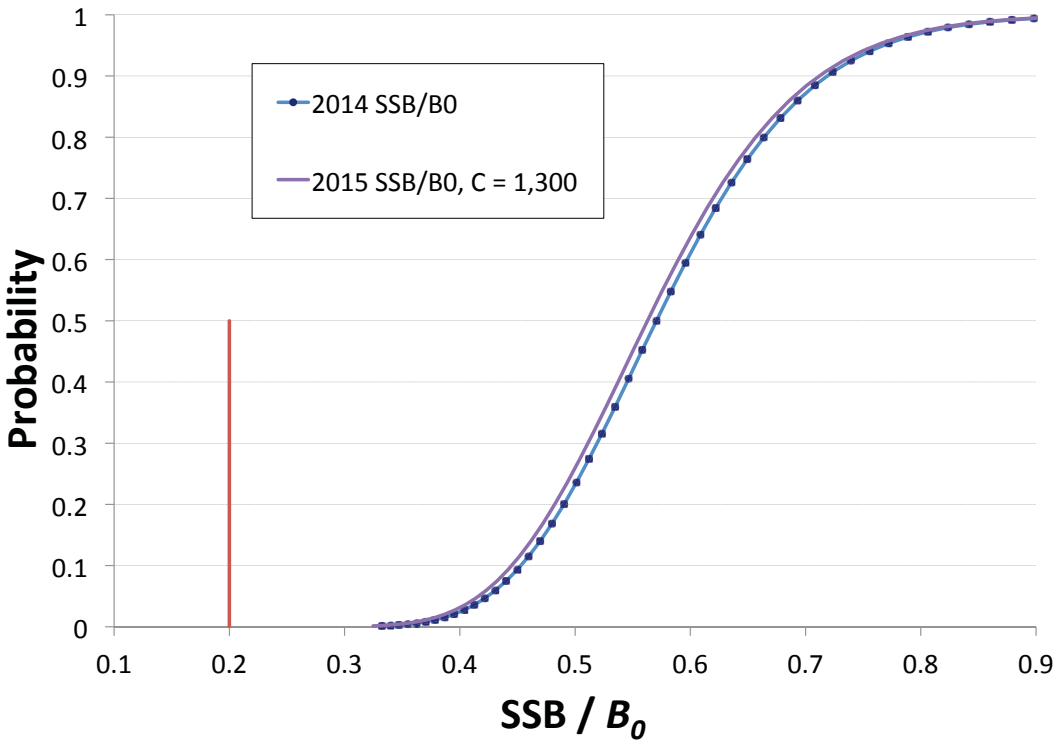

Figure 1.31. Estimated cumulative probability distribution of the 2014 and 2015 EBS pollock spawning biomass relative to B_0. C represents catch

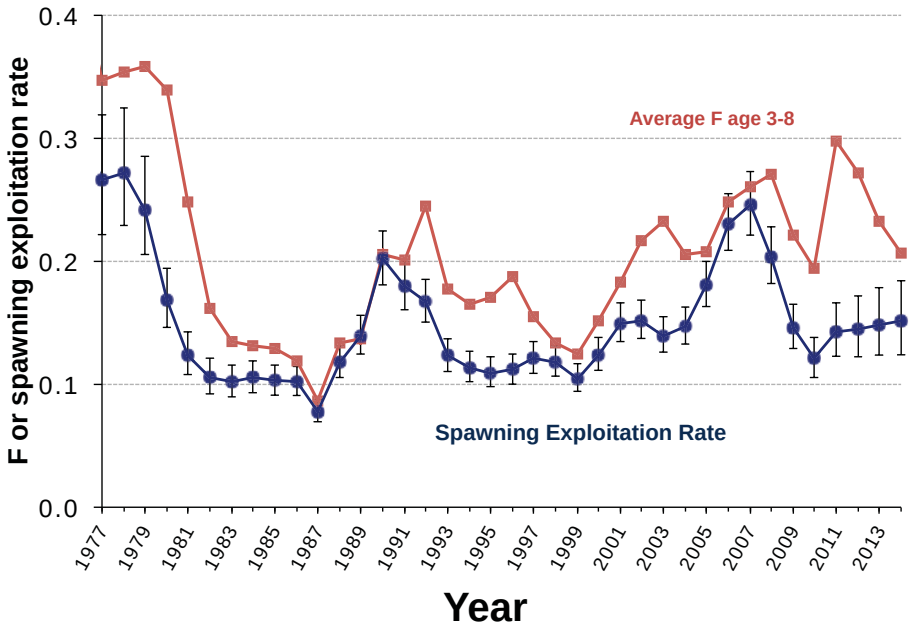

Figure 1.32. Estimated spawning exploitation rate (defined as the annual percent removals of spawning females due to the fishery) and average fishing mortality (ages 3-8) for EBS pollock, 1977-2014. Error bars represent two standard deviations from the estimates.

Year	2	3	4	5	6	7	8	9	10
1964	0.01	0.04	0.20	0.21	0.21	0.20	0.19	0.18	0.17
1965	0.01	0.05	0.20	0.19	0.17	0.16	0.15	0.15	0.14
1966	0.01	0.05	0.17	0.16	0.15	0.14	0.14	0.13	0.13
1967	0.03	0.16	0.24	0.24	0.23	0.23	0.23	0.22	0.22
1968	0.03	0.13	0.27	0.25	0.24	0.23	0.22	0.22	0.21
1969	0.03	0.18	0.23	0.22	0.20	0.20	0.20	0.20	0.22
1970	0.07	0.24	0.23	0.23	0.22	0.26	0.26	0.26	0.41
1971	0.07	0.28	0.32	0.35	0.34	0.33	0.34	0.34	0.65
1972	0.13	0.39	0.40	0.39	0.38	0.38	0.38	0.40	0.64
1973	0.17	0.45	0.52	0.52	0.52	0.51	0.51	0.51	0.67
1974	0.23	0.57	0.56	0.55	0.55	0.54	0.55	0.55	0.58
1975	0.11	0.54	0.50	0.47	0.46	0.45	0.45	0.45	0.52
1976	0.09	0.38	0.47	0.44	0.43	0.42	0.42	0.41	0.43
1977	0.11	0.29	0.35	0.37	0.36	0.36	0.35	0.35	0.35
1978	0.10	0.31	0.36	0.36	0.35	0.36	0.37	0.37	0.37
1979	0.06	0.26	0.32	0.40	0.39	0.38	0.40	0.39	0.39
1980	0.02	0.15	0.32	0.38	0.40	0.39	0.39	0.38	0.38
1981	0.01	0.07	0.20	0.31	0.30	0.30	0.30	0.30	0.33
1982	0.00	0.03	0.12	0.20	0.21	0.20	0.21	0.22	0.28
1983	0.00	0.03	0.09	0.14	0.19	0.18	0.19	0.21	0.30
1984	0.00	0.03	0.08	0.16	0.16	0.18	0.19	0.21	0.31
1985	0.01	0.03	0.06	0.12	0.19	0.18	0.20	0.21	0.33
1986	0.01	0.03	0.08	0.11	0.17	0.17	0.16	0.19	0.28
1987	0.00	0.02	0.04	0.07	0.11	0.11	0.16	0.16	0.20
1988	0.01	0.08	0.07	0.14	0.14	0.19	0.18	0.18	0.18
1989	0.01	0.04	0.09	0.12	0.16	0.21	0.20	0.19	0.19
1990	0.01	0.04	0.17	0.23	0.25	0.27	0.28	0.27	0.24
1991	0.01	0.03	0.12	0.21	0.24	0.33	0.28	0.33	0.31
1992	0.01	0.07	0.10	0.18	0.30	0.38	0.45	0.47	0.46
1993	0.00	0.04	0.16	0.13	0.20	0.27	0.27	0.27	0.25
1994	0.00	0.01	0.09	0.24	0.22	0.22	0.21	0.20	0.20
1995	0.00	0.01	0.04	0.15	0.31	0.27	0.25	0.23	0.22
1996	0.01	0.02	0.02	0.08	0.26	0.39	0.36	0.33	0.30
1997	0.01	0.02	0.04	0.09	0.18	0.30	0.31	0.35	0.32
1998	0.00	0.02	0.04	0.09	0.19	0.19	0.27	0.31	0.31
1999	0.00	0.04	0.06	0.09	0.14	0.21	0.21	0.20	0.18
2000	0.00	0.02	0.09	0.14	0.14	0.24	0.28	0.23	0.21
2001	0.00	0.02	0.07	0.19	0.28	0.27	0.27	0.25	0.24
2002	0.00	0.02	0.08	0.18	0.35	0.34	0.33	0.31	0.27
2003	0.00	0.05	0.08	0.21	0.33	0.37	0.35	0.30	0.25
2004	0.00	0.02	0.16	0.18	0.24	0.32	0.31	0.28	0.25
2005	0.00	0.02	0.11	0.28	0.31	0.28	0.25	0.23	0.21
2006	0.00	0.05	0.13	0.27	0.37	0.35	0.32	0.29	0.27
2007	0.00	0.05	0.13	0.27	0.41	0.37	0.33	0.30	0.29
2008	0.00	0.03	0.13	0.26	0.43	0.41	0.36	0.35	0.32
2009	0.00	0.03	0.11	0.18	0.31	0.35	0.34	0.35	0.36
2010	0.00	0.01	0.15	0.21	0.23	0.27	0.30	0.29	0.28
2011	0.00	0.02	0.08	0.38	0.46	0.44	0.42	0.40	0.38
2012	0.00	0.02	0.11	0.17	0.41	0.46	0.45	0.43	0.41
2013	0.00	0.01	0.11	0.17	0.31	0.30	0.49	0.49	0.49
2014	0.00	0.01	0.11	0.24	0.24	0.24	0.40	0.40	0.40
5-yr Avera	**0.00**	**0.02**	**0.11**	**0.23**	**0.33**	**0.34**	**0.41**	**0.40**	**0.39**
5-yr Max	**0.00**	**0.02**	**0.15**	**0.38**	**0.46**	**0.46**	**0.49**	**0.49**	**0.49**
5-yr Min	**0.00**	**0.01**	**0.08**	**0.17**	**0.23**	**0.24**	**0.30**	**0.29**	**0.28**

Figure 1.33. Estimated instantaneous age-specific fishing mortality rates for EBS pollock, 1964-2014. (note that these are the continuous form of fishing mortality rate as specified in Eq. 1; colors correspond to low (green) and high (red) values).

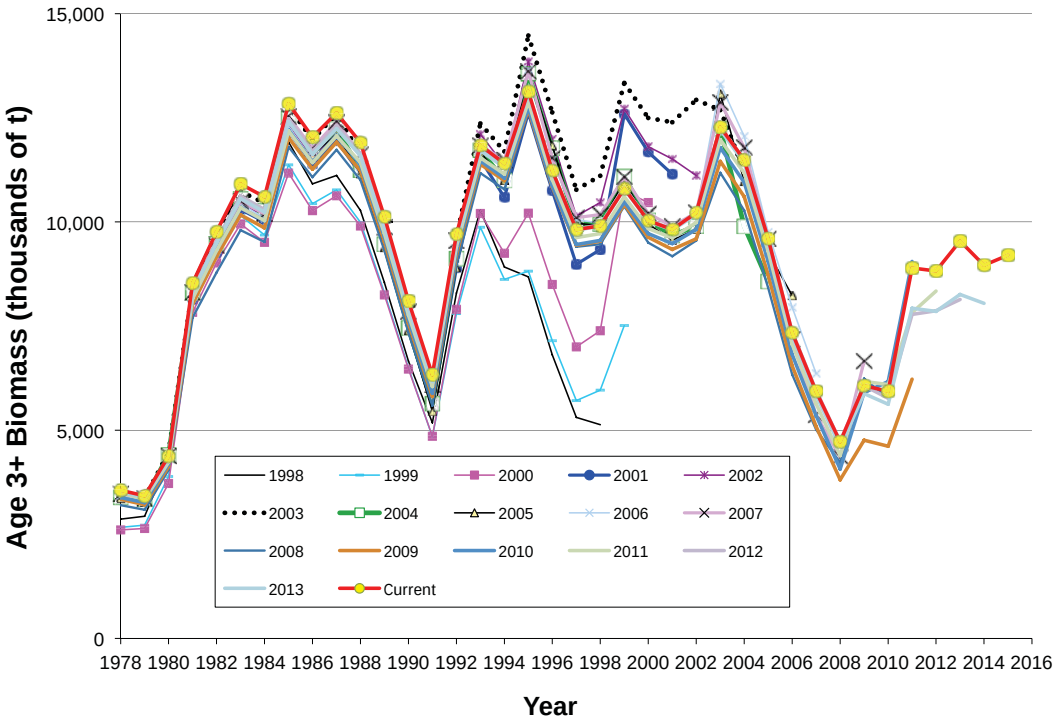

Figure 1.34. Comparison of the current assessment results with past assessments of **begin-year** EBS age-3+ pollock biomass, 1978-2015.

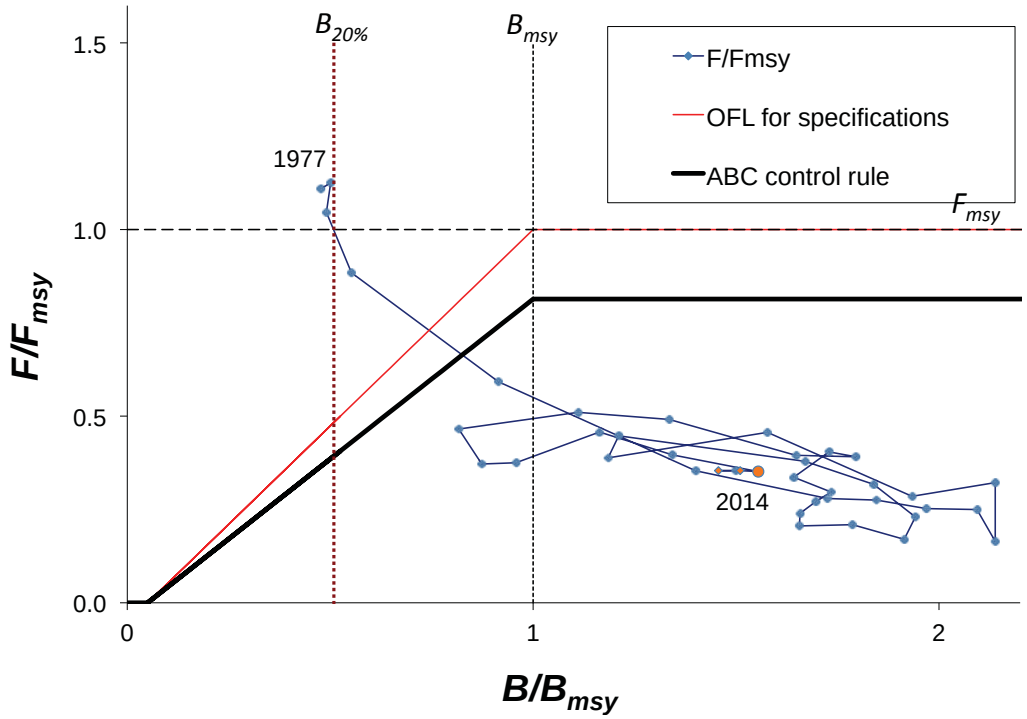

Figure 1.35. Estimated spawning biomass relative to annually estimated F_{MSY} values and fishing mortality rates for EBS pollock, 1977-2014 (plus 2015 and 2016 in highlighted dots). *Note that the control rules for OFL and ABC are designed for setting specifications in future years.*

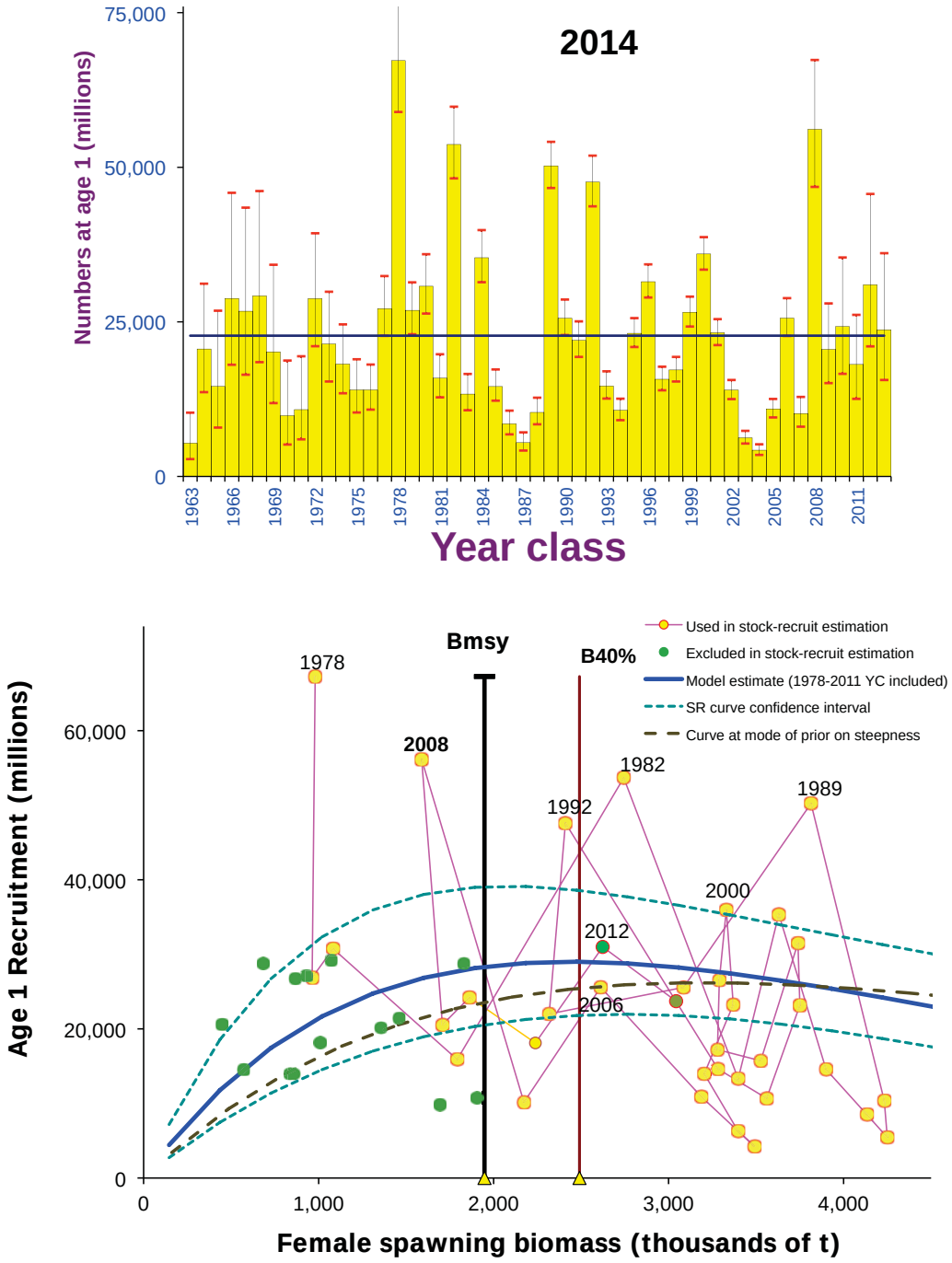

Figure 1.36. Year-class strengths by year (as age-1 recruits, upper panel) and relative to female spawning biomass (thousands of tons, lower panel) for EBS pollock. Labels on points correspond to year classes labels (measured as one-year olds). Solid line in upper panel represents the mean age-1 recruitment for all years since 1964 (1963-2013 year classes). Vertical lines in lower panel indicate B_{MSY} and $B_{40\%}$ level, curve represents fitted stock-recruitment relationship with dashed lines representing approximate lower and upper 95% confidence limits about the estimated curve.

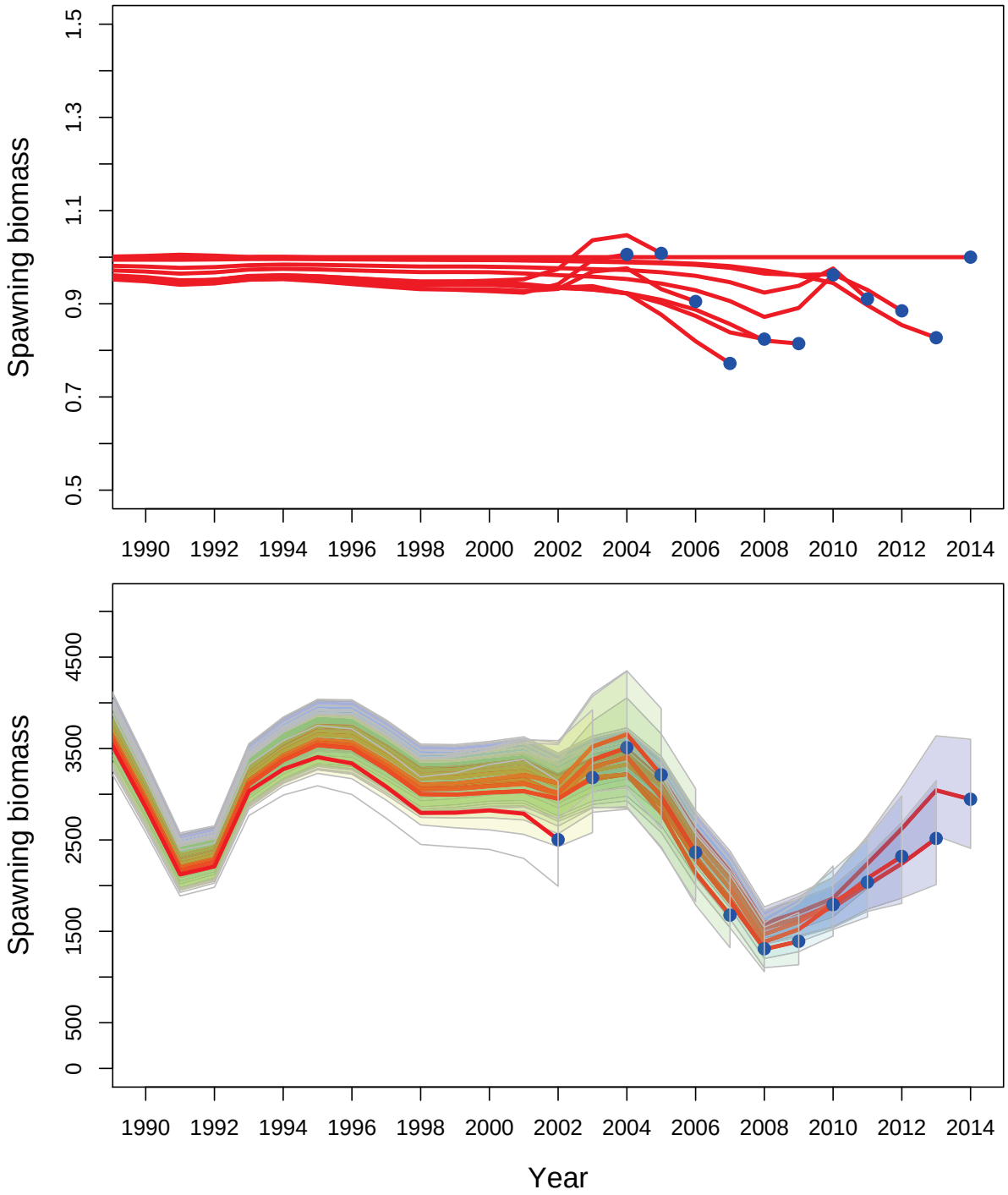

Figure 1.37. Retrospective patterns of model 1 for EBS pollock spawning in retrospective year for 2002-2014 showing the point estimates relative to the terminal year (top panel) and approximate confidence bounds on absolute scale (±2 standard deviations; bottom panel). Mohn's rho was estimated at -0.11 for the 10-year period.

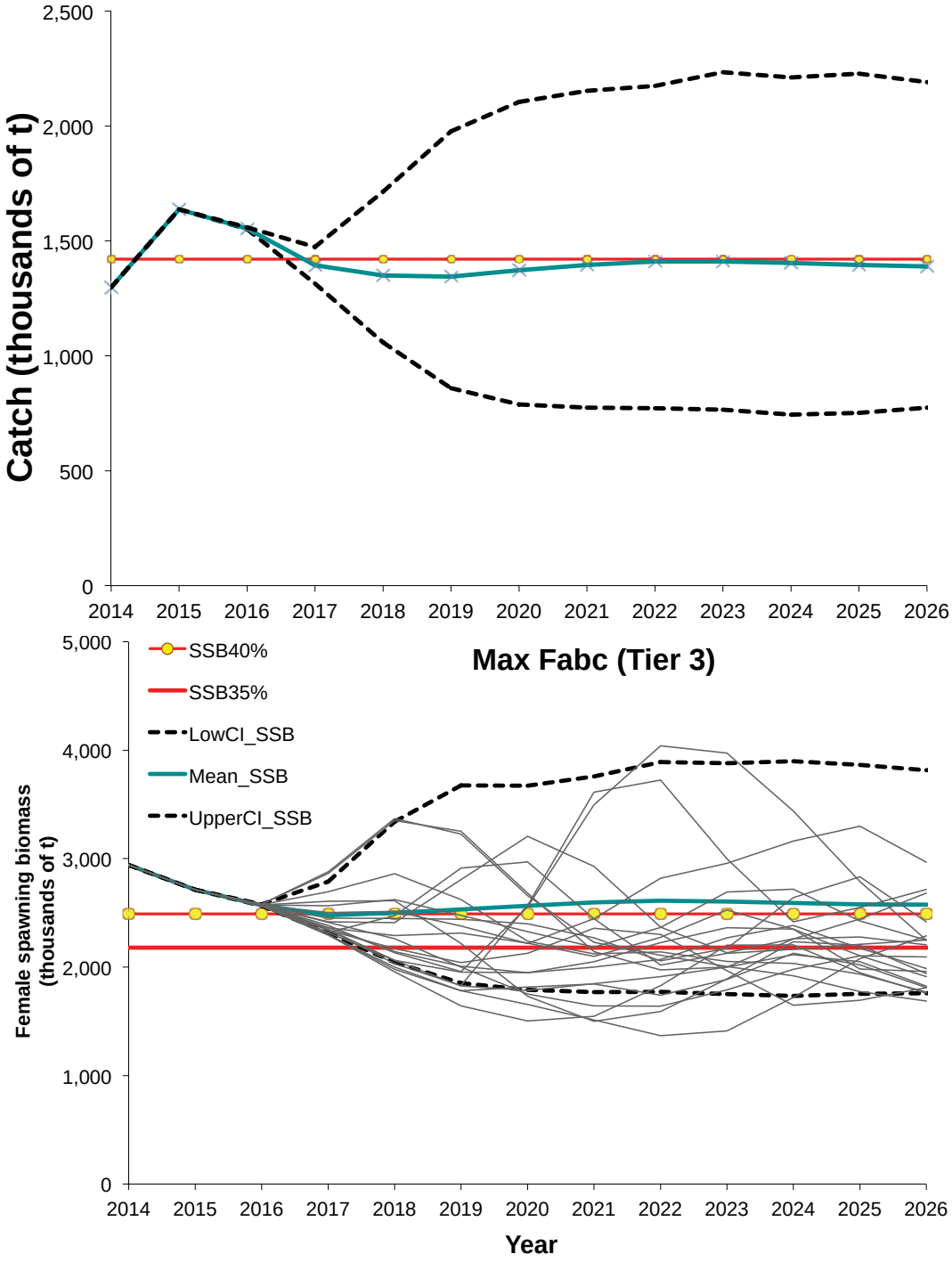

Figure 1.38. Projected EBS **Tier 3** pollock **yield** (top) and **female spawning biomass** (bottom) relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines). $B_{40\%}$ is computed from average recruitment from 1978-2012. Future harvest rates follow the guidelines specified under Tier 3 Scenario 1. The grey lines represent a sub-sample of simulated trajectories. Note that the numbers at age 2 in 2014 were set to their median value.

Model details

An explicit age-structured model with the catch equation and population dynamics model as described in Fournier and Archibald (1982) and elsewhere (Hilborn and Walters 1992, Schnute and Richards 1995, McAllister and Ianelli 1997). Catch in numbers at age in year t ($C_{t,a}$) and total catch biomass (Y_t) were

$$
\begin{aligned}
C_{t,a} &= \frac{F_{t,a}}{Z_{t,a}}\left(1-e^{-Z_{a,t}}\right)N_{t,a}, \qquad 1 \le t \le T \quad 1 \le a \le A \\
N_{t+1,a+1} &= N_{t,a}e^{-Z_{t,a}} \qquad 1 \le t \le T \quad 1 \le a < A \\
N_{t+1,A} &= N_{t,A-1}e^{-Z_{t,A-1}} + N_{t,A}e^{-Z_{t,A}} \quad 1 \le t \le T \\
Z_{t,a} &= F_{t,a} + M_{t,a} \\
C_{t\cdot} &= \sum_{a=1}^{A} C_{t,a} \\
p_{t,a} &= C_{t,a}/C_{t\cdot} \\
Y_t &= \sum_{a=1}^{A} w_a C_{t,a} \text{ , and}
\end{aligned}
\qquad \text{..... (Eq. 1)}
$$

where

T is the number of years,

A is the number of age classes in the population,

$N_{t,a}$ is the number of fish age a in year t,

$C_{t,a}$ is the catch of age class a in year t,

$p_{t,a}$ is the proportion of the total catch in year t, that is in age class a,

C_t is the total catch in year t,

w_a is the mean body weight (kg) of fish in age class a,

Y_t is the total yield biomass in year t,

$F_{t,a}$ is the instantaneous fishing mortality for age class a, in year t,

M_{ta} is the instantaneous natural mortality in year t for age class a, and

Z_{ta} is the instantaneous total mortality for age class a, in year t.

We reduced the freedom of the parameters listed above by restricting the variation in the fishing mortality rates ($F_{t,a}$) following Butterworth et al. (2003) by assuming that

$$F_{t,a} = s_{t,a}\mu^f e^{\varepsilon_t} \quad \varepsilon_t \sim N\left(0, \sigma_E^2\right) \qquad \text{..... (Eq. 2)}$$

$$S_{t+1,a} = s_{t,a}e^{\gamma_t} \quad \gamma_t \sim N\left(0, \sigma_s^2\right) \qquad \text{..... (Eq. 3)}$$

where $s_{t,a}$ is the selectivity for age class a in year t, and μ^f is the median fishing mortality rate over time.

If the selectivities ($s_{t,a}$) are constant over time then fishing mortality rate decomposes into an age component and a year component. This assumption creates what is known as a separable model. If selectivity in fact changes over time, then the separable model can mask important changes in fish abundance. In our analyses, we constrain the variance term s_s^2 to allow selectivity to change slowly over time–thus improving our ability to estimate γ_t. Also, to provide regularity in the age component, we placed a curvature penalty on the selectivity coefficients using the squared second-differences. We selected a simple random walk as our time-series effect on these quantities. Prior assumptions about the

relative variance quantities were made. For example, we assume that the variance of transient effects (e.g., s_E^2) is large to fit the catch biomass precisely. Perhaps the largest difference between the model presented here and those used for other groundfish stocks is in how we model selectivity of both the fishery and survey gear types. The approach taken here assumes that large differences between a selectivity coefficient in a given year for a given age should not vary too much from adjacent years and ages (unless the data suggest otherwise, e.g., Lauth et al. 2004). The magnitude of these changes is determined by the prior variances as presented above. For the application here selectivity is allowed to change in each year. The basis for this model specification was to better account for the high levels of sampling and to avoid over-simplifying real changes in age-specific fishing mortality. The mean selectivity going forward for projections and ABC deliberations is the simple mean of the estimates from 2010-2014.

Bottom-trawl survey selectivity was set to be asymptotic yet retain the properties desired for the characteristics of this gear. Namely, that the function should allow flexibility in selecting age 1 pollock over time. The functional form of this selectivity is:

$$
\begin{aligned}
s_{t,a} &= \left[1 + e^{-\alpha_t\ a-\beta_t}\ \right]^{-1},\ a > 1 \\
s_{t,a} &= \mu_s e^{\delta_t^{\mu}},\qquad\qquad a = 1 \\
\alpha_t &= \bar{\alpha} e^{\delta_t^{\alpha}} \\
\beta_t &= \bar{\beta} e^{\delta_t^{\beta}}
\end{aligned}
\qquad \text{..... (Eq. 4)}
$$

where the parameters of the selectivity function follow a random walk process as in Dorn et al. (2000):

$$
\begin{aligned}
\delta_t^{\mu} - \delta_{t+1}^{\mu} &\sim N\ 0, \sigma_{\delta^{\mu}}^2 \\
\delta_t^{\alpha} - \delta_{t+1}^{\alpha} &\sim N\ 0, \sigma_{\delta^{\alpha}}^2 \\
\delta_t^{\beta} - \delta_{t+1}^{\beta} &\sim N\ 0, \sigma_{\delta^{\beta}}^2
\end{aligned}
\qquad \text{..... (Eq. 5)}
$$

The parameters to be estimated in this part of the model are thus $\bar{\alpha}, \bar{\beta}, \delta_t^{\mu}, \delta_t^{\alpha}, \text{and } \delta_t^{\beta}$ for t=1982, 1983,…2014. The variance terms for these process-error parameters were specified to be 0.04.

For the natural mortality-at-age options, we followed the Lorenzen (1996) equation:

$$M_a = 3.69 \bar{W}_a^{-0.305}$$

and for the Gislason et al. (2010) :

$$\ln M_a = 0.55 - 1.61 \ln L_a + 1.44 \ln L_{\infty} + \ln K$$

with L_{∞}, K equal to 706 mm and K equal to 0.1757.

In 2008 the AT survey selectivity approach was modified. As an option, the age one pollock observed in this trawl can be treated as an index and are not considered part of the age composition (which then ranges from age 2-15). This was done to improve some interaction with the flexible selectivity smoother that is used for this gear and was compared. Additionally, the annual specification of input sigmas was allowed for the AT data. This allowed better flexibility for this survey that occurs at irregular intervals and reduces the number of parameters estimated (previously, the random walk penalty occurred for every year regardless of whether a survey occurred).

A diagnostic approach to evaluate input variance specifications (via sample size under multinomial assumptions) was added in this assessment. This method uses residuals from mean ages together with the

concept that the sample variance of mean age (from a given annual data set) varies inversely with input sample size. It can be shown that for a given set of input proportions at age (up to the maximum age A) $p_{a,i}$ and sample size N_i for year i, an adjustment factor f for input sample size can be computed when compared with the assessment model predicted proportions at age ($\hat{p}_{ij}$) and model predicted mean age ($\hat{\bar{a}}$):

$$f = \mathrm{var}\left(r_i^a \sqrt{\frac{N_i}{s_i}} \right)^{-1}$$

$$r_i^a = \bar{a}_i - \hat{\bar{a}}_i$$

$$s_i = \left[\sum_j^A \bar{a}_i^2 p_{ij} - \hat{\bar{a}}_i^2 \right]^{0.5} \quad \text{..... (Eq. 6)}$$

where r_i^a is the residual of mean age and

$$\hat{\bar{a}}_i = \sum_j^A j\hat{p}_{ij}, \qquad \bar{a}_i = \sum_j^A j p_{ij} \quad \text{..... (Eq. 7)}$$

For this assessment, we use the above relationship as a diagnostic for evaluating input sample sizes by comparing model predicted mean ages with observed mean ages and the implied 95% confidence bands. This method provided support for modifying the frequency of allowing selectivity changes (e.g., Fig. 1.39).

Recruitment

In these analyses, recruitment (R_t) represents numbers of age-1 individuals modeled as a stochastic function of spawning stock biomass. A further modification made in Ianelli et al. (1998) was to have an environmental component to account for the differential survival attributed to larval drift (e.g., Wespestad et al. 2000). (k_t):

$$R_t = f(B_{t-1}) e^{k_t + t_t}, \qquad t_t \sim N\left(0, s_R^2\right) \quad \text{..... (Eq. 8)}$$

with mature spawning biomass during year t was defined as:

$$B_t = \sum_{a=1}^{15} w_a f_a N_{at} \quad \text{..... (Eq. 9)}$$

and f_a, the proportion of mature females at age is as shown in the sub-section titled Natural mortality and maturity at age under Parameters estimated independently above.

A reparameterized form for the stock-recruitment relationship following Francis (1992) was used. For the *optional* Beverton-Holt form (the Ricker form presented in Eq. 12 was adopted for this assessment) we have:

$$R_t = f(B_{t-1}) = \frac{B_{t-1} e^{e_t}}{a + b B_{t-1}} \quad \text{..... (Eq. 10)}$$

where

R_t is recruitment at age 1 in year t,

B_t is the biomass of mature spawning females in year t,

e_t is the recruitment anomaly for year t,

α, β are stock-recruitment function parameters.

Values for the stock-recruitment function parameters α and β are calculated from the values of R_0 (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the steepness of the stock-recruit relationship (h). The steepness is the fraction of R_0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992), so that:

$$\alpha = \tilde{B}_0 \frac{1-h}{4h}$$
$$\beta = \frac{5h-1}{4hR_0}$$

..... (Eq. 11)

where

$\tilde{B}_0$ is the total egg production (or proxy, e.g., female spawning biomass) in the absence of exploitation (and recruitment variability) expressed as a fraction of R_0.

Some interpretation and further explanation follows. For steepness equal 0.2, then recruits are a linear function of spawning biomass (implying no surplus production). For steepness equal to 1.0, then recruitment is constant for all levels of spawning stock size. A value of h = 0.9 implies that at 20% of the unfished spawning stock size will result in an expected value of 90% unfished recruitment level. Steepness of 0.7 is a commonly assumed default value for the Beverton-Holt form (e.g., Kimura 1988). The prior distribution for steepness used a beta distribution as in Ianelli et al. (2001) is shown in Fig. 1.40. The prior on steepness was specified to be a symmetric form of the Beta distribution with alpha=beta=14.93 implying a prior mean of 0.6 and CV of 12% (implying that there is about an 8% chance that the steepness is greater than 0.7). This conservative prior is consistent with previous years' application and serves to constrain the stock-recruitment curve from favoring steep slopes (uninformative priors result in F_{MSY} values near an F_{SPR} of about $F_{18\%}$, a value considerably higher than the default proxy of $F_{35\%}$). The residual pattern for the post-1977 recruits used in fitting the curve with a more diffuse prior resulted in all estimated recruits being below the curve for stock sizes less than B_{MSY} (except for the 1978 year class). We believe this to be driven primarily by the apparent negative-slope for recruits relative to stock sizes above B_{MSY} and as such, provides a potentially unrealistic estimate of productivity at low stock sizes. This prior was elicited from the rationale that residuals should be reasonably balanced throughout the range of spawning stock sizes. Whereas this is somewhat circular (i.e., using data for prior elicitation), the point here is that residual patterns (typically ignored in these types of models) are being qualitatively considered.

In past years the value of s_R was fixed at 0.9. In 2013 an iterative approach to estimating the value was adopted which involved the following steps:

1) Estimate the recruitment variability about the stock recruitment with negligible constraint, and compute the resulting standard deviation of the residuals, σ_{R_u} (which results in a value of 0.731)
2) Estimate the value of stock recruitment variability within the model (σ_{R_E} = 0.598)
3) Compute the approximate value of specified variability as $\sigma_R = \sqrt{\sigma_{R_u}^2 - \sigma_{R_E}\left(\sigma_{R_u} - \sigma_{R_E}\right)}$ which results in a value of 0.674; preliminary results with this value results in unreasonably high estimated productivity from the stock-recruit curve. Further analysis are required to ascertain whether the impact on stock productivity would lead to robust management measures.

To have the critical value for the stock-recruitment function (steepness, h) on the same scale for the Ricker model, we begin with the parameterization of Kimura (1990):

$$R_t = f\left(B_{t-1}\right) = B_{t-1} e^{a\left(1 - B_{t-1}/j_0 R_0\right)} / j_0 \quad \text{(Eq. 12)}$$

It can be shown that the Ricker parameter a maps to steepness as:

$$h = \frac{e^a}{e^a + 4} \quad \text{(Eq. 13)}$$

so that the prior used on h can be implemented in both the Ricker and Beverton-Holt stock-recruitment forms. Here the term j_0 represents the equilibrium unfished spawning biomass per-recruit.

Diagnostics

In 2006 a replay feature was added where the time series of recruitment estimates from a particular model is used to compute the subsequent abundance expectation had no fishing occurred. These recruitments are adjusted from the original estimates by the ratio of the expected recruitment given spawning biomass (with and without fishing) and the estimated stock-recruitment curve. I.e., the recruitment under no fishing is modified as:

$$R_t' = \hat{R}_t \frac{f\left(S_t'\right)}{f\left(\hat{S}_t\right)} \quad \text{(Eq. 14)}$$

where $\hat{R}_t$ is the original recruitment estimate in year t with $f\left(S_t'\right)$ and $f\left(\hat{S}_t\right)$ representing the stock-recruitment function given spawning biomass under no fishing and under the fishing scenario, respectively.

The assessment model code allows retrospective analyses (e.g., Parma 1993, and Ianelli and Fournier 1998). This was designed to assist in specifying how spawning biomass patterns (and uncertainty) have changed due to new data. The retrospective approach simply uses the current model to evaluate how it may change over time with the addition of new data based on the evolution of data collected over the past several years.

Parameter estimation

The objective function was simply the sum of the negative log-likelihood function and logs of the prior distributions. To fit large numbers of parameters in nonlinear models it is useful to be able to estimate certain parameters in different stages. The ability to estimate stages is also important in using robust likelihood functions since it is often undesirable to use robust objective functions when models are far from a solution. Consequently, in the early stages of estimation we use the following log-likelihood function for the survey and fishery catch at age data (in numbers):

$$f = n \cdot \sum_{a,t} p_{at} \ln \hat{p}_{at} \quad ,$$

$$p_{at} = \frac{O_{at}}{\sum_{a} O_{at}}, \qquad \hat{p}_{at} = \frac{\hat{C}_{at}}{\sum_{a} \hat{C}_{at}}$$

$$\hat{C} = C \cdot E_{ageing}$$

$$E_{ageing} = \begin{pmatrix} b_{1,1} & b_{1,2} & b_{1,3} & \cdots & b_{1,15} \\ b_{2,1} & b_{2,2} & & & \\ b_{3,1} & & \ddots & & \\ \vdots & & & \ddots & \\ b_{15,2} & & & & b_{15,15} \end{pmatrix}$$

..... (Eq. 15)

where A, and T, represent the number of age classes and years, respectively, n is the sample size, and O_{at}, $\hat{O}_{at}$ represent the observed and predicted numbers at age in the catch. The elements $b_{i,j}$ represent ageing mis-classification proportions are based on independent agreement rates between otolith age readers. For the models presented this year, the option for including aging errors was re-evaluated.

Sample size values were revised and are shown in the main document. Strictly speaking, the amount of data collected for this fishery indicates higher values might be warranted. However, the standard multinomial sampling process is not robust to violations of assumptions (Fournier et al. 1990). Consequently, as the model fit approached a solution, we invoke a robust likelihood function which fit proportions at age as:

$$\prod_{a=1}^{A} \prod_{t=1}^{T} \frac{\left(\exp\left\{ -\frac{p_{t,a} - \hat{p}_{t,a}^{\ 2}}{2\ \eta_{t,a} + 0.1/T\ \ \tau^2} \right\} + 0.01 \right)}{\sqrt{2\pi\ \ \eta_{t,a} + 0.1/T\ \ \tau}}$$

..... (Eq. 16)

Taking the logarithm we obtain the log-likelihood function for the age composition data:

$$-1/2 \sum_{a=1}^{A} \sum_{t=1}^{T} \log_e\ 2\pi\ \ \eta_{t,a} + 0.1/T\ \ - \sum_{a=1}^{A} T \log_e\ \tau$$
$$+ \sum_{a=1}^{A} \sum_{t=1}^{T} \log_e \left[\exp\left\{ -\frac{p_{t,a} - \hat{p}_{t,a}^{\ 2}}{2\ \eta_{t,a} + 0.1/T\ \ \tau^2} \right\} + 0.01 \right]$$

..... (Eq. 17)

where $\eta_{t,a} = p_{t,a}\ 1 - p_{t,a}$

and $t^2 = 1 / n$

gives the variance for $p_{t,a}$

$$\eta_{t,a} + 0.1/T\ \ \tau^2 .$$

Completing the estimation in this fashion reduces the model sensitivity to data that would otherwise be considered outliers.

Within the model, predicted survey abundance accounted for within-year mortality since surveys occur during the middle of the year. As in previous years, we assumed that removals by the survey were insignificant (i.e., the mortality of pollock caused by the survey was considered insignificant). Consequently, a set of analogous catchability and selectivity terms were estimated for fitting the survey observations as:

$$\hat{N}^s_{t,a} = e^{-0.5Z_{t,a}} N_{t,a} q^s_t s^s_{t,a} \quad \text{(Eq. 18)}$$

where the superscript *s* indexes the type of survey (AT or BTS).

$$\hat{N}^s_{t,a} = e^{-0.5Z_{t,a}} w_{t,a} N_{t,a} q^s_t s^s_{t,a} \quad \text{(Eq. 19)}$$

For the AVO index, the values for selectivity were assumed to be the same as for the AT survey and the mean weights at age over time was also assumed to be equal to the values estimated for the AT survey.

For these analyses we chose to keep survey catchabilities constant over time (though they are estimated separately for the AVO index and for the AT and bottom trawl surveys). The contribution to the negative log-likelihood function (ignoring constants) from the surveys is given by either the lognormal distribution:

$$\sum_t \left(\frac{\ln\ A^s_t / \hat{N}^s_t\ ^2}{2\sigma^2_{s,t}} \right) \quad \text{(Eq. 20)}$$

where A^s_t is the total (numerical) abundance estimate with variance $S^{\ 2}_{s,t}$ from survey *s* in year *t* or optionally, the normal distribution is used:

$$\sum_t \left(\frac{A^s_t - \hat{N}^s_t\ ^2}{2\sigma^2_{s,t}} \right).$$

The AT survey and AVO index is modeled using a lognormal distribution whereas for the BTS survey, a normal distribution was applied.

For model configurations in which the BTS data are corrected for estimated efficiency, a multivariate lognormal distribution was used. For the negative-log likelihood component this was modeled as

$$0.5\mathbf{X}\Sigma^{-1}\mathbf{X}'$$

where $\mathbf{X}$ is a vector of observed minus model predicted values for this index and S is the estimated covariance matrix provided from the method provided in Kotwicki et al. 2013.

The contribution to the negative log-likelihood function for the observed total catches (O_t) by the fishery is given by

$$\sum_t \left(\frac{\ln\ O_t / \hat{C}_t\ ^2}{2\sigma^2_{c,t}} \right) \quad \text{(Eq. 21)}$$

where $S_{c,t}$ is pre-specified (set to 0.05) affecting the accuracy of the overall observed catch in biomass. Similarly, the contribution of prior distributions (in negative log-density) to the log-likelihood function include $\lambda_\varepsilon \sum_t \varepsilon^2 + \lambda_\gamma \sum_{t,a} \gamma^2_{t,a} + \lambda_\delta \sum_t \delta^2_t$ where the size of the λ*'s* represent prior assumptions about the variances of these random variables. Most of these parameters are associated with year-to-year and age specific deviations in selectivity coefficients. For a presentation of this type of Bayesian approach to modeling errors-in-variables, the reader is referred to Schnute (1994). To facilitate estimating such a large number of parameters, automatic differentiation software extended from Greiwank and Corliss (1991) and

developed into C++ class libraries was used. This software provided the derivative calculations needed for finding the posterior mode via a quasi-Newton function minimization routine (e.g., Press et al. 1992). The model implementation language (ADModel Builder) gave simple and rapid access to these routines and provided the ability estimate the variance-covariance matrix for all dependent and independent parameters of interest.

The approach we use to solve for F_{MSY} and related quantities (e.g., B_{MSY}, MSY) within a general integrated model context was shown in Ianelli et al. (2001). In 2007 this was modified to include uncertainty in weight-at-age as an explicit part of the uncertainty for F_{MSY} calculations. This involved estimating a vector of parameters (w_i^{future}) on future mean weights for each age i, i= (1, 2,…,15), given actual observed mean and variances in weight-at-age over the period 1991-2013. The values of $\overline{w}_i, \sigma^2_{w_i}$ based on available data and (if this option is selected) estimates the parameters subject to the natural constraint:

$$w_i^{future} \sim N\left(\overline{w}_i, \sigma^2_{w_i}\right) \quad \text{..... (Eq. 22).}$$

Note that this converges to the mean values over the time series of data (no other likelihood component within the model is affected by future mean weights-at-age) while retaining the natural uncertainty that can propagate through estimates of F_{MSY} uncertainty. This latter point is essentially a requirement of the Tier 1 categorization.

Tier 1 projections

Tier 1 projections were calculated two ways. First, for 2015 and 2016 ABC and OFL levels, the harmonic mean F_{MSY} value was computed and the analogous harvest rate ($\hat{u}_{HM}$) applied to the estimated geometric mean fishable biomass at B_{MSY}:

$$ABC = B'_{GM}\hat{u}_{HM}\zeta$$

$$B'_{GM} = e^{\ln\left(\hat{B}'\right)-0.5\sigma_B^2}$$

$$\hat{u}_{HM} = e^{\ln u_{msy}-0.5\sigma^2_{u_{msy}}} \quad \text{..... (Eq. 23)}$$

$$\zeta = \frac{B_t / B_{msy} - 0.05}{1-0.05} \qquad B_t < B_{msy}$$

$$\zeta = 1 \qquad B_t \geq B_{msy}$$

where $\hat{B}'$ is the point estimate of the fishable biomass defined as (for a given year)

$$\sum_{j=1}^{15} N_j s_j w_j \quad \text{..... (Eq. 24)}$$

with N_j, s_j and w_j the estimated population numbers (begin year), selectivity and weights-at-age j, respectively. B_{MSY} and B_t are the point estimates spawning biomass levels at equilibrium F_{MSY} and in year t (at time of spawning). For these projections, catch must be specified (or solved for if in the current year when $B_t < B_{MSY}$). For longer term projections a form of operating model (as has been presented for the evaluation of $B_{20\%}$) with feedback (via future catch specifications) using the control rule and assessment model would be required.

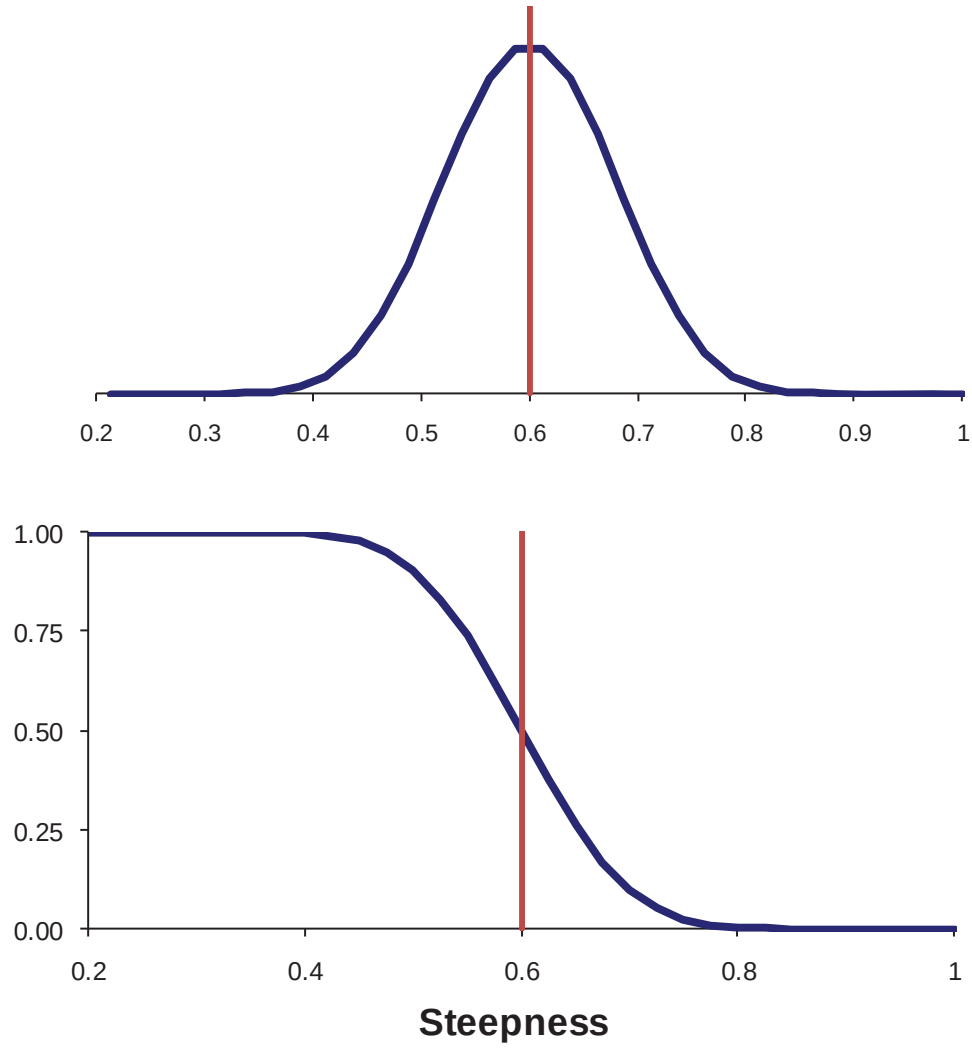

Figure 1.39. Cumulative prior probability distribution of steepness based on the beta distribution with α and β set to values which assume a mean and CV of 0.6 and 0.12, respectively. This prior distribution implies that there is about 8% chance that the value for steepness is greater than 0.7. See text for discussion.

Chapter 1A: Assessment of the pollock stock in the Aleutian Islands

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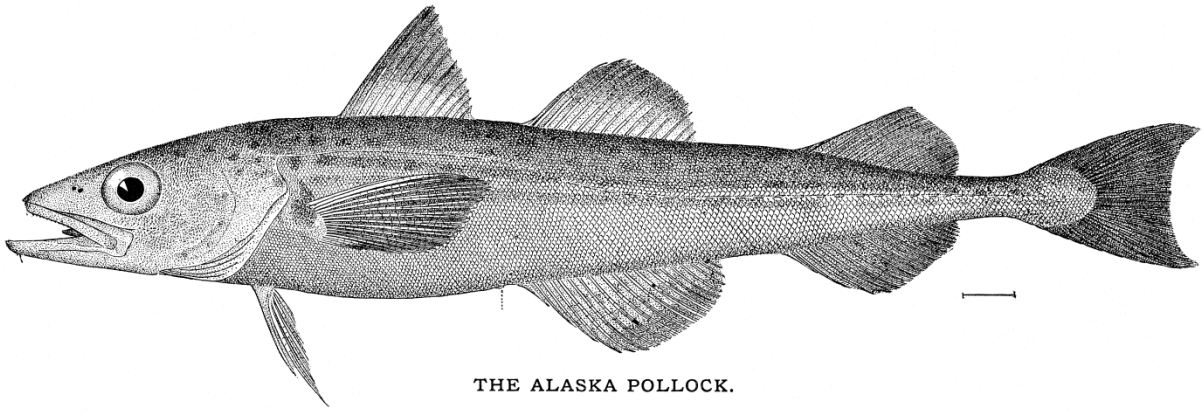

THE ALASKA POLLOCK.

Executive Summary

This year the authors' recommended model is different from last year's in that we include age 1 pollock. The change in results due to this model adjustment is minimal, but adding the age ones provides consistency among the three pollock stock assessments for the Alaska Region and allows for easier comparisons among different modeling platforms such as Stock Synthesis 3. The 2014 summer bottom trawl survey estimate, 2013 finalized catch estimate, and 2014 fishery catch estimate were included in this year's assessment. Note that the 2014 summer bottom trawl estimate (85,316 t) was nearly double the 2012 estimate (44,281 t) which was the lowest on record estimated for the area west of 170° w longitude. As in the previous five years there has been no directed fishing for pollock in the Aleutian Islands. As of October 4 there has been only 2,348 t of bycatch, primarily in the arrowtooth flounder and Pacific cod fisheries.

Summary of Changes in Assessment Inputs

Summary of changes in assessment inputs

- Catches for 1978 to 2014 were updated to latest estimates from the catch accounting system (CAS). There were no significant changes except a decrease of the 2013 estimate from 3,500 t to 2,964 t and the addition of the 2014 estimate at 3,000 t.

Summary changes in the assessment model

- For Model 2, the Authors' preferred model, age one pollock were included. The changes to the model make minimal changes to the results, but make the assessment consistent with the other assessment models for this species in the Alaska Region. It also allows for easier assessment of consistency among other modeling platforms such as Stock Synthesis 3.
- Model 3 also includes age 1 but is substantially different with the addition of a vector of differential natural mortality over ages. Natural mortality for Ages 1, 2, and 15 are modeled as deviations from the natural mortality for ages 3-14 fit with a log normal prior on M with a mean of 0.2 and CV of 0.2.

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Summary of Results

- The maximum permissible ABC for 2015 and 2016 (assuming the five year average F in 2015 for estimation of 2016 ABC) under Tier 3b are 29,659 t (F=0.25) and 31,900 t (F=0.27), respectively.
- The OFL for 2015 and 2016 under Tier 3b are 36,005 (F=0.32) t and 38,699 t (F=0.33), respectively.
- Long-term F_{OFL} and F_{ABC} are 0.395 and 0.315 respectively.
- If the 2015 catch is max TAC of 19,000 t the 2016 projected total age 1+ biomass would be 249,768 t, the 2016 female spawning biomass would be 74,448 t, the 2016 maximum permissible ABC would be 25,915 t, and the 2016 OFL would be 31,553 t.

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015*	2016*
M (natural mortality rate)	0.18		0.18	
Tier	3b		3b	
Projected total (age 2+ for previous and age 1+ for current) biomass (t)	259,525	289,307	228,102	249,523
Projected female spawning biomass (t)				
Projected	81,711	87,479	70,012	71,772
$B_{100\%}$	240,016		207,606	
$B_{40\%}$	96,006		83,042	
$B_{35\%}$	84,006		72,662	
F_{OFL}	0.33	0.33	0.32	0.33
$maxF_{ABC}$	0.26	0.28	0.25	0.27
F_{ABC}	0.26	0.28	0.25	0.27
OFL (t)	42,811	47,713	36,005	38,699
maxABC (t)	35,048	39,412	29,659	31,900
ABC (t)	35,048	39,412	29,659	31,900
Status	As determined *this* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	no	n/a	no	n/a
Overfished	n/a	no	n/a	no
Approaching overfished	n/a	no	n/a	no

* After 2015, catch of the five year average *F* of 0.0096

* Projections are based on estimated catches of 1,237 t and 1,253 t used in place of maximum permissible ABC for 2015 and 2016,based on the five-year average F (2009-2013) of 0.0096.

Responses to SSC and Plan Team Comments on Assessments in General

None

Response to SSC and Plan Team comments specific to this assessment

- There were no SSC comments from 2013 specific to the AI pollock stock assessment.

Introduction

Walleye pollock (*Gadus chalcogrammus;* Coulson et al. 2006; Carr and Marshall 2008; here after pollock) are distributed throughout the Aleutian Islands (AI) with concentrations in areas and depths dependent on diel and seasonal migration. The population of pollock in the AI incurred an apparent drop in abundance from the mid-1980s to the mid-1990s (1986 bottom trawl survey estimate of 444,000 t to a 1994 bottom trawl survey estimate of 78,000 t). Since 1994 the abundance point estimate has been variable, but considering the variance of the survey estimates the trend appears relatively flat (Fig 1A.1). The 2012 survey abundance was a record low at 44,281 t. The 2014 survey abundance estimate at 85,316 t nearly doubled the 2012 estimate. The low 2012 estimate is thought to be anomalous due to the very low temperatures in the region affecting availability of the species to the bottom trawl survey. The precipitous decline between 1986 and 1991 may be in part due to undocumented fishing by foreign vessels claiming catch from the Central Bering Sea (CBS), as the documented fishing levels alone cannot account for the decline (Table 1A.1). A number of foreign fishing vessels were observed fishing in the AI during this time period (Egan 1988a; Egan 1988b) while claiming catch from the CBS. The most recent surveys show that the AI pollock population is predominantly concentrated in the eastern portion of the Aleutian Island chain, closer to the Eastern Bering Sea shelf. Surveys from the 1980's and 1990's estimated higher proportions of pollock biomass in the central and western Aleutians (Fig 1A.1). This recent spatial change in population abundance may reflect a spatial contraction of the stock in the Eastern Bering Sea after the collapse of the Central Bering Sea population in the early 1990's, low AI pollock recruitments since the mid 1980's, documented higher exploitation rate of the AI pollock in the mid- to late 1990's, and possibly a high undocumented exploitation rate in the late 1980's by foreign fishers.

The degree of independence of the Aleutian Islands pollock from pollock of other areas is not well understood. Bailey et al. (1999) presented a review of the meta-population structure of pollock throughout the north Pacific region identifying possible meta-populations in the Eastern Bering Sea, but little data from the Aleutian Islands region were available at the time and therefore his population model doesn't consider these fish. Recent genetic studies, which included samples from the Aleutian Islands near Adak Island, have shown a lack of genetic heterogeneity among Northeast Pacific and Bering Sea pollock that could be used for stock definition (Grant et al. 2010). Grant et al. (2006) found and later confirmed (Grant et al. 2010) the greatest genetic differences occurred between samples from Asia and the Eastern North Pacific with mirror-image haplogroup clines between them. Grant et al. (2010) interpreted that the genetic differences across the Pacific Ocean and mirror-image haplogroup clines likely reflect divergence during ice-age isolations and subsequent expansion into the central North Pacific on each side with gene flow across the contact zone. The pollock in the AI therefore are most likely a mixed population from both Asian and North American and the result of re-colonization from both sides of the Pacific post ice-age.

For management purposes, the pollock population in the Eastern Bering Sea and Aleutian Islands (BSAI) has been split into three stocks. These stocks are: Eastern Bering Sea (EBS) pollock occupying the eastern Bering Sea shelf from Unimak Pass to the U.S.-Russia Convention line, Aleutian Islands (AI) pollock encompassing the pollock in the Aleutian Islands shelf region from 170°W to the U.S.-Russia Convention line; and the Central Bering Sea-Bogoslof Island (CBS-BI) pollock. These three management stocks probably have some degree of exchange. The CBS-BI stock is a group that forms a distinct spawning aggregation that has some connection with the deep water region of the Aleutian Basin. This stock assessment concentrates on the pollock of the Aleutian Islands and assumes that these fish are distinct enough from the CBS-BI and EBS meta-populations to model their dynamics separately.

Although the genetics evidence points to a mixed population, other evidence suggests that the AI pollock are separated from the EBS stock at smaller temporal time scales than current genetic techniques can identify, including disparate size at age and asynchrony in high recruitment events. It appears that the AI pollock are much more similar to the Gulf of Alaska (GOA) pollock than the EBS pollock in size at age, with the GOA pollock being significantly larger than the EBS fish and AI pollock being significantly larger than the GOA pollock (Fig.1A.2). This may be a latitudinal effect with the more southern AI

pollock encountering a longer summer growing period. Similar latitudinal differences have been observed in both Pacific and Atlantic cod (Gadus *macrocephalus* and *morhua*; Ormseth and Norcross 2009). Although the AI and EBS shared some larger-than-the-mean (normalized at post-1979) recruitment events (1977, 1978, 1982, 1989, and 2000) the AI shared more with the GOA (1976, 1977, 1978, 1985, 1989, and 2000). All three regions shared four of these higher recruitment events (1977, 1978, 1989, and 2000). In addition, the AI had unique high recruitment events in 1981, 1983, 1986, and 1987. Although the evidence is rather weak and not by any means conclusive, the size at age and asynchronous recruitments suggest some degree of separation between the EBS and the pollock of these three regions.

Previously, Ianelli et al. (1997) developed a model for Aleutian Islands pollock and concluded that the spatial overlap and the nature of the fisheries precluded a clearly defined "stock" since much of the catch was removed very close to the eastern edge of the region and appeared continuous with catch further to the east. In some years, a large portion of the pollock removed in the Aleutian Islands Region was from deep-water regions and appeared to be most aptly assigned as CBS-BI pollock. Since 2003 these deep-water catches have been excluded from the stock assessment data and only the area designated as the Near-Rat-Andreanof Islands area (NRA) or the area closest to the Aleutian Islands have been used in the stock assessment (Fig 1A.3). In 2003 through 2007 the authors' preferred stock assessment model excluded the fishery dependent data from east of 174°W longitude. In 2007 a CIE review deemed the east-west data split as inappropriate and the authors' preferred model has since included all fisheries dependent data from the entire NRA region.

Fishery

The nature of the pollock fishery in the Aleutian Islands Region has varied considerably since 1977 due to changes in the fleet makeup and in regulations. During the late 1970s through the 1980s the fishing fleet was primarily foreign and joint venture (JV) where US catcher vessels delivered to foreign motherships. The last JV delivery was conducted in 1989 when the domestic fleet began operating in earnest. The distribution of observed catch differed between the foreign and JV fishery (1977-1989; Barbeaux et al. 2013 Fig. 1A.4) and the domestic fishery (1989-2009; Barbeaux et al. 2013 Fig. 1A.4). The JV and foreign fishery operated in the deep basin area extending westward to Bowers Ridge and in the eastern most portions of the Aleutian Islands. Some operations took place out to the west but observer coverage was limited. In the early domestic period (1991-1998) the fishery was more dispersed along the Aleutian Islands chain with no observed catches along Bowers Ridge and fewer operations in the deep basin area. The majority of catch in the beginning of the domestic fishery came from the eastern areas along the 170°W longitude line, and around Seguam Island in both Seguam and Amukta passes (Fig. 1A.4). As the fishery progressed more pollock were removed from the north side of Atka Island around 174°W and later near 177°W northwest of Adak Island inside Bobrof Island. While the overall catch level was relatively low, the domestic fishery moved far to the west near Buldir Island in 1998 (Table 1A.2). In 1999 the North Pacific Fishery Management Council (NPFMC) closed the Aleutian Islands region to directed pollock fishing due to concerns for Steller sea lion recovery.

In 2003 the entire AI pollock quota was allocated to the Aleut Corporation and in 2005 the directed fishery was reopened. The fishery was still restricted to areas outside of 20 nm of Steller sea lion rookeries and haulouts, limiting fishing to two small areas with commercial concentrations of pollock within easy delivery distance to Adak Island. One area is a 4 mile stretch of shelf break located northwest of Atka Island between Koniuji Island and North Cape of Atka Island, the other is a 7 mile stretch located east of Nazan Bay in an area referred to as Atka flats. Bycatch of Pacific ocean perch (POP) can be very high in both these areas and it appears that pollock and POP share these areas intermittently; depending on time of day, season, and tide. Although there may be other areas further west that may have commercial concentrations of pollock, to date there have been no attempts by the reopened directed fishery to explore these areas.

Two catcher processor vessels attempted directed fishing for pollock in February 2005, but failed to find commercially harvestable quantities outside of Steller sea lion critical habitat closure areas and in the end removed less than 200 t of pollock. In addition, bycatch rates of Pacific ocean perch were prohibitively high in areas where pollock aggregations were observed. The 2005 fishery is thought to have resulted in a net loss of revenue for participating vessels. Data on specific bycatch and discard rates for the 2005 fishery are not presented due to issues of data confidentiality.

In 2006 and 2007 the Aleut Corporation, in partnership with the Alaska Fisheries Science Center (AFSC), Adak Fisheries LLC and the owners and operators of the F/V Muir Milach, conducted the Aleutian Islands Cooperative Acoustic Survey Study (AICASS) to test the technical feasibility of conducting acoustic surveys of pollock in the Aleutian Islands using small (<32 m) commercial fishing vessels (Barbeaux and Fraser 2009). This work was supported under an exempted fishing permit that allowed directed pollock fishing within Steller sea lion critical habitat. A total of 932 t and 1,100 t of pollock were harvested during these studies in 2006 and 2007 respectively, and biological data collected during the studies were treated in the stock assessment as fishery data. In 2008, additional surveys of Aleutian Islands region pollock in the same area were conducted on board the R/V Oscar Dyson and in cooperation with the F/V Muir Milach; the work was funded through a North Pacific Research Board grant and less than 10 t of groundfish were taken for the study. In 2009 the directed pollock fishery in the Aleutian Islands region took 403 t, and 1,326 t were taken as bycatch in other fisheries, predominantly the Pacific cod and rockfish fisheries. In 2010 through 2012 financial problems with the Adak processing plant greatly hindered the directed fishery. In 2010, 2011, 2012, and 2013 50 t, 0 t, 0 t, and 0 t were harvested in the directed fishery. As of October 6, 2014, 0 t had been taken in the directed fishery for 2014. In 2010, 2011, 2012, and 2013 1,285, 1,208 t, 975 t, and 2,964 t were harvested as bycatch in other fisheries. In 2014, as of October 6, 2,347 t had been taken as bycatch in other fisheries. The increase in catch for 2013 and 2014 has been primarily in the arrowtooth flounder fishery. This fishery changed fishing tactics to fish more shallow than in previous years to avoid Greenland turbot bycatch. Table 1A.3 provides a history of ABC, OFL, TAC, and catch for Aleutian Islands pollock since 1991. Since 2005 the TAC has been constrained to 19,000 t or the ABC, whichever is lower, by statute.

Data

Source	Data	Years
NMFS AI Bottom Trawl Survey (AI.BIOMASS_INPFC)	Survey Biomass	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, and 2014
NMFS AI Bottom Trawl Survey (RACEBASE.SPECIMEN)	Survey Age Data	1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, and 2012
AKFIN Domestic Blend (COUNCIL.COMPREHENSIVE_BLEND_CA)	Total Catch	1991-2014
Ianelli et al. 2001	Total Catch	1978-1990
Observer Program (OBSINT.DEBRIEFED_AGE)	Fishery Age Data	1978-1987, 1994-1996, and 1998
AICASS	Fishery Age Data	2006 - 2008

Catch estimates

Estimates of pollock catch in the Aleutian Islands Region are derived from a variety of data sources (Table 1A.1). The foreign-reported database (held at AFSC) is the main source of information for the

early period catches, and was used to derive the official catch statistics until about 1980 when the observer data were introduced to provide more reliable estimates. The foreign and joint-venture (JV) blend data take into account observer data and reported catches and formed the basis of the official catch statistics until 1990. The NMFS Observer data are the raw observed catch estimates and provide an indication of the amount of catch observed relative to the current estimates from the blend data. The foreign reported catch database was used to partition catches among areas for the period 1977-1984, and the observer data were used to apportion catches from 1985-1990 These proportions were then expanded to match the total catch. The Alaska Fisheries Information Network (AKFIN) provides the Domestic Blend data for 1991-2014. Estimates of pollock discard levels have been available since 1990. During the years when directed fishing was allowed pollock discards represented a small fraction of the total catch (Table 1A.4).

Fishery age composition

Otoliths, weight, and length samples were collected through shore-side sampling and by at-sea observers. The number of age samples and length samples were highly variable (Table 1A.5 and Table 1A.6) and sampling effort in the directed fishery was very low after 1998. The age composition data collected in the 2006, 2007, and 2008 AICASS were used as fishery data. Estimates of the catch-age compositions used in this assessment are shown in Table 1A.7. Fishery average weights-at-ages are provided in Table 1A.8.

From 1983 through 1987 the 1978 year class was predominate in the fishery (Fig. 1A.5). It wasn't until 1990s that the 1989 year class made up a larger proportion of the fishery catch at age data than the 1978 year class. Although the 1981 and 1983 year classes were large in comparison to recent recruitments they were dwarfed by the 1978 recruitment event. There were insufficient age data collected from the fishery between 1988 and 1993, 1997, and between 1999 and 2005 to construct an age distribution.

The age data collected during the 2006-2008 AICASS (Barbeaux et. al. 2011) revealed that the 1999 and 2000 year class made up a large portion of the adult population and were relatively large recruitment events for all three study years compared to more recent recruitments for this stock. In 2008 the 1998 year class appeared to be larger than previous years, but this may be due to high level of aging error as the agreement between age readers was only between 20.5% and 43.6% for this study. The low level of agreement between age readers compared to Bering Sea pollock was due to the high number of older fish in this stock and the low definition of the annuli in the AI pollock. This has been a consistent problem for the AICASS data with aging agreement averaging less than 50% across all years of data.

Survey data

The National Marine Fisheries Service in conjunction with the Fisheries Agency of Japan conducted bottom trawl surveys in the Aleutian Islands region (from ~165°W to ~170°E) in 1980, 1983, and 1986. The Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering Division (RACE) conducted bottom trawl surveys in this region in 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, and 2014. The Aleutian Islands bottom trawl survey planned for 2008 was canceled due to budgetary constraints. The earlier cooperative survey biomass estimates are not comparable with biomass estimates obtained from the RACE trawl surveys because of differences in the nets, fishing power of the vessels, and sampling design. In the early surveys, biomass estimates were computed using relative fishing power coefficients (RFPC) and were based on the most efficient trawl during each survey. Such methods result in pollock biomass estimates that are higher than those obtained using the standard methods employed in the RACE surveys. In the NRA area, the early survey (1980-1986) abundance ranged from 267 to 440 thousand tons and the later surveys (1991-2014) ranged from 44 to 175 thousand tons (Table 1A.9) with a peak in survey abundance in 2002. Plots of CPUE by tow show the relative distribution of pollock to be variable between years and areas (Fig. 1A.1 and Fig. 1A.6) but with an obvious decreasing trend in the Western and Central AI.

The RACE Aleutian Islands bottom trawl (AIBT) surveys prior to 2004 indicate that most of the pollock biomass was distributed roughly equally between the Eastern (541) and Central Aleutian Islands area (542). The 2004 Aleutian Islands trawl survey showed a significant decline in the Central Aleutian Islands area and a near doubling of the Eastern Aleutians Islands pollock abundance estimate from the 2002 survey. In the 2006 AIBT survey the Central and Western biomass estimates remained stable while the Eastern population was nearly half the 2004 estimate and back to 2002 levels, but the *CV* for this estimate was 90.2%. The 2010 survey shows an increase in abundance throughout the survey area with a larger increase in the Eastern area and slight increases in the Central and Western area. The Eastern portion of the survey continues to have by far the highest abundance levels, but the *CV* for the Eastern area remains high at 64%. During the 1991-2002 surveys, a number of large to medium-sized tows were encountered throughout the Aleutians indicating a fairly well distributed population. This is very different from the 2004 through 2014 survey estimates which indicated a low level of pollock abundance in both Central and Western areas, and a much higher pollock density in the Eastern area with only a few large hauls making up the majority of the abundance. The 2004 survey encountered a single large tow near Seguam pass that when expanded to the entire stratum made up the majority of the estimated pollock biomass. The 2006 and 2010 surveys revealed very few pollock throughout the NRA, except for large tows in Seguam Pass and in the Delerof Islands. The 2006 and 2010 survey found higher concentrations of pollock in the Delerof Islands than in 2004, but are consistent with the distribution of pollock in the 2002 survey. The 2012 and 2014 again show very little pollock in this area. The general trend for the 2002 through 2014 pollock distribution is a low level of pollock abundance in the Central and Western Aleutians with a more abundant, but patchy distribution of pollock in the Eastern Aleutians resulting in highly imprecise survey estimates. Although the largest proportion of the pollock biomass in the 2012 and 2014 surveys were observed in the Eastern Aleutians (Area 541), the surveys did not find large concentrations of pollock in the east as it had in the prior two surveys. The 2014 survey estimate for the NRA area was 85,316 t, 93% higher than the 2012 estimate. The 2014 estimate for Area 543, the western Aleutians, was 176% higher than the 2012 estimate, Area 542 was down 8% and Area 541 was up 102% , from the 2012 biomass estimates (Fig. 1A.1). The 2014 survey had a greater number of tows in Area 541 with higher CPUE compared to the previous five surveys. The 2014 estimate for Area 542 was the lowest recorded. The estimate for Area 543 was the highest estimate since 1997.

Survey proportion at age and length frequencies

The survey data from 1994 and 1997 are consistent with the fishery data in that the 1989 year class was larger than the mean recruitment from the time series. The 2000 and 2002 surveys don't show any particularly dominant year class, while the 2004 through 2010 survey age data show the 1999 and 2000 year classes as dominant (Fig. 1A.5 and Table 1A.10). The AIBTS weight-at-age data are presented in Table 1A.11. The 1991 survey age data is questionable since most of the age data were collected in only a few survey hauls in the Western Aleutians area. For this reason the 1991 age composition data have been down-weighted in the stock assessment model.

The length data for the 2002 through 2014 surveys are shown in Figure 1A.7. All of the survey length data distributions are multimodal with a mode for the age-1 pollock between 15 and 22 cm and another for pollock greater than age 4 between 50 and 70 cm. Ages 2 and 3 year old fish are generally low or missing from bottom trawl surveys as it is believed these fish are more pelagic than the adults and age 1 pollock. The 2002, 2012, and 2014 surveys show a larger number of pollock in the age-2 size range (mode between 20 and 40 cm) compared to other years. Age data from the 2014 AIBTS data are not yet available, but given the length at age for AI pollock (Fig. 1A.2) we can speculate on the age composition of the modes. The 19 cm mode most likely corresponds to age-1 pollock from the 2013 year class, the small modes between 20 and 30 cm are likely age 2 fish representing the 2012 year class, and fish near the 38 cm mode are likely age-3 pollock from the 2011 year class. Fish greater than 45 cm comprise a mix of the 2000 through 2010 year classes and beyond. The mode of age 1 fish in 2012 is larger than in any other survey, this year class is likely the large mode observed at 38cm in the 2014 survey data.

Other Surveys

In addition to the bottom trawl survey there has been one echo integration-trawl survey in a portion of the NRA. The R/V Kaiyo Maru conducted a survey between 170°W and 178°W longitude in the winter of 2002 after completing a survey of the Bogoslof region (Nishimura et al. 2002). Due to difficulties in operating their large mid-water trawl on the steep slope area, they determined that their biological sampling in this area were insufficient for accurate species identification and biomass estimation.

In 2006 and 2007, acoustic survey studies were completed in the central Aleutian Islands region aboard a 32m commercial trawler (F/V Muir Milach) equipped with a 38 kHz SIMRAD ES-60 acoustic system. The Aleutian Islands Cooperative Acoustic Survey Study (AICASS) was conducted to assess the feasibility of using a small commercial fishing vessel to estimate the abundance of pollock in waters off the central Aleutian Islands. In 2008 this survey was expanded to include the R/V Oscar Dyson to survey the same area as the F/V Muir Milach. The results of the 2006 survey are presented in an AFSC Technical Memorandum (Barbeaux and Fraser 2009) and the 2007 survey results were described in the 2009 Aleutian Islands pollock stock assessment (Barbeaux et al. 2009). In summary, both surveys were able to conduct scientific quality acoustic surveys in the Aleutian Islands during the winter months using commercially available echosounders and a commercial fishing vessel. In 2006 there was a high degree of variability between surveys due to the small area being surveyed, pollock movement, and potential overlap with the fishery being conducted during the survey period. In 2007 the spatial distribution of pollock varied between surveys with pollock abundance decreasing in an area inside Boborof Island near Ship Rock and in an area north of Atka Island known as the Knoll and increasing elsewhere in the study area.

The 2008 AICASS was conducted to investigate whether cooperative biomass assessments and surveys could be an effective way to manage fisheries at the local scales that are important to predators such as Steller sea lions. The study included two acoustic surveys one conducted by the R/V Oscar Dyson and the other by the F/V Muir Milach. The first acoustic survey conducted 16-29 February by the R/V Oscar Dyson between 173° W and 178° W resulted in a pollock biomass estimate of 36,135 t for the surveyed area. The second survey conducted 23-27 March between 174.17°W and 178° W resulted in a biomass estimate of 29,041 t. For the same area the R/V Oscar Dyson survey had a biomass estimate of 27,128 t, each of the estimates for the smaller area are within the margin of error of the other. The later F/V Muir Milach survey showed fewer pollock in the Tanaga area and more pollock in the Knoll area. The size of the pollock from the two 2008 surveys were consistent with each other with a mode between 60 and 65 cm, but were larger than the pollock observed in the 2006 and 2007 surveys (See Barbeaux et al 2013, Fig. 1A.9).

Analytic Approach

The 2014 Aleutian Islands walleye pollock stock assessment uses the same modeling approach as in last year's assessment; implemented through the Assessment Model for Alaska (here referred to as AMAK). AMAK is a variation of the "Stock Assessment Toolbox" model presented to the Plan Team in the 2002 Atka mackerel stock assessment (Lowe et al. 2002), with some small adjustments to the model and a user-friendly graphic interface.

The abundance, mortality, recruitment, and selectivity of the Aleutian Islands pollock were assessed with a stock assessment model constructed with AMAK as implemented using the ADMB software. The ADMB is a C++ software language extension and automatic differentiation library. It allows for estimation of large numbers of parameters in non-linear models using automatic differentiation software developed into C++ libraries (Fournier 1998). The optimizer in ADMB is a quasi-Newton routine (Press et al. 1992). The model is determined to have converged when the maximum parameter gradient is less

than a small constant (set to 1 x 10^{-7}). A feature of ADMB and AMAK is that it includes post-convergence routines to calculate standard errors (or likelihood profiles) for quantities of interest.

Model structure

AMAK models catch-at-age with the standard Baranov catch equation. The population dynamics follows numbers-at-age over the period of catch history with natural and age-specific fishing mortality occurring throughout the age groups that are modeled (Model 1 ages 2-15+ and Model 2 and Model 3 ages 1-15+). Age-2 (Model 1) or Age-1 (Model 2 and Model 3) recruitment in each year is estimated as deviations from a mean value expected from an underlying stock-recruitment curve. Model 1 and Model 2 estimate natural mortality across all ages. Model 3 estimates natural mortality as a vector of deviations from the mean (see *Natural Mortality* in the **Parameters Estimated Inside the Assessment Model** section below for more detail). For all models deviations between observations and expected values are quantified with a specified error model and cast in terms of a penalized log-likelihood. This overall log-likelihood (L) is the weighted sum of the calculated log-likelihoods for each data component and model penalties. The component weights are inversely proportional to the specified (or in some cases, estimated) variances. Appendix A Tables 1 –3 provide a description of the variables used, and the basic equations describing the population dynamics of Aleutian Islands pollock and likelihood equations. The models presented since 2007 were modified from that of Barbeaux et al. (2003). These modifications include:

- The addition of a feature that allows a user-specified age-range for which to apply the survey (or other abundance index) catchability. For example, specifying the age-range of 5-12 (as was done for this assessment) means that the average age-specific catchability of the survey is set to the parametric value (either specified as fixed, as in this assessment, or estimated).

The quasi[1] likelihood components and the distribution assumption of the error structure are given below:

Likelihood Component	Distribution Assumption
Catch biomass	Lognormal
Catch age composition	Multinomial
Survey catch biomass	Lognormal
Survey catch age composition	Multinomial
Recruitment deviations	Lognormal
Stock recruitment curve	Lognormal
Selectivity smoothness (in age-coefficients, survey and fishery)	Lognormal
Selectivity change over time (fishery only)	Lognormal
Priors (where applicable)	Lognormal

The age-composition components are heavily influenced by the sample size assumptions specified for the multinomial likelihood. In this year's model the multinomial sample sizes for the fishery were calculated as the minimum of the number of sampled hauls or 100 plus the number of sampled hauls divided by the mean number of sampled hauls. A value of 100 was specified for survey catch-at-age data.

[1] The likelihood is *quasi* because model penalties (e.g., non-parametric smoothers) are included.

Fishery data*	Year	1978	1979	1980	1981	1982	1983	1984	1985	1986
	$\dot{N}_{i,\bullet}$	100	33	100	100	101	101	104	102	101
	Year	1987	1988	1991	1992	1993	1994	1995	1996	1997
	$\dot{N}_{i,\bullet}$	101	101	101	103	103	103	103	103	101
	Year	1998	2006	2007	2008					
	$\dot{N}_{i,\bullet}$	101	100	100	100					
Survey data	Year	1980	1983	1986	1991					
	$\dot{N}_{i,\bullet}$	1**	1**	1**	1**					
	Year	1994	1997	2000	2002	2004	2006	2010	2012	
	$\dot{N}_{i,\bullet}$	100	100	100	100	100	100	100	100	

*2006, 2007, and 2008 effective sample sizes were set at 100 for this assessment

**The 1980-1991 values were down-weighted because the samples collected in these years were not representative of the region considered.

Parameters Estimated Outside the Assessment Model

Weight-at-age

We estimated weight-at-age separately for the survey and for the fishery. We obtained survey estimates from AIBT surveys and computed fishery estimates from observer data and the 2006-2008 AICASS. The fishery weight-at-age values from 1978 to 2014 are given in Table 1A.8 and the survey weight-at-age values are given in Table 1A.11. For all years and age classes for both the survey and fishery data weight at age by year were predicted using generalized additive models with time period and age as the independent variables (Barbeaux et al. 2011). Five time periods were defined (F1 = 1978-1984, F2= 1985-1989, D1=1990-1994, D2=1995-1998, D3=1999-2014). These time periods correspond to the early foreign fishery (f1), the late foreign fishery and joint venture fishery (F2), the early domestic fishery (D1) the late domestic fishery (D2), and the period of limited AI pollock fisheries (D3). These weight-at-age values are important for converting model estimated catch-at-age (in numbers) to estimated total annual harvests (by weight).

Maturity at Age

Previous to 2008, assessments used the maturity schedule developed for the Bering Sea by Wespestad and Terry (1984; Table 1A.14). The CIE panel commented that given the differences in size-at-age there likely is a difference in maturity-at-age between the Bering Sea and Aleutian Islands. The authors agree, but maturity studies have not been conducted specifically for Aleutian Islands pollock and given the lack of a substantial fishery, not likely to occur in the near future. Aleutian Islands pollock size at age is more similar to that observed in the Gulf of Alaska than in the Bering Sea (Fig. 1A.2). In addition, population density in the Aleutians is more similar to the GOA than the Bering Sea. Both last year's and this year's assessment used the Gulf of Alaska pollock 1983-2003 average proportion mature at age for our maturity O-give (Dorn et al. 2009). The GOA pollock tended to mature slightly later with 50% mature at between 4 and 5 years of age while the Bering Sea pollock reach 50% mature at between 3 and 4 years of age (Table 1A.12 and Fig. 1A.8).

Recruitment

We used an area-parameterized form of the Beverton-Holt stock recruitment relationship based on Francis (1992). Values for the stock recruitment function parameters α and β are calculated from the values of R_0 (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the "steepness"

(h) of the stock-recruit relationship. The "steepness" parameter is the fraction of R_0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992). As an example, a value of $h = 0.7$ implies that at 20% of the unfished spawning stock size will result in an expected value of 70% of the unfished recruitment level. The steepness parameter (h) was fixed at 0.7 and the recruitment variance (σ_R^2) was fixed at a value of 0.6 for both model runs. In previous assessments model runs with different values of h were conducted but were found to have little effect on the model results.

Parameters Estimated Inside the Assessment Model

Deviations between the observations and the expected values are quantified with a specified error structure. Lognormal error is assumed for estimates of survey and fishery catch, and a multinomial error structure is assumed for analysis of the survey and fishery age compositions. These error structures are used to estimate the following parameters conditionally within the model.

Fishing Mortality

Fishing mortality in all models was parameterized to be separable with both an age component (selectivity) and a year component. In all models selectivity is conditioned so that the mean value over all ages will be equal to one. To provide regularity in the age component, a penalty was imposed on sharp shifts in selectivity between ages using the sum of squared second differences. In addition, the age component parameters are assumed constant for the last 8 age groups (ages 8-15). Selectivity was allowed to change in temporal blocks for 1978-1989, 1990-1998, 1999-2008, and 2009-2014. The 1990 change was selected for the change from a foreign to a domestic fishery, in 1999 the directed fishery for pollock was closed, and in 2008 the arrowtooth flounder fishery was begun in the AI changing bycatch patterns.

Survey Selectivity and Catchability

In all three models presented for the bottom trawl survey, survey selectivity-at-age follows the parameterization similar to the fishery selectivity-at-age presented above. The selectivity-at-age relationship is modeled with a smoothed non-parametric relationship that can take on any shape (with penalties controlling the degree of change and curvature specified by the user). To provide regularity in the age component, a penalty was imposed on sharp shifts in selectivity-at-age between ages using the sum of squared second differences. In addition, the age component parameters are assumed constant for the last 8 age groups (ages 8 -15). As noted above, the model allows specification of the age-range over which the catchability parameter is applied. For Aleutian Islands pollock, ages 5-12 were selected to have the average catchability (factoring selectivity components) equal to the catchability parameter value. None of the 2014 models have inter-annually varying survey selectivity.

In the 2004 Aleutian Islands pollock stock assessment the focus of our analysis was to evaluate a key model assumption: the extent to which the NMFS summer bottom trawl survey catchability should be estimated by the available data (resulting in very high stock sizes) or constrained to be close to a value of 1.0 (implying that the area-swept survey method during the summer months reasonably applies to a fishery that will likely occur during the winter). We provided evidence that suggests that fixing the value of survey catchability to 1.0 is unreasonable. However, recognizing that no other information is available to "anchor" the assessment model to an absolute biomass level, the authors were reluctant to proceed with specifying influential prior distributions on catchability values. The effects of the fishery on the pollock population dynamics appear to be poorly determined given the available data. This could be due to a number of factors including: characteristics of Aleutian Islands pollock relative to adjacent regions, poor quality data, and the possibility that the fishing effects are minor relative to other factors. The latter point is likely to be true at least for the recent period since 1999 when the fishery removals have been minor. Therefore, for all models we assumed a fixed catchability value of 1.00.

Natural Mortality

For Models 1 and 2 natural mortality was estimated using a prior with a mean of 0.2 with a *CV* of 0.2. Previous assessments (Barbeaux et al. 2007) suggest that Aleutian Islands pollock is less productive than the Eastern Bering Sea stock and model fits suggest that *M* should be closer to 0.2 than the value of 0.3 used in the Eastern Bering Sea and Gulf of Alaska pollock assessments (Ianelli et al. 2009; Dorn et al. 2009). In the current assessment we assume a prior value of $M = 0.2$ based on the studies of Wespestad and Terry (1984) for the Central Bering Sea (Table 1A.13). Natural mortality can be reasonably estimated in this case using the AICASS age data because steepness (h), the recruitment variance (σ_R^2), and survey catchability (q) are assumed to be known. Model 3 is a new configuration and allows for age-specific natural mortality rates. An age-specific natural mortality has been used by Ianelli et al. (2013) for the Bering Sea pollock with a higher natural mortality rate for age 1 and 2. In this model we allowed different natural mortality for ages 1, 2, and 15. These were fit as lognormal offsets from natural mortality for ages 3 through 14. In Model 3 we fixed the shape of the natural mortality vector iteratively by running the model with different values for 1, 2, and 15, and evaluating the likelihood of each iteration. The best fit model had the lowest –loglikelihood.

Results

Model Evaluation

Three model configurations are presented for this stock assessment cycle. Model 1 is the model presented in the 2013 assessment with recruitment at age 2. Model 2 is the same model but with recruitment at age 1. Model 3 is Model 2 except with age-varying natural mortality.

All models were configured with a survey catchability of 1.0 for ages 5-12, a stock recruitment steepness parameter (h) of 0.7 and recruitment variance (σ_R^2) of 0.6. Recruitment was modeled using data from 1978-2008. Natural mortality for Models 1 and 2 was estimated within each model with a prior with a mean of 0.2 and *CV* of 0.2. For Model 3 natural mortality was age-specific and fit for ages 1, 2, and 15 as deviations from the mean value fit for ages 3-14. For all three models the aging error component of the models was configured as described by Ianelli et al. (2003) in the 2003 Bering Sea pollock stock assessment (Table 1A.15).

Model fit criteria results are shown in Table 1A.16 and key results are presented in Table 1A.17 and Figure 1A.9, Figure 1A.10, Figure 1A.11, Figure 1A.12, Figure 1A.13, and Figure 1A.14. Because there was a change in the underlying data a direct comparison of likelihoods between models and among years is not possible. Between Model 1 and Model 2 the fits to the data were very similar as were results (Fig. 1A.9). Exercises undertaken earlier in the year comparing SS3 to AMAK results required the inclusion of the age-1 data and showed little difference between AMAK with and without the age-1 data (Fig. 1A.10), we therefore decided to include the age-1 pollock in the latest models. The main reason for inclusion of age-1 pollock in this year's model is that the inclusion facilitates comparison among modeling platforms and would allow an easier transition to another sampling platform if that became necessary. The authors prefer Model 2 over Model 1 simply because it makes comparisons among model platforms easier.

Model 2 and Model 3 can be compared directly using likelihood methods (Table 1A.16 and Table 1A.17). Model 3 provides only marginal improvements in fit to all data components. Similar to previous years, the model fit to the survey index was poor for all models (Fig. 1A.11), particularly for the 1991, 1994, 2012, and 2014 survey values. This is not surprising given the high level of variance in the survey point estimates, the high intra-annual variability of the estimates, and the fact that the survey estimates are from the summer while the fishery is conducted in the winter.

The fit to the survey age composition data was good, except for the data prior to 1991 which, for sampling reasons, were given less weight than the following years (Fig. 1A.11). The fishery age-

composition data (Fig. 1A.12) were not fit as well as the survey catch-at-age data, but the fits were still relatively good. Observed and model derived mean ages matched well for all models, except for the 1995 and 2014 fishery data and 1994 survey data (Fig. 1A.13). Fishery age data was highly variable which probably reflects the diversity in sampling locations for the fishery in different years. There doesn't appear to be any obvious or consistent patterns in the residuals for either the fishery or survey catch-at-age fits (Fig. 1A.14) for any of the models explored.

Like previous years, recruitment variability was high and the same (0.89) for all three models presented. The mean natural mortality across all ages was similar for all three models 0.2 for Model 1, 0.19 for Model 2 and 0.23 for Model 3. The iterative approach used for Model 3 resulted in a U-shaped natural mortality with higher values for the younger ages (1-3) and 15+ age group (Table 1A.13). Selectivity curves for all three models (Fig. 1A.15) were similar for both the survey and the fishery. For fishery selectivity there is an apparent shift in selectivity between Model 2 and Model 3 to higher selectivity for fish between ages 4 and 7. A shift in the survey selectivity is also apparent between Model 2 and Model 3 with an increase in selectivity for ages 3 to 8. The increase in age 1, 2, and 15+ natural mortality and decrease in natural mortality for ages 3-14 would explain the model fitting higher selectivity for the age-4 to age-7 pollock for both the fishery and survey.

Although Model 3 provides a marginally better fit to the data, Model 3 presents a substantial change in how we are modeling natural mortality. As this was not presented in September and has not been properly vetted yet, the authors believe that it would be prudent to not use this model for management of the AI pollock stock this year. The fits to Model 1 and Model 2 are nearly identical for all of the data components, and the results from the two models are very similar. To facilitate future comparisons among modeling platforms the authors chose Model 2 as the preferred model for this year.

Abundance and exploitation trends

As indicated in the 2004 stock assessment analysis (Barbeaux et al. 2004), the abundance trend is highly conditioned on the assumptions made about the area-swept survey trawl catchability. Even with catchability fixed at 1.0, the uncertainty in the abundance trend and level is very high. Bearing in mind the high degree of uncertainty, total biomass estimates (Table 1A.19, Fig. 1A.16, and Fig. 1A.17) in the 1980's for the Aleutian Islands area reached a peak of 839,070 t in 1982 primarily due to the 1978 year class which was well above average (Table 1A.20, Fig. 1A.19, Fig. 1A.20, Fig. 1A.21). The model shows a large decline in the stock since its 1982 peak, hitting its lowest biomass levels in 2000 at 164,785 t. Total age 1+ biomass increased from 2000 to 2004 after cessation of directed fishing in the area. The increasing trend leveled off after 2005 due to poor recruitment after 2000. Average recruitments for 1990-1999 (48 million) and 2000-2009 (44 million) were well below the average for 1978-1989 (246 million). Biomass increased from 2007 onward due to low fishing pressure and the more prominent 2006 year class in the recent survey age data. Estimated pollock catch at age in numbers from 1978 to 2014 are given in Table 1A.21.

Female Spawning Stock Biomass (SSB) rose to 274,810 t in 1984 from below 100,000t in the 1970s due to the large 1978 year class (Fig.1A.17 and Fig. 1A.18). SSB peaked in 1988 as the larger than average 1981, 1984 and 1987 year classes matured. Even though there was a higher than average 1989 year class the SSB began to drop in the early 1990s in the face of heavy fishing pressure and dipped to a low of 59,439 t in 1999 ($B_{29\%}$ or 21% of the 1988 value) after a decade of poor recruitments and high fishing pressure. The highest full selection fishing mortality occurred in 1995 (F_{full} = 0.36 and Catch/biomass = 0.24) when the fishery harvested more than 82% of the 1994 survey biomass estimate (Fig. 1A.18 and Fig.1A.19). The authors' preferred Model 2 shows higher exploitation rates beginning in 1990 (F_{avg} = 0.18) continuing through 1998 (Table 1A.22). The early 1990s fishery appeared to concentrate on the older fish, particularly the 1978 year class, this is consistent with a switch in the domestic fishery to concentrating on spawning aggregations for roe (Fig. 1A.19, and Fig. 1A.20). The status of AI pollock in 2013 and 2014 was assessed to be well above $B_{20\%}$ and had low exploitation rates (Fig. 1A.22).

There was a steep decline in pollock abundance in the Aleutian Islands in association with the senescence of the 1978 year class without another large year class to replace it and high fishery removals. It is reasonable to conclude that although the fishery had exploitation rates below F_{OFL}, the amount of removals taken in the 1990s would not have been sustainable given recent recruitment and was largely supported by the 1978 year class. We simulated the expected total biomass under no fishing by taking the raw numbers at age from 1978 and the 1979-2008 number of recruits at age 1 and projected them forward using the model derived natural mortality rate. This exercise reveals that according to the authors' preferred model there was a significant decline in the abundance of pollock due to fishing, but since the cessation of fishing in 1999 and very low removal levels since 2005, the stock has stabilized and increased (Fig.1A.23). The simulation shows the 2014 female spawning stock biomass to be at 78% of what it would have been without fishing, but at a low in 1999 at 28% of the unfished stock.

Recruitment

Recruitment variance (σ_R^2) was fixed at a value of 0.6, and the authors' preferred model estimates recruitment variability was 0.89. For comparison the recruitment variability in the 2013 authors' preferred model was 0.91. The 1978 year-class is the largest (1.258 billion age-1 recruits; Table 1A.23 and Fig. 1A.21) and is highly influential with a large part of the fishery removals being composed of this year class (Fig. 1A.19 and Fig. 1A.20). The years 1976-1986 had several large year classes in comparison to more recent recruitment. The mean recruitment of age-1 pollock for 1978-1989 was 249 million, while the mean recruitment at age-1 between 1998 and 2008 was 45 million fish, with no year classes since the 1989 year class exceeding the overall 1978-2008 mean recruitment of 131 million age-1 recruits. Since the start of the domestic fishery in 1990, the two largest year classes have been the 1989 year class at 217 million age-1 recruits and the 2000 year class with 98 million age-1 recruits. Given our limited time series we are unable to determine whether the larger year classes in the late 1970's and early 1980's were anomalous or whether they are part of a larger cycle. The bottom line is that pollock year class strength has been much lower in the 1990's and 2000's than in the previous decade leading to lower abundance of pollock in the Aleutian Islands, even without substantial local fishing pressure over the previous nine years.

The 1978 year class in particular is highly influential. The mean recruitment for 1978 - 2008 without the 1978 year class was 71% (93 million) of the mean recruitment with the 1978 year class (131 million). If the 1978 year class is anomalous, it may be inflating the biological reference points and may be causing an overestimation of the expected productivity of this system, particularly if the 1978 year class originated elsewhere. Whether AI pollock recruitment is synchronous with other areas is an open question (e.g., the 1978, 1989, and 2000 year classes are also strong in the EBS region, Ianelli et al. 2005). The AI recruitment appears to be just as, or even more, correlated with the Gulf of Alaska (GOA) stock (Fig. 1A.3; Barbeaux et al. 2009) and the extent to which these adjacent stocks interact is an active area of research.

Retrospective analysis

We systematically removed each year's data from the model for 10 years to evaluate the retrospective pattern in the preferred model's performance. For the past 20+ years the estimates from the data limited models are not outside of the 95% confidence intervals. However there is a trend in the more recent estimates which are consistently higher than the current model estimates (Fig. 1A.24). The large decline in the 2012 and 2014 biomass estimates would not have been anticipated in the preferred model. The performance of the Aleutian Islands pollock preferred model was reasonable given the unexpectedly low estimates of abundance in the bottom trawl survey estimates for 2012 and 2014. Mohn's rho for the authors' preferred Model 2 was estimated at 0.085.

Projections and harvest alternatives

For management purposes we use the yield projections estimated from the 2014 authors' preferred Model 2. We used the 2014 authors' preferred Model 2 estimated terminal (2008-2014) fishery selectivity at age (Table 1A.18 and Fig. 1A.15) for all projections.

Reference fishing mortality rates and yields

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC ($max\ F_{ABC}$). The fishing mortality rate used to set ABC (F_{ABC}) may be less than or equal to this maximum permissible level. The overfishing and maximum allowable ABC fishing mortality rates are given in terms of percentages of unfished female spawning biomass ($F_{SPR\%}$), on fully selected age groups. The associated long-term average female spawning biomass that would be expected under average estimated recruitment from 1978-2008 for the authors' preferred model (130.6 million age 1 fish) and F equal to $F_{40\%}$ and $F_{35\%}$ are denoted $B_{40\%}$ and $B_{35\%}$, respectively. The Tiers require reference point estimates for biomass level determinations. We present the following reference points for NRA pollock for Tier 3 of Amendment 56. For our analyses, we estimated the following values from the authors' preferred model:

Female spawning biomass	Model AI
$B_{100\%}$	207,991 t
$B_{40\%}$	83,197 t
$B_{35\%}$	72,797 t
B_{2015}	67,889 t

Specification of OFL and Maximum Permissible ABC

For the Authors' preferred Model 2, the projected year 2015 female spawning biomass (SB_{14}) is estimated to be 67,889 t, below the $B_{40\%}$ value of 83,197 t placing NRA pollock in Tier 3b. The maximum permissible ABC and OFL values under Tier 3b for 2015 are:

Harvest Strategy	FSPR%	Fishing Mortality Rate	2014 Projected yield (t)
$max\ F_{ABC}$	*Adjusted* $F_{40\%}$	0.25	29,818 t
F_{OFL}	*Adjusted* $F_{35\%}$	0.32	36,005 t

If the estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ were deemed not reliable, then under Tier 5 with estimated natural mortality of 0.186 and the 2014 AIBT survey biomass, the 2015 ABC would be 5,978 t (85,316 t x 0.75 x 0.186 = 11,902 t) and under Tier 5 with an assumed natural mortality of 0.3 the 2014 ABC would be 19,136 t.

ABC Considerations and Recommendation

ABC Considerations

There remains considerable uncertainty in the Aleutian Islands pollock assessment. We've noted some concerns below:

1) The level of interaction between the Aleutian stock and the Eastern Bering Sea stock is unknown. It is evident that some interaction does occur and that the abundance and composition of the eastern portion of the Aleutian Islands stock is highly confounded with that of the Eastern Bering

Sea stock. Overestimation of the Aleutian Islands pollock stock productivity due to an influx of Eastern Bering Sea stock is a significant risk.

2) As indicated in the 2004 AI pollock stock assessment (Barbeaux et al. 2004), AIBT survey catchability is probably less than 1.0, but we have no data to concretely anchor the value at anywhere less than 1.0. We therefore employ a default value for catchability of 1.00. This provides a conservative total biomass estimate.

3) Recent (1991 through 2014) AI bottom trawl surveys are highly uncertain with an average *CV* of 0.36. The 2002, 2004, 2006, 2010, 2012, and 2014 estimates of *CV* are 0.38, 0.78, 0.48, 0.33, 0.55, and 0.24 respectively. This results in considerable uncertainty in the model results.

4) The authors' preferred model suggests that currently a large proportion of the stock in the Aleutians is composed of much older fish (10% age 10+ by number) which make up a large proportion of the catch (36% age 10+ by number). These results are highly reliant on the estimated selectivity curves.

5) Aging error is a significant concern for this stock with aging comparisons for the 2006 through 2008 age data at between 20% and 47% agreement.

6) If the 1978 year class is anomalous, it may be inflating the biological reference points in and may be causing an overestimation of the expected productivity of this system, particularly if the 1978 year class originated elsewhere.

7) The low 2012 and 2014 bottom trawl survey estimates can't be explained by estimated natural mortality or catch. The availability of pollock to the survey may not be static and therefore the index could be unreliable. Migration of pollock outside the survey area could also explain this decline, but less likely.

ABC Recommendations

The pollock spawning stock biomass and total age 1+ biomass in the NRA appears to have been increasing slightly (+4.2% and +12.2% annually) since 1999. The projected total age 1+ biomass for 2015 is 228,467 t. Assuming the five year average F of 0.0096 the estimated female spawning biomass projected for 2016 is 74,448 t. Under this scenario the maximum permissible Tier 3b 2015 ABC (F_{maxABC} = 0.25) is 29,818 t and OFL (F_{OFL} = 0.32) is 36,005 t and the 2016 ABC (F_{maxABC} = 0.27) is 31,900 t and OFL (F_{OFL} = 0.33) is 38,669 t which are the authors' recommended ABC and OFLs.

Standard Harvest Scenarios and Projection Methodology

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3, of Amendment 56. This set of projections encompasses eight harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2014 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2015 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2014. For this value we calculated the maximum percentage difference between the year-end catch and catch as of September 30 for 2008-2013 and corrected the 2014 September 30 estimate by this value. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined

from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2015 and 2016, are as follows (a "*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2015 recommended in the assessment to the *max* F_{ABC} for 2015. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to the 2009-2013 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 4: In all future years, F is set equal to $F_{75\%}$. (Rationale: This scenario represents a very conservative harvest rate and was requested by the Alaska Regional Office based on public comment.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2014 or 2) above 1/2 of its MSY level in 2014 and above its MSY level in 2024 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2027 under this scenario, then the stock is not approaching an overfished condition.)

The author included one more scenario in order to take into consideration the congressionally mandated TAC cap on pollock harvest from the Aleutian Islands area.

Scenario 8: In 2015 through 2026 the TAC is increased to 19,000 t or *max* F_{ABC} whichever is lower. (Rationale: 19,000 is the AI pollock cap set by Congressional mandate).

Projections and status determination

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2014:

a. If spawning biomass for 2014 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b. If spawning biomass for 2014 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c. If spawning biomass for 2014 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6. If the mean spawning

biomass for 2024 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario #7:

a. If the mean spawning biomass for 2017 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.
b. If the mean spawning biomass for 2017 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c. If the mean spawning biomass for 2017 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2027. If the mean spawning biomass for 2026 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

The projected yields, female spawning biomass, and the associated fishing mortality rates for the eight harvest strategies for the authors' preferred model are shown in Table 1A.24. In the authors' preferred model under a Tier 3b harvest strategy of an adjusted $F_{40\%}$ (Scenario 1), female spawning biomass is projected to be below $B_{35\%}$ through 2019, be below $B_{40\%}$ through 2021, then be above $B_{40\%}$ for the remainder of the projection (Fig.1A.25 and Fig.1A.26). Female spawning biomass is projected be above ½ $B_{35\%}$ but below $B_{35\%}$ when fishing at F_{OFL} (Fig.1A.27) through 2020 in Scenario 7. The female spawning biomass is projected to remain below $B_{40\%}$ through the end of the projection for both Scenario 6 and Scenario 7. Please note again that the fishing mortality rates are prescribed on the basis of the harvest scenario and the spawning biomass in each year. Thus, fishing mortality rates may not be constant within the projection if spawning biomass drops below $B_{40\%}$ in any run due to the harvest control rules.

The associated long-term average female spawning biomass that would be expected under average estimated recruitment from 1978-2008 (130.1 million age 1 fish) and $F = F_{35\%}$, denoted $B_{35\%}$ is estimated to be 72,797 t. This value ($B_{35\%}$), is used in the status determination criteria. Female spawning biomass for 2014 (70,658 t) is projected to be above 1/2 $B_{35\%}$ thus, the NRA pollock stock is *above* its minimum stock size threshold (MSST) and is *not overfished*. Female spawning biomass for 2027 is projected to be above $B_{35\%}$ in Scenario 7, and is expected to be above $B_{35\%}$ in 2024 in Scenario 6, therefore the NRA pollock stock is *not* expected to fall below its MSST in two years and is *not approaching an overfished condition*.

Projections under Scenario 8 (Fig.1A.25, Fig.1A.26, and Table 1A.24), show that the stock could support a constant catch of 19,000 t. Currently the stock is at $B_{34\%}$ and the long-term expected yield at $B_{40\%}$ is 42,694 t and at $B_{35\%}$ is 40,442 t, well above the 19,000 t cap.

The SSC asked that the probability of the spawning stock biomass being below $B_{20\%}$ in 2015 be computed for stocks in Tier 3b. We computed the number of standard deviations the 2015 spawning biomass (B_{2015}) was from $B_{20\%}$, assuming B_{2015} was normally distributed. B_{2015} is estimated in the stock assessment model (non-projected) to be at 70,090 t with a standard deviation of 8,130 t and $B_{20\%}$ is estimated at 41,598 t, therefore B_{2015} is 3.5 standard deviations from $B_{20\%}$. Under the assumption of a normal error distribution there is a 0.0002 % chance of the AI pollock stock currently being below $B_{20\%}$.

Ecosystem Considerations

Pollock is a commercially important species. It is also important as prey to other fish, birds, and marine mammals, and has been the focus of substantial research in Alaskan ecosystems, especially in the Gulf of Alaska (GOA; Hollowed et al. 2000). To determine the ecosystem relationships of juvenile and adult pollock in the Aleutian Islands (AI), we first examined the diet data collected for pollock. Diet data are collected aboard NMFS bottom trawl surveys in the AI ecosystem during the summer (May – August). In the AI, a total of 1,458 pollock stomachs were collected between the 1991 and 1994 bottom trawl surveys (n=688 and 770, respectively) and used in this analysis. The diet compositions reported here reflect the

size and spatial distribution of pollock in each survey (see Appendix A, "Diet calculations" for detailed methods from Barbeaux et al. 2006). Juvenile pollock were defined as fish less than 20 cm in length, which roughly corresponds to 0 and 1 year old fish, and adult pollock were defined as fish 20 cm in length or greater, roughly corresponding to age 2+ fish.

In the AI, pollock diet data reflects a closer connection with open oceanic environments than in either the Eastern Bering Sea (EBS) or the GOA. Similar to the other ecosystems, euphausiids and copepods together make up the largest proportion of AI adult pollock diet (29% and 19%, respectively); however, it is only in the AI that adult pollock rely on mesopelagic forage fish in the family Myctophidae for 24% of their diet, and AI juvenile pollock have a lower proportion of euphausiids and a higher proportion of gelatinous filter feeders than in the GOA or EBS (Fig.1A. 28, left panels). We took this diet composition information and convert it to broad ranges of tons consumed annually by pollock in the AI using the Sense routine (Aydin et al. 1997), which incorporates information on pollock consumption derived from the stock assessment (see Appendix A from Barbeaux et al. 2006, "ration calculations" for detailed methods), as well as uncertainty in all other food web model parameters. As estimated by the Sense routine, AI adult pollock consumed between 100 and 900 thousand metric tons of euphausiids annually during the early 1990s, with similar ranges of myctophid and copepod consumption. Juvenile AI pollock consumed an additional estimated 100 to 900 thousand tons of copepods per year (Fig.1A.28, right panels).

Using diet data for all predators of pollock and consumption estimates for those predators, as well as fishery catch data, we next estimated the sources of pollock mortality in the AI. Sources of mortality were compared against the total production of pollock as estimated in the AI pollock stock assessment model. In the AI, integration of this single species information with predation within the food web model suggests that most adult pollock mortality was caused by the pollock trawl fishery during the early 1990s (48%; Fig.1A.29, left panels). (Fishery catch of pollock in the AI has subsequently declined to less than half the early 1990s catch by the late 1990s, and the directed fishery was closed in 1999 (Ianelli et al. 2005). Therefore, AI pollock likely now experience predation mortality exceeding fishing mortality as in the EBS and GOA ecosystems.) The major predators of AI adult pollock are Pacific cod, Steller sea lions, pollock themselves, halibut, and skates. In the AI, juvenile pollock have a very different set of predators from adult pollock; Atka mackerel cause most juvenile pollock mortality (71%). Estimates of the tonnage of adult pollock consumed by predators from the Sense routines (Aydin et al.1997) ranged from 8 to 27 thousand tons consumed by Pacific cod annually during the early 1990s, while Atka mackerel were estimated to consume between 75 and 410 thousand tons of juvenile pollock annually in the AI ecosystem (Fig.1A.29, right panels).

After reviewing the diet compositions and mortality sources of pollock in the AI, we shifted focus slightly to view pollock and the pollock fishery within the context of the larger AI food web. When viewed within the AI food web, the pollock trawl fishery (in red; Fig.1A.30) is a relatively high trophic level (TL) predator which interacts mostly with adult pollock, but also with many other species (in green; Fig. 1A.32). The diverse pollock fishery bycatch ranges from high TL predators such as salmon sharks, sleeper sharks, and arrowtooth flounder, to mid TL pelagic forage fish and squid, to low TL benthic invertebrates such as crabs and shrimp, but all of these catches represent extremely small flows. Because the pollock trawl fishery contributes significant fishery offal and discards back into each ecosystem, these flows to fishery detritus groups are represented as the only "predator consumption" flows from the fishery; the biomass of retained catch represents a permanent removal from the system.

In the AI food web model, we included detailed information on bycatch for each fishery. This data was collected in the early 1990s when the AI pollock fishery was much larger than it is at present. During the early 1990's, the pollock trawl fishery was extremely species-specific in the AI ecosystem, with pollock representing over 90% of its total catch by weight (Fig.1A. 31). No single bycatch species accounted for more than 1% of the catch. Although these catches are small in terms of percentage, the high volume

pollock fisheries still account for the majority of bycatch of pelagic species in the BSAI management areas, including smelts, salmon sharks, and squids (Gaichas et al. 2004).

Pollock is also a very important prey species in the wider AI food web. When both adult and juvenile pollock food web relationships are included, over two thirds of all species groups turn out to be directly linked to pollock either as predators or prey in the food web model (Fig.1A.32). In the AI, the significant predators of pollock (blue boxes joined by blue lines) include halibut, cod, Alaska skates, Steller sea lions, and the pollock trawl fishery. Significant prey of pollock (green boxes joined by green lines) are myctophids, euphausiids, copepods, benthic shrimps, and amphipods, with juveniles preying on the euphausiids and copepods.

We investigated whether these differences in pollock diet, mortality, and relationships between the EBS and AI might suggest different ecosystem roles for pollock in these areas. We used the diet and mortality results integrated with information on uncertainty in the food web using the Sense routines (Aydin et al in review) and a perturbation analysis with each model food web to explore the ecosystem relationships of pollock further. Two questions are important in determining the ecosystem role of pollock: which species groups are pollock important to, and which species groups are important to pollock?

First, the importance of pollock to other groups within the AI ecosystem was assessed using a model simulation analysis where pollock survival was decreased (mortality was increased) by a small amount, 10%, over 30 years to determine the potential effects on other living groups. This analysis also incorporated the uncertainty in model parameters using the Sense routines, resulting in ranges of possible outcomes. Figure 1A.33 shows the resulting percent change in the biomass of each species after 30 years for 50% of feasible ecosystems with 95% confidence intervals (error bars in Figure1A.33. Species showing the largest median changes from baseline conditions are presented in descending order from left to right. Therefore, the largest change resulting from a 10% decrease in pollock survival in both ecosystems is a decrease in adult pollock biomass, as might have been expected from such a perturbation. However, the decrease in pollock biomass resulting from the 10% survival reduction is uncertain in AI: the 50% intervals range from a 5-37% decrease in the AI (Fig.1A.33, upper panel). Along with the decrease in pollock biomass predicted in this simulation is a decrease in pollock fishery catch. The next largest median effect is on juvenile pollock, which are predicted to decrease in 50% of feasible ecosystems, but the 95% interval includes zero, suggesting that the decrease is uncertain. The simulation further suggests the possibility that herring, Atka mackerel, and other miscellaneous deepwater fish might increase slightly as a result of a decrease in pollock survival; however, for all of these species groups the 95% intervals cross zero, so the direction of change is uncertain. Therefore, this analysis suggests that in the AI ecosystem during the early 1990's, pollock were most important to themselves, and to the pollock fishery.

To determine which groups were most important to pollock in each ecosystem, we conducted the inverse of the analysis presented above. In this simulation, each species group in the ecosystem had survival reduced by 10% and the system was allowed to adjust over 30 years. The strongest median effects on AI adult pollock are presented in Fig. 1A.33 (lower panel). The largest effect on adult pollock was the reduction in biomass resulting from the reduced survival of juvenile pollock, although the 95% intervals include zero change, indicating considerable uncertainty in this result. (The same caution applies to the interpretation of all of the results of this simulation as all of the 95% intervals contain zero). It is interesting, however, that reduced survival of juvenile Atka mackerel had a larger median effect on adult pollock biomass than the direct effect of reduced adult pollock survival itself (Fig. 1A.33, lower panel), and that the effect is positive. Adult Atka mackerel show the same pattern, which is likely explained by the amount of mortality caused by Atka mackerel on juvenile pollock in the AI food web model (see Fig. 1A.29, lower panels). Reduced survival of Atka mackerel adults or juveniles apparently relieves considerable mortality on juvenile pollock in this model, accounting for the increases in pollock biomass predicted (which is similar in magnitude to the increase predicted from reducing the pollock fishery catch

by 10%). Although this result is uncertain, it does indicate an important interaction between two commercially important species in the AI ecosystem which might be further investigated.

Ecosystem effects on Aleutian Islands Walleye Pollock

The following ecosystem considerations are summarized in Table 1A.25.

Prey availability/abundance trends

Adult walleye pollock in the Aleutian Islands consume a variety of prey, primarily large zooplankton, copepods, and myctophids. Figure 1A.32 highlights the trophic level of pollock in relation to its prey and predators. No time series of information is available on Aleutian Islands for large zooplankton, copepod, or myctophid abundance.

Predator population trends

The abundance trend of Aleutian Islands Pacific cod is decreasing, and the trend for Aleutian Islands arrowtooth flounder is relatively stable. Northern fur seals and Steller sea lions west of 178°W longitude are showing declines, while Steller sea lions east of 178°W longitude have shown some slight increases. Declining trends in predator abundance could lead to possible decreases in walleye pollock mortality. The population trends of seabirds are mixed, some increases, some decreases, and others stable. Seabird population trends could affect young-of-the-year mortality.

Changes in habitat quality

Water temperature in the Aleutian Islands is variable among survey years particularly for bottom depth at the preferred depth range of pollock (Fig. 1A.34, Fig. 1A.35, and Fig. 1A 36). The 2012 Aleutian Islands summer bottom temperatures indicated that water temperatures were substantially cooler than the 2004-2010 surveys (Lowe et. al. 2012). Bottom temperatures could possibly affect fish distribution. The 2014 AI bottom trawl survey shows a swing of bottom and surface temperature values to above the means for the entire time series (1991-2014) and similar to the 2004-2010 bottom temperatures.

AI pollock fishery effects on the ecosystem

AI pollock fishery contribution to bycatch

Prior to 1998, levels of bycatch in the pollock fishery of prohibited species, forage, HAPC biota, marine mammals and birds, and other sensitive non-target species was very low compared to other fisheries in the region. The AI pollock fishery opening in 2005 was limited to only four hauls, within these four hauls the bycatch level of POP was very high (~50%). In addition to the lack of commercially harvestable levels of pollock, the high levels of POP bycatch convinced fishers to discontinue the fishery in 2005. The 2006 and 2007 AI pollock fisheries were conducted in conjunction with the AICASS, Pacific ocean perch was the most substantial bycatch species and made up 3% of the catch in 2006 and 11% in 2007. The 2008 directed pollock fishery had an observed bycatch rate of 1% with 97% of this being POP. In 2009 there was no observer coverage of the directed fishery and in 2010 there was less than 1% bycatch in the directed fishery which caught less than 50 tons of pollock. There was no directed pollock fishery in the Aleutians in 2011 through 2013.

Concentration of AI pollock catches in time and space

Since no EFP is proposed for 2014 there is expected to only be a very limited fishery in 2014, if any at all. The only shore-based plant capable of processing the Aleutian Islands' pollock catch in Adak is currently not configured to do so and no pollock processing is expected there in 2014.

AI pollock fishery effects on amount of large size walleye pollock

The AI pollock fishery in the Aleutian Islands was closed between 1999 and 2005. There was only a very limited fishery in 2005 (< 200t), 2006 (932 t), 2007 (1,300 t), 2008 (382 t), 2009 (400 t), 2010 (50 t), 2011 (0 t), 2012 (0 t), 2013 (0 t), and 2014 (0 t). Year to year differences observed in the previous decade cannot be attributed to the fishery and must be attributed to natural fluctuations in recruitment. Fishers have indicated that the larger pollock in the Aleutian Islands will be targeted. But the low level of fishing mortality is not expected to greatly affect the size distribution of pollock in the AI.

AI pollock fishery contribution to discards and offal production

The 2015 Aleutian Islands pollock fishery, if pursued, is expected to be conducted by catcher vessels delivering unsorted catch to the processing plant in Adak, and therefore very little discard or offal production is expected from this fishery. Currently the plant is out of operation and therefore no fishery is expected.

AI Pollock fishery effects on AI pollock age-at-maturity and fecundity

The effects of the fishery on the age-at-maturity and fecundity of AI pollock are unknown. No studies on AI pollock age-at-maturity or fecundity have been conducted. Studies are needed to determine if there have been changes over time and whether changes could be attributed to the fishery. Little impact is expected if the fishery continues to be conducted in the limited capacity it has been over recent years.

Data gaps and research priorities

Very little is known about the AI pollock stock structure and their relation to Western Bering Sea, Eastern Bering Sea, Gulf of Alaska, Bogoslof and Central Bering Sea pollock. Studies on the migration of pollock in the North Pacific should be explored in order to obtain an understanding of how the stocks relate spatially and temporally and how neighboring fisheries affect local abundances. Time series data sets on prey species abundance in the Aleutian Islands would be useful for a more clear understanding of ecosystem affects. Studies to determine the impacts of environmental indicators such as temperature regime on AI Aleutian pollock are needed. Currently, we rely on studies from the eastern Bering Sea and Gulf of Alaska for our estimates of life history parameters (e.g. maturity-at-age, fecundity, and natural mortality) for the NRA pollock. Studies specific to the NRA to determine whether there are any differences from the eastern Bering Sea and Gulf of Alaska stocks and whether there have been any changes in life history parameters over time would be informative.

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Tables

Table 1A.1. Estimates of walleye pollock catches from the entire Aleutian Islands Region by source, 1977-2012. Units are in metric tons.

Year	Official Foreign & JV Blend	Domestic Blend	Foreign Reported	NMFS Observed Catch*	Total Best Estimates
1977	7,367		7,827	5	7,367
1978	6,283		6,283	234	6,283
1979	9,446		9,505	58	9,446
1980	58,157		58,477	883	58,157
1981	55,517		57,056	2,679	31,258
1982	57,753		62,624	11,847	50,322
1983	59,021		44,544	12,429	44,442
1984	77,595		67,103	48,538	42,901
1985	58,147		48,733	43,844	47,070
1986	45,439		14,392	29,464	23,810
1987	28,471			17,944	26,257
1988	41,203			21,987	36,864
1989	10,569			5,316	10,569
1990		79,025		59,935	79,025
1991		98,604		53,647	98,604
1992		52,352		36,581	52,352
1993		57,132		44,552	57,132
1994		58,659		43,430	58,659
1995		64,925		53,647	64,925
1996		29,062		23,482	29,062
1997		25,940		19,623	25,940
1998		23,798		21,032	23,798
1999		1,010		492	1,010
2000		1,244		573	1,244
2001		1,010		477	1,010
2002		1,177		519	1,177
2003		1,649		1,562	1,649
2004		1,158		1,074	1,158
2005		1,621		1,359	1,621
2006		1,745		540	1,745
2007		2,519		1,182	2,519
2008		1,278		996	1,278
2009		1,662		1,409	1,662
2010		1,285		1,261	1,285
2011		1,208		1,198	1,208
2012		975		927	975
2013		2,964		2,953	2,964
2014		2,347		2,342	2,347

*Extrapolated catch from observed fishing not a total catch estimate.

** as of October 7, 2014

Table 1A.2. Estimates of Aleutian Islands Region walleye pollock catch by the three management sub-areas. Units are in metric tons.

Year	East 541	Central 542	West 543	Total	Year	East 541	Central 542	West 543	Total
1977	4,402	0	2,965	7,367	1996	9,226	19,574	261	29,062
1978	5,267	712	305	6,283	1997	8,110	16,799	1,031	25,940
1979	1,488	1,756	6,203	9,446	1998	1,374	2,603	19,821	23,798
1980	28,284	7,097	22,775	58,157	1999	484	420	105	1,010
1981	43,461	10,074	1,982	55,517	2000	615	461	169	1,244
1982	54,173	1,205	2,376	57,753	2001	333	387	105	1,010
1983	56,577	1,250	1,194	59,021	2002	862	182	133	1,177
1984	64,172	5,760	7,663	77,595	2003	565	758	326	1,649
1985	19,885	38,163	100	58,147	2004	397	513	248	1,158
1986	38,361	7,078	0	45,439	2005	689	415	517	1,621
1987	28,086	386	0	28,471	2006	1,036	488	220	1,745
1988	40,685	517	0	41,203	2007	1,919	476	124	2,519
1989	10,569	0	0	10,569	2008	872	293	112	1,278
1990	69,170	9,425	430	79,025	2009	1,020	400	243	1,662
1991	98,032	561	11	98,604	2010	754	382	150	1,285
1992	52,140	206	6	52,352	2011	695	447	66	1,208
1993	54,512	2,536	83	57,132	2012	503	427	45	975
1994	58,091	554	15	58,659	2013	2,342	309	313	2,964
1995	28,109	36,714	102	64,925	2014*	2,060	176	111	2,347

*as of October 7, 2014

Table 1A.3. Time series of ABC, TAC, OFL, and total catch for Aleutian Islands Region walleye pollock fisheries 1991-2014. Units are in metric tons.

YEAR	ABC	TAC	OFL	CATCH	CATCH/TAC
1991	101,460	72,250	NA	98,604	136%
1992	51,600	47,730	62,400	52,352	110%
1993	58,700	51,600	NA	57,132	111%
1994	56,600	56,600	60,400	58,659	104%
1995	56,600	56,600	60,400	64,925	115%
1996	35,600	35,600	47,000	29,062	82%
1997	28,000	28,000	38,000	25,940	93%
1998	23,800	23,800	31,700	23,798	100%
1999	23,800	2,000	31,700	1,010	51%
2000	23,800	2,000	31,700	1,244	62%
2001	23,800	2,000	31,700	825	41%
2002	23,800	1,000	31,700	1,177	116%
2003	39,400	1,000	52,600	1,649	167%
2004	39,400	1,000	52,600	1,158	116%
2005	29,400	19,000	39,100	1,621	9%
2006	29,400	19,000	39,100	1,745	9%
2007	44,500	19,000	54,500	2,519	13%
2008	28,160	19,000	34,040	1,278	7%
2009	26,873	19,000	32,553	1,662	9%
2010	33,100	19,000	40,000	1,285	7%
2011	36,700	19,000	44,500	1,208	6%
2012	32,500	19,000	39,600	975	5%
2013	37,300	19,000	45,600	2,964	16%
2014	35,048	19,000	42,811	2,347	12%

* As of October 7, 2014

Table 1A.4. Estimated walleye pollock catch discarded and retained for the Aleutian Islands Region based on NMFS blend data, 1990-2014.

Year	Catch Retained	Discard	Total	Discard Percentage
1990	69,682	9,343	79,025	12%
1991	93,373	5,231	98,604	5%
1992	49,369	2,983	52,352	6%
1993	55,399	1,733	57,132	3%
1994	57,286	1,373	58,659	2%
1995	63,545	1,380	64,925	2%
1996	28,067	994	29,062	3%
1997	25,323	618	25,940	2%
1998	23,636	162	23,798	1%
1999	529	480	1,010	48%
2000	455	790	1,244	63%
2001	445	380	825	46%
2002	398	779	1,177	66%
2003	1,181	468	1,649	28%
2004	871	287	1,158	25%
2005	1,297	324	1,621	20%
2006	1,434	311	1,745	18%
2007	2,094	425	2,519	17%
2008	1,197	81	1,278	6%
2009	1,268	395	1,662	24%
2010	1,143	142	1,285	11%
2011	1,133	75	1,208	6%
2012	880	95	975	10%
2013	2,856	107	2,964	4%
2014	2,237	110	2,347	5%

Table 1A.5. Sampling levels in Aleutian Islands Region sub-regions based on foreign, J.V., and domestic walleye pollock observer data 1978 - 2014.

	NRA Area			Aleutian Islands Area Basin		
Year	Fish Measured	Hauls Sampled	Vessels Sampled	Fish Measured	Hauls Sampled	Vessels Sampled
1978	6,229	112	11	0	0	0
1979	2,294	33	6	0	0	0
1980	6,779	116	10	0	0	0
1981	11,143	94	13	1,913	15	3
1982	36,932	331	25	11,151	84	7
1983	27,474	240	21	20,744	174	21
1984	54,980	527	35	157,388	1,223	81
1985	29,185	228	25	68,923	460	58
1986	22,918	193	15	39,875	268	48
1987	47,138	352	26	2,665	26	8
1988	23,376	192	18	4,528	37	14
1989	7,431	57	7	0	0	0
1990	67,280	582	35	55	35	11
1991	3,957	34	13	24,025	396	24
1992	22,120	185	40	26,525	234	26
1993	23,559	214	30	26,218	225	31
1994	20,838	203	41	19,524	205	35
1995	31,082	350	34	340	32	16
1996	18,745	194	40	90	1	1
1997	17,722	190	31	77	1	1
1998	10,494	123	15	93	1	1
1999	135	6	4	0	0	0
2000	186	10	5	0	0	0
2001	119	6	3	0	0	0
2002	112	4	4	0	0	0
2003	544	25	7	21	1	1
2004	331	15	4	34	2	1
2005	559	27	8	10	1	1
2006	59	3	3	30	2	1
2007	830	21	9	330	12	1
2008	129	7	3	0	0	0
2009	647	29	10	0	0	0
2010	529	17	7	0	0	0
2011	697	63	6	0	0	0
2012	154	13	5	0	0	0
2013	930	42	9	0	0	0
2014	513	25	5	0	0	0
Total	498,150	4,863		404,559	3,435	

Table 1A.6. Number of aged and weighed fish in the NRA pollock fishery used to estimate fishery age composition. Age data from the AICASS used in the model for 2006, 2007, and 2008 are in bold.

	Number Aged			Number Weighed		
Year	Males	Females	Total	Males	Females	Total
1978	167	273	440	187	294	481
1979	124	178	302	126	183	309
1980	93	167	260	188	291	479
1981	117	143	260	246	270	516
1982	464	519	983	572	642	1214
1983	60	63	123	278	308	586
1984	80	65	145	139	151	290
1985	77	113	190	295	355	650
1986	140	147	287	323	324	647
1987	131	142	273	136	147	283
1988	34	33	67	66	65	131
1989	0	0	0	112	147	259
1990	0	0	0	340	410	750
1991	5	5	10	20	30	50
1992	9	19	28	34	45	79
1993	38	45	83	48	56	104
1994	84	78	162	102	106	208
1995	64	70	134	147	158	305
1996	70	60	130	93	83	176
1997	15	15	30	15	15	30
1998	124	143	267	126	145	271
1999	0	0	0	0	0	0
2000	0	1	1	3	17	20
2001	0	1	1	12	7	19
2002	0	0	0	1	1	2
2003	1	0	1	33	31	64
2004	0	0	0	4	15	19
2005	2	2	4	21	9	30
2006	**150**/0	**183**/0	**333**/0	**1,315**/0	**1,630**/0	**2,945**/0
2007	**542**/0	**526**/0	**1,068**/0	**701**/71	**605**/58	**1,306**/129
2008	**366**/0	**359**/0	**725**/0	**1,142**/1	**1,031**/1	**2,173**/2
2009	10	5	15	50	40	90
2010	0	0	0	29	38	67
2011	0	0	0	37	37	74
2012	0	0	0	8	9	17
2013	0	0	0	57	87	144
2014	0	0	0	18	41	59

Table 1A.7. Estimates of catch-age composition from the Aleutian Islands commercial fishery 1978-1987, 1994-1996, 1998, and the Aleutian Islands cooperative acoustic surveys for 2006-2008. Shaded cells are the highest proportion for the year.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1978	0.014	0.000	0.020	0.091	0.052	0.327	0.082	0.099	0.116	0.098	0.072	0.018	0.008	0.001	0.004
1979	0.010	0.004	0.117	0.139	0.132	0.177	0.147	0.077	0.078	0.048	0.032	0.028	0.002	0.001	0.006
1980	0.000	0.127	0.060	0.049	0.090	0.194	0.145	0.144	0.079	0.071	0.024	0.007	0.004	0.004	0.001
1981	0.031	0.000	0.113	0.091	0.064	0.093	0.156	0.152	0.113	0.093	0.036	0.027	0.015	0.013	0.003
1982	0.001	0.000	0.001	0.686	0.095	0.019	0.028	0.051	0.054	0.034	0.014	0.007	0.005	0.003	0.002
1983	0.060	0.000	0.000	0.000	0.534	0.112	0.069	0.053	0.074	0.059	0.034	0.000	0.000	0.005	0.000
1984	0.071	0.002	0.087	0.000	0.038	0.506	0.120	0.100	0.058	0.016	0.001	0.000	0.001	0.000	0.000
1985	0.002	0.005	0.016	0.225	0.050	0.128	0.426	0.082	0.038	0.021	0.003	0.003	0.000	0.001	0.000
1986	0.002	0.000	0.086	0.006	0.131	0.018	0.095	0.332	0.134	0.057	0.094	0.018	0.026	0.000	0.000
1987	0.012	0.000	0.000	0.245	0.068	0.068	0.010	0.033	0.423	0.041	0.042	0.002	0.022	0.015	0.018
1994	0.006	0.000	0.000	0.018	0.282	0.057	0.102	0.107	0.067	0.054	0.032	0.080	0.034	0.020	0.141
1995	0.006	0.000	0.018	0.049	0.000	0.267	0.014	0.110	0.111	0.022	0.065	0.046	0.086	0.020	0.187
1996	0.030	0.000	0.000	0.013	0.055	0.071	0.273	0.126	0.099	0.085	0.037	0.033	0.013	0.057	0.106
1998	0.004	0.000	0.015	0.003	0.265	0.085	0.055	0.038	0.074	0.064	0.052	0.143	0.062	0.070	0.070
2006	0.023	0.000	0.010	0.000	0.021	0.354	0.143	0.026	0.013	0.044	0.047	0.039	0.029	0.091	0.159
2007	0.001	0.000	0.004	0.009	0.007	0.046	0.272	0.250	0.074	0.042	0.039	0.065	0.022	0.039	0.131
2008	0.004	0.000	0.000	0.004	0.008	0.018	0.035	0.196	0.210	0.106	0.020	0.075	0.076	0.069	0.177

Table 1A.8. NRA pollock fishery average weight-at-age in kilograms used in authors' preferred model.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1978	0.160	0.122	0.358	0.568	0.675	0.753	0.856	0.986	1.106	1.187	1.249	1.341	1.467	1.497	1.243
1979	0.160	0.146	0.383	0.555	0.620	0.663	0.731	0.825	0.912	0.963	0.991	1.045	1.145	1.196	1.025
1980	0.160	0.197	0.510	0.762	0.878	0.937	0.999	1.088	1.183	1.244	1.262	1.285	1.348	1.374	1.196
1981	0.160	0.126	0.335	0.546	0.681	0.744	0.773	0.812	0.873	0.924	0.929	0.905	0.894	0.879	0.787
1982	0.160	0.125	0.316	0.535	0.717	0.817	0.845	0.871	0.934	0.997	0.989	0.917	0.867	0.866	0.864
1983	0.160	0.149	0.318	0.508	0.698	0.829	0.879	0.911	0.981	1.048	1.016	0.899	0.851	0.933	1.133
1984	0.160	0.215	0.380	0.534	0.698	0.845	0.932	0.993	1.080	1.146	1.092	0.961	0.939	1.157	1.752
1985	0.160	0.319	0.512	0.616	0.735	0.877	0.996	1.098	1.209	1.278	1.211	1.075	1.082	1.403	2.453
1986	0.160	0.248	0.493	0.579	0.636	0.720	0.807	0.895	0.994	1.066	1.033	0.927	0.907	1.158	1.734
1987	0.160	0.096	0.430	0.697	0.817	0.870	0.886	0.912	0.991	1.111	1.194	1.180	1.126	1.105	1.060
1988	0.160	0.253	0.395	0.564	0.704	0.791	0.855	0.926	1.000	1.049	1.065	1.060	1.045	1.011	0.950
1989	0.160	0.253	0.395	0.564	0.704	0.791	0.855	0.926	1.000	1.049	1.065	1.060	1.045	1.011	0.950
1990	0.160	0.253	0.395	0.564	0.704	0.791	0.855	0.926	1.000	1.049	1.065	1.060	1.045	1.011	0.950
1991	0.416	0.494	0.588	0.706	0.855	1.029	1.202	1.340	1.423	1.457	1.465	1.463	1.453	1.431	1.396
1992	0.416	0.494	0.588	0.706	0.855	1.029	1.202	1.340	1.423	1.457	1.465	1.463	1.453	1.431	1.396
1993	0.416	0.494	0.588	0.706	0.855	1.029	1.202	1.340	1.423	1.457	1.465	1.463	1.453	1.431	1.396
1994	0.416	0.508	0.583	0.683	0.813	0.962	1.107	1.221	1.290	1.317	1.319	1.309	1.295	1.275	1.247
1995	0.416	0.602	0.691	0.813	0.976	1.165	1.351	1.495	1.578	1.607	1.606	1.594	1.579	1.557	1.525
1996	0.179	0.177	0.248	0.405	0.649	0.954	1.219	1.372	1.441	1.471	1.467	1.420	1.346	1.293	1.299
1997	0.179	0.256	0.371	0.558	0.859	1.238	1.540	1.652	1.650	1.670	1.748	1.827	1.840	1.791	1.740
1998	0.179	0.277	0.383	0.552	0.774	0.995	1.157	1.253	1.312	1.362	1.400	1.413	1.400	1.385	1.397
1999	0.179	0.256	0.371	0.558	0.859	1.238	1.540	1.652	1.650	1.670	1.748	1.827	1.840	1.791	1.740
2000	0.179	0.256	0.371	0.558	0.859	1.238	1.540	1.652	1.650	1.670	1.748	1.827	1.840	1.791	1.740
2001	0.179	0.256	0.371	0.558	0.859	1.238	1.540	1.652	1.650	1.670	1.748	1.827	1.840	1.791	1.740
2002	0.179	0.256	0.371	0.558	0.859	1.238	1.540	1.652	1.650	1.670	1.748	1.827	1.840	1.791	1.740
2003	0.179	0.256	0.371	0.558	0.859	1.238	1.540	1.652	1.650	1.670	1.748	1.827	1.840	1.791	1.740
2004	0.179	0.256	0.371	0.558	0.859	1.238	1.540	1.652	1.650	1.670	1.748	1.827	1.840	1.791	1.740
2005	0.179	0.256	0.371	0.558	0.859	1.238	1.540	1.652	1.650	1.670	1.748	1.827	1.840	1.791	1.740
2006	0.179	0.319	0.459	0.705	1.048	1.392	1.621	1.722	1.772	1.844	1.951	2.052	2.085	2.021	1.893
2007	0.179	0.251	0.375	0.610	0.963	1.327	1.561	1.643	1.665	1.710	1.801	1.898	1.939	1.892	1.784
2008	0.179	0.223	0.345	0.575	0.930	1.316	1.589	1.706	1.744	1.789	1.869	1.958	2.003	1.974	1.890
2009	0.179	0.256	0.371	0.558	0.859	1.238	1.540	1.652	1.650	1.670	1.748	1.827	1.840	1.791	1.740
2010	0.179	0.256	0.371	0.558	0.859	1.238	1.540	1.652	1.650	1.670	1.748	1.827	1.840	1.791	1.740
2011	0.179	0.256	0.371	0.558	0.859	1.238	1.540	1.652	1.650	1.670	1.748	1.827	1.840	1.791	1.740
2012	0.179	0.256	0.371	0.558	0.859	1.238	1.540	1.652	1.650	1.670	1.748	1.827	1.840	1.791	1.740
2013	0.179	0.256	0.371	0.558	0.859	1.238	1.540	1.652	1.650	1.670	1.748	1.827	1.840	1.791	1.740
2014	0.179	0.256	0.371	0.558	0.859	1.238	1.540	1.652	1.650	1.670	1.748	1.827	1.840	1.791	1.740

Table 1A.9. Pollock biomass estimates from the Aleutian Islands Groundfish Survey, 1980-2014.

	Eastern Area 541	Central Area 542	Western Area 543	Unalaska-Umnak Area (~165W-170W)	NRA 170W - 170E	
					Biomass	CV
1980	80,242	180,227	6,884	6,770	267,353	0.34
1983	164,286	183,542	118,234	104,515	466,063	0.17
1986	211,589	175,886	55,732	40,059	443,208	0.23
1991	60,932	50,259	26,701	51,644	137,891	0.19
1994	37,355	27,174	14,213	39,696	78,741	0.19
1997	38,541	36,764	18,115	65,400	93,420	0.22
2000	56,084	42,969	6,870	22,462	105,922	0.28
2002	54,634	108,179	13,140	181,334	175,953	0.38
2004	112,040	11,763	6,605	235,658	130,408	0.78
2006	69,996	18,002	6,514	18,006	94,512	0.48
2010	104,320	28,675	7,938	110,986	140,932	0.33
2012	31,488	7,433	5,360	13,237	44,281	0.55
2014	63,723	6,807	14,787	69,168	85,316	0.24

Table 1A.10. Aleutian Islands bottom trawl survey pollock proportion-at-age used in authors' preferred model. Shaded cells are the highest proportion for the year.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1983	0.001	0.107	0.046	0.019	0.448	0.173	0.055	0.059	0.049	0.024	0.011	0.004	0.001	0.000	0.000
1986	0.002	0.058	0.367	0.031	0.140	0.054	0.071	0.152	0.086	0.023	0.006	0.007	0.002	0.000	0.000
1991	0.061	0.049	0.128	0.298	0.125	0.029	0.036	0.021	0.063	0.027	0.043	0.014	0.045	0.031	0.028
1994	0.144	0.046	0.096	0.123	0.172	0.092	0.068	0.054	0.026	0.058	0.051	0.032	0.004	0.012	0.020
1997	0.042	0.067	0.070	0.106	0.110	0.082	0.060	0.122	0.083	0.040	0.067	0.044	0.035	0.025	0.046
2000	0.105	0.024	0.045	0.084	0.119	0.106	0.108	0.071	0.037	0.045	0.090	0.046	0.048	0.046	0.027
2002	0.043	0.046	0.095	0.093	0.068	0.073	0.106	0.076	0.075	0.056	0.068	0.046	0.058	0.026	0.071
2004	0.064	0.009	0.091	0.176	0.117	0.094	0.031	0.034	0.043	0.033	0.069	0.081	0.052	0.047	0.059
2006	0.039	0.006	0.083	0.093	0.093	0.171	0.117	0.080	0.023	0.034	0.042	0.041	0.046	0.069	0.064
2010	0.076	0.007	0.071	0.177	0.143	0.046	0.019	0.051	0.053	0.095	0.109	0.051	0.040	0.005	0.056
2012	0.129	0.018	0.053	0.018	0.075	0.236	0.106	0.016	0.015	0.038	0.053	0.108	0.080	0.042	0.016

Table 1A.11. Aleutian Islands bottom trawl survey pollock average weight-at-age in kilograms used in authors' preferred model.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1978	0.069	0.173	0.372	0.605	0.763	0.857	0.937	1.006	1.069	1.129	1.173	1.236	1.360	1.475	1.504
1979	0.069	0.173	0.372	0.605	0.763	0.857	0.937	1.006	1.069	1.129	1.173	1.236	1.360	1.475	1.504
1980	0.069	0.173	0.372	0.605	0.763	0.857	0.937	1.006	1.069	1.129	1.173	1.236	1.360	1.475	1.504
1981	0.069	0.173	0.372	0.605	0.763	0.857	0.937	1.006	1.069	1.129	1.173	1.236	1.360	1.475	1.504
1982	0.069	0.173	0.372	0.605	0.763	0.857	0.937	1.006	1.069	1.129	1.173	1.236	1.360	1.475	1.504
1983	0.063	0.163	0.458	0.642	0.715	0.824	0.919	1.031	1.022	1.193	1.199	1.081	1.442	1.593	1.428
1984	0.069	0.173	0.372	0.605	0.763	0.857	0.937	1.006	1.069	1.129	1.173	1.236	1.360	1.475	1.504
1985	0.069	0.173	0.372	0.605	0.763	0.857	0.937	1.006	1.069	1.129	1.173	1.236	1.360	1.475	1.504
1986	0.056	0.196	0.457	0.588	0.709	0.798	0.875	0.970	1.036	1.134	1.026	1.016	1.277	1.189	1.279
1987	0.065	0.180	0.388	0.600	0.736	0.820	0.893	0.970	1.036	1.064	1.068	1.096	1.162	1.231	1.274
1988	0.065	0.180	0.388	0.600	0.736	0.820	0.893	0.970	1.036	1.064	1.068	1.096	1.162	1.231	1.274
1989	0.065	0.180	0.388	0.600	0.736	0.820	0.893	0.970	1.036	1.064	1.068	1.096	1.162	1.231	1.274
1990	0.065	0.180	0.388	0.600	0.736	0.820	0.893	0.970	1.036	1.064	1.068	1.096	1.162	1.231	1.274
1991	0.109	0.207	0.531	0.749	0.828	0.944	1.051	1.209	1.195	1.186	1.322	1.046	1.289	1.118	1.077
1992	0.079	0.206	0.448	0.735	0.941	1.068	1.191	1.320	1.400	1.419	1.435	1.477	1.496	1.436	1.316
1993	0.079	0.206	0.448	0.735	0.941	1.068	1.191	1.320	1.400	1.419	1.435	1.477	1.496	1.436	1.316
1994	0.049	0.205	0.462	0.821	0.960	1.124	1.339	1.419	1.752	1.698	1.544	1.615	2.706	1.417	1.682
1995	0.079	0.206	0.448	0.735	0.941	1.068	1.191	1.320	1.400	1.419	1.435	1.477	1.496	1.436	1.316
1996	0.044	0.161	0.416	0.701	0.903	1.047	1.175	1.295	1.373	1.416	1.482	1.552	1.559	1.539	1.558
1997	0.051	0.211	0.381	0.700	0.894	0.999	1.149	1.327	1.301	1.354	1.458	1.506	1.495	1.497	1.479
1998	0.044	0.161	0.416	0.701	0.903	1.047	1.175	1.295	1.373	1.416	1.482	1.552	1.559	1.539	1.558
1999	0.044	0.161	0.416	0.701	0.903	1.047	1.175	1.295	1.373	1.416	1.482	1.552	1.559	1.539	1.558
2000	0.030	0.166	0.447	0.724	0.927	0.967	1.211	1.351	1.410	1.422	1.535	1.622	1.654	1.522	1.664
2001	0.041	0.184	0.475	0.731	0.950	1.160	1.298	1.432	1.604	1.719	1.751	1.755	1.722	1.673	1.652
2002	0.037	0.226	0.464	0.700	1.029	1.165	1.340	1.273	1.725	1.947	1.699	1.876	1.756	1.823	1.775
2003	0.041	0.184	0.475	0.731	0.950	1.160	1.298	1.432	1.604	1.719	1.751	1.755	1.722	1.673	1.652
2004	0.031	0.222	0.486	0.787	0.939	0.993	1.347	1.292	1.735	1.553	1.704	1.595	1.593	1.575	1.506
2005	0.041	0.184	0.475	0.731	0.950	1.160	1.298	1.432	1.604	1.719	1.751	1.755	1.722	1.673	1.652
2006	0.047	0.182	0.467	0.621	0.920	1.217	1.247	1.298	1.513	1.830	1.731	1.600	1.665	1.659	1.576
2007	0.041	0.184	0.475	0.731	0.950	1.160	1.298	1.432	1.604	1.719	1.751	1.755	1.722	1.673	1.652
2008	0.041	0.184	0.475	0.731	0.950	1.160	1.298	1.432	1.604	1.719	1.751	1.755	1.722	1.673	1.652
2009	0.041	0.184	0.475	0.731	0.950	1.160	1.298	1.432	1.604	1.719	1.751	1.755	1.722	1.673	1.652
2010	0.047	0.213	0.454	0.722	0.948	1.029	1.529	1.357	1.544	1.678	1.863	1.913	1.738	1.748	1.725
2011	0.041	0.184	0.475	0.731	0.950	1.160	1.298	1.432	1.604	1.719	1.751	1.755	1.722	1.673	1.652
2012	0.035	0.167	0.458	0.784	1.039	1.157	1.367	1.672	1.724	1.563	1.730	1.943	1.707	1.670	1.665
2013	0.041	0.184	0.475	0.731	0.950	1.160	1.298	1.432	1.604	1.719	1.751	1.755	1.722	1.673	1.652
2014	0.041	0.184	0.475	0.731	0.950	1.160	1.298	1.432	1.604	1.719	1.751	1.755	1.722	1.673	1.652

Table 1A.12. Percentage mature females at age from Wespestad and Terry (1984) for the BSAI and mean percentage of mature females at age for the Gulf of Alaska from Dorn et al. (2009) for 1983-2006 (GOA).

Age	1	2	3	4	5	6	7	8	9	10	11	12	13-15
BSAI	0.0	0.8	28.9	64.1	84.2	90.1	94.7	96.3	97.0	97.8	98.4	99.0	100
GOA	0.0	0.1	2.1	26.9	56.5	81.3	89.9	95.9	98.4	99.0	100	100	100

Table 1A.13. Estimated instantaneous natural mortality rates (*M*) by age from Wespestad and Terry (1984) for the Bering Sea and natural mortality rates in Model 2 (M2) and Model 3 (M3).

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
M	0.85	0.45	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5
M2	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
M3	0.86	0.68	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.37

Table 1A.14. Estimated von Bertalanffy growth curve parameters and length-weight regression parameters for walleye pollock sampled during the U.S.-Japan 1980, 1983, and 1986 groundfish surveys and the 1991, 1994, 1997, 2000, 2002, 2006, 2010, 2012, and 2014 RACE groundfish surveys.

	L_{inf}	K	t_0	a	b
1980	51.92	0.414	-0.525	0.0132	2.858
1983	53.26	0.383	0.002	0.0178	2.768
1986	51.02	0.443	-0.084	0.0142	2.831
1991	54.55	0.392	-0.361	0.0104	2.912
1994	61.58	0.330	-0.102	0.0069	3.022
1997	61.41	0.286	-0.397	0.0081	2.983
2000	62.58	0.306	-0.048	0.0064	3.019
2002	64.36	0.289	-0.127	0.0066	3.018
2004	61.76	0.332	-0.189	0.0065	3.022
2006	64.45	0.271	-0.278	0.0000075	2.991
2010	65.01	0.267	-0.279	0.0000083	2.981
2012	66.70	0.260	-0.144	0.0000069	3.005
2014	NA	NA	NA	0.0000072	2.996

Table 1A.15. Aging error matrix used in the authors' preferred model developed from aging validation tests for 2006-2008.

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1	0.9744	0.0256	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0256	0.9488	0.0256	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0389	0.9222	0.0389	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0000	0.0000	0.0537	0.8927	0.0537	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000	0.0692	0.8615	0.0692	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0000	0.0000	0.0851	0.8299	0.0851	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	0.0000	0.0000	0.0000	0.0000	0.0001	0.1007	0.7985	0.1007	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.1159	0.7678	0.1159	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000
9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.1305	0.7383	0.1305	0.0004	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0007	0.1442	0.7100	0.1442	0.0007	0.0000	0.0000	0.0000
11	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0013	0.1571	0.6832	0.1571	0.0013	0.0000	0.0000
12	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0022	0.1689	0.6577	0.1689	0.0022	0.0000
13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0034	0.1798	0.6337	0.1798	0.0034
14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0049	0.1896	0.6110	0.1945
15+	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0068	0.1985	0.7948

Table 1A.16. Evaluation of 2014 Aleutian Islands pollock model. Comparisons of likelihoods between Model 1 and Model 2 are not valid because the two models are based on different data.

	Model 1	**Model 2**	**Model 3**
Number of Parameters	136	137	137
Survey Catchability	1.00	1.00	1.00
Fishery Average Effective *N*	49.80	47.21	45.80
Survey Average Effective *N*	84.14	78.85	95.01
RMSE Survey	0.55	0.55	0.56
RMSE Fish Ages (2-15)	0.041	0.042	0.042
RMSE Survey Ages (2-15)	0.041	0.039	0.037
-Log Likelihoods			
Survey Index	29.536	30.493	29.832
Fishery Age Comp	247.249	275.080	268.686
Survey Age Comp	59.624	67.836	53.696
Catch	0.881	0.937	0.882
Sub Total	337.290	374.346	353.096
-log Penalties			
Recruitment	51.864	52.210	49.393
Selectivity Constraints			
Survey	3.794	1.810	1.858
Fishery	18.260	15.562	16.697
Prior	0.005	0.065	2.978
Fpen	0.001	0.001	0.001
Residual	0.006	0.012	0.000
Total	411.219	444.006	424.023

Table 1A.17. Key results for the evaluations of Aleutian Islands pollock models.

	Model 1	Model 2	Model 3
Model Conditions			
Survey Catchability	1.00	1.00	1.00
Mean Natural Mortality	0.20	0.19	0.22
Fishing Mortalities			
Max $F_{1978-2014}$	0.264	0.242	0.250
F_{2013}	0.016	0.015	0.014
Stock Abundance			
Initial Biomass (1978; thousands of tons)	465.30	462.68	365.54
CV	9%	8%	7%
2014 Total Biomass 1+ (thousands of tons)	203.65	203.14	195.69
CV	12%	12%	11%
2014 Female SSB (thousands of tons)	71.22	68.28	70.67
CV	11%	11%	12%
1978 Year Class (billions at age 1)	1.19	1.26	2.77
	11%	11%	16%
Recruitment Variability (1978-2010)	0.89	0.89	0.89
Recruitment variance (σ_R^2)	0.60	0.60	0.60
Steepness (*h*)	0.70	0.70	0.70

Table 1A.18 Model 2 estimates of 2014 fishery and survey selectivity-at-age used in projections.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
Survey	0.183	0.235	0.333	0.469	0.626	0.786	0.905	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Fishery	0.014	0.030	0.066	0.141	0.281	0.500	0.765	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 1A.19. The authors' preferred Model 2 estimates of pollock biomass with approximate lower (LCI) and upper (UCI) 95% confidence bounds for age 1+ biomass and female spawning stock biomass (SSB) estimates.

Model 2	**Total Biomass (Age 1+)**			**Female SSB**		
Year		**LCI**	**UCI**		**LCI**	**UCI**
1978	462,679	392,168	545,868	144,510	121,603	171,732
1979	524,607	448,503	613,625	157,392	133,262	185,892
1980	648,030	557,386	753,416	161,356	136,513	190,720
1981	777,009	662,570	911,214	147,477	122,490	177,563
1982	839,070	715,600	983,845	191,977	161,860	227,697
1983	823,679	700,808	968,094	243,743	205,881	288,569
1984	824,847	703,648	966,922	275,810	232,648	326,979
1985	811,251	697,230	943,917	265,271	223,931	314,242
1986	814,447	706,863	938,405	257,856	218,345	304,515
1987	823,567	723,392	937,613	276,346	238,185	320,621
1988	803,206	714,206	903,296	284,616	249,670	324,453
1989	752,991	676,183	838,524	278,275	247,073	313,418
1990	726,350	660,809	798,391	262,566	236,559	291,433
1991	597,040	541,563	658,201	211,945	191,064	235,109
1992	499,089	449,756	553,833	173,062	155,579	192,509
1993	440,489	396,238	489,683	153,639	138,241	170,752
1994	372,005	332,146	416,647	131,453	117,614	146,921
1995	301,506	264,585	343,578	106,530	93,749	121,052
1996	241,992	206,899	283,037	82,490	70,840	96,056
1997	211,828	177,819	252,341	72,358	60,980	85,858
1998	191,573	158,335	231,788	65,702	54,301	79,497
1999	165,104	133,223	204,614	59,439	48,015	73,581
2000	164,785	133,888	202,812	60,948	49,612	74,874
2001	169,620	138,533	207,682	61,237	50,149	74,777
2002	181,871	149,076	221,881	60,594	49,892	73,591
2003	194,211	159,486	236,497	61,655	50,954	74,604
2004	197,872	162,732	240,598	66,684	55,192	80,570
2005	195,255	160,891	236,960	72,057	59,632	87,070
2006	188,429	155,447	228,409	73,720	60,947	89,169
2007	182,509	150,711	221,015	71,417	58,998	86,449
2008	183,739	151,496	222,843	68,180	56,219	82,686
2009	191,402	157,267	232,945	66,353	54,657	80,551
2010	194,099	158,738	237,336	67,233	55,308	81,730
2011	192,847	157,029	236,837	69,876	57,233	85,314
2012	192,687	156,027	237,960	70,970	57,740	87,233
2013	195,203	156,991	242,717	69,787	56,466	86,252
2014	203,141	161,093	256,164	68,279	54,786	85,094
2015	214,200	161,729	266,671	70,090	55,620	88,325

Table 1A.20. Authors' preferred Model 2 estimates of pollock numbers at age in billions (10^9).

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Total	% of 15+
1978	0.12	0.11	0.09	0.11	0.06	0.09	0.02	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.02	0.69	3.3%
1979	1.26	0.10	0.09	0.07	0.09	0.05	0.07	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.02	1.82	1.1%
1980	0.04	1.04	0.08	0.08	0.06	0.07	0.04	0.06	0.01	0.01	0.01	0.01	0.01	0.00	0.02	1.54	1.2%
1981	0.05	0.04	0.86	0.07	0.06	0.04	0.05	0.03	0.04	0.01	0.01	0.01	0.01	0.00	0.01	1.28	1.0%
1982	0.31	0.04	0.03	0.70	0.05	0.05	0.03	0.04	0.02	0.03	0.01	0.01	0.00	0.00	0.01	1.33	0.9%
1983	0.12	0.26	0.04	0.02	0.55	0.04	0.03	0.02	0.02	0.01	0.02	0.00	0.00	0.00	0.01	1.16	0.9%
1984	0.49	0.10	0.21	0.03	0.02	0.42	0.03	0.02	0.02	0.02	0.01	0.01	0.00	0.00	0.01	1.40	0.7%
1985	0.10	0.41	0.08	0.17	0.02	0.02	0.32	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.01	1.21	0.7%
1986	0.10	0.08	0.33	0.07	0.14	0.02	0.01	0.24	0.02	0.01	0.01	0.01	0.00	0.01	0.01	1.06	0.8%
1987	0.21	0.08	0.07	0.28	0.06	0.11	0.01	0.01	0.19	0.01	0.01	0.01	0.01	0.00	0.01	1.07	1.0%
1988	0.12	0.18	0.07	0.06	0.22	0.05	0.09	0.01	0.01	0.14	0.01	0.01	0.00	0.01	0.01	0.98	1.1%
1989	0.06	0.10	0.15	0.05	0.04	0.18	0.03	0.07	0.01	0.01	0.11	0.01	0.01	0.00	0.01	0.84	1.4%
1990	0.22	0.05	0.08	0.12	0.04	0.04	0.14	0.03	0.05	0.01	0.00	0.09	0.01	0.00	0.01	0.90	1.4%
1991	0.04	0.18	0.04	0.07	0.10	0.03	0.03	0.10	0.02	0.03	0.00	0.00	0.05	0.00	0.01	0.71	1.5%
1992	0.06	0.03	0.15	0.03	0.05	0.07	0.02	0.02	0.06	0.01	0.02	0.00	0.00	0.03	0.01	0.58	1.6%
1993	0.05	0.05	0.03	0.12	0.03	0.04	0.05	0.02	0.01	0.04	0.01	0.01	0.00	0.00	0.03	0.49	6.0%
1994	0.09	0.04	0.04	0.02	0.10	0.02	0.03	0.04	0.01	0.01	0.03	0.00	0.01	0.00	0.02	0.45	4.4%
1995	0.03	0.07	0.03	0.03	0.02	0.07	0.01	0.02	0.02	0.01	0.00	0.02	0.00	0.01	0.01	0.36	3.6%
1996	0.05	0.03	0.06	0.03	0.03	0.01	0.05	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.31	3.5%
1997	0.03	0.04	0.02	0.05	0.02	0.02	0.01	0.03	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.26	3.1%
1998	0.02	0.03	0.03	0.02	0.04	0.02	0.01	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.22	4.4%
1999	0.03	0.02	0.02	0.03	0.01	0.03	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.20	3.6%
2000	0.07	0.03	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.24	2.8%
2001	0.10	0.06	0.02	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.30	2.7%
2002	0.03	0.08	0.05	0.02	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.00	0.01	0.00	0.01	0.27	3.1%
2003	0.02	0.02	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.25	3.2%
2004	0.03	0.02	0.02	0.06	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.23	5.1%
2005	0.02	0.02	0.02	0.02	0.05	0.03	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.21	5.3%
2006	0.05	0.01	0.02	0.01	0.01	0.04	0.02	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.22	5.2%
2007	0.09	0.04	0.01	0.02	0.01	0.01	0.03	0.02	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.27	4.5%
2008	0.04	0.07	0.03	0.01	0.01	0.01	0.01	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.26	5.6%
2009	0.02	0.03	0.06	0.03	0.01	0.01	0.01	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.24	5.8%
2010	0.05	0.02	0.03	0.05	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.00	0.00	0.00	0.01	0.24	6.0%
2011	0.03	0.04	0.02	0.02	0.04	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.24	6.0%
2012	0.09	0.03	0.03	0.01	0.02	0.03	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.28	4.7%
2013	0.06	0.07	0.02	0.03	0.01	0.02	0.03	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.30	4.4%
2014	0.07	0.05	0.06	0.02	0.02	0.01	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.31	5.0%

Table 1A.21. Authors' preferred Model 2 estimated NRA region pollock catch at age in millions (10^6). **2014** catch numbers estimated with the 2014 total year end catch estimate of 3,000 t.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Total
1978	0.07	0.12	0.25	0.86	0.78	1.7	0.56	0.71	0.54	0.39	0.26	0.13	0.1	0.08	0.71	7.26
1979	1.08	0.17	0.42	0.93	1.88	1.45	2.85	0.87	0.9	0.69	0.5	0.33	0.16	0.12	0.99	13.34
1980	0.18	8.54	1.75	4.55	5.72	9.64	6.6	11.95	2.95	3.03	2.32	1.68	1.12	0.54	3.75	64.32
1981	0.15	0.21	12.94	2.9	4.18	4.33	6.39	3.96	5.64	1.39	1.43	1.1	0.79	0.53	2.03	47.97
1982	1.08	0.31	0.55	36.38	4.54	5.42	4.94	6.62	3.26	4.64	1.14	1.17	0.9	0.65	2.1	73.7
1983	0.31	1.33	0.48	0.93	34.55	3.58	3.76	3.11	3.3	1.62	2.31	0.57	0.59	0.45	1.37	58.26
1984	1.02	0.43	2.3	0.91	1.0	30.87	2.83	2.73	1.8	1.91	0.94	1.34	0.33	0.34	1.05	49.8
1985	0.19	1.6	0.86	5.06	1.13	1.04	28.65	2.43	1.87	1.23	1.3	0.64	0.91	0.23	0.95	48.09
1986	0.11	0.19	1.98	1.17	3.92	0.74	0.61	15.54	1.05	0.81	0.53	0.56	0.28	0.4	0.51	28.4
1987	0.25	0.19	0.41	4.83	1.63	4.63	0.78	0.6	12.36	0.84	0.64	0.42	0.45	0.22	0.72	28.97
1988	0.21	0.63	0.6	1.45	9.73	2.77	7.07	1.11	0.68	14.07	0.95	0.73	0.48	0.51	1.07	42.06
1989	0.03	0.1	0.39	0.42	0.57	3.25	0.83	1.98	0.25	0.15	3.15	0.21	0.16	0.11	0.35	11.95
1990	0.84	0.4	1.54	5.45	4.25	5.22	26.47	6.07	11.63	1.46	0.9	18.53	1.25	0.96	2.72	87.69
1991	0.17	1.59	0.83	3.33	10.04	5.16	5.11	22.47	4.19	8.03	1.01	0.62	12.8	0.87	2.55	78.77
1992	0.16	0.19	1.94	1.07	3.66	7.34	3.06	2.64	9.42	1.76	3.37	0.42	0.26	5.36	1.43	42.08
1993	0.18	0.35	0.46	4.87	2.3	5.29	8.65	3.16	2.24	7.99	1.49	2.86	0.36	0.22	5.76	46.18
1994	0.39	0.41	0.87	1.2	10.78	3.37	6.23	8.85	2.64	1.87	6.67	1.24	2.39	0.3	5	52.21
1995	0.16	0.76	0.86	1.91	2.2	12.9	3.21	5.1	5.87	1.75	1.24	4.42	0.82	1.58	3.51	46.29
1996	0.17	0.18	0.93	1.1	2.09	1.58	7.44	1.6	2.05	2.35	0.7	0.5	1.77	0.33	2.04	24.83
1997	0.08	0.24	0.28	1.51	1.54	1.95	1.21	4.98	0.87	1.12	1.29	0.38	0.27	0.97	1.3	17.99
1998	0.08	0.19	0.6	0.74	3.39	2.31	2.39	1.3	4.4	0.77	0.99	1.14	0.34	0.24	2	20.88
1999	0	0	0.01	0.04	0.04	0.14	0.09	0.08	0.03	0.12	0.02	0.03	0.03	0.01	0.06	0.7
2000	0.01	0.01	0.01	0.03	0.07	0.07	0.19	0.1	0.07	0.03	0.11	0.02	0.03	0.03	0.07	0.85
2001	0.01	0.01	0.01	0.01	0.03	0.07	0.05	0.12	0.05	0.04	0.02	0.06	0.01	0.01	0.05	0.55
2002	0	0.02	0.03	0.03	0.03	0.06	0.12	0.07	0.14	0.06	0.05	0.02	0.07	0.01	0.07	0.78
2003	0	0.01	0.06	0.08	0.07	0.07	0.11	0.17	0.08	0.17	0.07	0.05	0.02	0.08	0.1	1.14
2004	0	0.01	0.01	0.08	0.1	0.07	0.05	0.07	0.09	0.05	0.09	0.04	0.03	0.01	0.1	0.8
2005	0	0.01	0.01	0.03	0.17	0.2	0.1	0.07	0.08	0.1	0.05	0.1	0.04	0.03	0.13	1.12
2006	0.01	0	0.01	0.02	0.05	0.24	0.2	0.09	0.05	0.06	0.07	0.04	0.07	0.03	0.12	1.06
2007	0.02	0.02	0.01	0.04	0.05	0.1	0.41	0.3	0.11	0.06	0.07	0.09	0.04	0.09	0.18	1.59
2008	0	0.02	0.02	0.01	0.03	0.04	0.06	0.21	0.13	0.05	0.03	0.03	0.04	0.02	0.12	0.81
2009	0	0.01	0.05	0.04	0.03	0.06	0.07	0.09	0.25	0.15	0.06	0.03	0.04	0.05	0.16	1.09
2010	0.01	0.01	0.02	0.07	0.06	0.03	0.06	0.06	0.06	0.17	0.1	0.04	0.02	0.02	0.14	0.87
2011	0	0.01	0.01	0.03	0.1	0.08	0.04	0.06	0.04	0.05	0.13	0.08	0.03	0.02	0.13	0.81
2012	0.01	0.01	0.01	0.01	0.04	0.12	0.08	0.03	0.04	0.03	0.03	0.08	0.05	0.02	0.09	0.65
2013	0.02	0.04	0.03	0.08	0.06	0.17	0.43	0.25	0.08	0.1	0.07	0.07	0.19	0.12	0.26	1.97
2014	**0.02**	**0.03**	**0.08**	**0.06**	**0.13**	**0.09**	**0.21**	**0.47**	**0.2**	**0.06**	**0.08**	**0.05**	**0.06**	**0.16**	**0.31**	**2.01**

Table 1A.22. Authors' preferred Model 2 estimates of full-selection fishing mortality and exploitation rates for NRA pollock.

Year	F[a]	Catch/Biomass Rate[b]
1978	0.024	0.014
1979	0.038	0.018
1980	0.178	0.090
1981	0.127	0.040
1982	0.155	0.060
1983	0.113	0.054
1984	0.092	0.052
1985	0.086	0.058
1986	0.050	0.029
1987	0.051	0.032
1988	0.077	0.046
1989	0.022	0.014
1990	0.182	0.109
1991	0.200	0.165
1992	0.129	0.105
1993	0.163	0.130
1994	0.216	0.158
1995	0.242	0.215
1996	0.158	0.120
1997	0.128	0.122
1998	0.170	0.124
1999	0.006	0.006
2000	0.007	0.008
2001	0.005	0.005
2002	0.007	0.006
2003	0.009	0.008
2004	0.006	0.006
2005	0.008	0.008
2006	0.008	0.009
2007	0.011	0.014
2008	0.006	0.007
2009	0.009	0.009
2010	0.007	0.007
2011	0.007	0.006
2012	0.005	0.005
2013	0.015	0.015
2014*	0.015	0.015

[a] Average fishing mortality rates over all ages

[b] Catch/biomass rate is the ratio of catch to beginning year age 1+ biomass.

* Assuming catch of 3,000t

Table 1A.23. Authors' preferred Model 2 estimates of pollock recruitment (in millions), age 2 for 2013 and age 1 for 2014 model.

2013 Authors' preferred Model			2014 Authors' preferred Model		
Year	Index at age 2	St. Dev.	Year	Index at age 1	St. Dev.
1978	109.9	23.4	1978	121.1	29.4
1979	143.8	34.5	1979	1,258.5	141.9
1980	1404.6	150.6	1980	43.9	16.1
1981	49.4	19.1	1981	52.3	16.9
1982	78.5	22.4	1982	309.7	54.8
1983	250.5	39.7	1983	122.6	38.5
1984	149.8	29.9	1984	489.2	78.2
1985	197.6	31.4	1985	98.1	37.0
1986	55.4	15.8	1986	95.9	33.7
1987	95.8	18.2	1987	214.7	39.9
1988	123.3	19.0	1988	121.3	25.1
1989	73.9	13.4	1989	60.2	15.6
1990	44.5	9.9	1990	217.2	27.2
1991	161.7	18.4	1991	40.5	9.8
1992	28.6	6.5	1992	58.4	11.2
1993	38.8	7.2	1993	51.5	10.7
1994	37.0	7.3	1994	85.6	14.4
1995	54.0	9.5	1995	31.7	7.6
1996	25.4	5.8	1996	50.8	9.9
1997	37.5	7.3	1997	31.1	6.8
1998	24.2	5.4	1998	22.3	5.4
1999	17.2	4.1	1999	33.4	7.1
2000	27.5	5.8	2000	72.9	12.4
2001	58.5	10.4	2001	97.5	15.4
2002	81.1	13.5	2002	28.8	6.4
2003	23.5	5.6	2003	22.4	5.5
2004	19.2	4.8	2004	26.8	6.2
2005	23.8	6.2	2005	17.4	5.0
2006	18.6	5.7	2006	45.7	10.4
2007	45.8	12.9	2007	86.7	18.3
2008	64.8	17.8	2008	41.6	10.5
2009	40.4	13.3	2009	22.3	7.1
2010	32.5	10.4	2010	46.2	12.6
2011	55.9	26.2	2011	34.4	12.2
2012	57.7	27.5	2012	86.3	26.0
2013	58.5	28.1	2013	64.1	30.3
2014			2014	65.5	31.3
Ave 78-10	115.0		Ave 78-10	124.8	
Med 78-10	54.0		Med 78-10	52.3	

Table 1A.24. Projections of Authors' preferred Model female spawning biomass (in thousands of t), fishing mortality (*F*), and catch (in thousands of t) for NRA pollock for the 8 scenarios. Fishing mortality rates given are based on the *average* fishing mortality over all ages *(B_0=207.606 kt, B_{40}=83.042 kt, B_{35}=72.662 kt, and ½ B_{35}=36.331 kt)*.

Sp.Biomass	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
2014	68.28	68.28	68.28	68.28	68.28	68.28	68.28	68.28
2015	67.89	67.89	70.22	69.01	70.31	67.31	67.89	68.81
2016	61.10	61.10	74.45	67.06	75.05	58.27	61.10	65.75
2017	59.07	59.07	79.80	67.33	80.88	55.49	58.69	64.60
2018	60.49	60.49	86.89	70.13	88.40	56.60	58.37	66.16
2019	65.57	65.57	97.31	76.64	99.25	61.41	62.35	71.87
2020	72.86	72.86	110.87	86.13	113.27	68.18	68.64	81.08
2021	79.14	79.14	124.40	95.35	127.29	73.69	73.90	90.73
2022	83.58	83.58	136.90	103.24	140.31	77.25	77.32	99.98
2023	85.83	85.83	147.60	109.10	151.58	78.68	78.70	108.08
2024	86.94	86.94	156.83	113.54	161.38	79.18	79.18	115.28
2025	87.89	87.89	165.12	117.30	170.24	79.71	79.70	122.00
2026	88.91	88.91	172.47	120.56	178.12	80.47	80.47	128.16
2027	89.21	89.21	177.97	122.55	184.10	80.63	80.62	132.87
F	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
2014	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2015	0.25	0.25	0.01	0.13	0.00	0.32	0.25	0.16
2016	0.23	0.23	0.01	0.13	0.00	0.27	0.23	0.17
2017	0.22	0.22	0.01	0.13	0.00	0.26	0.27	0.18
2018	0.22	0.22	0.01	0.13	0.00	0.26	0.27	0.18
2019	0.24	0.24	0.01	0.13	0.00	0.28	0.28	0.17
2020	0.25	0.25	0.01	0.13	0.00	0.30	0.30	0.16
2021	0.26	0.26	0.01	0.13	0.00	0.31	0.31	0.15
2022	0.26	0.26	0.01	0.13	0.00	0.32	0.32	0.14
2023	0.27	0.27	0.01	0.13	0.00	0.32	0.32	0.13
2024	0.27	0.27	0.01	0.13	0.00	0.33	0.33	0.12
2025	0.27	0.27	0.01	0.13	0.00	0.33	0.33	0.12
2026	0.28	0.28	0.01	0.13	0.00	0.33	0.33	0.11
2027	0.27	0.27	0.01	0.13	0.00	0.33	0.33	0.11
Catch	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
2014	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
2015	29.66	29.66	1.24	16.56	0.00	36.01	29.66	19.00
2016	22.60	22.60	1.26	15.26	0.00	25.33	22.60	19.00
2017	20.79	20.79	1.34	15.16	0.00	22.54	25.42	19.00
2018	21.69	21.69	1.47	15.75	0.00	23.34	24.96	19.00
2019	24.43	24.43	1.63	16.87	0.00	26.49	27.35	19.00
2020	28.03	28.03	1.81	18.39	0.00	30.72	31.13	19.00
2021	32.26	32.26	2.05	20.64	0.00	35.45	35.63	19.00
2022	35.87	35.87	2.32	23.01	0.00	39.06	39.13	19.00
2023	37.93	37.93	2.55	24.74	0.00	40.87	40.89	19.00
2024	39.00	39.00	2.73	25.98	0.00	41.65	41.65	19.00
2025	39.37	39.37	2.87	26.76	0.00	41.72	41.71	19.00
2026	39.63	39.63	3.00	27.38	0.00	41.83	41.82	19.00
2027	39.91	39.91	3.11	27.98	0.00	42.11	42.10	19.00

Table 1A.25. Ecosystem effects on AI walleye pollock

Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	**Stomach contents, ichthyoplankton surveys**	None	Unknown
Predator population trends			
Marine mammals	**Fur seals declining, Steller sea lions increasing slightly in central, decreasing in West.**	Possibly lower mortality on walleye pollock	No concern
Birds	**Stable, some increasing some decreasing**	May affect young-of-year mortality	Unknown
Fish (Pacific cod, arrowtooth flounder)	**Pacific cod—decreasing, arrowtooth--stable**	Possible decreases to walleye pollock mortality	No concern
Changes in habitat quality			
Temperature regime	**The 2012 AI summer bottom temperature was colder than average**	Cooling could affect apparent distribution.	Unknown

***The AI walleye pollock* effects on ecosystem**			
Indicator	**Observation**	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	**Expected to be heavily monitored**	Likely to be a minor contribution to mortality	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	**Expected to be heavily monitored.**	Bycatch levels should be low.	Unknown
HAPC biota (seapens/whips, corals, sponges, anemones)	**Very low bycatch levels of seapens/whips, sponge and coral catches expected in the pelagic fishery**	Bycatch levels and destruction of benthic habitat expected to be minor given the pelagic fishery.	No concern
Marine mammals and birds	**Very minor direct-take expected**	Likely to be very minor contribution to mortality	No concern
Sensitive non-target species	**Expected to be heavily monitored**	Unknown given that this fishery was closed between 1999 and 2005. The 2006 AICASS had 3% POP bycatch, the only significant bycatch. The 2005-2009 fishery had high bycatch of POP, but bycatch of other species was very low in fishery prior to 1999.	No concern
Other non-target species	**Very little bycatch.**	Unknown	No concern
Fishery concentration in space and time	**Newly opened areas should spread the fishery out more than under previous SSL protection measures.**	Depending on concentration of pollock outside of critical habitat could have an effect.	Possible concern
Fishery effects on amount of large size target fish	**Depends on highly variable year-class strength**	Natural fluctuation	Possible Concern
Fishery contribution to discards and offal production	**Offal production—unknown. 2015 fishery not expected to be significant.**	Unknown	Unknown
Fishery effects on age-at-maturity and fecundity	**Unknown**	Unknown	Unknown

Figures

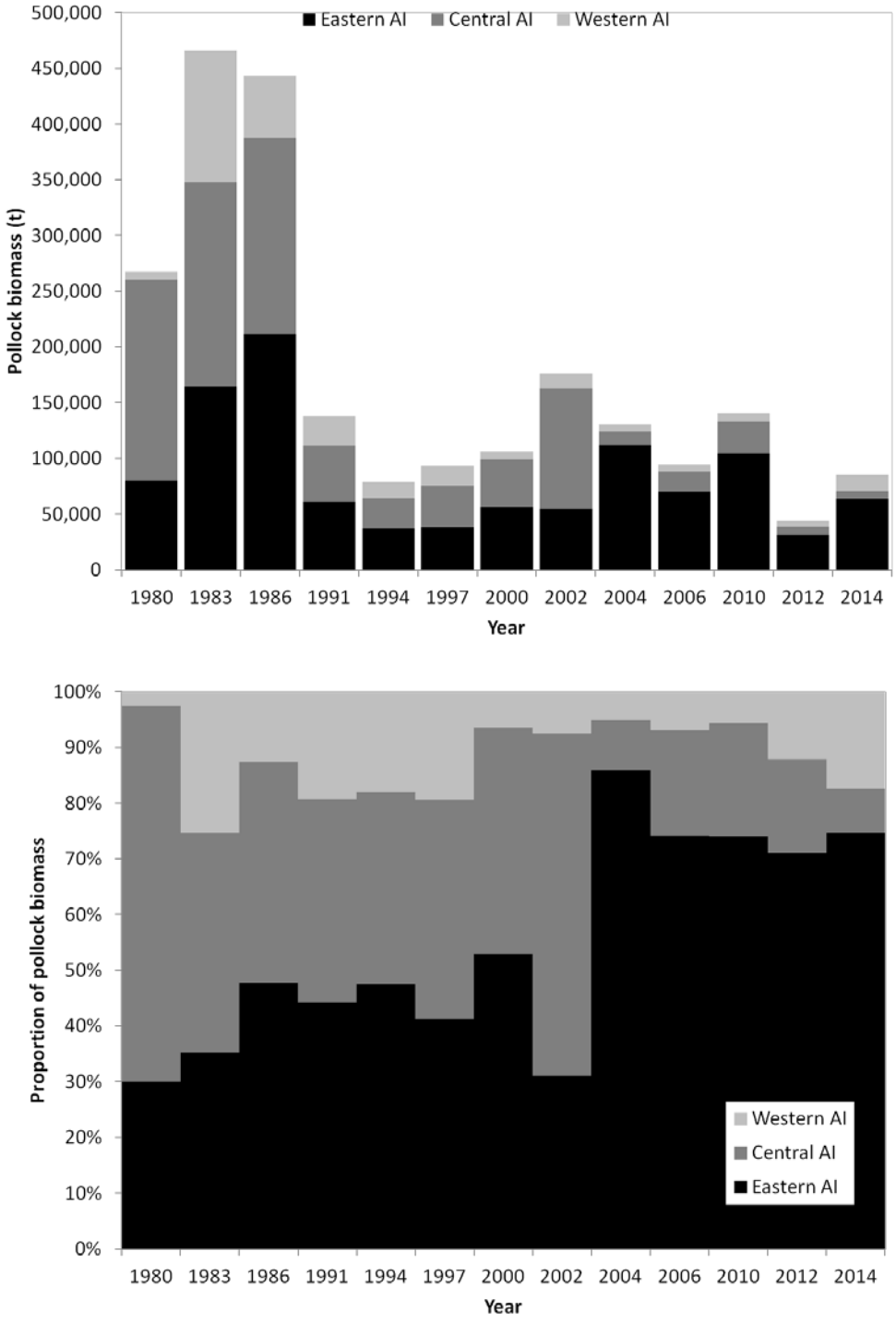

Figure 1A.1 Aleutian Islands bottom trawl survey pollock biomass (top) and proportion of biomass (bottom) for the three Aleutian Island management regions.

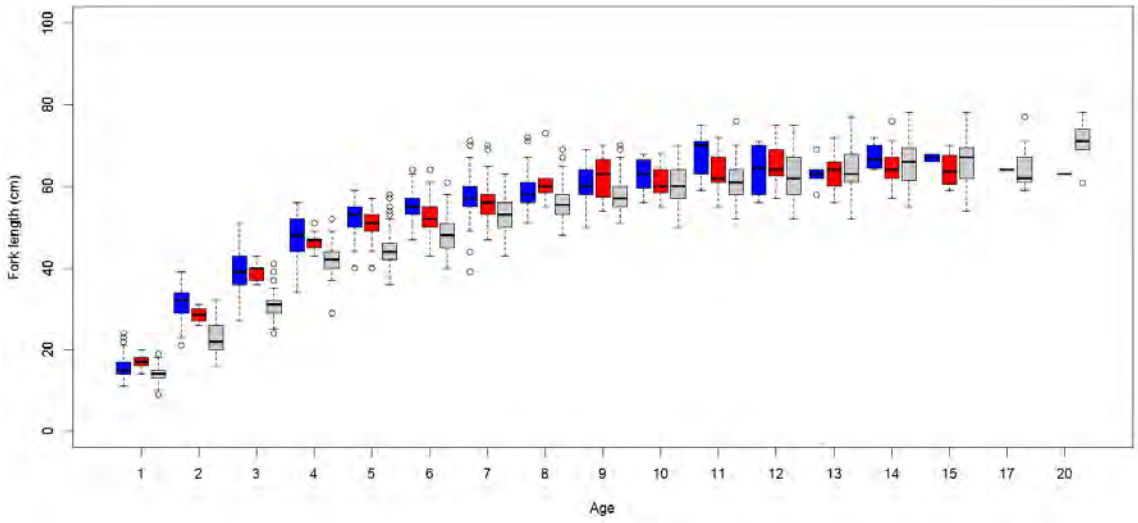

Figure 1A.2. Length at age for Aleutian Islands (red), Gulf of Alaska (blue), and Bering Sea (grey) pollock from the 2012 Aleutian Islands, 2013 Bering Sea, and 2013 Gulf of Alaska bottom trawl surveys.

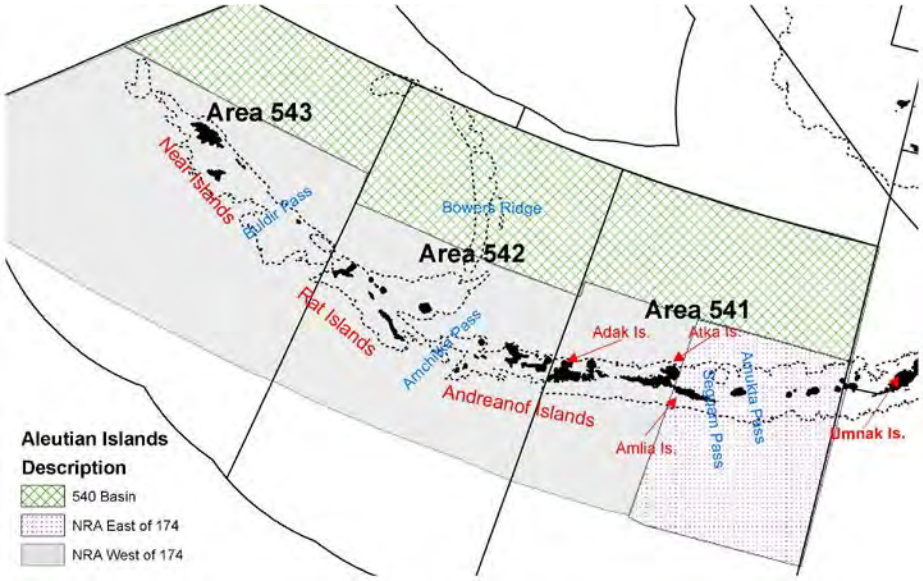

Figure 1A. 3. Regions defined for consideration of alternative data partitions for Aleutian Islands Region pollock. The abbreviation "NRA" represents the Near, Rat, and Andreanof Island group. There are no models for 2014 that consider the NRA east-west partition.

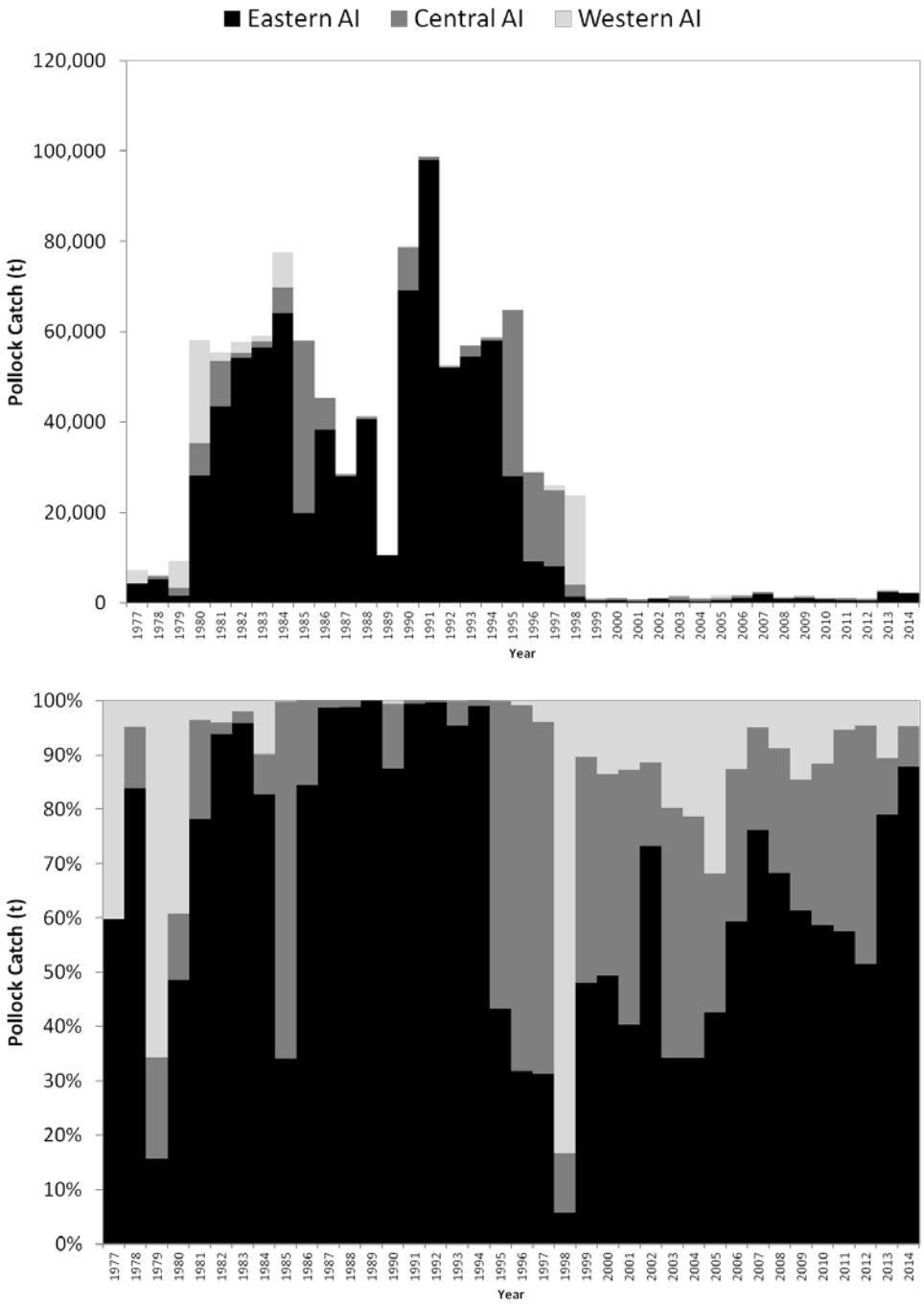

Figure 1A.4. Pollock catch by NMFS reporting area for 1977- 2014 by total catch (top) and percentage of catch by area (bottom).

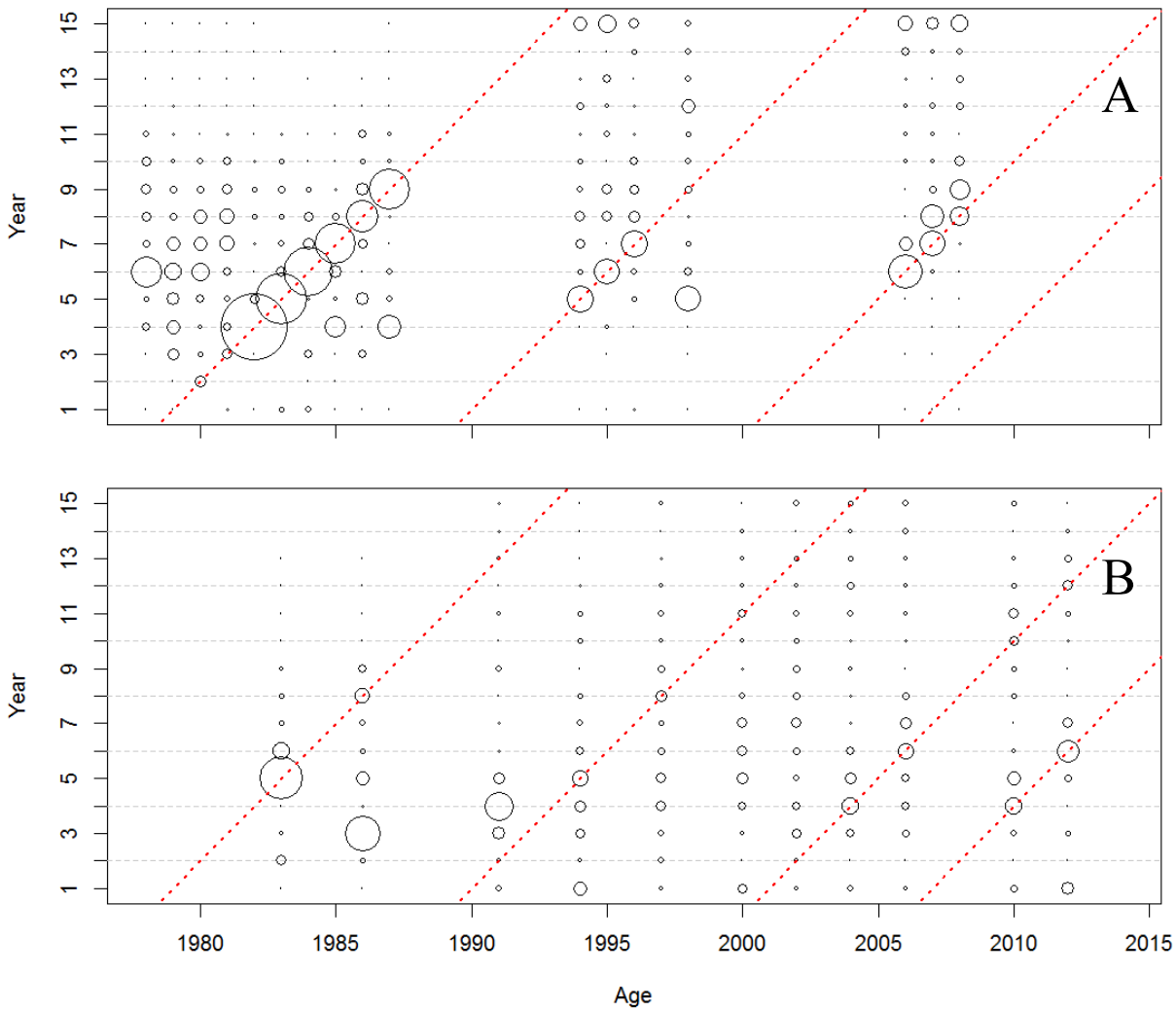

Figure 1A.5. Age distributions for 1978-2008 Aleutian Islands pollock fishery (A; top) and 1980 - 2014 Aleutian Islands Bottom Trawl surveys (B; bottom). The 1978, 1989, 2000, and 2006 year classes are indicated by the diagonal dashed lines.

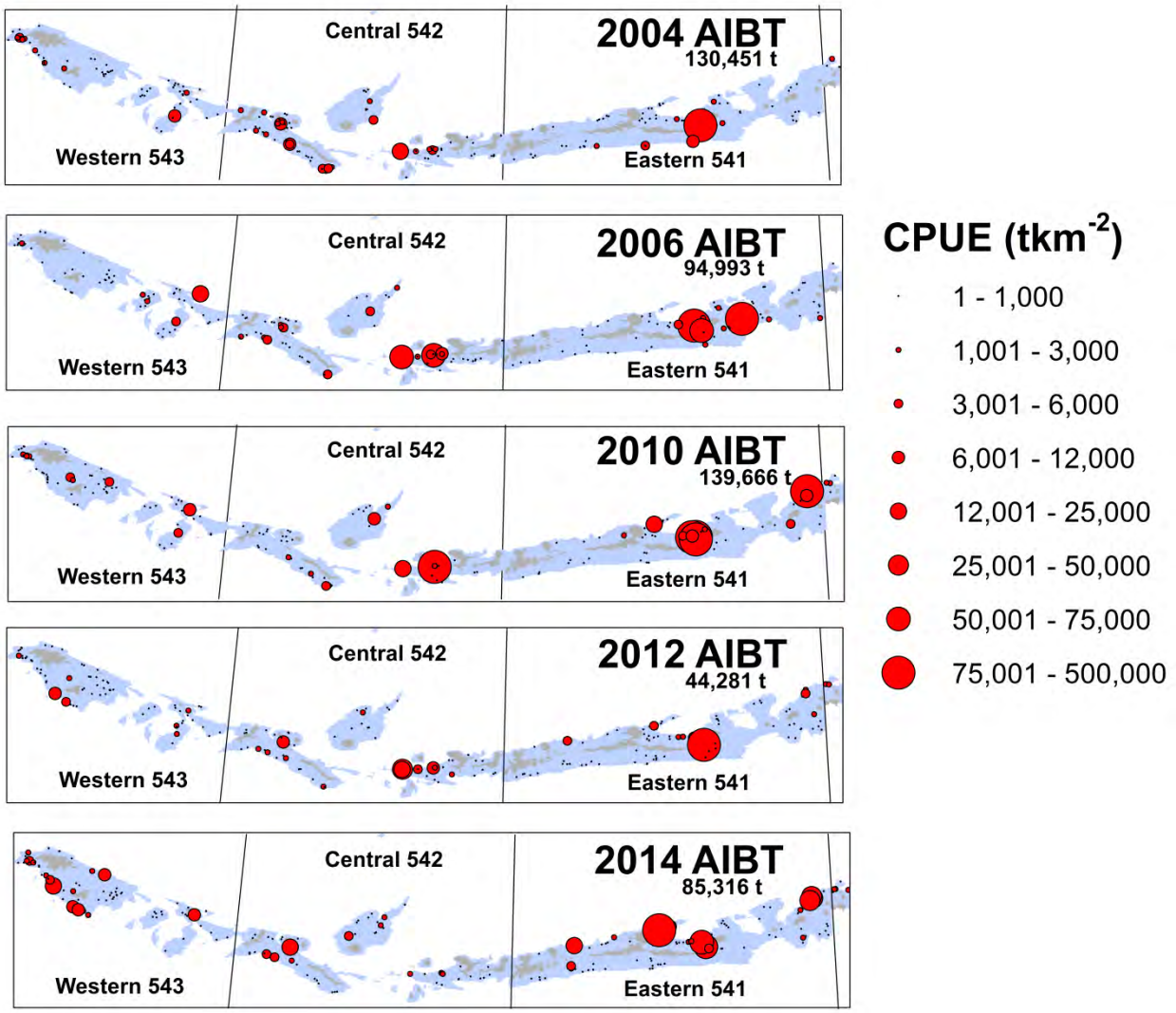

Figure 1A.6. Catch per unit effort (tkm^{-2}) for surveys of pollock in the Aleutian Islands Region, 2004-2014. The shaded area is the Aleutian Islands shelf area less than 300m depth.

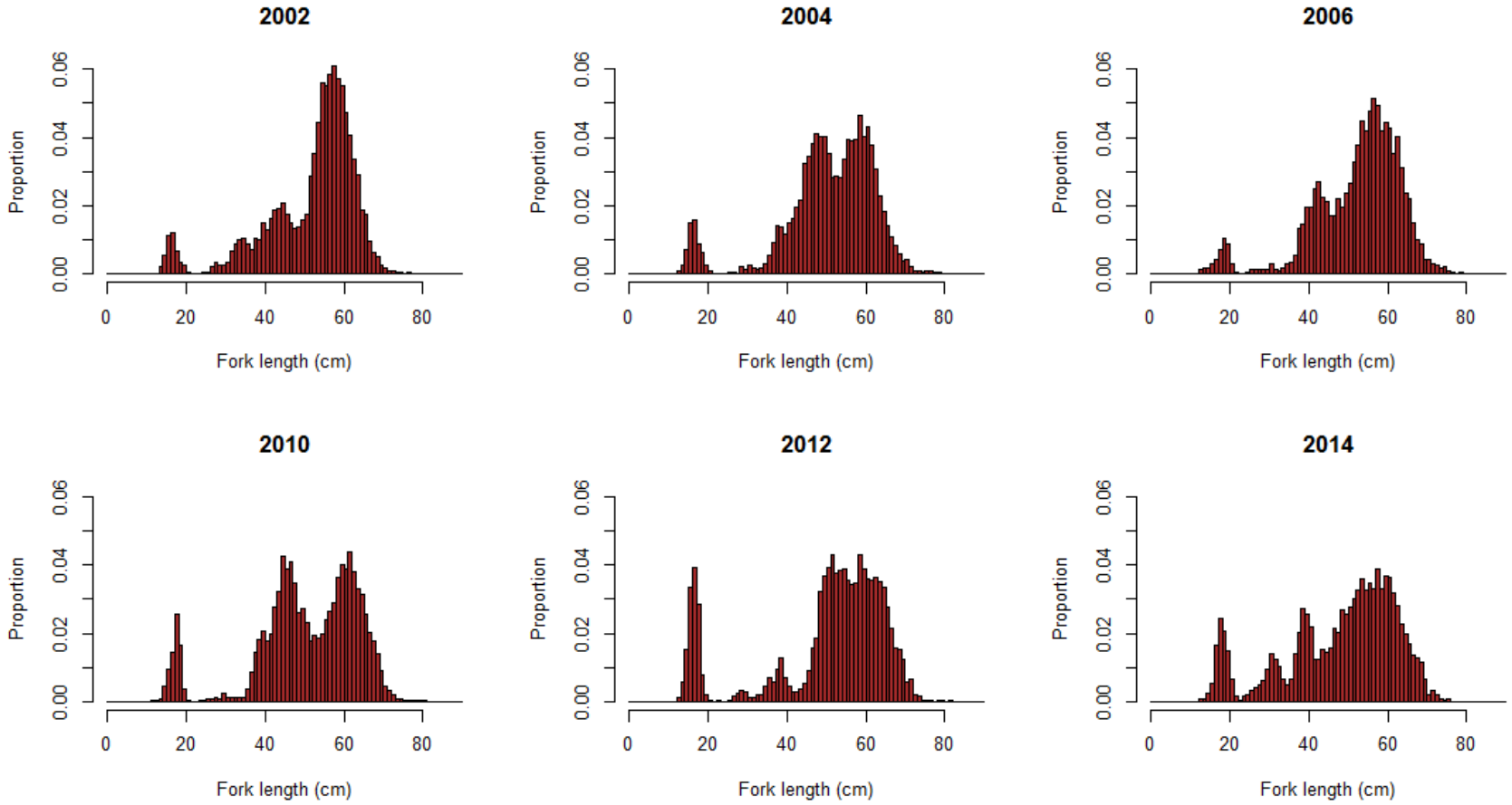

Figure 1A.7. Length distributions for 2002-2014 Aleutian Islands bottom trawl surveys.

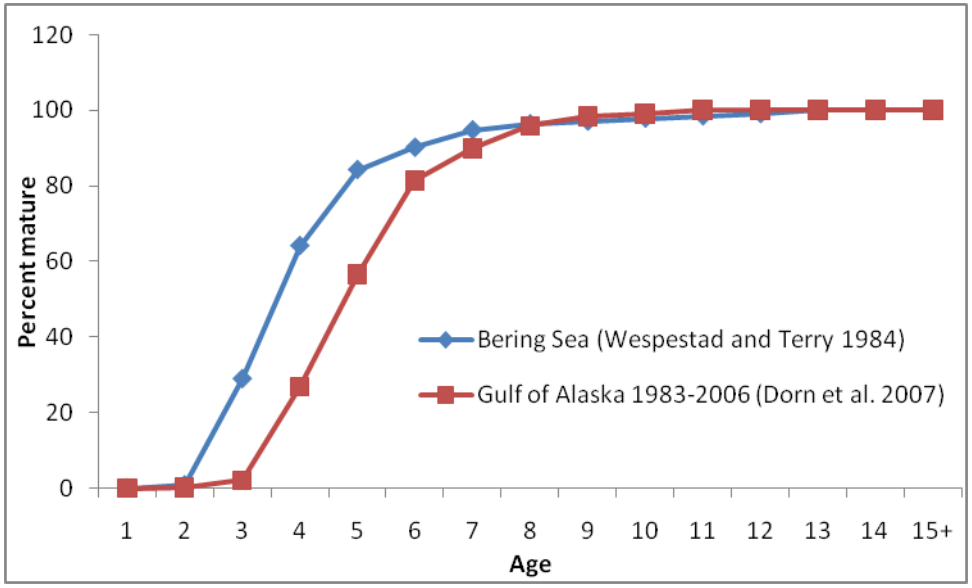

Figure 1A.8. Percent mature at age for Bering Sea pollock (Wespestad and Terry 1984) and the mean percent mature at age for 1983-2006 for Gulf of Alaska pollock (Dorn et al. 2007).

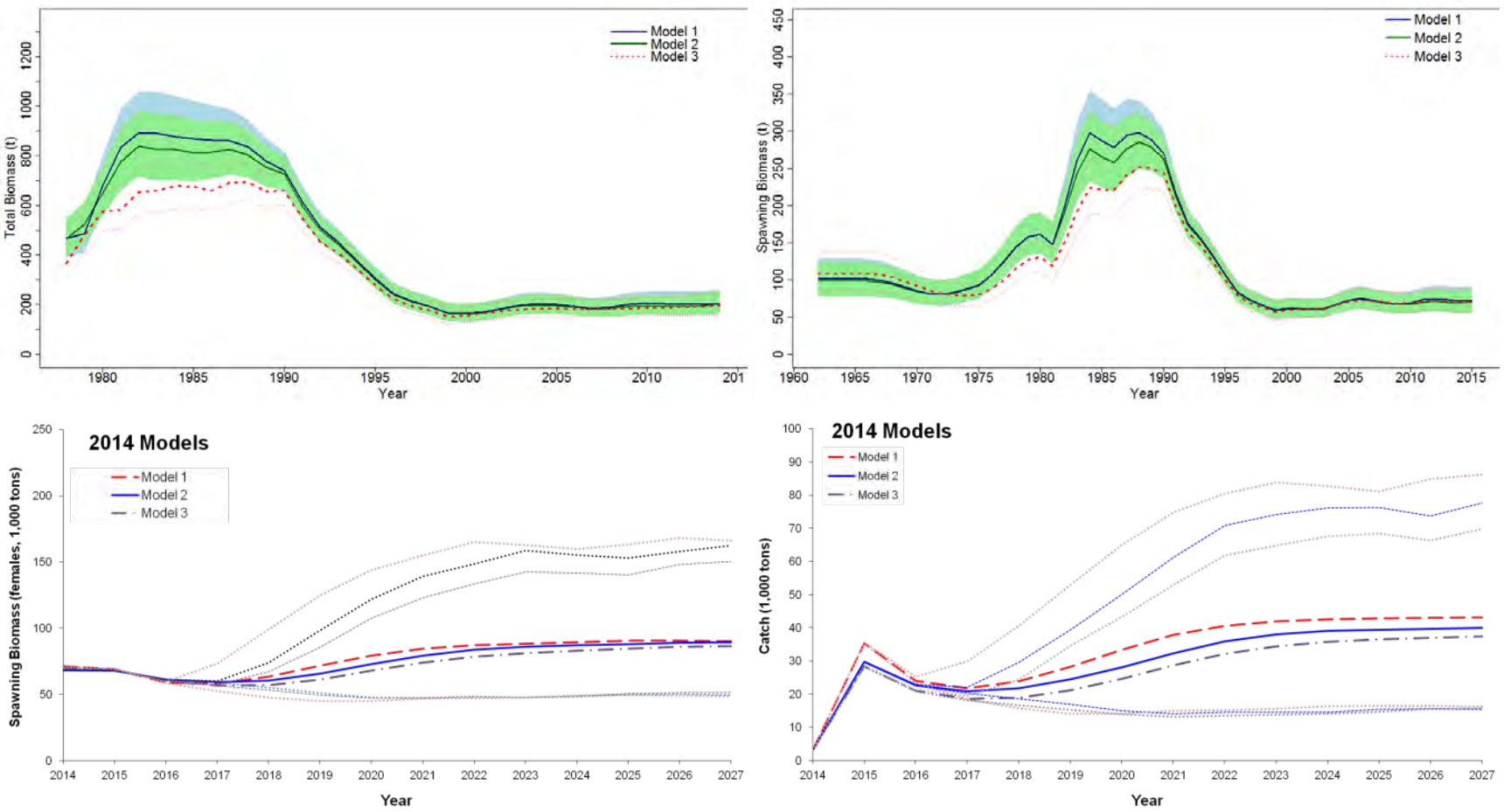

Figure 1A.9. Total biomass (top left), spawning biomass (top right), and spawning biomass (bottom left) and catch projection (bottom right) from Model 1, Model 2, and Model 3.

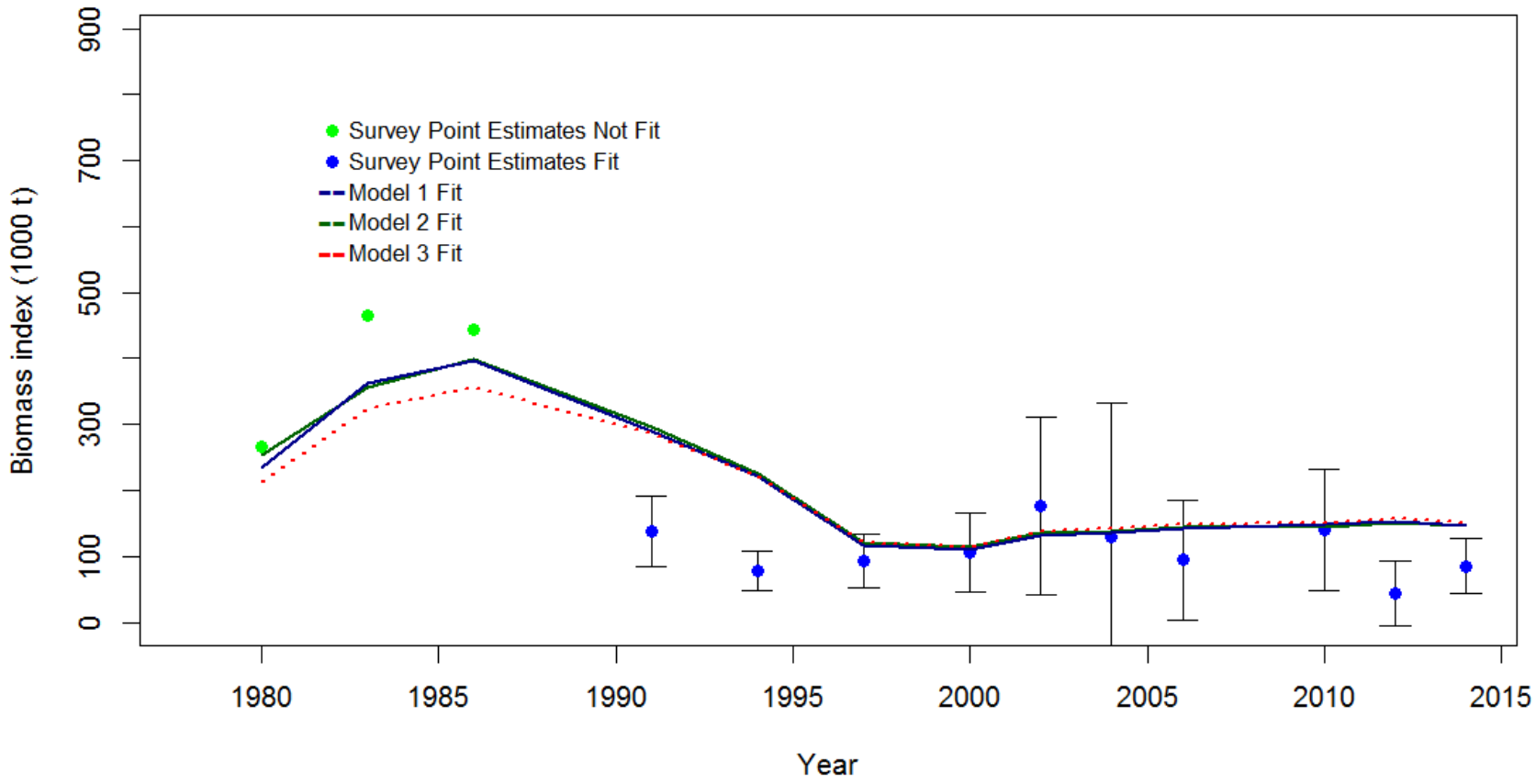

Figure 1A.10. Model fits to NMFS summer bottom trawl survey.

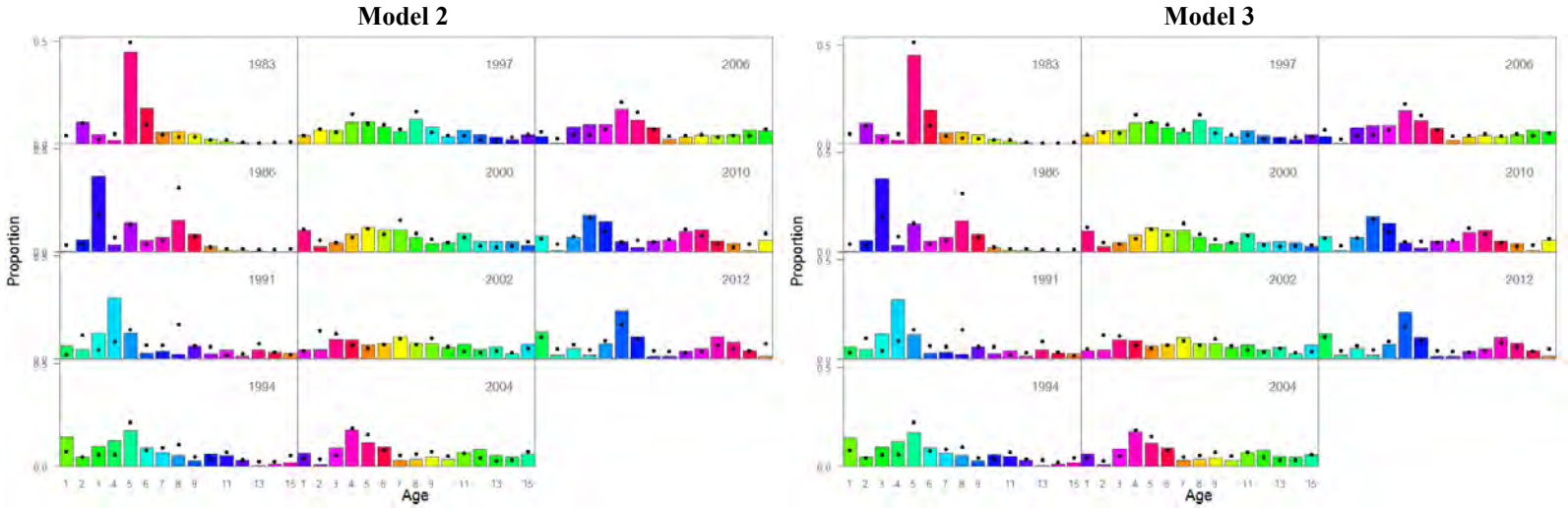

Figure 1A.11. Aleutian Islands pollock Model 2 and Model 3 fit to NMFS summer bottom trawl survey age composition data. The "●" symbol are the model predictions and columns are the observed proportions at age (with colors corresponding to cohorts).

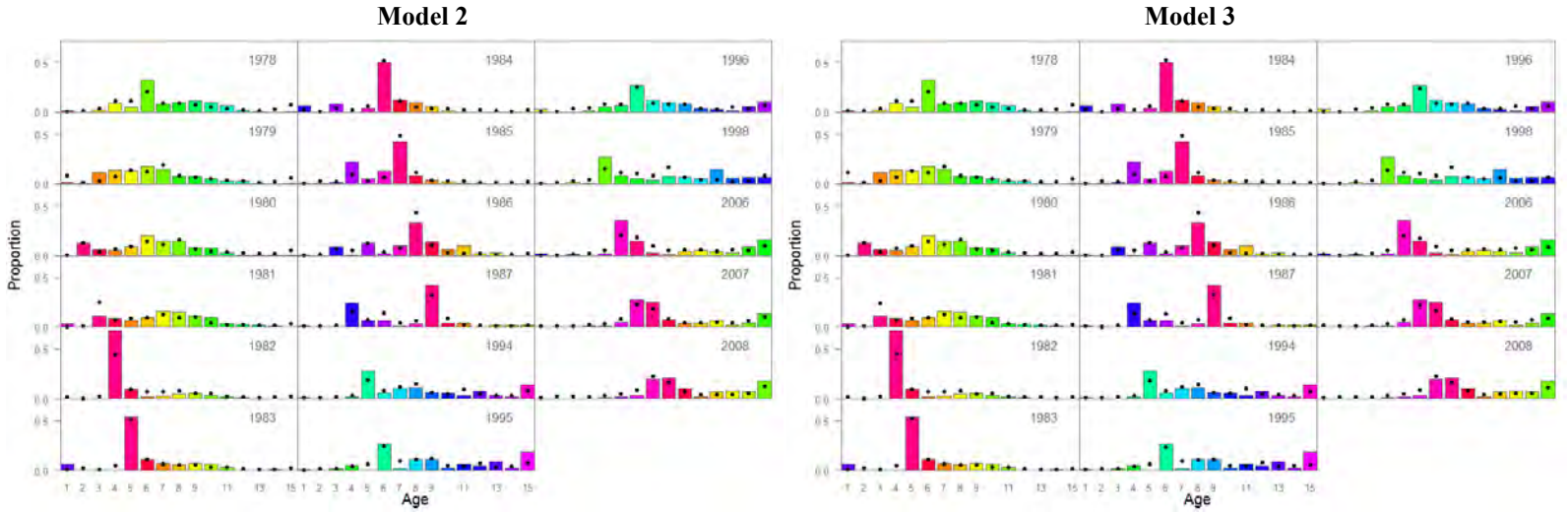

Figure 1A.12. Model 2 and Model 3 fits to fishery age composition data for Aleutian Islands pollock. The "●" symbol are the model predictions and columns are the observed proportions at age (with colors corresponding to cohorts).

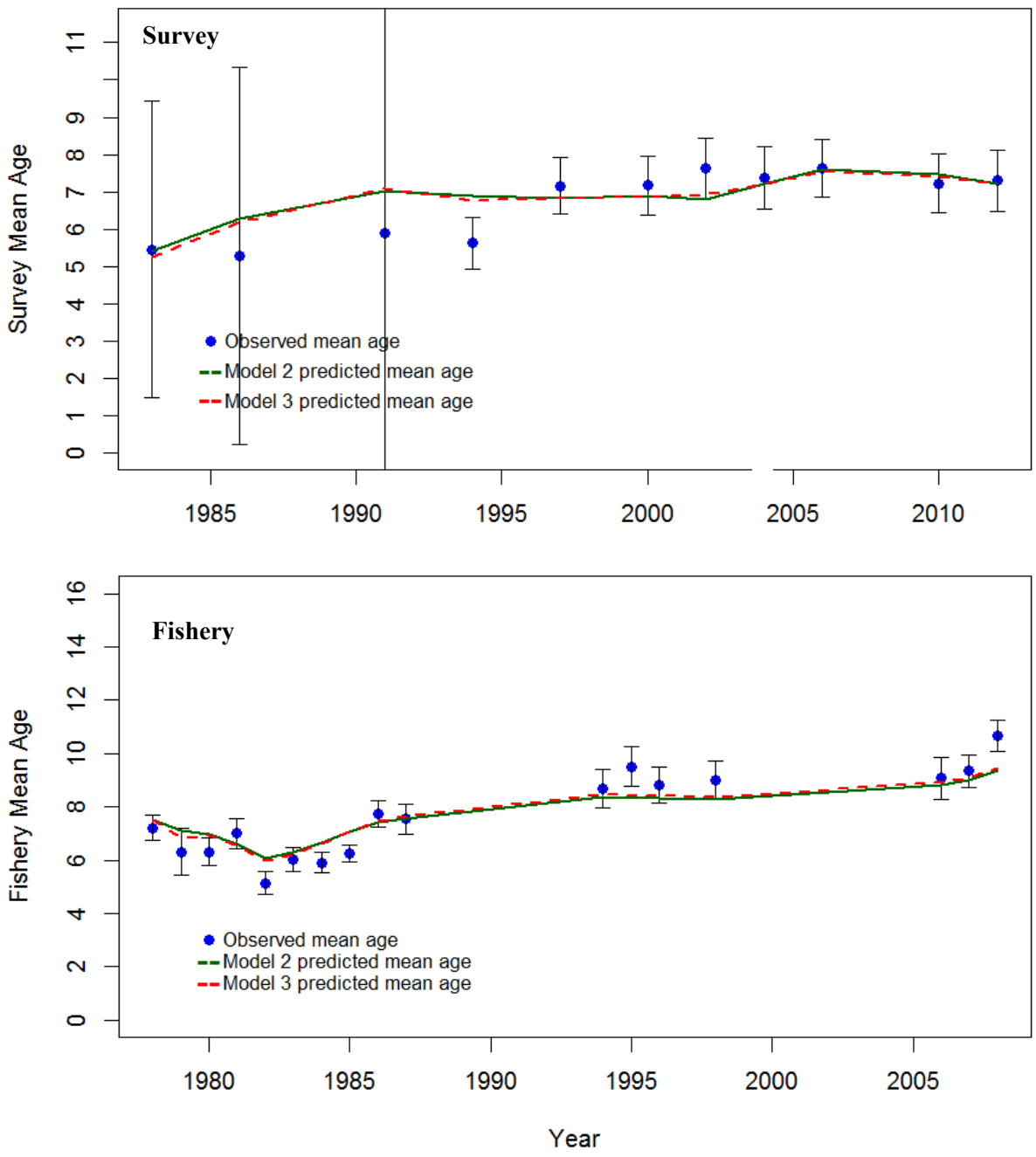

Figure 1A.13. Observed mean age and model derived mean age from the AIBTS (top) and fishery catch at age data (bottom) for Model 2 and Model 3. The confidence intervals are adjusted by the multinomial sample sizes used in the models.

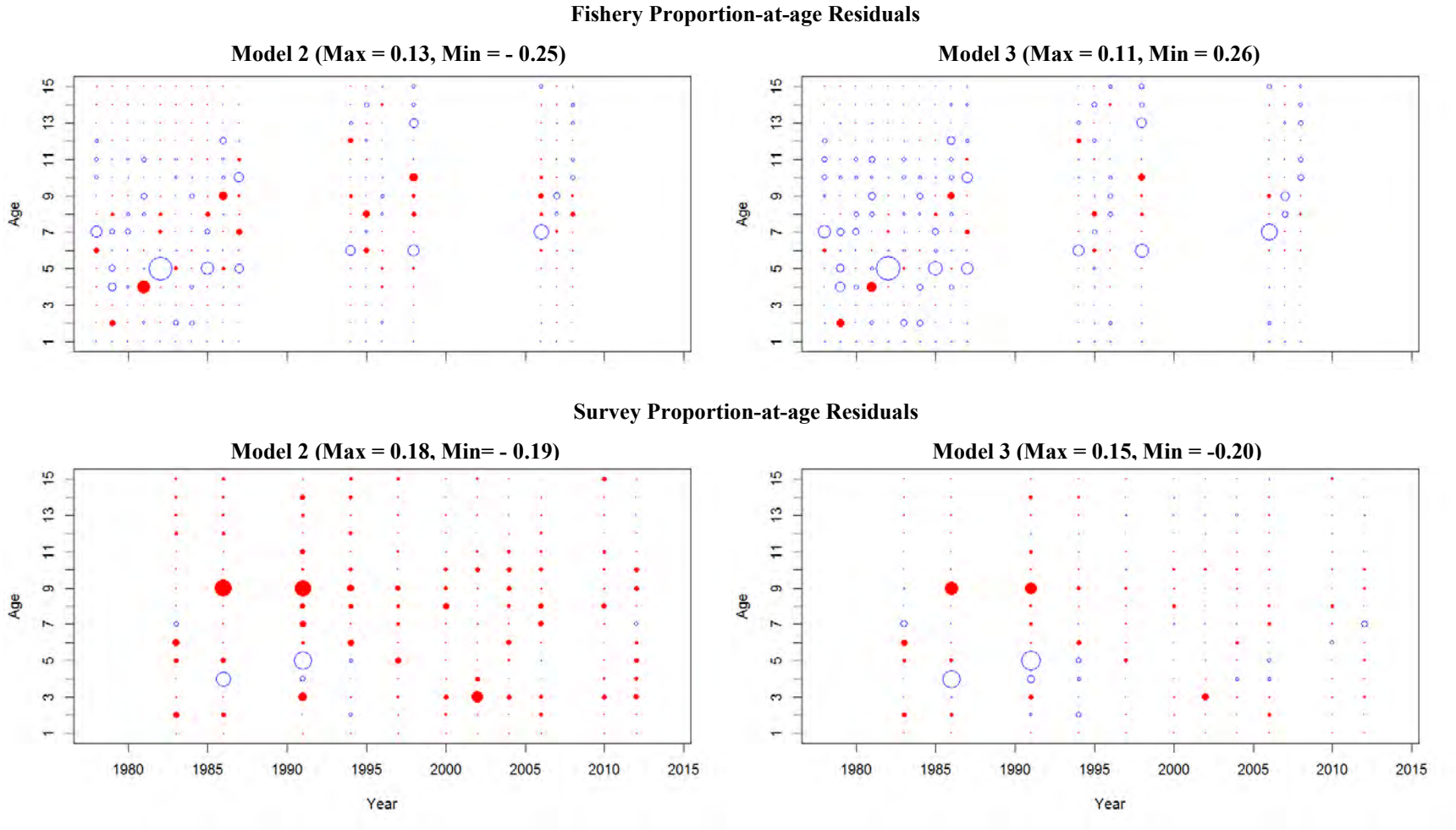

Figure 1A.14. Standardized residuals for fits to the fishery (top) and survey (bottom) proportion-at-age data for AI pollock Model 2 and Model 3.

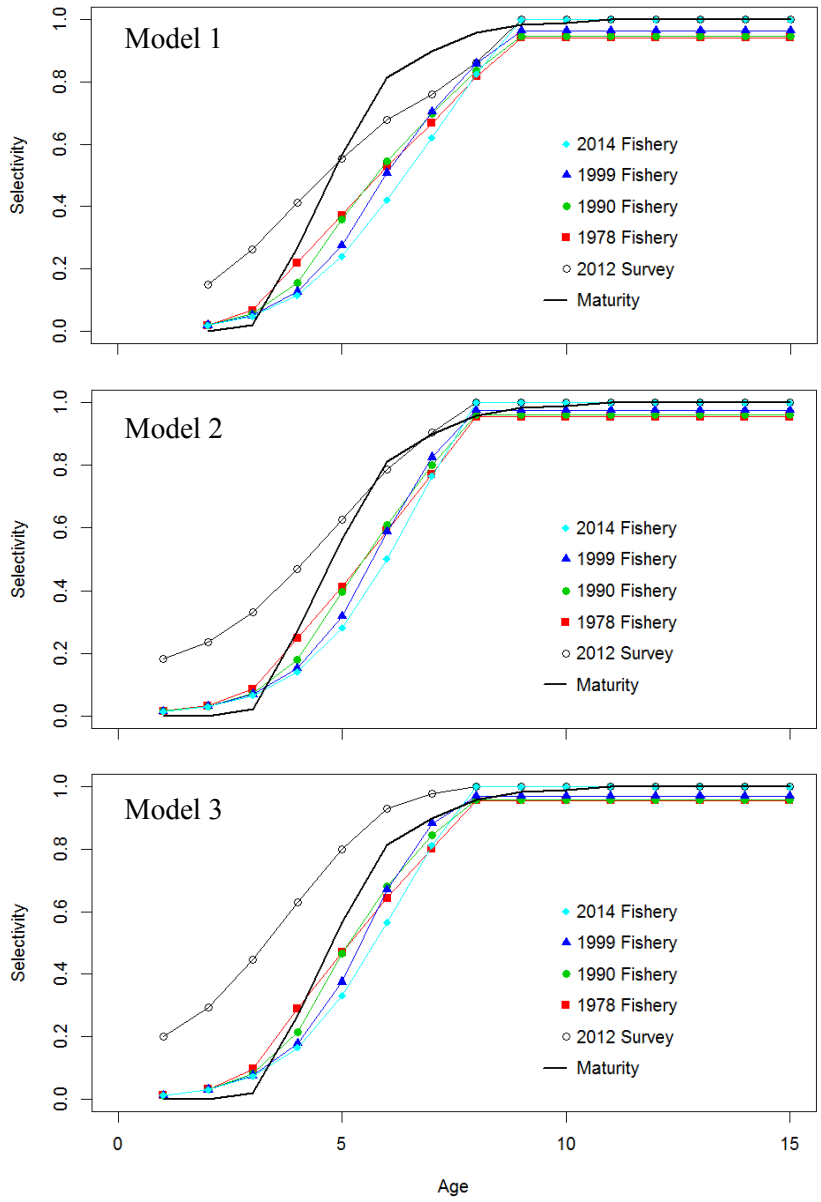

Figure 1A.15. Fishery and survey selectivity estimates with maturity at age for Aleutian Islands pollock models.

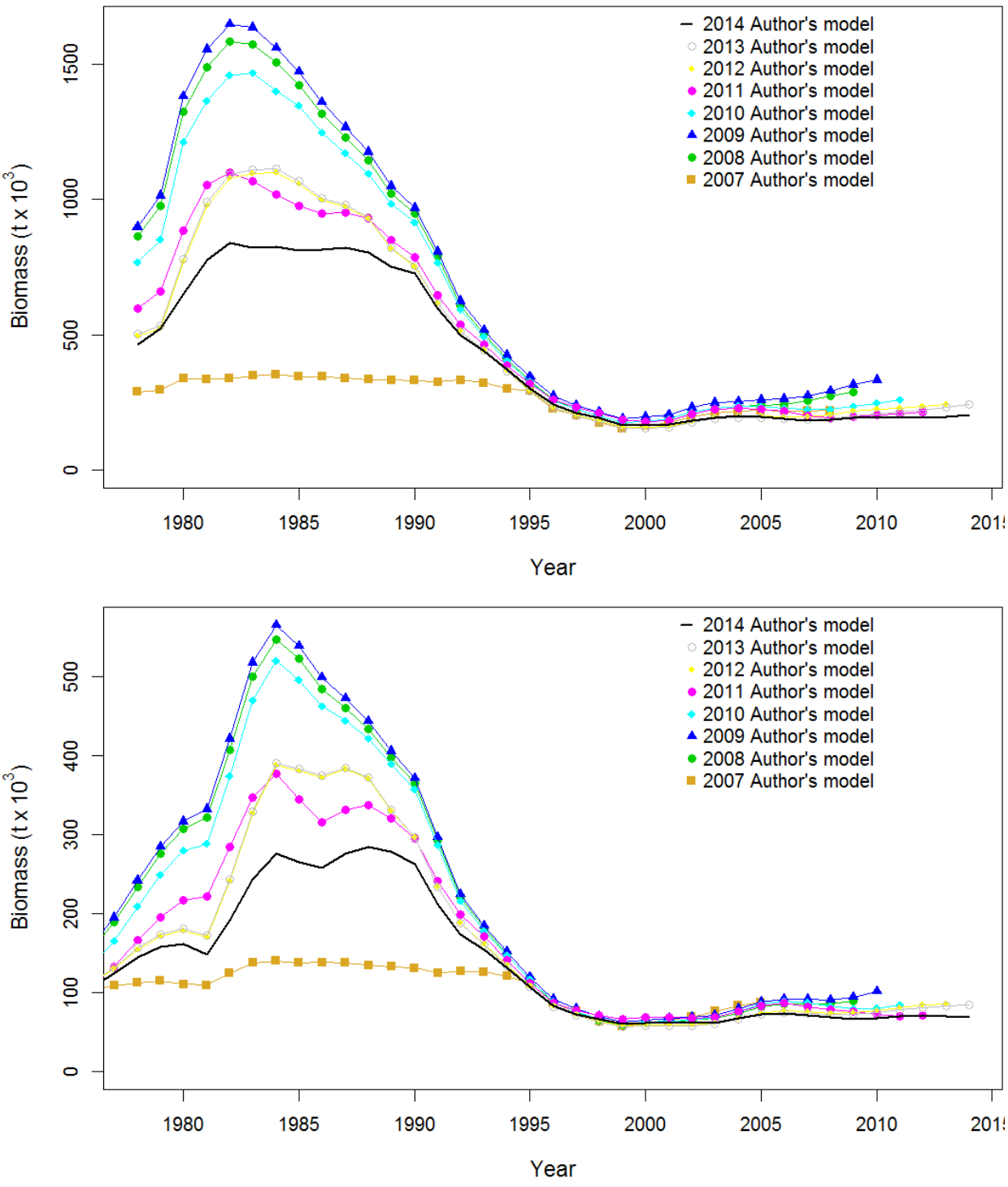

Figure 1A.16. Total (top) and spawning (bottom) biomass trajectories for the 2014 Authors' preferred model compared with the 2007 through 2013 Authors' preferred models.

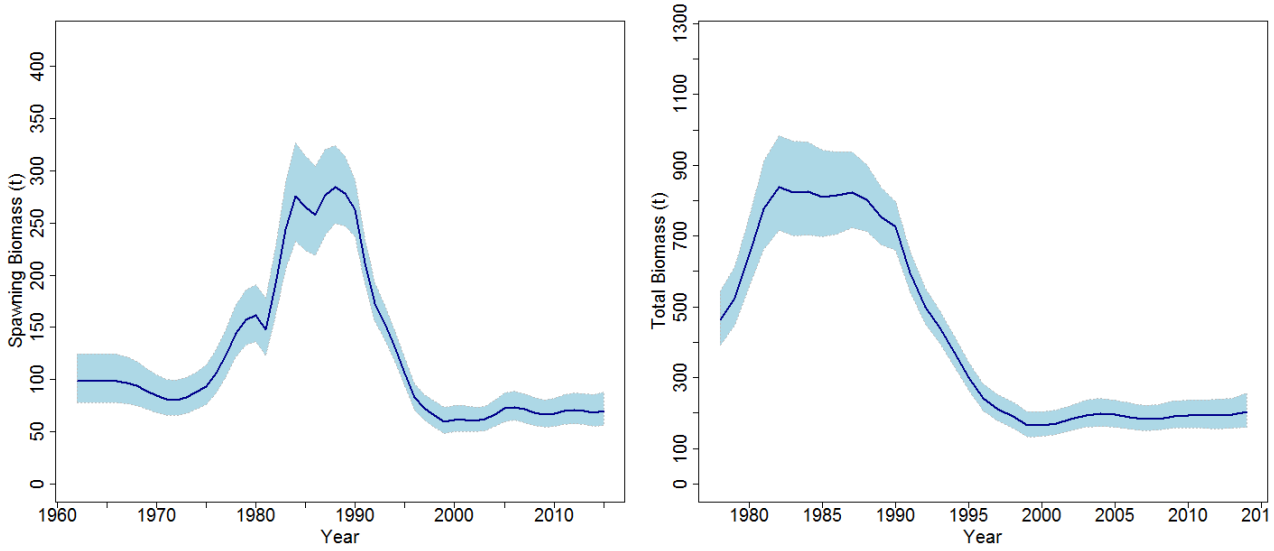

Figure 1A.17. Estimates of Aleutian Islands pollock spawning biomass (left) and age 1+ total biomass (right) in 1,000s of tons from the authors' preferred Model 2. Confidence intervals are two standard deviations.

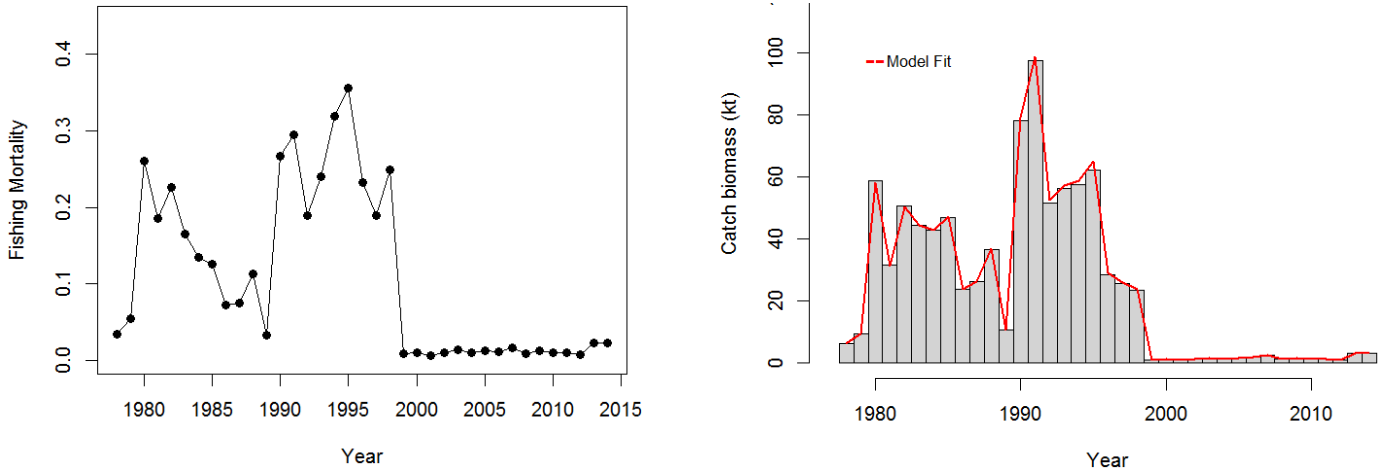

Figure 1A.18 Fishing mortality rates (left) and fits to total catch in 1,000s of tons (right) for AI pollock over time 1978-2014. Fishing mortality rates are based on the average over ages 1-15.

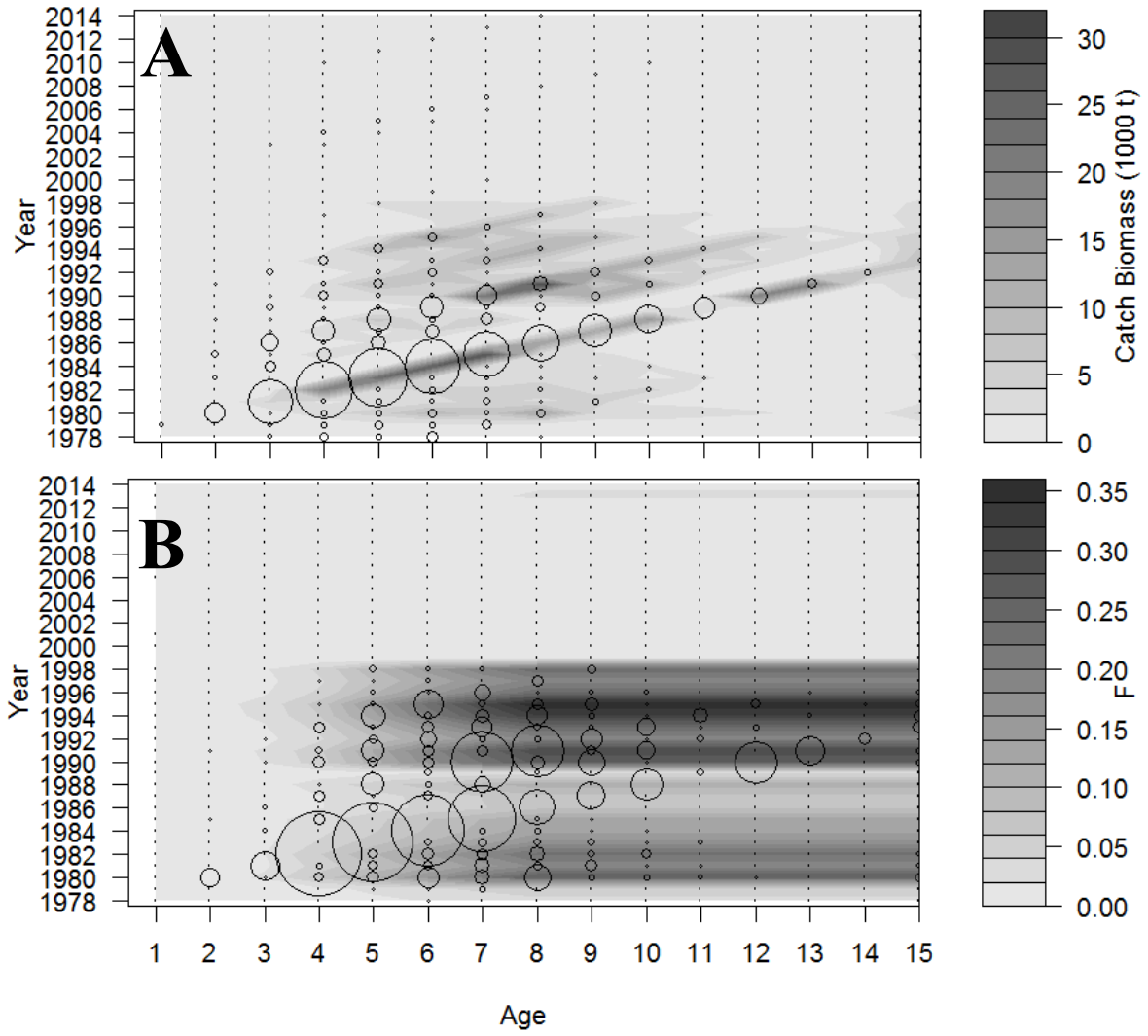

Figure 1A.19 AI pollock authors' preferred Model 2 (A-contour) catch biomass in 1,000s of tons and (A-bubbles) total biomass and (B-contour) fishing mortality rates and (B-bubbles) catch biomass by age. Total biomass is scaled to 1/20th of the catch biomass in the bubble plots

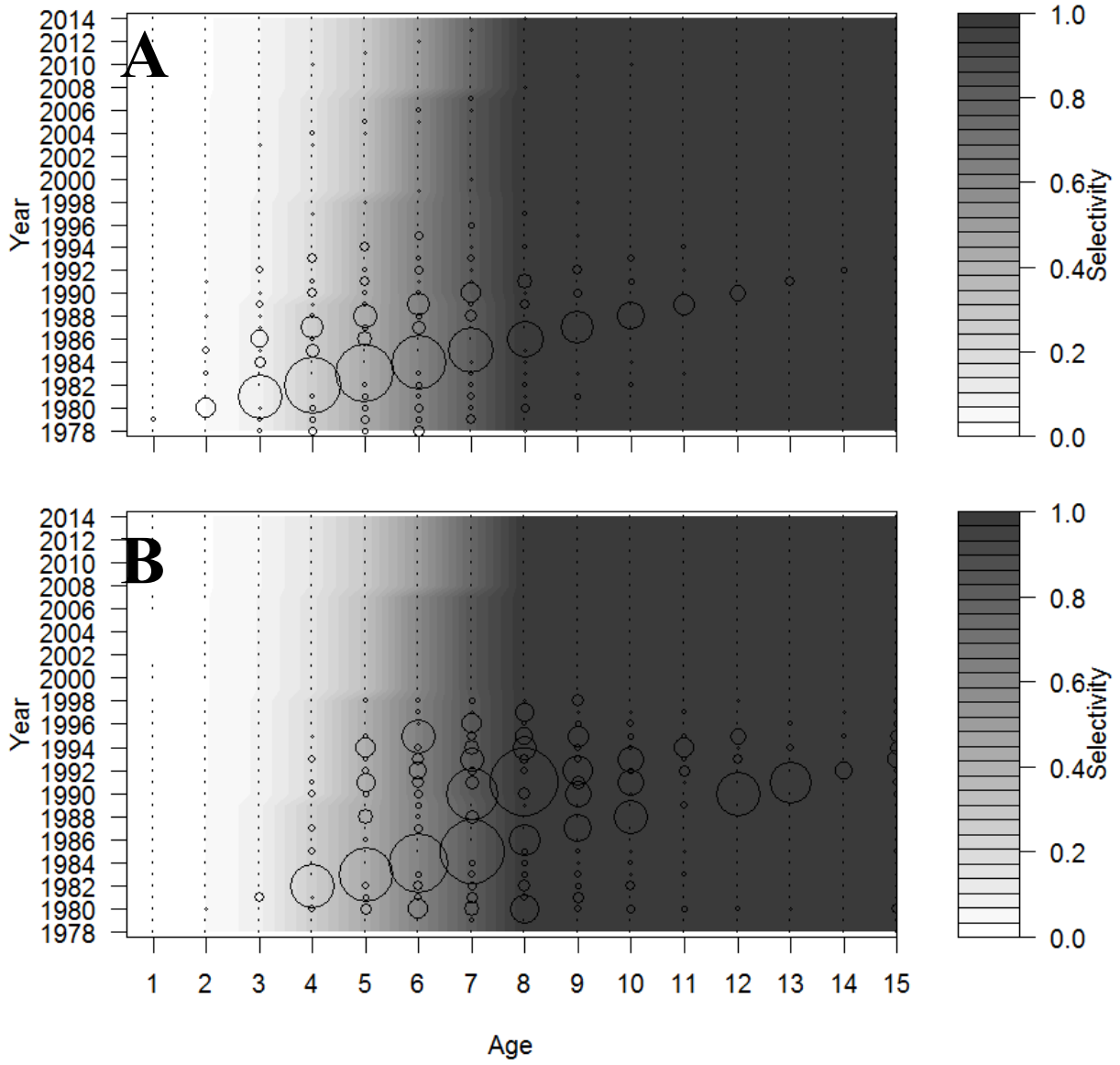

Figure 1A.20 Contour plots of fishery selectivity by age for AI pollock with bubble plots of (A) total biomass at age and (B) catch biomass at age for the Authors' preferred Model 2. Total biomass is scaled to 1/20 of the catch biomass bubbles.

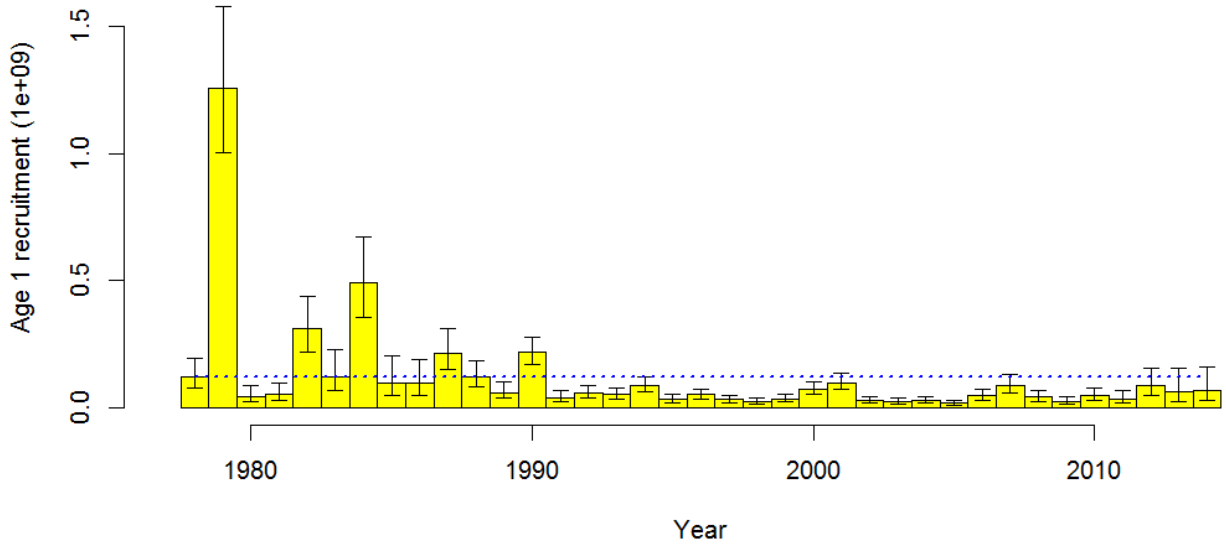

Figure 1A.21. Authors' preferred model estimates of Aleutian Islands pollock age 1 recruitment. The vertical bars represent the upper and lower 95% confidence bounds. The dotted line is the 1978-2010 mean age 1 recruitment.

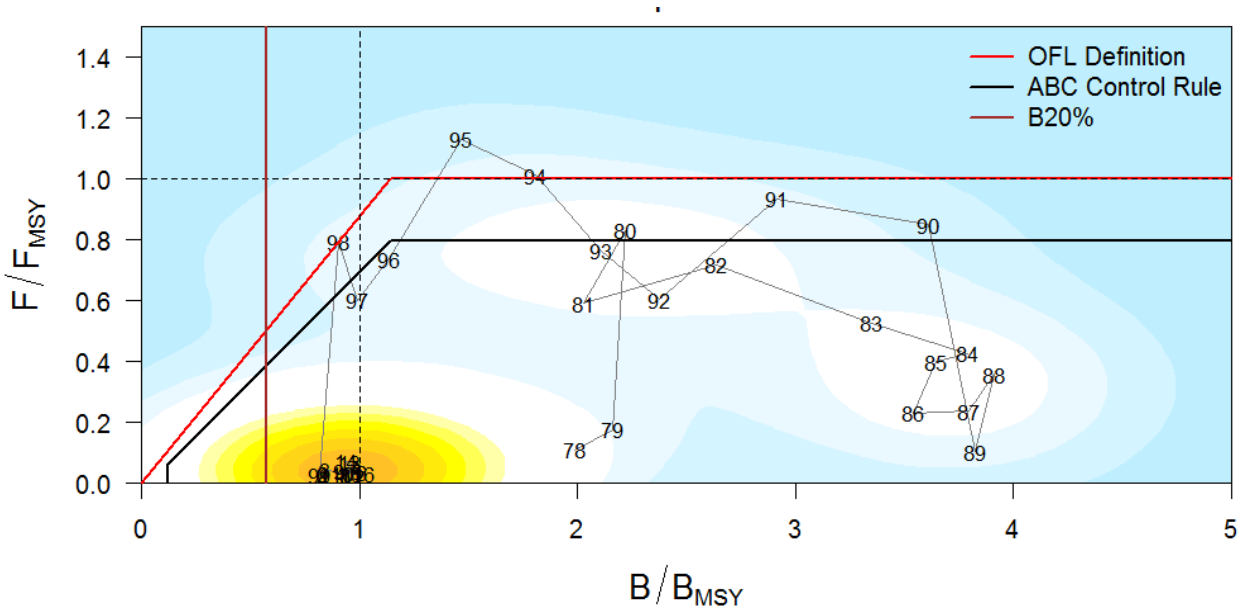

Figure 1A.22. Aleutian Islands pollock spawning biomass relative to B_{msy} and full-selection fishing mortality relative to F_{msy} (1978-2016). The ratio of fishing mortality to F_{msy} is calculated using the estimated selectivity pattern in that year. Color is scaled relative to density of points in the region from high orange to low blue. 2015 and 2016 are plotted with catch assumed to be at the five-year average F (Alternative 3).

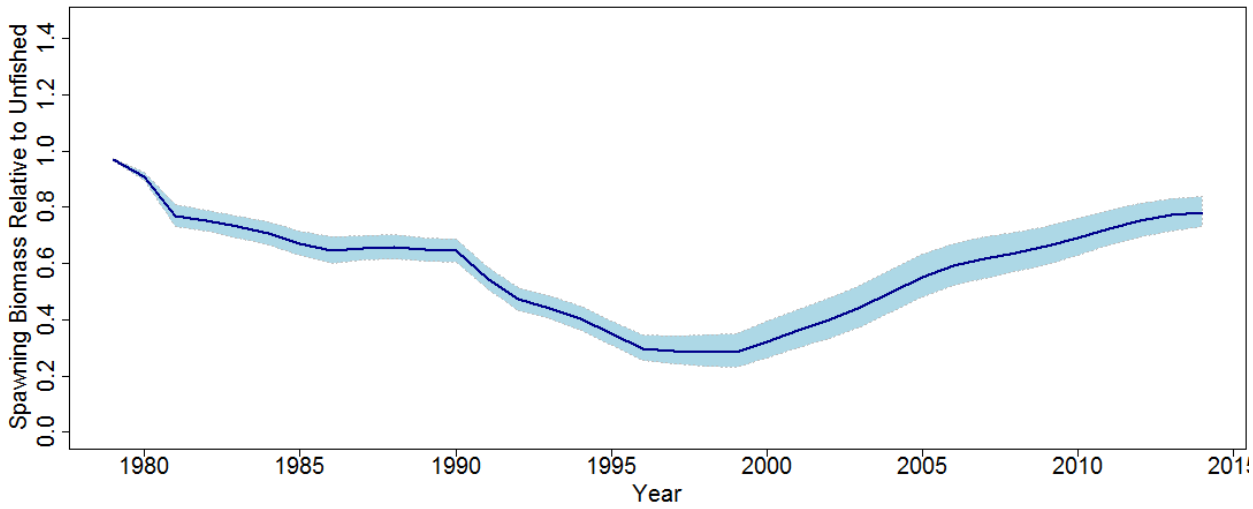

Figure 1A.23. Aleutian Islands pollock ratio of spawning biomass with fishing relative to spawning biomass without fishing for the authors' preferred model with 95% confidence interval (shaded).

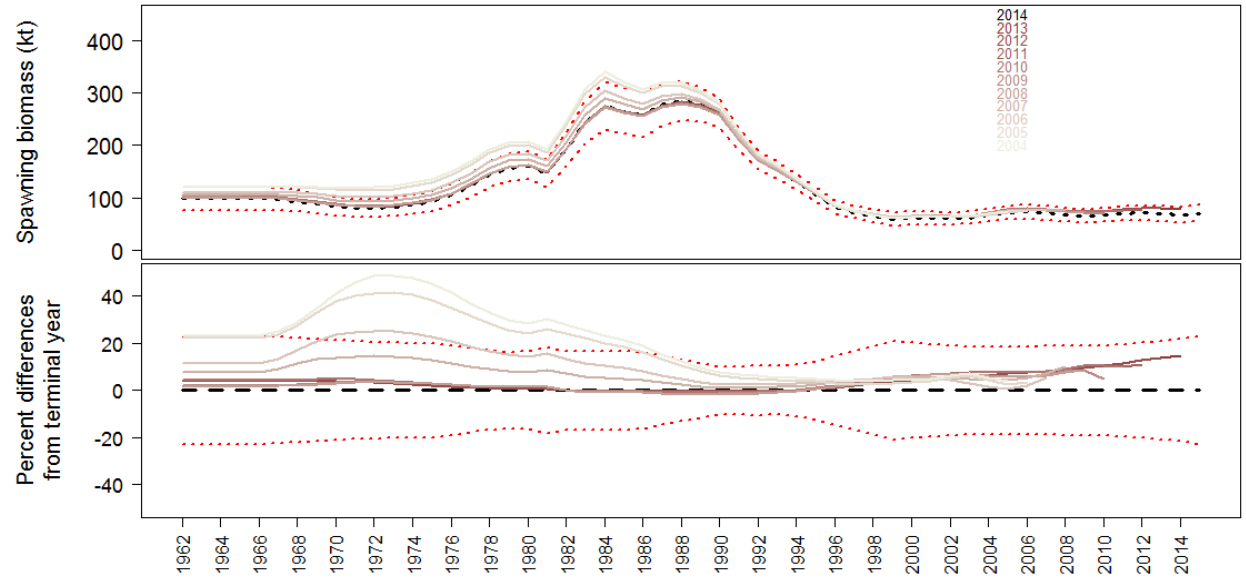

Figure 1A.24 Retrospective analysis for Authors' preferred Model 2 with data for the previous 10 years being systematically removed from the model. Black dashed line is the 2014 Model 2 estimate, the red dotted lines are the 95% confidence intervals calculated as ±1.96×standard deviation.

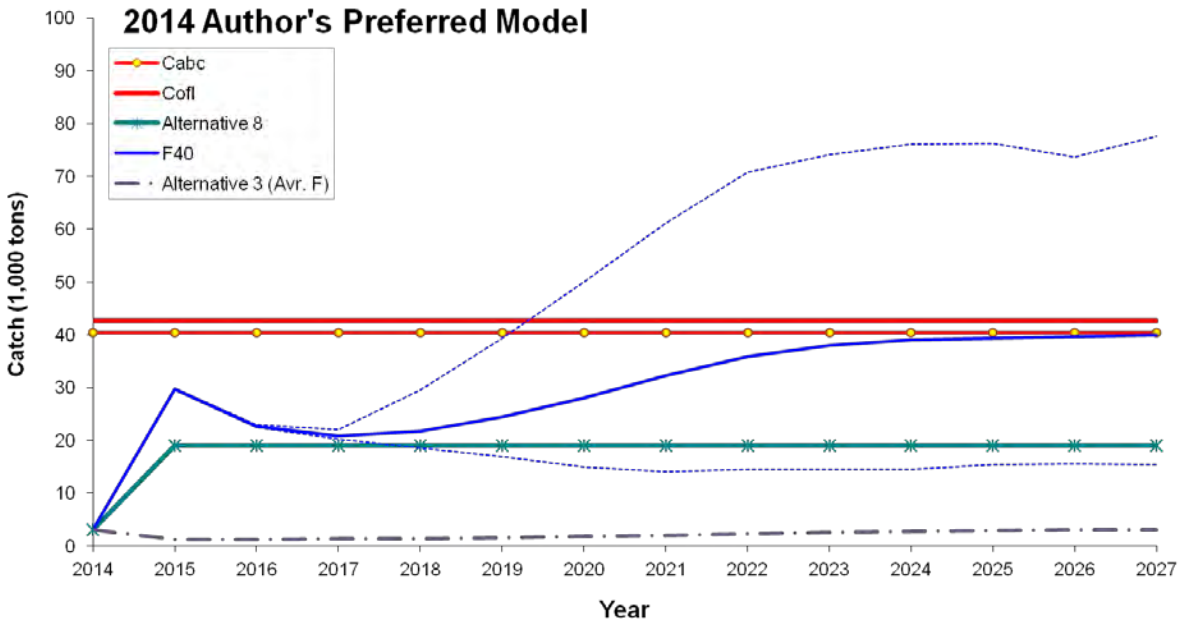

Figure 1A.25 Authors' preferred Model 2 projected catch for $F_{40\%}$, Alternative 3 (average F), and Alternative 8 (19,000t) ABC scenarios.

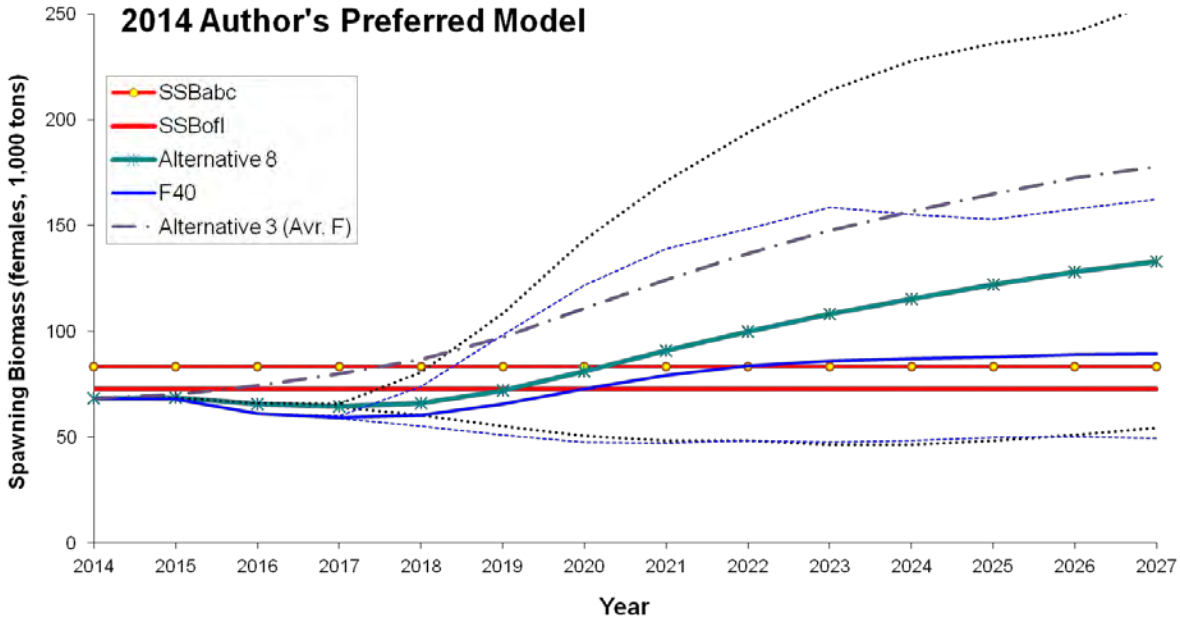

Figure 1A.26 Authors' preferred Model 2 projected spawning biomass for $F_{40\%}$ Alternative 3 (average F), and Alternative 8 (19,000t) ABC scenarios.

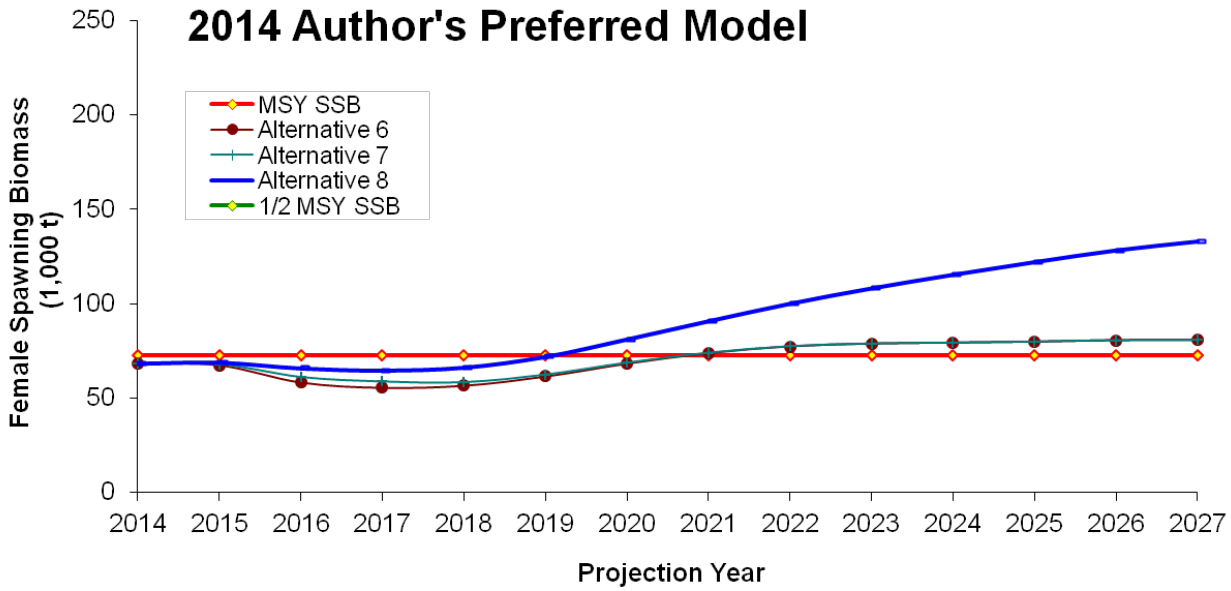

Figure 1A.27 Authors' preferred Model 2 projected spawning biomass for MSY, ½MSY, and Alternatives 6, 7, and 8 ABC scenarios from the authors' preferred model.

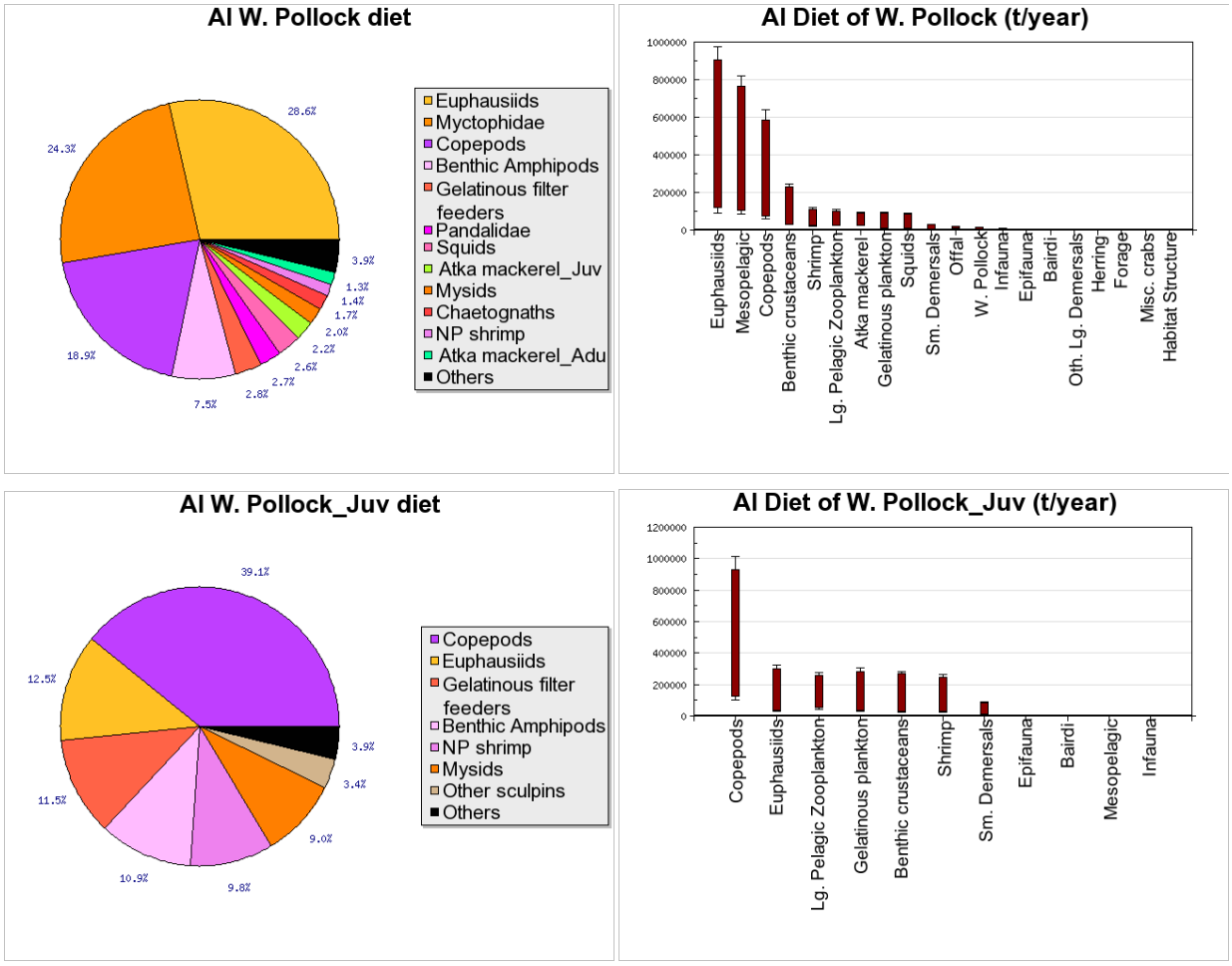

Figure 1A.28. Diet composition (left) and estimated consumption of prey (right) by AI adult (top) and juvenile (bottom) pollock. Diets are estimated from stomach collections taken aboard NMFS bottom trawl surveys in 1991-1994. See Appendix A Barbeaux et al. 2006 for detailed methods.

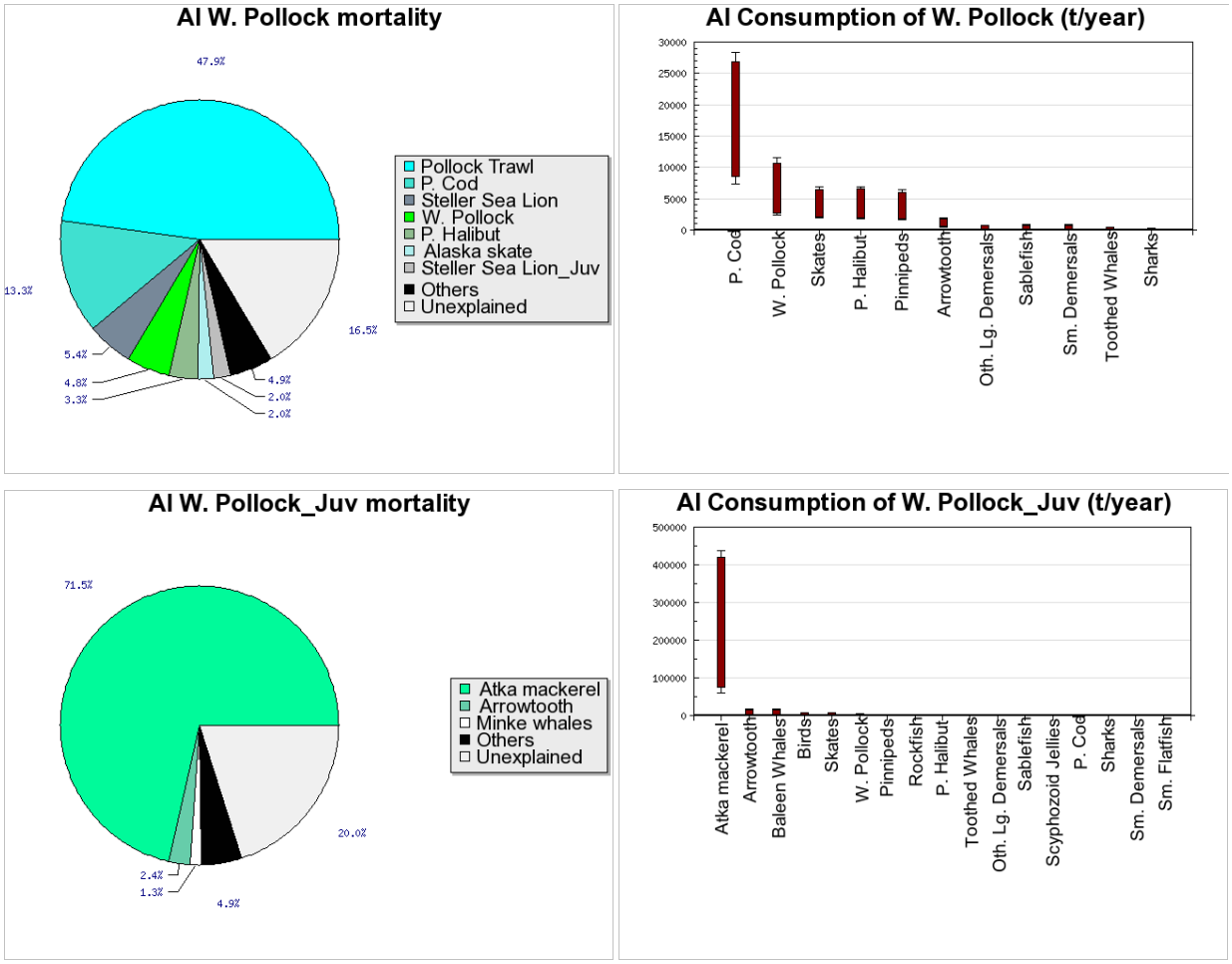

Figure 1A.29. Mortality sources (left) and estimated consumption by predators (right) of AI adult (top) and juvenile (bottom) pollock. Mortality sources reflect pollock predator diets estimated from stomach collections taken aboard NMFS bottom trawl surveys in 1991-1994, pollock predator consumption rates estimated from stock assessments and other studies, and catch of pollock by all fisheries in the same time periods. Annual consumption ranges incorporating uncertainty in food web model parameters were estimated by the Sense routines (Aydin et al. 2004). See Appendix A Barbeaux et al. 2006 for detailed methods.

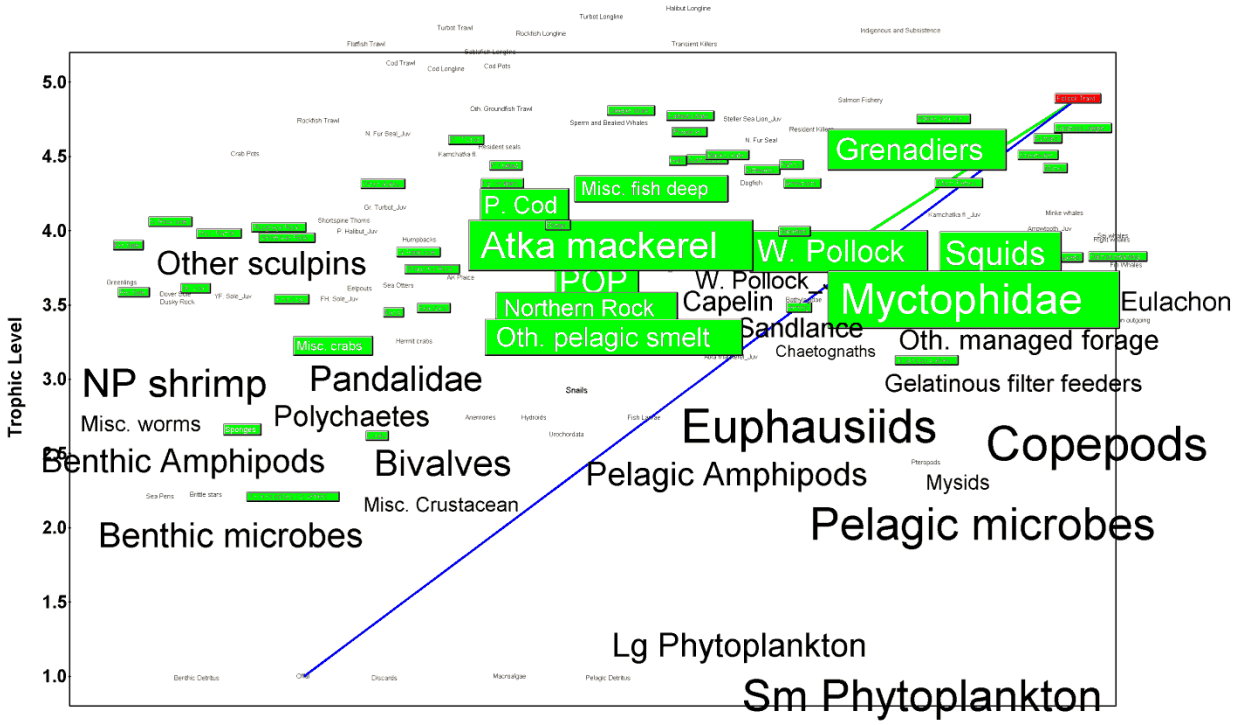

Figure 1A.30. The pollock trawl fishery in the AI food web. Species taken by the pollock fishery (in red) are highlighted in green, with the most significant flow to pollock indicated with a green line. Box size is proportional to biomass and lines between boxes represent the most significant energy flows. From Aydin et al. (2004).

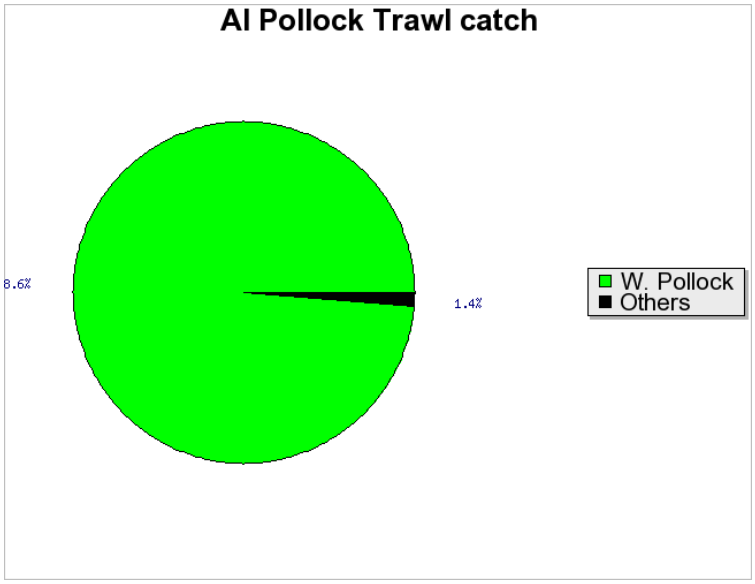

Figure 1A.31. Catch composition of the AI pollock trawl fishery during the early 1990's, as used in the food web model (Aydin et al. 2004).

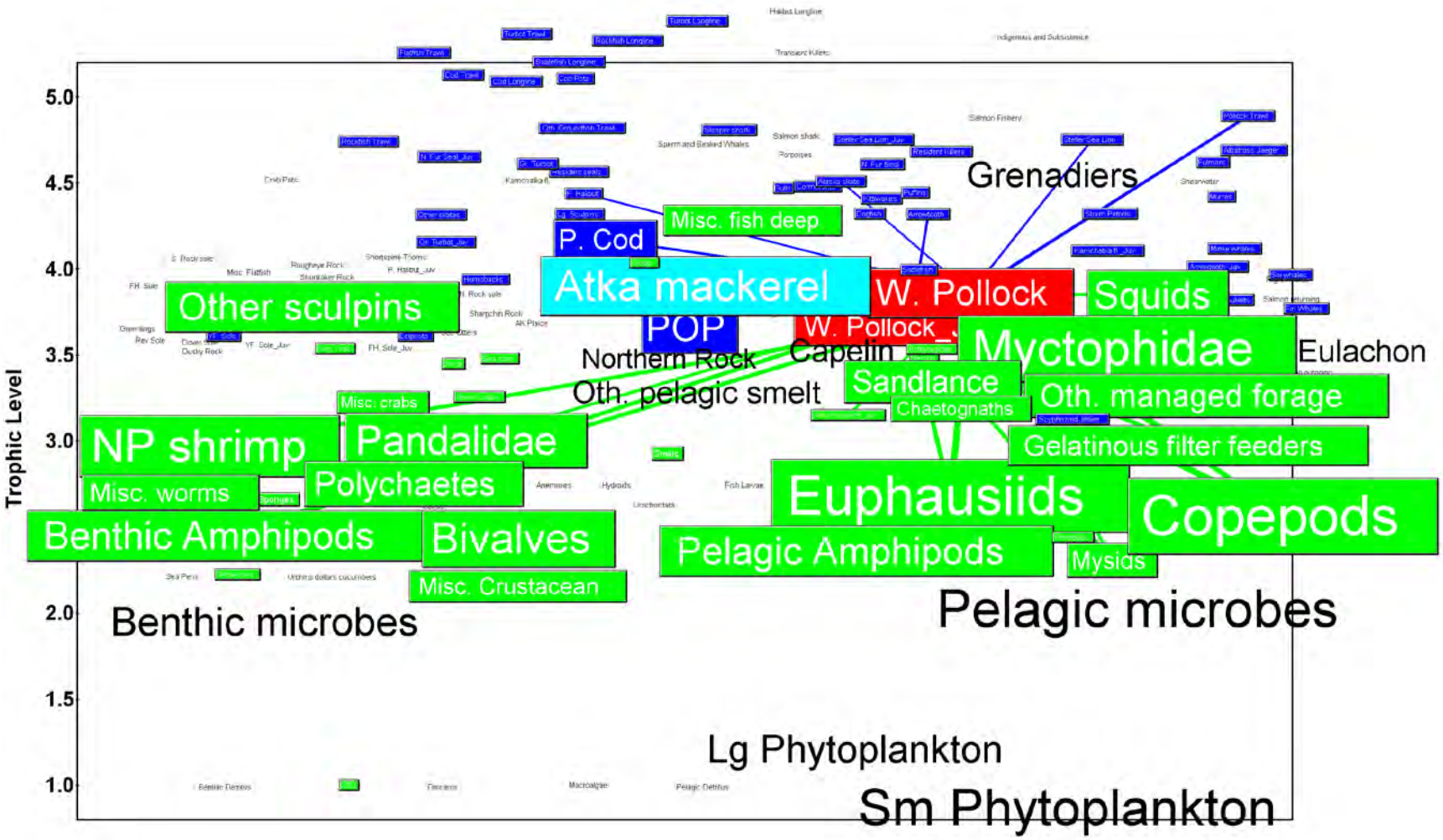

Figure 1A.32. Adult and juvenile pollock (highlighted in red) in the AI food web (Aydin et al 2004). Predators of pollock are dark blue, prey of pollock are green, and species that are both predators and prey of pollock are light blue. Box size is proportional to biomass and lines between boxes represent the most significant energy flows.

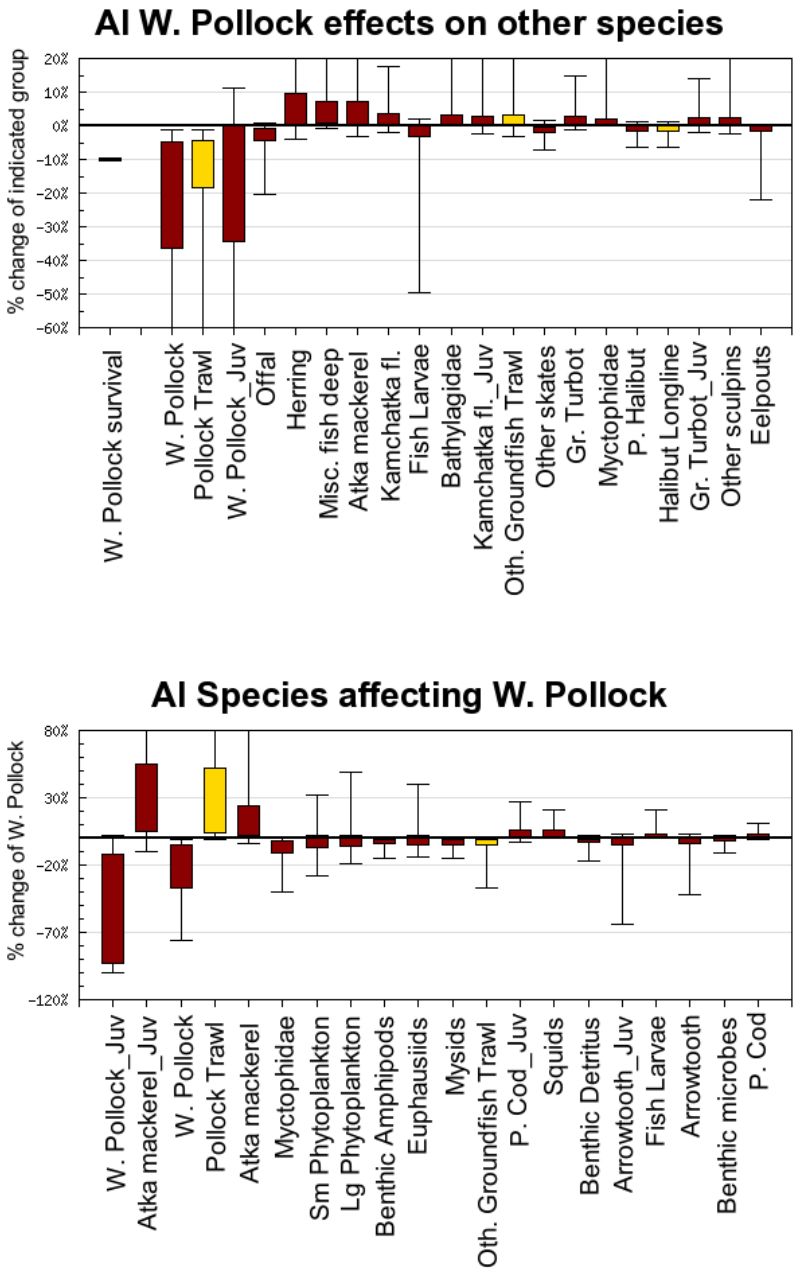

Figure 1A.33. (upper panel) Effect of changing pollock survival on fishery catch (yellow) and biomass of other species (dark red), from a simulation analysis where pollock survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. (lower panel) Effect of reducing fisheries catch (yellow) and other species survival (dark red) on pollock biomass, from a simulation analysis where survival of each x axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. In both panels, boxes show resulting percent change in the biomass of each species on the x axis after 30 years for 50% of feasible ecosystems, error bars show results for 95% of feasible ecosystems (see Aydin et al. in review for detailed Sense methods).

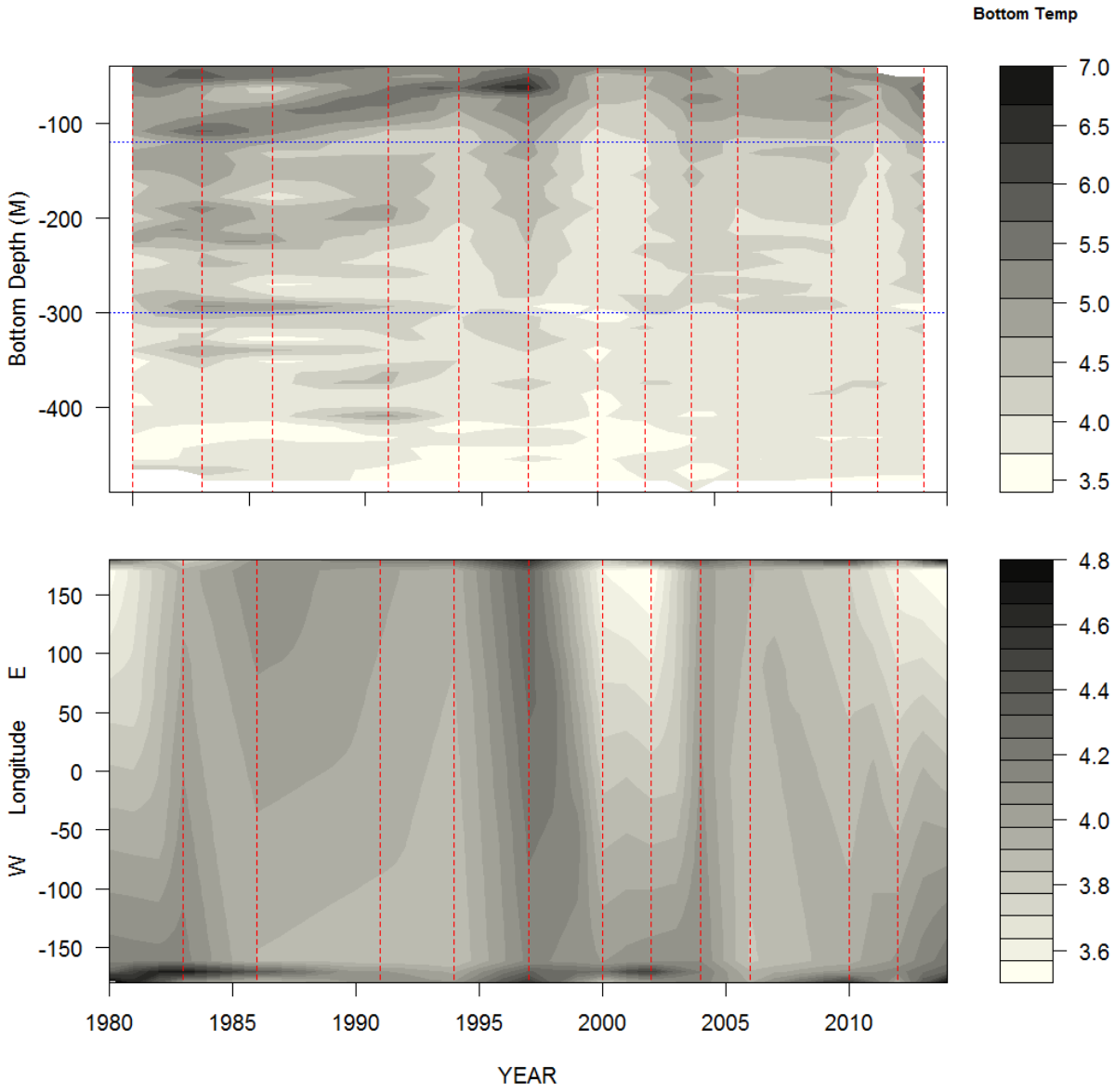

Figure 1A.34 Mean bottom temperatures by 10 m bottom depth (top) and by 1 degree longitude (bottom) by year. Red lines indicate years with survey data. Note the E longitudes (positive values) are further west in the Aleutian Islands. Blue lines are at -120 and -300, the area of highest densities for pollock in the AI.

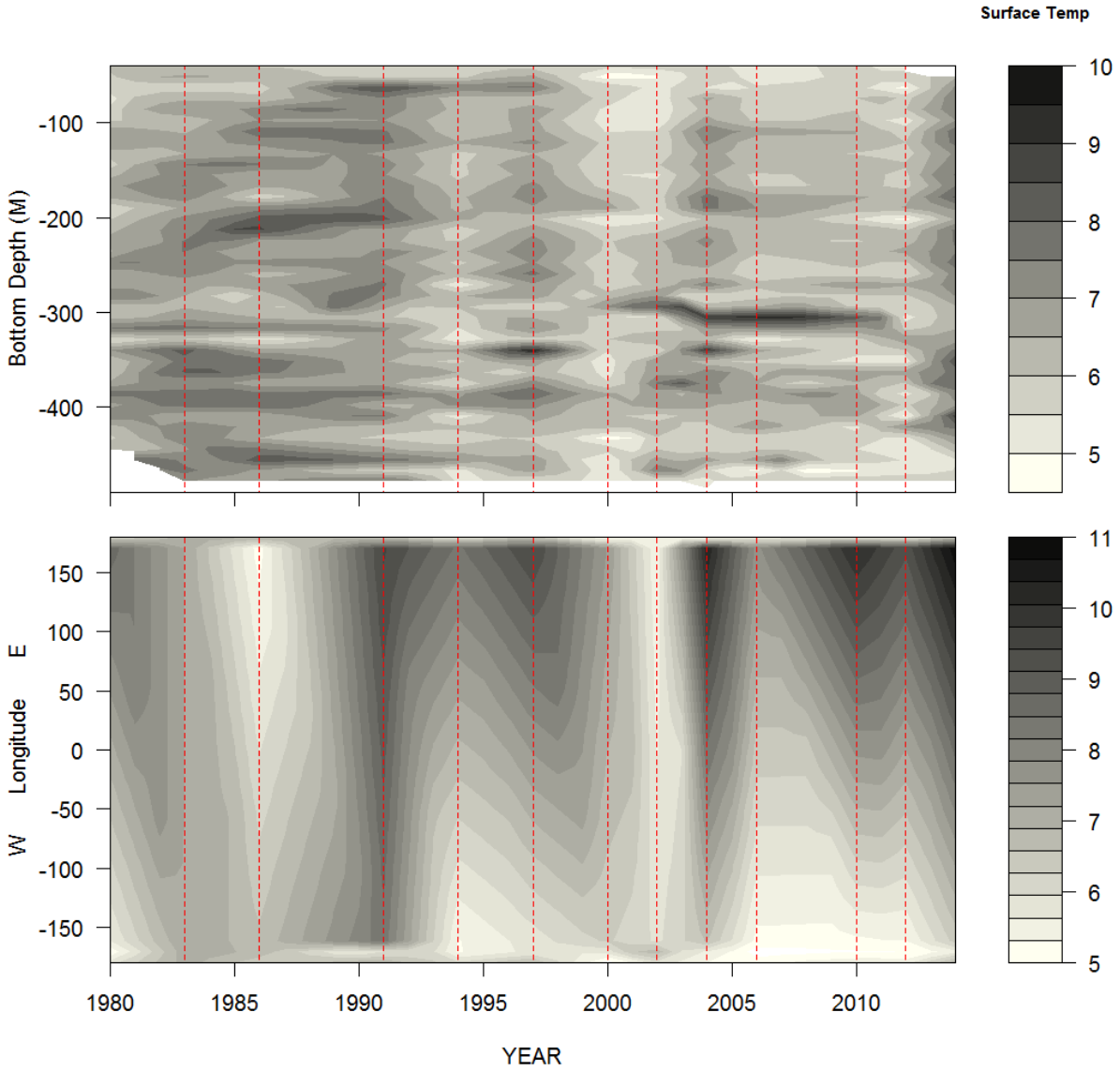

Figure 1A.35 Mean surface temperature by 10 m bottom depth (top) and 1 degree longitude (bottom) by year. Red lines indicate years with survey data. Note the E Longitudes (positive values) are further west in the Aleutian Islands

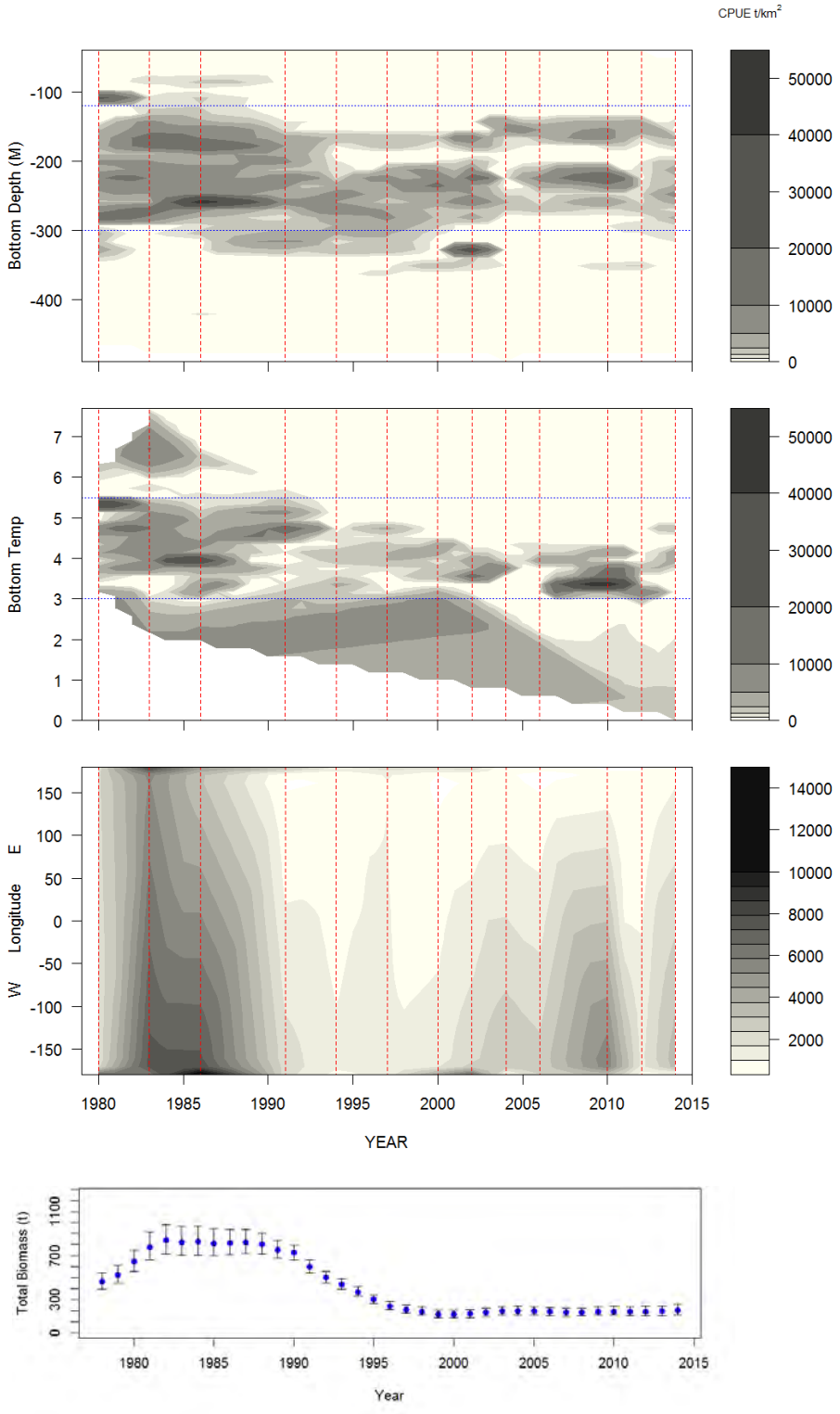

Figure 1A.36 Pollock CPUE t/km^2 by 10m bottom depth (top), 0.1 degree C bottom temperature (middle top), 10 degree longitude (middle bottom), and Model 2 predicted total biomass in 1000's t (Bottom) by year. Red lines indicate years with survey data. Note the E Longitude is further west in the Aleutian Islands

Appendix 1A-A

Table A-1. Variable descriptions and model specification for Authors' Preferred Model.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1963, …., 2007}	I	
Age index: j = {1, 2, 3, …, 14^{+}}	j	
Mean weight by age j	W_j	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity parameterization
Instantaneous Natural Mortality	M	Fit with M=0.20 and CV = 0.2, constant over all ages for Models 1 and 2. Model 3 M = vector fit as deviates from initial M.
Proportion females mature at age j	p_j	Definition of spawning biomass
Sample size for proportion at age j in year i	T_i	Scales multinomial assumption about estimates of proportion at age
Survey catchability coefficient	q^s	Prior distribution = lognormal(1.0 , σ_q^2)
Stock-recruitment parameters	R_0	Unfished equilibrium recruitment
	h	Stock-recruitment steepness
	σ_R^2	Recruitment variance
Estimated parameters		
$\phi_i(26),\ R_0,\ h,\ \varepsilon_i(41), \sigma_R^2,\ \mu^f,\ \mu^s,\ M,\ \eta_j^s(39),\ \eta_j^f c(13),\ q^s(3)$		

Note that the number of selectivity parameters estimated depends on the model configuration.

Table A-2. Variables and equations describing implementation of the Assessment Model for Alaska (AMAK).

Description	Symbol/Constraints	Key Equation(s)
Survey abundance index (s) by year	Y_i^s	$\hat{Y}_i^s = q_i^s \sum_{j=1}^{14^+} s_j^s W_{ij} e^{Z_{i,j}\frac{7}{12}} N_{ij}$
Catch biomass by year	C_i	$\hat{C}_i = \sum_j W_{ij} N_{ij} \frac{F_{ij}}{Z_{ij}}\left(1-e^{-Z_{ij}}\right)$
Proportion at age j, in year i	P_{ij}, $\sum_{j=1}^{14} P_{ij} = 1.0$	$P_{ij} = \frac{N_{ij} s_{ij}^f}{\sum_{k=1}^{15} N_{ik} s_{ik}^f}$
Initial numbers at age	$j = 1$	$N_{1977,1} = e^{\mu_R + \varepsilon_{1977}}$
	$1 < j < 13$	$N_{1977,j} = e^{\mu_R + \varepsilon_{1978-j}} \prod_{j=1}^{j} e^{-M}$
	$j = 14^+$	$N_{1977,15} = N_{1977,14}\left(1-e^{-M}\right)^{-1}$
Subsequent years ($i > 1963$)	$j = 1$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
	$i < j < 13$	$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
	$j = 14^+$	$N_{i,14^+} = N_{i-1,14}\, e^{-Z_{i-1,13}} + N_{i-1,15}\, e^{-Z_{i-1,14}}$
Year effect, i = 1963, …, 2007	ε_i, $\sum_{i=1963}^{2007} \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
Index catchability	μ^s, μ^f	$q_i^s = e^{\mu^s}$
Mean effect		
Age effect	η_j^s, $\sum_{j=1}^{15^+} \eta_j^s = 0$	$s_j^s = e^{\eta_j^s}$ $j \le$ maxage
		$s_j^s = e^{\eta_{\text{maxage}}^s}$ $j >$ maxage
Instantaneous fishing mortality		$F_{ij} = e^{\mu_f + \eta_j^f + \phi_i}$
mean fishing effect	μ_f	
annual effect of fishing in year i	ϕ_i, $\sum_{i=1977}^{2007} \phi_i = 0$	
age effect of fishing (regularized) In year time variation allowed	η_{ij}^f, $\sum_{j=1}^{15^+} \eta_{ij} = 0$	$s_{ij}^f = e^{\eta_j^f}$, $j \le$ maxage $s_{ij}^f = e^{\eta_{\text{maxage}}^f}$ $j >$ maxage
In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \ne$ change year
Natural Mortality	M	
Total mortality		$Z_{ij} = F_{ij} + M$
Recruitment	$\tilde{R}_i$	$\tilde{R}_i = \frac{\alpha B_i}{\beta + B_i}$,
Beverton-Holt form		$\alpha = \frac{4hR_0}{5h-1}$ and $\beta = \frac{B_0(1-h)}{5h-1}$ where h=0.8
		$B_0 = \tilde{R}_0 \varphi$
		$\varphi = \frac{e^{-15M} W_{15} p_{15}}{1-e^{-M}} + \sum_{j=1}^{15} e^{-M(j-1)} W_j p_j$

Table A-3. Specification of objective function that is minimized (i.e., the penalized negative of the log-likelihood).

Likelihood /penalty component		Description / notes
Abundance indices	$L_1 = \lambda_1 \sum_i \ln\left(Y_i^s \Big/ \hat{Y}_i^s\right)^2 \frac{1}{2\sigma_i^2}$	Survey abundance
Prior on smoothness for selectivities	$L_2 = \sum_l \lambda_2^l \sum_{j=1}^{15^+} \left(\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l\right)^2$	Smoothness (second differencing), Note: $l=\{s,$ or $f\}$ for survey and fishery selectivity
Prior on recruitment regularity	$L_3 = \lambda_3 \sum_{i=1963}^{2007} \varepsilon_i^2$	Influences estimates where data are lacking (e.g., if no signal of recruitment strength is available, then the recruitment estimate will converge to median value).
Catch biomass likelihood	$L_4 = \lambda_4 \sum_{i=1963}^{2007} \ln\left(C_i / \hat{C}_i\right)^2$	Fit to catch biomass in each year (
Proportion at age likelihood	$L_5 = -\sum_{l,i,j} T_{ij}^l P_{ij}^l \ln\left(\hat{P}_{ij}^l \cdot P_{ij}^l\right)$	$L=\{s, f\}$ for survey and fishery age composition observations
Fishing mortality regularity	$L_6 = \lambda_6 \sum_{i=1963}^{2007} \phi_i^2$	(relaxed in final phases of estimation)
Priors	$L_7 = \left[\lambda_7 \frac{\ln\left(M/\hat{M}\right)^2}{2\sigma_M^2} + \lambda_8 \frac{\ln\left(q/\hat{q}\right)^2}{2\sigma_q^2}\right]$	Prior on natural mortality, and survey catchability (reference case assumption that these are precisely known at 0.3 and 1.0, respectively).
Overall objective function to be minimized	$\dot{L} = \sum_{i=1}^{7} L_i$	

Appendix 1A-B Supplemental catch data

In order to comply with the Annual Catch Limit (ACL) requirements, we present non-commercial removals and estimates of pollock removals from the halibut fishery from the Halibut Fishery Incidental Catch Estimation (HFICE) to help estimate total catch and removals from NMFS managed stocks in Alaska.

Estimates of total removals that do not occur during directed groundfish fishing activities includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System (CAS) estimates. Current pollock research removals are insignificant relative to the fishery catch, being smaller than the observation error assumed for the catch estimate. Total removals from activities other than directed fishery were near 35.6 tons in 2010 (Table C-1).. This is ~0.1% of the 2014 recommended ABC of 35,048 t. There were no data available on pollock removals due to subsistence, personal use, or recreational catch. It is assumed that pollock catches during these activities would be minimal in AI management area.

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Table C-1 Total removals of walleye pollock (t) from the NRA area from activities not related to directed fishing, since 1978.

	NMFS Acoustic	Bottom Trawl	Long Line*	AICASS**	IPHC*	Japanese Surveys	Atka Tagging	Total
1978								
1979								
1980	2.5	37.9				97.7		138.10
1981								
1982	5.7	0.8						6.50
1983		28.1				396.7		424.80
1984								
1985								
1986		10.6				248.1		258.70
1987								
1988								
1989								
1990								
1991		30.0						30.00
1992								
1993								
1994		26.9						26.90
1995								
1996			0.09					0.09
1997		23.2						23.20
1998			0.11					0.11
1999								
2000		30.9	0.05					30.95
2001								
2002		35.5	0.10					35.60
2003								
2004		18.2	0.06					18.26
2005								
2006		17.8	0.05					17.85
2007								
2008			0.05	7.6				7.65
2009								
2010		35.3	0.26		0.02			35.58
2011					0.06		3.2	3.26
2012		13.0						13.00
2013								
2014		20.7						20.70

* Data only available for 2010

** Aleutian Islands Cooperative Acoustic Survey, 2008 only; 2006 and 2007 AICASS catch included in CAS

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1.B. Assessment of walleye pollock in the Bogoslof Island Region

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Executive Summary

The 2014 winter Bogoslof pollock (*Gadus chalcogrammus*) acoustic-trawl (AT) survey increased relative to the 2012 survey by 67% but this remains at only 25% of the 1991-2014 mean. The following summarizes the 2014 ABC and OFL levels using Tier 5 values and assuming a natural mortality of 0.2:

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2014	2015	2015	2016
M (natural mortality rate)	0.2	0.2	0.2	0.2
Tier	5	5	5	5
Biomass (t)	67,063	67,063	106,000	106,000
F_{OFL}	0.200	0.200	0.200	0.200
$maxF_{ABC}$	0.150	0.150	0.150	0.150
F_{ABC}	0.150	0.150	0.150	0.150
OFL (t)	13,413	13,413	21,200	21,200
maxABC (t)	10,059	10,059	15,900	15,900
ABC (t)	10,059	10,059	15,900	15,900
Status	As determined *this* year for:		As determined *this* year for:	
	2012	2013	2013	2014
Overfishing	No	n/a	No	n/a

Response to SSC and Plan Team comments

General comments:

There were no general comments pertaining to this Tier 5 assessment

Comments specific to this assessment

The SSC noted that this stock has not been fished for a long enough time that catch curve analysis could be used to estimate recent natural mortality. This would be a useful check on the assumed value.

The age-structured model was updated which allowed for a more statistically sound approach to estimating natural mortality. A short summary of this is presented for contrast with the assumption of constant natural mortality of 0.2.

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Introduction

Alaska pollock (*Gadus chalcogrammus*) are broadly distributed throughout the North Pacific with largest concentrations found in the Eastern Bering Sea. The Bogoslof region is noted for having distinct spawning aggregations that appear to be independent from pollock spawning in nearby regions. The Bogoslof management district (INPFC area 518) was established in 1992 in response to fisheries and surveys conducted during the late 1980s, which consistently found a discrete aggregation of spawning pollock in this area during the winter. The degree to which this aggregation represents a unique, self-recruiting stock is unknown but the persistence of this aggregation suggests some spawning site fidelity that called for independent management. The Bogoslof region pollock has also been connected with the historical abundance of pollock found in the central Bering Sea (Donut Hole) due to concentrations of pollock that appeared to be moving toward this region prior to spawning (Smith 1981).

Collectively, pollock found in the Donut Hole and in the Bogoslof region are considered a single stock, the Aleutian Basin stock. Currently, based on an agreement from a Central Bering Sea convention meeting, it is assumed that 60% of the Aleutian Basin pollock population spawns in the Bogoslof region (Fig. 1B.1). The actual distribution of Aleutian Basin pollock is unknown and likely varies depending on environmental conditions and the age-structure of the stock. The Bogoslof component of the Aleutian Basin stock is one of three management stocks of pollock recognized in the BSAI region. The other stocks include pollock found in the large area of the Eastern Bering Sea shelf region and those in the Aleutian Islands near-shore region (i.e., less than 1000m depth; Barbeaux et al. 2004). The Aleutian Islands, Eastern Bering Sea and Aleutian Basin stocks probably intermingle, but the exchange rate and magnitude are unknown. The degree to which the Bogoslof spawning component contributes to subsequent recruitment to the Aleutian Basin stock also is unknown. From an early life-history perspective, the opportunities for survival of eggs and larvae from the Bogoslof region seem smaller than for other areas (e.g., north of Unimak Island on the shelf). There is a high degree of synchronicity among strong year-classes from these three areas, which suggests either that the spawning source contributing to recruitment is shared or that conditions favorable for survival are shared. From a biological perspective, the degree to which these management units are reasonable definitions depends on the active exchange among these stocks. If they are biologically distinct and have different levels of productivity, then management should be adjusted accordingly. Bailey et al. (1999) present a thorough review of population structure of pollock throughout the north Pacific region. They note that adjacent stocks were not genetically distinct but that differentiation between samples collected on either side of the N. Pacific was evident.

There are some characteristics that distinguish Bogoslof region pollock from other areas. Growth rates appear different (based on mean-lengths at age) and pollock sampled in the Bogoslof Island survey tend to be much older. For example, the average percentage (by numbers of fish older than age 6) of age 15 and older pollock observed from the Bogoslof AT surveys (1988-2012) is 18%; in the EBS region (from model estimates), the average from this period is only 2%. The information available for pollock in the Aleutian Basin and the Bogoslof Island area indicates that these fish may belong to the same "stock". The pollock found in winter surveys are generally older than age 4 and are considered distinct from eastern Bering Sea pollock. Further study on stock structure (relating age compositions in adjacent regions) should help understand this possibility. Although data on the age structure of Bogoslof pollock show that a majority of pollock originated from year classes that were also strong on the shelf, 1972, 1978, 1982, 1984, 1989, 1992, 1996, 2000, and 2006 there has been some indication that there are strong year classes appearing on the shelf that have not been as strong (in a relative sense) in the Bogoslof region (Ianelli et al., 2004).

Fishery

Prior to 1977, few pollock were caught in the Donut Hole or Bogoslof region (Low and Ikeda 1978). Japanese scientists first reported significant quantities of pollock in the Aleutian Basin in the mid-to-late

1970's, but large-scale fisheries in the Donut Hole only began in the mid-1980's. By 1987 significant components of these catches were attributed to the Bogoslof Island region (Table 1B.1); however, the actual locations were poorly documented. The Bogoslof fishery primarily targeted winter spawning-aggregations but in 1992, this area was closed to directed pollock fishing.

In 1991, the only year with extensive observer data, the fishery timing coincided with the open seasons for the EBS and Aleutian Islands pollock fisheries (the Bogoslof management district was established in 1992 by FMP amendment 17). However, after March 23, 1991 the EBS region was closed to fishing and some effort was re-directed to the Aleutian Islands region near the Bogoslof district. In subsequent years, seasons for the Aleutian Islands pollock fishery were managed separately. Bycatch and discard levels were relatively low from these areas when there was a directed fishery (e.g., 1991). Updated estimates of pollock bycatch levels from other fisheries were small in recent years (Table 1B.2). The increase in pollock bycatch in 2010 (9 t in 2008 to 73 in 2009 and 176 t in 2010) can be attributed to the non-pelagic trawl arrowtooth flounder target fishery. The majority of pollock bycatch in the Bogoslof region continues to be occurring in the non-pelagic trawl arrowtooth flounder target fishery. For all fisheries there were 57 t of pollock catch in 2013 and 428 t in 2014.

Data

Survey and fishery

NMFS acoustic-trawl survey biomass estimates are the primary data source used in this assessment. Since 2000, the values have varied between 292,000 t and 67,000 t. The most recent AT survey of the Bogoslof spawning stock was conducted in March of 2014 (McKelvey and Stienessen, in prep; Table 1B.3) and resulted in a biomass estimate of 112,070 t. The 2012 survey was the lowest observed. For supplemental studies (the age structured model) additional age-specific information was needed. This included the catch at age in the fishery (for only 1988) and mean weights at age (Tables 1B.4). Additionally, the survey age-specific data were used (Tables 1B.5 and 1B.6).

Analytical approach

Model Structure

Survey biomass averaging

The model for harvest recommendations was based on using a Tier-5 approach with some modifications based on Plan Team and SSC recommendations. First, used a process error model recommended by the Plan Team for estimating a mean biomass over a number of surveys was also explored. This model estimates biomass (B_t) over time as a random effects model of the form:

$$B_t = B_{t-1} e^{\varepsilon_t} \qquad \varepsilon_t \sim N\left(0, \sigma_\varepsilon^2\right)$$

with process errors ε_t estimated as random effects and σ_ε^2 also estimated with the observations and errors from Table 1B.3 included in the likelihood. The model was fit using ADMB (Fournier et al. 2012). This model provides alternative estimates of survey biomass in 2015 which weights the relative influence of past survey estimates between process error variances and that specified as observation errors.

Evaluation of natural mortality estimate

Another analysis was undertaken to evaluate the SSC's recommendation to evaluate the natural mortality as used in the Tier 5 calculation. They suggested that a catch-curve analysis to examine mortality rates under the current bycatch-only status of Bogoslof pollock might be useful. However, since an age-structured stock assessment model has been constructed in the past (Ianelli et al. 2005) it was considered useful for this task since natural mortality can easily be estimated in that configuration and it, unlike a

catch curve approach, requires fewer assumptions about the data and appropriateness of the likelihoods. Consequently a model configured similarly to that used for Aleutian Islands pollock (AMAK) was used with updated survey age data. For brevity, two model configurations were developed, one in which the assumed natural mortality was fixed at 0.2 and the other where it was freely estimated with a diffuse prior distribution.

More recently the SSC has requested an analysis of natural mortality rates since fishing in this region has been curtailed for some time and survey data are relatively plentiful. They suggested that a catch-curve analysis to examine mortality rates under the current bycatch-only status of Bogoslof pollock might be useful. Consequently, the original age-structured stock assessment model (Ianelli et al. 2005 updated with the same model configuration as Aleutian Islands pollock) was used with the new survey age data. For brevity, two model configurations were developed, one in which the assumed natural mortality was fixed at 0.2 and the other where it was freely estimated with a diffuse prior distribution. The catch data used are as reported from 1977-2014 and fit to one year of fishery age composition data (from 1988) and 20 years of survey age compositions:

Source	Type	Years
Fishery	Catch biomass	1977-2014
Fishery	Catch age composition	1988
Acoustic trawl survey	Population biomass (q=1)	1988-2003, 2005-2007, 2009, 2012, 2014
Acoustic trawl survey	Proportions at age	1988-2003, 2005-2007, 2009, 2012

Parameters Estimated Outside the Assessment Model

The model extended from ages 4-15+ pollock, assumed that the survey index catchability was constant and fixed at a value of 1.0, and that selectivity was also estimated at age but constant over time for both the survey and fishery. Mean weights were based on survey and fishery data when they were available and assumed to be constant otherwise and presented in the tables. The assumed proportion mature-at-age was:

Age	4	5	6	7	8	9	10+
	0.30	0.80	0.90	0.95	0.96	0.97	1.00

Results

Results clearly indicated that the fixed natural mortality did a much better job fitting the "plus group" (ages 15 and older) as observed in the 20 years of survey age composition data (Fig. 1B.2). The fit to the survey trend was also improved (Fig. 1B.3), but the impact on the current spawning biomass was relatively minor (Fig. 1B.4). Recent periods of recruitment, excluding the large 1978 year-class, were similar for both model configurations but had different scales with higher recruitment for the model with higher natural mortality (Fig. 1B.5). Running the model using MCMC over a chain of one million samples (keeping each 200th) provides a marginal posterior distribution in which the median and the mean were 0.2992, and 0.3000, respectively (Fig. 1B.6). The mode of the posterior distribution was 0.297, all nearly identical to the values assumed for the eastern Bering Sea pollock stock.

Results of the Plan Team recommended process error method gave nearly identical estimates as using the most recent survey (106,000 t of biomass for the process error model compared to 112,070 t; Fig. 1B.2). However, accounting for the 2012 survey (which was the lowest observed) the survey averaging approach provides a lower value of 106,000 t from which to make the Tier 5 calculations.

Regarding the age-structured model evaluation of natural mortality, the evidence suggests that a higher value is more consistent with the data should be considered as an alternative for use in the Tier 5 calculation. All options are presented in the Harvest Recommendations section below.

Harvest Recommendations

Maximum permissible ABC and OFL estimates for 2015 and 2016 under Tier 5 relies exclusively on the NMFS biennial acoustic trawl survey biomass estimate. Biomass was based on the survey averaging approach.

The Tier 5 ABC formula is:

$ABC = B_{2014} \times M \times 0.75$

Using the alternatives requested by the Plan Team and SSC (i.e., alternative survey averaging and examination of natural mortality) gives the following options for consideration:

Description	M	Biomass	ABC	OFL
Recent survey, M=0.2	0.2	112,070	16,811	22,414
Recent survey, M estimated	0.3	112,070	25,216	33,621
Survey average, M=0.2	0.2	106,000	15,900	21,200
Survey average, M estimated	0.3	106,000	23,850	31,800

For consistency with previous years calculations the recommended ABC is based on the survey average biomass and the natural mortality as in previous years. This results in a maximum permissible Tier 5 ABC of 15,900 t for 2015 and 2016 and an OFL of 21,200 t. The alternative recommendation which uses both the new survey average method and the revised estimate of M would give an ABC and OFL of 23,850 t and 31,800 t, respectively.

Ecosystem considerations

In general, a number of key issues for ecosystem conservation and management can be highlighted. These include:

Preventing overfishing;
Avoiding habitat degradation;
Minimizing incidental bycatch (via multi-species analyses of technical interactions);
Controlling the level of discards; and
Considering multi-species trophic interactions relative to harvest policies.

For the case of pollock, the NPFMC and NMFS continue to manage the fishery on the basis of these issues in addition to the single-species harvest approach. The prevention of overfishing is clearly set out as a main guideline for management. Habitat degradation has been minimized in the pollock fishery by converting the industry to pelagic-gear only. Bycatch in the pollock fleet is closely monitored by the NMFS observer program, and individual species caught incidentally are managed on that basis. Discarding rates have been greatly reduced in this fishery and multi-species interactions is an ongoing research project within NMFS with extensive food-habit studies and simulation analyses to evaluate a number of "what if" scenarios with multi-species interactions.

As reported in Loughlin and Miller (1989) pups of Northern fur seals, *Callorhinus ursinus*, were first observed on Bogoslof Island in 1980. By 1988 the population had grown at a rate of 57% per year to over 400 individuals, including 80+ pups, 159 adult females, 22 territorial males, and 188 sub-adult males. They noted that the rookery is in the same location where solitary male fur seals were seen in 1976 and 1979 and is adjacent to a large northern sea lion rookery. On July 22, 2005 NMFS surveys resulted in counts of 1,123 adult males, a substantial increase over this time period (L. Fritz, AFSC, pers. comm.). The estimated number of Northern fur seal pups born on Bogoslof Island increased from 5,096 (SE = 33) to 12,631 (SE = 335) (Angliss and Allen, 2007). This suggests that conditions in the ecosystem have changed and appear to favor Northern fur seals. The extent that this is due to environmental conditions is unknown. However, pollock abundance may play only a small role since during peak abundance levels, the Northern fur seal abundance was at very low levels. Also, pollock are most concentrated in this region during winter months when Northern fur seals have migrated to more southern areas.

Data gaps and research priorities

Previous assessments (e.g., Ianelli et al. 2004) developed a full-age structure model which was further refined (Ianelli et al. 2005) to include the effect of Donut Hole catches in the 1980s. In that study they assumed that 75% of the Donut Hole catches came from the Bogoslof stock, which is in accord with past practices of international pollock workshops (which used a range from 60 to 80%). However, concerns about this assumption were raised due to the uncertain degree of interchange between Bogoslof fish and central BS fish. In the SSC's December 2006 minutes they noted that additional research is needed to better understand the extent of these linkages. Data to help understand these linkages are not forthcoming and substantial resources (e.g., tagging, extensive survey efforts) would be required. Hence the source and dynamics of recruitment to the Bogoslof region remains unclear.

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Table 1B.1 Catch in tons from the Donut Hole and the Bogoslof Island area, 1977-2014.

Year	Donut Hole (t)	Bogoslof Island (t)	Total (t)
1977		11,500	11,500
1978		9,600	9,600
1979		16,100	16,100
1980		13,100	13,100
1981		22,600	22,600
1982		14,700	14,700
1983		21,500	21,500
1984	181,200	22,900	204,100
1985	363,400	13,700	377,100
1986	1,039,800	34,600	1,074,400
1987	1,326,300	377,436	1,703,736
1988	1,395,900	87,813	1,483,713
1989	1,447,600	36,073	1,483,673
1990	917,400	151,672	1,069,072
1991	293,400	316,038	609,438
1992	10,000	241	10,241
1993	1,957	886	2,843
1994		556	556
1995		334	334
1996		499	499
1997		163	163
1998		8	8
1999		29	29
2000		29	29
2001		258	258
2002		1,042	1,042
2003		24	24
2004		<1	<1
2005		<1	<1
2006		<1	<1
2007		<1	<1
2008		9	9
2009		73	73
2010		176	176
2011		173	173
2012		79	79
2013		57	57
2014		428	428

Table 1B.2. Estimated retained, discarded, and total pollock catch (t) from the Bogoslof region. Source: NMFS Regional office Blend database and catch accounting system.

Year	Discarded	Retained	Total
1991	20,327	295,711	316,038
1992	240	1	241
1993	308	578	886
1994	11	545	556
1995	267	66	334
1996	7	492	499
1997	13	150	163
1998	3	5	8
1999	11	18	29
2000	20	10	29
2001	28	231	258
2002	12	1,031	1,042
2003	19	5	24
2004	< 1		< 1
2005	< 1	< 1	< 1
2006	< 1	< 1	< 1
2007	< 1	< 1	< 1
2008	< 1	9	9
2009	6	67	73
2010	53	124	176
2011	23	150	173
2012	5	74	9
2013	< 1	56	57
2014	54	374	428

Table 1B.3. Biomass (tons) of pollock as surveyed in the Bogoslof region, 1988-2014. For additional details see McKelvey and Stienessen (in prep).

Year	Survey biomass estimates (t)	Survey area (nmi^2)	Relative error
1988	2,395,737	NA	*22%*
1989	2,125,851	NA	*22%*
1990		No survey	
1991	1,289,006	8,411	12%
1992	940,198	8,794	20%
1993	635,405	7,743	9%
1994	490,077	6,412	12%
1995	1,104,124	7,781	11%
1996	682,277	7,898	20%
1997	392,402	8,321	14%
1998	492,396	8,796	19%
1999	475,311	NA	*22%*
2000	301,402	7,863	14%
2001	232,170	5,573	10%
2002	225,712	2,903	12%
2003	197,851	2,993	22%
2004		No survey	
2005	253,459	3,112	17%
2006	240,059	1,803	12%
2007	291,580	1,870	12%
2008		No survey	
2009	110,191	1,803	19%
2010		No survey	
2011		No survey	
2012	67,063	3,656	10%
2013		No survey	
2014	112,070	1,150	12%

Table 1B.4. Catch at age (top row, italics) and average weight at age assumed for fishery in the age-structured model for Bogoslof pollock.

	4	5	6	7	8	9	10	11	12	13	14	15
1988	*0.10*	*0.50*	*3.27*	*2.47*	*1.64*	*3.50*	*12.01*	*2.88*	*2.87*	*2.02*	*0.89*	*0.54*
1977	0.45	0.59	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1978	0.45	0.59	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1979	0.45	0.59	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1980	0.45	0.59	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1981	0.45	0.59	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1982	0.45	0.59	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1983	0.45	0.59	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1984	0.45	0.59	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1985	0.45	0.59	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1986	0.45	0.59	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1987	0.45	0.59	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1988	0.45	0.59	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1989	0.45	0.59	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1990	0.45	0.59	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1991	0.45	0.59	0.72	0.84	0.88	1.00	1.11	1.13	1.19	1.21	1.26	1.24
1992	0.45	0.59	0.66	0.74	0.90	0.96	1.15	1.17	1.20	1.13	1.18	1.30
1993	0.45	0.59	0.77	0.93	1.08	1.19	1.24	1.39	1.51	1.63	1.59	1.46
1994	0.45	0.59	0.73	0.71	0.99	1.29	1.23	1.20	1.33	1.31	1.28	1.28
1995	0.45	0.59	0.84	0.85	1.00	1.24	1.31	1.37	1.49	1.40	1.34	1.49
1996	0.45	0.59	0.82	0.96	0.97	1.06	1.14	1.37	1.45	1.49	1.68	1.46
1997	0.45	0.59	0.75	0.89	1.07	1.08	1.24	1.33	1.42	1.57	1.45	1.42
1998	0.45	0.59	0.64	0.77	1.04	1.19	1.26	1.32	1.35	1.50	1.52	1.63
1999	0.45	0.59	0.74	0.88	1.03	1.11	1.21	1.34	1.41	1.52	1.55	1.50
2000	0.45	0.59	0.74	0.84	1.00	1.12	1.21	1.29	1.37	1.42	1.43	1.42
2001	0.45	0.59	0.74	0.84	1.01	1.14	1.22	1.31	1.39	1.44	1.45	1.44
2002	0.45	0.59	0.75	0.85	1.02	1.16	1.23	1.32	1.41	1.47	1.47	1.46
2003	0.45	0.59	0.75	0.85	1.01	1.15	1.23	1.32	1.40	1.46	1.46	1.46
2004	0.45	0.59	0.75	0.86	1.02	1.14	1.23	1.33	1.41	1.47	1.48	1.48
2005	0.45	0.59	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2006	0.45	0.59	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2007	0.45	0.59	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2008	0.45	0.59	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2009	0.45	0.59	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2010	0.45	0.59	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2011	0.45	0.59	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2012	0.45	0.59	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2013	0.45	0.59	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2014	0.45	0.59	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47

Table 1B.5. Weight at age for the acoustic-trawl survey in age-structured model for Bogoslof pollock.

	4	5	6	7	8	9	10	11	12	13	14	15
1977	0.45	0.50	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1978	0.45	0.50	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1979	0.45	0.50	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1980	0.45	0.50	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1981	0.45	0.50	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1982	0.45	0.50	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1983	0.45	0.50	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1984	0.45	0.50	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1985	0.45	0.50	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1986	0.45	0.50	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1987	0.45	0.50	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1988	0.45	0.50	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1989	0.45	0.50	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1990	0.45	0.50	0.72	0.84	0.94	1.03	1.10	1.16	1.21	1.25	1.29	1.31
1991	0.45	0.50	0.72	0.84	0.88	1.00	1.11	1.13	1.19	1.21	1.26	1.24
1992	0.45	0.50	0.66	0.74	0.90	0.96	1.15	1.17	1.20	1.13	1.18	1.30
1993	0.45	0.50	0.77	0.93	1.08	1.19	1.24	1.39	1.51	1.63	1.59	1.46
1994	0.45	0.50	0.73	0.71	0.99	1.29	1.23	1.20	1.33	1.31	1.28	1.28
1995	0.45	0.50	0.84	0.85	1.00	1.24	1.31	1.37	1.49	1.40	1.34	1.49
1996	0.45	0.50	0.82	0.96	0.97	1.06	1.14	1.37	1.45	1.49	1.68	1.46
1997	0.45	0.50	0.75	0.89	1.07	1.08	1.24	1.33	1.42	1.57	1.45	1.42
1998	0.45	0.50	0.64	0.77	1.04	1.19	1.26	1.32	1.35	1.50	1.52	1.63
1999	0.45	0.50	0.74	0.88	1.03	1.11	1.21	1.34	1.41	1.52	1.55	1.50
2000	0.45	0.50	0.74	0.84	1.00	1.12	1.21	1.29	1.37	1.42	1.43	1.42
2001	0.45	0.50	0.74	0.84	1.01	1.14	1.22	1.31	1.39	1.44	1.45	1.44
2002	0.45	0.50	0.75	0.85	1.02	1.16	1.23	1.32	1.41	1.47	1.47	1.46
2003	0.45	0.50	0.75	0.85	1.01	1.15	1.23	1.32	1.40	1.46	1.46	1.46
2004	0.45	0.50	0.75	0.86	1.02	1.14	1.23	1.33	1.41	1.47	1.48	1.48
2005	0.45	0.50	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2006	0.45	0.50	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2007	0.45	0.50	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2008	0.45	0.50	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2009	0.45	0.50	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2010	0.45	0.50	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2011	0.45	0.50	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2012	0.45	0.50	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2013	0.45	0.50	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47
2014	0.45	0.50	0.74	0.86	1.02	1.13	1.22	1.33	1.40	1.48	1.50	1.47

Table 1B.6. Estimated survey numbers at age from the acoustic-trawl surveys used in the age-structured model for Bogoslof pollock.

	4	5	6	7	8	9	10	11	12	13	14	15
1988	-	27.94	326.71	246.84	163.68	350.07	1,200.88	287.82	287.33	201.95	89.24	53.89
1989	6.00	15.00	58.00	363.00	147.00	194.00	91.00	1,105.00	222.00	223.00	82.00	180.00
1991	2.00	12.00	46.00	213.00	93.00	160.00	44.00	92.00	60.00	373.00	119.00	202.00
1992	2.00	27.00	54.00	97.00	74.00	71.00	55.00	57.00	33.00	34.00	142.00	327.00
1993	33.00	17.00	44.00	46.00	48.00	42.00	28.00	51.00	25.00	27.00	42.00	209.00
1994	21.00	86.00	26.00	38.00	36.00	36.00	17.00	27.00	23.00	13.00	9.00	146.00
1995	6.00	75.00	278.00	105.00	68.00	80.00	53.00	54.00	19.00	59.00	32.00	248.00
1996	0.50	6.00	96.00	187.00	85.00	40.00	37.00	24.00	24.00	12.00	36.00	117.00
1997	0.50	4.00	16.00	55.00	88.00	38.00	28.00	16.00	16.00	13.00	7.00	57.00
1998	0.50	11.00	61.00	34.00	70.00	77.00	32.00	25.00	21.00	19.00	18.00	67.00
1999	2.00	5.00	29.00	77.00	34.00	50.00	75.00	29.00	27.00	25.00	16.00	48.00
2000	1.00	6.00	4.00	14.00	30.00	16.00	28.00	45.00	21.00	16.00	11.00	36.00
2001	1.00	14.00	12.00	10.00	10.00	14.00	12.00	18.00	31.00	13.00	7.00	27.00
2002	5.00	3.00	41.00	11.00	8.00	6.00	7.00	8.00	14.00	30.00	9.00	29.00
2003	8.00	6.00	7.00	25.00	11.00	4.00	5.00	4.00	10.00	8.00	26.00	21.00
2005	5.00	81.00	31.00	13.00	11.00	22.00	7.00	3.00	5.00	4.00	5.00	37.00
2006	4.00	55.00	104.00	18.00	6.00	6.00	9.00	3.00	2.00	4.00	5.00	25.00
2007	1.00	8.00	92.00	70.00	17.00	3.00	3.00	8.00	4.00	1.00	5.00	24.00
2009	-	1.00	1.00	7.00	23.00	26.00	8.00	1.00	1.00	1.00	0.44	4.78
2012	0.14	1.38	14.96	9.65	2.24	0.89	2.36	6.74	7.85	1.12	0.20	1.06

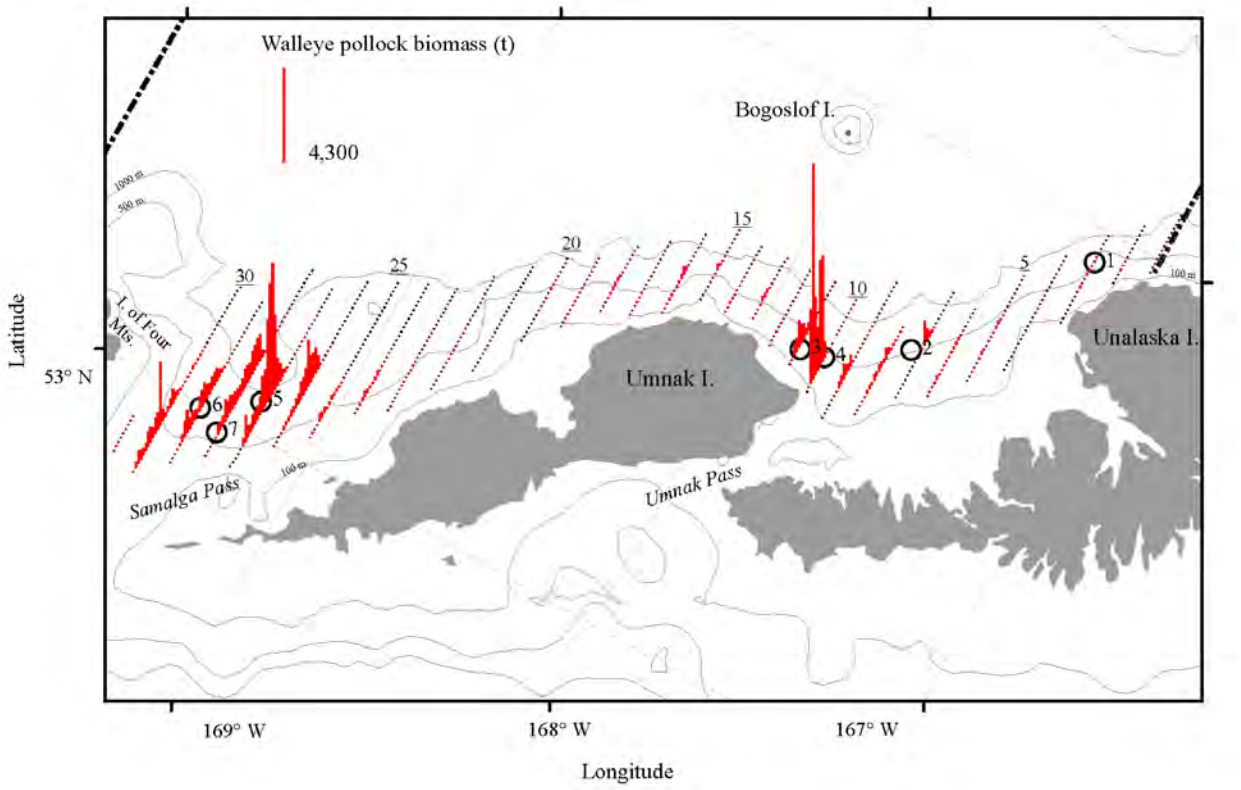

Figure 1B.1. Distribution of pollock biomass (t) observed along transects during the winter 2014 acoustic-trawl survey. Transect numbers are underlined; trawl haul locations are indicated by circles.

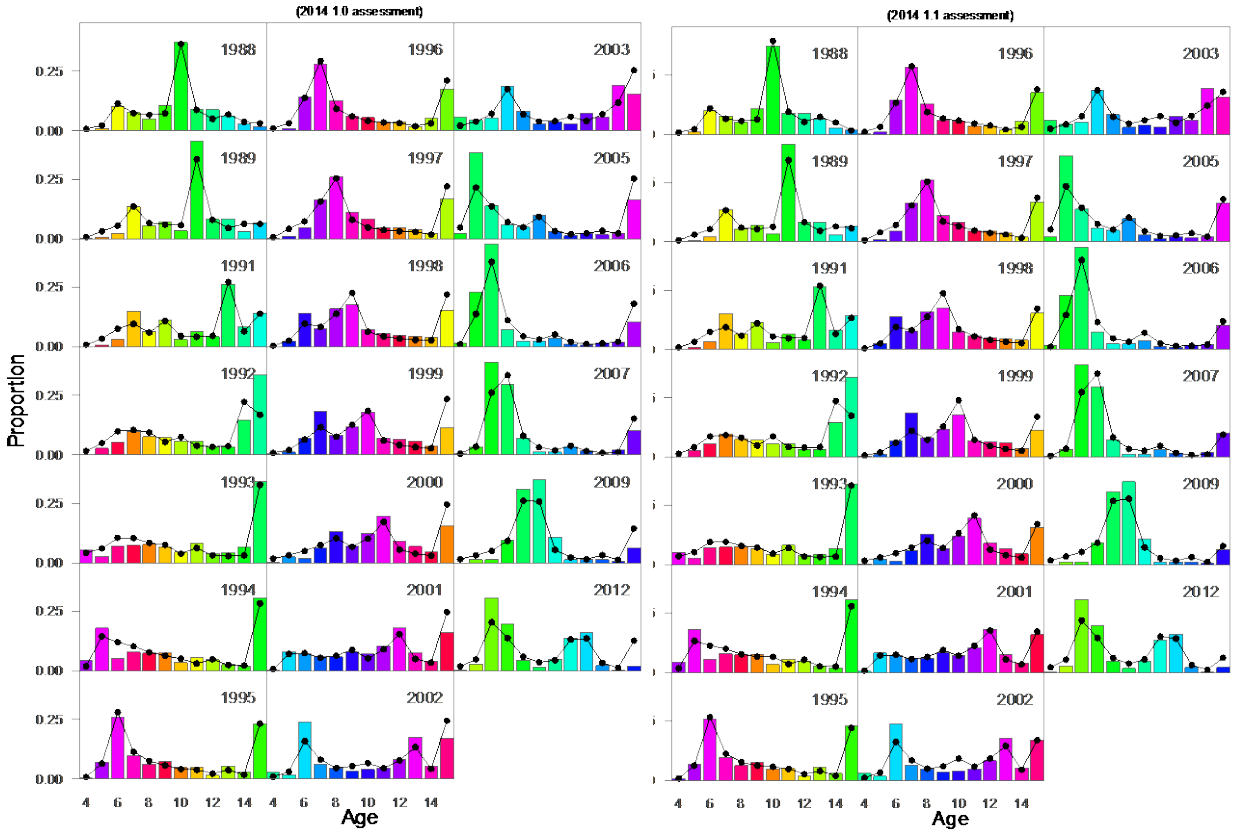

Figure 1B.2. Comparisons of the Bogoslof pollock age-structured model fits to the survey age compositions when natural mortality (M) was assumed to be 0.2 (left panels) compared to when M was freely estimated (right panels).

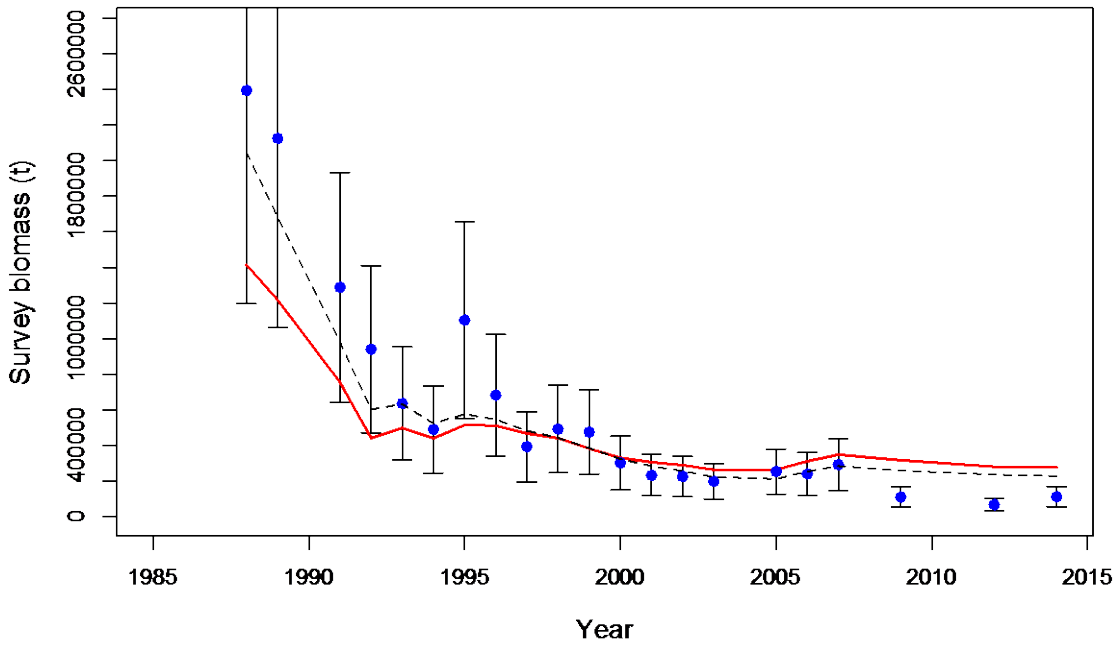

Figure 1B.3. Comparisons of the Bogoslof pollock age-structured model fits to the survey index data when natural mortality (M) was assumed to be 0.2 (solid line) compared to when M was freely estimated (dashed line).

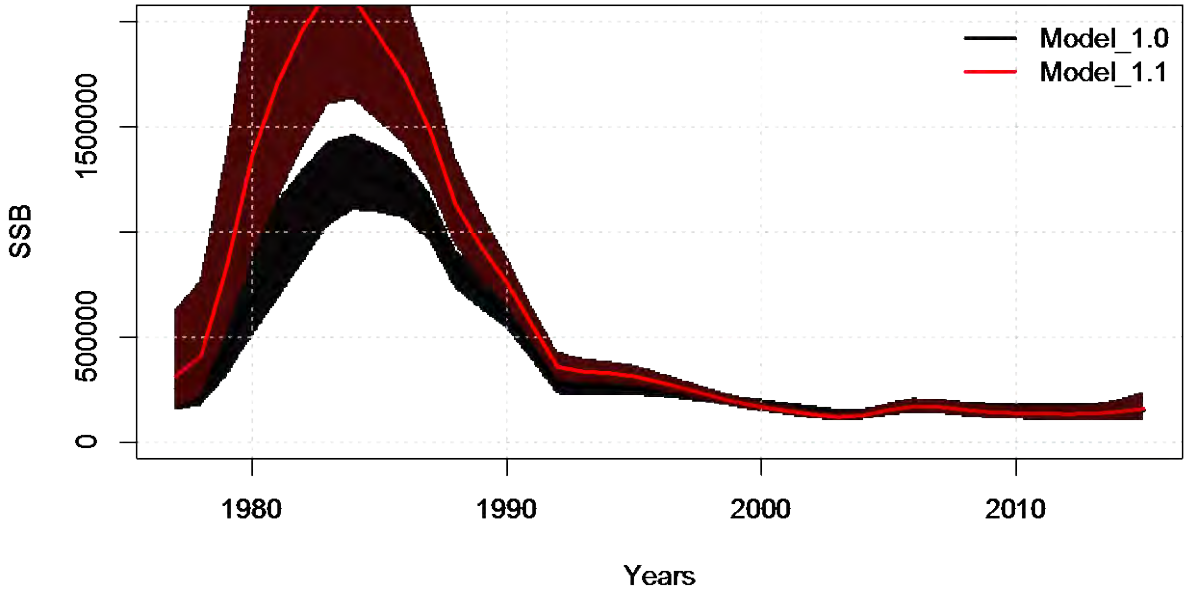

Figure 1B.4. Comparisons of the Bogoslof pollock age-structured model results in spawning biomass (SSB) in t when natural mortality (M) was assumed to be 0.2 (Model 1.0) compared to when M was freely estimated (Model 1.1).

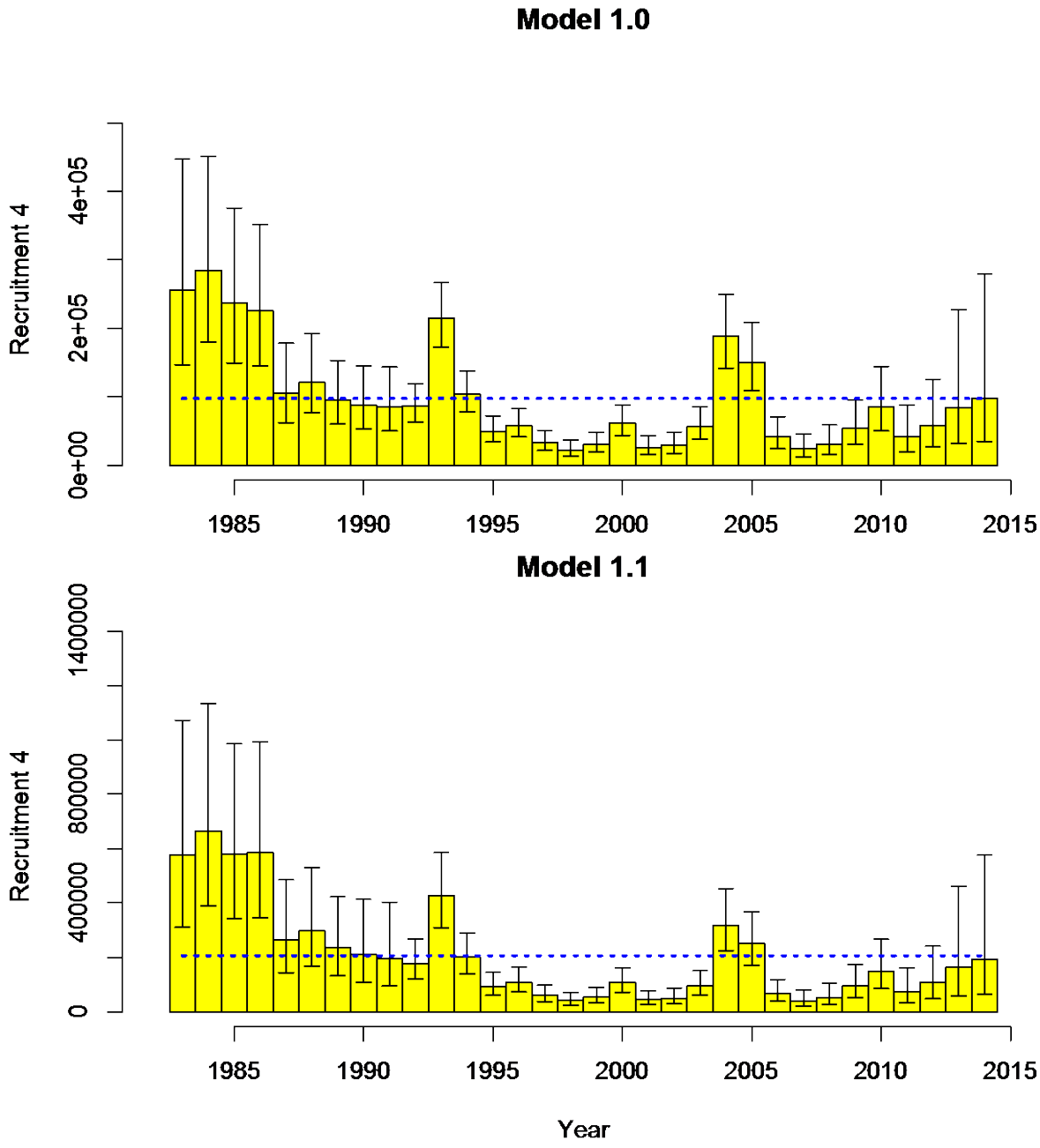

Figure 1B.5. Comparisons of the Bogoslof pollock age-structured model results in recruitment (at age 4) in t when natural mortality (M) was assumed to be 0.2 (Model 1.0; top) compared to when M was freely estimated (Model 1.1; bottom).

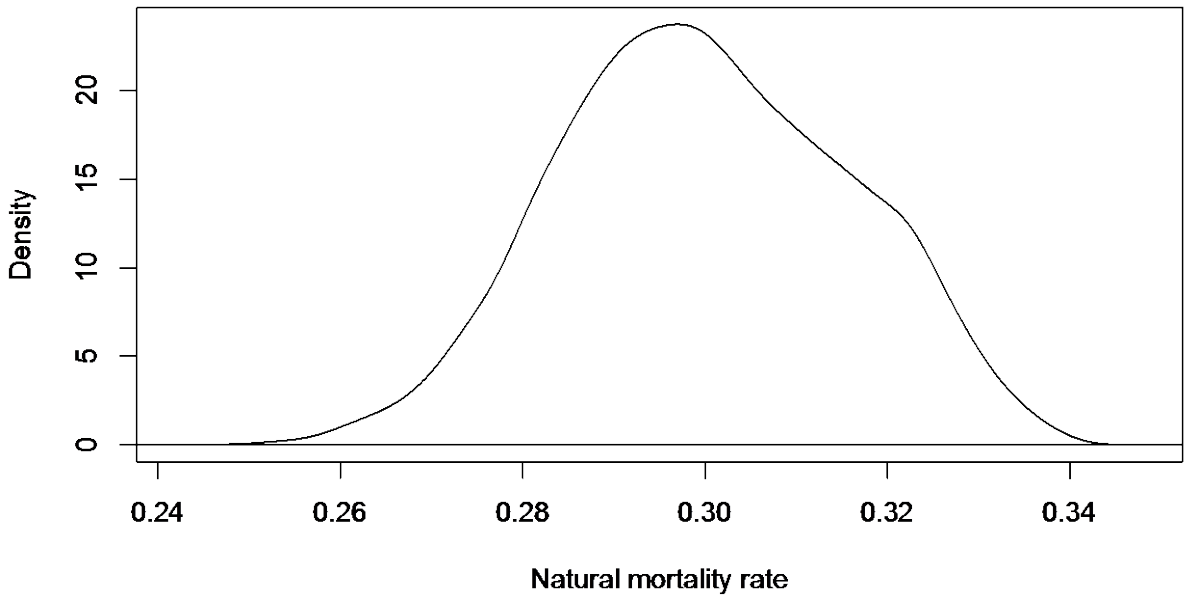

Figure 1B.6. Posterior marginal distribution of one million MCMC samples for the Bogoslof pollock age-structured model for natural mortality (M) under Model 1.1 configuration. The median and the mean were 0.2992, and 0.3000, respectively.

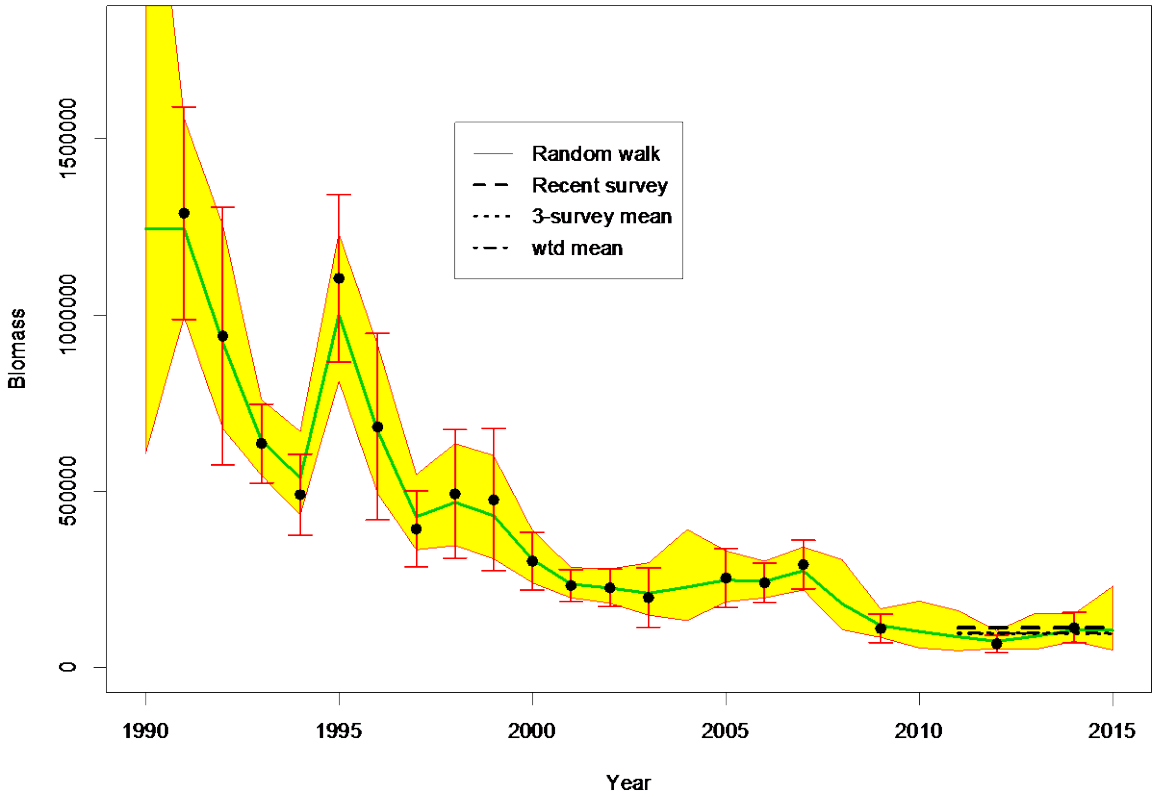

Figure 1B.7. Bogoslof Island pollock survey estimates fitted to a process error model for averaging recruitment. The shade represents the approximate 90% confidence interval from the model. Note that the lines described in the legend appear for the last few years and are difficult to distinguish given the scale.

Chapter 2: Assessment of the Pacific Cod Stock in the Eastern Bering Sea

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EXECUTIVE SUMMARY

Summary of Changes in Assessment Inputs

Relative to the November edition of last year's BSAI SAFE report, the following substantive changes have been made in the EBS Pacific cod stock assessment.

Changes in the Input Data

1) Catch data for 1991-2013 were updated, and preliminary catch data for 2014 were incorporated.
2) Commercial fishery size composition data for 2013 were updated, and preliminary size composition data from the 2014 commercial fisheries were incorporated.
3) Size composition data from the 2014 EBS shelf bottom trawl survey were incorporated.
4) The numeric abundance estimate from the 2014 EBS shelf bottom trawl survey was incorporated (the 2014 estimate of 1,222 million fish was up about 49% from the 2013 estimate).
5) Age composition data from the 2013 EBS shelf bottom trawl survey were incorporated.
6) Mean length at age data from the 2013 EBS shelf bottom trawl survey were incorporated.
7) Seasonal catch per unit effort (CPUE) data for the trawl, longline, and pot fisheries from 2013 were updated, and preliminary CPUE data for the trawl, longline, and pot fisheries from 2014 were incorporated.

Changes in the Assessment Methodology

Many changes have been made or considered in the stock assessment model since the 2013 assessment (Thompson 2013). Six models were presented in this year's preliminary assessment (Appendix 2.1), as requested in March and April by the Joint Team Subcomittee on Pacific Cod Models and the SSC (including one "optional" model). After reviewing the preliminary assessment, the BSAI Plan Team and SSC requested two models for inclusion in the final assessment: the base model that has been used for setting harvest specifications in 2011, 2012, and 2013; and a slightly modified version of the "optional" model from the preliminary assessment. The author recommends retaining the base model for the purpose of setting final harvest specifications for 2015 and preliminary harvest specifications for 2016.

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Summary of Results

The principal results of the present assessment, based on the current model, are listed in the table below (biomass and catch figures are in units of t) and compared with the corresponding quantities from last year's assessment as specified by the SSC:

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2014	2015	2015*	2016*
M (natural mortality rate)	0.34	0.34	0.34	0.34
Tier	3a	3a	3a	3a
Projected total (age 0+) biomass (t)	1,570,000	1,640,000	1,680,000	1,770,000
Projected female spawning biomass (t)	361,000	389,000	409,000	473,000
$B_{100\%}$	796,000	796,000	824,000	824,000
$B_{40\%}$	318,000	318,000	330,000	330,000
$B_{35\%}$	279,000	279,000	288,000	288,000
F_{OFL}	0.34	0.34	0.35	0.35
$maxF_{ABC}$	0.28	0.28	0.29	0.29
F_{ABC}	0.28	0.28	0.21	0.20
OFL (t)	299,000	319,000	346,000	389,000
maxABC (t)	255,000	272,000	295,000	316,000
ABC (t)	255,000	272,000	255,000	287,000
Status	As determined *last* year for:		As determined *this* year for:	
	2012	2013	2013	2014
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

*Projections are based on estimated catches of 212,000 t and 231,000 t for 2015 and 2016, respectively.

Responses to SSC and Plan Team Comments on Assessments in General

JPT1 (9/13 minutes): *"The Teams recommended that SAFE chapter authors continue to include 'other' removals as an appendix. Optionally, authors could also calculate the impact of these removals on reference points and specifications, but are not required to include such calculations in final recommendations for OFL and ABC."* "Other" removals are presented in Appendix 2.2. Impacts of such removals on reference points and specifications were calculated in Attachment 2.4 of the 2012 assessment (Thompson and Lauth 2012).

JPT2 (9/13 minutes): *"In conformity with the main recommendations of the working group, the Teams recommended the following:*

1. *Assessment authors should routinely do retrospective analyses extending back 10 years, plot spawning biomass estimates and error bars, plot relative differences, and report Mohn's rho (revised).*
2. *If a model exhibits a retrospective pattern, try to investigate possible causes.*
3. *Communicate the uncertainty implied by retrospective variability in biomass estimates.*
4. *For the time being, do not disqualify a model on the grounds of poor retrospective performance alone.*

5. *Do consider retrospective performance as one factor in model selection."*

This comment is addressed in the "Results" section, under "Model Evaluation" and also in a new subsection entitled "Retrospective Analysis," located under "Time Series Results."

JPT3 (9/13 minutes): *"The Teams recommended that each stock assessment model incorporate the best possible estimate of the current year's removals. The Teams plan to inventory how their respective authors address and calculate total current year removals. Following analysis of this inventory, the Teams will provide advice to authors on the appropriate methodology for calculating current year removals to ensure consistency across assessments and FMPs."* This comment is addressed under the "Standard Harvest Scenarios, Projection Methodology, and Projection Results" subsection of the "Results" section.

SSC1 (10/13 minutes): *"We agree with the recommendations of the Plan Team that retrospective analyses extending back 10 years and including Mohn's revised ρ, should routinely be presented in the assessments, and that retrospective patterns should be taken into consideration when selecting a model and when communicating uncertainties associated with biomass estimates. The SSC also notes that a strong retrospective bias should be one of the criteria considered when setting ABCs and could provide justification for recommending a higher or lower ABC."* See response to comment JPT2. Consideration of retrospective bias in the context of ABC is addressed in the "Harvest Recommendations" subsection of the "Results" section.

SSC2 (12/13): *"During public testimony, it was proposed that assessment authors should consider projecting the reference points for the future two years (e.g., 2014 and 2015) on the phase diagrams. It was suggested that this forecast would be useful to the public. The SSC agrees. The SSC appreciated this suggestion and asks the assessment authors to do so in the next assessment."* Figure 2.15 includes projected values for the next two years.

JPT4 (9/14): Regarding catch projections, *"the Teams recommend that authors choose a method that appears to be appropriate for their stock, and this method be clearly documented. The Teams recommend authors establish their best available estimate of catch in the current year and the next two years. The Teams recommend that authors should also document how those projected catches were determined in the Harvest Recommendations section (ideally Scenario 2)."* See response to comment JPT3. Estimation of projected catches is addressed in the same subsection, and those estimated catches are used in Scenario 2.

SSC3 (10/14): Regarding comment JPT4, *"The SSC supports these recommendations."* See response to comments JPT3 and JPT4.

Responses to SSC and Plan Team Comments Specific to this Assessment

Nineteen comments specific to this assessment were addressed in the preliminary assessment (Appendix 2.1). In the interest of efficiency, they are not repeated in this section. BSAI Plan Team (BPT) and SSC comments that were developed following completion of the preliminary assessment are shown below.

BPT1 (9/14 minutes): *"The Team recommends that the author present fits of Models 1 and 6 in November. The L1 parameter of Model 6 should be estimated as a single rather than time-varying value to stiffen the fit and eliminate the questionable values in the series of annual estimates of L1."* Models 1 and 6 from the preliminary assessment are included here as Models 1 and 2. The *L1* parameter is now time-invariant in both models.

SSC4 (10/14 minutes): *"The SSC agrees with the Plan Team and also notes that the laborious re-weighting procedure does not need to be repeated for Model 6. The SSC also agrees with the Plan Team regarding estimation of a single L1 parameter for growth instead of the annual estimates."* See response to comment BPT1. The iterative tuning process that was used to estimate certain parameters in Model 6 (now Model 2) during the preliminary assessment was not repeated here.

INTRODUCTION

General

Pacific cod (*Gadus macrocephalus*) is a transoceanic species, occurring at depths from shoreline to 500 m. The southern limit of the species' distribution is about 34° N latitude, with a northern limit of about 65° N latitude (Lauth 2011). Pacific cod is distributed widely over the eastern Bering Sea (EBS) as well as in the Aleutian Islands (AI) area. Tagging studies (e.g., Shimada and Kimura 1994) have demonstrated significant migration both within and between the EBS, AI, and Gulf of Alaska (GOA). However, recent research indicates the existence of discrete stocks in the EBS and AI (Canino et al. 2005, Cunningham et al. 2009, Canino et al. 2010, Spies 2012). Although the resource in the combined EBS and AI (BSAI) region had been managed as a single unit since 1977, last year separate 2014-2015 harvest specifications were set for the two areas.

Pacific cod is not known to exhibit any special life history characteristics that would require it to be assessed or managed differently from other groundfish stocks in the EBS or AI areas.

Review of Life History

Pacific cod eggs are demersal and adhesive. Eggs hatch in about 15 to 20 days. Spawning takes place in the sublittoral-bathyal zone (40 to 290 m) near bottom. Eggs sink to the bottom after fertilization and are somewhat adhesive. Optimal temperature for incubation is 3° to 6°C, optimal salinity is 13 to 23 parts per thousand (ppt), and optimal oxygen concentration is from 2 to 3 ppm to saturation. Little is known about the optimal substrate type for egg incubation.

Little is known about the distribution of Pacific cod larvae, which undergo metamorphosis at about 25 to 35 mm. Larvae are epipelagic, occurring primarily in the upper 45 m of the water column shortly after hatching, moving downward in the water column as they grow.

Juveniles occur mostly over the inner continental shelf at depths of 60 to 150 m. Adults occur in depths from the shoreline to 500 m, although occurrence in depths greater than 300 m is fairly rare. Preferred substrate is soft sediment, from mud and clay to sand. Average depth of occurrence tends to vary directly with age for at least the first few years of life.

It is conceivable that mortality rates, both fishing and natural, may vary with age in Pacific cod. In particular, very young fish likely have higher natural mortality rates than older fish (note that this may not be particularly important from the perspective of single-species stock assessment, so long as these higher natural mortality rates do not occur at ages or sizes that are present in substantial numbers in the data). For example, Leslie matrix analysis of a Pacific cod stock occurring off Korea estimated the instantaneous natural mortality rate of 0-year-olds at 2.49% per day (Jung et al. 2009). This may be compared to a mean estimate for age 0 Atlantic cod (*Gadus morhua*) in Newfoundland of 4.17% per day, with a 95% confidence interval ranging from about 3.31% to 5.03% (Gregory et al. in prep.); and age 0 Greenland cod (*Gadus ogac*) of 2.12% per day, with a 95% confidence interval ranging from about 1.56% to 2.68% (Robert Gregory and Corey Morris, *pers. commun.*).

Although little is known about the likelihood of age-dependent natural mortality in adult Pacific cod, it has been suggested that Atlantic cod may exhibit increasing natural mortality with age (Greer-Walker 1970).

At least one study (Ueda et al. 2006) indicates that age 2 Pacific cod may congregate more, relative to age 1 Pacific cod, in areas where trawling efficiency is reduced (e.g., areas of rough substrate), causing their selectivity to decrease. Also, Atlantic cod have been shown to dive in response to a passing vessel (Ona and Godø 1990), which may complicate attempts to estimate catchability or selectivity. It is not known whether Pacific cod exhibit a similar response.

As noted above, Pacific cod are known to undertake seasonal migrations, the timing and duration of which may be variable (Savin 2008).

FISHERY

Description of the Directed Fishery

During the early 1960s, a Japanese longline fishery harvested EBS Pacific cod for the frozen fish market. Beginning in 1964, the Japanese trawl fishery for walleye pollock (*Theragra chalcogramma*) expanded and cod became an important bycatch species and an occasional target species when high concentrations were detected during pollock operations. By the time that the Magnuson Fishery Conservation and Management Act went into effect in 1977, foreign catches of Pacific cod had consistently been in the 30,000-70,000 t range for a full decade. In 1981, a U.S. domestic trawl fishery and several joint venture fisheries began operations in the EBS. The foreign and joint venture sectors dominated catches through 1988, but by 1989 the domestic sector was dominant and by 1991 the foreign and joint venture sectors had been displaced entirely.

Presently, the Pacific cod stock is exploited by a multiple-gear fishery, including trawl, longline, pot, and jig components (although catches by jig gear are very small in comparison to the other three main gear types, with an average annual catch of less than 200 t since 1992). The breakdown of catch by gear during the most recent complete five-year period (2009-2013) is as follows: longline gear accounted for an average of 57% of the catch, trawl gear accounted for an average of 31%, and pot gear accounted for an average of 12%.

In the EBS, Pacific cod are caught throughout much of the continental shelf, with NMFS statistical areas 509, 513, 517, 519, and 521 each accounting for at least 5% of the average catch over the most recent 5-year period (2009-2013).

Catches of Pacific cod taken in the EBS for the periods 1964-1980, 1981-1990, and 1991-2014 are shown in Tables 2.1a, 2.1b, and 2.1c, respectively. The catches in Tables 2.1a and 2.1b are broken down by fleet sector (foreign, joint venture, domestic annual processing). The catches in Table 2.1b are also broken down by gear to the extent possible. The catches in Table 2.1c are broken down by gear.

Effort and CPUE

Figures 2.1 and 2.2 show, subject to confidentiality restrictions, the approximate locations in which hauls or sets sampled during 2013 and 2014 contained Pacific cod. To create these figures, the areas managed under the FMP were divided into 20 km × 20 km squares. For each gear type, a square is shaded if hauls/sets containing Pacific cod from more than two distinct vessels were sampled in it during the respective gear/season/year (Figure 2.1) or gear/year (Figure 2.2). Figure 2.1 shows locations of sampled EBS hauls/sets containing Pacific cod for trawl, longline, and pot gear, for the January-April, May-July,

and August-December seasons. Figure 2.2 shows locations of sampled EBS hauls/sets for the same gear types, but aggregated across seasons. More squares are shaded in Figure 2.2 than in Figure 2.1 because aggregating across seasons increases the number of squares that satisfy the confidentiality constraint.

Various gear-specific time series of fishery catch per unit effort (CPUE) are plotted in Figure 2.3. Most CPUE time series are either flat or increasing since about the middle of the last decade.

Discards

The catches shown in Tables 2.1b and 2.1c include estimated discards. Discards of Pacific cod in the EBS Pacific cod fisheries are shown for each year 1991-2014 in Table 2.2. Amendment 49, which mandated increased retention and utilization of Pacific cod, was implemented in 1998. From 1991-1997, discard rates in the Pacific cod fishery averaged about 3.3%. Since then, they have averaged about 1.8%.

Management History

The history of acceptable biological catch (ABC), overfishing level (OFL), and total allowable catch (TAC) levels is summarized and compared with the time series of aggregate (i.e., all-gear, combined area) commercial catches in Table 2.3. Note that, with the exception of 2014, this time series pertains to the combined BSAI region, so the catch time series differs from that shown in Table 2.1, which pertains to the EBS only.

From 1980 through 2013, TAC averaged about 83% of ABC (ABC was not specified prior to 1980), and from 1980 through 2013 aggregate commercial catch averaged about 92% of TAC. In 10 of these 34 years, TAC equaled ABC exactly, and in 8 of these 34 years (24%), catch exceeded TAC (by an average of 3%). However, three of those overages occurred in 2007, 2008, and 2010, when TAC was reduced by 3% to account for a small, State-managed fishery inside State of Alaska waters within the AI subarea (similar reductions have been made in all years since 2006); thus, while the combined Federal and State catch exceeded the Federal TAC in 2007, 2008, and 2010 by 2% or less, the overall target catch (Federal TAC plus State GHL) was *not* exceeded.

Total catch has been less than OFL in every year since 1993.

Changes in ABC over time are typically attributable to three factors: 1) changes in resource abundance, 2) changes in management strategy, and 3) changes in the stock assessment model. Assessments conducted prior to 1985 consisted of simple projections of survey numbers at age. In 1985, the assessment was expanded to consider all survey numbers at age from 1979-1985. From 1985-1991, the assessment was conducted using an *ad hoc* separable age-structured model. In 1992, the assessment was conducted using the Stock Synthesis modeling software (Methot 1986, 1990) with age-based data. All assessments from 1993 through 2003 continued to use the Stock Synthesis modeling software, but with length-based data. Age data based on a revised ageing protocol were added to the model in the 2004 assessment. At about that time, a major upgrade in the Stock Synthesis architecture resulted in a substantially new product, labeled "SS2" (Methot 2005). The assessment was migrated to SS2 in 2005, and several changes have been made to the model in most years since then (see Appendix 2.3). A note on nomenclature: The label "SS2" was dropped in 2008. Since then, the program has been known simply as "Stock Synthesis" or "SS," with several versions typically produced each year, each given an alpha-numeric label.

Beginning with the 2014 fishery, the Board of Fisheries for the State of Alaska established a guideline harvest level (GHL) in State waters between 164 and 167 degrees west longitude in the EBS subarea (this supplemented a GHL that had been set aside for the Aleutian Islands subarea since 2006). The State's

procedure for setting GHLs for the two subareas is to sum the subarea ABCs, then set a GHL in each subarea equal to 3% of the total.

Table 2.4 lists all amendments to the BSAI Groundfish FMP that reference Pacific cod explicitly.

DATA

This section describes data used in the current stock assessment models. It does not attempt to summarize all available data pertaining to Pacific cod in the EBS.

The following table summarizes the sources, types, and years of data included in the data file for at least one of the stock assessment models:

Source	Type	Years
Fishery	Catch biomass	1977-2014
Fishery	Catch size composition	1977-2014
Fishery	Catch per unit effort	1991-2014
EBS shelf bottom trawl survey	Numerical abundance	1982-2014
EBS shelf bottom trawl survey	Size composition	1982-2014
EBS shelf bottom trawl survey	Age composition	1994-2013
EBS shelf bottom trawl survey	Mean size at age	1994-2013

Fishery

Catch Biomass

Catches taken in the EBS for the period 1977-2014 are shown for the three main gear types in Table 2.5. Table 2.5 makes use of two different types of season: catch seasons and selectivity seasons. The catch seasons are defined as January-February, March-April, May-July, August-October, and November-December. Three selectivity seasons are defined by combining catch seasons 1 and 2 into selectivity season 1, equating catch season 3 with selectivity season 2, and combining catch seasons 4 and 5 into selectivity season 3. The catch seasons were the result of a statistical analysis described in the 2010 preliminary assessment (Thompson et al. 2010), and the selectivity seasons were chosen to correspond as closely as possible to the traditional seasons used in assessments prior to 2010 (given the revised catch seasons).

In years for which estimates of the distribution by gear or period were not available, proxies based on other years' distributions were used to create Table 2.5. Catches for the years 1977-1980 may or may not include discards.

Catches for the August-October and November-December seasons of 2014 were estimated by the method described under Scenario 2 in the "Harvest recommendations" subsection of the "Results" section. With these two exceptions, the catches shown in Table 2.5 consist of "official" data from the NMFS Alaska Region. However, other removals of Pacific cod are known to have occurred over the years, including removals due to subsistence fishing, scientific research, and fisheries managed under other FMPs. Estimates of such other removals are shown in Appendix 2.2.

Catch Size Composition

Fishery size compositions are presently available, by gear, for at least one gear type in every year from 1977 through the first part of 2014. Beginning with the 2010 assessment (Thompson et al. 2010), size composition data are based on 1-cm bins ranging from 4 to 120 cm. Because displaying these data would add a large number of pages to the present document, they are not shown here but are available at: http://www.afsc.noaa.gov/REFM/Docs/2014/EBS_Pcod_fishery_sizecomp_data.xlsx.

Catch Per Unit Effort

Fishery catch per unit effort data are available by gear and season for the years 1991-2014 and are shown in Table 2.6. Units are kg/minute for trawl gear, kg/hook for longline gear, and kg/pot for pot gear; data for 2014 are partial. The "sigma" values shown in the tables are intended only to give an idea of the relative variability of the respective point estimates, and are not actually used in any of the analyses presented here.

Survey

EBS Shelf Bottom Trawl Survey

Estimates of total abundance (both in biomass and numbers of fish) obtained from the trawl surveys are shown in Table 2.7, together with their respective standard errors. Upper and lower 95% confidence intervals are also shown for the biomass estimates. Survey results indicate that biomass remained relatively constant from 1982 through 1988. The highest biomass ever observed by the survey was the 1994 estimate of 1,368,120 t. Following the high observation in 1994, the survey biomass estimate declined steadily through 1998. The survey biomass estimates remained in the 596,000-619,000 t range from 2002 through 2005. However, the survey biomass estimates dropped after 2005, producing an all-time low in 2007 and again in 2008. Estimated biomass more than doubled between 2009 and 2010, then remained relatively stable for the next three years, followed by another large (36%) this year. The 2014 estimate is the fifth highest in the time series.

Numerical abundance has shown more variability than biomass, with the estimates since 2007 generally well above average pre-2007 levels (with the exception of 2008, estimates since 2007 have all been at least 15% above the pre-2007 average). The 2013 estimate was down 24% from the 2012 estimate, but the 2014 estimate is up 49% from the 2013 estimate, and is the second highest estimate in the time series.

The relative size compositions from the EBS shelf bottom trawl survey for the years 1982-2014 are shown in Table 2.8 (actual numbers of fish measured are shown in column 2 in the upper portion of the first page). The 1982-2014 time series is shown according to the 1-cm bins described above for fishery size composition data. Rows in Table 2.8 sum to the actual number of fish measured in each year.

Age compositions from the 1994-2013 surveys are available. The age compositions and actual sample sizes are shown in Table 2.9.

Mean size-at-age data are available for all of the years in which age compositions are available. These are shown, along with sample sizes, in Table 2.10.

ANALYTIC APPROACH

Model Structure (General)

Although Pacific cod in the EBS and AI were managed on a BSAI-wide basis through 2013, the stock assessment model has always been configured for the EBS stock only. Since 1992, the assessment model has always been developed under some version of the SS modeling framework (technical details given in Methot and Wetzel 2013; see especially Appendix A to that paper). A history of previous model structures, including details of the present model, is given in Appendix 2.3.

Two models are presented here: Model 1, the base model that has been used for the last three years, and Model 2, which differs from Model 1 in several respects, as detailed below.

Version 3.24s (compiled on 07/24/13) of SS was used to run the models in this assessment. SS is programmed using the ADMB software package (Fournier et al. 2012). The current SS user manual is available at: https://drive.google.com/a/noaa.gov/?tab=mo#folders/0Bz1UsDoLaOMLN2FiOTI3MWQtZDQwOS00YWZkLThmNmEtMTk2NTA2M2FjYWVh.

Development of the final versions of both models included calculation of the Hessian matrix. These models also passed a "jitter" test of 50 runs with a jitter parameter (equal to half the standard deviation of the logit-scale distribution from which initial values are drawn) of 0.10 (or 0.01, in the event that too few runs converged when the jitter parameter was set at 0.10). In the event that a jitter run produced a better value for the objective function than the base run, then: 1) the model was re-run starting from the final parameter file from the best jitter run, 2) the resulting new control file became the new base run, and 3) the entire process (starting with a new set of jitter runs) was repeated until no jitter run produced a better value for the objective function than the most recent base run.

Model 1: main features

Model 1 is the model that has been used to recommend harvest specifications for the last three years (2011-2013), and its structure was documented in the assessments for each of those years. Briefly, some of the main features characterizing this model are as follow:

1. Age- and time-invariant natural mortality, estimated outside the model
2. Parameters governing time-invariant mean length at age estimated internally
3. Parameters governing width of length-at-age distribution (for a given mean) estimated internally
4. Ageing bias parameters estimated internally
5. Standard deviations of *dev* vectors fixed at the values estimated in 2009
6. Survey catchability fixed at the value estimated in 2009 (based on Nichol et al. 2007)
7. Gear-and-season-specific catch and selectivity for the fisheries
8. Double normal selectivity for the fisheries and survey (see Appendix 2.3 for parameterization)
9. Length-based selectivity for the fisheries
10. Age-based selectivity for the survey
11. Fishery selectivity estimated for "blocks" of years
12. Survey selectivity constant over time, except with annual *dev*s for the *ascending_width* parameter
13. Survey size composition data used in all years, including those years with age composition data (at the request of Plan Team members, inclusion of survey size composition data in all years was instituted in the 2011 assessment and has been retained ever since, based on the view that the costs of double-counting are outweighed by the benefits of including this information for estimation of growth parameters)

14. Fishery CPUE data included but not used for estimation
15. Mean size at age included but not used for estimation

Model 2: main features

Some of the main differences between Model 2 and Model 1 were as follow:

1. Each year consisted of a single season instead of five.
2. A single fishery was defined instead of nine season-and-gear-specific fisheries.
3. The survey was assumed to sample age 1 fish at true age 1.5 instead of 1.41667.
4. Initial abundances were estimated for the first ten age groups instead of the first three.
5. The natural mortality rate was estimated internally.
6. The base value of survey catchability was estimated internally.
7. Survey catchability was allowed to vary annually.
8. Selectivity for both the fishery and the survey were allowed to vary annually.
9. Selectivity for both the fishery and survey was modeled using a random walk with respect to age (SS selectivity-at-age pattern #17) instead of the usual double normal. Selectivity-at-age pattern #17 in SS has one parameter for each age in the model. Except for age 0, the parameter for any given age represents the logarithm of the ratio of selectivity at that age to selectivity at the previous age (i.e., the backward first difference on the log scale). Age 0 fish are often expected to have a selectivity of zero, which can be achieved in this selectivity pattern by setting the parameter for age 0 equal to -1000, as was done for all six models presented here. As with other parameters in SS, each parameter in this selectivity pattern is associated with a prior distribution (see "Iterative tuning of prior distributions for selectivity parameters" in the next subsection).

Model 2: iterative tuning

Three types of iterative tuning were involved in the development of Model 2 during this year's preliminary assessment (Appendix 2.1). The first of these applied only to the prior distributions for selectivity parameters, and the second applied to all time-varying parameters except catchability, and the third applied only to time-varying catchability.

Because this type of iterative tuning is time-consuming, it was not possible to redo the analysis for the final assessment; instead, the values resulting from the tuning procedure in the preliminary assessment were retained here (see also Comment SSC4). By way of comparison, a slightly less time-consuming procedure was used to tune some of the same (or analogous) parameters in a precursor to Model 1 from the 2009 assessment (Thompson et al., 2009) and, by request of the Plan Team, those values have not been re-tuned since.

Iterative tuning of prior distributions for selectivity parameters

Initially, the model was run with recruitment as the only time-varying quantity, with the standard deviation of log-scale recruitment estimated internally (i.e., as a free parameter), and with large standard deviations in the prior distributions for all selectivity parameters.

Once the initial model converged, a pair of transformed logistic curves was fit to the point estimates of the fishery and survey selectivity schedules (a *transformed* logistic curve was used because the selectivity parameters in pattern #17 consist of the backward first differences of selectivity on the log scale, rather than selectivity itself; Thompson and Palsson 2013). The respective transformed logistic curve (fishery or survey) was then used to specify a new set of means for the selectivity prior distributions (one for each

age). A constant (across age) prior standard deviation was then computed such that no age had a prior CV (on the selectivity scale, not the transformed scale) less than 50%.

The model was then run with the new set of prior means and constant prior standard deviations (one for the fishery, one for the survey), then a new pair of transformed logistic curves was fit to the results, and the process was repeated until convergence was achieved. The converged set of prior means for ages 1-12 (on the transformed scale, not the selectivity scale) estimated in the preliminary assessment was as follows (ages 13+ all had prior means of 0 for both the fishery and the survey):

Age:	1	2	3	4	5	6
Fishery:	2.940E+00	2.937E+00	2.887E+00	2.258E+00	6.028E-01	4.471E-02
Survey:	5.020E+00	6.074E-01	2.533E-03	7.680E-06	2.300E-08	0

Age:	7	8	9	10	11	12
Fishery:	2.420E-03	1.280E-04	6.770E-06	3.580E-07	1.900E-08	1.000E-09
Survey:	0	0	0	0	0	0

The converged prior standard deviations were 0.350 for the fishery and 0.319 for the survey (both constant across age).

Iterative tuning of time-varying parameters other than catchability

Two main loops were involved in the iterative tuning of time-varying parameters other than catchability. These loops were designed to produce the quantities needed in order to use the method of Thompson and Lauth (2012, Annex 2.1.1) for estimating the standard deviation of a *dev* vector:

1. Estimating "unconstrained" estimates of the standard deviation(s) of the *dev*s for a particular parameter or parameter vector. The purpose of this loop was to determine the vector of *dev*s for an individual parameter or parameter vector that would be obtained if the *dev*s were completely unconstrained by their respective σs. The following individual parameters and parameter vectors were included in this exercise: *L1* (length at age 1.5), age 0 recruitment, the vector of age-specific fishery selectivity parameters, and the vector of age-specific survey selectivity parameters. For parameter vectors especially, this was not always a straightforward process, as estimating a large matrix of age×year *dev*s is difficult if the *dev*s are unconstrained. In general, though, the procedure was to begin with a small (constant across age, in the case of a parameter vector) value of σ; calculate the standard deviation of the estimated *dev*s; then increase the value of σ gradually until the standard deviation of the estimated *dev*s reached an asymptote.
2. Estimating "iterated" estimates of the standard deviations for the *dev*s. Again proceeding one parameter or parameter vector fleet at a time, this loop began with σ set at the unconstrained value(s) estimated in the first loop. The standard deviation(s) of the estimated *dev*s then became the age-specific σ(s) for the next run, and the process was repeated until convergence was achieved.

For age 0 recruitment, the final value of σ (after application of the algorithm described by Thompson and Lauth (2012)) obtained in the preliminary assessment was 0.657. Because recruitments are log-transformed, the *dev*s are specified as being normal and additive.

In the case of a vector of age-specific selectivity parameters, it is common for some ages to be "tuned" out during the second loop (i.e., the σs converge on zero). For Model 2, all ages were tuned out except age 4 for the fishery and ages 2 and 3 for the survey. The final values of σ (after application of the

algorithm described by Thompson and Lauth (2012)) obtained in the preliminary assessment were 0.158 for fishery age 4 and 0.106 for survey ages 2 and 3 (note that these *dev*s are all normal and additive).

Unfortunately, the way that selectivity pattern #17 is implemented in SS, large gradients tend to result if significant *dev*s occur at the age of peak selectivity. Because survey selectivity for Model 2 tended to peak at age 3, it turned out to be impossible to include *dev*s for age 3, so Model 2 included survey selectivity *dev*s for age 2 only.

Iterative tuning of time-varying catchability

Unlike the size composition or age composition data sets, the time series of survey abundance includes not only a series of expected values, but a corresponding series of standard errors as well. This formed the basis for the iterative tuning of the σ term for time-varying catchability in Model 2. The procedure involved iteratively adjusting σ until the root-mean-squared-standardized-residual equaled unity. The final value of σ obtained in the preliminary assessment was 0.089 (normal and additive, because SS works in terms of $\ln(Q)$ rather than Q).

Parameters Estimated Outside the Assessment Model

Natural Mortality

A value of 0.34 has been used for the natural mortality rate M in all BSAI Pacific cod stock assessments since 2007 (Thompson et al. 2007b). This value was based on Equation 7 of Jensen (1996) and an age at maturity of 4.9 years (Stark 2007). In response to a request from the SSC, the 2008 assessment included a discussion of alternative values and a justification for the value chosen (Thompson et al. 2008). However, it should be emphasized that, even if Jensen's Equation 7 is exactly right, variability in the estimate of the age at maturity implies that the point of estimate of 0.34 is accompanied by some level of uncertainty. Using the variance for the age at 50% maturity published by Stark (0.0663), the 95% confidence interval for M extends from about 0.30 to 0.38.

The value of 0.34 adopted in 2007 replaced the value of 0.37 that had been used in all BSAI Pacific cod stock assessments from 1993 through 2006.

For historical completeness, some other published estimates of M for Pacific cod are shown below:

Area	Author	Year	Value
Eastern Bering Sea	Low	1974	0.30-0.45
	Wespestad et al.	1982	0.70
	Bakkala and Wespestad	1985	0.45
	Thompson and Shimada	1990	0.29
	Thompson and Methot	1993	0.37
Gulf of Alaska	Thompson and Zenger	1993	0.27
	Thompson and Zenger	1995	0.50
British Columbia	Ketchen	1964	0.83-0.99
	Fournier	1983	0.65

Model 1 in this assessment fixes M at the value of 0.34 used since 2007. Model 2 estimates M internally.

Variability in Estimated Age

Variability in estimated age in SS is based on the standard deviation of estimated age between "reader" and "tester" age determinations. Weighted least squares regression has been used in the past several assessments to estimate a proportional relationship between standard deviation and age. The regression was recomputed this year, yielding an estimated slope of 0.08560 (i.e, the standard deviation of estimated age was modeled as 0.08560 × age) and a weighted R^2 of 0.93. This regression corresponds to a standard deviation at age 1 of 0.086 and a standard deviation at age 20 of 1.712. These parameters were used for the models in the present assessment.

Weight at Length

Long-term base values of the parameters governing the weight-at-length schedule were re-estimated in the 2012 assessment using the method described in Annex 2.1.2 of Thompson and Lauth (2012), based on fishery data collected from 1974 through 2011.

Using the functional form weight = $\alpha \times \text{length}^{\beta}$, where weight is measured in kg and length is measured in cm, the long-term base values for the parameters were estimated as $\alpha = 6.358 \times 10^{-6}$ and $\beta = 3.157$.

Seasonal additive log-scale offsets from the base parameter values were re-estimated in this year's preliminary assessment, resulting in the following values:

Season:	Jan-Feb	Mar-Apr	May-Jul	Aug-Oct	Nov-Dec
α:	-2.281E-02	2.768E-03	1.920E-02	2.304E-03	-1.416E-02
β:	5.250E-03	-6.470E-04	-4.535E-03	-5.386E-04	3.276E-03

The above values for the base parameters and seasonal offsets were used for both models in the present assessment.

Model 2 allows for *inter*-annual as well as *intra*-annual variability in weight-length parameters (Model 1 allows for intra-annual variability only). Annual additive offsets from the base values were estimated in this year's preliminary assessment (values show below) and used for Model 2.

Year:	1977	1978	1979	1980	1981	1982	1983	1984
α offset:	1.72E-06	-2.80E-06	9.84E-07	-6.15E-07	3.29E-07	2.32E-06	-2.94E-08	1.11E-05
β offset:	-5.87E-02	1.53E-01	-3.52E-02	2.03E-02	-1.98E-02	-7.27E-02	9.10E-03	-2.64E-01

Year:	1985	1986	1987	1988	1989	1990	1991	1992
α offset:	-1.37E-06	-2.60E-06	-5.71E-07	-2.52E-06	-1.62E-06	8.15E-07	1.29E-06	-1.39E-07
β offset:	7.05E-02	1.43E-01	2.90E-02	1.46E-01	9.37E-02	-1.74E-02	-4.90E-02	-5.05E-03

Year:	1993	1994	1995	1996	1997	1998	1999	2000
α offset:	2.27E-06	1.19E-07	-1.33E-06	7.15E-06	7.51E-07	1.22E-06	1.48E-06	1.72E-06
β offset:	-6.04E-02	-4.87E-03	6.12E-02	-1.87E-01	-4.06E-02	-5.83E-02	-5.64E-02	-5.17E-02

Year:	2001	2002	2003	2004	2005	2006	2007	2008
α offset:	3.58E-06	1.00E-06	-6.92E-07	1.67E-06	-3.61E-07	5.69E-07	1.04E-07	3.87E-06
β offset:	-1.10E-01	-3.64E-02	2.80E-02	-5.98E-02	1.70E-02	-2.11E-02	1.87E-04	-1.19E-01

Year:	2009	2010	2011	2012	2013
α offset:	-1.12E-06	8.26E-07	4.03E-07	2.52E-06	-1.12E-06
β offset:	5.25E-02	-3.36E-02	-2.24E-02	-9.35E-02	4.30E-02

Maturity

A detailed history and evaluation of parameter values used to describe the maturity schedule for BSAI Pacific cod was presented in the 2005 assessment (Thompson and Dorn 2005). A length-based maturity schedule was used for many years. The parameter values used for this schedule in the 2005 and 2006 assessments were set on the basis of a study by Stark (2007) at the following values: length at 50% maturity = 58 cm and slope of linearized logistic equation = –0.132. However, in 2007, changes in SS allowed for use of either a length-based or an age-based maturity schedule. Beginning with the 2007 assessment, the accepted model has used an age-based schedule with intercept = 4.88 years and slope = –0.965 (Stark 2007). The use of an age-based rather than a length-based schedule follows a recommendation from the maturity study's author (James Stark, Alaska Fisheries Science Center, personal communication). The age-based parameters were retained for the models in the present assessment.

Standard Deviation of Log Recruitment

The standard deviation specified for log-scale age 0 recruitment was estimated iteratively in the 2009 assessment (Thompson et al. 2009), by matching the input value to the standard deviation of the estimated *dev*s. The resulting value of 0.57 was retained for Model 1 in the present assessment. This parameter was set iteratively in Model 2, using the method described in Annex 2.1.1 of Thompson and Lauth (2012).

Catchability

In the 2009 assessment (Thompson et al. 2009), catchability for the post-1981 trawl survey was estimated iteratively by setting the average (weighted by numbers at length) of the product of catchability and selectivity for the 60-81 cm size range equal to the point estimate of 0.47 obtained by Nichol et al. (2007). The resulting value of 0.77 was retained for Model 1 in the present assessment. Catchability was estimated internally in Model 2.

Parameters Estimated Inside the Assessment Model

A total of 186 parameters were estimated inside SS for Model 1. These include:

1. all three von Bertalanffy growth parameters
2. standard deviation of length at ages 1 and 20
3. mean ageing bias at ages 1 and 20
4. log mean recruitment since the 1976-1977 regime shift
5. offset for log-scale mean recruitment prior to the 1976-1977 regime shift
6. *dev*s for log-scale initial (i.e., 1977) abundance at ages 1 through 3
7. annual log-scale recruitment *dev*s for 1977-2013
8. initial (equilibrium) fishing mortality for the Jan-Apr trawl fishery
9. gear-, season-, and-block-specific selectivity parameters for nine fisheries
10. base values for all survey selectivity parameters
11. annual *dev*s for the *ascending_width* parameter of the survey selectivity function

A total of 203 parameters were estimated inside SS for Model 2. With the exceptions of the initial fising mortality rate, base values for selectivity patterns, and selectivity *dev*s, these included all of the parameters listed above for Model 1 (Model 2 estimated an initial fishing mortality rate, base values of selectivity parameters, and selectivity *dev*s also, but the nature and number of those parameters was different than in Model 1). In addition, Model 2 estimated the natural mortality rate, a fourth growth parameter (Richards' growth coefficient), the base value of log-scale survey catchability, and annual catchability offsets.

In Model 1, uniform prior distributions were used for all parameters, except that *dev* vectors were constrained by input standard deviations ("sigma"), which are somewhat analogous to a joint prior distribution.

In Model 2, the base selectivity parameters had normal priors, while other non-*dev* parameters had uniform priors (as in Model 1).

For all parameters estimated within individual SS runs, the estimator used was the mode of the logarithm of the joint posterior distribution, which was in turn calculated as the sum of the logarithms of the parameter-specific prior distributions and the logarithm of the likelihood function.

In addition to the above, the full set of year-, season-, and gear-specific fishing mortality rates were also estimated internally, but not in the same sense as the above parameters. The fishing mortality rates are determined (almost) exactly as functions of other model parameters, because SS assumes that the input total catch data are true values rather than estimates, so the fishing mortality rates can be computed algebraically given the other parameter values and the input catch data. An option does exist in SS for treating the fishing mortality rates as full parameters, but previous explorations have indicated that adding these parameters has almost no effect on other model output (Methot and Wetzell 2013).

Objective Function Components

Both models in this assessment include likelihood components for initial (equilibrium) catch, trawl survey relative abundance, fishery and survey size composition, survey age composition, recruitment, "softbounds" (equivalent to an extremely weak prior distribution used to keep parameters from hitting bounds), and parameter deviations. In addition, Model 2 includes an objective function component for prior distributions (Model 1 uses only uniform prior distributions, so does not need an objective function for prior distributions).

In SS, emphasis factors are specified to determine which likelihood components receive the greatest attention during the parameter estimation process. As in previous assessments, all likelihood components were given an emphasis of 1.0 here.

Use of Size Composition Data in Parameter Estimation

Size composition data are assumed to be drawn from a multinomial distribution specific to a particular year, gear, and season within the year (Model 1) or just year (Model 2). In the parameter estimation process, SS weights a given size composition observation according to the emphasis associated with the respective likelihood component and the sample size specified for the multinomial distribution from which the data are assumed to be drawn. In developing the model upon which SS was originally based, Fournier and Archibald (1982) suggested truncating the multinomial sample size at a value of 400 in order to compensate for contingencies which cause the sampling process to depart from the process that gives rise to the multinomial distribution. For many years, the Pacific cod assessments assumed a multinomial sample size equal to the square root of the true length sample size, rather than the true length sample size itself. Given the true length sample sizes observed in the EBS Pacific cod data, this procedure tended to give values somewhat below 400 while still providing SS with usable information regarding the appropriate effort to devote to fitting individual length samples.

Although the "square root rule" for specifying multinomial sample sizes gave reasonable values, the rule itself was largely *ad hoc*. In an attempt to move toward a more statistically based specification, the 2007 assessment used the harmonic means from a bootstrap analysis of the available fishery length data from 1990-2006 (Thompson et al. 2007b). The harmonic means were smaller than the actual sample sizes, but still ranged well into the thousands. A multinomial sample size in the thousands would likely overemphasize the size composition data. As a compromise, the harmonic means were rescaled proportionally in the 2007 assessment so that the average value (across all samples) was 300. However, the question then remained of what to do about years not covered by the bootstrap analysis (2007 and pre-1990) and what to do about the survey samples. The solution adopted in the 2007 assessment was based on an observed consistency in the ratios between the harmonic means (the raw harmonic means, not the rescaled harmonic means) and the actual sample sizes: Whenever the actual sample size exceeded about 400 fish, for the years prior to 1999 the ratio was very consistently close to 0.16, and for the years after 1998 the ratio was very consistently close to 0.34.

This consistency was used to specify the missing values as follows: For fishery data, records with actual sample sizes less than 400 were omitted. Then, the sample sizes for fishery length compositions from years prior to 1999 were tentatively set at 16% of the actual sample size, and the sample sizes for fishery length compositions from 2007 were tentatively set at 34% of the actual sample size. For the pre-1982 trawl survey, length compositions were tentatively set at 16% of an assumed sample size of 10,000. For the post-1981 trawl survey length compositions, sample sizes were tentatively set at 34% of the actual sample size. Then, with sample sizes for fishery length compositions from 1990-2007 tentatively set at their bootstrap harmonic means (not rescaled), all sample sizes were adjusted proportionally so that the average was 300.

The same procedure was used in the 2008 and 2009 assessments. For the 2010 assessment, however, this procedure had to be modified somewhat, because the bootstrap values for the 1990-2006 size composition data did not match the new bin and seasonal structures. To be as consistent as possible with the approach used to set sample sizes in the 2008 and 2009 assessments, the 2010 and 2011 assessments set sample sizes by applying the 16/34% rule for *all* size composition records with actual sample sizes greater than 400 (not just those lying outside the set of 1990-2006 fishery data), then rescaling proportionally to achieve an average sample size of 300. The same procedure was used for the 2012-2013 assessments, except the pre-1982 trawl survey data were no longer used. Model 1 in this year's assessment uses the

same procedure as the 2012-2013 assessments. Model 2 uses a similar procedure, except that the input sample sizes for the fishery and survey scaled so that the average is 300 *for each*, rather than 300 for all size composition data combined. The full sets of input sample sizes are shown in Table 2.11.

Use of Age Composition Data in Parameter Estimation

Like the size composition data, the age composition data are assumed to be drawn from a multinomial distribution specific to a particular gear, year, and season within the year. Input sample sizes for the multinomial distributions were computed by scaling the actual number of otoliths read in each year (Table 2.9, column 2) proportionally such that the average of the input sample sizes was equal to 300, giving the following:

Year:	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
N:	204	163	203	205	181	245	245	263	248	360
Year:	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
N:	284	365	371	411	346	403	369	358	371	405

Use of Fishery CPUE and Survey Relative Abundance Data in Parameter Estimation

Fishery CPUE data are included in the Model 1 for comparative purposes only, and are not included at all in Model 2. Their respective catchabilities (in Model 1) are estimated analytically, not statistically.

For the trawl surveys, each year's survey abundance estimate is assumed to be drawn from a lognormal distribution specific to that year. The model's estimate of survey abundance in a given year serves as the geometric mean for that year's lognormal distribution, and the ratio of the survey abundance estimate's standard error to the survey abundance estimate itself serves as the distribution's coefficient of variation, which is then transformed into the "sigma" parameter for the lognormal distribution.

Use of Recruitment Deviation "Data" in Parameter Estimation

The likelihood component for recruitment is different from traditional likelihoods because it does not involve "data" in the same sense that traditional likelihoods do. Instead, the log-scale recruitment *dev* plays the role of the datum in a normal distribution with mean zero and specified (or estimated) standard deviation; but, of course, the *dev*s are parameters, not data.

RESULTS

Model Evaluation

The two models used in this assessment are described under "Model Structure" above.

Goodness of Fit, Parameter Estimates, and Derived Quantities

Table 2.12 shows the objective function value for each data component and sub-component in the model. The first part of the table shows negative log-likelihoods (and negative log priors) for the aggregate data components. The second and third parts of the table break down the CPUE (Model 1 only) and size composition components into fleet-specific values. For the CPUE component, the fishery values are shown for completeness, but they are shaded to indicate that they do not count toward the total. Because the two models contain very different data in many respects, objective function values are not comparable across models. Table 2.12 also shows parameter counts for the two models, broken down into the

following categories: 1) unconstrained parameters (i.e., parameters with non-constraining uniform prior distributions), 2) parameters with priors (other than uniform), and 3) constrained *dev*s.

Table 2.13 provides alternative measures of how well the model fits the fishery CPUE (Model 1 only) and survey relative abundance data. The first column shows root mean squared errors (RMSE; values closer to the average log-scale standard error in the data (0.11) are better), mean normalized residuals (MNR; values closer to zero are better), standard deviations of normalized residuals (SDNR; values closer to unity are better), and correlations between observed and estimated values (values to unity are better). The first 9 rows of Table 2.13 pertain to the fishery CPUE data. Although Model 1 does not actually attempt to fit these data (only the survey CPUE are used), of the 9 correlations with fishery CPUE, all but one are positive. The most important parts of this table are the entries for the shelf trawl survey (last two rows), which is something that both models actually try to fit. Model 2 does much better than Model 1 by any of the four measures presented.

Figure 2.4 shows the model's fit to the trawl survey abundance data. Model 1's estimates fall within the 95% confidence intervals 76% of the time; Model 2's do so 97% of the time.

Table 2.14 shows how output "effective" sample sizes ("Neff," McAllister and Ianelli 1997) compare to input sample sizes ("Ninp") for the size composition data. Three sets of ratios are provided for each fleet: 1) the arithmetic mean ("A") of the Neff/Ninp ratio, 2) the ratio of arithmetic mean Neff to arithmetic mean Ninp, and 3) the ratio of harmonic mean ("H") Neff to arithmetic mean Ninp. Both models give ratios greater (usually *much* greater) than unity for all cases for all three measures, except for the Aug-Dec longline fishery in Model 1, using the the measure with the harmonic mean in the numerator (ratio=0.88).

Table 2.15 provides a similar analysis for the age composition data, except that the rows in the main part of this table correspond to individual records rather than fisheries or surveys (all age composition data come from the survey). The bottom two rows in the table show the ratios of the means (using the arithmetic mean as the numerator in the next-to-last row and the harmonic mean in the last row). For Model 1, both ratios are less than unity. For Model 2, the ratio based on the arithmetic mean is greater than unity, but the ratio based on the harmonic mean is less than unity.

The model's fits to the age composition data are shown in Figure 2.5. Estimates of mean size at ages 1 through 3 (at the time of the survey) from the model are compared to the long-term average survey size composition (through 50 cm) in Figure 2.6. Both models tends to match the modes, within one or two cm. Model 1's fits to the mean-size-at-age data are shown in Figure 2.7 (recall that the model does not actually attempt to fit these data, and Model 2 does not include these data at all). Because of the large number of size composition records (n=416), figures showing the model's fits to these data are not included in this document, but are available at: http://www.afsc.noaa.gov/REFM/Docs/2014/EBS_Pcod_sizecomp fits.xlsx.

Table 2.16 displays all of the parameters (except fishing mortality rates, because these are functions of other parameters) estimated internally in the model, along with the standard deviations of those estimates, plus selected constants. Tables 2.16a-b (with a few exceptions) show parameters that are common to both models: Table 2.16a shows biological parameters, ageing bias, recruitment (except annual *dev*s), initial fishing mortality, log catchability (base value only for Model 2), and initial age composition parameters; and Table 2.16b shows annual log-scale recruitment *dev*s (these are plotted in Figure 2.8). Tables 2.16c-d show parameters that are unique to Model 1: Table 2.16c shows fishery selectivity parameters, and Table 2.16d shows survey selectivity parameters. Tables 2.16e-g show parameters that are unique to Model 2: Table 2.16e shows annual log catchability offsets, Table 2.16f shows fishery selectivity parameters, and Table 2.16g shows survey selectivity parameters.

Table 2.17 shows estimates of fishing mortality. Table 2.17a shows fishing mortality by year in both models, and Table 2.17 b shows full-selection seasonal fishing mortality rates for each gear type and year in Model 1 only (Table 2.17b). In Table 2.17a, two measures of annual fishing mortality are shown for each model. The first is an "average" fishing mortality rate across ages 6-18. This age range was determined in the 2013 assessment as the set of ages for which fishery selectivity was at least 80% on average across all gear types and seasons (ages 19-20 also met this criterion, but SS generates a warning if the last two age groups are included in the average). The second measure of fishing mortality ("Apical F") is the rate corresponding to the length of full selection.

Figure 2.9 shows the time series of spawning biomass relative to $B_{100\%}$ as estimated by each model.

Figure 2.10 shows trawl survey selectivity as estimated by the model. Both models show variability aver time for selectivity at age 1. For Model 1, this is due to the fact that annual *dev*s are estimated for the *ascending_width* parameter. For Model 2, it is due to the fact that annual *dev*s are estimated for the age 1 selectivity parameter. The shapes of the profiles are qualitatively similar, although the profile for Model 1 declines more at older ages than does the profile for Model 2. For example, in Model 1, all ages greater than 10 have selectivity estimates less than about 0.25, whereas in Model 2, all ages greater than 10 have selectivity estimates less than about 0.40.

Figure 2.11 shows fishery selectivity for the two models. Figure 2.11a shows gear-, season-, and block-specific fishery selectivity as estimated by Model 1. In general, selectivities that are not forced to be asymptotic tend to show decreasing selectivity at large size in Model 1. Figure 2.11b shows the pattern of annually varying fishery selectivity as estimated by Model 2. The only time variability occurs at ages less than 4. Model 2 also exhibits bimodality, with a dominant mode at age 6 and a secondary mode at age 13.

Per request of the SSC (see Comment SSC8 in Appendix 2.1), Figure 2.12 shows likelihood profiles with respect to *M* for each model. The value of survey catchability is also shown (constant for Model 1, but co-varying with *M* for Model 2, as both parameters were estimated internally for Model 2). Model 1 assumes a value of 0.34 for *M*, but the likelihood profile indicates that a value of 0.40 would provide a better fit to the data. Model 2 estimates *M* internally at a value of 0.344, very close to the value assumed in Model 1.

Table 2.18 contains selected output from the standard projection model, based on SS parameter estimates from Models 1 and 2, along with the probability that the maximum permissible ABC in each of the next two years will exceed the corresponding true-but-unknown OFL and the probability that the stock will fall below $B_{20\%}$ in each of the next five years (probabilities are given by SS rather than the standard projection model). Note that some of the quantities in Table 2.18 are conditional on catches estimated under Scenario 2 ("author's F") in the "Harvest Recommendations" section.

Evaluation Criteria

The following criteria were considered in evaluating the model:

1. Does the model satisfy the SSC's requests that model changes be kept to a minimum?
2. Does the model contain new features that merit further evaluation before being adopted?
3. Would use of the model for setting 2015-2016 harvest specifications pose a significant risk to the stock?

The first criterion is suggested by a number of SSC minutes over the last couple of years:

- From the June 2012 meeting (listed as Comment SSC5 in Attachment 2.1 to the 2012 assessment): *"…Given the Plan Team's (and SSC's) reluctance in previous years to consider a new author-recommended model in the fall that incorporates a large number of potentially influential changes in a single model (for example changes in growth, selectivities, and catchability), the SSC encourages the authors to evaluate changes in one or a few structural elements at a time."*
- From the June 2013 meeting (listed as Comment SSC6 in Appendix 2.1 to the 2013 assessment): *"The SSC recommends that model changes be kept to a minimum to ensure that we can track model sensitivities to specific changes in model structure."*
- From the December 2013 meeting (listed as Comment SSC3 in this year's Appendix 2.1): *"…The SSC discussed the need for a more incremental approach to implementing changes to the model…."*

Because Model 1 is the base model (having been used for the last three years), adopting it for the present harvest specifications cycle would, by definition, keep the number of model changes to a minimum. Model 2, in contrast, contains a large number of potentially influential changes, including changes in growth, selectivity, and catchability; and does not satisfy the stated need for a more incremental approach to implementing changes to the base model.

In the context of the second criterion, one new feature of Model 2 that stands out is its use of SS selectivity pattern #17, which treats selectivity as a random walk with respect to age. Although this pattern has several benefits (see "Discussion" section in Appendix 2.1), some aspects could benefit from further evaluation, specifically:

- Selectivity pattern #17 involves internal rescaling so that selectivity reaches a peak value of unity at some integer age. Restricting peak selectivity to occur at an integer age means that the function is not entirely differentiable, which is potentially problematic in ADMB.
- Although a substantial improvement in goodness of fit can sometimes be achieved by allowing annual *dev*s at the age of peak selectivity, this is sometimes accompanied by a large final gradient in the objective function (most likely related to the item in the previous bullet), which is usually considered to be symptomatic of a problem with the model.
- In some situations, a substantial improvement in goodness of fit can be achieved by estimating selectivity at unrealistically low values for all ages except for a few that are very close to the age-plus group.

With respect to the third criterion, Model 1 estimates a much higher maximum permissible ABC than Model 2 (Table 2.18). As discussed below in the "Retrospective Analysis" section, Model 1 appears to over-estimate the size of the stock by a substantial amount consistently ($\rho = 0.494$), in contrast to Model 2, which appears to show almost no systematic over- or under-estimation ($\rho = -0.049$). If ABC were set at the maximum permissible level, and if the stock were at a low level of abundance, this suggests that adoption of Model 1 might impose an unacceptable risk to the stock. However, it is not necessary to set ABC at the maximum permissible level, neither model suggests that spawning biomass is dangerously low, and both models suggest that spawning biomass has been increasing steadily since 2009 or 2010. Although adoption of Model 1 would result in the seventh-highest OFL in history, catches of Pacific cod have never exceeded ABC during the last 20 years, so OFL may not be much of a consideration in practice.

On the basis of the above, Model 1 is recommended for use in setting final harvest specifications for 2015 and preliminary harvest specifications for 2016.

Final Parameter Estimates and Associated Schedules

As noted previously, estimates of all statistically estimated parameters in the model are shown in Table 2.16. Estimates of both aggregated annual and year-, gear-, and season-specific fishing mortality rates from Model 1 are shown in Table 2.17.

Schedules of selectivity at length for the commercial fisheries from Model 1 are shown in Table 2.19, and schedules of selectivity at age for the trawl surveys from Model 1 are shown in Table 2.20. The trawl survey selectivity schedule and all fishery selectivity schedules for Model 1 are plotted in Figures 2.11 and 2.12, respectively.

Schedules of length at age and weight at age for the population, length at age for each gear-and-season-specific fishery and each survey, and weight at age for each gear-and-season-specific fishery and the survey from Model 1 are shown in Tables 2.21, and 2.22, and 2.23, respectively.

Time Series Results

Definitions

The biomass estimates presented here will be defined in three ways: 1) age 0+ biomass, consisting of the biomass of all fish aged 0 years or greater in January of a given year; 2) age 3+ biomass, consisting of the biomass of all fish aged 3 years or greater in January of a given year; and 3) spawning biomass, consisting of the biomass of all spawning females in a given year. The recruitment estimates presented here will be defined as numbers of age 0 fish in a given year. To supplement the full-selection fishing mortality rates already shown in Table 2.17, an alternative "effective" fishing mortality rate will be provided here, defined for each age and time as $-\ln(N_{a+1,t+1}/N_{a,t})-M$, where N = number of fish, a = age measured in years, t = time measured in years, and M = instantaneous natural mortality rate. In addition, the ratio of full-selection fishing mortality to $F_{35\%}$ will be provided.

Biomass

Table 2.24 shows the time series of age 0+, age 3+, and female spawning biomass for the years 1977-2014 as estimated last year and this year (projections through 2015 are also shown for this year's assessment). The estimated spawning biomass time series are accompanied by their respective standard deviations.

The estimated time series of EBS age 0+, age 3+, and female spawning biomass are shown, together with the observed time series of trawl survey biomass, in Figure 2.13. Confidence intervals are shown for estimates of female spawning biomass and for the trawl survey biomass estimates. The average ratio of estimated age 0+ biomass to survey biomass over the time series is 1.79. Given that the catchability coefficient is fixed at 0.77, estimation of biomasses at least 30% (on average) higher than observed by the survey is to be expected.

Recruitment and Numbers at Age

Table 2.25 shows the time series of age 0 recruitment (1000s of fish) for the years 1977-2013 as estimated last year and this year. Both estimated time series are accompanied by their respective standard deviations.

For the time series as a whole, the largest year class appears to have been the 1977 cohort, followed by the 2008 cohort. The year classes since 2006 include four of the top ten year classes of all time (2006,

2008, 2011, and 2013; although it should be emphasized that the estimate of the 2013 cohort's rank is very preliminary). The set of year classes comprising the top ten is the same this year as last year, except that the 2013 cohort has bumped the 2010 cohort down to #11.

Recruitment estimates for the entire time series (1977-2013) are shown in Figure 2.14, along with their respective 95% confidence intervals.

The coefficient of autocorrelation for the recruitment time series is –0.12.

To date, it has not been possible to estimate a reliable stock-recruitment relationship for this stock. A possible relationship between recruitment and an environmental index is discussed in the "Ecosystem Considerations" section, under "Ecosystem Effects on the Stock."

The estimated time series of numbers at age is shown in Table 2.26.

Fishing Mortality

Table 2.27 shows "effective" fishing mortality by age and year for ages 1-19 and years 1977-2014.

Figure 2.15 plots the estimated trajectory of relative fishing mortality and relative female spawning biomass from 1977 through 2016 based on full-selection fishing mortality, overlaid with the current harvest control rules (projected values for 2015 and 2016 are from Scenario 2 under "Harvest Recommendations," below). It should be noted that, except for the projection years, this trajectory is based on SS output, which may not match the estimates obtained by the standard projection program exactly. Note that fishing mortality rates for the years 2006-2012 appear to have been higher than the F_{OFL} control rule. This may be due to a retrospective bias, as discussed in the next subsection.

Retrospective Analysis

Figure 2.16 shows the retrospective behavior of Model 1 with respect to female spawning biomass over the years 2004-2014. This figure was obtained by conducting ten additional model runs, dropping the 2014 data to create the run labeled "2013," dropping the 2013-2014 data to create the run labeled "2012," and so forth (the run labeled "2014" is this year's model run). In an attempt to quantify the results of this type of retrospective analysis, Mohn (1999) introduced a statistic labeled ρ, which has since been redefined to represent the average relative bias in terminal year estimates of a given quantity (in this case, female spawning biomass) across retrospective runs. For Model 1, $\rho = 0.494$, indicating that Model 1 tends to overestimate spawning biomass in the current year by nearly 50%. This ρ value is higher (in absolute terms) than any of the 20 examples of BSAI and GOA groundfish stocks reported in the 2013 report of the Retrospective Working Group. Not only is the retrospective bias of Model 1 high and positive on average, it is positive in all runs shown in Figure 2.16 except one (2013), ranging from 0.181-1.006 for the remaining years.

Determining the cause of a retrospective bias can be difficult. One oft-considered possibility is that certain parameters are constrained in the model to be constant over time, whereas the model would behave better if those parameters were allowed to vary over time. Examining the correlation between estimated parameter values and the number of "peels" (i.e., the number of data years dropped in each sequential run) in a retrospective analysis has been suggested as an appropriate diagnostic tool. For all estimated parameters in Model 1 (except those that get eliminated from the model during the peeling process, leaving a total of 154), correlation coefficients with respect to number of peels were computed.

The results are shown in Figure 2.17, in the form of a cumulative distribution function. For example, 23 parameters (15% of the total) had a correlation (in absolute value) of at least 0.90 with respect to number of peels. These are listed below (naming conventions for selectivity parameters follow Table 2.16):

Init. age 2 ln(abundance) dev	P1_Jan-Apr_Trawl_1977	P3_Aug-Dec_Trawl_2000
Init. F (Jan-Apr trawl fishery)	P1_Jan-Apr_Trawl_1990	P1_Jan-Apr_Longline_1980
Recruitment dev for 1987	P3_Jan-Apr_Trawl_1977	P1_May-Jul_Longline_1980
Recruitment dev for 1991	P3_Jan-Apr_Trawl_1990	P1_May-Jul_Longline_1985
Recruitment dev for 1997	P1_Aug-Dec_Trawl_1980	P1_Aug-Dec_Longline_1990
Recruitment dev for 1999	P1_Aug-Dec_Trawl_2000	P3_Aug-Dec_Longline_1990
Recruitment dev for 2000	P3_Aug-Dec_Trawl_1977	P6_Jan-Apr_Pot_1977
Recruitment dev for 2002	P3_Aug-Dec_Trawl_1980	

All of the parameters in the above list already pertain to a specific year or block of years in the time series, so it is not clear that adding time variability to an existing estimated parameter will solve the problem. Moreover, Model 2, which had a ρ value of only -0.049, had a CDF fairly similar to that shown in Figure 2.17, indicating that high correlations *per se* might not be a perfect diagnostic. Another possibility is that certain quantities that are fixed in the model (i.e., not estimated internally) could be causing the problem, for example catchability, which is fixed in Model 1 at a value of 0.77. However, there was not sufficient time to investigate this as a possible cause of the retrospective bias in the present assessment.

For the time being, the most important result of the retrospective analysis is that there appears to be a significant chance that Model 1 overestimates spawning biomass in the current year, perhaps by a considerable amount. It should be noted, however, that only one model run was conducted for each peel in the retrospective analysis (i.e., no "jitter" analysis was conducted), meaning it is possible that some of the retrospective runs may not have converged to the true minimum of the objective function.

Harvest Recommendations

Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines the "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. Because reliable estimates of reference points related to maximum sustainable yield (MSY) are currently not available but reliable estimates of reference points related to spawning per recruit are available, Pacific cod in the EBS have generally been managed under Tier 3 of Amendment 56. Tier 3 uses the following reference points: $B_{40\%}$, equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing; $F_{35\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 35% of the level that would be obtained in the absence of fishing; and $F_{40\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 40% of the level that would be obtained in the absence of fishing. The following formulae apply under Tier 3:

3a) Stock status: $B/B_{40\%} > 1$

$F_{OFL} = F_{35\%}$

$F_{ABC} \leq F_{40\%}$

3b) Stock status: $0.05 < B/B_{40\%} \leq 1$

$F_{OFL} = F_{35\%} \times (B/B_{40\%} - 0.05) \times 1/0.95$

$F_{ABC} \leq F_{40\%} \times (B/B_{40\%} - 0.05) \times 1/0.95$

3c) Stock status: $B/B_{40\%} \leq 0.05$

$F_{OFL} = 0$

$F_{ABC} = 0$

For a stock exploited by multiple gear types, estimation of $F_{35\%}$ and $F_{40\%}$ requires an assumption regarding the apportionment of fishing mortality among those gear types. For this assessment, the apportionment was based on Model 1's estimates of fishing mortality by gear for the five most recent complete years of data (2009-2013). The average fishing mortality rates for those years implied that total fishing mortality was divided among the three main gear types according to the following percentages: trawl 30%, longline 56%, and pot 14%. This apportionment results in estimates of $F_{35\%}$ and $F_{40\%}$ equal to 0.35 and 0.29, respectively.

Model 1's estimates of $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 824,000 t, 330,000 t, and 288,000 t, respectively.

Specification of OFL and Maximum Permissible ABC

Given the assumptions of Scenario 1 (below), female spawning biomass for 2015 and 2016 is estimated by Model 1 to be well above the $B_{40\%}$ value of 330,000 t, thereby placing Pacific cod in sub-tier "a" of Tier 3 for both 2015 and 2016. Given this, Model 1 estimates OFL, maximum permissible ABC, and the associated fishing mortality rates for 2015 and 2016 as follows:

Year	Overfishing Level	Maximum Permissible ABC
2015	Catch = 346,000 t	Catch = 295,000 t
2016	Catch = 389,000 t	Catch = 316,000 t
2015	$F = 0.35$	$F = 0.29$
2016	$F = 0.35$	$F = 0.29$

The age 0+ biomass projections for 2015 and 2016 from Model 1 (using SS rather than the standard projection model) are 1,680,000 t and 1,770,000 t.

For comparison, the age 3+ biomass projections for 2015 and 2016 from Model 1 (again using SS) are 1,590,000 t and 1,730,000 t.

Standard Harvest Scenarios, Projection Methodology, and Projection Results

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with an estimated vector of numbers at age for January 1, 2015. This requires an appropriate estimate of total catch for 2014. Because each year's stock assessment is finalized before complete (i.e., year-long) catch data are available for that year, it is necessary to extrapolate the available catch data through the end of the year.

Twelve estimators were evaluated to determine the best method of estimating total current-year catch as a function of previous intra-annual fishery performance. Typically, current-year catch data are available through the beginning of October. In the seasonal structure used by Model 1, the last two "catch seasons"

span the months August-October and November-December, meaning that current-year catch data are missing for part of season 4 and all of season 5. All 12 estimators therefore involved extrapolating the catch for seasons 1-3 through the end of the year. The estimators consisted of two groups of six each. One group was based on the average *absolute* amounts of catch taken in some number of previous years during seasons 4-5, and the other was based on the average *relative* amounts of catch taken in some number of previous years during seasons 4-5. For both groups, averages were taken over a range of previous years spanning 1 to 6. The results of this analysis are shown in Figure 2.18. Although it may be difficult to identify the best estimator by eye, it turned out that all of the "absolute" estimators performed better than any of the "relative" estimators, and the best "absolute" estimator simply assumed that this year's catch during seasons 4-5 was equal to last year's catch during seasons 4-5.

Because management of the EBS Pacific cod fishery has a very strong track record of keeping catch below TAC, however, this estimator was used only in the event that it did not result in a current-year catch greater than current-year TAC. In the case of the 2014 fishery, the estimator resulted in a catch greater than TAC, so TAC was used as the best estimate of the catch for 2014.

In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Except for the first two projection years under Scenario 2 (see paragraph below), total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

For the first two projection years under Scenario 2, total catch was computed based on two factors: 1) the relationship between previous ABCs and previous catches, and 2) the fact that catch has never exceeded ABC in the last 20 years. Computation of an appropriate estimator is complicated by the fact that, prior to 2014, the Pacific cod ABC applied to the EBS and AI combined, but, as in 2014, future ABCs are anticipated to apply to the EBS only. To adjust for this, a series of "pseudo-ABCs" was computed for the years 1995-2013 by multiplying each BSAI ABC by the corresponding ratio of EBS catch to BSAI catch. Catch for the EBS was then regressed against the EBS pseudo-ABC, giving an intercept of about 59,200 t and a slope of about 0.6. This regression intersects the catch=ABC line at a value of about 148,000 t, meaning that future catch is assumed to equal future ABC whenever the latter is less than 148,000 t, while future catch is assumed to follow the regression whenever ABC is greater than 148,000 t. The data, the catch=ABC line, the regression line, and the estimator are shown in Figure 2.19.

Five of the seven standard scenarios are sometimes used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TACs for 2015 and 2016, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

> *Scenario 1*: In all future years, *F* is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
>
> *Scenario 2*: In all future years, *F* is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2015 recommended in the assessment to the *max* F_{ABC} for 2015. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to the 2009-2013 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 4: In all future years, the upper bound on F_{ABC} is set at $F_{60\%}$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is 1) above its MSY level in 2014 or 2) above 1/2 of its MSY level in 2014 and expected to be above its MSY level in 2024 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its MSY level in 2016 or 2) above 1/2 of its MSY level in 2016 and expected to be above its MSY level in 2026 under this scenario, then the stock is not approaching an overfished condition.)

Projections corresponding to the standard scenarios are shown for Model 1 in Tables 2.28-2.34.

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2015, it does not provide the best estimate of OFL for 2016, because the mean 2016 catch under Scenario 6 is predicated on the 2015 catch being equal to the 2015 OFL, whereas the actual 2015 catch will likely be less than the 2015 OFL. Table 2.18 contains the appropriate one- and two-year ahead projections for both ABC and OFL under Model 1.

ABC Recommendation

Since 2005, the SSC has set ABC at the maximum permissible level every year with the exception of the 2007 assessment cycle, when the SSC held the 2008-2009 ABCs constant at the 2007 level. Specifications for 2006-2011 were set under Tier 3b, and specifications for 2012-2015 were set under Tier 3a.

In the present assessment, spawning biomass is estimated to be well above $B_{40\%}$, and is projected to increase further. These increases are fueled largely by the 2006, 2008, and 2010, and 2011 year classes, whose strengths have now been confirmed by multiple surveys. The 2013 year class also appears to be strong, although this result is highly preliminary, being based entirely on the results of this year's survey.

At the same time, continuing concerns regarding estimation of survey catchability should be kept in mind. The present estimate, upon which the above projections depend, is based on results from 11 archival tags (Nichol et al. 2007) which showed that the probability of a tag (fish) occurring within 2.5 m of the bottom at any given time during daylight hours was 47%. Although the number of data points from those 11 tags

is quite large (~17,000), implying that the probability *for that particular group of 11 fish* is estimated very precisely, previous analyses have shown that there is considerable uncertainty regarding this probability *for the stock as a whole* (Thompson et al. 2009, p. 428; Thompson 2013, p. 344). Moreover, when catchability was estimated freely in the 2013 preliminary assessment (Thompson 2013), the estimate went up substantially, and the estimate of 2012 spawning biomass dropped by 56%. It is important to note that the study by Nichol et al. dealt with the behavior of fish in the absence of an interaction with a vessel or trawl. Therefore, the results of that study may be entirely accurate in the context of the study conditions, but they may not provide a good point estimate for use in the stock assessment if Pacific cod undertake a dive response to an oncoming vessel or trawl, as Atlantic cod (*Gadus morhua*) have been shown to do (Handegard and Tjøstheim 2005).

The Team and SSC have also suggested that the catchability estimate may need to be revised upward:

- From the October 2013 SSC minutes: *"In addition to the recommended model configurations, the SSC would like to see a model or models that fix survey catchability at Q=1…. Our rationale for this request is based on the increasing evidence that catchability is higher and quite possibly much higher than the current standard assumption…. Evidence from an unpublished study conducted in 2012 (Lauth) suggests that there is no difference in catchability between the low-opening (2.5 m) trawl used in the Bering Sea survey and the high opening (7 m) trawl used in the Gulf of Alaska survey. Moreover, observations of acoustic backscatter showed that Pacific cod tended to be near the bottom in the study area, consistent with a dive response to passing vessels commonly observed in other gadids."*
- From the December 2013 SSC minutes: *"The SSC re-iterates its concerns over the best value for the catchability coefficient.… The default assumption in most assessments is that survey catchability is 1, unless there is strong evidence to the contrary. The evidence for a lower Q has been put into question based on recent work…."*
- From the September 2014 Team minutes: *"All of the recent field work done by RACE has indicated that the bulk of the cod are very near the bottom when the survey trawl passes, contradicting the conclusion from the tag data. This suggests that catchability is near 1… The Team believes that the issue of whether to fix survey catchability at a low value (rather than at 1, or near 1…) should be resolved by next year at the latest."*
- From the October 2014 SSC minutes: *"Recent acoustic field work conducted by AFSC/RACE indicates that the bulk of the cod biomass is very near the bottom when the survey trawl passes, which is in contradiction to the archival tag data. This suggests that catchability is near 1…. Additional analysis will be forthcoming in the next assessment cycle that may help resolve this issue."*

Finally, there is the issue of the apparently large and positive retrospective bias in Model 1's estimates of current-year spawning biomass (see "Retrospective Analysis" above). The amount of bias, while almost always positive, varies from year to year. Moreover, there does not appear to be a scientific consensus as to the appropriate management response to the existence of a retrospective bias, at least not in very precise terms. However, it is probably fair to conclude that the existence of a positive retrospective bias does not argue in favor of increasing the Pacific cod ABC for 2015.

As noted above, there is precedent (*viz*., the 2007 assessment cycle) for holding ABC constant when the assessment involves an inordinate level of uncertainty.

Given all of the above, it does not seem appropriate to recommend an increase in ABC at this time. The recommended ABC for 2015 is therefore the same as the current (2014) value of 255,000 t. Holding fishing mortality constant at the rate that results in a 2015 ABC of 255,000 t (85.4% of *max* F_{ABC}; see Scenario 2, Table 2.29) gives a 2016 ABC of 287,000 t, which is the recommended ABC for 2016.

Area Allocation of Harvests

No recommendations are made regarding area allocation of harvests.

Status Determination

Under the MSFCMA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing. This report involves the answers to three questions: 1) Is the stock being subjected to overfishing? 2) Is the stock currently overfished? 3) Is the stock approaching an overfished condition?

Is the stock being subjected to overfishing? The official BSAI catch estimate for the most recent complete year (2013) is 250,274 t. This is less than the 2013 BSAI OFL of 359,000 t. Therefore, the combined BSAI stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest Scenarios #6 and #7 are used in these determinations as follows:

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2014:

a. If spawning biomass for 2014 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2014 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c. If spawning biomass for 2014 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 2.33). If the mean spawning biomass for 2024 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario #7 (Table 2.33):

a. If the mean spawning biomass for 2016 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2016 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2016 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2026. If the mean spawning biomass for 2026 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

Based on the above criteria and Tables 2.33 and 2.34, the stock is not overfished and is not approaching an overfished condition.

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the Stock

A primary ecosystem phenomenon affecting the Pacific cod stock seems to be the occurrence of periodic "regime shifts," in which central tendencies of key variables in the physical environment change on a scale spanning several years to a few decades (Zador, 2011). One well-documented example of such a regime shift occurred in 1977, and shifts occurring in 1989 and 1999 have also been suggested (e.g., Hare and Mantua 2000). In the present assessment, an attempt was made to estimate the change in mean recruitment of EBS Pacific cod associated with the 1977 regime shift. According to the assessment model, pre-1977 mean recruitment was only about 31% of post-1976 mean recruitment. Establishing a link between environment and recruitment within a particular regime is more difficult. In the 2004 assessment (Thompson and Dorn 2004), for example, the correlations between age 1 recruits spawned since 1977 and monthly values of the Pacific Decadal Oscillation (Mantua et al. 1997) were computed and found to be very weak.

In the 2012 assessment, annual log-scale recruitment *dev*s estimated by the assessment model were regressed against each of several environmental indices summarized by Zador (2011). The highest univariate correlation was obtained for the spring-summer North Pacific Index (NPI), which was developed by Trenberth and Hurrell (1994). The NPI is the area-weighted sea level pressure over the region 30°N-65°N, 160°E-140°W. Further investigations were conducted with monthly NPI data from the Climate Analysis Section of the National Center for Atmospheric Research. The best univariate model obtained in the 2012 analysis was a linear regression of recruitment *dev*s from 1977-2011 against the October-December average NPI (from the same year), giving a correlation of 0.52 (R^2=0.27). This analysis was updated and expanded for the 2013 assessment, including a cross-validation analysis indicating a very low probability that the correlation is entirely spurious. Vestfals et al. (in press) also noted a positive correlation between Pacific cod recruitment and the NPI, although not the October-December average NPI in particular.

The above analysis was updated again this year, including the cross-validation. The NPI time series was updated through 2013, and this year's estimated time series (1977-2013) of recruitment *dev*s was used, giving a correlation of 0.54 (R^2=0.29). The time series, regression line, and 95% confidence interval are shown in the upper panel of Figure 2.20. The most recent datum (2013, magenta diamond in the upper panel) represents both the fourth-largest value in the NPI time series and the fourth-largest value in the recruitment time series.

As in last year's analysis, the cross-validation involved creation of 100,000 "training" data sets, each one obtained by randomly sub-sampling 50% of the data without replacement. A regression was performed on each of the training sets, and then the performance of each regression was computed against the corresponding "test" (i.e., non-training) data set. When the NPI *was not* included as an explanatory variable (i.e., only the intercept of the regression was estimated), the RMSE (computed across all 100,000 test data sets) was 0.69, but when the NPI *was* included as an explanatory variable, the RMSE was reduced to 0.61. The distribution of slope parameter estimates from the cross-validation is shown in the middle panel of Figure 2.20. Two years, 1990 and 2002 (yellow and green diamonds in the upper panel), turned out to be far more influential than any other year in determining the magnitude of the estimated slope, and both of these influences were negative (lower panel of Figure 2.20). In other words, the positive slope is not due to the influence of outliers; if anything, the outliers are making the relationship appear less strong than would be the case without them.

The prey and predators of Pacific cod have been described or reviewed by Albers and Anderson (1985), Livingston (1989, 1991), Lang et al. (2003), Westrheim (1996), and Yang (2004). The composition of

Pacific cod prey varies to some extent by time and area. In terms of percent occurrence, some of the most important items in the diet of Pacific cod in the BSAI and GOA have been polychaetes, amphipods, and crangonid shrimp. In terms of numbers of individual organisms consumed, some of the most important dietary items have been euphausids, miscellaneous fishes, and amphipods. In terms of weight of organisms consumed, some of the most important dietary items have been walleye pollock, fishery offal, yellowfin sole, and crustaceans. Small Pacific cod feed mostly on invertebrates, while large Pacific cod are mainly piscivorous. Predators of Pacific cod include Pacific cod, halibut, salmon shark, northern fur seals, Steller sea lions, harbor porpoises, various whale species, and tufted puffin. Major trends in the most important prey or predator species could be expected to affect the dynamics of Pacific cod to some extent.

Fishery Effects on the Ecosystem

Potentially, fisheries for Pacific cod can have effects on other species in the ecosystem through a variety of mechanisms, for example by relieving predation pressure on shared prey species (i.e., species which serve as prey for both Pacific cod and other species), by reducing prey availability for predators of Pacific cod, by altering habitat, by imposing bycatch mortality, or by "ghost fishing" caused by lost fishing gear.

Incidental Catch Taken in the Pacific Cod Fisheries

Incidental catches taken in the Pacific cod fisheries are summarized in Tables 2.35-2.38. Catches for 2014 in each of these tables are incomplete. Table 2.35 shows incidental catch of FMP species, other than squid and the members of the former "other species" complex, taken from 1991-2014 by each of the three main gear types. Table 2.36 shows incidental catch of squid and the members of the former "other species" complex taken from 2003-2014, aggregated across gear types. Table 2.37 shows incidental catch of prohibited species taken from 1991-2014, plus mortality estimates for halibut, aggregated across gear types. Table 2.38 shows incidental catch of non-target species groups taken from 2003-2014, aggregated across gear types.

Steller Sea Lions

Sinclair and Zeppelin (2002) showed that Pacific cod was one of the four most important prey items of Steller sea lions in terms of frequency of occurrence averaged over years, seasons, and sites, and was especially important in winter. Pitcher (1981) and Calkins (1998) also showed Pacific cod to be an important winter prey item in the GOA and BSAI, respectively. Furthermore, the size ranges of Pacific cod harvested by the fisheries and consumed by Steller sea lions overlap, and the fishery operates to some extent in the same geographic areas used by Steller sea lion as foraging grounds (Livingston (ed.), 2002).

The Fisheries Interaction Team of the Alaska Fisheries Science Center has been engaged in research to determine the effectiveness of recent management measures designed to mitigate the impacts of the Pacific cod fisheries (among others) on Steller sea lions. Results from studies conducted in 2002-2003 were summarized by Conners et al. (2004). These studies included a tagging feasibility study, which may evolve into an ongoing research effort capable of providing information on the extent and rate to which Pacific cod move in and out of various portions of Steller sea lion critical habitat. Nearly 6,000 cod with spaghetti tags were released, of which approximately 1,000 had been returned as of September, 2003.

Seabirds

The following is a summary of information provided by Livingston (ed., 2002): In both the BSAI and GOA, the northern fulmar (*Fulmarus glacialis*) comprises the majority of seabird bycatch, which occurs primarily in the longline fisheries, including the hook and line fishery for Pacific cod. Shearwater

(*Puffinus* spp.) distribution overlaps with the Pacific cod longline fishery in the Bering Sea, and with trawl fisheries in general in both the Bering Sea and GOA. Black-footed albatross (*Phoebastria nigripes*) is taken in much greater numbers in the GOA longline fisheries than the Bering Sea longline fisheries, but is not taken in the trawl fisheries. The distribution of Laysan albatross (*Phoebastria immutabilis*) appears to overlap with the longline fisheries in the central and western Aleutians. The distribution of short-tailed albatross (*Phoebastria albatrus*) also overlaps with the Pacific cod longline fishery along the Aleutian chain, although the majority of the bycatch has taken place along the northern portion of the Bering Sea shelf edge (in contrast, only two takes have been recorded in the GOA). Some success has been obtained in devising measures to mitigate fishery-seabird interactions. For example, on vessels larger than 60 ft. LOA, paired streamer lines of specified performance and material standards have been found to reduce seabird incidental take significantly.

Fishery Usage of Habitat

The following is a summary of information provided by Livingston (ed., 2002): The longline and trawl fisheries for Pacific cod each comprise an important component of the combined fisheries associated with the respective gear type in each of the three major management regions (BS, AI, and GOA). Looking at each gear type in each region as a whole (i.e., aggregating across all target species) during the period 1998-2001, the total number of observed hauls/sets was as follows:

Gear	BS	AI	GOA
Trawl	240,347	43,585	68,436
Longline	65,286	13,462	7,139

In the BS, both longline and trawl effort was concentrated north of False Pass (Unimak Island) and along the shelf edge represented by the boundary of areas 513, 517 (in addition, longline effort was concentrated along the shelf edge represented by the boundary of areas 521-533). In the AI, both longline and trawl effort were dispersed over a wide area along the shelf edge. The catcher vessel longline fishery in the AI occurred primarily over mud bottoms. Longline catcher-processors in the AI tended to fish more over rocky bottoms. In the GOA, fishing effort was also dispersed over a wide area along the shelf, though pockets of trawl effort were located near Chirikof, Cape Barnabus, Cape Chiniak and Marmot Flats. The GOA longline fishery for Pacific cod generally took place over gravel, cobble, mud, sand, and rocky bottoms, in depths of 25 fathoms to 140 fathoms.

Impacts of the Pacific cod fisheries on essential fish habitat were further analyzed in an environmental impact statement by NMFS (2005), followed by a 5-year review in 2010 (NMFS 2010). A second 5-year review is currently in progress.

DATA GAPS AND RESEARCH PRIORITIES

Significant improvements in the quality of this assessment could be made if future research were directed toward closing certain data gaps. At this point, the most critical needs pertain to trawl survey catchability and selectivity, specifically: 1) to understand the factors determining these characteristics, 2) to understand whether/how these characteristics change over time, and 3) to obtain accurate estimates of these characteristics. Ageing also continues to be an issue, as the assessment models consistently estimate a positive ageing bias. Longer-term research needs include improved understanding of: 1) the ecology of Pacific cod in the EBS, including spatial dynamics, trophic and other interspecific relationships, and the relationship between climate and recruitment; 2) ecology of species taken as bycatch in the Pacific cod fisheries, including estimation of biomass, carrying capacity, and resilience; and 3) ecology of species that interact with Pacific cod, including estimation of interaction strengths, biomass, carrying capacity, and resilience.

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Reviewers: Anne Hollowed and the BSAI Groundfish Plan Team provided reviews of this assessment.

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Table 2.1a—Summary of 1964-1980 catches (t) of Pacific cod in the EBS by fleet sector. "For." = foreign, "JV" = joint venture processing, "Dom." = domestic annual processing. Catches by gear are not available for these years. Catches may not always include discards.

Year	For.	JV	Dom.	Total
1964	13,408	0	0	13,408
1965	14,719	0	0	14,719
1966	18,200	0	0	18,200
1967	32,064	0	0	32,064
1968	57,902	0	0	57,902
1969	50,351	0	0	50,351
1970	70,094	0	0	70,094
1971	43,054	0	0	43,054
1972	42,905	0	0	42,905
1973	53,386	0	0	53,386
1974	62,462	0	0	62,462
1975	51,551	0	0	51,551
1976	50,481	0	0	50,481
1977	33,335	0	0	33,335
1978	42,512	0	31	42,543
1979	32,981	0	780	33,761
1980	35,058	8,370	2,433	45,861

Table 2.1b—Summary of 1981-1990 catches (t) of Pacific cod in the EBS by area, fleet sector, and gear type. All catches include discards. "LLine" = longline, "Subt." = sector subtotal. Breakdown of domestic annual processing by gear is not available prior to 1988.

	Foreign			Joint Venture		Domestic Annual Processing				
Year	Trawl	LLine	Subt.	Trawl	Subt.	Trawl	LLine	Pot	Subt.	Total
1981	30,347	5,851	36,198	7,410	7,410	n/a	n/a	n/a	12,899	56,507
1982	23,037	3,142	26,179	9,312	9,312	n/a	n/a	n/a	25,613	61,104
1983	32,790	6,445	39,235	9,662	9,662	n/a	n/a	n/a	45,904	94,801
1984	30,592	26,642	57,234	24,382	24,382	n/a	n/a	n/a	43,487	125,103
1985	19,596	36,742	56,338	35,634	35,634	n/a	n/a	n/a	51,475	143,447
1986	13,292	26,563	39,855	57,827	57,827	n/a	n/a	n/a	37,923	135,605
1987	7,718	47,028	54,746	47,722	47,722	n/a	n/a	n/a	47,435	149,903
1988	0	0	0	106,592	106,592	93,706	2,474	299	96,479	203,071
1989	0	0	0	44,612	44,612	119,631	13,935	145	133,711	178,323
1990	0	0	0	8,078	8,078	115,493	47,114	1,382	163,989	172,067

Table 2.1c—Summary of 1991-2014 catches (t) of Pacific cod in the EBS. The small catches taken by "other" gear types have been merged proportionally with the catches of the gear types shown. Catches for 2013 are through October 6.

Year	Trawl	Longline	Pot	Total
1991	129,393	77,505	3,343	210,241
1992	77,276	79,420	7,514	164,210
1993	81,792	49,296	2,098	133,186
1994	85,294	78,898	8,071	172,263
1995	111,250	97,923	19,326	228,498
1996	92,029	88,996	28,042	209,067
1997	93,995	117,097	21,509	232,601
1998	60,855	84,426	13,249	158,529
1999	51,939	81,520	12,408	145,867
2000	53,841	81,678	15,856	151,376
2001	35,670	90,394	16,478	142,542
2002	51,118	100,371	15,067	166,555
2003	46,717	108,775	19,959	175,451
2004	57,866	108,614	17,264	183,745
2005	52,638	113,184	17,114	182,936
2006	53,236	96,610	18,969	168,814
2007	45,700	77,181	17,248	140,129
2008	33,497	89,183	17,368	140,048
2009	36,959	96,606	13,609	147,174
2010	41,297	81,855	19,723	142,875
2011	64,085	117,103	28,063	209,250
2012	75,424	128,516	28,737	232,676
2013	81,619	124,823	30,261	236,702
2014	69,921	97,256	33,552	200,729

Table 2.2—Discards (t) of Pacific cod in the Pacific cod fishery, by area, gear, and year for the period 1991-2014 (2014 data are current through October 20). The small amounts of discards taken by other gear types have been merged proportionally into the gear types shown. Note that Amendment 49, which mandated increased retention and utilization, was implemented in 1998. Note also that the version of this table in the 2012 and 2013 assessments inadvertently included discards of Pacific cod in *all* fisheries, not just the Pacific cod fishery.

Year	Trawl	Longline	Pot	Total
1991	1,278	1,493	4	2,774
1992	3,314	1,768	59	5,141
1993	5,449	2,234	25	7,708
1994	4,599	2,917	161	7,677
1995	7,988	3,669	222	11,879
1996	2,971	2,833	391	6,194
1997	3,330	3,187	79	6,596
1998	102	2,456	52	2,610
1999	353	1,285	52	1,691
2000	207	2,267	71	2,546
2001	142	1,531	52	1,726
2002	557	2,066	91	2,715
2003	240	1,772	160	2,171
2004	158	1,814	48	2,019
2005	86	2,600	63	2,750
2006	193	1,528	63	1,784
2007	238	1,373	45	1,656
2008	13	1,280	156	1,449
2009	126	1,503	16	1,645
2010	154	1,402	19	1,574
2011	121	1,860	32	2,013
2012	136	1,754	40	1,930
2013	215	3,060	101	3,377
2014	190	2,373	114	2,678

Table 2.3—History of **BSAI** Pacific cod catch, TAC, ABC, and OFL (t). Catch for 2014 is through October 6. Note that specifications through 2013 were for the combined BSAI region, so BSAI catch is shown rather than the EBS catches from Table 2.1 for the period 1977-2013. Source for historical specifications: NPFMC staff.

Year	Catch	TAC	ABC	OFL
1977	36,597	58,000	-	-
1978	45,838	70,500	-	-
1979	39,354	70,500	-	-
1980	51,649	70,700	148,000	-
1981	63,941	78,700	160,000	-
1982	69,501	78,700	168,000	-
1983	103,231	120,000	298,200	-
1984	133,084	210,000	291,300	-
1985	150,384	220,000	347,400	-
1986	142,511	229,000	249,300	-
1987	163,110	280,000	400,000	-
1988	208,236	200,000	385,300	-
1989	182,865	230,681	370,600	-
1990	179,608	227,000	417,000	-
1991	220,038	229,000	229,000	-
1992	207,278	182,000	182,000	188,000
1993	167,391	164,500	164,500	192,000
1994	193,802	191,000	191,000	228,000
1995	245,033	250,000	328,000	390,000
1996	240,676	270,000	305,000	420,000
1997	257,765	270,000	306,000	418,000
1998	193,256	210,000	210,000	336,000
1999	173,998	177,000	177,000	264,000
2000	191,060	193,000	193,000	240,000
2001	176,749	188,000	188,000	248,000
2002	197,356	200,000	223,000	294,000
2003	207,907	207,500	223,000	324,000
2004	212,618	215,500	223,000	350,000
2005	205,635	206,000	206,000	265,000
2006	193,025	194,000	194,000	230,000
2007	174,486	170,720	176,000	207,000
2008	171,277	170,720	176,000	207,000
2009	175,756	176,540	182,000	212,000
2010	171,875	168,780	174,000	205,000
2011	220,109	227,950	235,000	272,000
2012	250,899	261,000	314,000	369,000
2013	250,274	260,000	307,000	359,000
2014	200,729	246,897	255,000	299,000

Table 2.4—Amendments to the BSAI Fishery Management Plan (FMP) that reference Pacific cod explicitly (excerpted from Appendix A of the FMP).

Amendment 2, implemented January 12, 1982:

For Pacific cod, decreased maximum sustainable yield to 55,000 t from 58,700 t, increased equilibrium yield to 160,000 t from 58,700 t, increased acceptable biological catch to 160,000 t from 58,700 t, increased optimum yield to 78,700 t from 58,700 t, increased reserves to 3,935 t from 2,935 t, increased domestic annual processing (DAP) to 26,000 t from 7,000 t, and increased DAH to 43,265 t from 24,265 t.

Amendment 4, implemented May 9, 1983, supersedes Amendment 2:

For Pacific Cod, increased equilibrium yield and acceptable biological catch to 168,000 t from 160,000 t, increased optimum yield to 120,000 t from 78,700 t, increased reserves to 6,000 t from 3,935 t, and increased TALFF to 70,735 t from 31,500 t.

Amendment 10, implemented March 16, 1987:

Established Bycatch Limitation Zones for domestic and foreign fisheries for yellowfin sole and other flatfish (including rock sole); an area closed to all trawling within Zone 1; red king crab, C. bairdi Tanner crab, and Pacific halibut PSC limits for DAH yellowfin sole and other flatfish fisheries; a C. bairdi PSC limit for foreign fisheries; and a red king crab PSC limit and scientific data collection requirement for U.S. vessels fishing for Pacific cod in Zone 1 waters shallower than 25 fathoms.

Amendment 24, implemented February 28, 1994, and effective through December 31, 1996:

1. Established the following gear allocations of BSAI Pacific cod TAC as follows: 2 percent to vessels using jig gear; 44.1 percent to vessels using hook-and-line or pot gear, and 53.9 percent to vessels using trawl gear.
2. Authorized the seasonal apportionment of the amount of Pacific cod allocated to gear groups. Criteria for seasonal apportionments and the seasons authorized to receive separate apportionments will be set forth in regulations.

Amendment 46, implemented January 1, 1997, superseded Amendment 24:

Replaced the three year Pacific cod allocation established with Amendment 24, with the following gear allocations in BSAI Pacific cod: 2 percent to vessels using jig gear; 51 percent to vessels using hook-and-line or pot gear; and 47 percent to vessels using trawl gear. The trawl apportionment will be divided 50 percent to catcher vessels and 50 percent to catcher processors. These allocations as well as the seasonal apportionment authority established in Amendment 24 will remain in effect until amended.

Amendment 49, implemented January 3, 1998:

Implemented an Increased Retention/Increased Utilization Program for pollock and Pacific cod beginning January 1, 1998 and rock sole and yellowfin sole beginning January 1, 2003.

Amendment 64, implemented September 1, 2000, revised Amendment 46:

Allocated the Pacific cod Total Allowable Catch to the jig gear (2 percent), fixed gear (51 percent), and trawl gear (47 percent) sectors.

Amendment 67, implemented May 15, 2002, revised Amendment 39:

Established participation and harvest requirements to qualify for a BSAI Pacific cod fishery endorsement for fixed gear vessels.

Amendment 77, implemented January 1, 2004, revised Amendment 64:

Implemented a Pacific cod fixed gear allocation between hook and line catcher processors (80 percent), hook and line catcher vessels (0.3 percent), pot catcher processors (3.3 percent), pot catcher vessels (15 percent), and catcher vessels (pot or hook and line) less than 60 feet (1.4 percent).

Amendment 85, partially implemented on March 5, 2007, superseded Amendments 46 and 77:

Implemented a gear allocation among all non-CDQ fishery sectors participating in the directed fishery for Pacific cod. After deduction of the CDQ allocation, the Pacific cod TAC is apportioned to vessels using jig gear (1.4 percent); catcher processors using trawl gear listed in Section 208(e)(1)-(20) of the AFA (2.3 percent); catcher processors using trawl gear as defined in Section 219(a)(7) of the Consolidated Appropriations Act, 2005 (Public Law 108-447) (13.4 percent); catcher vessels using trawl gear (22.1 percent); catcher processors using hook-and-line gear (48.7 percent); catcher vessels ≥60’ LOA using hook-and-line gear (0.2 percent); catcher processors using pot gear (1.5 percent); catcher vessels ≥60’ LOA using pot gear (8.4 percent); and catcher vessels <60’ LOA that use either hook-and-line gear or pot gear (2.0 percent).

Table 2.5 (p. 1 of 4)— EBS catch (t) of Pacific cod by year, gear, and season for the years 1977-2014 as configured in Model 1. Because direct estimates of gear- and period-specific catches are not available for the years 1977-1980, the figures shown here are estimates derived by distributing each year's total catch according to the average proportion observed for each gear/period combination during the years 1981-1988. The small amounts of catch from "other" gear types have been merged into the gear types listed below proportionally.

		Trawl fishery			Longline fishery			Pot fishery		
Year	Season	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec
1977	Jan-Feb	5974	0	0	740	0	0	0	0	0
1977	Mar-Apr	5974	0	0	740	0	0	0	0	0
1977	May-Jul	0	7080	0	0	544	0	0	0	0
1977	Aug-Oct	0	0	5475	0	0	1733	0	0	0
1977	Nov-Dec	0	0	3429	0	0	1646	0	0	0
1978	Jan-Feb	7884	0	0	977	0	0	0	0	0
1978	Mar-Apr	7884	0	0	977	0	0	0	0	0
1978	May-Jul	0	9343	0	0	717	0	0	0	0
1978	Aug-Oct	0	0	7226	0	0	2286	0	0	0
1978	Nov-Dec	0	0	4526	0	0	2172	0	0	0
1979	Jan-Feb	6452	0	0	800	0	0	0	0	0
1979	Mar-Apr	6452	0	0	800	0	0	0	0	0
1979	May-Jul	0	7646	0	0	587	0	0	0	0
1979	Aug-Oct	0	0	5914	0	0	1871	0	0	0
1979	Nov-Dec	0	0	3704	0	0	1778	0	0	0
1980	Jan-Feb	7355	0	0	912	0	0	0	0	0
1980	Mar-Apr	7355	0	0	912	0	0	0	0	0
1980	May-Jul	0	8716	0	0	669	0	0	0	0
1980	Aug-Oct	0	0	6741	0	0	2133	0	0	0
1980	Nov-Dec	0	0	4222	0	0	2027	0	0	0
1981	Jan-Feb	6027	0	0	514	0	0	0	0	0
1981	Mar-Apr	6027	0	0	514	0	0	0	0	0
1981	May-Jul	0	12405	0	0	673	0	0	0	0
1981	Aug-Oct	0	0	15439	0	0	2179	0	0	0
1981	Nov-Dec	0	0	10743	0	0	1971	0	0	0
1982	Jan-Feb	8697	0	0	145	0	0	0	0	0
1982	Mar-Apr	8697	0	0	145	0	0	0	0	0
1982	May-Jul	0	16449	0	0	389	0	0	0	0
1982	Aug-Oct	0	0	14224	0	0	1312	0	0	0
1982	Nov-Dec	0	0	8174	0	0	1154	0	0	0
1983	Jan-Feb	16303	0	0	1176	0	0	0	0	0
1983	Mar-Apr	16303	0	0	1176	0	0	0	0	0
1983	May-Jul	0	24351	0	0	1087	0	0	0	0
1983	Aug-Oct	0	0	19453	0	0	1627	0	0	0
1983	Nov-Dec	0	0	11353	0	0	1378	0	0	0
1984	Jan-Feb	19295	0	0	2005	0	0	0	0	0
1984	Mar-Apr	19295	0	0	2005	0	0	0	0	0
1984	May-Jul	0	26290	0	0	2421	0	0	0	0
1984	Aug-Oct	0	0	20844	0	0	10463	0	0	0
1984	Nov-Dec	0	0	12523	0	0	9754	0	0	0
1985	Jan-Feb	22269	0	0	5481	0	0	0	0	0
1985	Mar-Apr	22269	0	0	5481	0	0	0	0	0
1985	May-Jul	0	30250	0	0	3881	0	0	0	0
1985	Aug-Oct	0	0	20713	0	0	11260	0	0	0
1985	Nov-Dec	0	0	11155	0	0	10690	0	0	0

Table 2.5 (p. 2 of 4)— EBS catch (t) of Pacific cod by year, gear, and season for the years 1977-2014 as configured in Model 1.

		Trawl fishery			Longline fishery			Pot fishery		
Year	Season	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec
1986	Jan-Feb	23914	0	0	3558	0	0	0	0	0
1986	Mar-Apr	23914	0	0	3558	0	0	0	0	0
1986	May-Jul	0	29689	0	0	2071	0	0	0	0
1986	Aug-Oct	0	0	20057	0	0	8785	0	0	0
1986	Nov-Dec	0	0	11191	0	0	8639	0	0	0
1987	Jan-Feb	25765	0	0	8379	0	0	0	0	0
1987	Mar-Apr	25765	0	0	8379	0	0	0	0	0
1987	May-Jul	0	23285	0	0	4671	0	0	0	0
1987	Aug-Oct	0	0	15932	0	0	13617	0	0	0
1987	Nov-Dec	0	0	10731	0	0	13376	0	0	0
1988	Jan-Feb	50988	0	0	214	0	0	0	0	0
1988	Mar-Apr	50988	0	0	214	0	0	0	0	0
1988	May-Jul	0	42602	0	0	571	0	0	0	0
1988	Aug-Oct	0	0	32137	0	0	1005	0	0	0
1988	Nov-Dec	0	0	23583	0	0	773	0	0	0
1989	Jan-Feb	50984	0	0	1524	0	0	13	0	0
1989	Mar-Apr	50984	0	0	1524	0	0	13	0	0
1989	May-Jul	0	36816	0	0	4074	0	0	49	0
1989	Aug-Oct	0	0	15561	0	0	4235	0	0	46
1989	Nov-Dec	0	0	9899	0	0	2579	0	0	25
1990	Jan-Feb	40658	0	0	5268	0	0	0	0	0
1990	Mar-Apr	40658	0	0	5268	0	0	0	0	0
1990	May-Jul	0	27930	0	0	13730	0	0	657	0
1990	Aug-Oct	0	0	9063	0	0	14197	0	0	526
1990	Nov-Dec	0	0	5262	0	0	8650	0	0	198
1991	Jan-Feb	34996	0	0	8229	0	0	20	0	0
1991	Mar-Apr	65276	0	0	12317	0	0	522	0	0
1991	May-Jul	0	16403	0	0	20115	0	0	410	0
1991	Aug-Oct	0	0	12271	0	0	21276	0	0	2306
1991	Nov-Dec	0	0	6420	0	0	9312	0	0	369
1992	Jan-Feb	23310	0	0	13660	0	0	13	0	0
1992	Mar-Apr	31836	0	0	22121	0	0	833	0	0
1992	May-Jul	0	11784	0	0	27051	0	0	5321	0
1992	Aug-Oct	0	0	8182	0	0	16319	0	0	1992
1992	Nov-Dec	0	0	1788	0	0	0	0	0	0
1993	Jan-Feb	27998	0	0	22396	0	0	24	0	0
1993	Mar-Apr	35294	0	0	21434	0	0	1597	0	0
1993	May-Jul	0	5552	0	0	4744	0	0	2093	0
1993	Aug-Oct	0	0	6944	0	0	3002	0	0	0
1993	Nov-Dec	0	0	1544	0	0	564	0	0	0
1994	Jan-Feb	13856	0	0	22458	0	0	0	0	0
1994	Mar-Apr	43634	0	0	29089	0	0	4159	0	0
1994	May-Jul	0	4453	0	0	6210	0	0	1792	0
1994	Aug-Oct	0	0	20070	0	0	20718	0	0	3133
1994	Nov-Dec	0	0	2691	0	0	0	0	0	0
1995	Jan-Feb	31939	0	0	29936	0	0	23	0	0
1995	Mar-Apr	58159	0	0	34516	0	0	7715	0	0
1995	May-Jul	0	1145	0	0	4161	0	0	7342	0
1995	Aug-Oct	0	0	19770	0	0	21305	0	0	2927
1995	Nov-Dec	0	0	119	0	0	8802	0	0	640

Table 2.5 (p. 3 of 4)— EBS catch (t) of Pacific cod by year, gear, and season for the years 1977-2014 as configured in Model 1.

		Trawl fishery			Longline fishery			Pot fishery		
Year	Season	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec
1996	Jan-Feb	21151	0	0	28835	0	0	25	0	0
1996	Mar-Apr	50436	0	0	29471	0	0	12571	0	0
1996	May-Jul	0	6797	0	0	4179	0	0	11600	0
1996	Aug-Oct	0	0	10543	0	0	23629	0	0	4347
1996	Nov-Dec	0	0	1475	0	0	3278	0	0	728
1997	Jan-Feb	25713	0	0	31971	0	0	30	0	0
1997	Mar-Apr	52321	0	0	30578	0	0	9639	0	0
1997	May-Jul	0	5174	0	0	8145	0	0	7352	0
1997	Aug-Oct	0	0	9321	0	0	21323	0	0	3780
1997	Nov-Dec	0	0	2366	0	0	24250	0	0	637
1998	Jan-Feb	15535	0	0	29256	0	0	1719	0	0
1998	Mar-Apr	27765	0	0	19060	0	0	5613	0	0
1998	May-Jul	0	4940	0	0	3709	0	0	5321	0
1998	Aug-Oct	0	0	12586	0	0	16155	0	0	1890
1998	Nov-Dec	0	0	1330	0	0	13196	0	0	454
1999	Jan-Feb	17660	0	0	30548	0	0	1900	0	0
1999	Mar-Apr	24661	0	0	20876	0	0	4937	0	0
1999	May-Jul	0	3028	0	0	3283	0	0	5420	0
1999	Aug-Oct	0	0	5658	0	0	20571	0	0	2054
1999	Nov-Dec	0	0	229	0	0	4986	0	0	56
2000	Jan-Feb	18935	0	0	30652	0	0	11647	0	0
2000	Mar-Apr	23194	0	0	8195	0	0	4105	0	0
2000	May-Jul	0	3800	0	0	1394	0	0	1077	0
2000	Aug-Oct	0	0	6199	0	0	22107	0	0	1667
2000	Nov-Dec	0	0	590	0	0	17816	0	0	0
2001	Jan-Feb	7963	0	0	18209	0	0	2205	0	0
2001	Mar-Apr	13895	0	0	16568	0	0	11279	0	0
2001	May-Jul	0	3500	0	0	3882	0	0	1005	0
2001	Aug-Oct	0	0	8904	0	0	30966	0	0	2970
2001	Nov-Dec	0	0	803	0	0	19751	0	0	641
2002	Jan-Feb	13410	0	0	35198	0	0	1845	0	0
2002	Mar-Apr	21130	0	0	14486	0	0	8407	0	0
2002	May-Jul	0	8163	0	0	1903	0	0	531	0
2002	Aug-Oct	0	0	8594	0	0	34463	0	0	2997
2002	Nov-Dec	0	0	291	0	0	14335	0	0	803
2003	Jan-Feb	15383	0	0	35435	0	0	11693	0	0
2003	Mar-Apr	16459	0	0	17106	0	0	1661	0	0
2003	May-Jul	0	6752	0	0	2748	0	0	454	0
2003	Aug-Oct	0	0	7794	0	0	35121	0	0	5143
2003	Nov-Dec	0	0	264	0	0	18004	0	0	1430
2004	Jan-Feb	21886	0	0	37436	0	0	9023	0	0
2004	Mar-Apr	17432	0	0	16627	0	0	2854	0	0
2004	May-Jul	0	9773	0	0	2915	0	0	946	0
2004	Aug-Oct	0	0	8766	0	0	31394	0	0	3841
2004	Nov-Dec	0	0	75	0	0	20181	0	0	596
2005	Jan-Feb	27360	0	0	46935	0	0	9034	0	0
2005	Mar-Apr	15119	0	0	6612	0	0	3114	0	0
2005	May-Jul	0	7410	0	0	3289	0	0	0	0
2005	Aug-Oct	0	0	2892	0	0	35344	0	0	4549
2005	Nov-Dec	0	0	113	0	0	20756	0	0	407

Table 2.5 (p. 4 of 4)— EBS catch (t) of Pacific cod by year, gear, and season for the years 1977-2014 as configured in Model 1. Aug-Oct and Nov-Dec catches for 2014 are extrapolated.

		Trawl fishery			Longline fishery			Pot fishery		
Year	Season	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec
2006	Jan-Feb	28595	0	0	45149	0	0	10608	0	0
2006	Mar-Apr	13917	0	0	6017	0	0	3297	0	0
2006	May-Jul	0	6347	0	0	1905	0	0	364	0
2006	Aug-Oct	0	0	4357	0	0	42490	0	0	3887
2006	Nov-Dec	0	0	70	0	0	1013	0	0	799
2007	Jan-Feb	15947	0	0	42943	0	0	10702	0	0
2007	Mar-Apr	16302	0	0	1917	0	0	1139	0	0
2007	May-Jul	0	10225	0	0	1213	0	0	479	0
2007	Aug-Oct	0	0	3190	0	0	30304	0	0	4922
2007	Nov-Dec	0	0	67	0	0	777	0	0	0
2008	Jan-Feb	15579	0	0	41873	0	0	8850	0	0
2008	Mar-Apr	7093	0	0	3657	0	0	1951	0	0
2008	May-Jul	0	3868	0	0	2665	0	0	225	0
2008	Aug-Oct	0	0	6306	0	0	33019	0	0	6218
2008	Nov-Dec	0	0	655	0	0	7966	0	0	124
2009	Jan-Feb	12194	0	0	44713	0	0	9395	0	0
2009	Mar-Apr	9602	0	0	3726	0	0	1722	0	0
2009	May-Jul	0	4174	0	0	2239	0	0	257	0
2009	Aug-Oct	0	0	10491	0	0	35381	0	0	1301
2009	Nov-Dec	0	0	403	0	0	10494	0	0	1081
2010	Jan-Feb	16329	0	0	40595	0	0	10695	0	0
2010	Mar-Apr	8170	0	0	2050	0	0	1726	0	0
2010	May-Jul	0	3980	0	0	2903	0	0	268	0
2010	Aug-Oct	0	0	9596	0	0	25041	0	0	5418
2010	Nov-Dec	0	0	1601	0	0	12702	0	0	1801
2011	Jan-Feb	21217	0	0	28954	0	0	15345	0	0
2011	Mar-Apr	20796	0	0	26321	0	0	2297	0	0
2011	May-Jul	0	7276	0	0	14057	0	0	595	0
2011	Aug-Oct	0	0	13351	0	0	30921	0	0	8954
2011	Nov-Dec	0	0	1728	0	0	17438	0	0	0
2012	Jan-Feb	39029	0	0	33164	0	0	19238	0	0
2012	Mar-Apr	14803	0	0	24916	0	0	2295	0	0
2012	May-Jul	0	8666	0	0	21092	0	0	790	0
2012	Aug-Oct	0	0	11672	0	0	27628	0	0	6171
2012	Nov-Dec	0	0	1058	0	0	21260	0	0	893
2013	Jan-Feb	35435	0	0	38743	0	0	19229	0	0
2013	Mar-Apr	17157	0	0	22243	0	0	2801	0	0
2013	May-Jul	0	5977	0	0	13875	0	0	0	0
2013	Aug-Oct	0	0	20907	0	0	26500	0	0	5891
2013	Nov-Dec	0	0	1608	0	0	22770	0	0	3567
2014	Jan-Feb	31400	0	0	32476	0	0	21523	0	0
2014	Mar-Apr	23274	0	0	27604	0	0	4458	0	0
2014	May-Jul	0	7055	0	0	21136	0	0	230	0
2014	Aug-Oct	0	0	20907	0	0	26500	0	0	5891
2014	Nov-Dec	0	0	1406	0	0	19917	0	0	3120

Table 2.6 (page 1 of 3)— Fishery CPUE as configured in Model 1. Units are kg/minute for trawl gear, kg/hook for longline gear, and kg/pot for pot gear.

Jan-Apr trawl fishery				May-Jul trawl fishery				Aug-Dec trawl fishery			
Year	Season	CPUE	Sigma	Year	Season	CPUE	Sigma	Year	Season	CPUE	Sigma
1991	Jan-Feb	55.864	0.091	1991	May-Jul	36.761	0.202	1991	Aug-Oct	71.702	0.597
1992	Jan-Feb	60.427	0.160	1992	May-Jul	38.568	0.288	1992	Aug-Oct	57.517	0.766
1993	Jan-Feb	62.047	0.155	1993	May-Jul	39.902	0.465	1993	Aug-Oct	113.970	0.499
1994	Jan-Feb	51.965	0.220	1994	May-Jul	26.767	0.246	1994	Aug-Oct	56.308	0.386
1995	Jan-Feb	88.482	0.121	1995	May-Jul	59.393	1.654	1995	Aug-Oct	60.164	0.320
1996	Jan-Feb	48.331	0.131	1996	May-Jul	29.174	0.311	1996	Aug-Oct	34.896	0.288
1997	Jan-Feb	75.605	0.121	1997	May-Jul	24.880	0.256	1997	Aug-Oct	62.619	0.562
1998	Jan-Feb	59.920	0.157	1998	May-Jul	26.245	0.300	1998	Aug-Oct	38.995	0.302
1999	Jan-Feb	42.399	0.118	1999	May-Jul	15.672	0.422	1999	Aug-Oct	20.611	0.364
2000	Jan-Feb	34.522	0.122	2000	May-Jul	32.694	0.291	2000	Aug-Oct	15.070	0.523
2001	Jan-Feb	25.452	0.165	2001	May-Jul	60.120	0.295	2001	Aug-Oct	16.662	0.247
2002	Jan-Feb	35.892	0.139	2002	May-Jul	39.985	0.207	2002	Aug-Oct	15.141	0.194
2003	Jan-Feb	24.642	0.167	2003	May-Jul	49.493	0.208	2003	Aug-Oct	19.171	0.154
2004	Jan-Feb	62.609	0.137	2004	May-Jul	34.588	0.162	2004	Aug-Oct	21.519	0.152
2005	Jan-Feb	43.993	0.115	2005	May-Jul	24.100	0.170	2005	Aug-Oct	15.932	0.827
2006	Jan-Feb	36.397	0.106	2006	May-Jul	30.653	0.185	2006	Aug-Oct	26.772	0.373
2007	Jan-Feb	30.849	0.094	2007	May-Jul	39.485	0.113	2007	Aug-Oct	18.147	0.675
2008	Jan-Feb	24.385	0.150	2008	May-Jul	40.650	0.248	2008	Aug-Oct	60.047	0.333
2009	Jan-Feb	37.853	0.169	2009	May-Jul	33.932	0.289	2009	Aug-Oct	54.154	0.224
2010	Jan-Feb	41.949	0.135	2010	May-Jul	32.031	0.333	2010	Aug-Oct	73.484	0.196
2011	Jan-Feb	50.737	0.109	2011	May-Jul	49.228	0.256	2011	Aug-Oct	56.918	0.200
2012	Jan-Feb	97.338	0.098	2012	May-Jul	117.192	0.245	2012	Aug-Oct	52.247	0.252
2013	Jan-Feb	67.061	0.081	2013	May-Jul	39.218	0.288	2013	Aug-Oct	82.463	0.139
2014	Jan-Feb	57.039	0.087	2014	May-Jul	54.974	0.233	2014	Aug-Oct	65.232	0.350
1991	Mar-Apr	61.454	0.058					1993	Nov-Dec	32.678	0.906
1992	Mar-Apr	48.269	0.069					1996	Nov-Dec	29.543	0.477
1993	Mar-Apr	48.840	0.073					1997	Nov-Dec	31.309	1.083
1994	Mar-Apr	52.428	0.053					1998	Nov-Dec	16.891	0.641
1995	Mar-Apr	55.463	0.061					1999	Nov-Dec	12.994	0.955
1996	Mar-Apr	33.954	0.051					2009	Nov-Dec	28.369	1.170
1997	Mar-Apr	45.985	0.062					2010	Nov-Dec	40.079	0.675
1998	Mar-Apr	31.809	0.071					2011	Nov-Dec	20.796	1.170
1999	Mar-Apr	35.675	0.085					2012	Nov-Dec	52.570	1.281
2000	Mar-Apr	31.397	0.084					2013	Nov-Dec	17.174	1.654
2001	Mar-Apr	21.213	0.105								
2002	Mar-Apr	26.640	0.102								
2003	Mar-Apr	28.131	0.094								
2004	Mar-Apr	42.816	0.115								
2005	Mar-Apr	48.932	0.113								
2006	Mar-Apr	56.188	0.140								
2007	Mar-Apr	45.097	0.091								
2008	Mar-Apr	40.343	0.194								
2009	Mar-Apr	55.557	0.182								
2010	Mar-Apr	55.766	0.264								
2011	Mar-Apr	76.788	0.147								
2012	Mar-Apr	76.796	0.153								
2013	Mar-Apr	64.027	0.137								
2014	Mar-Apr	61.848	0.101								

Table 2.6 (page 2 of 3)— Fishery CPUE as configured in Model 1. Units are kg/minute for trawl gear, kg/hook for longline gear, and kg/pot for pot gear.

Jan-Apr longline fishery			
Year	Season	CPUE	Sigma
1991	Jan-Feb	1.124	0.154
1992	Jan-Feb	0.873	0.088
1993	Jan-Feb	0.654	0.065
1994	Jan-Feb	0.728	0.067
1995	Jan-Feb	0.895	0.068
1996	Jan-Feb	0.878	0.068
1997	Jan-Feb	0.989	0.072
1998	Jan-Feb	0.888	0.073
1999	Jan-Feb	0.743	0.067
2000	Jan-Feb	0.730	0.069
2001	Jan-Feb	0.586	0.079
2002	Jan-Feb	0.680	0.061
2003	Jan-Feb	0.517	0.052
2004	Jan-Feb	0.562	0.060
2005	Jan-Feb	0.626	0.055
2006	Jan-Feb	0.747	0.062
2007	Jan-Feb	0.734	0.045
2008	Jan-Feb	0.794	0.067
2009	Jan-Feb	0.893	0.068
2010	Jan-Feb	0.781	0.066
2011	Jan-Feb	0.716	0.082
2012	Jan-Feb	0.774	0.081
2013	Jan-Feb	0.736	0.062
2014	Jan-Feb	0.604	0.068
1991	Mar-Apr	0.993	0.109
1992	Mar-Apr	0.858	0.070
1993	Mar-Apr	0.669	0.061
1994	Mar-Apr	0.735	0.060
1995	Mar-Apr	0.841	0.061
1996	Mar-Apr	0.756	0.066
1997	Mar-Apr	0.829	0.077
1998	Mar-Apr	0.619	0.075
1999	Mar-Apr	0.617	0.066
2000	Mar-Apr	0.617	0.096
2001	Mar-Apr	0.539	0.072
2002	Mar-Apr	0.676	0.082
2003	Mar-Apr	0.530	0.067
2004	Mar-Apr	0.579	0.075
2005	Mar-Apr	0.678	0.112
2006	Mar-Apr	0.796	0.111
2007	Mar-Apr	0.693	0.153
2008	Mar-Apr	0.774	0.144
2009	Mar-Apr	1.159	0.170
2010	Mar-Apr	0.829	0.194
2011	Mar-Apr	0.703	0.072
2012	Mar-Apr	0.597	0.081
2013	Mar-Apr	0.659	0.082
2014	Mar-Apr	0.519	0.072

May-Jul longline fishery			
Year	Season	CPUE	Sigma
1991	May-Jul	0.771	0.075
1992	May-Jul	0.530	0.052
1993	May-Jul	0.551	0.174
1994	May-Jul	0.713	0.132
1995	May-Jul	0.760	0.177
1996	May-Jul	0.669	0.176
1997	May-Jul	0.657	0.119
1998	May-Jul	0.496	0.182
1999	May-Jul	0.637	0.141
2000	May-Jul	0.610	0.167
2001	May-Jul	0.514	0.106
2002	May-Jul	0.405	0.136
2003	May-Jul	0.376	0.109
2004	May-Jul	0.367	0.114
2005	May-Jul	0.385	0.105
2006	May-Jul	0.366	0.160
2007	May-Jul	0.406	0.141
2008	May-Jul	0.366	0.139
2009	May-Jul	0.384	0.150
2010	May-Jul	0.419	0.155
2011	May-Jul	0.374	0.087
2012	May-Jul	0.429	0.079
2013	May-Jul	0.424	0.090
2014	May-Jul	0.365	0.067

Aug-Dec longline fishery			
Year	Season	CPUE	Sigma
1991	Aug-Oct	0.595	0.062
1992	Aug-Oct	0.512	0.068
1994	Aug-Oct	0.576	0.067
1995	Aug-Oct	0.587	0.069
1996	Aug-Oct	0.542	0.060
1997	Aug-Oct	0.580	0.064
1998	Aug-Oct	0.398	0.063
1999	Aug-Oct	0.481	0.060
2000	Aug-Oct	0.404	0.052
2001	Aug-Oct	0.398	0.051
2002	Aug-Oct	0.372	0.045
2003	Aug-Oct	0.342	0.044
2004	Aug-Oct	0.312	0.047
2005	Aug-Oct	0.330	0.045
2006	Aug-Oct	0.391	0.046
2007	Aug-Oct	0.402	0.038
2008	Aug-Oct	0.307	0.047
2009	Aug-Oct	0.348	0.049
2010	Aug-Oct	0.352	0.060
2011	Aug-Oct	0.369	0.058
2012	Aug-Oct	0.321	0.060
2013	Aug-Oct	0.355	0.056
2014	Aug-Oct	0.373	0.108
1991	Nov-Dec	0.551	0.092
1995	Nov-Dec	0.648	0.109
1996	Nov-Dec	0.590	0.274
1997	Nov-Dec	0.577	0.072
1998	Nov-Dec	0.501	0.071
1999	Nov-Dec	0.541	0.119
2000	Nov-Dec	0.416	0.066
2001	Nov-Dec	0.432	0.065
2002	Nov-Dec	0.394	0.071
2003	Nov-Dec	0.365	0.059
2004	Nov-Dec	0.441	0.065
2005	Nov-Dec	0.385	0.064
2006	Nov-Dec	0.433	0.212
2007	Nov-Dec	0.449	0.329
2008	Nov-Dec	0.449	0.086
2009	Nov-Dec	0.428	0.090
2010	Nov-Dec	0.447	0.086
2011	Nov-Dec	0.447	0.085
2012	Nov-Dec	0.476	0.076
2013	Nov-Dec	0.479	0.070

Table 2.6 (page 3 of 3)— Fishery CPUE as configured in Model 1. Units are kg/minute for trawl gear, kg/hook for longline gear, and kg/pot for pot gear.

Jan-Apr pot fishery			
Year	Season	CPUE	Sigma
2000	Jan-Feb	56.553	0.151
2001	Jan-Feb	72.207	0.499
2002	Jan-Feb	81.893	0.262
2003	Jan-Feb	73.858	0.137
2004	Jan-Feb	78.980	0.168
2005	Jan-Feb	85.328	0.167
2006	Jan-Feb	83.292	0.152
2007	Jan-Feb	64.671	0.108
2008	Jan-Feb	81.642	0.206
2009	Jan-Feb	92.345	0.187
2010	Jan-Feb	88.535	0.166
2011	Jan-Feb	130.718	0.151
2012	Jan-Feb	138.710	0.146
2013	Jan-Feb	128.974	0.142
2014	Jan-Feb	105.380	0.144
1992	Mar-Apr	86.412	0.418
1993	Mar-Apr	84.191	0.134
1994	Mar-Apr	89.313	0.106
1995	Mar-Apr	91.679	0.093
1996	Mar-Apr	73.485	0.076
1997	Mar-Apr	93.226	0.119
1998	Mar-Apr	77.558	0.182
1999	Mar-Apr	67.604	0.193
2000	Mar-Apr	45.310	0.161
2001	Mar-Apr	69.247	0.135
2002	Mar-Apr	61.628	0.174
2004	Mar-Apr	65.936	0.386
2006	Mar-Apr	116.202	0.418
2014	Mar-Apr	183.575	0.350

May-Jul pot fishery			
Year	Season	CPUE	Sigma
1991	May-Jul	64.037	0.248
1992	May-Jul	66.730	0.076
1993	May-Jul	90.669	0.226
1994	May-Jul	75.421	0.171
1995	May-Jul	72.065	0.097
1996	May-Jul	55.819	0.088
1997	May-Jul	46.843	0.113
1998	May-Jul	49.999	0.128
1999	May-Jul	47.466	0.123

Aug-Dec pot fishery			
Year	Season	CPUE	Sigma
1991	Aug-Oct	88.556	0.131
1992	Aug-Oct	30.252	0.112
1994	Aug-Oct	97.172	0.150
1995	Aug-Oct	57.783	0.152
1996	Aug-Oct	49.758	0.135
1997	Aug-Oct	47.938	0.165
1998	Aug-Oct	32.057	0.278
1999	Aug-Oct	37.675	0.211
2001	Aug-Oct	46.493	0.167
2002	Aug-Oct	42.331	0.187
2003	Aug-Oct	57.632	0.173
2004	Aug-Oct	48.802	0.208
2005	Aug-Oct	45.872	0.191
2006	Aug-Oct	55.342	0.184
2007	Aug-Oct	65.356	0.150
2008	Aug-Oct	57.252	0.162
2009	Aug-Oct	72.836	0.264
2010	Aug-Oct	82.936	0.208
2011	Aug-Oct	81.445	0.146
2012	Aug-Oct	64.934	0.128
2013	Aug-Oct	87.471	0.127
2014	Aug-Oct	86.671	0.286
1991	Nov-Dec	91.633	0.259
1995	Nov-Dec	53.251	0.186
1996	Nov-Dec	46.456	0.418
1997	Nov-Dec	41.829	0.409
1998	Nov-Dec	41.138	0.795
2001	Nov-Dec	40.740	0.625
2002	Nov-Dec	55.955	0.414
2003	Nov-Dec	60.093	0.331
2004	Nov-Dec	66.375	0.447
2006	Nov-Dec	37.187	0.418
2010	Nov-Dec	104.985	0.370
2013	Nov-Dec	90.404	0.211

Table 2.7— Total biomass and abundance, with standard deviations, as estimated by EBS shelf bottom trawl surveys, 1982-2014. For biomass, lower and upper 95% confidence intervals are also shown.

	Biomass (t)				Abundance (1000s of fish)	
Year	Estimate	Std. deviation	L95% CI	U95% CI	Estimate	Std. deviation
1982	1,013,061	73,621	867,292	1,158,831	583,781	38,064
1983	1,187,096	120,958	942,640	1,431,553	752,456	80,566
1984	1,048,493	63,632	922,501	1,174,484	680,883	49,913
1985	1,001,112	55,845	890,540	1,111,684	841,108	113,438
1986	1,118,006	69,626	980,146	1,255,866	838,217	83,855
1987	1,104,868	68,304	969,627	1,240,109	728,974	48,488
1988	960,962	76,961	808,579	1,113,344	507,560	35,581
1989	833,473	62,713	709,300	957,645	292,247	19,986
1990	691,256	51,455	589,376	793,136	423,835	36,466
1991	514,407	38,039	439,090	589,725	488,892	51,108
1992	551,369	45,780	460,725	642,013	601,795	70,551
1993	691,494	54,580	583,425	799,562	852,837	106,923
1994	1,360,790	247,737	865,316	1,856,263	1,232,175	152,212
1995	1,002,961	91,622	821,550	1,184,372	757,910	75,473
1996	889,366	87,521	716,076	1,062,657	607,198	88,384
1997	604,439	68,120	468,199	740,678	485,643	70,802
1998	558,510	45,182	469,050	647,970	537,342	48,429
1999	584,884	50,616	484,664	685,104	501,554	46,620
2000	531,171	43,160	445,714	616,627	483,808	44,188
2001	833,626	76,247	681,133	986,119	985,569	94,981
2002	618,680	69,082	480,516	756,845	566,471	57,676
2003	590,973	62,121	466,732	715,214	498,873	62,220
2004	596,279	35,216	526,552	666,007	424,662	36,140
2005	606,415	43,047	521,182	691,648	450,918	63,358
2006	517,698	28,341	461,583	573,813	394,051	23,784
2007	423,703	34,811	354,080	493,326	733,374	195,955
2008	403,125	26,822	350,018	456,232	476,697	49,413
2009	421,291	34,969	352,053	490,530	716,637	62,705
2010	860,210	102,307	657,642	1,062,778	887,836	117,022
2011	896,039	66,843	763,690	1,028,388	836,822	79,207
2012	890,665	100,473	689,718	1,091,612	987,973	91,589
2013	791,958	73,952	644,054	939,862	750,889	124,917
2014	1,079,712	153,299	769,895	1,389,528	1,122,144	143,618

Table 2.8 (page 1 of 3)—Trawl survey size composition, by year and cm (sample size in column 2).

Year	N	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1982	10547	0	0	0	0	0	1	7	8	18	24	46	54	100	63	46	50	43
1983	13148	0	0	0	0	0	7	101	301	474	473	499	476	449	411	262	258	124
1984	12142	0	0	0	0	0	6	25	36	54	43	27	26	27	32	49	32	67
1985	16884	0	0	0	0	0	4	54	98	174	141	212	282	299	370	498	503	522
1986	15378	0	0	0	0	1	23	38	93	133	130	202	175	177	150	93	34	27
1987	10601	0	0	0	0	0	0	14	3	7	24	38	60	80	110	122	122	154
1988	9994	0	0	0	0	0	0	1	8	7	28	13	27	26	23	42	27	18
1989	9999	0	0	0	0	0	2	2	17	44	35	68	85	109	107	103	66	40
1990	5628	0	0	0	0	0	26	72	105	155	152	187	239	262	207	151	118	90
1991	7222	0	0	0	0	0	6	31	93	111	138	135	161	131	135	127	106	134
1992	9603	0	0	0	0	0	0	1	17	82	184	190	173	148	196	218	232	248
1993	10402	0	0	0	0	1	3	29	82	193	430	296	407	355	322	322	346	315
1994	13924	0	0	0	0	0	3	10	5	27	42	77	92	100	100	116	136	111
1995	9210	0	0	0	0	0	3	12	15	13	19	41	37	42	56	59	81	68
1996	9347	0	0	0	0	0	1	2	11	9	23	33	48	64	53	66	69	64
1997	9175	0	0	0	0	0	8	17	65	114	167	193	192	196	212	284	226	218
1998	9575	0	0	0	0	0	1	4	24	55	86	119	105	137	91	45	22	6
1999	11700	0	0	0	0	0	1	15	55	102	111	123	94	113	78	42	29	41
2000	12548	0	0	0	4	10	23	51	99	137	298	478	582	442	278	274	141	87
2001	19745	0	0	0	0	5	6	27	62	127	205	314	453	662	715	769	681	664
2002	12239	0	0	0	0	1	3	6	22	45	65	81	102	160	112	168	111	72
2003	12357	0	0	1	0	1	3	5	11	56	92	138	205	232	205	249	254	281
2004	10806	0	2	0	0	0	1	4	19	44	84	150	106	194	187	218	213	136
2005	11289	0	0	0	0	0	0	1	4	22	43	87	138	201	248	304	284	301
2006	12132	0	1	0	4	7	40	101	336	405	427	453	401	343	330	359	280	243
2007	12812	0	0	0	0	7	7	129	481	1163	1425	1398	1141	731	715	511	326	400
2008	12981	0	0	1	0	0	6	54	169	350	380	390	350	312	227	151	75	40
2009	16678	1	0	0	7	36	106	401	972	1059	1088	879	744	651	486	460	318	219
2010	7569	0	0	0	0	0	1	5	18	24	29	50	50	56	46	31	15	17
2011	20741	0	0	0	0	0	8	20	76	142	258	306	385	413	597	627	906	887
2012	13074	0	0	6	0	0	74	379	687	732	563	424	417	310	409	395	208	128
2013	18696	0	0	0	0	1	9	50	116	147	207	222	283	240	177	127	35	21
2014	17941	0	0	0	1	0	1	9	90	117	239	341	467	520	658	499	608	490

Year	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
1982	19	8	9	2	8	17	24	39	66	87	123	192	221	239	305	320	236	197
1983	77	46	30	9	5	18	35	45	56	97	121	138	169	154	199	131	119	104
1984	75	95	129	234	315	378	455	569	589	637	564	468	388	346	294	221	156	106
1985	641	556	553	320	212	130	92	101	107	160	220	216	273	300	310	314	290	346
1986	20	22	72	114	218	360	449	697	629	616	638	653	580	557	448	402	349	332
1987	125	81	61	46	63	76	118	123	200	273	302	324	292	281	205	232	201	173
1988	26	35	48	68	77	88	87	109	84	124	122	137	179	190	269	215	195	211
1989	19	21	30	4	15	15	36	14	34	31	24	33	37	69	33	107	109	134
1990	57	35	42	43	33	47	77	78	96	104	98	93	119	125	80	114	97	68
1991	86	71	72	78	100	98	167	193	266	286	325	289	372	308	251	262	196	174
1992	216	228	113	119	134	182	262	288	303	349	375	351	310	304	243	217	177	149
1993	325	218	136	97	62	55	67	86	95	175	207	232	291	316	239	245	226	195
1994	103	91	132	121	171	154	206	321	430	552	639	730	766	671	642	471	362	288
1995	34	24	19	37	47	89	108	158	194	228	218	245	225	198	155	217	249	239
1996	54	36	20	22	24	58	65	130	164	195	229	276	237	250	192	201	168	157
1997	226	177	105	58	41	41	34	70	109	103	154	223	231	222	174	159	155	138
1998	4	17	24	57	72	182	275	381	493	598	626	611	513	538	343	261	229	166
1999	49	39	54	110	110	197	227	221	309	268	294	307	240	227	197	191	240	290
2000	33	9	12	25	39	77	119	170	197	220	259	305	222	197	184	188	174	199
2001	442	350	219	136	112	160	226	313	365	507	656	829	826	917	802	697	510	407
2002	52	35	17	42	62	105	159	240	266	433	473	553	552	519	379	400	313	293
2003	252	237	199	218	154	120	66	57	59	79	57	115	145	316	216	319	240	275
2004	143	113	64	55	72	90	102	186	195	219	236	273	301	317	310	341	313	326
2005	289	361	361	387	376	289	210	137	135	141	115	158	178	197	197	207	231	288
2006	146	105	65	54	56	55	64	86	115	168	189	246	243	264	245	303	263	298
2007	230	121	122	42	44	65	86	124	117	154	122	140	147	124	114	93	93	76
2008	21	40	70	162	307	479	550	707	745	719	681	559	461	341	281	200	161	151
2009	114	35	28	33	82	94	173	254	337	397	468	436	339	306	221	213	215	225
2010	9	13	31	60	127	194	242	356	431	418	395	395	324	269	184	165	106	95
2011	851	536	286	110	34	37	55	48	57	72	122	137	188	164	232	229	272	287
2012	48	31	10	28	37	59	84	178	259	269	358	352	390	279	309	190	158	98
2013	64	86	268	398	654	785	983	1078	840	908	652	658	415	310	240	180	174	145
2014	521	308	218	111	102	90	71	95	220	245	417	330	483	460	498	349	311	184

Table 2.8 (page 2 of 3)—Trawl survey size composition, by year and cm.

Year	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
1982	145	147	127	139	178	203	283	303	272	327	330	285	283	270	251	237	275	259	268	224	259
1983	59	64	81	96	146	156	213	262	291	279	294	315	254	247	246	223	306	284	264	262	248
1984	100	87	59	92	76	91	92	95	108	135	105	110	95	110	144	132	159	168	199	201	156
1985	355	392	418	518	504	518	485	472	361	324	245	194	169	129	97	94	103	102	104	86	87
1986	220	194	138	126	136	163	185	216	205	246	218	248	269	258	275	288	299	226	252	251	175
1987	186	222	209	297	328	334	332	319	323	251	249	262	157	156	134	120	146	140	98	122	92
1988	141	184	165	239	222	197	318	277	294	277	247	308	266	230	251	250	260	220	214	227	194
1989	117	126	102	116	115	140	177	167	176	184	176	200	254	237	260	246	234	328	293	219	222
1990	58	67	52	47	38	38	31	35	48	38	40	25	51	31	62	53	65	58	73	71	74
1991	144	119	85	68	64	61	52	61	53	61	74	49	62	42	72	90	58	75	40	34	42
1992	125	179	147	216	187	219	240	186	185	160	143	153	119	108	88	78	57	63	29	42	51
1993	150	159	179	180	217	218	229	266	204	183	190	157	150	128	112	117	107	87	63	64	78
1994	196	115	133	114	221	189	164	232	255	264	300	172	189	230	189	181	175	219	251	252	162
1995	314	378	371	417	422	394	342	335	293	199	189	153	142	115	98	108	95	88	93	86	72
1996	168	154	176	214	239	288	261	292	320	301	297	323	272	282	281	244	254	206	166	152	132
1997	145	136	125	127	135	135	171	194	228	152	172	134	150	180	187	160	167	124	213	164	173
1998	146	134	100	118	117	133	126	168	118	114	134	111	94	89	82	82	72	62	78	90	76
1999	308	380	485	508	584	557	504	394	409	311	233	199	165	142	145	117	117	93	105	93	87
2000	223	256	267	303	306	347	308	355	321	391	342	351	262	315	239	256	194	202	183	159	159
2001	299	217	189	176	152	157	187	229	281	229	265	251	230	263	274	256	235	219	224	188	208
2002	249	287	256	405	357	453	393	387	278	330	189	228	184	167	137	162	130	157	90	109	123
2003	291	318	361	343	390	456	426	461	415	390	277	276	234	246	260	198	185	166	149	124	144
2004	254	244	213	208	188	181	156	149	152	176	172	207	201	162	182	172	185	167	192	142	157
2005	252	204	194	203	207	216	167	205	168	193	132	171	127	144	129	135	111	111	101	99	100
2006	253	244	209	200	161	171	145	151	127	157	147	191	169	175	145	174	137	182	105	128	90
2007	61	73	77	74	68	82	76	85	79	80	60	75	74	82	68	72	59	54	48	52	47
2008	133	130	117	143	128	138	138	139	113	135	121	124	127	134	114	108	101	112	90	113	103
2009	302	304	362	380	379	347	334	279	288	247	180	146	143	116	102	93	82	75	78	85	88
2010	65	75	78	124	132	232	154	165	160	157	124	134	106	147	114	155	151	139	95	139	112
2011	403	458	673	801	859	925	872	790	633	510	346	349	277	265	184	230	225	265	184	276	241
2012	81	61	46	63	59	85	81	130	111	196	188	239	285	379	323	408	309	316	218	198	168
2013	126	184	153	230	292	361	431	519	407	386	349	326	258	259	195	210	136	192	142	214	193
2014	190	145	203	282	444	458	656	676	609	560	492	425	285	216	203	206	182	165	191	249	248
Year	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1982	261	265	228	227	206	197	193	201	123	174	126	135	74	74	74	66	46	35	38	29	21
1983	265	251	199	227	200	200	188	166	181	171	145	179	127	116	76	78	74	63	54	38	44
1984	217	171	200	202	190	164	199	182	177	170	153	147	83	119	97	105	75	84	57	68	46
1985	91	85	148	111	110	113	170	124	134	147	147	136	135	120	138	107	135	100	95	59	75
1986	171	120	146	111	81	99	76	84	70	87	105	99	89	70	90	86	69	81	71	62	84
1987	141	136	124	132	121	133	123	132	134	111	115	94	59	90	53	55	54	24	43	34	34
1988	199	166	207	165	116	124	99	138	106	106	82	116	84	84	56	79	71	48	41	55	71
1989	198	290	183	227	243	183	168	241	214	136	200	104	184	197	166	153	142	107	150	106	63
1990	83	88	87	77	77	53	79	54	59	33	62	43	52	51	52	47	32	37	37	24	36
1991	41	34	52	44	43	26	45	41	47	46	48	32	31	25	40	32	27	14	16	19	22
1992	50	66	45	36	25	32	31	47	35	32	24	14	21	23	21	15	24	15	18	25	29
1993	66	56	57	52	36	67	36	37	62	28	28	14	15	15	14	16	12	12	11	12	12
1994	219	153	205	164	180	160	126	84	133	62	102	49	67	30	40	20	29	13	21	9	9
1995	93	99	104	100	87	70	54	60	72	71	69	50	54	45	36	28	22	37	20	25	21
1996	140	99	94	85	79	58	60	60	56	55	45	56	61	31	44	36	27	29	35	22	22
1997	122	130	107	111	115	101	99	92	80	69	56	61	53	29	18	31	20	28	16	11	10
1998	66	77	88	86	75	65	98	59	64	48	46	52	55	38	52	29	37	21	21	25	13
1999	72	117	86	94	80	95	64	70	49	61	70	49	45	51	37	28	28	23	26	27	25
2000	149	112	101	90	85	54	65	58	52	36	50	33	38	31	34	29	22	12	14	22	22
2001	184	148	197	132	154	151	106	82	105	67	77	56	51	33	38	25	19	27	20	31	17
2002	125	101	113	107	99	57	107	72	64	66	57	48	35	36	31	25	31	24	13	10	20
2003	138	116	96	70	95	64	72	69	66	67	76	47	56	40	40	36	35	26	28	16	18
2004	166	148	140	138	121	102	100	86	104	81	63	72	59	57	33	49	44	42	44	31	27
2005	117	84	118	83	127	104	112	101	101	77	83	74	70	59	72	51	72	54	65	49	44
2006	97	105	95	106	90	88	98	61	96	51	71	60	58	64	67	57	59	42	57	44	58
2007	61	50	60	49	49	45	46	32	43	40	31	24	32	23	38	21	19	14	12	17	17
2008	113	91	81	81	88	62	71	64	71	44	53	35	39	23	43	19	23	21	23	13	16
2009	71	84	77	53	64	71	52	38	48	30	40	29	21	24	13	17	14	15	14	4	13
2010	100	71	90	58	67	40	42	29	22	16	19	17	9	6	7	8	10	3	7	2	2
2011	301	227	294	184	249	172	205	152	159	115	126	61	78	51	50	27	25	21	15	14	18
2012	164	97	120	86	104	78	79	63	66	46	72	37	47	24	29	21	20	19	18	6	10
2013	234	192	212	203	234	213	193	163	141	136	109	104	92	51	63	44	31	44	29	31	8
2014	198	191	203	135	139	110	106	62	62	52	66	56	53	65	49	43	40	29	28	20	15

Table 2.8 (page 3 of 3)—Trawl survey size composition, by year and cm.

Year	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
1982	27	25	13	8	7	9	3	6	4	1	3	4	0	3	0	1	2	1	0
1983	25	24	20	14	9	1	7	5	3	9	1	1	2	3	0	2	0	1	0
1984	40	31	33	27	22	28	12	16	19	12	9	4	8	6	0	4	3	2	1
1985	59	50	48	21	37	22	22	16	14	10	8	7	9	4	1	3	7	2	4
1986	56	53	43	29	26	35	18	21	18	30	10	16	13	5	4	6	2	7	2
1987	45	28	29	29	29	9	7	15	9	10	13	6	10	10	2	4	6	3	1
1988	62	53	31	30	11	27	15	6	15	2	15	2	6	6	6	5	1	4	8
1989	53	84	61	74	88	43	60	42	14	42	30	19	24	28	32	14	11	20	11
1990	37	10	23	18	23	19	10	10	19	11	5	5	5	6	11	10	3	1	1
1991	33	24	21	12	13	8	13	7	8	6	3	5	4	1	6	8	3	2	3
1992	14	16	15	11	13	14	6	10	8	13	6	7	7	4	7	8	3	9	1
1993	11	9	4	12	10	4	7	8	8	4	3	4	7	3	7	5	5	4	3
1994	10	12	5	9	8	9	7	4	6	35	13	9	3	1	3	6	4	2	1
1995	20	18	12	13	10	7	8	7	7	4	11	3	4	4	10	1	3	2	3
1996	24	24	15	25	10	13	22	17	9	3	3	6	10	3	5	4	3	2	2
1997	9	12	17	12	10	8	9	9	4	3	8	7	2	6	3	2	4	0	1
1998	16	9	15	11	8	10	7	4	3	5	5	10	3	6	3	1	2	2	1
1999	19	13	17	15	12	11	17	16	6	16	6	5	5	5	2	5	6	6	3
2000	12	18	19	8	9	5	9	26	7	7	7	4	4	10	2	8	5	3	1
2001	17	12	11	13	5	10	6	6	5	7	5	4	2	4	6	1	2	1	5
2002	14	6	6	3	7	2	4	5	2	2	4	5	5	1	3	2	3	6	1
2003	21	22	11	14	7	9	6	7	5	4	4	3	2	1	0	1	1	0	0
2004	23	23	16	22	10	25	13	19	14	13	6	4	8	4	3	4	4	2	2
2005	40	40	32	25	17	28	20	23	14	10	14	10	8	4	9	5	3	4	0
2006	50	51	37	42	39	34	20	35	16	23	15	18	10	10	6	11	9	1	7
2007	18	10	10	9	25	11	8	9	15	10	13	8	3	8	4	6	2	3	2
2008	12	16	14	12	8	20	11	10	8	12	5	10	10	10	9	3	8	9	2
2009	6	7	4	4	7	6	6	3	4	5	1	1	1	2	3	5	2	3	1
2010	4	2	2	1	3	4	0	2	1	2	1	1	2	0	0	2	1	0	1
2011	7	14	10	7	3	4	4	4	4	1	5	3	4	7	2	1	0	1	0
2012	4	7	6	6	4	4	4	1	1	2	2	1	3	3	2	0	0	1	2
2013	29	12	24	12	10	7	7	4	3	5	4	4	5	1	2	0	1	0	1
2014	16	8	8	8	4	4	6	3	1	6	2	3	2	0	0	3	1	2	0

Year	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118+
1982	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	4	3	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	1	2	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	3	1	3	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
1989	10	22	1	23	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	5	0	6	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1991	0	1	0	6	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
1992	4	3	3	3	2	1	1	1	0	0	0	0	0	0	0	0	0	1	0
1993	1	2	2	1	8	3	0	1	0	0	0	0	0	0	0	2	0	0	0
1994	2	9	6	3	1	7	0	0	1	0	1	0	0	0	0	0	0	0	0
1995	5	1	3	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0
1996	4	1	2	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
1997	2	0	0	1	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1998	1	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	2	1	0	2	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
2000	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	1	1	0	2	1	3	1	0	1	0	0	0	0	0	0	0	0	0	0
2002	1	0	0	1	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0
2003	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	0	1	0	5	0	1	0	0	2	0	1	0	0	0	0	0	0	0	0
2005	4	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	5	3	2	3	2	0	1	0	0	2	0	0	0	0	0	0	0	0	0
2007	3	2	8	1	2	1	2	0	1	0	0	0	1	0	0	0	0	0	0
2008	4	3	7	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
2009	2	1	1	0	1	2	0	0	1	0	0	0	0	0	0	0	0	0	0
2010	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	2	2	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2014	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2.9—Age compositions observed by the EBS shelf bottom trawl survey, 1994-2013. "Nact" = actual sample size (these get rescaled so that the average across all age compositions equals 300).

Year	Nact	0	1	2	3	4	5	6	7	8	9	10	11	12+
1994	715	0.0000	0.0847	0.3807	0.1737	0.1186	0.1180	0.0813	0.0207	0.0077	0.0043	0.0016	0.0008	0.0010
1995	571	0.0000	0.0543	0.2593	0.4173	0.1018	0.0765	0.0528	0.0134	0.0073	0.0062	0.0016	0.0016	0.0013
1996	711	0.0000	0.0568	0.2062	0.2019	0.2961	0.1314	0.0598	0.0286	0.0086	0.0038	0.0017	0.0016	0.0013
1997	719	0.0001	0.2538	0.1749	0.1639	0.1523	0.1161	0.0855	0.0224	0.0095	0.0023	0.0016	0.0011	0.0005
1998	635	0.0000	0.0768	0.4475	0.1976	0.1113	0.0576	0.0587	0.0287	0.0160	0.0038	0.0006	0.0007	0.0003
1999	860	0.0000	0.0800	0.1942	0.3021	0.2354	0.0791	0.0577	0.0291	0.0129	0.0061	0.0012	0.0016	0.0006
2000	860	0.0000	0.2339	0.1129	0.1622	0.2402	0.1519	0.0588	0.0133	0.0151	0.0051	0.0034	0.0014	0.0005
2001	920	0.0000	0.2905	0.2390	0.1890	0.0883	0.0862	0.0682	0.0252	0.0076	0.0020	0.0013	0.0010	0.0004
2002	870	0.0005	0.0799	0.1884	0.3066	0.2421	0.0720	0.0590	0.0369	0.0093	0.0031	0.0011	0.0004	0.0005
2003	1263	0.0000	0.1734	0.1615	0.2470	0.2095	0.1155	0.0408	0.0285	0.0152	0.0036	0.0005	0.0005	0.0007
2004	995	0.0000	0.1444	0.1635	0.2744	0.1283	0.1301	0.0918	0.0356	0.0191	0.0078	0.0021	0.0021	0.0005
2005	1279	0.0000	0.1799	0.2438	0.2087	0.1240	0.0639	0.0813	0.0549	0.0242	0.0101	0.0036	0.0042	0.0005
2006	1300	0.0000	0.3251	0.1424	0.1681	0.1168	0.0931	0.0624	0.0468	0.0290	0.0103	0.0032	0.0012	0.0008
2007	1441	0.0000	0.6947	0.0955	0.0677	0.0429	0.0431	0.0178	0.0148	0.0079	0.0052	0.0018	0.0009	0.0008
2008	1213	0.0000	0.2109	0.4473	0.1458	0.0867	0.0490	0.0291	0.0102	0.0098	0.0055	0.0025	0.0020	0.0013
2009	1412	0.0000	0.4547	0.1872	0.2320	0.0655	0.0284	0.0143	0.0086	0.0043	0.0018	0.0009	0.0007	0.0003
2010	1292	0.0000	0.0464	0.4819	0.1786	0.2027	0.0632	0.0144	0.0077	0.0025	0.0013	0.0005	0.0006	0.0001
2011	1253	0.0001	0.2796	0.0700	0.3694	0.1080	0.0903	0.0275	0.0068	0.0028	0.0015	0.0010	0.0005	0.0004
2012	1301	0.0000	0.3659	0.2338	0.0590	0.2358	0.0622	0.0300	0.0074	0.0022	0.0016	0.0006	0.0001	0.0002
2013	1418	0.0000	0.0975	0.4367	0.1804	0.1066	0.1119	0.0501	0.0116	0.0033	0.0009	0.0002	0.0003	0.0002

Table 2.10—Mean size (cm) at age from age-length key applied to respective size compositions, and sample sizes. Mean lengths for samples of size zero result from application of area-specific long-term average age-length keys. These data are used in Model 1 only.

Average length (cm) at age:

Year	0	1	2	3	4	5	6	7	8	9	10	11	12
1994	11.00	18.71	31.71	39.84	49.36	58.12	64.30	70.64	79.14	89.16	96.00	92.17	96.06
1995	11.00	17.47	32.36	43.13	52.95	62.32	69.94	76.23	82.88	84.75	93.73	92.67	93.83
1996	11.00	17.69	31.62	41.36	50.29	57.65	67.57	75.89	82.40	89.16	91.06	93.13	94.46
1997	11.00	17.28	32.23	42.20	51.38	59.70	64.57	72.89	78.97	89.31	92.19	92.97	94.75
1998	11.00	15.42	30.80	38.07	49.42	59.05	66.96	70.06	78.32	89.71	90.55	92.14	93.36
1999	0.00	15.80	29.52	40.22	46.13	56.38	65.52	71.48	79.07	81.78	93.50	90.63	97.61
2000	0.00	15.26	30.30	38.21	47.59	54.00	59.29	72.62	73.90	83.33	82.28	81.25	94.73
2001	11.00	17.88	31.36	36.77	48.26	55.42	61.78	66.41	77.18	84.43	77.93	88.73	94.42
2002	11.00	16.53	30.09	36.73	46.78	55.44	63.04	69.02	72.53	81.20	93.92	92.80	95.40
2003	11.00	18.02	29.82	41.05	48.40	56.50	65.19	70.50	74.98	82.61	83.54	83.42	94.09
2004	0.00	17.27	30.16	38.00	49.22	57.08	64.96	70.09	75.15	85.12	88.19	87.26	96.20
2005	11.00	18.51	26.52	39.02	48.42	56.64	64.06	72.19	78.45	82.21	89.65	87.28	96.44
2006	0.00	15.32	30.91	38.69	47.68	55.85	64.85	73.48	82.38	86.64	89.23	94.05	97.36
2007	0.00	15.04	30.97	41.16	50.90	59.63	67.01	74.62	82.30	84.03	94.01	91.10	92.19
2008	0.00	15.26	29.74	41.31	53.69	61.42	66.49	73.30	80.20	82.82	88.67	95.41	97.22
2009	0.00	14.14	31.06	42.44	51.70	59.89	66.22	71.68	77.04	82.67	89.83	88.76	93.00
2010	0.00	15.53	30.53	43.50	53.86	59.42	66.28	70.70	80.80	81.80	90.58	87.27	96.38
2011	11.00	18.21	33.27	43.94	53.81	62.60	67.86	72.93	77.15	85.86	83.77	84.27	90.11
2012	0.00	14.02	32.08	44.64	53.54	61.26	68.52	72.94	80.67	82.64	93.03	94.01	94.82
2013	0.00	15.55	28.78	43.97	50.66	62.09	66.50	75.12	77.07	82.70	89.88	86.78	98.42

Number of samples at age (0 indicates mean length inferred from long-term average age-length key):

Year	0	1	2	3	4	5	6	7	8	9	10	11	12
1994	0	40	213	143	109	89	73	26	12	7	1	2	0
1995	0	23	138	194	89	55	38	14	9	6	1	1	2
1996	0	34	143	138	183	101	65	37	5	2	0	1	2
1997	0	94	92	109	125	120	110	38	21	5	3	2	0
1998	0	56	145	97	94	73	88	47	28	6	0	1	0
1999	0	84	167	195	162	105	77	44	17	8	0	1	0
2000	0	112	102	130	204	177	82	21	19	6	6	1	0
2001	0	163	156	153	132	124	118	42	15	6	4	5	1
2002	1	72	153	202	186	80	88	63	15	6	2	0	2
2003	0	163	197	191	189	193	129	111	66	17	1	4	0
2004	0	141	133	197	128	151	129	59	32	17	4	4	0
2005	0	141	218	238	171	112	146	121	73	29	18	10	0
2006	0	205	176	179	168	155	140	133	93	36	10	4	1
2007	0	268	206	191	155	211	108	119	75	62	21	12	7
2008	0	141	262	244	188	134	97	45	45	28	13	8	6
2009	0	222	259	325	187	133	100	82	47	23	13	12	4
2010	0	105	344	229	296	144	71	48	30	13	5	7	0
2011	0	186	148	315	178	218	107	40	20	12	11	8	1
2012	0	163	289	130	284	161	151	55	30	20	11	3	2
2013	0	133	289	264	171	272	163	81	25	10	3	4	2

Table 2.11—Input multinomial sample sizes for length composition data as specified in the stock assessment models (S1…S5 = seasons 1-5, Srv. = shelf trawl survey).

	Model 1																Model 2	
	Trawl fishery					Longline fishery					Pot fishery					Srv.	Fish.	Srv.
Year	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5			
1977			10	13													2	
1978				34		8	23		42	17							12	
1979			17		6	74	24	32	12	20							18	
1980	23	63				8	6	30	13	19							16	
1981			51		15	7	5	26		11							11	
1982		25	20	5	13		12	16	34	19						241	14	257
1983	19	71	28	11	151	83	87	48	54	59						301	59	321
1984	78	98	91	22	34	67	91	82	191	736						278	144	296
1985	74	247	10	16	6	315	68	8	377	1084						386	213	412
1986	85	201	80	45		230	28	98	203	952			12	13		352	186	375
1987	257	178	103	154	81	696	202	101	621	1274			5	15		243	354	258
1988	729	321	34	6	35	12										229	110	244
1989	627		68		12				38					9		229	73	244
1990	223	570	276	5		14	82	624	628	308			7	72		129	271	137
1991	432	1032	54			167	248	562	925	289			17	120	13	165	373	176
1992	107	739	56			397	733	1043	543		6	10	247	117		220	386	234
1993	167	914				494	728	84				92	36			238	243	254
1994	111	1361	83			599	864	182	444			206	107	69		319	389	339
1995	89	902		8		608	780	101	499	219	7	272	342	96	62	211	385	225
1996	67	1304	96	41	14	748	747	105	752	38		439	462	179	20	214	484	228
1997	128	1113	30			761	806	269	840	717		272	348	128	23	210	525	224
1998	76	951	32	38	5	653	582	113	1000	869		214	243	51		219	466	233
1999	241	573	12	15		750	799	242	989	249		120	296	84		268	422	285
2000	201	534	37			693	400	132	1282	841	308	170				287	444	306
2001	75	309	42	53		565	679	331	1439	866	27	295	19	140	10	452	469	481
2002	164	321	91	123		994	557	213	1737	709	81	164	16	127	17	280	513	298
2003	123	419	101	151		1294	812	327	1921	1019	268	13		137	40	283	640	301
2004	148	258	136	86		1058	677	282	1684	843	160	35	14	118	18	247	520	263
2005	207	276	114			1232	304	319	1682	829	145	23		138		258	509	275
2006	282	159	83	13		973	298	153	1681	83	202	50	11	139	29	278	402	296
2007	190	214	147			894	76	90	1234	57	213	23		101		293	313	312
2008	167	93	32	21		816	193	210	1572	468	122	26		125		297	371	316
2009	86	58	28	67		730	117	165	1503	437	123	21		53	15	382	329	407
2010	165	37	17	59		786	76	150	973	440	144			116	37	173	290	184
2011	246	140	37	85		498	676	425	1033	447	166			171		475	379	506
2012	332	126	46	28		581	549	563	1034	588	206	29		241		299	418	319
2013	472	170	31	124		902	513	427	1107	701	129	9		197	79	428	526	456
2014	440	352	54			742	657	729	191		148	22		35		411	420	437

Table 2.12—Objective function components and parameter counts. Shaded cells indicate values not used in computing the total. Color scale extends from red (low) to green (high) in each row.

Obj. func. component	Model 1	Model 2
Equilibrium catch	0.01	0.00
Survey abundance index	-3.61	-60.32
Size composition	4948.11	992.08
Age composition	141.27	104.30
Recruitment	21.62	-0.11
Priors	n/a	14.77
"Softbounds"	0.03	0.00
Deviations	19.85	13.05
"F ballpark"	0.00	0.17
Total	5127.28	1063.93

CPUE component	Model 1	Model 2
Jan-Apr trawl fishery	233.86	n/a
May-Jul trawl fishery	-1.42	n/a
Aug-Dec trawl fishery	65.58	n/a
Jan-Apr longline fishery	302.02	n/a
May-Jul longline fishery	16.74	n/a
Aug-Dec longline fishery	156.46	n/a
Jan-Apr pot fishery	2.16	n/a
May-Jul pot fishery	-9.24	n/a
Aug-Dec pot fishery	17.76	n/a
Shelf trawl survey	-3.61	-60.32

Sizecomp component	Model 1	Model 2
Jan-Apr trawl fishery	1098.50	n/a
May-Jul trawl fishery	203.96	n/a
Aug-Dec trawl fishery	247.93	n/a
Jan-Apr longline fishery	757.87	n/a
May-Jul longline fishery	245.71	n/a
Aug-Dec longline fishery	1055.81	n/a
Jan-Apr pot fishery	133.02	n/a
May-Jul pot fishery	67.89	n/a
Aug-Dec pot fishery	245.53	n/a
Fishery	n/a	207.04
Shelf trawl survey	891.90	785.035

Parameter counts	Model 1	Model 2
Unconstrained parameters	115	13
Parameters with priors	0	73
Constrained deviations	71	117
Total	186	203

Table 2.13—Root mean squared errors (RMSE), mean normalized residuals (MNR), standard deviations of normalized residuals (SDNR), and observed:expected correlations (Corr.) for fishery CPUE and survey relative abundance time series. Fishery CPUE data are not used in fitting Model 1 and are not included at all in Model 2; fishery CPUE results are shown for comparison only.

Model	Fleet	RMSE	MNR	SDNR	Corr.
1	Jan-Apr trawl fishery	0.45	0.55	3.76	0.17
1	May-Jul trawl fishery	0.38	-0.15	1.61	0.34
1	Aug-Dec trawl fishery	0.69	0.19	2.37	0.13
1	Jan-Apr longline fishery	0.35	0.23	4.24	-0.10
1	May-Jul longline fishery	0.26	0.31	2.40	0.50
1	Aug-Dec longline fishery	0.23	0.15	3.58	0.35
1	Jan-Apr pot fishery	0.34	0.17	1.93	0.22
1	May-Jul pot fishery	0.21	0.04	1.51	0.21
1	Aug-Dec pot fishery	0.38	0.01	2.03	0.13
1	Shelf trawl survey	0.23	0.99	1.86	0.76
2	Shelf trawl survey	0.11	0.10	0.94	0.93

Table 2.14—Ratios of effective sample size to input sample size for each fishery and survey size composition time series. Mod. = model, Nrec = number of records, Ninp = input sample size, Neff = effective sample size, A(·) = arithmetic mean, H(·) = harmonic mean.

				Ratios		
Mod.	Fleet	Nrec	A(Ninp)	A(Neff/Ninp)	A(Neff)/A(Ninp)	H(Neff)/A(Ninp)
1	Jan-Apr trawl fish.	66	318	5.06	3.00	1.66
1	May-Jul trawl fish.	34	63	9.14	7.31	3.33
1	Aug-Dec trawl fish.	36	44	13.20	6.00	3.35
1	Jan-Apr longline fish.	70	471	8.54	4.00	1.16
1	May-Jul longline fish.	34	244	9.39	5.23	3.02
1	Aug-Dec longline fish.	65	669	6.43	3.15	0.88
1	Jan-Apr pot fish.	38	131	14.30	9.78	3.90
1	May-Jul pot fish.	16	136	18.56	7.79	1.84
1	Aug-Dec pot fish.	38	83	10.15	7.38	2.93
1	Trawl survey	33	282	2.01	1.71	1.05
2	Fishery	38	300	13.66	9.50	2.67
2	Trawl survey	33	300	2.33	1.98	1.23

Table 2.15—Input sample size, effective sample size, and ratio thereof for each year of age composition data from the bottom trawl survey. Last two rows show arithmetic and harmonic means. Color scale extends from red (low) to green (high) in each row.

		Effective N		Ratio	
Year	Input N	Model 1	Model 2	Model 1	Model 2
1994	204	400	240	1.96	1.18
1995	163	39	67	0.24	0.41
1996	203	303	588	1.50	2.90
1997	205	175	505	0.85	2.46
1998	181	1423	2046	7.86	11.30
1999	245	112	72	0.46	0.29
2000	245	90	58	0.37	0.24
2001	263	103	93	0.39	0.35
2002	248	82	85	0.33	0.34
2003	360	260	523	0.72	1.45
2004	284	30	59	0.11	0.21
2005	365	401	317	1.10	0.87
2006	371	143	405	0.39	1.09
2007	411	64	1494	0.16	3.64
2008	346	249	568	0.72	1.64
2009	403	100	440	0.25	1.09
2010	369	103	262	0.28	0.71
2011	358	193	136	0.54	0.38
2012	371	112	124	0.30	0.33
2013	405	129	229	0.32	0.56
Mean	300	226	416	0.94	1.57
Harm.	272	106	156	0.37	0.58

Table 2.16a—Biological parameters, ageing bias, recruitment (except annual *dev*s), initial fishing mortality, log catchability (base value only for Model 2), and initial age composition parameters used or estimated by the stock assessment models.

	Model 1		Model 2	
Parameter	Estimate	St. dev.	Estimate	St. dev.
Natural mortality	3.400E-01	_	3.440E-01	3.068E-02
Length at age 1 (cm)	1.418E+01	1.037E-01	1.628E+01	8.521E-02
Asymptotic length (cm)	9.234E+01	5.024E-01	9.573E+01	1.987E+00
Brody growth coefficient	2.402E-01	2.520E-03	2.341E-01	1.526E-02
Richards growth coefficient	n/a	n/a	8.699E-01	5.633E-02
SD of length at age 1 (cm)	3.530E+00	6.714E-02	3.360E+00	5.606E-02
SD of length at age 20 (cm)	9.903E+00	1.571E-01	8.859E+00	2.867E-01
Weight-length α (proportionality)	6.358E-06	_	6.358E-06	_
Weight-length β (exponent)	3.157E+00	_	3.157E+00	_
Age at 50% maturity	4.883E+00	_	4.883E+00	_
Maturity slope	-9.654E-01	_	-9.654E-01	_
Ageing bias at age 1 (years)	3.321E-01	1.340E-02	2.567E-01	2.827E-02
Ageing bias at age 20 (years)	3.350E-01	1.523E-01	7.736E-01	2.369E-01
Ageing error st. dev. at age 1	8.600E-02	_	8.600E-02	_
Ageing error st. dev. at age 20	1.712E+00	_	1.712E+00	_
ln(mean post-1976 recruitment)	1.322E+01	1.907E-02	1.321E+01	2.122E-01
Beverton-Holt "steepness"	1.000E+00	_	1.000E+00	_
σ(recruitment)	5.700E-01	_	6.570E-01	_
ln(pre-1977 recruitment offset)	-1.165E+00	1.308E-01	-7.339E-01	2.325E-01
Initial F (Jan-Apr trawl fishery)	6.436E-01	1.367E-01	n/a	n/a
Initial F (fishery)	n/a	n/a	9.338E-02	2.914E-02
ln(trawl survey catchability)	-2.614E-01	_	6.181E-02	1.147E-01
Initial age 10 ln(abundance) dev	n/a	n/a	-2.584E-01	5.897E-01
Initial age 9 ln(abundance) dev	n/a	n/a	-3.033E-01	5.801E-01
Initial age 8 ln(abundance) dev	n/a	n/a	-3.746E-01	5.661E-01
Initial age 7 ln(abundance) dev	n/a	n/a	-4.744E-01	5.476E-01
Initial age 6 ln(abundance) dev	n/a	n/a	-5.557E-01	5.296E-01
Initial age 5 ln(abundance) dev	n/a	n/a	-5.306E-01	5.216E-01
Initial age 4 ln(abundance) dev	n/a	n/a	-7.424E-02	5.090E-01
Initial age 3 ln(abundance) dev	1.289E+00	1.883E-01	1.638E-01	4.727E-01
Initial age 2 ln(abundance) dev	-7.295E-01	4.170E-01	-2.321E-01	5.500E-01
Initial age 1 ln(abundance) dev	1.403E+00	2.105E-01	7.000E-01	4.698E-01

Table 2.16b—Annual log-scale recruitment *dev*s estimated by the stock assessment models. Color scale extends from red (low) to green (high) in each column.

	Model 1		Model 2	
Year	Estimate	St. dev.	Estimate	St. dev.
1977	1.332E+00	1.093E-01	8.877E-01	2.376E-01
1978	4.571E-01	2.097E-01	6.873E-01	2.091E-01
1979	6.664E-01	1.092E-01	4.645E-01	1.384E-01
1980	-4.070E-01	1.350E-01	-3.076E-01	1.401E-01
1981	-9.229E-01	1.443E-01	-8.042E-01	1.599E-01
1982	9.547E-01	4.142E-02	7.322E-01	6.376E-02
1983	-5.532E-01	1.123E-01	-3.503E-01	1.227E-01
1984	7.446E-01	4.594E-02	6.488E-01	6.570E-02
1985	-1.086E-01	7.181E-02	-9.312E-02	9.597E-02
1986	-8.371E-01	9.461E-02	-6.812E-01	1.158E-01
1987	-1.167E+00	1.075E-01	-1.551E+00	2.099E-01
1988	-2.404E-01	5.656E-02	-2.080E-01	9.989E-02
1989	5.030E-01	4.022E-02	3.659E-01	7.212E-02
1990	2.911E-01	4.567E-02	3.625E-01	6.956E-02
1991	-3.226E-01	6.133E-02	-2.903E-01	9.704E-02
1992	5.876E-01	3.236E-02	6.110E-01	4.814E-02
1993	-4.611E-01	5.825E-02	-1.828E-01	7.280E-02
1994	-3.765E-01	5.102E-02	-4.074E-01	7.559E-02
1995	-2.807E-01	5.344E-02	-3.703E-01	7.914E-02
1996	6.227E-01	3.204E-02	4.937E-01	4.854E-02
1997	-2.826E-01	5.122E-02	-1.193E-01	6.588E-02
1998	-3.050E-01	4.948E-02	-2.214E-01	7.446E-02
1999	3.735E-01	3.152E-02	5.040E-01	4.786E-02
2000	-1.314E-01	3.698E-02	-3.398E-02	5.896E-02
2001	-8.945E-01	5.674E-02	-4.609E-01	6.744E-02
2002	-3.677E-01	3.824E-02	-4.483E-01	6.524E-02
2003	-5.952E-01	4.585E-02	-4.206E-01	6.350E-02
2004	-7.287E-01	5.035E-02	-7.036E-01	8.045E-02
2005	-5.917E-01	4.719E-02	-4.122E-01	7.786E-02
2006	6.706E-01	2.828E-02	5.003E-01	4.994E-02
2007	-5.230E-01	6.172E-02	3.039E-02	6.843E-02
2008	1.123E+00	3.646E-02	9.291E-01	5.086E-02
2009	-8.172E-01	1.126E-01	-8.483E-01	1.252E-01
2010	5.725E-01	5.992E-02	2.198E-01	8.324E-02
2011	1.024E+00	6.603E-02	7.474E-01	8.786E-02
2012	2.831E-02	1.135E-01	-4.361E-02	1.570E-01
2013	9.643E-01	1.455E-01	7.737E-01	1.953E-01

Table 2.16c—Fishery selectivity parameters estimated by Model 1.

Parameter	Estimate	St. dev.
P3_May-Jul_Trawl	5.614E+00	1.052E-01
P2_Jan-Apr_Longline	-4.523E+00	1.405E+00
P4_Jan-Apr_Longline	5.025E+00	1.451E-01
P3_May-Jul_Longline	5.027E+00	4.602E-02
P2_Aug-Dec_Longline	-2.117E+00	2.630E-01
P4_Aug-Dec_Longline	5.051E+00	3.322E-01
P2_Jan-Apr_Pot	-9.240E+00	1.825E+01
P3_Jan-Apr_Pot	5.008E+00	4.845E-02
P4_Jan-Apr_Pot	4.423E+00	2.861E-01
P3_May-Jul_Pot	4.927E+00	8.248E-02
P1_Jan-Apr_Trawl_1977	6.896E+01	3.160E+00
P1_Jan-Apr_Trawl_1985	7.618E+01	1.671E+00
P1_Jan-Apr_Trawl_1990	6.883E+01	1.105E+00
P1_Jan-Apr_Trawl_1995	7.399E+01	9.454E-01
P1_Jan-Apr_Trawl_2000	7.828E+01	1.205E+00
P1_Jan-Apr_Trawl_2005	7.736E+01	7.080E-01
P3_Jan-Apr_Trawl_1977	6.176E+00	1.773E-01
P3_Jan-Apr_Trawl_1985	6.617E+00	7.692E-02
P3_Jan-Apr_Trawl_1990	6.087E+00	5.883E-02
P3_Jan-Apr_Trawl_1995	6.298E+00	4.645E-02
P3_Jan-Apr_Trawl_2000	6.304E+00	6.127E-02
P3_Jan-Apr_Trawl_2005	6.009E+00	4.032E-02
P1_May-Jul_Trawl_1977	5.003E+01	1.706E+00
P1_May-Jul_Trawl_1985	5.110E+01	1.749E+00
P1_May-Jul_Trawl_1990	6.170E+01	1.546E+00
P1_May-Jul_Trawl_2000	5.283E+01	1.541E+00
P1_May-Jul_Trawl_2005	5.765E+01	1.438E+00
P1_Aug-Dec_Trawl_1977	6.263E+01	4.056E+00
P1_Aug-Dec_Trawl_1980	8.194E+01	5.746E+00
P1_Aug-Dec_Trawl_1985	8.638E+01	5.407E+00
P1_Aug-Dec_Trawl_1990	7.628E+01	3.498E+01
P1_Aug-Dec_Trawl_1995	1.025E+02	_
P1_Aug-Dec_Trawl_2000	5.610E+01	1.519E+00
P3_Aug-Dec_Trawl_1977	5.552E+00	3.311E-01
P3_Aug-Dec_Trawl_1980	6.664E+00	2.327E-01
P3_Aug-Dec_Trawl_1985	6.608E+00	2.336E-01
P3_Aug-Dec_Trawl_1990	6.346E+00	1.949E+00
P3_Aug-Dec_Trawl_1995	7.015E+00	8.921E-02
P3_Aug-Dec_Trawl_2000	5.220E+00	1.585E-01
P1_Jan-Apr_Longline_1977	5.908E+01	2.066E+00
P1_Jan-Apr_Longline_1980	7.234E+01	2.513E+00
P1_Jan-Apr_Longline_1985	7.502E+01	9.204E-01
P1_Jan-Apr_Longline_1990	6.606E+01	4.765E-01
P1_Jan-Apr_Longline_1995	6.572E+01	4.268E-01
P1_Jan-Apr_Longline_2000	6.352E+01	4.396E-01
P1_Jan-Apr_Longline_2005	6.711E+01	3.486E-01
P3_Jan-Apr_Longline_1977	5.151E+00	2.112E-01
P3_Jan-Apr_Longline_1980	5.909E+00	1.815E-01
P3_Jan-Apr_Longline_1985	5.851E+00	6.812E-02
P3_Jan-Apr_Longline_1990	5.225E+00	4.654E-02
P3_Jan-Apr_Longline_1995	5.304E+00	3.990E-02

Parameter	Estimate	St. Dev.
P3_Jan-Apr_Longline_2000	5.363E+00	4.166E-02
P3_Jan-Apr_Longline_2005	5.303E+00	3.023E-02
P6_Jan-Apr_Longline_1977	-1.305E+00	8.021E-01
P6_Jan-Apr_Longline_1980	4.299E-01	1.070E+00
P6_Jan-Apr_Longline_1985	-1.160E+00	4.385E-01
P6_Jan-Apr_Longline_1990	-4.633E-01	1.375E-01
P6_Jan-Apr_Longline_1995	-6.573E-01	1.402E-01
P6_Jan-Apr_Longline_2000	-1.152E+00	1.444E-01
P6_Jan-Apr_Longline_2005	-8.331E-01	1.380E-01
P1_May-Jul_Longline_1977	6.359E+01	2.215E+00
P1_May-Jul_Longline_1980	6.248E+01	1.363E+00
P1_May-Jul_Longline_1985	6.344E+01	1.121E+00
P1_May-Jul_Longline_1990	6.370E+01	4.883E-01
P1_May-Jul_Longline_2000	5.994E+01	5.436E-01
P1_May-Jul_Longline_2005	6.480E+01	4.792E-01
P1_Aug-Dec_Longline_1977	6.085E+01	2.197E+00
P1_Aug-Dec_Longline_1980	6.954E+01	1.650E+00
P1_Aug-Dec_Longline_1985	6.423E+01	7.632E-01
P1_Aug-Dec_Longline_1990	6.709E+01	7.241E-01
P1_Aug-Dec_Longline_1995	6.949E+01	7.057E-01
P1_Aug-Dec_Longline_2000	6.360E+01	4.304E-01
P1_Aug-Dec_Longline_2005	6.347E+01	3.548E-01
P3_Aug-Dec_Longline_1977	4.556E+00	3.191E-01
P3_Aug-Dec_Longline_1980	5.404E+00	1.386E-01
P3_Aug-Dec_Longline_1985	4.853E+00	8.898E-02
P3_Aug-Dec_Longline_1990	5.035E+00	7.664E-02
P3_Aug-Dec_Longline_1995	5.506E+00	5.369E-02
P3_Aug-Dec_Longline_2000	5.182E+00	4.152E-02
P3_Aug-Dec_Longline_2005	4.964E+00	3.542E-02
P6_Aug-Dec_Longline_1977	-2.576E+00	2.135E+00
P6_Aug-Dec_Longline_1980	5.958E-01	8.004E-01
P6_Aug-Dec_Longline_1985	2.619E-01	2.474E-01
P6_Aug-Dec_Longline_1990	2.647E+00	1.089E+00
P6_Aug-Dec_Longline_1995	9.532E+00	1.225E+01
P6_Aug-Dec_Longline_2000	-3.277E-01	1.866E-01
P6_Aug-Dec_Longline_2005	9.612E+00	1.044E+01
P1_Jan-Apr_Pot_1977	6.879E+01	9.213E-01
P1_Jan-Apr_Pot_1995	6.849E+01	5.463E-01
P1_Jan-Apr_Pot_2000	6.814E+01	5.154E-01
P1_Jan-Apr_Pot_2005	6.914E+01	5.055E-01
P6_Jan-Apr_Pot_1977	2.247E-01	5.596E-01
P6_Jan-Apr_Pot_1995	-2.156E-01	2.537E-01
P6_Jan-Apr_Pot_2000	-5.518E-01	2.358E-01
P6_Jan-Apr_Pot_2005	1.860E-01	2.286E-01
P1_May-Jul_Pot_1977	6.729E+01	8.667E-01
P1_May-Jul_Pot_1995	6.600E+01	7.259E-01
P1_Aug-Dec_Pot_1977	6.851E+01	1.195E+00
P1_Aug-Dec_Pot_2000	6.249E+01	6.695E-01
P3_Aug-Dec_Pot_1977	5.193E+00	1.204E-01
P3_Aug-Dec_Pot_2000	4.476E+00	1.006E-01

Table 2.16d—Survey selectivity parameters as estimated by Model 1.

Parameter	Estimate	St. dev.
P1	1.269E+00	5.451E-02
P2	-2.778E+00	4.194E-01
P3	-2.419E+00	4.337E-01
P4	2.679E+00	4.005E-01
P5	-9.992E+00	_
P6	-1.142E+00	3.620E-01
P3_dev_1982	-3.959E-02	3.196E-02
P3_dev_1983	-2.239E-02	1.814E-02
P3_dev_1984	-6.714E-02	2.818E-02
P3_dev_1985	1.404E-02	2.124E-02
P3_dev_1986	-3.218E-02	2.332E-02
P3_dev_1987	4.392E-02	3.992E-02
P3_dev_1988	-6.461E-02	3.228E-02
P3_dev_1989	-1.059E-01	1.929E-02
P3_dev_1990	-1.735E-02	2.115E-02
P3_dev_1991	-2.836E-02	2.274E-02
P3_dev_1992	9.523E-02	3.965E-02
P3_dev_1993	6.306E-02	2.950E-02
P3_dev_1994	-2.748E-02	2.214E-02
P3_dev_1995	-7.591E-02	2.048E-02
P3_dev_1996	-9.974E-02	1.842E-02
P3_dev_1997	-4.908E-02	1.590E-02
P3_dev_1998	-6.036E-02	1.962E-02
P3_dev_1999	-6.380E-02	1.806E-02
P3_dev_2000	-2.340E-02	1.644E-02
P3_dev_2001	1.752E-01	3.637E-02
P3_dev_2002	-4.301E-03	2.399E-02
P3_dev_2003	1.514E-02	2.015E-02
P3_dev_2004	-2.416E-03	2.046E-02
P3_dev_2005	5.681E-02	2.643E-02
P3_dev_2006	1.716E-01	3.647E-02
P3_dev_2007	2.121E-01	3.599E-02
P3_dev_2008	1.245E-01	3.623E-02
P3_dev_2009	1.240E-02	1.632E-02
P3_dev_2010	-2.260E-02	2.707E-02
P3_dev_2011	4.285E-02	2.052E-02
P3_dev_2012	3.834E-02	2.083E-02

Table 2.16e—Annual log-scale catchability offsets as estimated by Model 2.

Year	Estimate	St. dev.
1982	-1.347E-01	6.558E-02
1983	1.069E-03	7.222E-02
1984	-1.790E-02	6.246E-02
1985	3.271E-03	7.514E-02
1986	4.319E-02	6.837E-02
1987	2.789E-02	5.862E-02
1988	7.409E-03	5.951E-02
1989	-1.411E-01	6.039E-02
1990	-6.804E-02	6.954E-02
1991	-5.707E-02	7.057E-02
1992	-4.942E-02	7.232E-02
1993	3.126E-02	7.423E-02
1994	2.142E-01	7.244E-02
1995	1.174E-01	6.744E-02
1996	7.039E-02	7.578E-02
1997	-8.659E-03	7.612E-02
1998	2.466E-03	6.531E-02
1999	-2.644E-02	6.582E-02
2000	-8.377E-02	6.586E-02
2001	1.122E-01	6.699E-02
2002	-1.397E-02	6.798E-02
2003	-2.726E-02	7.267E-02
2004	-1.784E-02	6.388E-02
2005	2.222E-02	7.529E-02
2006	-5.731E-02	5.795E-02
2007	1.106E-02	8.391E-02
2008	-7.326E-02	6.920E-02
2009	-1.078E-01	6.616E-02
2010	4.726E-02	7.413E-02
2011	6.428E-03	6.831E-02
2012	7.487E-02	7.058E-02
2013	-5.785E-04	7.946E-02
2014	9.254E-02	7.813E-02

Table 2.16f—Fishery selectivity parameters as estimated by Model 2.

Parameter	Estimate	St. dev.
Age 1 base	2.940E+00	3.500E-01
Age 2 base	3.146E+00	3.106E-01
Age 3 base	2.994E+00	1.907E-01
Age 4 base	1.899E+00	2.189E-01
Age 5 base	9.605E-01	1.049E-01
Age 6 base	2.376E-01	1.353E-01
Age 7 base	-2.593E-01	1.888E-01
Age 8 base	-1.088E-01	2.400E-01
Age 9 base	-2.297E-01	2.679E-01
Age 10 base	-8.527E-02	2.809E-01
Age 11 base	2.887E-01	2.994E-01
Age 12 base	2.556E-01	3.239E-01
Age 13 base	2.274E-02	3.351E-01
Age 14 base	-5.140E-02	3.390E-01
Age 15 base	-9.215E-02	3.350E-01
Age 16 base	-4.080E-02	3.400E-01
Age 17 base	-1.953E-02	3.432E-01
Age 18 base	-7.952E-03	3.461E-01
Age 19 base	-3.248E-03	3.480E-01
Age 20 base	-4.809E-03	3.488E-01

Parameter	Estimate	St. dev.
Age 4 dev 1977	-2.351E-02	1.505E-01
Age 4 dev 1978	-4.844E-03	1.242E-01
Age 4 dev 1979	-1.554E-01	7.067E-02
Age 4 dev 1980	-1.143E-01	7.104E-02
Age 4 dev 1981	-2.162E-01	7.296E-02
Age 4 dev 1982	-1.980E-02	1.179E-01
Age 4 dev 1983	-7.268E-02	8.785E-02
Age 4 dev 1984	-1.807E-01	4.215E-02
Age 4 dev 1985	-3.788E-02	3.872E-02
Age 4 dev 1986	-9.415E-02	4.407E-02
Age 4 dev 1987	-8.251E-03	3.716E-02
Age 4 dev 1988	-2.232E-01	3.893E-02
Age 4 dev 1989	-1.771E-01	5.583E-02
Age 4 dev 1990	-1.124E-01	4.725E-02
Age 4 dev 1991	-4.815E-02	3.328E-02
Age 4 dev 1992	-8.397E-03	3.256E-02
Age 4 dev 1993	-9.054E-02	3.230E-02
Age 4 dev 1994	-7.911E-02	3.420E-02
Age 4 dev 1995	-5.930E-02	2.977E-02
Age 4 dev 1996	1.453E-02	4.426E-02
Age 4 dev 1997	-5.768E-02	3.398E-02
Age 4 dev 1998	-2.169E-02	3.590E-02
Age 4 dev 1999	-3.225E-02	2.967E-02
Age 4 dev 2000	1.278E-01	6.981E-02
Age 4 dev 2001	3.550E-02	4.897E-02
Age 4 dev 2002	-3.068E-02	3.021E-02
Age 4 dev 2003	2.128E-02	4.408E-02
Age 4 dev 2004	4.845E-02	5.935E-02
Age 4 dev 2005	4.517E-03	4.459E-02
Age 4 dev 2006	8.274E-02	6.122E-02
Age 4 dev 2007	1.028E-01	6.802E-02
Age 4 dev 2008	6.501E-02	4.835E-02
Age 4 dev 2009	1.362E-01	5.380E-02
Age 4 dev 2010	2.185E-01	8.188E-02
Age 4 dev 2011	1.053E-01	4.597E-02
Age 4 dev 2012	1.437E-01	8.412E-02
Age 4 dev 2013	-2.052E-02	3.320E-02
Age 4 dev 2014	7.757E-02	4.240E-02

Table 2.16g—Survey selectivity parameters as estimated by Model 2.

Parameter	Estimate	St. dev.
Age 1 base	5.020E+00	3.190E-01
Age 2 base	7.568E-01	1.606E-01
Age 3 base	1.860E-01	4.855E-02
Age 4 base	-1.338E-01	5.749E-02
Age 5 base	-4.541E-02	7.879E-02
Age 6 base	-1.294E-01	1.222E-01
Age 7 base	-3.186E-02	1.696E-01
Age 8 base	-2.310E-01	2.156E-01
Age 9 base	-2.028E-01	2.472E-01
Age 10 base	-8.219E-02	2.674E-01
Age 11 base	-5.096E-02	2.868E-01
Age 12 base	-3.937E-02	3.016E-01
Age 13 base	-5.490E-02	3.081E-01
Age 14 base	-2.934E-02	3.128E-01
Age 15 base	-1.431E-02	3.159E-01
Age 16 base	-1.504E-02	3.166E-01
Age 17 base	-1.567E-02	3.168E-01
Age 18 base	-1.314E-02	3.172E-01
Age 19 base	-9.784E-03	3.176E-01
Age 20 base	-6.857E-03	3.180E-01

Parameter	Estimate	St. dev.
Age 2 dev 1982	4.634E-02	3.634E-02
Age 2 dev 1983	-6.561E-04	2.080E-02
Age 2 dev 1984	1.014E-01	3.688E-02
Age 2 dev 1985	-1.280E-02	2.076E-02
Age 2 dev 1986	4.001E-02	2.628E-02
Age 2 dev 1987	-5.292E-03	2.995E-02
Age 2 dev 1988	5.390E-02	4.593E-02
Age 2 dev 1989	1.243E-01	3.048E-02
Age 2 dev 1990	3.035E-03	2.389E-02
Age 2 dev 1991	3.720E-02	2.543E-02
Age 2 dev 1992	-5.641E-02	2.461E-02
Age 2 dev 1993	-3.507E-02	2.082E-02
Age 2 dev 1994	5.859E-02	2.440E-02
Age 2 dev 1995	7.995E-02	2.854E-02
Age 2 dev 1996	1.040E-01	2.773E-02
Age 2 dev 1997	3.362E-02	2.008E-02
Age 2 dev 1998	8.650E-02	2.529E-02
Age 2 dev 1999	7.535E-02	2.405E-02
Age 2 dev 2000	3.060E-02	1.942E-02
Age 2 dev 2001	-7.407E-02	1.889E-02
Age 2 dev 2002	3.740E-02	2.326E-02
Age 2 dev 2003	-3.265E-02	1.999E-02
Age 2 dev 2004	1.163E-02	2.090E-02
Age 2 dev 2005	-4.114E-02	2.056E-02
Age 2 dev 2006	-6.592E-02	1.954E-02
Age 2 dev 2007	-1.304E-01	1.869E-02
Age 2 dev 2008	-2.780E-03	1.999E-02
Age 2 dev 2009	-3.697E-02	1.807E-02
Age 2 dev 2010	2.617E-02	2.829E-02
Age 2 dev 2011	-5.947E-02	1.906E-02
Age 2 dev 2012	-3.186E-02	1.903E-02
Age 2 dev 2013	3.542E-02	2.462E-02

Table 2.17a—Annual fishing mortality rates as estimated by Models 1 and 2. "F averaged over 6-18" represents an average rate across the specified age range; "Apical F" represents the fishing mortality rate at the length of peak selectivity. Color scale extends from red (low) to green (high) in each **column**.

	Model 1				Model 2			
	F averaged over 6-18		Apical F		F averaged over 6-18		Apical F	
Year	Estimate	St. dev.	Estimate	St. dev.	Estimate	St. dev.	Estimate	St. dev.
1977	7.03E-02	1.27E-02	7.82E-02	1.38E-02	9.65E-02	3.57E-02	1.24E-01	4.05E-02
1978	8.06E-02	1.31E-02	8.92E-02	1.44E-02	1.09E-01	4.02E-02	1.39E-01	4.53E-02
1979	5.64E-02	8.42E-03	6.27E-02	9.37E-03	8.43E-02	2.96E-02	1.02E-01	3.29E-02
1980	4.89E-02	6.23E-03	5.39E-02	7.66E-03	1.02E-01	3.29E-02	1.22E-01	3.62E-02
1981	4.66E-02	5.04E-03	5.02E-02	6.57E-03	7.89E-02	2.20E-02	9.82E-02	2.53E-02
1982	3.61E-02	2.85E-03	3.95E-02	4.06E-03	6.58E-02	1.25E-02	7.65E-02	1.40E-02
1983	5.00E-02	3.04E-03	5.53E-02	4.51E-03	8.12E-02	1.22E-02	8.98E-02	1.33E-02
1984	6.83E-02	3.66E-03	7.40E-02	4.78E-03	1.16E-01	1.54E-02	1.36E-01	1.92E-02
1985	8.29E-02	4.00E-03	9.48E-02	5.56E-03	1.23E-01	1.55E-02	1.52E-01	2.03E-02
1986	8.21E-02	3.73E-03	9.18E-02	5.05E-03	1.19E-01	1.50E-02	1.60E-01	2.11E-02
1987	9.41E-02	3.99E-03	1.06E-01	5.09E-03	1.28E-01	1.68E-02	1.83E-01	2.46E-02
1988	1.24E-01	4.59E-03	1.43E-01	7.58E-03	1.75E-01	1.84E-02	2.10E-01	2.22E-02
1989	1.21E-01	4.31E-03	1.32E-01	5.62E-03	1.51E-01	1.63E-02	1.94E-01	2.52E-02
1990	1.33E-01	4.46E-03	1.41E-01	6.09E-03	1.86E-01	1.67E-02	2.17E-01	2.23E-02
1991	2.05E-01	7.19E-03	2.20E-01	9.30E-03	3.15E-01	3.06E-02	4.00E-01	4.79E-02
1992	1.97E-01	7.46E-03	2.20E-01	9.05E-03	3.41E-01	4.12E-02	4.59E-01	5.62E-02
1993	1.56E-01	6.47E-03	1.83E-01	8.44E-03	2.32E-01	3.29E-02	3.31E-01	4.16E-02
1994	1.88E-01	8.97E-03	2.18E-01	1.64E-02	3.03E-01	3.60E-02	3.69E-01	4.27E-02
1995	2.53E-01	8.71E-03	3.20E-01	1.21E-02	3.98E-01	3.99E-02	4.47E-01	4.93E-02
1996	2.37E-01	8.35E-03	2.90E-01	1.09E-02	4.13E-01	4.06E-02	4.70E-01	5.16E-02
1997	2.76E-01	9.89E-03	3.30E-01	1.23E-02	4.41E-01	4.97E-02	5.38E-01	6.90E-02
1998	2.07E-01	7.57E-03	2.59E-01	1.01E-02	3.72E-01	4.02E-02	4.22E-01	4.62E-02
1999	2.03E-01	7.66E-03	2.46E-01	9.52E-03	3.58E-01	4.19E-02	4.38E-01	5.54E-02
2000	1.81E-01	6.60E-03	2.33E-01	8.32E-03	3.43E-01	4.22E-02	4.25E-01	5.25E-02
2001	1.56E-01	5.01E-03	2.00E-01	6.08E-03	2.81E-01	3.40E-02	3.43E-01	4.35E-02
2002	1.92E-01	5.59E-03	2.39E-01	6.94E-03	3.37E-01	3.45E-02	3.78E-01	3.98E-02
2003	2.01E-01	5.60E-03	2.55E-01	7.01E-03	3.37E-01	3.43E-02	4.03E-01	4.69E-02
2004	2.17E-01	5.81E-03	2.78E-01	7.41E-03	3.27E-01	3.37E-02	3.96E-01	4.72E-02
2005	2.57E-01	7.24E-03	3.03E-01	8.73E-03	3.54E-01	3.20E-02	4.04E-01	4.01E-02
2006	2.84E-01	8.77E-03	3.37E-01	1.06E-02	3.92E-01	3.62E-02	4.75E-01	5.31E-02
2007	2.74E-01	9.23E-03	3.25E-01	1.10E-02	3.68E-01	3.72E-02	4.60E-01	5.35E-02
2008	3.08E-01	1.11E-02	3.64E-01	1.33E-02	4.51E-01	4.90E-02	5.61E-01	6.57E-02
2009	3.37E-01	1.36E-02	4.00E-01	1.63E-02	5.41E-01	6.47E-02	6.63E-01	8.08E-02
2010	2.74E-01	1.16E-02	3.27E-01	1.41E-02	4.72E-01	5.90E-02	5.76E-01	7.22E-02
2011	3.23E-01	1.45E-02	3.82E-01	1.75E-02	5.62E-01	7.19E-02	6.51E-01	8.77E-02
2012	2.89E-01	1.45E-02	3.47E-01	1.79E-02	5.57E-01	7.04E-02	6.01E-01	7.79E-02
2013	2.59E-01	1.48E-02	3.02E-01	1.74E-02	4.43E-01	6.44E-02	5.06E-01	8.05E-02
2014	2.47E-01	1.63E-02	2.95E-01	1.97E-02	5.63E-01	9.15E-02	6.08E-01	9.93E-02

Table 2.17b— Model 1 estimates of seasonal full-selection fishing mortality rates, on an annual time scale. Sea1=Jan-Feb, Sea2=Mar-Apr, Sea3=May-Jul, Sea4=Aug-Oct, Sea5=Nov-Dec.

	Trawl fishery					Longline fishery					Pot fishery				
Year	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5
1977	0.083	0.086	0.054	0.047	0.041	0.016	0.016	0.006	0.024	0.031	0	0	0	0	0
1978	0.095	0.099	0.064	0.055	0.049	0.016	0.017	0.006	0.025	0.034	0	0	0	0	0
1979	0.069	0.071	0.042	0.038	0.033	0.012	0.013	0.005	0.018	0.024	0	0	0	0	0
1980	0.061	0.061	0.030	0.040	0.034	0.010	0.010	0.004	0.013	0.017	0	0	0	0	0
1981	0.033	0.032	0.032	0.063	0.059	0.004	0.004	0.002	0.009	0.010	0	0	0	0	0
1982	0.034	0.035	0.035	0.044	0.035	0.001	0.001	0.001	0.004	0.005	0	0	0	0	0
1983	0.054	0.056	0.050	0.053	0.044	0.005	0.005	0.003	0.004	0.005	0	0	0	0	0
1984	0.061	0.065	0.056	0.055	0.048	0.007	0.008	0.006	0.027	0.037	0	0	0	0	0
1985	0.078	0.083	0.066	0.064	0.051	0.024	0.026	0.010	0.034	0.047	0	0	0	0	0
1986	0.087	0.093	0.066	0.065	0.053	0.017	0.018	0.005	0.027	0.038	0	0	0	0	0
1987	0.096	0.102	0.052	0.053	0.052	0.042	0.045	0.013	0.042	0.060	0	0	0	0	0
1988	0.194	0.209	0.101	0.112	0.120	0.001	0.001	0.002	0.003	0.004	0	0	0	0	0
1989	0.206	0.224	0.099	0.058	0.054	0.008	0.009	0.012	0.015	0.013	0.000	0.000	0.000	0.000	0.000
1990	0.175	0.192	0.092	0.033	0.028	0.031	0.034	0.047	0.051	0.047	0.000	0.000	0.002	0.002	0.001
1991	0.180	0.376	0.067	0.056	0.043	0.061	0.104	0.087	0.099	0.065	0.000	0.004	0.002	0.011	0.003
1992	0.148	0.221	0.055	0.044	0.014	0.132	0.236	0.141	0.091	0.000	0.000	0.009	0.030	0.011	0.000
1993	0.188	0.256	0.025	0.036	0.011	0.223	0.227	0.025	0.016	0.004	0.000	0.018	0.012	0.000	0.000
1994	0.086	0.292	0.019	0.100	0.019	0.189	0.261	0.030	0.104	0.000	0.000	0.040	0.010	0.016	0.000
1995	0.213	0.428	0.005	0.196	0.002	0.243	0.310	0.021	0.108	0.064	0.000	0.077	0.039	0.015	0.005
1996	0.144	0.374	0.030	0.107	0.021	0.237	0.263	0.021	0.120	0.024	0.000	0.127	0.062	0.023	0.005
1997	0.179	0.405	0.025	0.099	0.037	0.266	0.283	0.043	0.115	0.192	0.000	0.098	0.041	0.021	0.005
1998	0.121	0.237	0.026	0.141	0.021	0.281	0.202	0.021	0.096	0.114	0.018	0.064	0.032	0.011	0.004
1999	0.146	0.222	0.016	0.065	0.004	0.324	0.241	0.020	0.126	0.043	0.022	0.063	0.035	0.013	0.000
2000	0.171	0.224	0.016	0.026	0.004	0.301	0.084	0.007	0.124	0.142	0.137	0.051	0.006	0.009	0.000
2001	0.066	0.122	0.015	0.038	0.005	0.160	0.155	0.018	0.168	0.157	0.022	0.119	0.005	0.015	0.005
2002	0.109	0.185	0.034	0.036	0.002	0.323	0.145	0.009	0.195	0.117	0.019	0.092	0.003	0.015	0.006
2003	0.127	0.146	0.028	0.033	0.002	0.333	0.172	0.013	0.198	0.147	0.124	0.019	0.003	0.026	0.010
2004	0.184	0.160	0.045	0.041	0.001	0.356	0.173	0.015	0.190	0.182	0.096	0.033	0.005	0.021	0.005
2005	0.262	0.161	0.041	0.016	0.001	0.503	0.079	0.021	0.217	0.189	0.098	0.038	0.000	0.028	0.004
2006	0.320	0.176	0.041	0.028	0.001	0.588	0.088	0.014	0.311	0.011	0.139	0.049	0.003	0.029	0.009
2007	0.210	0.240	0.076	0.023	0.001	0.655	0.033	0.011	0.254	0.010	0.165	0.020	0.004	0.042	0.000
2008	0.235	0.120	0.031	0.050	0.007	0.723	0.070	0.026	0.311	0.111	0.155	0.038	0.002	0.060	0.002
2009	0.209	0.182	0.031	0.071	0.004	0.854	0.077	0.024	0.327	0.134	0.189	0.038	0.003	0.013	0.015
2010	0.267	0.140	0.024	0.054	0.012	0.644	0.033	0.024	0.180	0.127	0.198	0.033	0.002	0.041	0.019
2011	0.276	0.285	0.035	0.059	0.011	0.344	0.329	0.099	0.187	0.143	0.209	0.033	0.005	0.057	0.000
2012	0.417	0.165	0.036	0.046	0.006	0.315	0.245	0.115	0.132	0.142	0.216	0.027	0.005	0.030	0.006
2013	0.311	0.159	0.023	0.077	0.008	0.307	0.189	0.068	0.119	0.145	0.170	0.026	0.000	0.027	0.024
2014	0.249	0.197	0.024	0.067	0.006	0.250	0.228	0.098	0.108	0.112	0.182	0.041	0.001	0.025	0.018

Table 2.18—Summary of key management reference points from the standard projection algorithm (last seven rows are from SS). All biomass figures are in t. Color scale: red = row minimum, green = row maximum.

Quantity	Model 1	Model 2
B100%	824,000	714,000
B40%	330,000	286,000
B35%	288,000	250,000
B(2015)	409,000	213,000
B(2016)	473,000	269,000
B(2015)/B100%	0.50	0.30
B(2016)/B100%	0.57	0.38
F40%	0.29	0.34
F35%	0.35	0.41
maxFABC(2015)	0.29	0.25
maxFABC(2016)	0.29	0.32
maxABC(2015)	295,000	112,000
maxABC(2016)	316,000	190,000
FOFL(2015)	0.35	0.30
FOFL(2016)	0.35	0.39
OFL(2015)	346,000	132,000
OFL(2016)	389,000	221,000
Pr(maxABC(2015)>truOFL(2015))	0.01	0.33
Pr(maxABC(2016)>truOFL(2016))	0.03	0.32
Pr(B(2015)<B20%)	0.00	0.02
Pr(B(2016)<B20%)	0.00	0.00
Pr(B(2017)<B20%)	0.00	0.00
Pr(B(2018)<B20%)	0.00	0.00
Pr(B(2019)<B20%)	0.00	0.00

Legend:
B100% = equilibrium unfished spawning biomass
B40% = 40% of B100% (the inflection point of the harvest control rules in Tier 3)
B35% = 35% of B100% (the BMSY proxy for Tier 3)
B(year) = projected spawning biomass for year
B(year)/B100% = ratio of spawning biomass to B100%
F40% = fishing mortality that reduces equilibrium spawning per recruit to 40% of unfished
F35% = fishing mortality that reduces equilibrium spawning per recruit to 35% of unfished
maxFABC(year) = maximum permissible ABC fishing mortality rate under Tier 3
maxABC(year) = maximum permissible ABC under Tier 3
FOFL(year) = OFL fishing mortality rate under Tier 3
OFL(year) = OFL under Tier 3
Pr(maxABC(year)>truOFL(year)) = probability that maxABC is greater than the "true" OFL
Pr(B(year)<B20%) = probability that spawning biomass is less than 20% of unfished

Table 2.19 (page 1 of 8)—Schedules of Pacific cod selectivity at length (cm) in the commercial fisheries as defined by parameter estimates. Years correspond to beginnings of blocks.

	January-April trawl fishery						May-July trawl fishery				
Len.	1977	1985	1990	1995	2000	2005	1977	1985	1990	2000	2005
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
6	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000
7	0.000	0.002	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000
8	0.000	0.002	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.001	0.000
9	0.001	0.002	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.001	0.000
10	0.001	0.003	0.000	0.001	0.000	0.000	0.003	0.002	0.000	0.001	0.000
11	0.001	0.003	0.001	0.001	0.000	0.000	0.004	0.003	0.000	0.002	0.000
12	0.001	0.004	0.001	0.001	0.000	0.000	0.005	0.004	0.000	0.002	0.000
13	0.001	0.005	0.001	0.001	0.000	0.000	0.007	0.005	0.000	0.003	0.001
14	0.002	0.006	0.001	0.001	0.001	0.000	0.009	0.007	0.000	0.004	0.001
15	0.002	0.007	0.001	0.002	0.001	0.000	0.011	0.009	0.000	0.005	0.001
16	0.003	0.008	0.002	0.002	0.001	0.000	0.015	0.011	0.000	0.007	0.002
17	0.004	0.009	0.002	0.003	0.001	0.000	0.019	0.014	0.001	0.009	0.002
18	0.005	0.011	0.003	0.003	0.001	0.000	0.024	0.018	0.001	0.012	0.003
19	0.006	0.013	0.004	0.004	0.002	0.000	0.030	0.023	0.001	0.015	0.004
20	0.007	0.015	0.004	0.005	0.002	0.000	0.037	0.029	0.002	0.020	0.006
21	0.008	0.017	0.006	0.006	0.002	0.000	0.046	0.037	0.002	0.025	0.007
22	0.010	0.020	0.007	0.007	0.003	0.001	0.057	0.046	0.003	0.031	0.010
23	0.012	0.023	0.008	0.008	0.004	0.001	0.070	0.056	0.004	0.039	0.013
24	0.015	0.026	0.010	0.010	0.005	0.001	0.084	0.069	0.006	0.048	0.016
25	0.018	0.030	0.013	0.012	0.006	0.001	0.102	0.083	0.007	0.059	0.020
26	0.022	0.034	0.016	0.014	0.007	0.002	0.122	0.100	0.010	0.072	0.026
27	0.026	0.039	0.019	0.017	0.008	0.002	0.144	0.120	0.012	0.088	0.033
28	0.031	0.045	0.023	0.020	0.010	0.003	0.170	0.143	0.016	0.105	0.041
29	0.036	0.051	0.027	0.024	0.012	0.003	0.199	0.168	0.020	0.126	0.050
30	0.043	0.058	0.033	0.028	0.014	0.004	0.231	0.197	0.026	0.149	0.062
31	0.050	0.065	0.039	0.033	0.017	0.005	0.267	0.229	0.032	0.176	0.075
32	0.058	0.073	0.046	0.039	0.020	0.006	0.306	0.264	0.040	0.205	0.091
33	0.068	0.083	0.054	0.045	0.024	0.008	0.347	0.303	0.050	0.238	0.109
34	0.079	0.093	0.064	0.053	0.028	0.010	0.392	0.344	0.061	0.274	0.130
35	0.091	0.103	0.074	0.061	0.032	0.012	0.439	0.388	0.074	0.314	0.154
36	0.104	0.115	0.086	0.070	0.038	0.015	0.488	0.435	0.090	0.356	0.181
37	0.120	0.128	0.100	0.081	0.044	0.018	0.538	0.484	0.108	0.401	0.211
38	0.136	0.142	0.115	0.092	0.051	0.022	0.590	0.535	0.129	0.448	0.245
39	0.155	0.157	0.133	0.105	0.059	0.027	0.642	0.586	0.153	0.498	0.281
40	0.175	0.174	0.151	0.119	0.069	0.032	0.693	0.638	0.179	0.548	0.321
41	0.197	0.191	0.172	0.135	0.079	0.039	0.743	0.689	0.209	0.600	0.364
42	0.221	0.210	0.195	0.152	0.090	0.046	0.790	0.739	0.243	0.652	0.409
43	0.246	0.229	0.220	0.171	0.103	0.055	0.835	0.787	0.279	0.703	0.457
44	0.274	0.250	0.247	0.191	0.117	0.065	0.876	0.832	0.319	0.752	0.507
45	0.303	0.272	0.275	0.213	0.132	0.076	0.912	0.873	0.361	0.800	0.558
46	0.334	0.296	0.306	0.236	0.149	0.089	0.943	0.909	0.407	0.843	0.610
47	0.367	0.320	0.339	0.262	0.167	0.104	0.967	0.940	0.455	0.883	0.661
48	0.401	0.346	0.373	0.288	0.187	0.120	0.985	0.966	0.504	0.918	0.712
49	0.437	0.372	0.409	0.317	0.208	0.139	0.996	0.984	0.555	0.948	0.761
50	0.473	0.400	0.447	0.347	0.232	0.159	1.000	0.996	0.607	0.971	0.808
51	0.511	0.428	0.486	0.378	0.256	0.181	1.000	1.000	0.659	0.988	0.851
52	0.550	0.457	0.526	0.411	0.283	0.206	1.000	1.000	0.709	0.997	0.890
53	0.589	0.487	0.566	0.444	0.311	0.233	1.000	1.000	0.759	1.000	0.924
54	0.628	0.518	0.607	0.479	0.340	0.262	1.000	1.000	0.805	1.000	0.953
55	0.667	0.549	0.648	0.515	0.371	0.293	1.000	1.000	0.849	1.000	0.975
56	0.705	0.580	0.688	0.551	0.403	0.326	1.000	1.000	0.888	1.000	0.990
57	0.743	0.611	0.728	0.588	0.437	0.361	1.000	1.000	0.923	1.000	0.998
58	0.779	0.643	0.766	0.625	0.471	0.398	1.000	1.000	0.951	1.000	1.000
59	0.814	0.674	0.803	0.661	0.507	0.437	1.000	1.000	0.974	1.000	1.000
60	0.846	0.705	0.838	0.698	0.543	0.477	1.000	1.000	0.990	1.000	1.000

Table 2.19 (page 2 of 8)—Schedules of Pacific cod selectivity at length (cm) in the commercial fisheries as defined by parameter estimates. Years correspond to beginnings of blocks.

	January-April trawl fishery						May-July trawl fishery				
Len.	1977	1985	1990	1995	2000	2005	1977	1985	1990	2000	2005
61	0.877	0.735	0.870	0.733	0.579	0.518	1.000	1.000	0.998	1.000	1.000
62	0.904	0.764	0.900	0.768	0.616	0.560	1.000	1.000	1.000	1.000	1.000
63	0.929	0.793	0.926	0.801	0.652	0.603	1.000	1.000	1.000	1.000	1.000
64	0.950	0.820	0.948	0.832	0.689	0.645	1.000	1.000	1.000	1.000	1.000
65	0.968	0.846	0.967	0.862	0.724	0.687	1.000	1.000	1.000	1.000	1.000
66	0.982	0.871	0.982	0.889	0.759	0.728	1.000	1.000	1.000	1.000	1.000
67	0.992	0.893	0.992	0.914	0.792	0.768	1.000	1.000	1.000	1.000	1.000
68	0.998	0.914	0.998	0.936	0.824	0.806	1.000	1.000	1.000	1.000	1.000
69	1.000	0.933	1.000	0.955	0.854	0.842	1.000	1.000	1.000	1.000	1.000
70	1.000	0.950	1.000	0.971	0.882	0.875	1.000	1.000	1.000	1.000	1.000
71	1.000	0.965	1.000	0.984	0.908	0.905	1.000	1.000	1.000	1.000	1.000
72	1.000	0.977	1.000	0.993	0.930	0.932	1.000	1.000	1.000	1.000	1.000
73	1.000	0.987	1.000	0.998	0.950	0.954	1.000	1.000	1.000	1.000	1.000
74	1.000	0.994	1.000	1.000	0.967	0.973	1.000	1.000	1.000	1.000	1.000
75	1.000	0.998	1.000	1.000	0.980	0.986	1.000	1.000	1.000	1.000	1.000
76	1.000	1.000	1.000	1.000	0.991	0.995	1.000	1.000	1.000	1.000	1.000
77	1.000	1.000	1.000	1.000	0.997	1.000	1.000	1.000	1.000	1.000	1.000
78	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
79	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
80	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
81	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
82	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
83	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
84	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
85	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
86	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
87	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
88	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
89	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
90	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
91	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
92	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
93	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
94	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
95	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
96	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
97	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
98	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
99	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
100	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
101	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
102	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
103	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
104	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
105	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
106	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
107	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
108	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
109	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
110	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
111	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
112	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
113	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
114	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
115	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
116	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
117	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
118	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
119	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
120	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 2.19 (page 3 of 8)—Schedules of Pacific cod selectivity at length (cm) in the commercial fisheries as defined by parameter estimates. Years correspond to beginnings of blocks.

	August-December trawl fishery						January-April longline fishery						
Len.	1977	1980	1985	1990	1995	2000	1977	1980	1985	1990	1995	2000	2005
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.002	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.002	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.002	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.003	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.003	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.004	0.001	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.005	0.002	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.005	0.002	0.003	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.001	0.006	0.002	0.003	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.001	0.007	0.003	0.004	0.002	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000
21	0.001	0.009	0.003	0.005	0.003	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000
22	0.002	0.010	0.004	0.006	0.003	0.002	0.000	0.001	0.000	0.000	0.000	0.000	0.000
23	0.002	0.012	0.004	0.007	0.003	0.003	0.001	0.001	0.000	0.000	0.000	0.000	0.000
24	0.003	0.014	0.005	0.008	0.004	0.004	0.001	0.002	0.001	0.000	0.000	0.001	0.000
25	0.004	0.016	0.006	0.010	0.005	0.005	0.001	0.002	0.001	0.000	0.000	0.001	0.000
26	0.005	0.018	0.007	0.012	0.005	0.007	0.002	0.003	0.001	0.000	0.000	0.001	0.000
27	0.007	0.021	0.009	0.014	0.006	0.010	0.003	0.004	0.001	0.000	0.001	0.002	0.000
28	0.010	0.024	0.010	0.017	0.007	0.014	0.004	0.005	0.002	0.000	0.001	0.003	0.000
29	0.012	0.028	0.012	0.020	0.008	0.019	0.005	0.006	0.002	0.001	0.001	0.004	0.001
30	0.016	0.032	0.014	0.023	0.009	0.025	0.007	0.008	0.003	0.001	0.002	0.005	0.001
31	0.021	0.037	0.016	0.027	0.010	0.033	0.010	0.010	0.004	0.001	0.002	0.007	0.002
32	0.026	0.042	0.018	0.032	0.012	0.043	0.014	0.012	0.005	0.002	0.004	0.010	0.002
33	0.033	0.047	0.021	0.037	0.013	0.056	0.019	0.015	0.006	0.003	0.005	0.013	0.003
34	0.042	0.053	0.025	0.044	0.015	0.071	0.026	0.019	0.008	0.004	0.007	0.017	0.004
35	0.052	0.060	0.028	0.050	0.017	0.090	0.035	0.023	0.010	0.006	0.009	0.022	0.006
36	0.064	0.068	0.033	0.058	0.019	0.112	0.046	0.028	0.013	0.008	0.012	0.029	0.008
37	0.078	0.076	0.037	0.067	0.021	0.139	0.059	0.034	0.016	0.011	0.017	0.037	0.011
38	0.095	0.085	0.042	0.077	0.024	0.170	0.076	0.041	0.019	0.014	0.022	0.047	0.015
39	0.115	0.095	0.048	0.087	0.027	0.206	0.097	0.049	0.024	0.019	0.029	0.060	0.020
40	0.137	0.106	0.055	0.099	0.030	0.246	0.122	0.059	0.029	0.026	0.037	0.075	0.026
41	0.163	0.118	0.062	0.113	0.034	0.291	0.151	0.070	0.036	0.034	0.048	0.093	0.034
42	0.192	0.131	0.070	0.127	0.037	0.341	0.185	0.082	0.043	0.044	0.061	0.114	0.043
43	0.224	0.145	0.079	0.143	0.042	0.395	0.224	0.097	0.052	0.057	0.077	0.139	0.055
44	0.260	0.159	0.089	0.161	0.046	0.453	0.268	0.113	0.063	0.073	0.096	0.168	0.070
45	0.299	0.175	0.099	0.180	0.051	0.513	0.317	0.132	0.075	0.092	0.118	0.200	0.088
46	0.342	0.192	0.111	0.200	0.057	0.576	0.371	0.152	0.089	0.115	0.145	0.237	0.109
47	0.387	0.211	0.123	0.222	0.063	0.639	0.430	0.175	0.105	0.142	0.175	0.278	0.134
48	0.436	0.230	0.137	0.246	0.070	0.701	0.491	0.200	0.123	0.173	0.210	0.323	0.162
49	0.486	0.250	0.152	0.271	0.077	0.761	0.555	0.228	0.143	0.209	0.249	0.372	0.195
50	0.538	0.272	0.168	0.298	0.084	0.818	0.621	0.258	0.165	0.250	0.293	0.425	0.233
51	0.592	0.295	0.185	0.326	0.093	0.869	0.685	0.291	0.190	0.295	0.341	0.480	0.275
52	0.645	0.319	0.203	0.356	0.101	0.913	0.748	0.326	0.218	0.345	0.392	0.537	0.321
53	0.698	0.343	0.222	0.387	0.111	0.949	0.807	0.363	0.248	0.399	0.447	0.595	0.371
54	0.749	0.369	0.243	0.419	0.121	0.976	0.861	0.402	0.281	0.457	0.505	0.654	0.425
55	0.798	0.396	0.265	0.452	0.132	0.993	0.908	0.442	0.316	0.518	0.565	0.712	0.482
56	0.843	0.424	0.288	0.486	0.144	1.000	0.947	0.485	0.353	0.580	0.625	0.767	0.541
57	0.884	0.452	0.312	0.521	0.156	1.000	0.975	0.528	0.393	0.643	0.685	0.819	0.601
58	0.920	0.481	0.337	0.557	0.169	1.000	0.993	0.572	0.435	0.705	0.744	0.867	0.661
59	0.950	0.511	0.364	0.592	0.183	1.000	1.000	0.617	0.478	0.765	0.799	0.909	0.721
60	0.973	0.541	0.391	0.628	0.198	1.000	1.000	0.662	0.523	0.821	0.850	0.944	0.777

Table 2.19 (page 4 of 8)—Schedules of Pacific cod selectivity at length (cm) in the commercial fisheries as defined by parameter estimates. Years correspond to beginnings of blocks.

	August-December trawl fishery						January-April longline fishery						
Len.	1977	1980	1985	1990	1995	2000	1977	1980	1985	1990	1995	2000	2005
61	0.990	0.571	0.419	0.664	0.213	1.000	1.000	0.706	0.568	0.871	0.895	0.971	0.830
62	0.998	0.602	0.448	0.699	0.230	1.000	0.991	0.748	0.614	0.915	0.934	0.989	0.878
63	1.000	0.633	0.478	0.734	0.247	1.000	0.973	0.789	0.660	0.951	0.964	0.999	0.919
64	1.000	0.663	0.509	0.768	0.265	1.000	0.946	0.828	0.705	0.977	0.985	1.000	0.953
65	1.000	0.693	0.540	0.800	0.283	1.000	0.910	0.864	0.749	0.994	0.997	1.000	0.978
66	1.000	0.723	0.571	0.831	0.303	1.000	0.868	0.897	0.791	1.000	1.000	0.996	0.994
67	1.000	0.752	0.602	0.860	0.323	1.000	0.820	0.926	0.831	1.000	1.000	0.982	1.000
68	1.000	0.780	0.634	0.887	0.344	1.000	0.768	0.950	0.868	0.999	0.998	0.959	1.000
69	1.000	0.808	0.665	0.911	0.366	1.000	0.714	0.970	0.901	0.992	0.987	0.928	0.999
70	1.000	0.834	0.696	0.933	0.388	1.000	0.659	0.985	0.930	0.978	0.969	0.889	0.992
71	1.000	0.858	0.727	0.952	0.411	1.000	0.606	0.995	0.955	0.956	0.943	0.845	0.975
72	1.000	0.881	0.756	0.968	0.434	1.000	0.554	1.000	0.974	0.927	0.910	0.796	0.951
73	1.000	0.903	0.785	0.981	0.458	1.000	0.505	1.000	0.988	0.894	0.872	0.744	0.919
74	1.000	0.923	0.813	0.991	0.483	1.000	0.460	1.000	0.997	0.856	0.831	0.692	0.881
75	1.000	0.940	0.840	0.997	0.508	1.000	0.419	0.996	1.000	0.815	0.786	0.639	0.838
76	1.000	0.956	0.865	1.000	0.533	1.000	0.383	0.988	1.000	0.773	0.741	0.588	0.792
77	1.000	0.969	0.888	1.000	0.558	1.000	0.351	0.975	0.999	0.730	0.695	0.540	0.744
78	1.000	0.980	0.910	1.000	0.584	1.000	0.324	0.957	0.988	0.689	0.651	0.495	0.696
79	1.000	0.989	0.929	1.000	0.610	1.000	0.301	0.936	0.969	0.648	0.608	0.454	0.648
80	1.000	0.995	0.947	1.000	0.635	1.000	0.281	0.913	0.940	0.610	0.569	0.417	0.602
81	1.000	0.999	0.962	1.000	0.661	1.000	0.266	0.887	0.904	0.575	0.532	0.384	0.559
82	1.000	1.000	0.974	1.000	0.686	1.000	0.253	0.860	0.862	0.544	0.500	0.356	0.519
83	1.000	1.000	0.985	1.000	0.711	1.000	0.243	0.833	0.814	0.516	0.471	0.333	0.483
84	1.000	1.000	0.992	1.000	0.736	1.000	0.236	0.805	0.764	0.491	0.446	0.313	0.451
85	1.000	1.000	0.997	1.000	0.760	1.000	0.230	0.779	0.711	0.471	0.425	0.296	0.424
86	1.000	1.000	1.000	1.000	0.784	1.000	0.225	0.755	0.658	0.453	0.407	0.283	0.400
87	1.000	1.000	1.000	1.000	0.807	1.000	0.222	0.732	0.606	0.438	0.392	0.273	0.379
88	1.000	1.000	1.000	1.000	0.828	1.000	0.219	0.711	0.557	0.426	0.381	0.264	0.363
89	1.000	1.000	1.000	1.000	0.850	1.000	0.217	0.693	0.510	0.417	0.371	0.258	0.349
90	1.000	1.000	1.000	1.000	0.870	1.000	0.216	0.676	0.468	0.409	0.363	0.253	0.338
91	1.000	1.000	1.000	1.000	0.888	1.000	0.215	0.663	0.429	0.403	0.358	0.249	0.329
92	1.000	1.000	1.000	1.000	0.906	1.000	0.215	0.651	0.395	0.399	0.353	0.247	0.322
93	1.000	1.000	1.000	1.000	0.923	1.000	0.214	0.641	0.365	0.395	0.350	0.245	0.317
94	1.000	1.000	1.000	1.000	0.938	1.000	0.214	0.633	0.340	0.393	0.347	0.243	0.313
95	1.000	1.000	1.000	1.000	0.951	1.000	0.214	0.627	0.319	0.391	0.346	0.242	0.310
96	1.000	1.000	1.000	1.000	0.963	1.000	0.213	0.621	0.301	0.389	0.344	0.242	0.308
97	1.000	1.000	1.000	1.000	0.973	1.000	0.213	0.617	0.286	0.388	0.343	0.241	0.307
98	1.000	1.000	1.000	1.000	0.982	1.000	0.213	0.614	0.275	0.388	0.343	0.241	0.305
99	1.000	1.000	1.000	1.000	0.989	1.000	0.213	0.612	0.266	0.387	0.342	0.241	0.305
100	1.000	1.000	1.000	1.000	0.995	1.000	0.213	0.610	0.259	0.387	0.342	0.240	0.304
101	1.000	1.000	1.000	1.000	0.998	1.000	0.213	0.609	0.253	0.387	0.342	0.240	0.304
102	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.608	0.249	0.386	0.342	0.240	0.303
103	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.607	0.246	0.386	0.341	0.240	0.303
104	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.607	0.244	0.386	0.341	0.240	0.303
105	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.607	0.242	0.386	0.341	0.240	0.303
106	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.606	0.241	0.386	0.341	0.240	0.303
107	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.606	0.240	0.386	0.341	0.240	0.303
108	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.606	0.240	0.386	0.341	0.240	0.303
109	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.606	0.239	0.386	0.341	0.240	0.303
110	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.606	0.239	0.386	0.341	0.240	0.303
111	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.606	0.239	0.386	0.341	0.240	0.303
112	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.606	0.239	0.386	0.341	0.240	0.303
113	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.606	0.239	0.386	0.341	0.240	0.303
114	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.606	0.239	0.386	0.341	0.240	0.303
115	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.606	0.239	0.386	0.341	0.240	0.303
116	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.606	0.239	0.386	0.341	0.240	0.303
117	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.606	0.239	0.386	0.341	0.240	0.303
118	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.606	0.239	0.386	0.341	0.240	0.303
119	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.606	0.239	0.386	0.341	0.240	0.303
120	1.000	1.000	1.000	1.000	1.000	1.000	0.213	0.606	0.239	0.386	0.341	0.240	0.303

Table 2.19 (page 5 of 8)—Schedules of Pacific cod selectivity at length (cm) in the commercial fisheries as defined by parameter estimates. Years correspond to beginnings of blocks.

	May-July longline fishery						August-December longline fishery						
Len.	1977	1980	1985	1990	2000	2005	1977	1980	1985	1990	1995	2000	2005
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000
28	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000
29	0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.001	0.000	0.000	0.001	0.001	0.000
30	0.001	0.001	0.001	0.001	0.003	0.000	0.000	0.001	0.000	0.000	0.002	0.002	0.000
31	0.001	0.002	0.001	0.001	0.004	0.001	0.000	0.001	0.000	0.000	0.002	0.003	0.001
32	0.001	0.002	0.002	0.001	0.006	0.001	0.000	0.002	0.000	0.000	0.003	0.004	0.001
33	0.002	0.003	0.002	0.002	0.009	0.001	0.000	0.002	0.000	0.001	0.004	0.005	0.002
34	0.003	0.005	0.003	0.003	0.012	0.002	0.001	0.003	0.001	0.001	0.006	0.007	0.002
35	0.005	0.007	0.005	0.005	0.017	0.003	0.001	0.005	0.001	0.001	0.008	0.010	0.003
36	0.007	0.010	0.007	0.007	0.023	0.004	0.002	0.006	0.002	0.002	0.011	0.014	0.005
37	0.010	0.014	0.010	0.009	0.032	0.006	0.003	0.009	0.003	0.003	0.014	0.019	0.007
38	0.014	0.020	0.014	0.013	0.043	0.009	0.004	0.011	0.005	0.004	0.018	0.025	0.011
39	0.019	0.027	0.020	0.018	0.056	0.013	0.007	0.015	0.007	0.006	0.023	0.033	0.015
40	0.026	0.036	0.027	0.025	0.074	0.018	0.010	0.020	0.010	0.008	0.029	0.044	0.021
41	0.035	0.048	0.037	0.034	0.095	0.024	0.016	0.026	0.015	0.012	0.037	0.057	0.029
42	0.047	0.064	0.049	0.046	0.121	0.033	0.024	0.033	0.021	0.017	0.046	0.073	0.040
43	0.062	0.083	0.065	0.060	0.152	0.044	0.035	0.042	0.030	0.023	0.058	0.092	0.053
44	0.081	0.106	0.084	0.079	0.189	0.059	0.051	0.053	0.041	0.031	0.071	0.116	0.071
45	0.104	0.135	0.108	0.101	0.231	0.077	0.072	0.067	0.056	0.042	0.088	0.143	0.092
46	0.132	0.168	0.136	0.128	0.280	0.099	0.099	0.083	0.075	0.055	0.106	0.175	0.118
47	0.165	0.208	0.170	0.161	0.333	0.125	0.133	0.102	0.098	0.072	0.128	0.213	0.150
48	0.203	0.253	0.209	0.199	0.393	0.157	0.177	0.124	0.128	0.093	0.153	0.255	0.188
49	0.248	0.304	0.255	0.243	0.456	0.195	0.229	0.150	0.163	0.119	0.182	0.302	0.231
50	0.298	0.360	0.306	0.292	0.523	0.238	0.291	0.180	0.206	0.150	0.214	0.354	0.281
51	0.354	0.421	0.363	0.347	0.592	0.287	0.361	0.213	0.255	0.186	0.249	0.410	0.337
52	0.415	0.486	0.424	0.408	0.661	0.342	0.439	0.251	0.311	0.227	0.289	0.470	0.399
53	0.479	0.554	0.489	0.472	0.729	0.401	0.524	0.292	0.374	0.275	0.331	0.532	0.465
54	0.547	0.624	0.557	0.540	0.793	0.466	0.611	0.338	0.442	0.328	0.377	0.596	0.534
55	0.616	0.693	0.627	0.609	0.852	0.533	0.698	0.386	0.514	0.386	0.426	0.660	0.605
56	0.685	0.759	0.696	0.678	0.903	0.602	0.781	0.438	0.589	0.449	0.477	0.723	0.677
57	0.752	0.821	0.762	0.745	0.945	0.671	0.856	0.493	0.665	0.516	0.531	0.783	0.746
58	0.815	0.876	0.824	0.808	0.976	0.739	0.918	0.549	0.739	0.584	0.585	0.838	0.811
59	0.871	0.923	0.879	0.865	0.994	0.802	0.965	0.607	0.808	0.653	0.640	0.888	0.869
60	0.919	0.960	0.925	0.914	1.000	0.860	0.992	0.664	0.870	0.721	0.694	0.930	0.919

Table 2.19 (page 6 of 8)—Schedules of Pacific cod selectivity at length (cm) in the commercial fisheries as defined by parameter estimates. Years correspond to beginnings of blocks.

	May-July longline fishery						August-December longline fishery						
Len.	1977	1980	1985	1990	2000	2005	1977	1980	1985	1990	1995	2000	2005
61	0.957	0.986	0.962	0.953	1.000	0.910	1.000	0.720	0.922	0.786	0.746	0.963	0.958
62	0.984	0.998	0.986	0.981	1.000	0.950	1.000	0.774	0.962	0.845	0.796	0.986	0.985
63	0.998	1.000	0.999	0.997	1.000	0.979	1.000	0.825	0.988	0.897	0.843	0.998	0.998
64	1.000	1.000	1.000	1.000	1.000	0.996	1.000	0.871	1.000	0.940	0.885	1.000	1.000
65	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.911	1.000	0.972	0.921	1.000	1.000
66	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.945	1.000	0.992	0.952	1.000	1.000
67	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.971	1.000	1.000	0.975	1.000	1.000
68	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.989	1.000	1.000	0.991	1.000	1.000
69	1.000	1.000	1.000	1.000	1.000	1.000	0.994	0.999	1.000	1.000	0.999	1.000	1.000
70	1.000	1.000	1.000	1.000	1.000	1.000	0.976	1.000	1.000	1.000	1.000	1.000	1.000
71	1.000	1.000	1.000	1.000	1.000	1.000	0.947	1.000	1.000	1.000	1.000	0.999	1.000
72	1.000	1.000	1.000	1.000	1.000	1.000	0.908	1.000	0.997	1.000	1.000	0.991	1.000
73	1.000	1.000	1.000	1.000	1.000	1.000	0.861	1.000	0.989	1.000	1.000	0.976	1.000
74	1.000	1.000	1.000	1.000	1.000	1.000	0.807	1.000	0.975	1.000	1.000	0.954	1.000
75	1.000	1.000	1.000	1.000	1.000	1.000	0.748	1.000	0.957	0.999	1.000	0.927	1.000
76	1.000	1.000	1.000	1.000	1.000	1.000	0.686	1.000	0.935	0.997	1.000	0.895	1.000
77	1.000	1.000	1.000	1.000	1.000	1.000	0.622	0.996	0.910	0.995	1.000	0.859	1.000
78	1.000	1.000	1.000	1.000	1.000	1.000	0.559	0.988	0.883	0.992	1.000	0.821	1.000
79	1.000	1.000	1.000	1.000	1.000	1.000	0.497	0.976	0.853	0.988	1.000	0.782	1.000
80	1.000	1.000	1.000	1.000	1.000	1.000	0.439	0.961	0.824	0.984	1.000	0.742	1.000
81	1.000	1.000	1.000	1.000	1.000	1.000	0.384	0.942	0.794	0.980	1.000	0.703	1.000
82	1.000	1.000	1.000	1.000	1.000	1.000	0.334	0.921	0.765	0.976	1.000	0.665	1.000
83	1.000	1.000	1.000	1.000	1.000	1.000	0.290	0.898	0.738	0.971	1.000	0.630	1.000
84	1.000	1.000	1.000	1.000	1.000	1.000	0.250	0.874	0.712	0.967	1.000	0.597	1.000
85	1.000	1.000	1.000	1.000	1.000	1.000	0.216	0.850	0.689	0.962	1.000	0.568	1.000
86	1.000	1.000	1.000	1.000	1.000	1.000	0.187	0.825	0.668	0.958	1.000	0.542	1.000
87	1.000	1.000	1.000	1.000	1.000	1.000	0.162	0.802	0.649	0.955	1.000	0.519	1.000
88	1.000	1.000	1.000	1.000	1.000	1.000	0.142	0.780	0.633	0.951	1.000	0.499	1.000
89	1.000	1.000	1.000	1.000	1.000	1.000	0.125	0.760	0.620	0.948	1.000	0.483	1.000
90	1.000	1.000	1.000	1.000	1.000	1.000	0.112	0.741	0.608	0.946	1.000	0.469	1.000
91	1.000	1.000	1.000	1.000	1.000	1.000	0.102	0.725	0.599	0.943	1.000	0.457	1.000
92	1.000	1.000	1.000	1.000	1.000	1.000	0.094	0.710	0.591	0.941	1.000	0.448	1.000
93	1.000	1.000	1.000	1.000	1.000	1.000	0.088	0.697	0.585	0.940	1.000	0.441	1.000
94	1.000	1.000	1.000	1.000	1.000	1.000	0.083	0.687	0.580	0.938	1.000	0.435	1.000
95	1.000	1.000	1.000	1.000	1.000	1.000	0.079	0.678	0.576	0.937	1.000	0.431	1.000
96	1.000	1.000	1.000	1.000	1.000	1.000	0.077	0.670	0.573	0.936	1.000	0.428	1.000
97	1.000	1.000	1.000	1.000	1.000	1.000	0.075	0.664	0.571	0.936	1.000	0.425	1.000
98	1.000	1.000	1.000	1.000	1.000	1.000	0.074	0.660	0.569	0.935	1.000	0.423	1.000
99	1.000	1.000	1.000	1.000	1.000	1.000	0.073	0.656	0.568	0.935	1.000	0.422	1.000
100	1.000	1.000	1.000	1.000	1.000	1.000	0.072	0.653	0.567	0.935	1.000	0.421	1.000
101	1.000	1.000	1.000	1.000	1.000	1.000	0.072	0.651	0.566	0.934	1.000	0.420	1.000
102	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.649	0.566	0.934	1.000	0.420	1.000
103	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.648	0.566	0.934	1.000	0.419	1.000
104	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.647	0.566	0.934	1.000	0.419	1.000
105	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.646	0.565	0.934	1.000	0.419	1.000
106	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.646	0.565	0.934	1.000	0.419	1.000
107	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.645	0.565	0.934	1.000	0.419	1.000
108	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.645	0.565	0.934	1.000	0.419	1.000
109	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.645	0.565	0.934	1.000	0.419	1.000
110	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.645	0.565	0.934	1.000	0.419	1.000
111	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.645	0.565	0.934	1.000	0.419	1.000
112	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.645	0.565	0.934	1.000	0.419	1.000
113	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.645	0.565	0.934	1.000	0.419	1.000
114	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.645	0.565	0.934	1.000	0.419	1.000
115	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.645	0.565	0.934	1.000	0.419	1.000
116	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.645	0.565	0.934	1.000	0.419	1.000
117	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.645	0.565	0.934	1.000	0.419	1.000
118	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.645	0.565	0.934	1.000	0.419	1.000
119	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.645	0.565	0.934	1.000	0.419	1.000
120	1.000	1.000	1.000	1.000	1.000	1.000	0.071	0.645	0.565	0.934	1.000	0.419	1.000

Table 2.19 (page 7 of 8)—Schedules of Pacific cod selectivity at length (cm) in the commercial fisheries as defined by parameter estimates. Years correspond to beginnings of blocks.

	January-April pot fishery				May-July pot		Sep-Dec pot	
Len.	1977	1995	2000	2005	1977	1995	1977	2000
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
31	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
32	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
33	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
34	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000
35	0.000	0.001	0.001	0.000	0.001	0.001	0.002	0.000
36	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.000
37	0.001	0.001	0.002	0.001	0.001	0.002	0.004	0.001
38	0.002	0.002	0.002	0.002	0.002	0.003	0.006	0.001
39	0.003	0.003	0.003	0.002	0.003	0.005	0.008	0.002
40	0.004	0.004	0.005	0.003	0.005	0.007	0.011	0.003
41	0.006	0.006	0.007	0.005	0.007	0.011	0.015	0.005
42	0.008	0.009	0.010	0.007	0.010	0.015	0.020	0.008
43	0.012	0.013	0.015	0.010	0.014	0.022	0.027	0.013
44	0.016	0.018	0.020	0.015	0.020	0.030	0.036	0.020
45	0.023	0.025	0.028	0.020	0.027	0.041	0.046	0.031
46	0.031	0.034	0.038	0.028	0.037	0.055	0.060	0.045
47	0.042	0.046	0.050	0.038	0.051	0.073	0.076	0.065
48	0.056	0.060	0.066	0.050	0.067	0.095	0.097	0.092
49	0.073	0.079	0.086	0.066	0.088	0.123	0.121	0.126
50	0.095	0.102	0.111	0.086	0.114	0.156	0.149	0.170
51	0.121	0.129	0.140	0.111	0.146	0.196	0.182	0.223
52	0.152	0.162	0.175	0.140	0.183	0.242	0.220	0.286
53	0.189	0.201	0.216	0.175	0.227	0.294	0.263	0.359
54	0.232	0.246	0.263	0.216	0.278	0.352	0.310	0.441
55	0.281	0.296	0.315	0.263	0.334	0.416	0.363	0.528
56	0.335	0.352	0.373	0.315	0.397	0.484	0.419	0.619
57	0.395	0.414	0.436	0.374	0.464	0.556	0.479	0.710
58	0.459	0.479	0.503	0.436	0.535	0.629	0.541	0.795
59	0.527	0.548	0.572	0.503	0.607	0.701	0.605	0.871
60	0.597	0.618	0.642	0.572	0.680	0.770	0.669	0.932

Table 2.19 (page 8 of 8)—Schedules of Pacific cod selectivity at length (cm) in the commercial fisheries as defined by parameter estimates. Years correspond to beginnings of blocks.

	January-April pot fishery				May-July pot		Sep-Dec pot	
Len.	1977	1995	2000	2005	1977	1995	1977	2000
61	0.667	0.687	0.711	0.642	0.750	0.834	0.731	0.975
62	0.735	0.754	0.777	0.711	0.816	0.891	0.790	0.997
63	0.799	0.817	0.838	0.777	0.875	0.937	0.845	1.000
64	0.858	0.874	0.892	0.838	0.924	0.971	0.893	1.000
65	0.909	0.922	0.936	0.892	0.963	0.993	0.934	1.000
66	0.949	0.959	0.970	0.936	0.988	1.000	0.966	1.000
67	0.979	0.985	0.991	0.970	0.999	1.000	0.987	1.000
68	0.996	0.998	1.000	0.991	1.000	1.000	0.999	1.000
69	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
70	1.000	0.998	0.994	1.000	1.000	1.000	1.000	1.000
71	0.992	0.985	0.974	0.996	1.000	1.000	1.000	1.000
72	0.975	0.960	0.941	0.982	1.000	1.000	1.000	1.000
73	0.948	0.924	0.896	0.958	1.000	1.000	1.000	1.000
74	0.915	0.880	0.844	0.926	1.000	1.000	1.000	1.000
75	0.877	0.831	0.786	0.888	1.000	1.000	1.000	1.000
76	0.836	0.780	0.726	0.847	1.000	1.000	1.000	1.000
77	0.794	0.728	0.668	0.804	1.000	1.000	1.000	1.000
78	0.754	0.679	0.613	0.763	1.000	1.000	1.000	1.000
79	0.716	0.634	0.563	0.723	1.000	1.000	1.000	1.000
80	0.683	0.594	0.520	0.688	1.000	1.000	1.000	1.000
81	0.654	0.559	0.483	0.657	1.000	1.000	1.000	1.000
82	0.630	0.531	0.453	0.630	1.000	1.000	1.000	1.000
83	0.611	0.508	0.429	0.609	1.000	1.000	1.000	1.000
84	0.595	0.491	0.410	0.592	1.000	1.000	1.000	1.000
85	0.584	0.477	0.396	0.578	1.000	1.000	1.000	1.000
86	0.575	0.467	0.386	0.569	1.000	1.000	1.000	1.000
87	0.569	0.460	0.379	0.561	1.000	1.000	1.000	1.000
88	0.564	0.455	0.374	0.556	1.000	1.000	1.000	1.000
89	0.561	0.452	0.371	0.553	1.000	1.000	1.000	1.000
90	0.559	0.450	0.369	0.550	1.000	1.000	1.000	1.000
91	0.558	0.448	0.367	0.549	1.000	1.000	1.000	1.000
92	0.557	0.448	0.367	0.548	1.000	1.000	1.000	1.000
93	0.557	0.447	0.366	0.547	1.000	1.000	1.000	1.000
94	0.556	0.447	0.366	0.547	1.000	1.000	1.000	1.000
95	0.556	0.447	0.366	0.547	1.000	1.000	1.000	1.000
96	0.556	0.446	0.366	0.547	1.000	1.000	1.000	1.000
97	0.556	0.446	0.366	0.546	1.000	1.000	1.000	1.000
98	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
99	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
100	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
101	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
102	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
103	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
104	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
105	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
106	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
107	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
108	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
109	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
110	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
111	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
112	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
113	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
114	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
115	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
116	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
117	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
118	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
119	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000
120	0.556	0.446	0.365	0.546	1.000	1.000	1.000	1.000

Table 2.20—Schedules of Pacific cod selectivity at age in the bottom trawl survey as defined by final parameter estimates.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1982	0.000	0.318	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1983	0.000	0.375	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1984	0.000	0.231	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1985	0.000	0.497	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1986	0.000	0.342	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1987	0.000	0.591	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1988	0.000	0.238	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1989	0.000	0.130	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1990	0.000	0.392	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1991	0.000	0.355	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1992	0.000	0.725	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1993	0.000	0.645	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1994	0.000	0.358	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1995	0.000	0.205	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1996	0.000	0.144	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1997	0.000	0.287	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1998	0.000	0.251	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1999	0.000	0.241	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
2000	0.000	0.372	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
2001	0.000	0.859	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
2002	0.000	0.436	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
2003	0.000	0.501	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
2004	0.000	0.443	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
2005	0.000	0.628	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
2006	0.000	0.855	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
2007	0.000	0.893	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
2008	0.000	0.785	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
2009	0.000	0.492	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
2010	0.000	0.375	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
2011	0.000	0.588	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
2012	0.000	0.574	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
2013	0.000	0.451	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242
2014	0.000	0.451	1.000	1.000	0.975	0.863	0.701	0.538	0.408	0.323	0.277	0.255	0.246	0.243	0.242	0.242	0.242	0.242	0.242	0.242	0.242

Table 2.21—Schedules of population length (cm) and weight (kg) by season and age as defined by final parameter estimates. Sea1=Jan-Feb, Sea2=Mar-Apr, Sea3=May-Jul, Sea4=Aug-Oct, Sea5=Nov=Dec. Lengths and weights correspond to season mid-points.

	Population length (cm)					Population weight (kg)				
Age	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5
1	9.35	10.96	12.97	16.49	20.19	0.01	0.02	0.03	0.05	0.10
2	23.02	25.74	28.99	32.69	35.60	0.15	0.20	0.28	0.41	0.55
3	37.82	39.96	42.52	45.42	47.71	0.68	0.77	0.90	1.15	1.38
4	49.46	51.15	53.16	55.44	57.24	1.57	1.66	1.81	2.13	2.43
5	58.62	59.94	61.52	63.32	64.74	2.67	2.72	2.85	3.23	3.58
6	65.82	66.86	68.10	69.52	70.63	3.84	3.82	3.91	4.32	4.71
7	71.48	72.30	73.28	74.39	75.26	4.98	4.89	4.91	5.35	5.75
8	75.93	76.58	77.35	78.22	78.91	6.02	5.85	5.82	6.26	6.67
9	79.44	79.94	80.55	81.24	81.78	6.94	6.69	6.60	7.05	7.46
10	82.19	82.59	83.07	83.61	84.03	7.73	7.41	7.27	7.71	8.13
11	84.36	84.67	85.05	85.47	85.81	8.39	8.01	7.82	8.26	8.68
12	86.06	86.31	86.60	86.94	87.20	8.94	8.51	8.28	8.71	9.14
13	87.40	87.60	87.83	88.09	88.30	9.38	8.91	8.65	9.08	9.50
14	88.46	88.61	88.79	89.00	89.16	9.75	9.24	8.95	9.38	9.80
15	89.29	89.41	89.55	89.71	89.84	10.04	9.50	9.19	9.62	10.03
16	89.94	90.03	90.15	90.27	90.37	10.27	9.71	9.38	9.80	10.22
17	90.45	90.53	90.61	90.71	90.79	10.45	9.88	9.53	9.96	10.37
18	90.85	90.91	90.98	91.06	91.12	10.60	10.01	9.65	10.08	10.49
19	91.17	91.22	91.27	91.33	91.38	10.72	10.12	9.75	10.17	10.59
20	91.61	91.64	91.68	91.72	91.75	10.88	10.27	9.89	10.31	10.72

Table 2.22—Schedules of fleet-specific length (cm) by season and age as defined by final parameter estimates. Sea1=Jan-Feb, Sea2=Mar-Apr, Sea3=May-Jul, Sea4=Aug-Oct, Sea5=Nov=Dec.

	Trawl fishery					Longline fishery					Pot fishery					Survey
Age	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5	
1	13.31	14.82	16.72	21.67	25.56	15.72	17.17	20.21	24.13	28.20	12.16	15.67	20.40	24.92	31.49	12.97
2	27.47	30.38	33.04	37.74	40.35	29.77	32.64	37.16	40.77	43.42	32.03	34.93	38.11	43.62	46.04	28.99
3	42.88	45.02	45.54	48.53	50.34	44.54	46.49	49.42	51.58	53.32	46.76	48.67	50.30	53.24	54.74	42.52
4	54.15	55.71	54.57	56.59	58.14	54.59	55.93	57.57	58.93	60.23	56.45	57.71	58.31	59.62	60.80	53.16
5	62.39	63.54	61.98	63.64	64.98	61.58	62.54	63.73	64.88	66.04	62.98	63.87	64.25	65.12	66.23	61.52
6	68.52	69.40	68.24	69.60	70.70	66.69	67.41	69.08	70.16	71.16	67.76	68.46	69.38	70.24	71.23	68.10
7	73.28	73.98	73.32	74.42	75.29	70.62	71.19	73.71	74.66	75.50	71.64	72.23	73.87	74.69	75.52	73.28
8	77.12	77.68	77.36	78.23	78.92	73.81	74.29	77.55	78.35	79.02	75.02	75.54	77.64	78.36	79.03	77.35
9	80.23	80.69	80.56	81.24	81.78	76.51	76.92	80.66	81.31	81.84	77.99	78.45	80.71	81.31	81.84	80.55
10	82.75	83.12	83.07	83.61	84.04	78.83	79.18	83.13	83.65	84.07	80.56	80.94	83.16	83.65	84.07	83.07
11	84.77	85.06	85.05	85.47	85.81	80.80	81.10	85.09	85.50	85.83	82.70	83.02	85.11	85.50	85.83	85.05
12	86.38	86.62	86.60	86.94	87.20	82.45	82.69	86.63	86.96	87.22	84.46	84.72	86.65	86.96	87.22	86.60
13	87.66	87.85	87.83	88.09	88.30	83.81	84.01	87.85	88.11	88.31	85.87	86.08	87.86	88.11	88.31	87.83
14	88.68	88.82	88.79	89.00	89.16	84.91	85.07	88.81	89.01	89.17	87.00	87.16	88.82	89.01	89.17	88.79
15	89.48	89.59	89.55	89.71	89.84	85.80	85.93	89.56	89.72	89.85	87.89	88.02	89.57	89.72	89.85	89.55
16	90.11	90.20	90.14	90.27	90.37	86.51	86.62	90.16	90.28	90.38	88.60	88.70	90.16	90.28	90.38	90.14
17	90.61	90.68	90.61	90.71	90.79	87.08	87.16	90.62	90.72	90.80	89.15	89.24	90.63	90.72	90.80	90.61
18	91.00	91.06	90.98	91.06	91.12	87.53	87.59	90.99	91.06	91.13	89.59	89.66	91.00	91.06	91.13	90.98
19	91.31	91.35	91.27	91.33	91.38	87.88	87.94	91.28	91.34	91.39	89.94	89.99	91.28	91.34	91.39	91.27
20	91.74	91.77	91.67	91.71	91.74	88.38	88.38	91.68	91.72	91.75	90.42	90.44	91.69	91.72	91.75	91.67

Table 2.23—Schedules of fleet-specific weight (kg) by season and age as defined by final parameter estimates. Sea1=Jan-Feb, Sea2=Mar-Apr, Sea3=May-Jul, Sea4=Aug-Oct, Sea5=Nov=Dec.

	Trawl fishery					Longline fishery					Pot fishery					Survey
Age	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5	
1	0.03	0.04	0.05	0.11	0.19	0.05	0.06	0.09	0.16	0.26	0.03	0.05	0.10	0.19	0.36	0.03
2	0.25	0.32	0.41	0.63	0.80	0.31	0.40	0.58	0.80	1.00	0.39	0.49	0.63	0.98	1.19	0.28
3	0.99	1.10	1.10	1.38	1.60	1.10	1.21	1.41	1.66	1.91	1.28	1.38	1.49	1.83	2.06	0.90
4	2.05	2.13	1.94	2.25	2.53	2.09	2.15	2.27	2.53	2.81	2.32	2.36	2.36	2.62	2.88	1.81
5	3.21	3.22	2.90	3.27	3.61	3.06	3.05	3.14	3.45	3.77	3.27	3.25	3.21	3.48	3.80	2.85
6	4.31	4.25	3.93	4.34	4.72	3.94	3.87	4.06	4.43	4.80	4.14	4.05	4.10	4.44	4.81	3.91
7	5.34	5.20	4.92	5.35	5.75	4.73	4.60	4.98	5.39	5.79	4.95	4.81	5.01	5.40	5.80	4.91
8	6.28	6.08	5.82	6.26	6.67	5.46	5.28	5.85	6.28	6.69	5.75	5.57	5.87	6.28	6.70	5.82
9	7.13	6.86	6.60	7.05	7.47	6.14	5.91	6.62	7.06	7.48	6.54	6.30	6.63	7.06	7.48	6.60
10	7.87	7.53	7.27	7.71	8.13	6.77	6.49	7.28	7.72	8.14	7.26	6.97	7.28	7.72	8.14	7.27
11	8.50	8.11	7.82	8.26	8.68	7.34	7.02	7.83	8.27	8.69	7.90	7.56	7.83	8.27	8.69	7.82
12	9.02	8.58	8.28	8.71	9.14	7.84	7.48	8.28	8.72	9.14	8.46	8.06	8.29	8.72	9.14	8.28
13	9.45	8.98	8.65	9.08	9.50	8.27	7.87	8.65	9.09	9.51	8.92	8.48	8.65	9.09	9.51	8.65
14	9.80	9.29	8.95	9.38	9.80	8.63	8.19	8.95	9.38	9.80	9.29	8.82	8.95	9.38	9.80	8.95
15	10.09	9.55	9.19	9.62	10.03	8.93	8.46	9.19	9.62	10.04	9.60	9.10	9.19	9.62	10.04	9.19
16	10.32	9.76	9.38	9.80	10.22	9.17	8.68	9.38	9.81	10.22	9.85	9.32	9.38	9.81	10.22	9.38
17	10.50	9.92	9.53	9.96	10.37	9.36	8.86	9.53	9.96	10.37	10.04	9.50	9.53	9.96	10.37	9.53
18	10.64	10.05	9.65	10.08	10.49	9.52	9.00	9.65	10.08	10.49	10.20	9.64	9.66	10.08	10.49	9.65
19	10.76	10.16	9.75	10.17	10.59	9.64	9.11	9.75	10.17	10.59	10.32	9.75	9.75	10.17	10.59	9.75
20	10.92	10.31	9.89	10.31	10.72	9.82	9.26	9.89	10.31	10.72	10.50	9.91	9.89	10.31	10.72	9.89

Table 2.24—Time series of EBS Pacific cod age 0+ biomass, age 3+ biomass, female spawning biomass (t), and standard deviation of spawning biomass ("SB SD") as estimated last year and this year under Model 1. Spawning biomasses listed for 2014 under last year's assessment and for 2015 under this year's assessment represent output from the standard projection model.

	Last year's assessment				This year's assessment			
Year	Age 0+	Age 3+	Spawn.	SB SD	Age 0+	Age 3+	Spawn.	SB SD
1977	561,621	553,541	157,153	31,383	591,789	583,189	166,807	32,473
1978	640,257	592,564	174,035	31,397	673,991	623,433	184,303	32,478
1979	810,988	692,685	201,152	32,341	851,180	731,198	212,668	33,417
1980	1,183,740	1,130,020	255,387	34,626	1,228,590	1,174,450	268,722	35,685
1981	1,608,760	1,548,960	359,542	38,170	1,654,360	1,593,140	374,761	39,140
1982	1,955,710	1,934,700	508,370	42,465	1,999,880	1,978,410	524,665	43,215
1983	2,134,940	2,115,170	650,040	44,805	2,176,460	2,156,140	666,225	45,293
1984	2,148,120	2,067,770	723,255	43,170	2,186,380	2,105,700	738,585	43,458
1985	2,129,910	2,106,260	719,565	38,729	2,163,030	2,138,880	733,640	38,886
1986	2,083,990	2,017,450	683,920	33,575	2,111,450	2,044,680	696,235	33,637
1987	2,069,030	2,040,920	660,835	29,068	2,090,360	2,061,760	670,945	29,050
1988	2,001,880	1,988,210	641,025	25,488	2,018,010	2,003,880	648,850	25,404
1989	1,803,710	1,792,190	603,990	22,529	1,816,540	1,804,590	609,820	22,403
1990	1,573,900	1,545,290	556,575	19,836	1,585,510	1,556,390	561,175	19,696
1991	1,374,340	1,320,330	480,137	17,063	1,385,830	1,331,370	484,294	16,935
1992	1,239,610	1,196,890	386,565	14,486	1,250,330	1,207,410	390,653	14,374
1993	1,231,310	1,204,240	338,645	12,666	1,240,290	1,212,580	342,483	12,567
1994	1,280,210	1,223,720	352,954	11,953	1,287,640	1,231,000	356,239	11,843
1995	1,310,130	1,288,940	356,898	11,957	1,315,290	1,293,960	359,402	11,818
1996	1,253,840	1,230,630	351,617	12,139	1,256,420	1,233,180	353,375	11,964
1997	1,174,940	1,146,330	341,393	12,116	1,175,170	1,146,310	342,350	11,904
1998	1,074,320	1,014,680	313,668	11,846	1,072,210	1,013,230	313,764	11,599
1999	1,102,280	1,077,070	299,245	11,502	1,096,100	1,070,880	298,490	11,218
2000	1,146,980	1,119,580	300,649	11,288	1,136,280	1,109,280	298,729	10,955
2001	1,169,800	1,121,990	330,058	11,228	1,154,260	1,107,370	326,584	10,829
2002	1,200,930	1,172,400	338,679	10,851	1,179,400	1,151,480	333,423	10,393
2003	1,185,320	1,170,620	332,244	10,158	1,157,830	1,143,210	326,080	9,653
2004	1,108,780	1,085,570	323,303	9,468	1,080,000	1,057,220	315,006	8,904
2005	994,247	975,421	293,807	8,905	962,376	944,101	283,523	8,285
2006	872,160	855,239	252,761	8,370	838,791	822,381	241,555	7,719
2007	769,195	745,362	218,450	7,846	734,535	711,516	206,900	7,177
2008	738,561	674,191	193,596	7,508	700,463	639,210	181,597	6,808
2009	808,198	780,237	180,024	7,605	761,111	733,346	166,996	6,820
2010	940,591	847,845	195,078	8,612	886,635	791,937	179,755	7,611
2011	1,163,810	1,146,670	246,167	11,188	1,110,430	1,091,380	227,899	9,756
2012	1,232,570	1,169,120	344,516	19,306	1,249,320	1,186,650	270,608	13,301
2013	1,347,910	1,264,450	316,266	20,736	1,373,860	1,286,090	321,496	18,086
2014	1,570,580	1,545,070	360,956	23,324	1,537,190	1,497,620	364,513	23,729
2015					1,678,010	1,594,630	409,446	28,093

Table 2.25—Time series of EBS Pacific cod age 0 recruitment (1000s of fish), with standard deviations, as estimated last year and this year under Model 1.

	Last year's values		This year's values	
Year	Recruits	Std. dev.	Recruits	Std. dev.
1977	1,767,430	196,764	1,776,400	197,362
1978	743,958	159,596	740,864	157,782
1979	900,256	98,659	913,365	97,721
1980	308,752	42,735	312,227	42,580
1981	180,686	27,113	186,390	27,473
1982	1,225,390	49,555	1,218,590	49,129
1983	265,226	31,477	269,779	31,121
1984	994,261	43,759	987,710	43,239
1985	417,784	30,607	420,795	30,302
1986	198,317	19,072	203,096	19,072
1987	141,601	15,750	146,013	15,693
1988	365,429	21,053	368,834	20,985
1989	776,481	31,931	775,657	31,615
1990	631,381	28,870	627,593	28,343
1991	333,648	21,232	339,745	21,109
1992	849,853	27,220	844,141	26,769
1993	296,575	17,591	295,784	17,305
1994	325,136	16,665	321,890	16,327
1995	353,081	19,679	354,252	19,292
1996	892,906	29,009	874,354	27,935
1997	356,171	18,279	353,606	17,742
1998	354,175	17,206	345,764	16,613
1999	701,237	21,312	681,454	20,277
2000	424,510	15,137	411,301	14,386
2001	194,385	11,269	191,772	10,829
2002	333,977	13,088	324,762	12,418
2003	268,995	13,026	258,661	12,225
2004	235,688	12,624	226,348	11,753
2005	270,182	14,125	259,582	13,073
2006	973,726	35,471	917,211	31,230
2007	287,293	19,704	278,036	18,500
2008	1,427,530	70,863	1,441,320	62,674
2009	177,938	24,410	207,181	24,276
2010	857,525	66,895	831,528	54,924
2011	1,265,700	110,346	1,305,490	95,353
2012	342,104	64,450	482,541	58,491
2013			1,230,400	188,607
Average	567,758		587,147	

Table 2.26—Numbers (1000s) at age at time of spawning (March) as estimated by Model 1.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1977	1776400	423634	35736	190691	43021	28978	18979	12251	7863	5036	3223	2062	1319	843	539	345	220	141	90	58	102
1978	740864	1264370	301400	25243	131358	28859	19199	12543	8104	5209	3341	2140	1370	876	561	359	229	147	94	60	106
1979	913365	527319	899591	212876	17364	87870	19053	12641	8265	5349	3443	2210	1416	907	581	371	238	152	97	62	110
1980	312227	650100	375217	636811	147927	11823	59228	12812	8504	5566	3605	2322	1491	956	612	392	251	161	103	66	117
1981	186390	222233	462593	266016	446450	102368	8103	40390	8717	5781	3783	2450	1578	1014	650	416	267	171	109	70	124
1982	1218590	132666	158124	327778	186301	308768	70144	5523	27452	5917	3922	2566	1661	1070	687	441	282	181	116	74	131
1983	269779	867350	94395	112020	229523	129023	212267	48027	3774	18742	4038	2676	1750	1133	730	469	301	193	123	79	140
1984	987710	192019	617085	66779	78040	157580	87720	143552	32398	2543	12621	2719	1801	1178	763	491	316	202	130	83	147
1985	420795	702995	136586	436090	46318	53002	105384	58186	94894	21392	1679	8333	1795	1190	778	504	325	209	134	86	152
1986	203096	299496	500060	96538	301979	31286	35155	69204	38039	61935	13957	1095	5439	1172	777	508	329	212	136	87	156
1987	146013	144551	213029	353286	66775	203737	20724	23048	45159	24779	40329	9089	714	3544	764	507	331	215	138	89	158
1988	368834	103918	102776	150250	243308	44594	132972	13359	14779	28903	15855	25811	5819	457	2271	490	325	213	138	89	159
1989	775657	262498	73865	72190	102164	160011	28587	83833	8342	9180	17904	9805	15948	3593	282	1401	302	200	131	85	153
1990	627593	552082	186701	51984	49165	67240	102929	18162	52946	5255	5776	11259	6165	10026	2259	177	881	190	126	82	149
1991	339745	446696	392786	132007	35674	32082	42364	63950	11241	32753	3252	3576	6974	3820	6214	1400	110	546	118	78	144
1992	844141	241818	317812	277550	89651	22439	19041	24563	36873	6483	18918	1881	2071	4043	2216	3606	813	64	317	68	129
1993	295784	600825	172042	224504	188299	56032	13166	10918	14049	21164	3736	10941	1091	1203	2351	1290	2101	474	37	185	115
1994	321890	210529	427546	121880	154860	123209	35165	8139	6747	8716	13184	2335	6853	684	756	1478	811	1322	298	23	189
1995	354252	229107	149770	301812	82597	96973	72407	20160	4653	3872	5025	7630	1355	3986	399	441	863	474	772	174	124
1996	874354	252142	163003	105861	205022	51582	56216	40552	11189	2582	2154	2800	4258	757	2228	223	247	483	265	432	167
1997	353606	622327	179385	115152	71734	127435	29746	31363	22467	6212	1439	1204	1569	2389	425	1252	125	139	272	149	338
1998	345764	251683	442793	126760	77704	43961	71994	16223	16978	12186	3381	786	659	860	1311	234	689	69	76	150	268
1999	681454	246101	179070	312882	85949	48716	25900	41343	9270	9719	6996	1946	453	380	497	758	135	398	40	44	242
2000	411301	485035	175119	126494	211635	53680	28638	14906	23791	5365	5657	4089	1141	266	224	293	447	80	235	24	169
2001	191772	292751	345188	123941	86352	136573	33448	17672	9226	14818	3361	3560	2582	722	169	142	186	284	51	150	123
2002	324762	136497	208330	243588	82992	53419	80726	19625	10472	5537	8988	2055	2189	1594	447	105	88	116	177	32	170
2003	258661	231155	97131	146846	161973	50550	30935	46331	11372	6147	3286	5378	1237	1323	966	272	64	54	71	108	123
2004	226348	184106	164482	68417	97263	97941	29101	17686	26764	6656	3637	1960	3226	745	799	585	165	39	33	43	140
2005	259582	161107	131021	116035	45183	57593	54248	15866	9722	14914	3754	2071	1124	1859	431	463	340	96	23	19	107
2006	917211	184762	114659	92587	77046	26757	31609	29014	8473	5222	8063	2040	1130	615	1020	237	255	187	53	12	70
2007	278036	652843	131497	81048	61550	45646	14684	16928	15547	4575	2842	4415	1123	624	340	565	131	142	104	29	46
2008	1441320	197897	464625	92863	53638	36287	24975	7844	9041	8359	2478	1548	2415	616	343	188	312	73	78	58	42
2009	207181	1025890	140843	327819	60683	30535	18958	12743	4018	4681	4372	1306	821	1286	329	184	101	167	39	42	53
2010	831528	147465	730119	99407	215111	34936	16151	9754	6551	2080	2441	2293	688	434	682	175	98	54	89	21	51
2011	1305490	591856	104951	516404	66700	131160	19980	9024	5431	3658	1166	1373	1293	389	245	386	99	55	30	51	41
2012	482541	929208	421213	74153	342601	38863	69072	10088	4519	2730	1850	593	701	663	200	126	199	51	29	16	47
2013	1230400	343458	661317	297973	49770	206806	21659	37312	5424	2440	1483	1010	325	385	365	110	70	110	28	16	35
2014	551811	875761	244442	467892	200560	30485	118304	12066	20701	3020	1365	832	569	183	218	206	62	40	62	16	29

Table 2.27—Model 1 estimates of "effective" fishing mortality (= -ln($N_{a+1,t+1}/N_{a,t}$)-M) at age and year.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1977	0.000	0.005	0.026	0.053	0.068	0.072	0.071	0.070	0.069	0.068	0.067	0.066	0.066	0.066	0.066	0.066	0.065	0.065	0.065
1978	0.000	0.006	0.030	0.061	0.078	0.082	0.082	0.080	0.079	0.078	0.077	0.077	0.076	0.076	0.076	0.076	0.076	0.076	0.076
1979	0.000	0.004	0.021	0.042	0.054	0.058	0.057	0.056	0.055	0.054	0.054	0.054	0.053	0.053	0.053	0.053	0.053	0.053	0.053
1980	0.000	0.003	0.014	0.029	0.041	0.048	0.050	0.051	0.052	0.052	0.052	0.052	0.052	0.052	0.051	0.051	0.051	0.051	0.051
1981	0.000	0.004	0.014	0.027	0.037	0.043	0.046	0.048	0.048	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049
1982	0.000	0.003	0.013	0.023	0.030	0.035	0.037	0.038	0.038	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
1983	0.000	0.005	0.018	0.032	0.043	0.049	0.052	0.053	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
1984	0.000	0.005	0.022	0.042	0.057	0.066	0.069	0.070	0.071	0.071	0.071	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070
1985	0.000	0.005	0.023	0.047	0.067	0.078	0.084	0.086	0.086	0.086	0.086	0.086	0.085	0.085	0.085	0.085	0.085	0.085	0.084
1986	0.000	0.005	0.023	0.046	0.065	0.076	0.081	0.084	0.085	0.085	0.085	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084
1987	0.000	0.005	0.023	0.050	0.074	0.088	0.094	0.096	0.096	0.095	0.094	0.094	0.093	0.093	0.092	0.092	0.092	0.092	0.091
1988	0.001	0.009	0.037	0.069	0.097	0.116	0.127	0.133	0.136	0.138	0.139	0.139	0.140	0.140	0.140	0.140	0.140	0.140	0.141
1989	0.000	0.008	0.035	0.067	0.094	0.111	0.120	0.124	0.126	0.127	0.127	0.127	0.128	0.128	0.128	0.128	0.128	0.128	0.128
1990	0.000	0.003	0.024	0.072	0.112	0.129	0.135	0.136	0.136	0.136	0.136	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135
1991	0.000	0.003	0.034	0.107	0.170	0.199	0.207	0.208	0.208	0.206	0.205	0.205	0.204	0.204	0.203	0.203	0.203	0.203	0.203
1992	0.000	0.002	0.027	0.099	0.167	0.196	0.202	0.200	0.196	0.193	0.191	0.189	0.188	0.187	0.187	0.186	0.186	0.185	0.185
1993	0.000	0.002	0.021	0.077	0.135	0.161	0.164	0.160	0.156	0.152	0.149	0.147	0.145	0.144	0.143	0.143	0.142	0.142	0.142
1994	0.000	0.003	0.026	0.093	0.160	0.191	0.196	0.192	0.188	0.184	0.181	0.179	0.177	0.176	0.175	0.175	0.174	0.174	0.173
1995	0.000	0.003	0.031	0.114	0.203	0.249	0.263	0.263	0.261	0.258	0.256	0.255	0.254	0.253	0.253	0.253	0.253	0.252	0.252
1996	0.000	0.003	0.028	0.107	0.192	0.233	0.244	0.242	0.238	0.235	0.232	0.231	0.229	0.228	0.228	0.227	0.227	0.227	0.226
1997	0.000	0.003	0.035	0.128	0.223	0.270	0.282	0.281	0.277	0.273	0.271	0.269	0.267	0.266	0.266	0.265	0.265	0.265	0.264
1998	0.000	0.002	0.026	0.095	0.168	0.204	0.213	0.212	0.209	0.206	0.204	0.203	0.202	0.201	0.201	0.200	0.200	0.200	0.200
1999	0.000	0.002	0.023	0.092	0.167	0.202	0.208	0.204	0.199	0.194	0.190	0.188	0.186	0.185	0.184	0.183	0.183	0.183	0.182
2000	0.000	0.003	0.033	0.103	0.166	0.190	0.189	0.179	0.170	0.162	0.157	0.153	0.151	0.149	0.147	0.146	0.145	0.145	0.144
2001	0.000	0.003	0.035	0.103	0.154	0.169	0.163	0.153	0.143	0.136	0.130	0.127	0.124	0.122	0.121	0.120	0.119	0.118	0.117
2002	0.000	0.004	0.040	0.120	0.182	0.201	0.195	0.183	0.172	0.163	0.157	0.153	0.150	0.148	0.146	0.145	0.144	0.143	0.142
2003	0.000	0.004	0.042	0.126	0.194	0.214	0.208	0.194	0.181	0.171	0.165	0.160	0.157	0.154	0.152	0.151	0.150	0.149	0.148
2004	0.000	0.005	0.048	0.138	0.210	0.233	0.227	0.213	0.200	0.191	0.184	0.179	0.176	0.173	0.171	0.170	0.169	0.168	0.167
2005	0.000	0.002	0.033	0.119	0.208	0.255	0.267	0.264	0.258	0.252	0.248	0.244	0.242	0.240	0.239	0.238	0.237	0.237	0.236
2006	0.000	0.002	0.032	0.124	0.225	0.279	0.294	0.290	0.283	0.276	0.271	0.267	0.264	0.262	0.260	0.259	0.258	0.257	0.256
2007	0.000	0.003	0.033	0.121	0.218	0.270	0.283	0.279	0.271	0.264	0.259	0.254	0.251	0.249	0.248	0.246	0.246	0.245	0.244
2008	0.000	0.003	0.040	0.145	0.254	0.309	0.320	0.314	0.304	0.296	0.289	0.284	0.281	0.278	0.276	0.275	0.274	0.273	0.272
2009	0.000	0.003	0.044	0.157	0.277	0.338	0.351	0.343	0.331	0.321	0.313	0.307	0.303	0.300	0.298	0.296	0.295	0.294	0.293
2010	0.000	0.003	0.034	0.123	0.220	0.273	0.285	0.281	0.272	0.265	0.259	0.255	0.252	0.249	0.248	0.247	0.246	0.245	0.244
2011	0.000	0.003	0.041	0.147	0.259	0.319	0.335	0.332	0.325	0.318	0.313	0.309	0.306	0.304	0.302	0.301	0.300	0.299	0.299
2012	0.000	0.003	0.035	0.127	0.229	0.286	0.303	0.303	0.297	0.292	0.287	0.284	0.281	0.279	0.278	0.277	0.276	0.276	0.275
2013	0.000	0.003	0.036	0.118	0.204	0.251	0.265	0.264	0.259	0.254	0.250	0.247	0.244	0.243	0.242	0.241	0.240	0.240	0.239
2014	0.000	0.003	0.033	0.113	0.198	0.245	0.258	0.257	0.251	0.246	0.242	0.239	0.237	0.236	0.235	0.234	0.233	0.232	0.232

Table 2.28—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in 2015-2027 (Scenario 1), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	295,000	295,000	295,000	295,000	0
2016	316,000	316,000	316,000	316,000	0
2017	320,000	320,000	320,000	320,000	2
2018	309,000	309,000	310,000	312,000	1,168
2019	275,000	285,000	288,000	312,000	12,866
2020	233,000	259,000	266,000	321,000	29,839
2021	195,000	241,000	249,000	342,000	45,794
2022	146,000	230,000	234,000	342,000	60,505
2023	122,000	222,000	225,000	338,000	68,676
2024	114,000	219,000	221,000	343,000	71,118
2025	112,000	217,000	218,000	340,000	70,682
2026	113,000	213,000	216,000	336,000	69,162
2027	113,000	215,000	215,000	335,000	68,341

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	403,000	403,000	403,000	403,000	0
2016	440,000	440,000	440,000	440,000	0
2017	462,000	462,000	462,000	462,000	47
2018	464,000	464,000	465,000	466,000	1,048
2019	439,000	445,000	447,000	460,000	7,415
2020	390,000	410,000	416,000	462,000	24,041
2021	332,000	375,000	387,000	476,000	47,779
2022	284,000	353,000	365,000	499,000	67,233
2023	256,000	338,000	353,000	496,000	77,213
2024	245,000	329,000	347,000	490,000	81,232
2025	242,000	328,000	344,000	494,000	81,829
2026	241,000	325,000	342,000	495,000	79,861
2027	242,000	323,000	340,000	492,000	77,423

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.29	0.29	0.29	0.29	0.00
2016	0.29	0.29	0.29	0.29	0.00
2017	0.29	0.29	0.29	0.29	0.00
2018	0.29	0.29	0.29	0.29	0.00
2019	0.29	0.29	0.29	0.29	0.00
2020	0.29	0.29	0.29	0.29	0.00
2021	0.29	0.29	0.29	0.29	0.00
2022	0.25	0.29	0.29	0.29	0.01
2023	0.22	0.29	0.28	0.29	0.02
2024	0.21	0.29	0.27	0.29	0.03
2025	0.21	0.29	0.27	0.29	0.03
2026	0.21	0.29	0.27	0.29	0.03
2027	0.21	0.29	0.27	0.29	0.03

Table 2.29—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = 0.854 \times max\ F_{ABC}$ in 2015-2027 (Scenario 2), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	212,000	212,000	212,000	212,000	0
2016	231,000	231,000	231,000	231,000	0
2017	303,000	303,000	303,000	303,000	2
2018	293,000	294,000	294,000	296,000	998
2019	263,000	272,000	275,000	295,000	11,054
2020	225,000	247,000	254,000	302,000	25,940
2021	189,000	229,000	237,000	319,000	40,290
2022	161,000	218,000	226,000	319,000	49,915
2023	128,000	212,000	217,000	315,000	58,033
2024	117,000	208,000	211,000	318,000	61,891
2025	110,000	205,000	208,000	316,000	62,320
2026	111,000	202,000	205,000	313,000	61,237
2027	109,000	202,000	204,000	313,000	60,491

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	409,000	409,000	409,000	409,000	0
2016	473,000	473,000	473,000	473,000	0
2017	518,000	518,000	518,000	518,000	47
2018	524,000	525,000	525,000	527,000	1,049
2019	499,000	505,000	507,000	521,000	7,442
2020	447,000	468,000	474,000	520,000	24,399
2021	384,000	428,000	440,000	533,000	49,363
2022	327,000	400,000	414,000	555,000	71,269
2023	287,000	382,000	396,000	554,000	84,596
2024	269,000	370,000	386,000	542,000	90,942
2025	262,000	364,000	380,000	553,000	92,670
2026	259,000	359,000	376,000	547,000	91,049
2027	259,000	357,000	373,000	545,000	88,446

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.21	0.21	0.21	0.21	0.00
2016	0.20	0.20	0.20	0.20	0.00
2017	0.25	0.25	0.25	0.25	0.00
2018	0.25	0.25	0.25	0.25	0.00
2019	0.25	0.25	0.25	0.25	0.00
2020	0.25	0.25	0.25	0.25	0.00
2021	0.25	0.25	0.25	0.25	0.00
2022	0.25	0.25	0.25	0.25	0.00
2023	0.22	0.25	0.25	0.25	0.01
2024	0.20	0.25	0.24	0.25	0.02
2025	0.20	0.25	0.24	0.25	0.02
2026	0.19	0.25	0.24	0.25	0.02
2027	0.19	0.25	0.24	0.25	0.02

Table 2.30—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that the upper bound on F_{ABC} is set the most recent five-year average fishing mortality rate in 2015-2027 (Scenario 3), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	345,000	345,000	345,000	345,000	0
2016	359,000	359,000	359,000	359,000	0
2017	306,000	306,000	306,000	306,000	2
2018	299,000	300,000	300,000	302,000	1,179
2019	269,000	278,000	282,000	306,000	12,988
2020	229,000	255,000	262,000	318,000	30,098
2021	193,000	238,000	247,000	341,000	45,976
2022	167,000	230,000	238,000	342,000	55,503
2023	150,000	223,000	233,000	339,000	60,506
2024	144,000	220,000	230,000	344,000	62,530
2025	141,000	218,000	227,000	340,000	62,162
2026	141,000	215,000	224,000	337,000	60,677
2027	139,000	215,000	223,000	336,000	59,910

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	399,000	399,000	399,000	399,000	0
2016	421,000	421,000	421,000	421,000	0
2017	433,000	433,000	433,000	433,000	47
2018	440,000	441,000	441,000	443,000	1,048
2019	421,000	427,000	429,000	442,000	7,413
2020	377,000	397,000	403,000	449,000	24,017
2021	323,000	366,000	377,000	466,000	47,691
2022	275,000	346,000	358,000	492,000	67,545
2023	241,000	333,000	346,000	490,000	79,365
2024	223,000	324,000	338,000	485,000	85,604
2025	214,000	321,000	333,000	489,000	87,858
2026	210,000	317,000	329,000	490,000	86,967
2027	207,000	314,000	326,000	489,000	85,182

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.35	0.35	0.35	0.35	0.00
2016	0.35	0.35	0.35	0.35	0.00
2017	0.30	0.30	0.30	0.30	0.00
2018	0.30	0.30	0.30	0.30	0.00
2019	0.30	0.30	0.30	0.30	0.00
2020	0.30	0.30	0.30	0.30	0.00
2021	0.30	0.30	0.30	0.30	0.00
2022	0.30	0.30	0.30	0.30	0.00
2023	0.30	0.30	0.30	0.30	0.00
2024	0.30	0.30	0.30	0.30	0.00
2025	0.30	0.30	0.30	0.30	0.00
2026	0.30	0.30	0.30	0.30	0.00
2027	0.30	0.30	0.30	0.30	0.00

Table 2.31—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that the upper bound on F_{ABC} is set at $F_{60\%}$ in 2015-2027 (Scenario 4), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	152,000	152,000	152,000	152,000	0
2016	177,000	177,000	177,000	177,000	0
2017	192,000	192,000	192,000	192,000	1
2018	196,000	196,000	197,000	198,000	578
2019	185,000	190,000	192,000	204,000	6,487
2020	166,000	179,000	183,000	212,000	15,682
2021	145,000	170,000	175,000	227,000	25,347
2022	128,000	164,000	169,000	230,000	32,208
2023	115,000	158,000	164,000	227,000	36,383
2024	109,000	155,000	161,000	233,000	38,531
2025	104,000	154,000	159,000	229,000	39,086
2026	103,000	152,000	157,000	229,000	38,575
2027	101,000	150,000	155,000	226,000	38,082

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	414,000	414,000	414,000	414,000	0
2016	497,000	497,000	497,000	497,000	0
2017	565,000	565,000	565,000	565,000	47
2018	607,000	607,000	608,000	610,000	1,050
2019	611,000	617,000	619,000	633,000	7,508
2020	577,000	598,000	604,000	653,000	25,306
2021	519,000	566,000	579,000	681,000	53,501
2022	457,000	540,000	555,000	720,000	81,147
2023	407,000	519,000	536,000	725,000	100,807
2024	371,000	505,000	523,000	720,000	112,940
2025	353,000	496,000	513,000	730,000	119,239
2026	339,000	488,000	505,000	721,000	120,613
2027	329,000	483,000	499,000	719,000	119,331

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.15	0.15	0.15	0.15	0.00
2016	0.15	0.15	0.15	0.15	0.00
2017	0.15	0.15	0.15	0.15	0.00
2018	0.15	0.15	0.15	0.15	0.00
2019	0.15	0.15	0.15	0.15	0.00
2020	0.15	0.15	0.15	0.15	0.00
2021	0.15	0.15	0.15	0.15	0.00
2022	0.15	0.15	0.15	0.15	0.00
2023	0.15	0.15	0.15	0.15	0.00
2024	0.15	0.15	0.15	0.15	0.00
2025	0.15	0.15	0.15	0.15	0.00
2026	0.15	0.15	0.15	0.15	0.00
2027	0.15	0.15	0.15	0.15	0.00

Table 2.32—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = 0$ in 2015-2027 (Scenario 5), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0	0	0	0	0
2016	0	0	0	0	0
2017	0	0	0	0	0
2018	0	0	0	0	0
2019	0	0	0	0	0
2020	0	0	0	0	0
2021	0	0	0	0	0
2022	0	0	0	0	0
2023	0	0	0	0	0
2024	0	0	0	0	0
2025	0	0	0	0	0
2026	0	0	0	0	0
2027	0	0	0	0	0

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	424,000	424,000	424,000	424,000	0
2016	559,000	559,000	559,000	559,000	0
2017	692,000	692,000	692,000	692,000	47
2018	799,000	800,000	801,000	802,000	1,051
2019	863,000	869,000	871,000	885,000	7,601
2020	872,000	895,000	901,000	952,000	26,612
2021	837,000	889,000	904,000	1,020,000	59,860
2022	779,000	875,000	894,000	1,090,000	97,554
2023	720,000	861,000	882,000	1,130,000	129,263
2024	666,000	846,000	869,000	1,150,000	152,268
2025	633,000	833,000	858,000	1,150,000	167,257
2026	607,000	824,000	848,000	1,160,000	174,856
2027	592,000	821,000	839,000	1,160,000	177,032

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00
2017	0.00	0.00	0.00	0.00	0.00
2018	0.00	0.00	0.00	0.00	0.00
2019	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00
2023	0.00	0.00	0.00	0.00	0.00
2024	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00
2026	0.00	0.00	0.00	0.00	0.00
2027	0.00	0.00	0.00	0.00	0.00

Table 2.33—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = F_{OFL}$ in 2015-2027 (Scenario 6), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	346,000	346,000	346,000	346,000	0
2016	360,000	360,000	360,000	360,000	0
2017	356,000	356,000	356,000	356,000	3
2018	336,000	337,000	338,000	340,000	1,394
2019	294,000	305,000	309,000	337,000	15,251
2020	244,000	274,000	283,000	348,000	34,819
2021	176,000	251,000	256,000	370,000	59,564
2022	137,000	230,000	238,000	368,000	74,178
2023	119,000	221,000	232,000	365,000	79,847
2024	114,000	219,000	230,000	370,000	81,022
2025	115,000	220,000	229,000	365,000	79,951
2026	114,000	218,000	227,000	371,000	78,258
2027	117,000	221,000	227,000	367,000	77,533

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	399,000	399,000	399,000	399,000	0
2016	421,000	421,000	421,000	421,000	0
2017	428,000	428,000	428,000	429,000	47
2018	420,000	420,000	421,000	422,000	1,048
2019	389,000	395,000	396,000	410,000	7,379
2020	338,000	358,000	364,000	409,000	23,574
2021	286,000	325,000	336,000	422,000	45,106
2022	250,000	307,000	320,000	443,000	59,918
2023	230,000	300,000	313,000	434,000	66,366
2024	223,000	297,000	311,000	435,000	68,900
2025	223,000	297,000	310,000	436,000	69,111
2026	222,000	296,000	309,000	440,000	67,243
2027	225,000	297,000	308,000	441,000	65,274

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.35	0.35	0.35	0.35	0.00
2016	0.35	0.35	0.35	0.35	0.00
2017	0.35	0.35	0.35	0.35	0.00
2018	0.35	0.35	0.35	0.35	0.00
2019	0.35	0.35	0.35	0.35	0.00
2020	0.35	0.35	0.35	0.35	0.00
2021	0.30	0.35	0.34	0.35	0.02
2022	0.26	0.33	0.32	0.35	0.03
2023	0.24	0.32	0.31	0.35	0.04
2024	0.23	0.31	0.31	0.35	0.04
2025	0.23	0.32	0.31	0.35	0.04
2026	0.23	0.31	0.31	0.35	0.04
2027	0.23	0.31	0.31	0.35	0.04

Table 2.34—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in each year 2015-2016 and $F = F_{OFL}$ thereafter (Scenario 7), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	295,000	295,000	295,000	295,000	0
2016	316,000	316,000	316,000	316,000	0
2017	375,000	375,000	375,000	375,000	3
2018	350,000	351,000	351,000	354,000	1,394
2019	302,000	314,000	318,000	346,000	15,251
2020	249,000	280,000	288,000	353,000	34,819
2021	182,000	256,000	261,000	373,000	58,335
2022	139,000	234,000	240,000	369,000	73,998
2023	119,000	222,000	232,000	366,000	79,891
2024	114,000	220,000	230,000	370,000	81,090
2025	115,000	220,000	229,000	365,000	79,998
2026	114,000	218,000	227,000	371,000	78,284
2027	117,000	221,000	227,000	367,000	77,546

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	403,000	403,000	403,000	403,000	0
2016	440,000	440,000	440,000	440,000	0
2017	457,000	457,000	457,000	458,000	47
2018	441,000	442,000	443,000	444,000	1,048
2019	404,000	410,000	412,000	425,000	7,379
2020	348,000	368,000	374,000	419,000	23,574
2021	291,000	331,000	342,000	428,000	45,218
2022	253,000	310,000	323,000	447,000	60,322
2023	231,000	301,000	314,000	436,000	66,728
2024	223,000	297,000	312,000	436,000	69,130
2025	223,000	297,000	310,000	437,000	69,231
2026	222,000	296,000	309,000	440,000	67,298
2027	225,000	297,000	308,000	441,000	65,296

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.29	0.29	0.29	0.29	0.00
2016	0.29	0.29	0.29	0.29	0.00
2017	0.35	0.35	0.35	0.35	0.00
2018	0.35	0.35	0.35	0.35	0.00
2019	0.35	0.35	0.35	0.35	0.00
2020	0.35	0.35	0.35	0.35	0.00
2021	0.31	0.35	0.34	0.35	0.02
2022	0.27	0.33	0.32	0.35	0.03
2023	0.24	0.32	0.31	0.35	0.04
2024	0.23	0.32	0.31	0.35	0.04
2025	0.23	0.32	0.31	0.35	0.04
2026	0.23	0.31	0.31	0.35	0.04
2027	0.23	0.31	0.31	0.35	0.04

Table 2.35a (page 1 of 2)—Incidental catch (t) of FMP species, other than squid and members of the former "other species" complex, taken in the Bering Sea trawl fishery for Pacific cod, 1991-2014 (2014 data current through October 20).

Trawl fishery

Species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Pollock	8595	17525	29180	23805	22637	19154	28775	7234	17200	9658	5663	8697
Pacific cod	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sablefish	1	9		2	0	5	3	4	10	13	36	34
Yellowfin Sole	33	269	817	3094	702	1812	821	753	425	1208	559	1520
Greenland Turbot	35	78	53	46	89	64	72	96	22	50	75	46
Arrowtooth Flounder	869	2603	1650	1994	1600	3088	2197	1488	1137	1039	2037	3229
Kamchatka Flounder												
Rock Sole	1746	3681	5509	7560	13681	9924	14501	5542	9794	7666	4981	5989
Flathead Sole					2836	2737	3363	1543	2108	1830	790	1496
Alaska Plaice												399
Other Flatfish								543	591	849	592	480
Flounder	753	2447	2652	3233								
Pacific Ocean Perch	620	365	378	118	105	66	149	42	25	137	33	11
Northern Rockfish												42
Rougheye Rockfish												
Shortraker Rockfish												
Sharpchin/Northern Rockfish		83	55								16	
Shortraker/Rougheye Rockfish		2										3
Shortraker/Rougheye/Sharpchin/Northern Rockfish	99	52	17	12	12	20	85	18	29	40	16	
Other Rockfish	21	47	18	2	22	8	4	27	8	15	8	28
Atka Mackerel	165	92	2	2	3	52	44	423	62	19	90	230

Table 2.35a (page 2 of 2)—Incidental catch (t) of FMP species, other than squid and members of the former "other species" complex, taken in the Bering Sea trawl fishery for Pacific cod, 1991-2014 (2014 data current through October 20).

Trawl fishery

Species/group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Pollock	8744	13299	9919	12078	16922	4289	3332	2241	3481	3524	3933	5437
Pacific cod	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sablefish	56	73	28	2	1	1					0	
Yellowfin Sole	1006	1840	1266	1438	645	322	306	469	1141	767	2679	1508
Greenland Turbot	71	76	10	20	82	8	1	5	0	1	2	2
Arrowtooth Flounder	4139	7859	3785	4297	1923	584	448	417	218	216	275	216
Kamchatka Flounder									6	7	16	29
Rock Sole	5134	8647	7461	4528	3864	974	750	848	1329	1146	818	1403
Flathead Sole	1445	2817	1350	2899	3748	360	479	167	222	235	239	215
Alaska Plaice	265	372	389	342	404	53	55	73	502	144	577	625
Other Flatfish	893	2063	1331	600	382	75	28	63	73	71	29	48
Flounder												
Pacific Ocean Perch	31	64	80	50	25	2	1	0	4	2	2	
Northern Rockfish	12	51	22	48	4	1	1	3	6	5	0	1
Rougheye Rockfish		1	1									
Shortraker Rockfish												
Sharpchin/Northern Rockfish												
Shortraker/Rougheye Rockfish	3											
Shortraker/Rougheye/Sharpchin/Northern Rockfish												
Other Rockfish	33	63	18	12	5	5	2	8	2	16	2	2
Atka Mackerel	3470	4442	652	367	123	10	28	46	69	35	10	2

Table 2.35b (page 1 of 2)—Incidental catch (t) of FMP species, other than squid and members of the former "other species" complex, taken in the Bering Sea longline fishery for Pacific cod, 1991-2014 (2014 data current through October 20).

Longline fishery

Species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Pollock	2098	3245	2117	2772	3037	2875	4461	3186	3907	4785	5894	6482
Pacific Cod	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sablefish	37	117	18	46	40	24	21	14	15	69	60	59
Yellowfin Sole	1	93	5	152	60	148	216	260	185	296	648	620
Greenland Turbot	185	523	148	267	326	377	454	294	170	151	161	221
Arrowtooth Flounder	1693	1545	700	1422	1754	2113	2182	1506	736	1119	1155	936
Kamchatka Flounder												
Rock Sole	18	29	12	19	38	45	36	39	29	29	28	32
Flathead Sole					254	270	338	407	281	318	268	375
Alaska Plaice												1
Other Flatfish					22	21	33	30	95	129	91	102
Flounder	253	274	205	212								
Pacific Ocean Perch	2	6	5	1	17	1	0	0	0	1	2	3
Northern Rockfish												9
Rougheye Rockfish												
Shortraker Rockfish												
Sharpchin/Northern Rockfish		1	2								7	
Shortraker/Rougheye Rockfish		20	18								25	19
Shortraker/Rougheye/Sharpchin/Northern Rockfish	14	15	10	21	20	37	13	15	9	31	8	
Other Rockfish	9	35	15	15	14	16	9	10	15	11	28	32
Atka Mackerel	0	2	1	0	6	2	0	0	0	1	1	2

Table 2.35b (page 2 of 2)—Incidental catch (t) of FMP species, other than squid and members of the former "other species" complex, taken in the Bering Sea longline fishery for Pacific cod, 1991-2014 (2014 data current through October 20).

Longline Fishery

Species/group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Pollock	7162	5309	4172	3040	3372	5285	4529	4168	5476	4821	5103	4260
Pacific Cod	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sablefish	66	19	21	22	14	4	2	2	16	3	3	3
Yellowfin Sole	631	616	717	485	264	507	653	198	674	1001	1422	1400
Greenland Turbot	182	218	165	65	115	72	79	106	173	121	15	14
Arrowtooth Flounder	1295	1365	1668	1322	1265	1208	1220	1100	961	961	580	370
Kamchatka Flounder									51	71	47	27
Rock Sole	45	37	48	21	14	20	25	5	20	26	33	50
Flathead Sole	372	593	618	539	352	334	248	265	334	291	372	476
Alaska Plaice	0	0	0	4	0	0	0	0	0	0	1	0
Other Flatfish	80	187	253	145	59	29	56	96	50	64	10	32
Flounder												
Pacific Ocean Perch	1	3	1	0	0	0	1	1	2	1	2	3
Northern Rockfish	6	5	6	6	5	4	4	11	13	9	18	23
Rougheye Rockfish	0	2	4	2	2	5	1	4	3	2	2	1
Shortraker Rockfish		26	19	4	22	12	21	48	20	14	8	9
Sharpchin/Northern Rockfish												
Shortraker/Rougheye Rockfish	18											
Shortraker/Rougheye/Sharpchin/Northern Rockfish												
Other Rockfish	10	28	19	10	22	18	7	47	36	23	28	35
Atka Mackerel	6	25	5	0	4	1	0	1	6	3	2	3

Table 2.35c(page 1 of 2)—Incidental catch (t) of FMP species, other than squid and members of the former "other species" complex, taken in the Bering Sea pot fishery for Pacific cod, 1991-2014 (2014 data current through October 20).

Pot fishery

Species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Pollock	2	7		4	15	32	64	43	23	58		29
Pacific Cod	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sablefish												
Yellowfin Sole	38	26			81	256	71	107	61	69		38
Greenland Turbot					1	0						
Alaska Plaice												
Arrowtooth Flounder	0	3			18	18	13	2				151
Kamchatka Flounder												
Rock Sole	0	1		0	0	8	2	1	2	1		
Flathead Sole						7			0			
Other Flatfish						3	1					
Flounder		1										
Pacific Ocean Perch					1	1						
Northern Rockfish												
Rougheye Rockfish												
Shortraker Rockfish												
Sharpchin/Northern Rockfish												
Shortraker/Rougheye Rockfish												
Shortraker/Rougheye/Sharpchin/Northern Rockfish	0				1	1	1					
Other Rockfish	0	1		0	3	6	3	2				
Atka Mackerel	1	10		6	80	53	48	15				

Table 2.35c (page 2 of 2)—Incidental catch (t) of FMP species, other than squid and members of the former "other species" complex, taken in the Bering Sea pot fishery for Pacific cod, 1991-2014 (2014 data current through October 20).

Pot fishery

Species/group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Pollock	18	9	8	26	12	11	17	8	7	4	7	14
Pacific Cod	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sablefish	0	1	0	4							0	
Yellowfin Sole	82	78	76	47	206	133	35	2	29	29	298	305
Greenland Turbot	0			1					0			
Alaska Plaice										0		
Arrowtooth Flounder	4	4	5	12	3	6	0	1	1	1	2	1
Kamchatka Flounder										0	0	
Rock Sole	3	2	1	2	3	1	0	1	0	1	1	2
Flathead Sole	0	1	1	0	2	1	0	0	0	0	0	0
Other Flatfish	1	1	1	1	1	0	0	0	0	0	2	0
Flounder												
Pacific Ocean Perch	1	0	0	1		0	0		0	0	0	
Northern Rockfish	1	1	1	1	1	2	0	0	1	1	0	0
Rougheye Rockfish		0	0									
Shortraker Rockfish								0				
Sharpchin/Northern Rockfish												
Shortraker/Rougheye Rockfish	0											
Shortraker/Rougheye/Sharpchin/Northern Rockfish												
Other Rockfish	5	3	3	4	1	1	0	2	2	1	5	3
Atka Mackerel	198	141	236	342	41	61	2	27	29	9	3	4

Table 2.36—Incidental catch (t) of squid and members of the former "other species" complex taken in the Bering Sea fisheries for Pacific cod, 2003-2014 (2014 data are current through October 8).

Species/group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Octopus	196	264	299	268	130	177	37	114	555	119	181	177
Sculpins, Large	817	2832	2248	1920	2087	1404	1060	1059	1647	1777	1470	1763
Sculpins, Other	1857	349	339	382	337	299	210	66	147	239	33	47
Shark, Other	20	20	10	4	2	2	5	2	3	1	1	1
Shark, Pacific Sleeper	121	228	188	123	44	20	14	15	20	10	20	26
Shark, Salmon	1	0	2	1							0	
Shark, Spiny Dogfish	11	8	11	6	2	7	17	13	7	19	18	6
Skate, Alaska								1493	2156	2676	3251	2642
Skate, Aleutian									103	231	121	106
Skate, Big		158	174	243	74	49	63	117	132	287	218	198
Skate, Longnose	0	12	21	20	1	1	1	5	4	3	9	10
Skate, Other	14742	17708	18843	14432	12740	13685	11886	9007	14133	14919	16684	14101
Skate, Whiteblotched									13	24	12	11
Squid	5	4	1	0	1	0	0	0	0	0	0	1

Table 2.37—Catches of prohibited species by Bering Sea fisheries for Pacific cod, 1991-2014 (2014 data are current through October 13). Herring and halibut catches (and halibut mortality totals) are in t, salmon and crab are in 1000s of individuals.

Species	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Bairdi Tanner Crab	764	439	230	319	330	455	293	152	158	180	155	355
Opilio Tanner (Snow) Crab	212	308	291	440	277	377	1019	803	540	404	251	508
Red King Crab	52	13	2	2	8	79	28	12	17	44	21	40
Blue King Crab												
Golden (Brown) King Crab												
Other King Crab	1	13	1	3	2	7	3	25	12	9	18	27
Herring		8	23	2	8	18	1	1	1	1	5	3
Chinook Salmon	4	5	6	7	7	6	5	2	2	1	3	2
Non-Chinook Salmon	0	0	0	1	1	0	0	1	0	0	2	1

Species	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Bairdi Tanner Crab	257	258	291	588	819	1265	528	390	325	120	241	
Opilio Tanner (Snow) Crab	162	222	195	342	1812	693	550	786	192	51	43	
Red King Crab	14	17	21	19	47	36	8	4	23	11	99	
Blue King Crab	3	3	1	4	173	9	15	123	1	1	0	
Golden (Brown) King Crab	0	0	0	0	0	0	1	0	0	0	0	
Other King Crab												
Herring	14	9	18	8	2	0	0	0	0	6	0	
Chinook Salmon	2	5	3	3	5	1	0	0	0	1	1	
Non-Chinook Salmon	1	7	1	7	1	0	0	0	0	0	0	

Halibut quantity	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Catch	5198	7256	3463	8657	8950	9175	8640	7234	6136	7273	6729	7329
Mortality				2069	2264	2326	2060	1719	1780	1537	1278	1789

Halibut quantity	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Catch	6696	6724	7901	6344	5787	6605	6067	6099	6387	7162	6758	3044
Mortality	1870	2065	1963	1812	1418	902	782	784	779	1038	861	481

Table 2.38—Incidental catch (t) of non-target species groups by Bering Sea Pacific cod fisheries, 2003-2014 (2014 data are current through October 8), sorted in order of descending average.

Species/group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Ave.
Sea star	438	423	439	316	235	181	139	135	191	454	279	577	317
Giant Grenadier	2	15	143	105	95	135	201	292	1126	494	171	65	237
Scypho jellies	668	709	399	66	110	47	93	43	186	68	338	77	234
Sea anemone unidentified	92	115	113	87	37	54	115	84	144	177	233	202	121
Misc fish	223	226	205	93	86	40	51	52	111	128	61	140	118
Grenadier	238	225	190	25	84	27	11	98	13	20	103	34	89
Sea pens whips	6	12	30	16	7	10	37	25	25	35	53	54	26
Snails	25	20	12	16	15	19	25	17	23	21	29	33	21
Eelpouts	47	35	42	17	18	7	2	2	4	11	24	38	21
Invertebrate unidentified	19	5	3	17	19	2	15	37	57	35	21	8	20
Benthic urochordata	14	4	10	5	1	2	1	10	35	65	51	34	19
Sponge unidentified	6	8	6	11	2	3	11	6	12	15	19	18	10
Misc crabs	8	4	4	16	28	6	2	5	4	5	12	8	9
Bivalves	5	16	6	5	2	11	9	3	11	11	12	7	8
Urchins/dollars/cucumbers	11	11	13	4	13	3	1	1	4	3	1	5	6
Corals Bryozoans	1	1	1	1	2	2	8	2	3	24	2	1	4
Hermit crab unidentified	5	3	2	2	2	1	1	1	1	1	1	1	2
Greenlings	6	3	2	2	0	1	0	0	0	0	0	0	1
Brittle star unidentified	1	1	0	1	0	0	0	0	1	1	1	1	1
Dark Rockfish						1	0	0	0	0	0	0	0
Misc crustaceans	0	0	0	1	1	0	0	0	0	0	0	0	0
Other osmerids	0	0	0	0	0		0	0	0	0	0		0
Pandalid shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0
Eulachon		0	0	0	0	0		0	0	0			0
Pacific Sand lance	0	0	0	0	0	0		0	0	0		0	0
Polychaete unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc inverts (worms etc)	0	0	0	0	0	0	0	0	0	0	0	0	0
Capelin		0			0	0		0	0	0	0	0	0
Stichaeidae	0	0	0	0	0	0	0	0					0
Lanternfishes (myctophidae)		0											0
Gunnels		0	0		0								0
Birds	0	0	0	0	0	0	0	0	0	0	0	0	0

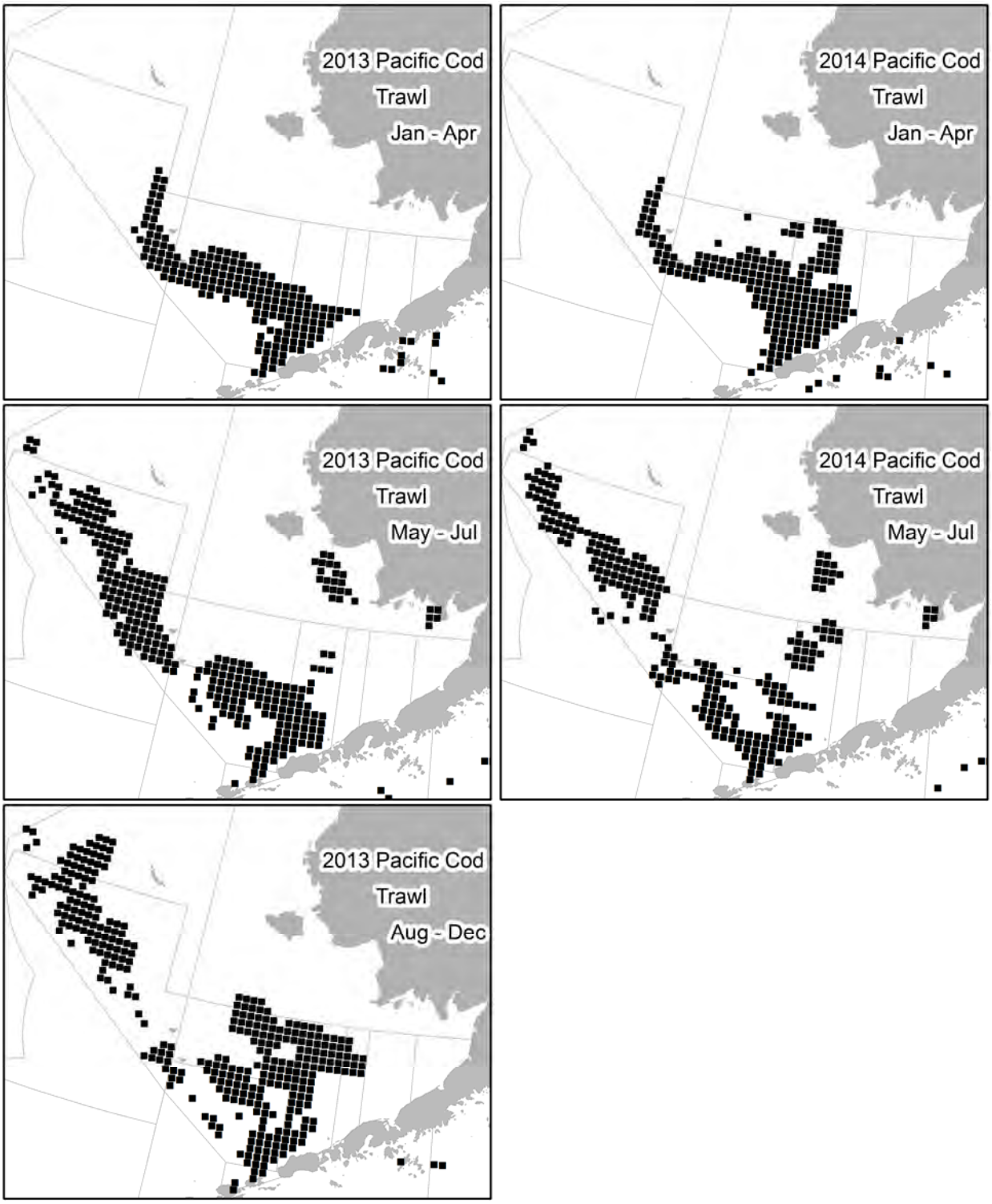


Figure 2.1a. EBS maps showing each 400 square km cell with trawl hauls containing Pacific cod from at least 3 distinct vessels by season in 2013-2014, overlaid against NMFS 3-digit statistical areas.

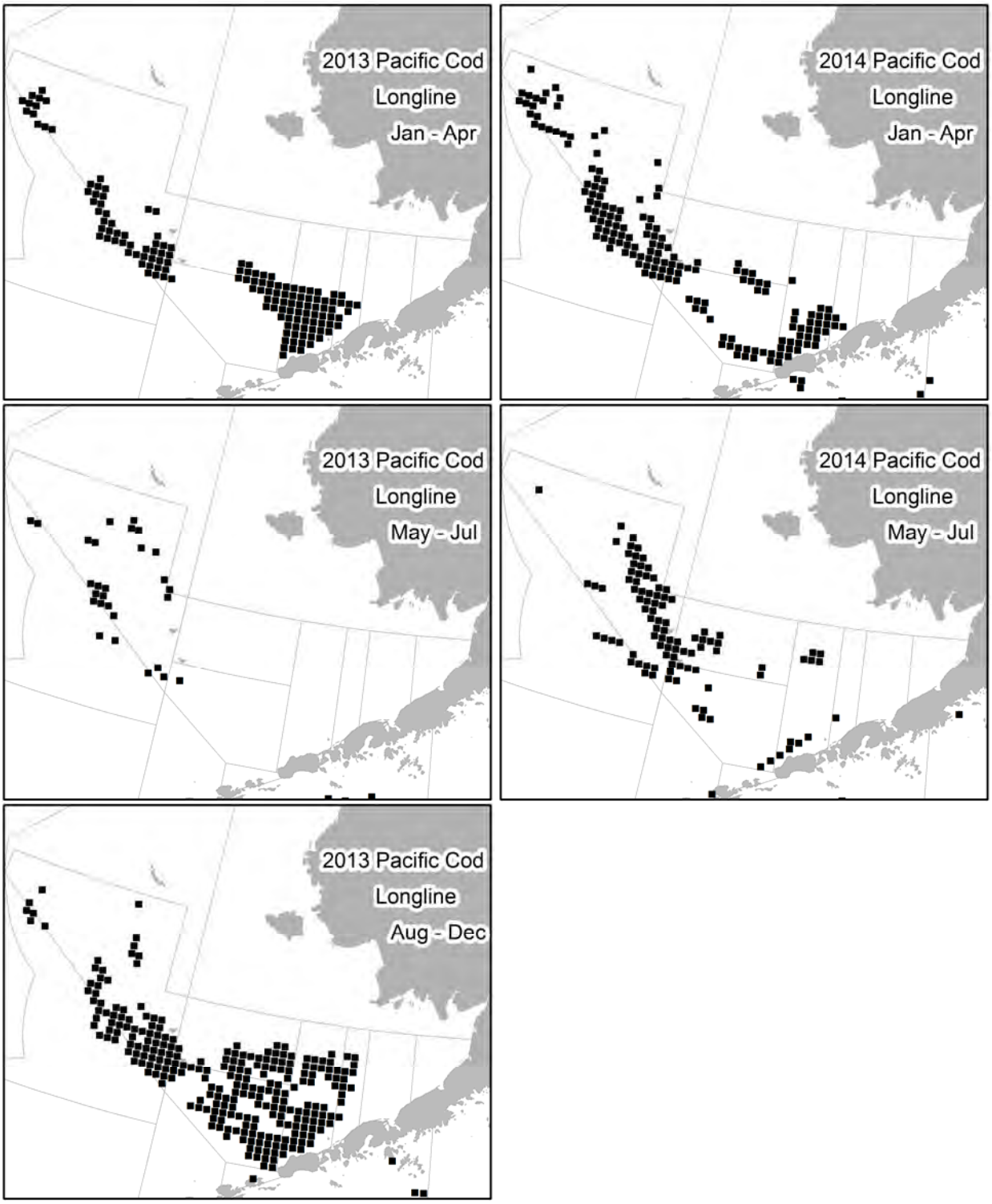


Figure 2.1b. EBS maps showing each 400 square km cell with longline sets containing Pacific cod from at least 3 distinct vessels by season in 2013-2014, overlaid against NMFS 3-digit statistical areas.

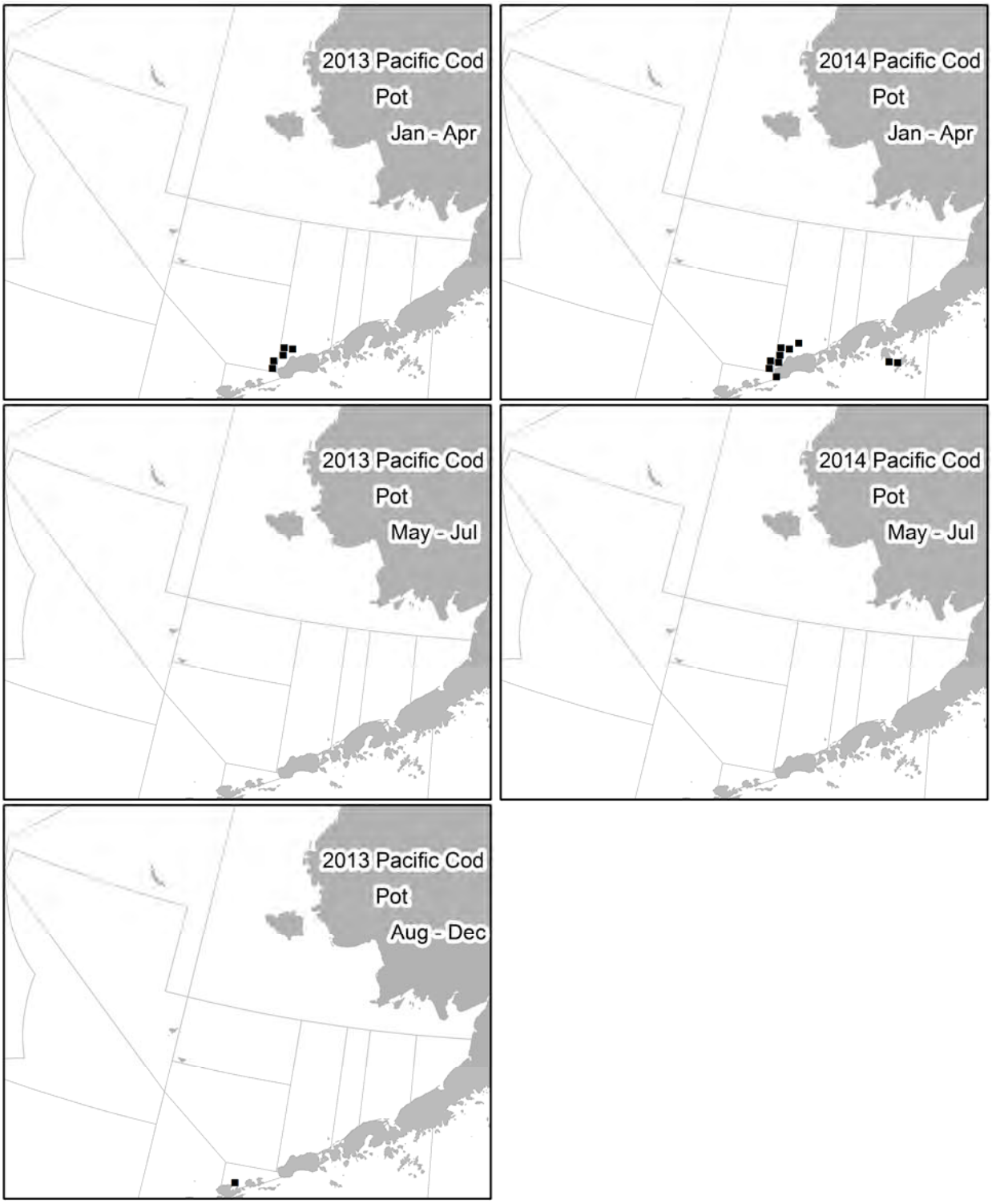


Figure 2.1c. EBS maps showing each 400 square km cell with pot sets containing Pacific cod from at least 3 distinct vessels by season in 2013-2014, overlaid against NMFS 3-digit statistical areas.

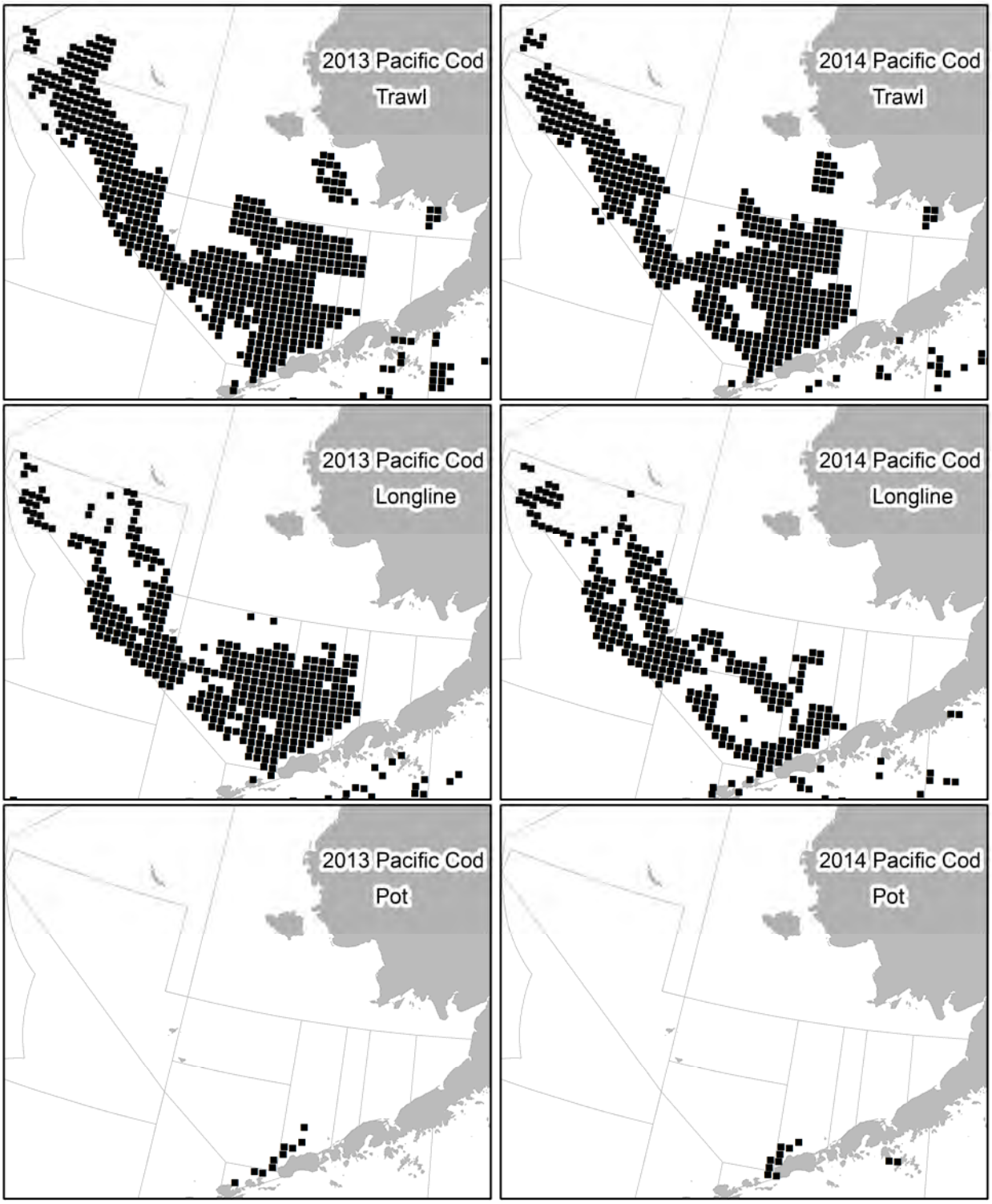


Figure 2.2. Maps showing each 400 square km cell with pot sets containing Pacific cod from at least 3 distinct vessels by season in 2013-2014, overlaid against NMFS 3-digit statistical areas.

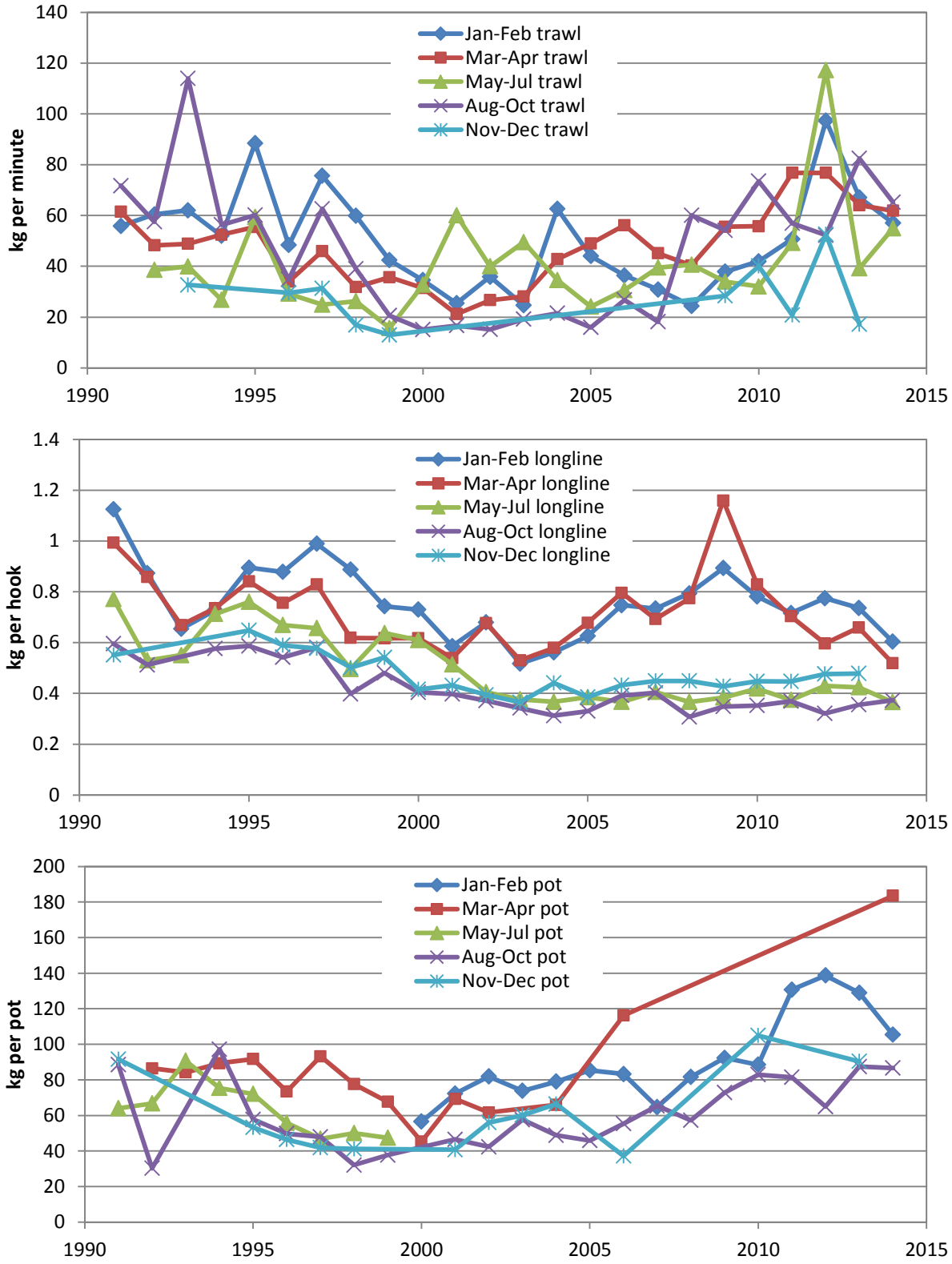


Figure 2.3—Time series of fishery catch per unit effort, by gear and season.

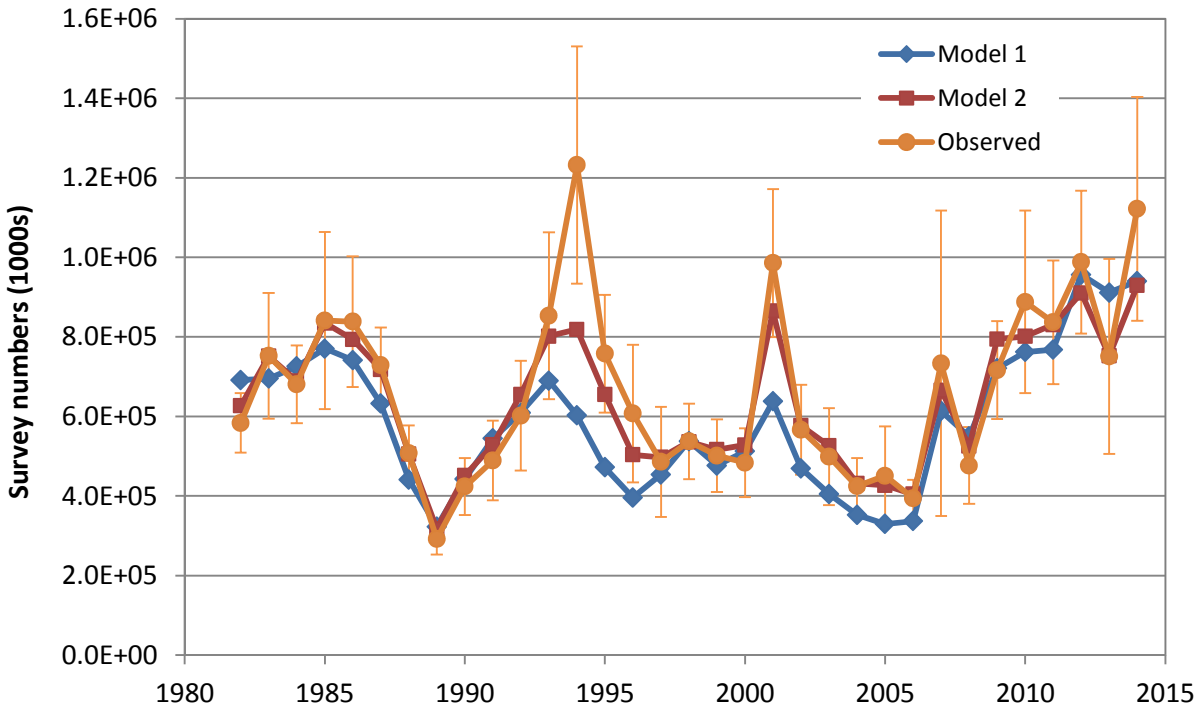


Figure 2.4—Model fits to the trawl survey abundance time series, with 95% confidence intervals for the observations.

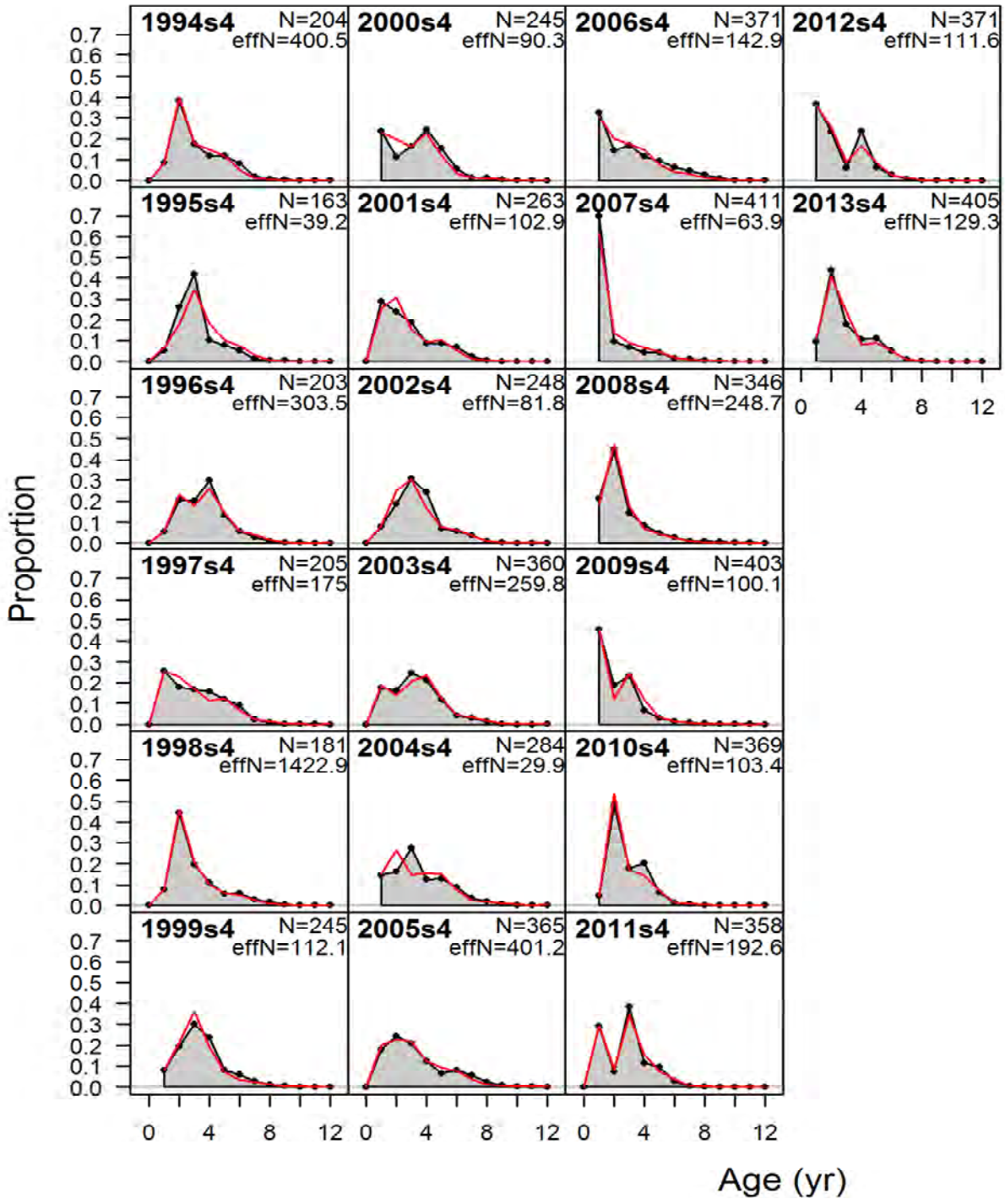


Figure 2.5a—Fit to trawl survey age composition data obtained by Model 1 (grey = observed, red = estimated).

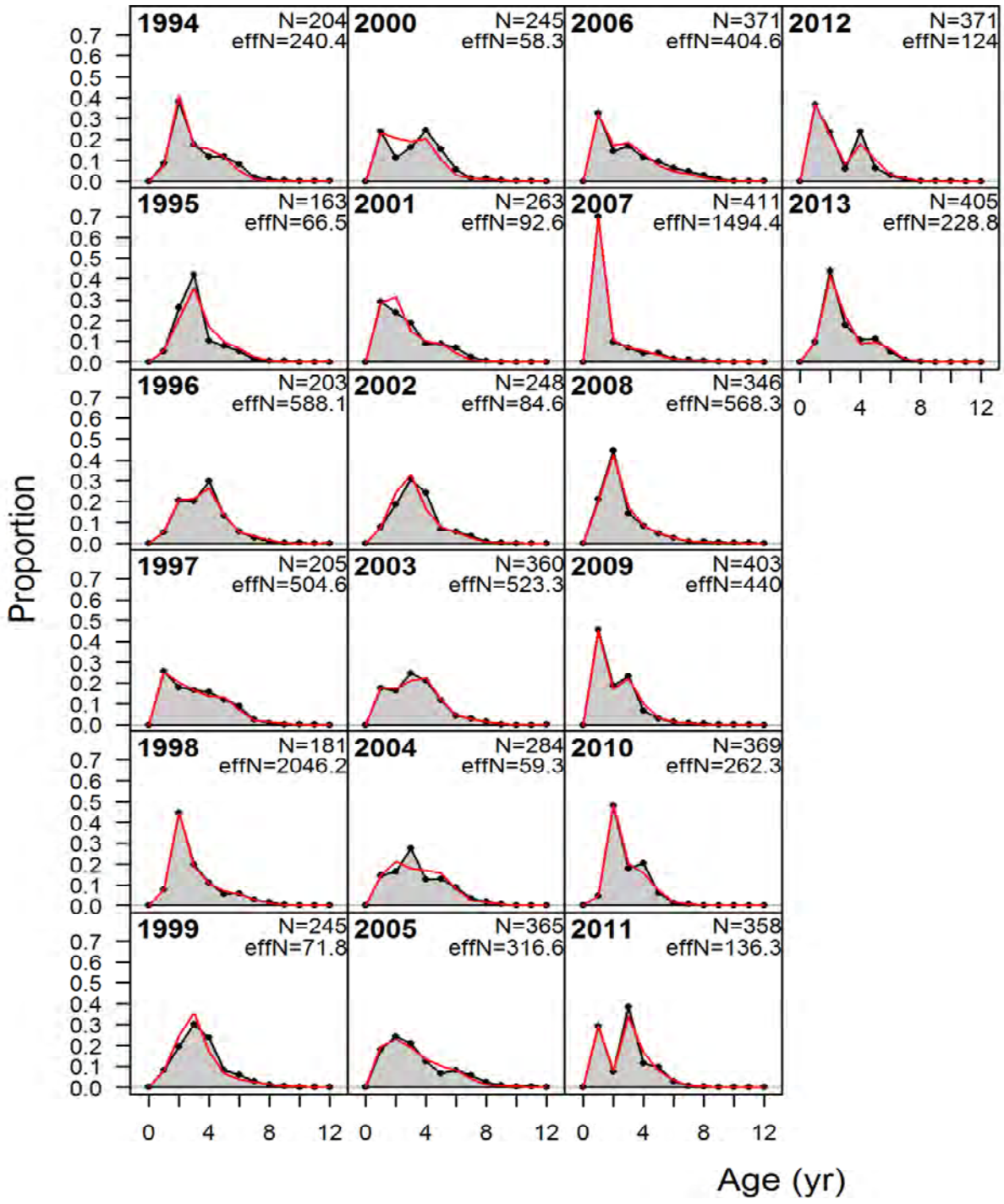


Figure 2.5b—Fit to trawl survey age composition data obtained by Model 2 (grey = observed, red = estimated).

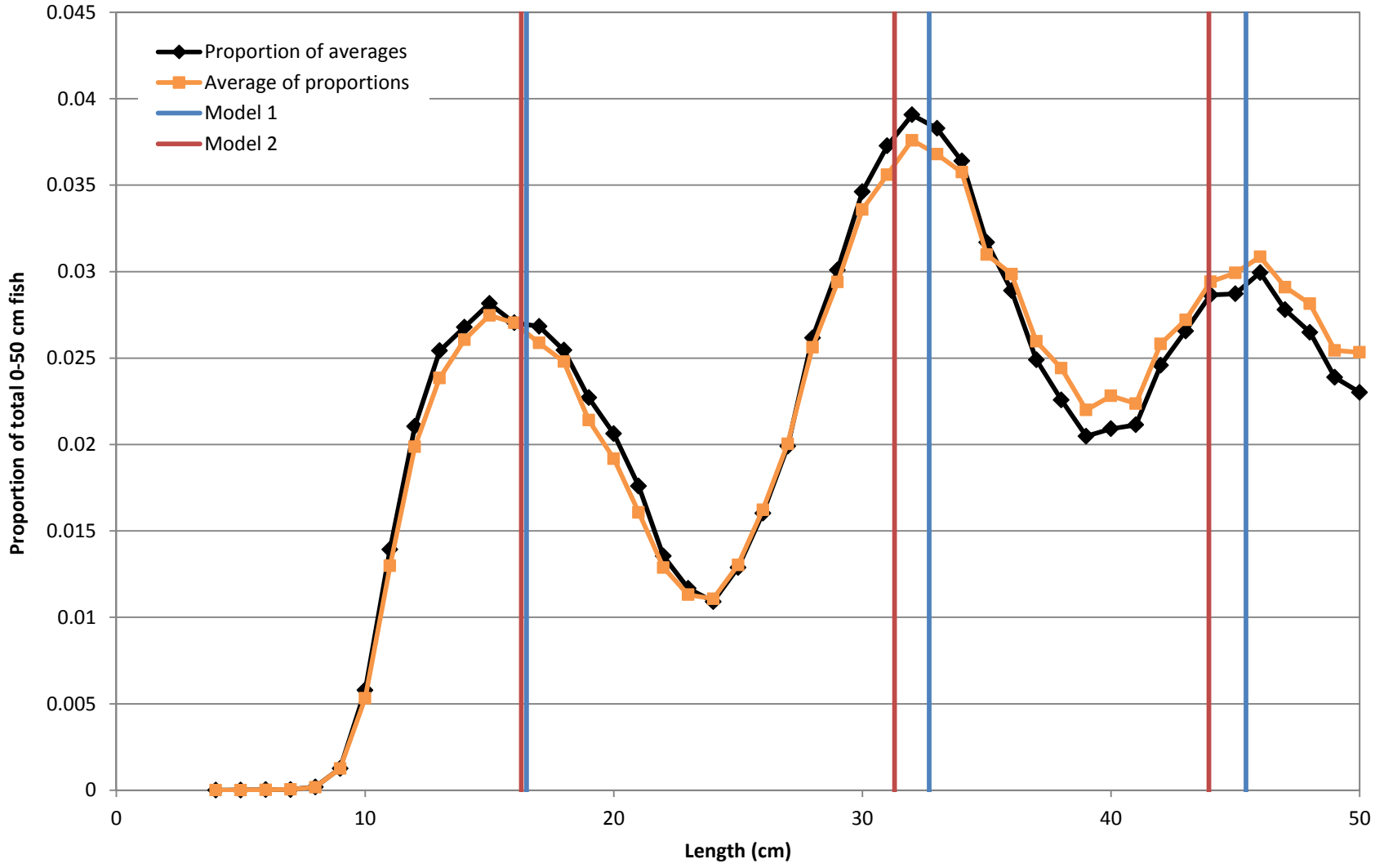


Figure 2.6—Estimates of mean size at ages 1-3 from Models 1 and 2, compared to long-term average survey size (0-50 cm) composition.

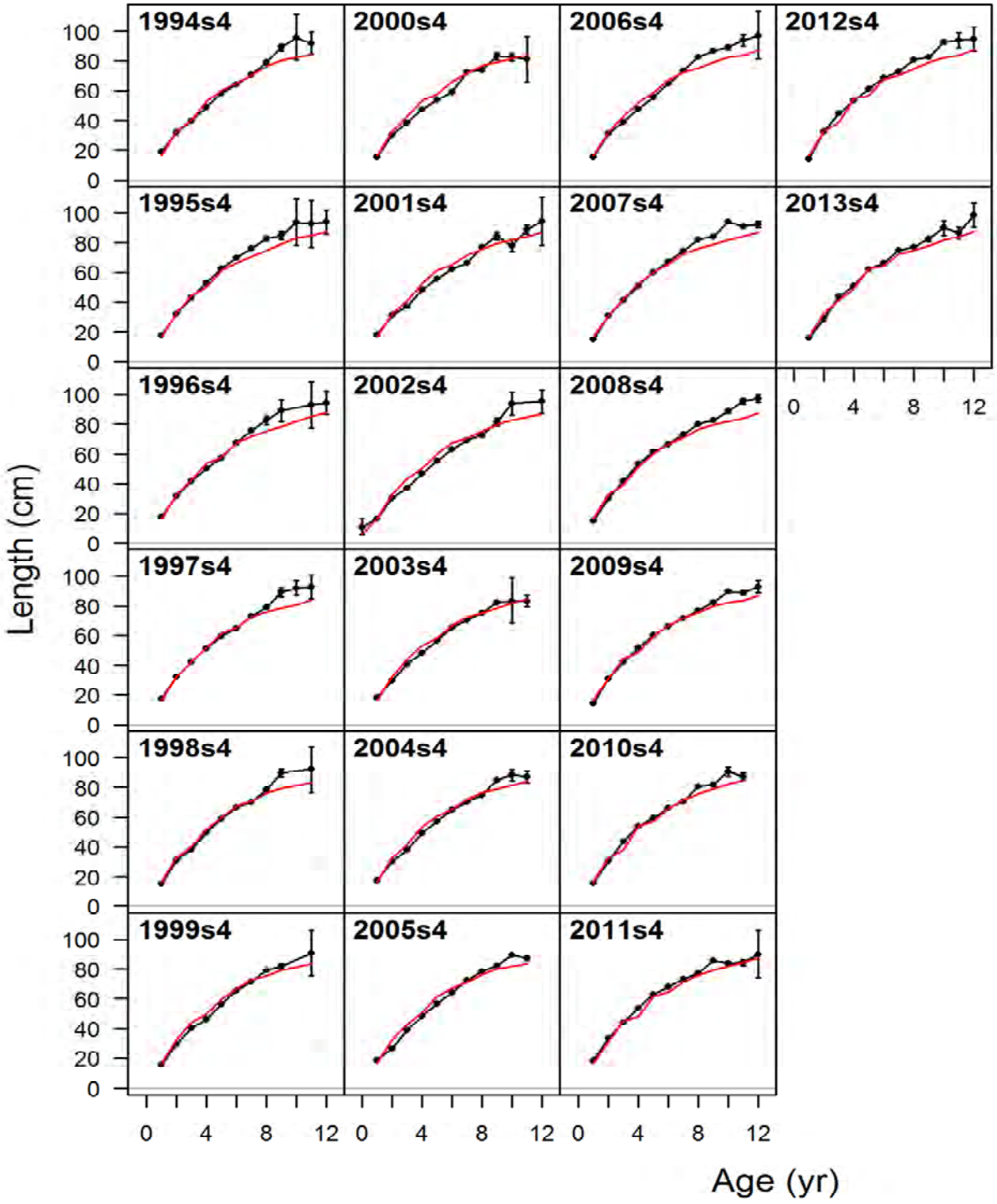


Figure 2.7—Fit to mean-size-at-age data from Model 1 (black = observed, red = estimated). Model 2 does not include mean-size-at-age data.

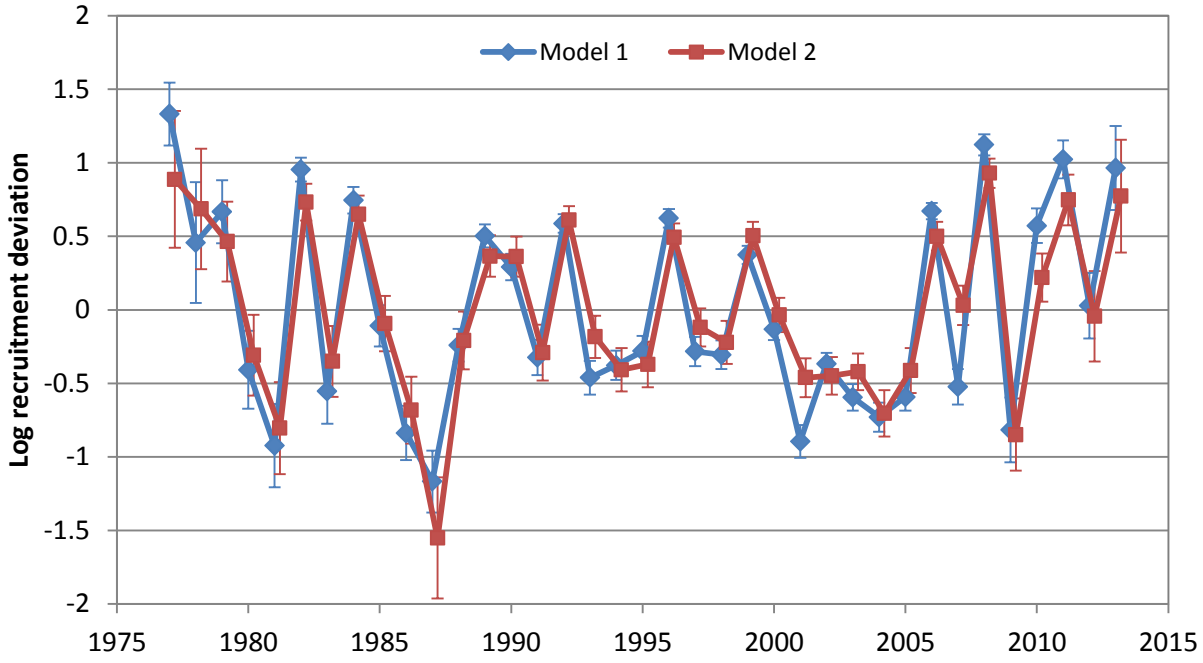


Figure 2.8—Time series of estimated log recruitment deviations as estimated by Models 1 and 2, with 95% confidence intervals.

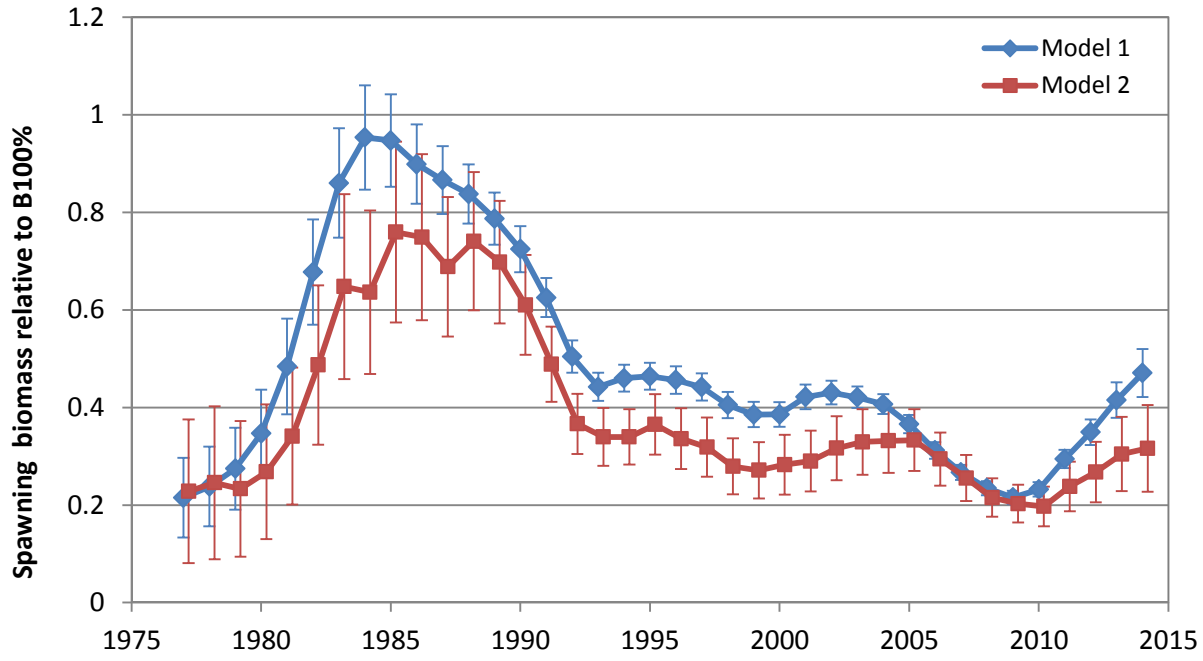
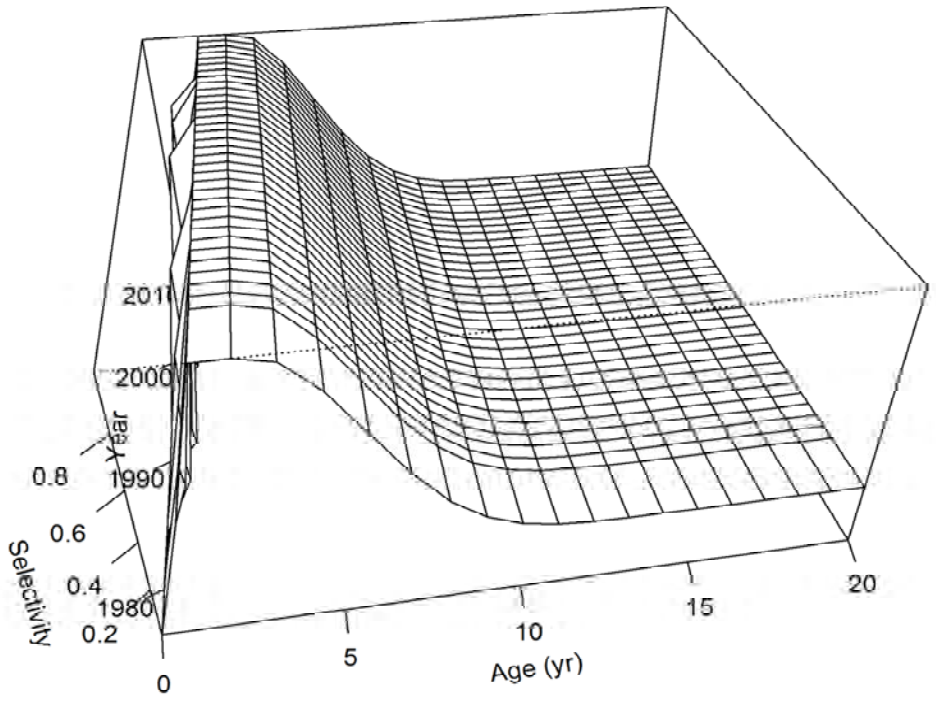


Figure 2.9—Time series of spawning biomass relative to $B_{100\%}$ as estimated by Models 1 and 2.

Model 1



Model 2

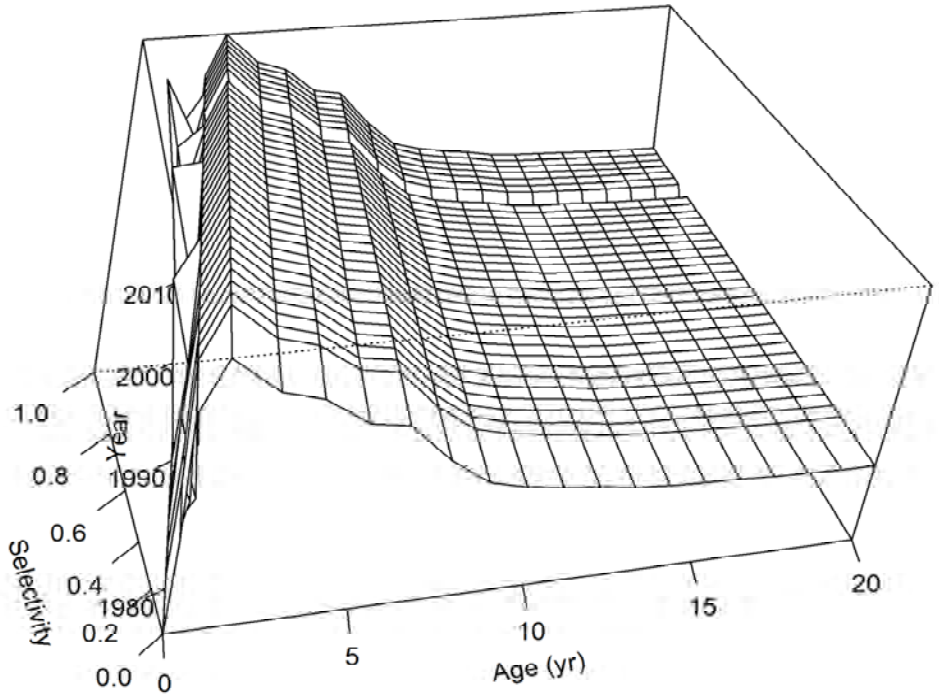


Figure 2.10—Trawl survey selectivity at age as estimated by Models 1 and 2.

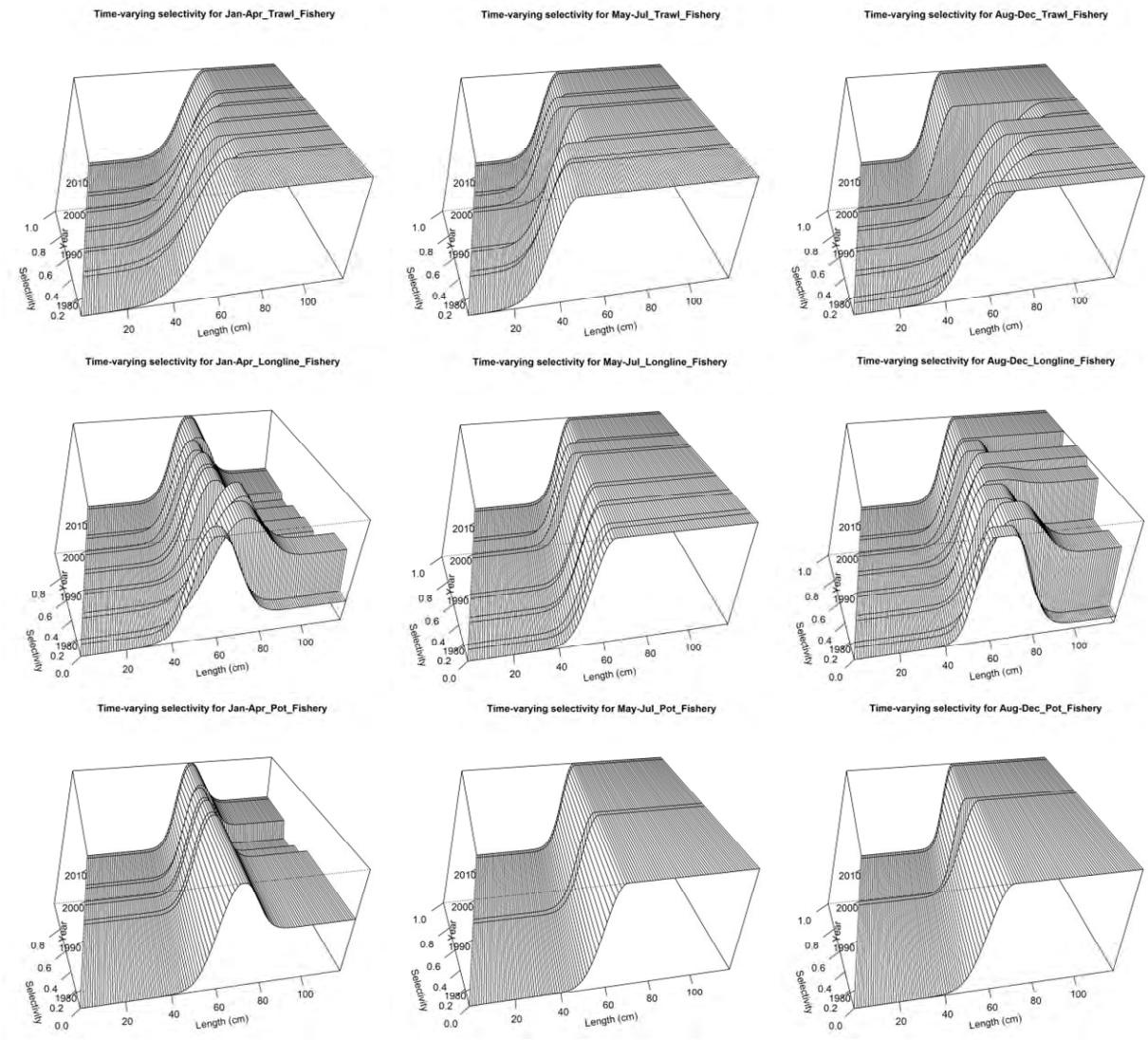


Figure 2.11a—Fishery selectivity at length (cm) as estimated by Model 1. Rows represent gear types (trawl, longline, and pot, respectively), and columns represent seasons (Jan-Apr, May-Jul, and Aug-Dec, respectively).

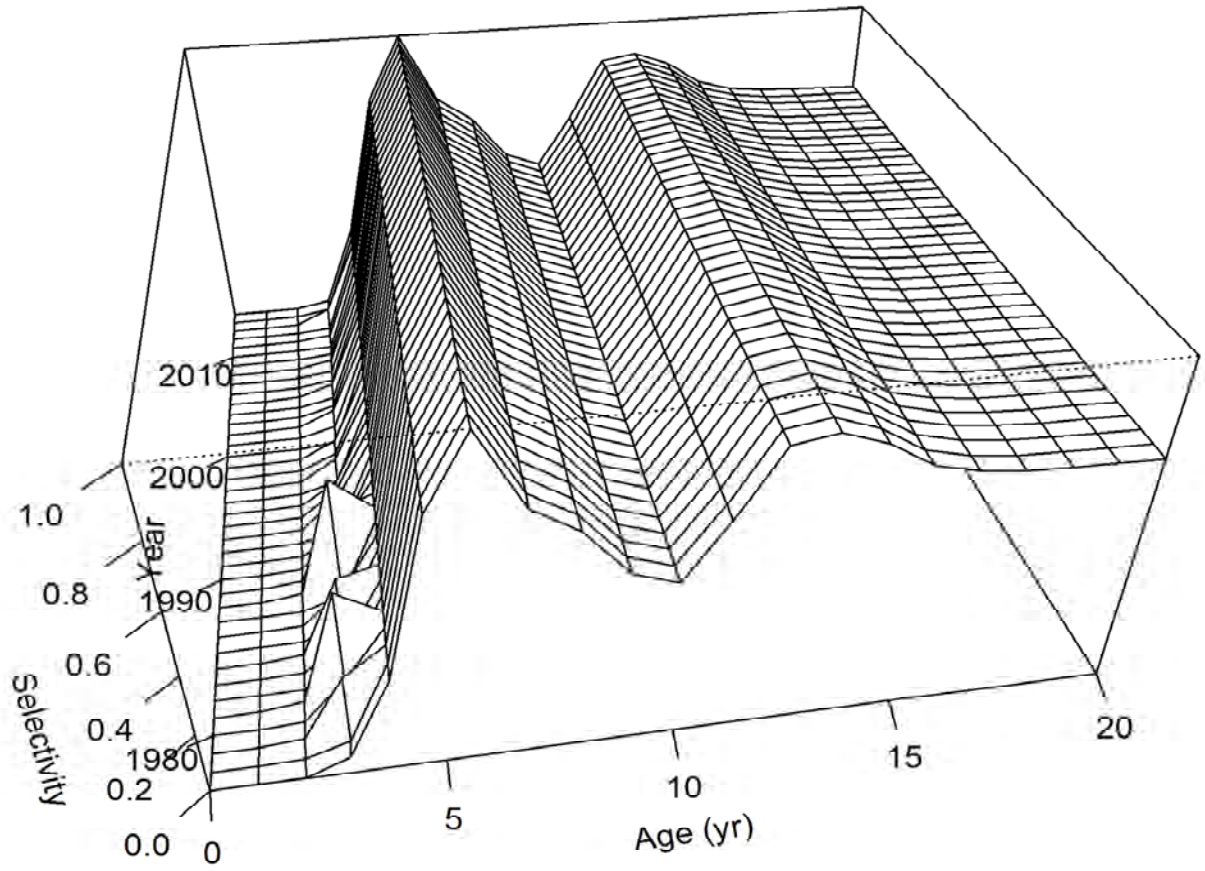


Figure 2.11b—Fishery selectivity at age as estimated by Model 2.

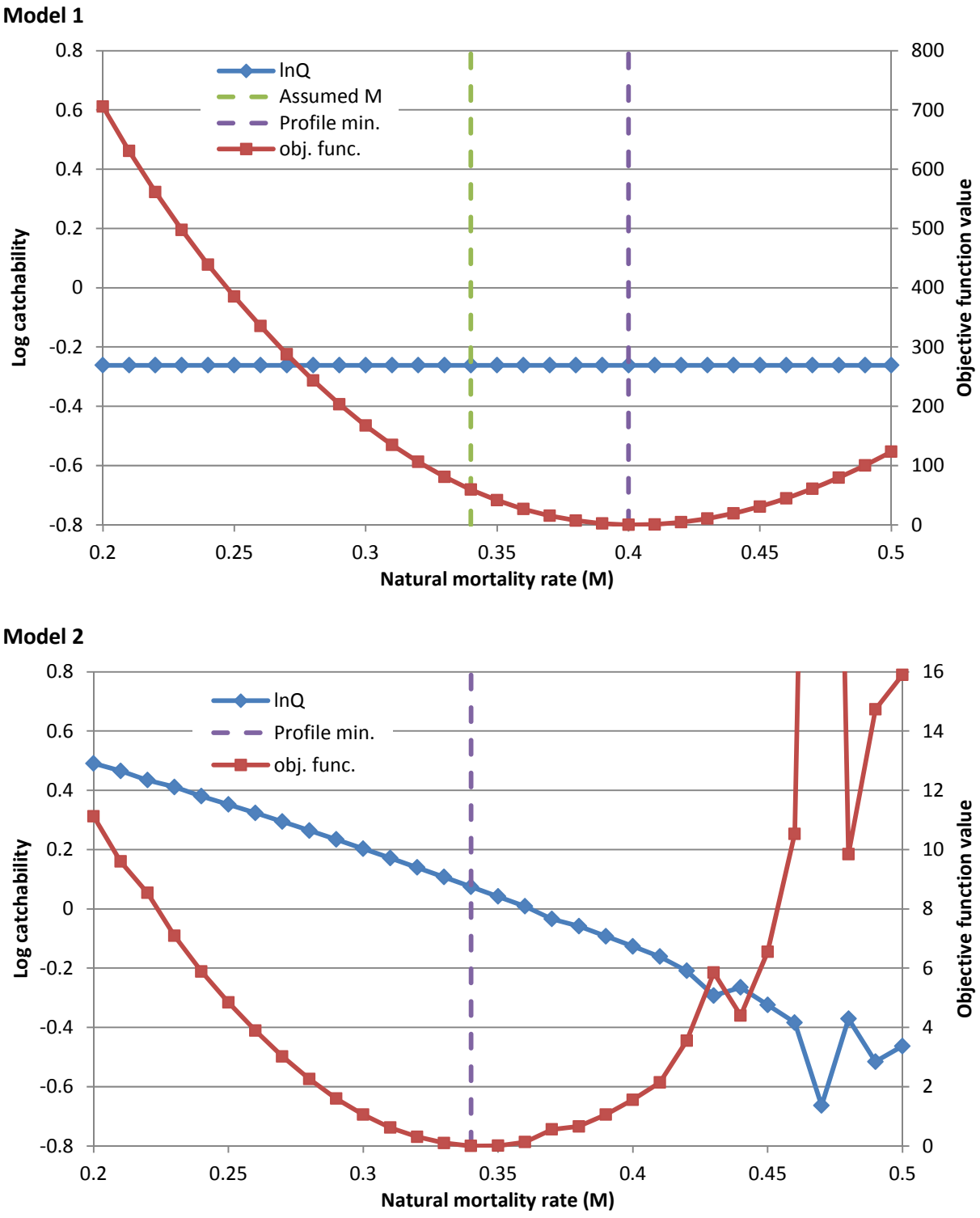


Figure 2.12— Likelihood profiles with respect to the natural mortality rate for Models 1 and 2. Objective function minima occur at M=0.40 (Model 1) and M=0.34 (Model 3). The relationship between M and log Q is also shown (Q is not estimated in Model 1). The jagged shapes for high values of M in Model 2 are likely due to lack of convergence in some runs.

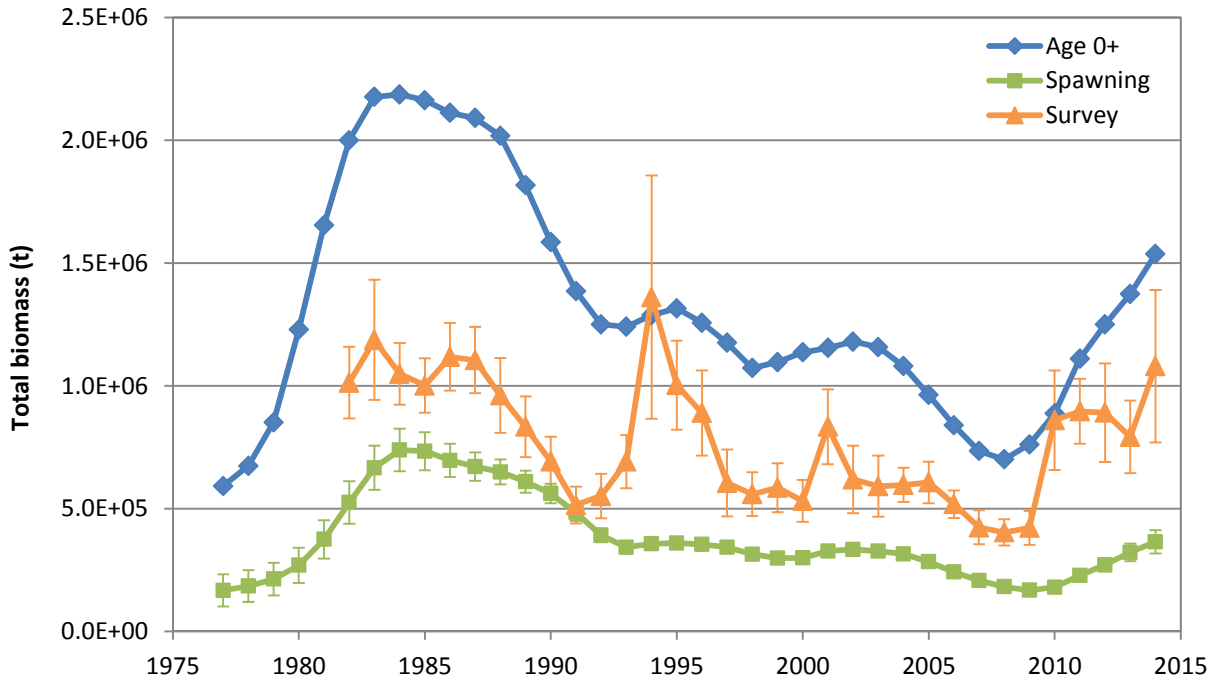


Figure 2.13—Time series of age 0+ and female spawning biomass as estimated by Model 1. Survey biomass is shown for comparison.

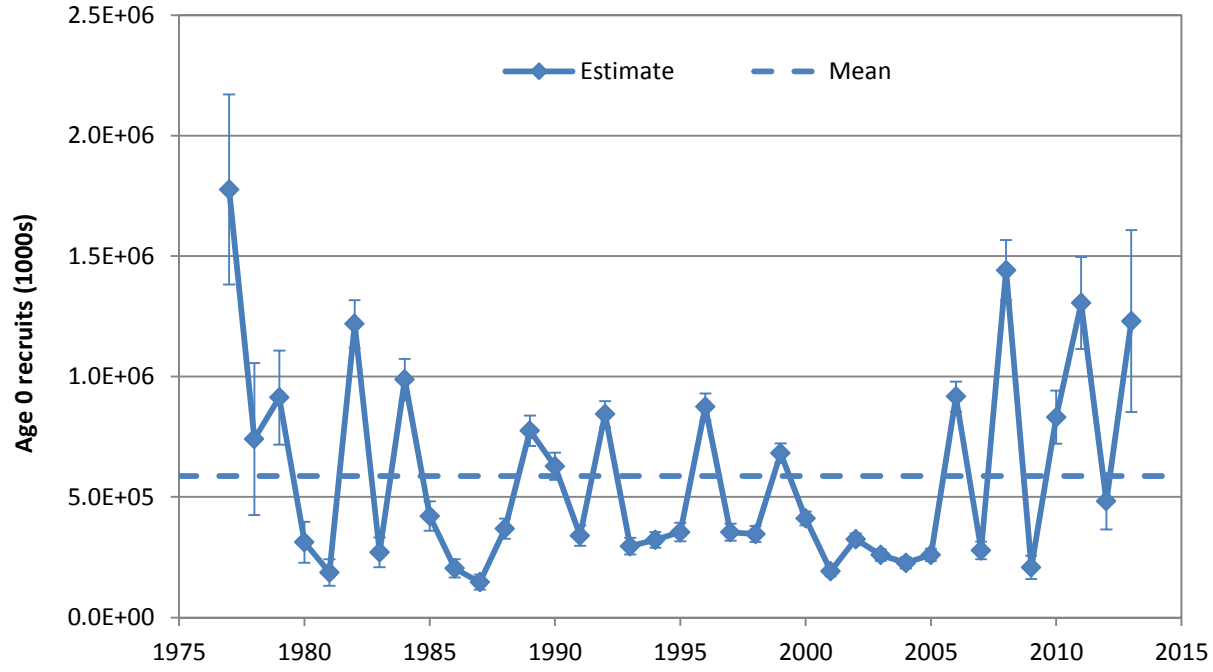


Figure 2.14—Time series of recruitment at age 0 as estimated Model 1.

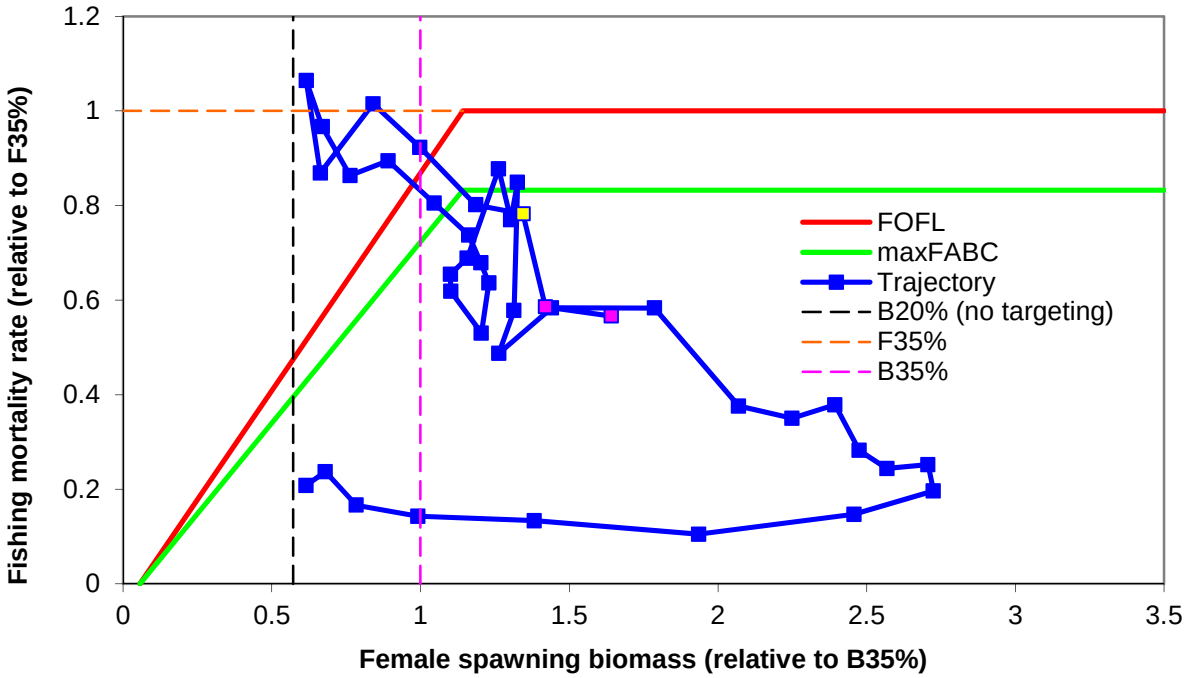


Figure 2.15—Trajectory of Pacific cod fishing mortality and female spawning biomass as estimated by the stock assessment model, 1977-present (yellow square = current year, magenta squares = first two projection years).

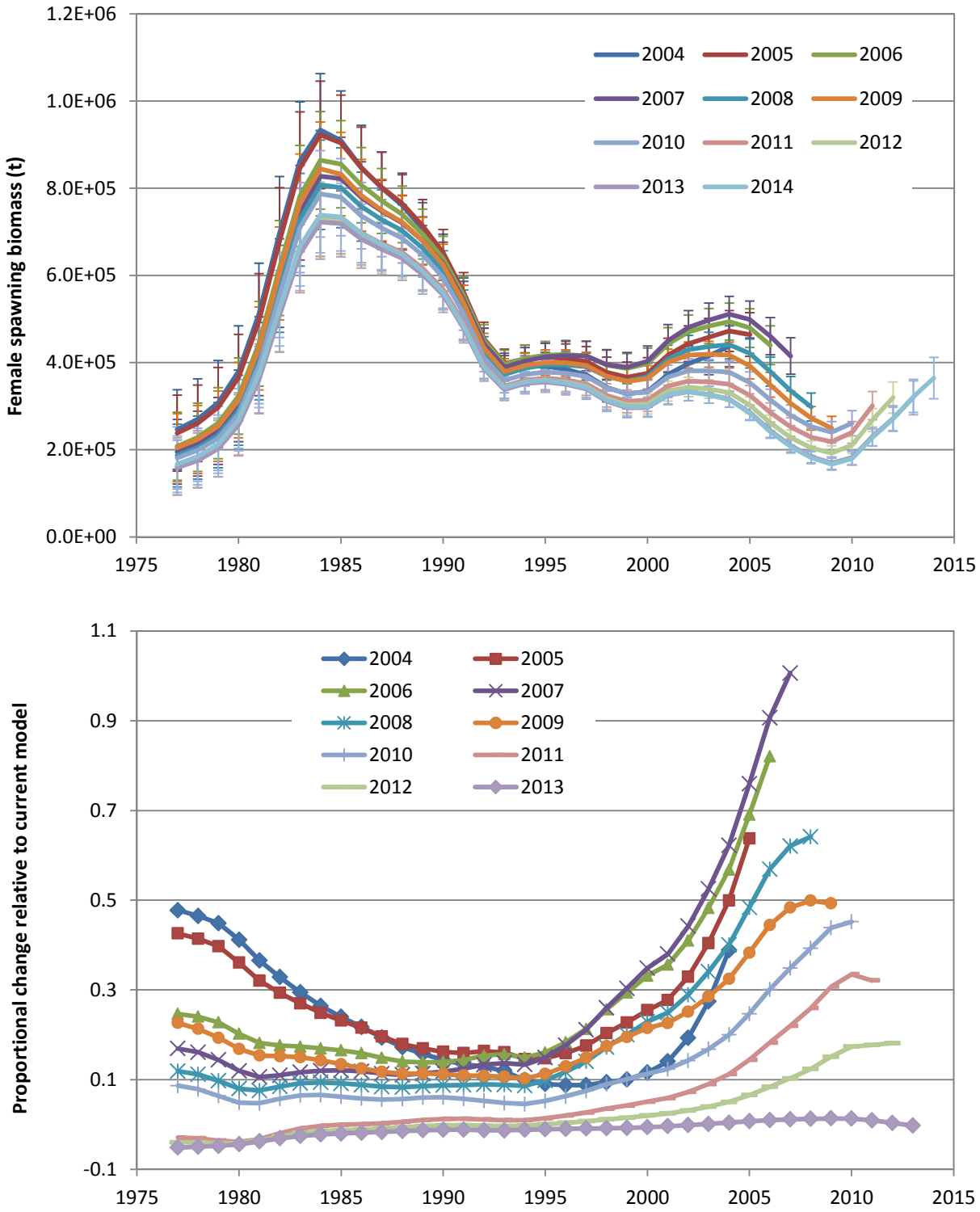


Figure 2.16—Retrospective analysis of spawning biomass estimates from Model 1. Top panel: spawning biomass time series with 95% confidence intervals from the current version of Model 1 (2014) and 10 retrospective runs (2004-2013) obtained by dropping one year of data at a time. Bottom panel: change in spawning biomass relative to the current version of Model 1 for each of 10 retrospective runs.

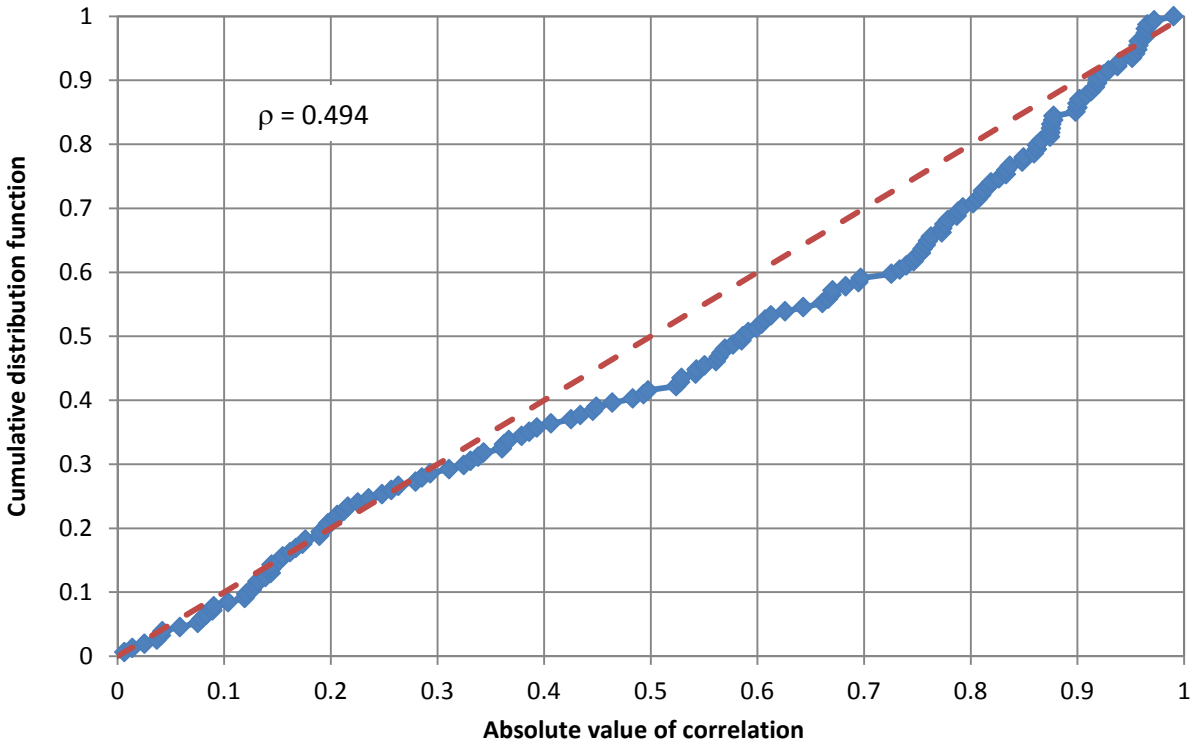


Figure 2.17—Cumulative distribution function (cdf) of correlations (absolute value) between model parameters and number of "peels" in retrospective runs. The diagonal dashed line represents the cdf that would be obtained from a uniform distribution. The statistic ρ represents the average (across peels) relative bias in terminal year estimates of spawning biomass.

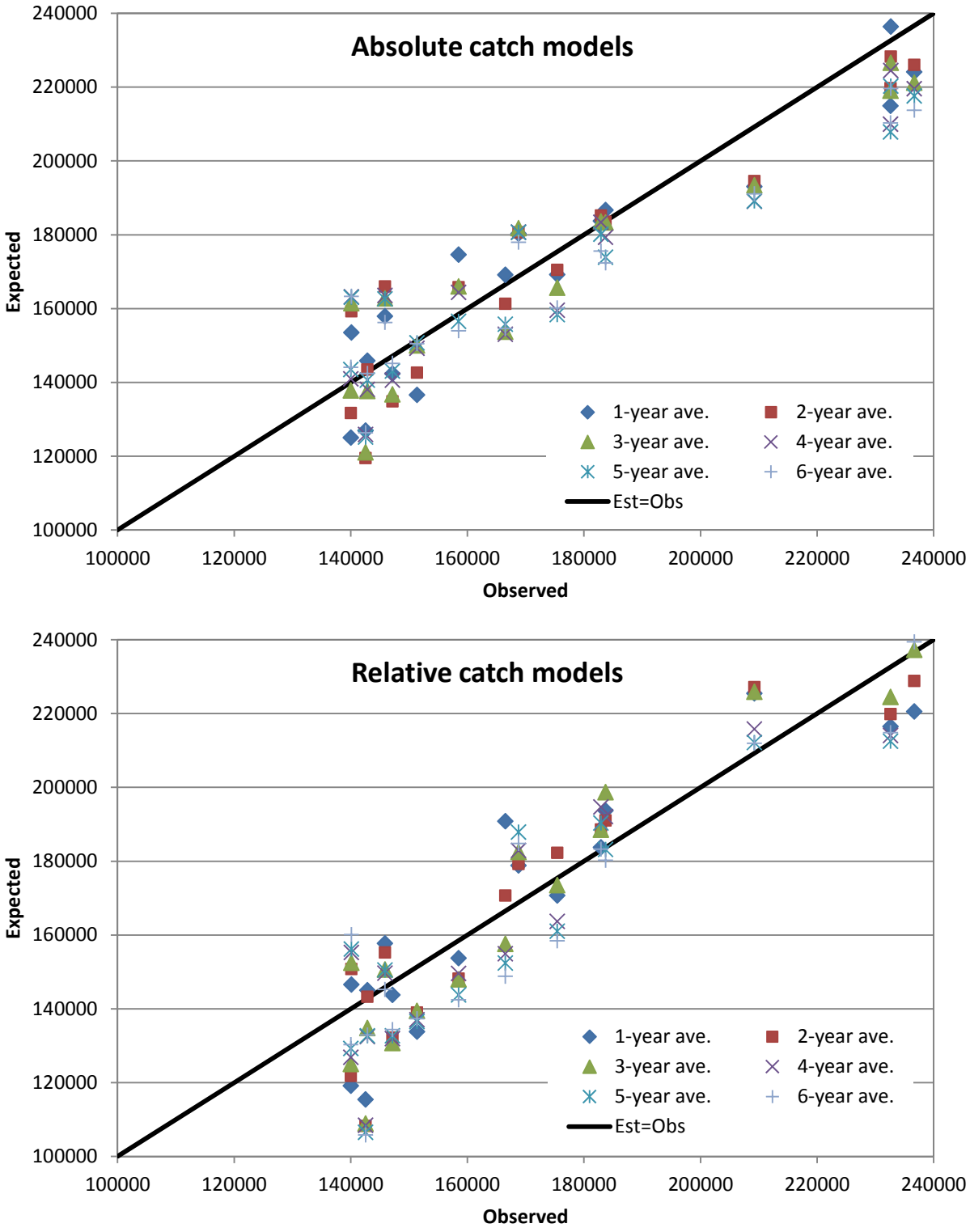


Figure 2.18—Estimators of current-year catch as a function of either absolute or relative August-December catch in some number (1-6) of previous years. Estimators with symbols closer to the diagonal line are better than others.

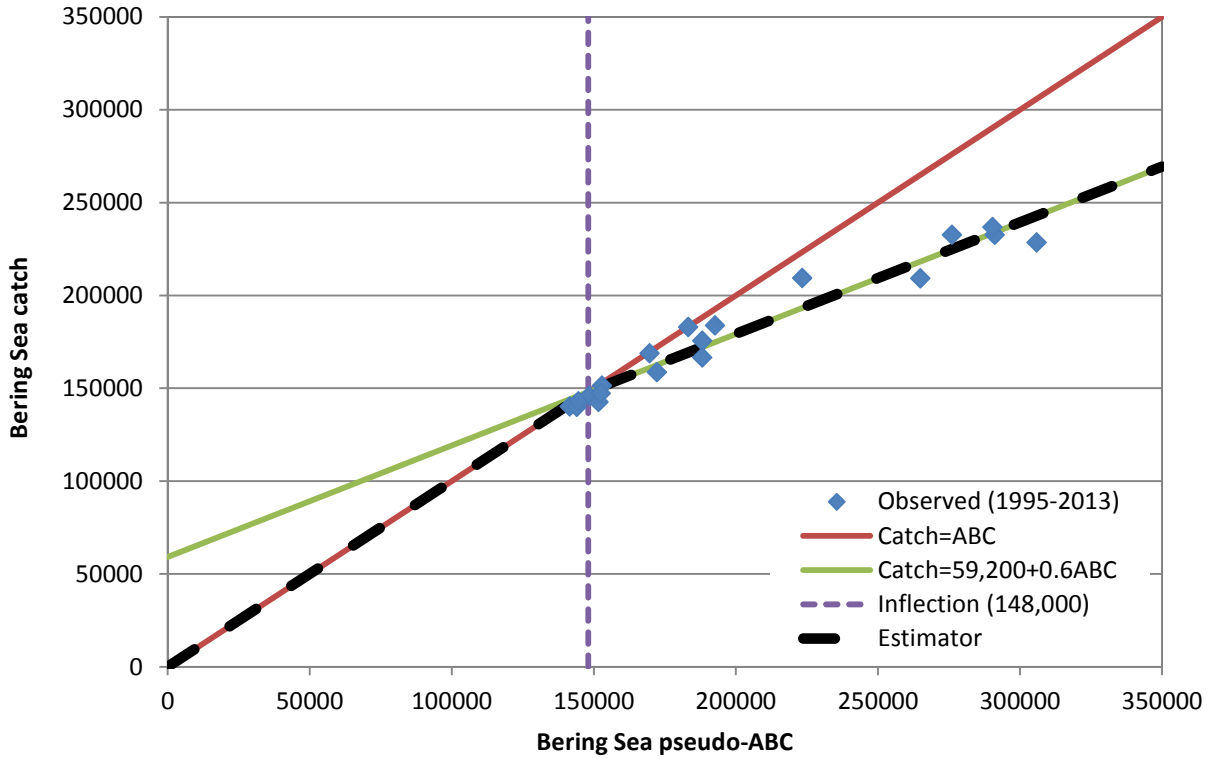


Figure 2.19—Estimation of catch as a function of ABC. Because Pacific cod ABCs through 2013 were specified for the entire BSAI region, "pseudo-ABCs" are shown here, computed by multiplying the overall ABC by the proportion of BSAI catch taken in the EBS. The estimator represented by the dashed black line segments was used to project 2015 and 2016 catch.

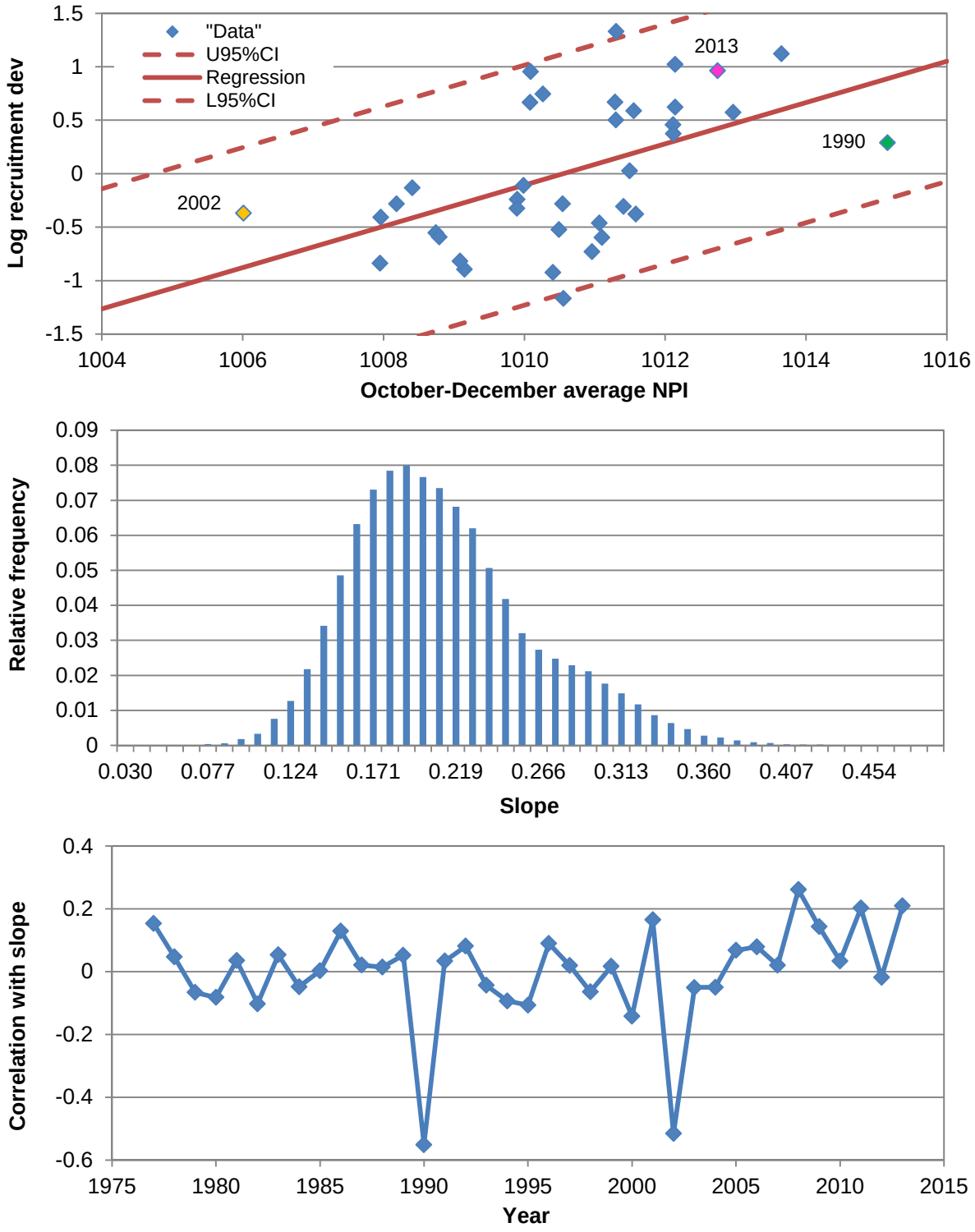


Figure 2.20—Environmental effects on recruitment. Upper panel: Estimated log recruitment *dev*s (age 0) versus same-year October-December average of the NPI, with regression line and 95% confidence interval. Middle panel: Distribution of the regression slope, as generated by a cross-validation analysis. Lower panel: Correlation between individual data points and regression slope. See text for details.

APPENDIX 2.1: PRELIMINARY ASSESSMENT OF THE PACIFIC COD STOCK IN THE EASTERN BERING SEA

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Introduction

This document represents an effort to respond to comments made by the BSAI Plan Team, the Joint BSAI and GOA Plan Teams, and the SSC on last year's assessment of the Pacific cod (*Gadus macrocephalus*) stock in the eastern Bering Sea (EBS, Thompson 2013).

Responses to SSC and Plan Team Comments on Assessments in General

Because last year's SSC and Plan Team comments pertaining to assessments in general all dealt with features of the final SAFE chapters, they will be addressed in this year's final assessment.

Responses to SSC and Plan Team Comments Specific to Eastern Bering Sea Pacific Cod

Note: In previous years, the full Joint Plan Teams have met in the spring to consider recommendations for models to be included in that year's Pacific cod assessments. In 2014, this task was delegated to a Joint Team Subcommittee (JTS) on Pacific Cod Models.

BPT1 (9/13 minutes): *"The Plan Team recommended that studies of the vertical distribution of Pacific cod continue in order to test the previous finding that the average product of survey catchability and selectivity across the 60-81 cm size range is 0.47 (based on vertical distribution from archival tags). These studies should include: 1) analysis of existing fish acoustic data (as recommended by Bob Lauth); and 2) depending on the results of that analysis, repeat the 2012 experiment in an area where Pacific cod are distributed farther off bottom and using an acoustic buoy to measure vertical response to the passing vessel."* When any such studies have been completed, their results will be evaluated for possible use in the assessment. See also comments BPT4 and SSC5.

BPT2 (9/13 minutes): *"The Team recommended the following candidate models for the November meeting, intended to provide a number of alternatives to the present standard Model 1:*

i. *Model 1: the standard for the last two years.*
ii. *Model 2a: Model 2 from the September meeting, with fixed M and freely estimated survey Q.*
iii. *Model 2b: Model 2 from the September meeting, with fixed M but annually varying survey Q (mean value and dev vector estimated freely).*
iv. *Model 3a: Model 3 from the September meeting, with asymptotic survey selectivity and a prior on survey Q.*
v. *Model 3b: Like Model 3a but with M estimated.*
vi. *Model 4: Same as last year's Model 4.*

The Team recommended that the author feel free to apply the iterative tuning procedures to Model 4 only, and use the values of the iteratively tuned quantities from Model 4 for the remaining models (other than Model 1) because all of the models other than Model 1 involve labor-intensive iterative tuning, and given

that all of these iteratively tuned models are based to some extent on Model 4." Because of last year's October government shutdown, this comment was not addressed in last year's final assessment, but was forwarded to the Joint Team Subcommittee on Pacific Cod Models for consideration at its March 2014 meeting. See comments JTS2, JTS3, and SSC7.

SSC1 (10/13 minutes): *"The SSC notes that all of the Pacific cod models are characterized by a large number of parameters and dome-shaped selectivities, features that were found to be associated with retrospective patterns and a higher risk of overfishing in the meta-analysis by Hanselman et al. (see separate section). The SSC has previously encouraged the authors to simplify the models when possible and appreciates the suggestion by Grant Thompson (AFSC) to consider omitting seasonal structure in one or more of these models in the future."* Because of last year's October government shutdown, this comment was not addressed in last year's final assessment, but was forwarded to the Joint Team Subcommittee on Pacific Cod Models for consideration at its March 2014 meeting. See comments JTS2, JTS3, and SSC7.

SSC2 (10/13 minutes): *"The SSC agrees with Plan Team recommendations regarding models to bring forward in December. In addition to the recommended model configurations, the SSC would like to see a model or models that fix survey catchability at Q=1. We suggest presenting variants of model 2a (or 2b with mean Q=1) and model 3a with Q=1. Our rationale for this request is based on the increasing evidence that catchability is higher and quite possibly much higher than the current standard assumption that selectivity in the 60-81 cm size range is 0.47, which is based on a limited study by Nichol (2007). Evidence from an unpublished study conducted in 2012 (Lauth) suggests that there is no difference in catchability between the low-opening (2.5 m) trawl used in the Bering Sea survey and the high opening (7 m) trawl used in the Gulf of Alaska survey. Moreover, observations of acoustic backscatter showed that Pacific cod tended to be near the bottom in the study area, consistent with a dive response to passing vessels commonly observed in other gadids. We note that the default assumption in most assessments is that survey catchability is 1, unless there is strong evidence to the contrary. The evidence to date consists of the vertical distribution of 11 tagged fish under undisturbed conditions over a period of one month (Nichol et al 2007)."* Because of last year's October government shutdown, this comment was not addressed in last year's final assessment, but was forwarded to the Joint Team Subcommittee on Pacific Cod Models for consideration at its March 2014 meeting. See comments JTS2, JTS3, and SSC7.

BPT3 (11/13 minutes): *"The Team recommended … the following candidate models for next year's September meeting:*

a. *Model 1: 2011-2012 standard (rationale: standard practice)*
b. *Model 2b: Model 4 from the 2012 assessment with fixed M, free survey selectivity, and annually varying survey Q (freely estimated mean and dev vector; rationale: … survey data simply cannot be fitted with a constant survey Q)*
c. *Model 3a: Model 4 from the 2012 assessment with fixed M, asymptotic survey selectivity, and Q=1 (rationale: an asymptotic candidate, one of the models requested by the SSC)*
d. *Model 3b: Like Model 3a but with M estimated (rationale: a check on the effect of freeing M)"*

This comment was forwarded to the Joint Team Subcommittee on Pacific Cod Models for consideration at its March 2014 meeting. See comments JTS2, JTS3, and SSC7.

BPT4 (11/13 minutes): *"The Team also repeated its previous recommendation that studies of the vertical distribution of Pacific cod continue in order to test the previous finding that the average product of survey catchability and selectivity across the 60-81 cm size range is 0.47 (based on vertical distribution from archival tags). These studies should include: 1) analysis of existing fish acoustic data (as recommended by Bob Lauth); and 2) depending on the results of that analysis, repeat the 2012*

experiment in an area where Pacific cod are distributed farther off bottom and using an acoustic buoy to measure vertical response to the passing vessel." When any such studies have been completed, their results will be evaluated for possible use in the assessment. See also comments BPT1 and SSC5.

SSC3 (12/13 minutes): *"The SSC re-iterates its concerns over the best value for the catchability coefficient (see December 2012 and October 2013 minutes), which prompted an SSC request additional model runs in October with catchability fixed at 1. In addition to the models already requested by the Plan Team in September 2013, this resulted in a large number of requested models. The Plan Team reduced the suite of models to three models in addition to the current base model, implementing changes to both Q and survey selectivity simultaneously and, secondly, exploring the effect of estimating M freely. The SSC discussed the need for a more incremental approach to implementing changes to the model. The two main issues of concern at this time are the shape of the selectivity function and the appropriate value for catchability (Q). Therefore, the SSC suggests a modeling approach that evaluates changes to selectivity and Q separately and in combination. To limit the number of requested model configurations, the SSC suggests that the Plan Team request for a model that freely estimates M be deferred to a future assessment."* This comment was forwarded to the Joint Team Subcommittee on Pacific Cod Models for consideration at its March 2014 meeting. See comments JTS2, JTS3, and SSC7.

SSC4 (12/13 minutes): *"Therefore, the SSC requests the following models to be brought forward in the 2014 assessment cycle. These recommendations pertain to the overall model structure only and would not preclude updating any of the models with new information. For example, if new estimates of catchability from the proposed analysis of acoustic data become available in time, they should be included in any of the models that are tuned to an empirical estimate of catchability.*

1. *The current base model (same as 2011, 2012) for comparison.*
2. *Model 4 from the 2012 assessment. Rationale: This model implemented a large number of changes relative to the base model and produced a good fit to the data in the 2012 assessment. However, the model was not accepted in 2012 because it had not been fully vetted. Re-fitting the model with 2 years of new data would allow further vetting of the model as a potential new base model and can serve as a basis for exploring the effects of modifying the shape of the survey selectivity function and changing Q.*
3. *Model 4 with annually varying survey Q (freely estimated mean and dev vector). Rationale: This follows a Plan Team recommendation reflecting the senior author's conviction that the survey data cannot be fitted with a constant survey Q. The SSC also notes that time-varying catchability was recognized at a recent international meeting as a possible avenue for improving stock assessments.*
4. *Model 4 with survey catchability fixed at Q=1. Rationale: The default assumption in most assessments is that survey catchability is 1, unless there is strong evidence to the contrary. The evidence for a lower Q has been put into question based on recent work and is more fully detailed in our October 2013 minutes. This model will allow an evaluation of the effect of fixing Q without also changing the way selectivity is parameterized to help untangle effects of changing Q and changing selectivity.*
5. *Model 4 with fixed Q = 1 and asymptotic survey selectivity. Rationale: This model was previously recommended by the SSC and recommended by the Plan Team in November 2013 to help understand the consequences of using dome-shaped versus asymptotic selectivity in the model."*

This comment was forwarded to the Joint Team Subcommittee on Pacific Cod Models for consideration at its March 2014 meeting. See comments JTS2, JTS3, and SSC7.

SSC5 (12/13 minutes): *"To improve our understanding of survey catchability and provide better empirical estimates of selectivity, the SSC endorses the Plan Team recommendations with regard to survey catchability, specifically studies of the vertical distribution of Pacific cod, including an analysis of existing acoustic data."* When any such studies have been completed, their results will be evaluated for possible use in the assessment. See also comments BPT1 and BPT4.

JTS1 (3/14 minutes): *"The subcommittee discussed the SSC's minute from December 2011 requesting that the final 2011 model for each stock be evaluated over "several amendment cycles," noting that the definition of "several" is unclear. For the EBS, the 2011 model was re-evaluated in 2012 and 2013. For the GOA, the 2011 model was re-evaluated in 2012, but not in 2013 due to the government shutdown in October of that year. For this year, the subcommittee proceeded under the assumption that the SSC wishes to continue re-evaluating the 2011 models. However, the subcommittee recommended that 2014 be the final year for re-evaluation of the 2011 models, unless the 2011 model in one or more regions is chosen as the final model in 2014."* The final 2011 model is included in this preliminary assessment as Model 1. However, see also comment SSC10.

JTS2 (3/14 minutes): *"For the EBS, the subcommittee recommended that the following models be developed for this year's preliminary assessment:*

- *Model 1: Final model from 2011 (same as the final models from 2012 and 2013)*
- *Model 2: Model 5 from the 2012 preliminary assessment (same as Model 4 from the 2012 final and 2013 preliminary assessments)*
- *Model 3: Same as Model 2 in this list, but with:*
    - *survey catchability fixed at 1.0*
- *Model 4: Model 2 from the 2013 preliminary assessment, but with:*
    - *an internally estimated constant added to each year's survey abundance sigma*
- *Model 5: Model 3 from the 2013 preliminary assessment, but with:*
    - *survey catchability fixed at 1.0*
    - *natural mortality estimated freely"*

The above models are included in this preliminary assessment. See also comments JTS3 and SSC7.

JTS3 (3/14 minutes): *"In addition to the models contained in the above lists, the subcommittee expressed special interest in certain other models, but left development of those up to the respective author's discretion rather than including them in the lists of requested models. For the EBS, the discretionary models were as follow:*

- *A new model (author's choice) with no seasonal structure*
- *A new model (author's choice) with gear-specific fisheries and no seasonal structure"*

The first of the above optional models is included in this preliminary assessment as Model 6. See also comments SSC1 and SSC7.

SSC6 (4/14 minutes): *"The process for developing and refining appropriate models for Pacific cod still needs to mature and the SSC recommends that the assessment authors continue to work with the subcommittee to refine this process."* The authors will continue to work with the subcommittee to refine the process of developing appropriate models for Pacific cod. The next meeting of the subcommittee is anticipated to take place in the spring of 2015.

SSC7 (4/14 minutes): *"For 2014, the SSC recommends as an alternative model the use of the time-varying, non-parametric selectivity function described above"* (the reference to "above" in this comment

pertains to a recommendation for modeling selectivity as a random walk with respect to age in the GOA Pacific cod assessment). Model 6 in this preliminary assessment includes the time-varying, non-parametric selectivity function.

SSC8 (4/14 minutes): *"Additionally, profiling over the natural mortality rate should be conducted to gain a better understanding of the relationship between global scaling (Q and its associated priors) and natural mortality rate. The mode of the M-profile should not be used as a basis for setting the natural mortality rate in the model as it is conditional on other structural assumptions in the model."* Likelihood profiles with respect to the natural mortality rate are included for all models in this preliminary assessment. The mode is not used for setting the natural mortality rate in Models 1-4, but it is used in Model 5 per request of the Joint Team Subcommittee on Pacific Cod Models (see comment JTS2) and Model 6 ("author's choice," per comment JTS3).

SSC9 (4/14 minutes): *"Lastly, the SSC recommends that as an overarching goal for these three areas, a common model structure be explored and based on the biology of Pacific cod and not devolve over time to address area-specific outliers or retrospective biases"* (the "three areas" referred to in this comment are the EBS, AI, and GOA). The model structures for all three areas already share several features in common. As further steps toward developing a common model structure, Model 6 in this preliminary assessment and all models in the preliminary assessment of the AI stock use the same fleet structure and the same approach to selectivity.

SSC10 (4/14 minutes): *"In light of the presentation, the SSC clarified its intent regarding the use of the base model ('base' being used here to identify the model accepted by the SSC in the previous year) for 'several' years. While the SSC cannot be prescriptive about the exact length of time this would be, the idea is to continue the use of the model until there is general agreement by the stock assessment authors, the Plan Team, and the SSC on discontinuing its use."* The model accepted by the SSC last year is included in this preliminary assessment as Model 1. However, an ambiguity remains: The SSC's request for continued evaluation of the final 2011 model (SSC minutes, December 2011) was not tied to that model being accepted by the SSC as the final model in each subsequent year. The question remains, then, as to how long the final 2011 model needs to be included among the set of candidate models in the event that the SSC chooses some other model as "final."

SSC11 (4/14 minutes): *"The SSC discussed the use of model averaging to ameliorate some of the problems of choosing among competing models with substantially different estimates. Essentially, the SSC agrees with the analyst that this approach should not be used until progress is made regarding issues about the selection of the competing models and averaging over models with nonlinearities in population and fishery processes."* Model averaging is not used in this preliminary assessment.

SSC12 (4/14 minutes): *"The SSC also discussed the nomenclature used to specify models in a historical context (when introduced and the model designator). While the SSC understands that this was useful for the historical presentation, it also notes that the nomenclature is confusing and probably not useful for the assessment in a given year. Furthermore, the use of 'base model' to denote any model that is proposed seems overly inclusive and perhaps should be restricted to the chosen model in a previous assessment year."* Use of the term "base model" will henceforth be restricted to denoting the chosen model in a previous assessment year.

Data

The data used in this preliminary assessment are identical to those used in last year's final assessment, except that estimates of base, seasonal, and annual weight-length parameters were updated using the method described in Thompson and Lauth (2012, Annex 2.1.2).

The following table summarizes the sources, types, and years of data included in the data file for one or more of the stock assessment models:

Source	Type	Years
Fishery	Catch biomass	1977-2013
Fishery	Catch size composition	1977-2013
Fishery	Catch per unit effort	1991-2013
EBS shelf bottom trawl survey	Numerical abundance	1982-2013
EBS shelf bottom trawl survey	Size composition	1982-2013
EBS shelf bottom trawl survey	Age composition	1994-2012
EBS shelf bottom trawl survey	Mean size at age	1994-2012

Model Structures

All of the models presented in this preliminary assessment were developed using Stock Synthesis (SS, Methot and Wetzel 2013). The version used to run all models was SS V3.24s, as compiled on 7/24/2013 (Methot 2013). Stock Synthesis is programmed using the ADMB software package (Fournier et al. 2012).

Six models are presented. As requested by the Joint Team Subcommittee (comment JTS2), Model 1 in this preliminary assessment is the same as last year's final model (which was also the final model in 2011 and 2012). Model 2 is the same as Model 5 in the 2012 preliminary assessment (which is the same as Model 4 in the 2012 final assessment and the 2013 preliminary assessment). Models 3-5 are all based on Model 2, with the following modifications: Model 3 has survey catchability (Q) fixed at 1.0; Model 4 estimates Q with a uniform prior and adds an internally estimated constant to each year's log-scale survey abundance standard deviation; and Model 5 fixes survey catchability at 1.0 (like Model 3), forces survey selectivity to be asymptotic, and estimates the natural mortality rate (M) freely. Model 6 is a new model, which collapses the season-and-gear-specific fisheries of Model 1 into a single fishery (comments SSC1 and JTS3) with time-varying, non-parametric selectivity (comment SSC7). Model 6 is similar in many respects to the models considered in this year's preliminary assessment of the Aleutian Islands (AI) Pacific cod stock.

All of the models in this preliminary assessment except Model 6 used a double-normal curve to model selectivity (SS selectivity-at-length pattern #24 for the fisheries in all models and for the survey in Models 2-4, and SS selectivity-at-age pattern #20 for the survey in Model 1). This functional form is constructed from two underlying and linearly rescaled normal distributions, with a horizontal line segment joining the two peaks. As configured in SS, the equation uses the following six parameters:

1. *beginning_of_peak_region* (where the curve first reaches a value of 1.0)
2. *width_of_peak_region* (where the curve first departs from a value of 1.0)
3. *ascending_width* (equal to twice the variance of the underlying normal distribution)
4. *descending_width* (equal to twice the variance of the underlying normal distribution)
5. *initial_selectivity* (at minimum length/age)
6. *final_selectivity* (at maximum length/age)

All but *beginning_of_peak_region* are transformed: The *ascending_width* and *descending_width* are log-transformed and the other three parameters are logit-transformed.

Development of the final versions of all models included calculation of the Hessian matrix. All models also passed a "jitter" test of 50 runs with a jitter parameter (equal to half the standard deviation of the logit-scale distribution from which initial values are drawn) of 0.01. In the event that a jitter run produced

a better value for the objective function than the base run, then: 1) the model was re-run starting from the final parameter file from the best jitter run, 2) the resulting new control file became the new base run, and 3) the entire process (starting with a new set of jitter runs) was repeated until no jitter run produced a better value for the objective function than the most recent base run.

Except for selectivity parameters in Model 6 and *dev* parameters in all models, all parameters were estimated with uniform prior distributions.

Model 1 used a data file with the same structure used for Model 1 in last year's final assessment. Models 2-5 used a common data file with the same structure used for Model 4 in last year's preliminary assessment. Model 6 used a unique data file structured to accommodate the features of that model.

Differences between Model 2 and Model 1, and between Model 6 and Model 1, are detailed below (separate sections are not presented for Models 3-5, because they each differ from Model 2 in only a few respects, as noted above).

Model 2

Some of the main differences between Model 2 and Model 1 were as follow:

1. An inter- and intra-annually varying weight-length representation based on an explicit phenological process (Thompson and Lauth 2012, Annex 2.1.2) was used. Model 1 also used an intra-annually varying weight-length representation, but each set of seasonal parameters was estimated independently of the other seasons, without being constrained by any phenological process.
2. "Tail compression" was turned off. This feature aggregates size composition bins with few or zero data on a record-by-record basis, which improves computational speed, but which also makes some of the graphs in the R4SS package difficult to interpret. In Model 1, tail compression is turned on.
3. Fishery CPUE data were omitted. In Model 1, fishery CPUE data were included for purposes of comparison, but are not used in estimation.
4. A new population length bin was added for fish in the 0-0.5 cm range, which was used for extrapolating the length-at age curve below the first reference age. In Model 1, the lower bound of the first population length bin was 0.5 cm.
5. Mean-size-at-age data were eliminated. In Model 1, mean-size-at-age data were included, but not used in estimation.
6. The number of estimated year class strengths in the initial numbers-at-age vector was set at 10. In Model 1, only 3 elements of the initial numbers-at-age vector were estimated, which causes an automatic warning in SS.
7. The Richards growth equation (Richards 1959, Schnute 1981, Schnute and Richards 1990) was used, which adds one more parameter. In Model 1, the von Bertalanffy equation—a special case of the Richards equation—was used.
8. The log-scale standard deviation of recruitment was estimated internally (i.e., as a free parameter estimated by ADMB). In Model 1, this parameter was held constant at the value of 0.57 that was estimated in the final 2009 assessment by matching the standard deviation of the recruitment *dev*s (normally distributed random deviations added to the base value of their respective parameter), per Plan Team request.
9. Survey selectivity was modeled as a function of length. In Model 1, survey selectivity was modeled as a function of age.
10. Fisheries were defined with respect to each of the five seasons, but not with respect to gear. In Model 1, fisheries were defined with respect to both season and gear.

11. Fishery selectivity curves were defined for each of the five seasons, but were not stratified by gear type. In Model 1, seasons 1-2 and 4-5 were lumped into a pair of "super" seasons for the purpose of defining fishery selectivity curves, and fishery selectivities were also *gear*-specific (3 super-seasons × 3 gears = 9 selectivity curves).
12. The selectivity curve for the fishery that came closest to being asymptotic on its own (in this case, the season 3 fishery) was forced to be asymptotic by fixing both *width_of_peak_region* and *final_selectivity* at a value of 10.0 and *descending_width* at a value of 0.0. In Model 1, six of the nine super-season × gear fisheries were forced to exhibit asymptotic selectivity.
13. The age composition sample size multiplier was tuned iteratively to set the mean of the ratio of effective sample size to input sample size equal to 1.0. In Model 1, the variance adjustment was fixed at 1.0.
14. The two parameters governing the ascending limb of the survey selectivity schedule were given annual additive *dev*s with each σ_{dev} tuned to match the estimate that would be appropriate for a univariate linear-normal model with random effects integrated out (Thompson and Lauth 2012, Annex 2.1.1). In Model 1, no *dev* vector corresponding to the *initial_selectivity* parameter was used, because it was "tuned out" in the 2009 final assessment; and σ_{dev} for the *ascending_width* parameter was left at the value of 0.07 estimated iteratively in the final 2009 assessment, per Plan Team request.
15. The logarithm of survey catchability ($\ln(Q)$) was re-tuned iteratively to set the average of the product of Q and survey selectivity across the 60-81 cm range equal to 0.47, corresponding to the Nichol et al. (2007) estimate. In Model 1, Q was left at the value of 0.77 estimated by a similar procedure in the final 2009 assessment, per Plan Team request.

As recommended in comment BPT2, quantities that were tuned iteratively in Model 2 (in 2012) were not re-tuned in Models 3-5.

Model 6: main features

Some of the main differences between Model 6 and Model 1 were as follow:

1. Each year consisted of a single season instead of five.
2. A single fishery was defined instead of nine season-and-gear-specific fisheries.
3. The survey was assumed to sample age 1 fish at true age 1.5 instead of 1.41667.
4. Initial abundances were estimated for the first ten age groups instead of the first three.
5. The natural mortality rate was estimated internally.
6. The base value of survey catchability was estimated internally.
7. Length at age 1.5 was allowed to vary annually.
8. Survey catchability was allowed to vary annually.
9. Selectivity for both the fishery and the survey were allowed to vary annually.
10. Selectivity for both the fishery and survey was modeled using a random walk with respect to age (SS selectivity-at-age pattern #17) instead of the usual double normal. Selectivity-at-age pattern #17 in SS has one parameter for each age in the model. Except for age 0, the parameter for any given age represents the logarithm of the ratio of selectivity at that age to selectivity at the previous age (i.e., the backward first difference on the log scale). Age 0 fish are often expected to have a selectivity of zero, which can be achieved in this selectivity pattern by setting the parameter for age 0 equal to -1000, as was done for all six models presented here. As with other parameters in SS, each parameter in this selectivity pattern is associated with a prior distribution (see "Iterative tuning of prior distributions for selectivity parameters" in the next subsection).

Model 6: iterative tuning

Three types of iterative tuning were involved in the development of Model 6. The first of these applied only to the prior distributions for selectivity parameters, and the second applied to all time-varying parameters except catchability, and the third applied only to time-varying catchability.

Iterative tuning of prior distributions for selectivity parameters

Initially, the model was run with recruitment as the only time-varying quantity, with the standard deviation of log-scale recruitment estimated internally (i.e., as a free parameter), and with large standard deviations in the prior distributions for all selectivity parameters.

Once the initial model converged, a pair of transformed logistic curves was fit to the point estimates of the fishery and survey selectivity schedules (a *transformed* logistic curve was used because the selectivity parameters in pattern #17 consist of the backward first differences of selectivity on the log scale, rather than selectivity itself ; Thompson and Palsson 2013). The respective transformed logistic curve (fishery or survey) was then used to specify a new set of means for the selectivity prior distributions (one for each age). A constant (across age) prior standard deviation was then computed such that no age had a prior CV (on the selectivity scale, not the transformed scale) less than 50%.

The model was then run with the new set of prior means and constant prior standard deviations (one for the fishery, one for the survey), then a new pair of transformed logistic curves was fit to the results, and the process was repeated until convergence was achieved. The converged set of prior means (on the transformed scale, not the selectivity scale) was as follows (ages 8+ all had prior means of 0 for both the fishery and the survey):

Age:	1	2	3	4	5	6	7
Fishery:	2.940	2.937	2.887	2.258	0.603	0.045	0.002
Survey:	5.020	0.607	0.003	0.000	0.000	0.000	0.000

The converged prior standard deviations were 0.350 for the fishery and 0.319 for the survey (both constant across age).

Iterative tuning of time-varying parameters other than catchability

Two main loops were involved in the iterative tuning of time-varying parameters other than catchability. These loops were designed to produce the quantities needed to use the method of Thompson and Lauth (2012, Annex 2.1.1) for estimating the standard deviation of a *dev* vector:

1. Estimating "unconstrained" estimates of the standard deviation(s) of the *dev*s for a particular parameter or parameter vector. The purpose of this loop was to determine the vector of *dev*s for an individual parameter or parameter vector that would be obtained if the *dev*s were completely unconstrained by their respective σs. The following individual parameters and parameter vectors were included in this exercise: *L1* (length at age 1.5), age 0 recruitment, the vector of age-specific fishery selectivity parameters, and the vector of age-specific survey selectivity parameters. For parameter vectors especially, this was not always a straightforward process, as estimating a large matrix of age×year *dev*s is difficult if the *dev*s are unconstrained. In general, though, the procedure was to begin with a small (constant across age, in the case of a parameter vector) value of σ; calculate the standard deviation of the estimated *dev*s; then increase the value of σ gradually until the standard deviation of the estimated *dev*s reached an asymptote.

2. Estimating "iterated" estimates of the standard deviations for the *dev*s. Again proceeding one parameter or parameter vector fleet at a time, this loop began with σ set at the unconstrained value(s) estimated in the first loop. The standard deviation(s) of the estimated *dev*s then became the age-specific σ(s) for the next run, and the process was repeated until convergence was achieved.

For *L1* and age 0 recruitment, the final values of σ (after application of the algorithm described by Thompson and Lauth (2012, Annex 2.1.1)) were 0.086 and 0.657, respectively (note that the *L1 dev*s are lognormal and multiplicative, while the recruitment *dev*s are normal and additive).

In the case of a vector of age-specific selectivity parameters, it is common for some ages to be "tuned" out during the second loop (i.e., the σs converge on zero). For Model 6, all ages were tuned out except age 4 for the fishery and ages 2 and 3 for the survey. The final values of σ (after application of the algorithm described by Thompson and Lauth (2012, Annex 2.1.1)) were 0.158 for fishery age 4 and 0.106 for survey ages 2 and 3 (note that these *dev*s are all normal and additive).

Unfortunately, the way that selectivity pattern #17 is implemented in SS, large gradients tend to result if significant *dev*s occur at the age of peak selectivity. Because survey selectivity for Model 6 tended to peak at age 3, it turned out to be impossible to include *dev*s for age 3, so Model 6 included survey selectivity *dev*s for age 2 only.

Iterative tuning of time-varying catchability

Unlike the size composition or age composition data sets, the time series of survey abundance includes not only a series of expected values, but a corresponding series of standard errors as well. This formed the basis for the iterative tuning of the σ term for time-varying catchability in Model 6. The procedure involved iteratively adjusting σ until the root-mean-squared-standardized-residual equaled unity. The resulting value of σ was 0.089 (normal and additive, because SS works in terms of ln(Q) rather than Q).

Parameters Estimated Outside the Assessment Model

Parameters estimated outside the assessment model were detailed in last year's final assessment (Thompson 2013). In particular, the natural mortality rate M was fixed at 0.34 in Models 1-4 (M was estimated internally in Models 5 and 6), the standard deviations of the ageing error matrix extended linearly from a value of 0.086 at age 1 to a value of 1.73 at age 20, and the parameters of the logistic maturity-at-age relationship were set at values of 4.88 years (age at 50% maturity) and −0.965 (slope) in all models. As noted in the data section, estimates of base, seasonal, and annual weight-length parameters were updated using the method described in Thompson and Lauth (2012, Annex 2.1.2).

Parameters Estimated Inside the Assessment Model

Parameters estimated inside SS vary to some extent between the six models. Internally estimated parameters common to all models include the von Bertalanffy growth parameters; standard deviation of length at ages 1 and 20; ageing bias at ages 1 and 20; log mean recruitment since the beginning of the time series; offset for log mean recruitment prior to the beginning of the time series; *dev*s for log-scale initial (i.e., 1977) abundance at ages 1 through 3; annual log-scale recruitment *dev*s for 1977-2012; initial (equilibrium) fishing mortality; and base values for all fishery and survey selectivity parameters (although the nature of these parameters varies between models). A complete list of parameters is presented in the "Parameters, Schedules, and Time Series Estimates" subsection of the "Results" section.

For all parameters estimated within individual SS runs, the estimator used is the mode of the logarithm of the joint posterior distribution, which is in turn calculated as the sum of the logarithms of the parameter-specific prior distributions and the logarithm of the likelihood function.

In addition to the above, the full set of annual fishing mortality rates are also estimated internally, but not in the same sense as the above parameters. The fishing mortality rates are determined (almost) exactly rather than estimated statistically because SS assumes that the input total catch data are true values rather than estimates, so the fishing mortality rates can be computed algebraically given the other parameter values and the input catch data. An option does exist in SS for treating the fishing mortality rates as full parameters, but previous explorations have indicated that adding these parameters has almost no effect on other model output (Methot and Wetzell 2013).

Likelihood Components

All six models include likelihood components for initial (equilibrium) catch, trawl survey relative abundance, fishery and survey size composition, survey age composition, recruitment, prior distributions (Model 6 only), "softbounds" (equivalent to an extremely weak prior distribution used to keep parameters from hitting bounds), and parameter deviations.

In SS, emphasis factors are specified to determine which likelihood components receive the greatest attention during the parameter estimation process. As in previous assessments of this stock, all likelihood components were given an emphasis of 1.0 here.

Results

Overview

The following table summarizes the status of the stock as estimated by the six models ("Value" is the point estimate, "SD" is the standard deviation to the point estimate, "FSB 2014" is female spawning biomass in 2014 (t), and "Bratio 2014" is the ratio of FSB 2014 to $B_{100\%}$:

	Model 1		Model 2		Model 3	
Quantity	Value	SD	Value	SD	Value	SD
FSB 2014	357,617	23,221	439,474	29,313	243,630	18,391
Bratio 2014	0.478	0.026	0.486	0.042	0.325	0.029

	Model 4		Model 5		Model 6	
Quantity	Value	SD	Value	SD	Value	SD
FSB 2014	95,727	18,881	162,445	14,289	245,145	36,050
Bratio 2014	0.151	0.028	0.290	0.026	0.346	0.053

The six models span wide ranges for these quantities. Estimates of FSB 2014 range from 96,000 t (Model 4) to 439,000 t (Model 2), and estimates of Bratio 2014 range from 0.15 (Model 4) to 0.49 (Model 2).

Goodness of Fit

Objective function values are shown for each model below (lower values are better, all else being equal; color scale extends from red (minimum) to green (maximum); note that the parameter counts include constrained deviations):

Component	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Survey index	-6.25	9.22	-12.25	-30.83	-19.78	-57.16
Size composition (fishery)	3813.17	2143.87	2093.76	2065.55	2094.71	204.11
Size composition (survey)	867.17	556.42	552.57	549.72	564.74	439.28
Age composition	138.69	128.56	124.32	121.30	119.69	117.08
Recruitment	21.38	15.58	17.09	15.08	9.31	0.18
Priors	0.00	0.00	0.00	0.00	0.00	15.50
Parameter *dev*s	20.65	22.48	23.54	28.01	24.48	26.95
Other	0.03	0.03	0.21	0.41	0.42	0.17
Total	4854.84	2876.15	2799.24	2749.25	2793.56	746.11
Number of parameters	184	144	144	146	142	230
AIC	10077.68	6040.30	5886.48	5790.50	5871.12	1952.22

Models 2-5 have far fewer parameters than Models 1 or 6 (although many of the parameters in Model 6 are constrained deviations). In addition to the problem of counting constrained deviations as full parameters, the AIC values are not comparable across all models due to the fact that different data files are used for Models 1, 2-5, and 6. Although Models 2-5 all used the same data file, the AIC value for Model 4 probably should not be compared to the values for Models 2, 3, and 5, because Model 4 includes an estimated parameter that inflates the log-scale standard errors for the survey abundance time series specified in the data file, which is equivalent to changing the data file. Among Models 2, 3, and 5, Model 5 has the lowest (best) AIC value. Model 5 also has the lowest (best) value for the overall objective function among this subset of models. Evidently, fixing Q at a value of 1.0 in Model 3, rather than the fixed value of 0.75 used in Model 2, allows Model 3 to fit the data better than Model 2 overall. Given that the only structural differences between Models 3 and 5 are that survey selectivity is forced to be asymptotic and M is estimated internally in Model 5, it is likely that the lower value for the objective function in Model 5 is due to internal estimation of M, because forcing survey selectivity to be asymptotic would be expected to result in a worse fit overall.

Figure 2.1.1a shows the fits of the six models to the trawl survey abundance data, and Figure 2.1.1b shows the same thing in terms of standardized residuals (note that the confidence intervals for the observed values do not account for the "extra" measurement error estimated by Model 4). Models 2, 3, and 6 all estimate a 2013 survey biomass within 10% the observed value (the estimates from Models 1, 4, and 5 are 17% high, 35% low, and 11% low, respectively). All models show a mix of positive and negative residuals. Models 1 and 2 tend to overestimate the survey abundance, although usually not by much. Some summary statistics are shown below, where the values for Model 4 incorporate the estimated "extra" measurement error (for comparison to the root mean squared residual, the average log-scale standard error in the data is 0.108, except for Model 4, where the value is 0.234):

Quantity	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Correlation (observed:expected)	0.929	0.909	0.957	0.963	0.974	0.993
Root mean squared residual	0.221	0.251	0.215	0.234	0.192	0.110
Mean standardized residual	0.913	1.032	0.783	0.045	0.225	0.094
Root mean squared stand. residual	2.042	2.266	1.947	1.001	1.822	0.992

Models 4 (given the estimated "extra" measurement error) and 6 do about as well or better than any of the other models by all of the above measures. Model 2 does the worst of all the models by any of the above measures.

Sample size ratios (effective sample size divided by input sample size) for the size composition data are shown in Table 2.1.1. All six models give values (either the mean of the ratios or the ratio of the means) far in excess of unity for both the fishery and the survey.

Figure 2.1.2 shows the models' fits to the survey age composition data. Effective sample sizes and negative log likelihoods are shown in Tables 2.1.2a and 2.1.2b. Models 3-6 give average effective sample sizes in excess of the average input sample size, while Models 1 and 2 do not. However, it should be noted that the values for Models 2-5 in the last two rows of Table 2.1.2a are not strictly comparable to those for Models 1 and 6, because the input sample sizes for Models 2-5 were all multiplied by a factor of 0.85 (a result of the tuning process used for Model 2).

Parameters, Schedules, and Time Series Estimates

Table 2.1.3 (spanning 14 pages) lists the constants and parameters listed in the SS control files for the six models, along with standard deviations for all estimated parameters. Constants are listed in Table 2.1.3a, main parameters (except recruitment and selectivity) common to most or all models are listed in Table 2.1.3b, recruitment *dev*s are listed in Table 2.1.3c, *L1 dev*s and ln(*Q*) *dev*s estimated by Model 6 are listed in Table 2.1.3d (transformed to the raw *L1* and *Q* scales and plotted in Figure 2.1.3), base selectivity parameters estimated by Model 1 are listed in Table 2.1.3e, block selectivity parameters and selectivity *dev*s estimated by Model 1 are listed in Table 2.1.3f (spanning 3 pages), base selectivity parameters estimated by Models 2-5 are listed in Table 2.1.3g, annual *dev*s for selectivity parameter #3 estimated by Models 2-5 are listed in Table 2.1.3h (see third paragraph under "Model Structures" for numbering of selectivity parameters), annual *dev*s for selectivity parameter #5 estimated by Models 2-5 are listed in Table 2.1.3i, base selectivity parameters estimated by Model 6 are listed in Table 2.1.3j, annual *dev*s for the age 4 fishery selectivity parameter estimated by Model 6 are shown in Table 2.1.3k, and annual *dev*s for the age 2 survey selectivity parameter estimated by Model 6 are shown in Table 2.1.3l. Quantities with "n/a" listed under "SD" were fixed rather than estimated.

Figure 2.1.4 (spanning six pages) shows the fishery selectivity schedules estimated by the six models. These schedules are time-varying for Models 1 and 6, but time-invariant for Models 2-5. Figure 2.1.5 shows the survey selectivity schedules estimated by the six models. These are all time-varying. All models except Model 5 (where survey was forced to be asymptotic) estimate that survey selectivity decreases substantially at larger sizes (Models 1-4) or older ages (Model 6).

Time series estimated by the six models are shown for female spawning biomass, relative (to $B_{100\%}$) female spawning biomass, and age 0 recruitment in Figures 2.1.6, 2.1.7, and 2.1.8, respectively. In most cases, Figures 2.1.6 and 2.1.7 are very similar except for scale. Models 1 and 2 tend to estimate the highest values of spawning biomass, while Models 4 and 5 tend to estimate the lowest. Figure 2.1.8 indicates a very high degree of synchrony among the estimates of recruitment, except in the first year of the time series (i.e., the 1977 year class). Model 4 tends to estimate the lowest recruitments of the six models.

Discussion

The models presented here span a wide range of structures, and in many cases the estimates produced by the models are similarly wide ranging. For example, as reported in the "Overview" subsection of the "Results" section, the estimates of female spawning biomass in 2014 range from 96,000 t (Model 4) to 439,000 t (Model 2), and estimates of this quantity relative to $B_{100\%}$ range from 0.15 (Model 4) to 0.49 (Model 2). Estimates of survey catchability range from 0.75 (Model 2) to 1.42 (Model 4). Other results, however, show greater similarity. For example, all models except Model 5, where survey selectivity was

forced to be asymptotic, indicate that survey selectivity decreases substantially at larger sizes (Models 2-4) or older ages (Models 1 and 6).

Although the natural mortality rate *M* is estimated internally in only Models 5 and 6, Figure 2A.1.9 shows the likelihood profiles with respect to *M* for each of the models. If *M* were estimated internally in all models, the estimates would range from a low of 0.36 (Model 6) to a high of 0.44 (Model 2). The entire range lies above the estimate of 0.34 that is hard-wired into Models 1-4, although the lower end of the range is close to that value.

All models presented here generally provided good-to-excellent fits to the size composition and age composition data, although Model 1's fit to the age composition data was a bit lacking, and the acceptable fits to the age composition data achieved by Models 2-5 were accomplished by down-weighting those data. However, none of the models except Models 4 and 6 (the only models that estimated *Q* internally) were able to estimate a survey abundance time series that is consistent with the standard errors in the data. Model 4 was able to do so by inflating the raw standard errors, while Model 6 did so by allowing *Q* to have annual *dev*s (note that the estimates of Q from these two models were quite different: 1.42 for Model 4 and 1.03 for Model 6)

Last year's preliminary assessment of the AI Pacific cod stock provided the first exploration of SS selectivity-at-age pattern #17 (random walk with age) for Pacific cod, and use of this pattern has been included here in Model 6. Some advantages of pattern #17 are the following:

1. Pattern #17 allows for use of prior distributions that are consistent with a logistic functional form without actually forcing the resulting selectivity schedule to be logistic.
2. Pattern #17 provides an alternative to the somewhat complicated parameterization of the double normal selectivity curve (which has been used in the EBS Pacific cod models for the last several years), in which the effects of some parameters are conditional on the values of other parameters, thus making it difficult to specify appropriate prior distributions.
3. The iterative tuning procedure used here for the means of the prior distributions provides a way to specify these quantities objectively and uniquely for each age.
4. Estimation of individual selectivities at age avoids the problem of mis-specifying a functional form *a priori*, which can have significant consequences (e.g., Kimura 1990, Clark 1999).

Model 6 also emphasized the potential time variability of both fishery and survey selectivity. Although a scientific consensus on how (or whether) to address this phenomenon has yet to be achieved, some of the presentations at the 2013 CAPAM selectivity workshop (Crone et al., 2013) seemed to favor allowing selectivity to vary over time.

Although Model 6 gives excellent fits to the data, various features of the model may require further evaluation before the model is accepted for use in management. For example, the annual values estimated for the *L1* parameter are only mildly consistent with existing data (not included in the data file) on time variability in that parameter. Figure 2.1.10 compares the time series of *L1* values estimated by Model 6 with three other time-varying measures: 1) the mean length at age 1.5 (i.e., age 1 at the time of the survey) estimated by the age readers, 2) the first mode in the survey size composition data, and 3) the mean of a normal distribution fit to the region around the first mode in the size composition data. The correlation between the Model 6 estimates and these three estimators is only 0.28, 0.07, and 0.05, respectively; and only the comparison with the age reader estimates produces a positive R^2 (=0.23). On the other hand, the range of Model 6 estimates is quite consistent with the 95% confidence interval for the time series of normal means (dashed lines in Figure 2.1.10).

It should be emphasized that iterative tuning used for various quantities in Model 2 was conducted two years ago, so the tuned values may no longer be optimal now that more data have been added. Moreover, Models 3-5 simply "borrow" the tuned quantities from Model 2. If these iterative tuning procedures were also applied to Models 3-5, the performance of those models would likely change somewhat.

As has been the case for decades now, the models tend to estimate sharply reduced survey selectivity at older ages (larger sizes) unless constrained to do otherwise (as in Model 5): Estimates of selectivity (ignoring Model 5) for the oldest/largest fish range from 0.21 (Model 1) to 0.35 (Model 6). However, except for the study by Nichol et al. (2007), studies by AFSC's RACE Division have failed to verify a mechanism capable of explaining this phenomenon.

In principle, confounding with *Q* might be an issue: Models 1 and 2 were both tuned (during a previous assessment) so that the average product of catchability and selectivity across the 60-81 cm size range equaled the value of 0.47 estimated by Nichol et al. (2007); Models 3-4 were both based on Model 2, so it is not surprising that they exhibit behavior similar to that of Model 2 in this regard; Model 6 was not tuned in this manner, yet it also estimates that survey selectivity decreases substantially once fish are greater than 3 years of age. Although there is a correlation between survey selectivity of oldest/largest fish and *Q* in Models 1-4 and 6, it is not particularly large (0.42); moreover, it is positive, whereas a negative correlation would be easier to explain (as a tradeoff between catchability and selectivity).

Confounding with *M* might also be an issue: Model 5 gave a better fit to the data than Model 3 (its closest relative) even though it forced survey selectivity to be asymptotic, because it also allowed for a higher value of *M* (about 23% higher than the value assumed in Models 1-4. However, Model 6 estimates *M* (at a value about 17% higher than the fixed value assumed in Models 1-4), *Q*, and all selectivity parameters internally; and it still shows substantially lower survey selectivity at older ages, indicating that the fixed value assumed for *M* in Models 1-4 may not be the main cause of declining selectivity at older ages (larger sizes).

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Table 2.1.1a—Effective sample size ratioss for size composition fits (Model 1).

Fleet	Model 1	
	Mean(Neff/N)	Mean(Neff)/Mean(N)
Jan-Apr_Trawl_Fishery	5.38	3.21
May-Jul_Trawl_Fishery	9.46	7.47
Aug-Dec_Trawl_Fishery	13.25	6.33
Jan-Apr_Longline_Fishery	8.66	4.06
May-Jul_Longline_Fishery	9.43	5.48
Aug-Dec_Longline_Fishery	6.49	3.21
Jan-Apr_Pot_Fishery	14.35	9.64
May-Jul_Pot_Fishery	18.16	7.63
Aug-Dec_Pot_Fishery	10.87	8.25
Post81_Shelf_Survey	2.03	1.72

Table 2.1.1b—Effective sample size ratios for size composition fits (Models 2-5).

Fleet	Mean(Neff/N)				Mean(Neff)/Mean(N)			
	Model 2	Model 3	Model 4	Model 5	Model 2	Model 3	Model 4	Model 5
Season1_Fishery	8.15	8.01	7.61	7.59	5.20	5.21	4.96	5.01
Season2_Fishery	6.79	6.72	6.62	6.37	4.29	4.24	4.19	4.07
Season3_Fishery	7.91	7.86	7.95	7.88	5.72	5.81	6.06	5.82
Season4_Fishery	9.57	9.78	10.40	9.08	3.50	3.45	3.66	3.06
Season5_Fishery	8.80	8.47	8.49	8.20	3.96	4.04	4.23	4.26
Trawl_Survey	3.12	3.14	3.39	3.17	2.65	2.69	2.88	2.73

Table 2.1.1c—Effective sample size ratiios for size composition fits (Model 6).

Fleet	Model 6	
	Mean(Neff/N)	Mean(Neff)/Mean(N)
Fishery	14.28	9.77
Survey	3.06	2.73

Table 2.1.2a—Effective sample sizes for age composition fits.

Year	N	Effective sample size					
		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
1994	205	468	413	421	356	406	424
1995	172	38	36	35	40	36	67
1996	204	316	350	384	449	388	371
1997	206	150	192	266	998	380	453
1998	182	1029	1010	2656	3024	1416	1625
1999	246	104	70	72	73	81	70
2000	248	110	57	52	59	60	63
2001	272	87	48	48	60	45	101
2002	271	87	86	83	82	85	82
2003	390	276	384	447	842	860	662
2004	298	31	36	36	38	36	52
2005	367	448	600	436	442	336	163
2006	372	148	139	151	133	179	243
2007	413	63	105	97	75	110	571
2008	347	212	257	354	705	695	232
2009	404	88	120	119	129	128	327
2010	370	147	224	221	325	204	218
2011	359	162	131	114	98	105	86
2012	374	82	117	105	97	91	103
Mean	300	213	230	321	422	297	311
Mean (Neff/N)		0.86	1.06	1.65	2.14	1.52	1.24
(Mean Neff)/(Mean N)		0.71	0.90	1.26	1.66	1.24	1.04

Table 2.1.2b—Negative log likelihoods for age composition fits.

Year	Negative ln(likelihood)					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
1994	3.15	3.74	3.13	3.08	2.83	3.09
1995	11.01	10.31	9.80	8.33	9.32	6.23
1996	2.07	2.73	1.93	1.45	1.57	1.51
1997	3.92	3.92	2.54	1.13	1.66	1.61
1998	1.05	1.43	0.91	0.90	0.88	0.99
1999	4.99	8.10	7.52	7.59	6.39	7.45
2000	7.27	12.38	12.87	11.89	11.31	12.17
2001	7.09	11.28	11.45	10.36	12.61	8.10
2002	6.75	6.20	6.29	6.96	6.38	6.97
2003	4.65	2.76	1.96	1.76	1.42	1.92
2004	22.40	17.14	17.28	17.07	17.74	13.85
2005	5.73	3.95	4.89	5.74	6.12	8.47
2006	10.50	8.56	7.57	7.36	5.34	6.79
2007	8.89	5.03	5.33	6.84	4.99	3.71
2008	4.52	3.10	2.54	2.05	1.87	3.80
2009	13.80	9.53	9.63	9.11	9.20	5.87
2010	4.07	3.35	3.06	2.67	3.21	3.93
2011	5.10	6.04	6.36	7.40	6.73	9.55
2012	11.74	9.01	9.26	9.61	10.12	11.08
Sum	138.69	128.56	124.32	121.30	119.69	117.08

Table 2.1.3a—Constants listed in the control files for the six models.

Parameter	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Weight-length a (proportionality)	5.99E-06	6.36E-06	6.36E-06	6.36E-06	6.36E-06	6.36E-06
Weight-length b (exponent)	3.17E+00	3.16E+00	3.16E+00	3.16E+00	3.16E+00	3.16E+00
Age at 50% maturity	4.88E+00	4.88E+00	4.88E+00	4.88E+00	4.88E+00	4.88E+00
Maturity slope	-9.65E-01	-9.65E-01	-9.65E-01	-9.65E-01	-9.65E-01	-9.65E-01
Ageing error st. dev. at age 1	8.50E-02	8.60E-02	8.60E-02	8.60E-02	8.60E-02	8.60E-02
Ageing error st. dev. at age 20	1.71E+00	1.73E+00	1.73E+00	1.73E+00	1.73E+00	1.73E+00
Weight-length a offset--season 1	-2.28E-02	-2.28E-02	-2.28E-02	-2.28E-02	-2.28E-02	n/a
Weight-length a offset--season 2	2.77E-03	2.77E-03	2.77E-03	2.77E-03	2.77E-03	n/a
Weight-length a offset--season 3	1.92E-02	1.92E-02	1.92E-02	1.92E-02	1.92E-02	n/a
Weight-length a offset--season 4	2.30E-03	2.30E-03	2.30E-03	2.30E-03	2.30E-03	n/a
Weight-length a offset--season 5	-1.42E-02	-1.42E-02	-1.42E-02	-1.42E-02	-1.42E-02	n/a
Weight-length b offset--season 1	5.25E-03	5.25E-03	5.25E-03	5.25E-03	5.25E-03	n/a
Weight-length b offset--season 2	-6.47E-04	-6.47E-04	-6.47E-04	-6.47E-04	-6.47E-04	n/a
Weight-length b offset--season 3	-4.54E-03	-4.54E-03	-4.54E-03	-4.54E-03	-4.54E-03	n/a
Weight-length b offset--season 4	-5.39E-04	-5.39E-04	-5.39E-04	-5.39E-04	-5.39E-04	n/a
Weight-length b offset--season 5	3.28E-03	3.28E-03	3.28E-03	3.28E-03	3.28E-03	n/a
Beverton-Holt "steepness"	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00

Table 2.1.3b—Main parameters estimated by the models.

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
Parameter	Value	SD	Value	SD	Value	SD	Value	SD	Value	SD	Value	SD
Natural mortality rate	3.40E-01	n/a	3.40E-01	n/a	3.40E-01	n/a	3.40E-01	n/a	4.17E-01	7.54E-03	3.57E-01	3.30E-02
Length at age 1 (cm)	1.41E+01	1.08E-01	1.38E+01	1.47E-01	1.38E+01	1.46E-01	1.41E+01	1.34E-01	1.38E+01	1.44E-01	1.69E+01	2.68E-01
Asymptotic length (cm)	9.22E+01	5.23E-01	9.02E+01	8.43E-01	9.43E+01	1.21E+00	9.45E+01	1.26E+00	1.04E+02	2.18E+00	9.84E+01	2.24E+00
Brody growth coefficient	2.41E-01	2.65E-03	2.83E-01	1.19E-02	2.61E-01	1.29E-02	2.99E-01	1.50E-02	2.25E-01	1.60E-02	2.17E-01	1.47E-02
Richards growth coefficient	n/a	n/a	7.97E-01	5.18E-02	8.16E-01	5.36E-02	5.80E-01	6.00E-02	8.25E-01	6.37E-02	9.38E-01	5.25E-02
SD of length at age 1 (cm)	3.54E+00	7.04E-02	3.44E+00	8.03E-02	3.50E+00	8.31E-02	3.58E+00	8.66E-02	3.55E+00	8.86E-02	3.04E+00	5.12E-02
SD of length at age 20 (cm)	1.01E+01	1.66E-01	1.02E+01	2.13E-01	1.04E+01	2.66E-01	1.02E+01	2.64E-01	1.10E+01	3.91E-01	8.75E+00	3.00E-01
Ageing bias at age 1 (years)	3.40E-01	1.29E-02	3.33E-01	1.48E-02	3.16E-01	1.66E-02	2.61E-01	2.44E-02	2.96E-01	1.87E-02	2.75E-01	2.82E-02
Ageing bias at age 20 (years)	2.80E-01	1.52E-01	3.43E-01	1.73E-01	5.70E-01	1.78E-01	1.01E+00	2.12E-01	7.75E-01	1.91E-01	6.96E-01	2.45E-01
ln(mean post-1976 recruitment)	1.32E+01	1.93E-02	1.34E+01	7.30E-02	1.31E+01	7.04E-02	1.29E+01	6.64E-02	1.34E+01	6.39E-02	1.32E+01	2.26E-01
SD of log recruitment	5.70E-01	n/a	7.97E-01	8.87E-02	8.00E-01	8.49E-02	7.57E-01	8.00E-02	6.97E-01	7.49E-02	6.57E-01	n/a
ln(pre-1977 recruitment offset)	-1.17E+00	1.31E-01	-1.28E+00	2.11E-01	-1.62E+00	1.57E-01	-1.62E+00	1.06E-01	-1.69E+00	1.15E-01	-7.66E-01	2.41E-01
Initial age 10 ln(abundance) dev	n/a	n/a	-4.50E-01	6.71E-01	-2.36E-01	7.39E-01	-5.05E-02	7.48E-01	-3.46E-02	6.88E-01	-2.36E-01	5.95E-01
Initial age 9 ln(abundance) dev	n/a	n/a	-5.58E-01	6.49E-01	-3.41E-01	7.20E-01	-9.76E-02	7.48E-01	-7.48E-02	6.83E-01	-2.92E-01	5.83E-01
Initial age 8 ln(abundance) dev	n/a	n/a	-6.58E-01	6.29E-01	-4.60E-01	6.97E-01	-1.76E-01	7.53E-01	-1.52E-01	6.78E-01	-3.74E-01	5.67E-01
Initial age 7 ln(abundance) dev	n/a	n/a	-7.19E-01	6.12E-01	-5.60E-01	6.70E-01	-2.78E-01	7.55E-01	-2.68E-01	6.67E-01	-4.79E-01	5.47E-01
Initial age 6 ln(abundance) dev	n/a	n/a	-6.82E-01	6.00E-01	-5.66E-01	6.41E-01	-3.32E-01	7.32E-01	-3.53E-01	6.34E-01	-5.64E-01	5.29E-01
Initial age 5 ln(abundance) dev	n/a	n/a	-5.25E-01	5.65E-01	-4.53E-01	5.65E-01	-2.67E-01	6.04E-01	-3.44E-01	5.25E-01	-5.52E-01	5.18E-01
Initial age 4 ln(abundance) dev	n/a	n/a	-5.63E-01	5.59E-01	-6.77E-01	5.42E-01	-6.92E-01	5.02E-01	-7.36E-01	4.62E-01	-1.38E-01	5.09E-01
Initial age 3 ln(abundance) dev	1.29E+00	1.89E-01	1.37E+00	2.48E-01	1.23E+00	2.25E-01	1.07E+00	1.94E-01	9.63E-01	1.97E-01	2.47E-01	4.48E-01
Initial age 2 ln(abundance) dev	-7.31E-01	4.18E-01	-4.70E-01	5.71E-01	-4.31E-01	5.29E-01	-4.24E-01	4.48E-01	-4.41E-01	4.19E-01	-2.31E-01	5.44E-01
Initial age 1 ln(abundance) dev	1.38E+00	2.14E-01	1.67E+00	2.63E-01	1.51E+00	2.38E-01	1.31E+00	2.12E-01	1.20E+00	2.13E-01	7.21E-01	4.52E-01
Initial fishing mortality rate	6.91E-01	1.51E-01	7.83E-01	2.17E-01	2.15E+00	7.99E-01	4.16E+00	2.38E+00	4.36E+00	2.04E+00	1.00E-01	3.32E-02
Survey "extra" SD	n/a	n/a	n/a	n/a	n/a	n/a	1.26E-01	3.35E-02	n/a	n/a	n/a	n/a
Survey ln(catchability)	-2.61E-01	n/a	-2.88E-01	n/a	0.00E+00	n/a	3.50E-01	4.95E-02	0.00E+00	n/a	2.53E-02	1.21E-01

Table 2.1.3c—Recruitment *dev*s estimated by the models.

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
Year	Value	SD	Value	SD	Value	SD	Value	SD	Value	SD	Value	SD
1977	1.36E+00	1.09E-01	1.30E+00	1.46E-01	8.95E-01	1.44E-01	6.44E-01	1.50E-01	5.05E-01	1.39E-01	8.49E-01	2.31E-01
1978	4.95E-01	2.11E-01	1.06E+00	1.81E-01	9.83E-01	1.50E-01	1.02E+00	1.28E-01	9.47E-01	1.19E-01	7.38E-01	1.91E-01
1979	6.86E-01	1.12E-01	4.34E-01	1.83E-01	4.39E-01	1.57E-01	4.14E-01	1.47E-01	4.52E-01	1.33E-01	4.96E-01	1.31E-01
1980	-3.84E-01	1.37E-01	-2.51E-01	1.58E-01	-2.19E-01	1.48E-01	-2.19E-02	1.30E-01	2.80E-02	1.25E-01	-1.93E-01	1.26E-01
1981	-9.20E-01	1.47E-01	-6.97E-01	1.59E-01	-7.26E-01	1.55E-01	-6.85E-01	1.54E-01	-6.60E-01	1.52E-01	-5.25E-01	1.35E-01
1982	9.94E-01	4.16E-02	9.44E-01	4.91E-02	9.16E-01	4.69E-02	9.31E-01	5.04E-02	9.09E-01	4.52E-02	7.93E-01	6.34E-02
1983	-5.36E-01	1.15E-01	-7.54E-01	1.53E-01	-7.18E-01	1.45E-01	-6.06E-01	1.34E-01	-5.94E-01	1.31E-01	-6.47E-01	1.55E-01
1984	7.85E-01	4.63E-02	7.71E-01	5.14E-02	7.90E-01	4.95E-02	8.47E-01	5.09E-02	8.35E-01	4.77E-02	7.07E-01	6.39E-02
1985	-8.09E-02	7.29E-02	8.63E-02	7.69E-02	1.39E-01	7.32E-02	2.40E-01	7.21E-02	2.10E-01	6.84E-02	-2.41E-02	9.39E-02
1986	-8.25E-01	9.68E-02	-8.44E-01	1.20E-01	-7.38E-01	1.15E-01	-6.38E-01	1.12E-01	-6.57E-01	1.06E-01	-6.51E-01	1.25E-01
1987	-1.16E+00	1.11E-01	-1.22E+00	1.43E-01	-1.03E+00	1.27E-01	-6.87E-01	9.78E-02	-7.12E-01	9.46E-02	-1.37E+00	1.99E-01
1988	-2.16E-01	5.72E-02	-2.12E-01	7.13E-02	-1.96E-01	6.91E-02	-1.88E-01	6.91E-02	-2.65E-01	6.84E-02	-1.67E-01	9.56E-02
1989	5.38E-01	4.04E-02	4.26E-01	5.16E-02	4.55E-01	4.90E-02	5.27E-01	4.89E-02	4.56E-01	4.65E-02	4.38E-01	6.99E-02
1990	3.32E-01	4.61E-02	3.35E-01	5.54E-02	4.12E-01	5.18E-02	5.03E-01	5.13E-02	4.46E-01	4.79E-02	3.42E-01	7.30E-02
1991	-3.06E-01	6.26E-02	-3.58E-01	8.17E-02	-2.72E-01	7.80E-02	-1.43E-01	7.29E-02	-2.02E-01	7.12E-02	-3.14E-01	1.01E-01
1992	6.29E-01	3.25E-02	5.18E-01	3.97E-02	5.88E-01	3.78E-02	6.52E-01	3.93E-02	6.00E-01	3.63E-02	6.19E-01	4.98E-02
1993	-4.23E-01	5.88E-02	-5.16E-01	7.09E-02	-4.05E-01	6.64E-02	-2.48E-01	6.36E-02	-3.18E-01	6.05E-02	-1.06E-01	7.26E-02
1994	-3.32E-01	5.14E-02	-5.42E-01	6.36E-02	-4.69E-01	5.98E-02	-3.87E-01	5.92E-02	-4.25E-01	5.47E-02	-3.49E-01	7.51E-02
1995	-2.50E-01	5.44E-02	-5.00E-01	6.72E-02	-4.82E-01	6.33E-02	-3.60E-01	5.95E-02	-4.87E-01	5.78E-02	-3.53E-01	7.95E-02
1996	6.78E-01	3.23E-02	5.10E-01	3.83E-02	4.84E-01	3.69E-02	4.79E-01	3.94E-02	4.01E-01	3.65E-02	5.52E-01	4.79E-02
1997	-2.40E-01	5.20E-02	-1.91E-01	5.81E-02	-1.23E-01	5.35E-02	-1.56E-02	5.15E-02	-9.59E-02	4.90E-02	-4.96E-02	6.55E-02
1998	-2.46E-01	4.98E-02	-1.58E-01	5.86E-02	-9.88E-02	5.48E-02	2.14E-02	5.24E-02	-2.82E-02	4.98E-02	-1.75E-01	7.51E-02
1999	4.37E-01	3.17E-02	5.73E-01	3.61E-02	6.04E-01	3.46E-02	6.67E-01	3.57E-02	5.86E-01	3.43E-02	4.94E-01	4.88E-02
2000	-6.45E-02	3.73E-02	6.72E-02	4.46E-02	1.48E-01	4.17E-02	2.79E-01	4.39E-02	2.34E-01	4.06E-02	4.16E-02	5.76E-02
2001	-8.46E-01	5.78E-02	-7.01E-01	6.68E-02	-6.25E-01	6.26E-02	-5.05E-01	5.92E-02	-5.46E-01	5.70E-02	-4.89E-01	7.06E-02
2002	-3.05E-01	3.88E-02	-3.14E-01	4.98E-02	-2.97E-01	4.71E-02	-2.23E-01	4.65E-02	-2.91E-01	4.42E-02	-3.61E-01	6.46E-02
2003	-5.22E-01	4.65E-02	-4.68E-01	5.71E-02	-4.69E-01	5.34E-02	-4.47E-01	5.19E-02	-4.87E-01	4.97E-02	-4.63E-01	6.82E-02
2004	-6.54E-01	5.16E-02	-5.15E-01	6.15E-02	-5.42E-01	5.75E-02	-5.24E-01	5.36E-02	-5.68E-01	5.30E-02	-5.53E-01	7.55E-02
2005	-5.18E-01	4.87E-02	-4.46E-01	6.07E-02	-4.98E-01	5.65E-02	-4.59E-01	5.20E-02	-5.14E-01	5.40E-02	-2.12E-01	7.07E-02
2006	7.64E-01	3.05E-02	8.51E-01	3.71E-02	7.59E-01	3.33E-02	6.63E-01	2.97E-02	6.36E-01	3.36E-02	5.85E-01	5.13E-02
2007	-4.56E-01	6.36E-02	-1.61E-01	7.74E-02	-2.16E-01	7.21E-02	-2.78E-01	6.50E-02	-2.63E-01	6.59E-02	1.45E-01	7.11E-02
2008	1.15E+00	4.29E-02	1.20E+00	4.71E-02	1.10E+00	4.63E-02	8.25E-01	5.74E-02	9.70E-01	4.87E-02	9.46E-01	6.05E-02
2009	-9.36E-01	1.32E-01	-1.08E+00	1.54E-01	-1.08E+00	1.46E-01	-1.30E+00	1.44E-01	-1.08E+00	1.35E-01	-1.27E+00	1.54E-01
2010	6.35E-01	7.27E-02	4.87E-01	7.12E-02	3.83E-01	7.00E-02	-5.09E-02	1.07E-01	2.29E-01	7.35E-02	2.68E-01	9.48E-02
2011	1.02E+00	8.02E-02	8.87E-01	9.04E-02	7.67E-01	8.76E-02	2.49E-01	1.34E-01	5.83E-01	9.12E-02	7.25E-01	1.17E-01
2012	-2.83E-01	1.81E-01	-5.19E-01	2.11E-01	-6.51E-01	2.06E-01	-1.20E+00	2.33E-01	-8.35E-01	2.03E-01	-4.64E-01	2.28E-01

Table 2.1.3d—Length at age 1.5 (*L1*) *dev*s and ln(*Q*) devs estimated by Model 6.

	L1 dev		ln(*Q*) *dev*	
Year	Value	SD	Value	SD
1982	-1.23E-01	2.18E-02	-1.22E-01	6.60E-02
1983	-9.03E-02	5.64E-02	3.61E-04	7.22E-02
1984	6.12E-02	2.06E-02	-3.08E-02	6.25E-02
1985	-6.71E-02	3.05E-02	5.64E-03	7.52E-02
1986	5.75E-02	3.43E-02	5.36E-02	6.83E-02
1987	9.02E-02	5.75E-02	3.35E-02	5.89E-02
1988	2.00E-02	3.45E-02	1.44E-02	5.97E-02
1989	-4.49E-02	2.62E-02	-1.36E-01	6.07E-02
1990	-6.55E-02	2.91E-02	-6.69E-02	6.94E-02
1991	5.15E-02	2.74E-02	-6.31E-02	7.05E-02
1992	1.15E-02	2.09E-02	-4.85E-02	7.24E-02
1993	4.41E-02	3.19E-02	4.02E-02	7.43E-02
1994	1.82E-02	3.46E-02	2.27E-01	7.26E-02
1995	3.53E-02	3.55E-02	1.30E-01	6.76E-02
1996	-1.06E-02	2.25E-02	7.83E-02	7.57E-02
1997	-1.06E-01	3.23E-02	-2.35E-03	7.61E-02
1998	-5.17E-02	3.45E-02	3.27E-03	6.54E-02
1999	-3.30E-02	2.23E-02	-2.66E-02	6.58E-02
2000	3.59E-02	2.05E-02	-8.28E-02	6.60E-02
2001	-4.11E-03	3.57E-02	1.19E-01	6.71E-02
2002	8.11E-02	2.46E-02	-7.61E-03	6.79E-02
2003	2.70E-02	3.03E-02	-1.95E-02	7.27E-02
2004	1.64E-01	2.34E-02	-9.88E-03	6.39E-02
2005	-6.66E-02	2.34E-02	2.01E-02	7.53E-02
2006	-1.17E-01	1.97E-02	-5.49E-02	5.79E-02
2007	-1.12E-01	2.63E-02	4.87E-03	8.40E-02
2008	-1.45E-01	2.03E-02	-9.82E-02	6.94E-02
2009	-3.06E-02	5.42E-02	-1.34E-01	6.67E-02
2010	8.47E-02	1.96E-02	4.22E-02	7.46E-02
2011	-2.05E-01	2.23E-02	2.52E-02	6.99E-02
2012	-1.22E-01	3.49E-02	9.48E-02	7.27E-02
2013	n/a	n/a	1.09E-02	8.03E-02

Table 2.1.3e—Base selectivity parameters estimated by Model 1 (unlisted parameters were all fixed at 0).

	Model 1	
Parameter	Value	SD
Jan-Apr trawl fishery parameter 5	-999	n/a
Jan-Apr trawl fishery parameter 6	10	n/a
May-Jul trawl fishery parameter 3	5.64E+00	1.04E-01
May-Jul trawl fishery parameter 5	-999	n/a
May-Jul trawl fishery parameter 6	10	n/a
Aug-Dec trawl fishery parameter 5	-999	n/a
Aug-Dec trawl fishery parameter 6	10	n/a
Jan-Apr longline fishery parameter 2	-4.86E+00	2.00E+00
Jan-Apr longline fishery parameter 4	5.08E+00	1.44E-01
Jan-Apr longline fishery parameter 5	-999	n/a
May-Jul longline fishery parameter 3	5.02E+00	4.98E-02
May-Jul longline fishery parameter 5	-999	n/a
May-Jul longline fishery parameter 6	10	n/a
Aug-Dec longline fishery parameter 2	-2.15E+00	2.79E-01
Aug-Dec longline fishery parameter 4	5.13E+00	3.39E-01
Aug-Dec longline fishery parameter 5	-999	n/a
Jan-Apr trawl fishery parameter 2	-9.24E+00	1.82E+01
Jan-Apr trawl fishery parameter 3	5.00E+00	4.92E-02
Jan-Apr trawl fishery parameter 4	4.45E+00	2.88E-01
Jan-Apr trawl fishery parameter 5	-999	n/a
May-Jul trawl fishery parameter 3	4.93E+00	8.12E-02
May-Jul trawl fishery parameter 5	-999	n/a
May-Jul trawl fishery parameter 6	10	n/a
Aug-Dec trawl fishery parameter 5	-999	n/a
Aug-Dec trawl fishery parameter 6	10	n/a
trawl survey parameter 1	1.28E+00	5.58E-02
trawl survey parameter 2	-3.09E+00	5.85E-01
trawl survey parameter 3	-2.11E+00	4.33E-01
trawl survey parameter 4	2.93E+00	3.96E-01
trawl survey parameter 5	-9.99E+00	n/a
trawl survey parameter 6	-1.30E+00	4.47E-01

Table 2.1.3f—Block selectivity parameters and annual selectivity *dev*s estimated by Model 1 (p. 1 of 3).

	Model 1	
Parameter	Value	SD
Jan-Apr trawl fish. par. 1 block 1977	6.92E+01	3.06E+00
Jan-Apr trawl fish. par. 1 block 1985	7.66E+01	1.69E+00
Jan-Apr trawl fish. par. 1 block 1990	6.89E+01	1.11E+00
Jan-Apr trawl fish. par. 1 block 1995	7.41E+01	9.25E-01
Jan-Apr trawl fish. par. 1 block 2000	7.84E+01	1.20E+00
Jan-Apr trawl fish. par. 1 block 2005	7.59E+01	7.55E-01
Jan-Apr trawl fish. par. 3 block 1977	6.18E+00	1.71E-01
Jan-Apr trawl fish. par. 3 block 1985	6.63E+00	7.66E-02
Jan-Apr trawl fish. par. 3 block 1990	6.09E+00	5.88E-02
Jan-Apr trawl fish. par. 3 block 1995	6.30E+00	4.54E-02
Jan-Apr trawl fish. par. 3 block 2000	6.30E+00	6.06E-02
Jan-Apr trawl fish. par. 3 block 2005	5.97E+00	4.52E-02
May-Jul trawl fish. par. 1 block 1977	5.04E+01	1.72E+00
May-Jul trawl fish. par. 1 block 1985	5.15E+01	1.76E+00
May-Jul trawl fish. par. 1 block 1990	6.21E+01	1.57E+00
May-Jul trawl fish. par. 1 block 2000	5.32E+01	1.53E+00
May-Jul trawl fish. par. 1 block 2005	5.91E+01	1.46E+00
Aug-Dec trawl fish. par. 1 block 1977	6.27E+01	4.01E+00
Aug-Dec trawl fish. par. 1 block 1980	8.22E+01	5.64E+00
Aug-Dec trawl fish. par. 1 block 1985	8.70E+01	5.37E+00
Aug-Dec trawl fish. par. 1 block 1990	7.74E+01	3.94E+01
Aug-Dec trawl fish. par. 1 block 1995	1.02E+02	n/a
Aug-Dec trawl fish. par. 1 block 2000	5.74E+01	1.91E+00
Aug-Dec trawl fish. par. 3 block 1977	5.55E+00	3.27E-01
Aug-Dec trawl fish. par. 3 block 1980	6.67E+00	2.27E-01
Aug-Dec trawl fish. par. 3 block 1985	6.62E+00	2.28E-01
Aug-Dec trawl fish. par. 3 block 1990	6.39E+00	2.10E+00
Aug-Dec trawl fish. par. 3 block 1995	7.01E+00	8.80E-02
Aug-Dec trawl fish. par. 3 block 2000	5.25E+00	1.93E-01

Table 2.1.3f—Block selectivity parameters and annual selectivity devs estimated by Model 1 (p. 2 of 3).

	Model 1	
Parameter	Value	SD
Jan-Apr longline fish. par. 1 block 1977	5.91E+01	2.07E+00
Jan-Apr longline fish. par. 1 block 1980	7.25E+01	2.50E+00
Jan-Apr longline fish. par. 1 block 1985	7.52E+01	9.13E-01
Jan-Apr longline fish. par. 1 block 1990	6.61E+01	4.78E-01
Jan-Apr longline fish. par. 1 block 1995	6.58E+01	4.27E-01
Jan-Apr longline fish. par. 1 block 2000	6.35E+01	4.44E-01
Jan-Apr longline fish. par. 1 block 2005	6.71E+01	3.67E-01
Jan-Apr longline fish. par. 3 block 1977	5.15E+00	2.09E-01
Jan-Apr longline fish. par. 3 block 1980	5.91E+00	1.79E-01
Jan-Apr longline fish. par. 3 block 1985	5.86E+00	6.71E-02
Jan-Apr longline fish. par. 3 block 1990	5.23E+00	4.64E-02
Jan-Apr longline fish. par. 3 block 1995	5.30E+00	3.97E-02
Jan-Apr longline fish. par. 3 block 2000	5.36E+00	4.17E-02
Jan-Apr longline fish. par. 3 block 2005	5.32E+00	3.20E-02
Jan-Apr longline fish. par. 6 block 1977	-1.32E+00	8.18E-01
Jan-Apr longline fish. par. 6 block 1980	3.98E-01	1.08E+00
Jan-Apr longline fish. par. 6 block 1985	-1.28E+00	4.67E-01
Jan-Apr longline fish. par. 6 block 1990	-4.78E-01	1.39E-01
Jan-Apr longline fish. par. 6 block 1995	-6.90E-01	1.42E-01
Jan-Apr longline fish. par. 6 block 2000	-1.18E+00	1.48E-01
Jan-Apr longline fish. par. 6 block 2005	-8.83E-01	1.45E-01
May-Jul longline fish. par. 1 block 1977	6.35E+01	2.22E+00
May-Jul longline fish. par. 1 block 1980	6.26E+01	1.36E+00
May-Jul longline fish. par. 1 block 1985	6.35E+01	1.12E+00
May-Jul longline fish. par. 1 block 1990	6.37E+01	5.16E-01
May-Jul longline fish. par. 1 block 2000	5.99E+01	5.59E-01
May-Jul longline fish. par. 1 block 2005	6.46E+01	5.26E-01
Aug-Dec longline fish. par. 1 block 1977	6.07E+01	2.18E+00
Aug-Dec longline fish. par. 1 block 1980	6.98E+01	1.61E+00
Aug-Dec longline fish. par. 1 block 1985	6.45E+01	7.59E-01
Aug-Dec longline fish. par. 1 block 1990	6.71E+01	7.24E-01
Aug-Dec longline fish. par. 1 block 1995	6.96E+01	7.00E-01
Aug-Dec longline fish. par. 1 block 2000	6.37E+01	4.29E-01
Aug-Dec longline fish. par. 1 block 2005	6.34E+01	3.62E-01
Aug-Dec longline fish. par. 3 block 1977	4.54E+00	3.19E-01
Aug-Dec longline fish. par. 3 block 1980	5.42E+00	1.34E-01
Aug-Dec longline fish. par. 3 block 1985	4.88E+00	8.70E-02
Aug-Dec longline fish. par. 3 block 1990	5.04E+00	7.61E-02
Aug-Dec longline fish. par. 3 block 1995	5.51E+00	5.30E-02
Aug-Dec longline fish. par. 3 block 2000	5.18E+00	4.12E-02
Aug-Dec longline fish. par. 3 block 2005	4.97E+00	3.64E-02
Aug-Dec longline fish. par. 6 block 1977	-2.65E+00	2.28E+00
Aug-Dec longline fish. par. 6 block 1980	4.44E-01	7.86E-01
Aug-Dec longline fish. par. 6 block 1985	2.26E-01	2.56E-01
Aug-Dec longline fish. par. 6 block 1990	2.59E+00	1.05E+00
Aug-Dec longline fish. par. 6 block 1995	9.50E+00	1.29E+01
Aug-Dec longline fish. par. 6 block 2000	-3.70E-01	1.96E-01
Aug-Dec longline fish. par. 6 block 2005	9.73E+00	7.55E+00

Table 2.1.3f—Block selectivity parameters and annual selectivity *dev*s estimated by Model 1 (p. 3 of 3).

	Model 1	
Parameter	Value	SD
Jan-Apr pot fish. par. 1 block 1977	6.87E+01	9.22E-01
Jan-Apr pot fish. par. 1 block 1995	6.85E+01	5.48E-01
Jan-Apr pot fish. par. 1 block 2000	6.81E+01	5.18E-01
Jan-Apr pot fish. par. 1 block 2005	6.89E+01	5.12E-01
Jan-Apr pot fish. par. 6 block 1977	2.47E-01	5.67E-01
Jan-Apr pot fish. par. 6 block 1995	-2.27E-01	2.54E-01
Jan-Apr pot fish. par. 6 block 2000	-5.60E-01	2.38E-01
Jan-Apr pot fish. par. 6 block 2005	2.10E-01	2.33E-01
May-Jul pot fish. par. 1 block 1977	6.73E+01	8.59E-01
May-Jul pot fish. par. 1 block 1995	6.60E+01	7.15E-01
Aug-Dec pot fish. par. 1 block 1977	6.86E+01	1.19E+00
Aug-Dec pot fish. par. 1 block 2000	6.20E+01	6.84E-01
Aug-Dec pot fish. par. 1 block 1977	5.19E+00	1.19E-01
Aug-Dec pot fish. par. 1 block 2000	4.45E+00	1.07E-01
Survey par. 3 dev 1982	-5.22E-02	3.35E-02
Survey par. 3 dev 1983	-5.41E-02	1.69E-02
Survey par. 3 dev 1984	-9.10E-02	2.79E-02
Survey par. 3 dev 1985	-1.05E-02	2.07E-02
Survey par. 3 dev 1986	-5.63E-02	2.29E-02
Survey par. 3 dev 1987	2.68E-02	4.22E-02
Survey par. 3 dev 1988	-8.47E-02	3.27E-02
Survey par. 3 dev 1989	-1.29E-01	1.83E-02
Survey par. 3 dev 1990	-4.33E-02	2.04E-02
Survey par. 3 dev 1991	-5.27E-02	2.22E-02
Survey par. 3 dev 1992	7.78E-02	4.16E-02
Survey par. 3 dev 1993	3.80E-02	2.96E-02
Survey par. 3 dev 1994	-5.14E-02	2.16E-02
Survey par. 3 dev 1995	-1.03E-01	1.95E-02
Survey par. 3 dev 1996	-1.25E-01	1.75E-02
Survey par. 3 dev 1997	-7.71E-02	1.48E-02
Survey par. 3 dev 1998	-8.43E-02	1.89E-02
Survey par. 3 dev 1999	-9.02E-02	1.71E-02
Survey par. 3 dev 2000	-5.06E-02	1.53E-02
Survey par. 3 dev 2001	1.52E-01	3.75E-02
Survey par. 3 dev 2002	-2.70E-02	2.36E-02
Survey par. 3 dev 2003	-1.03E-02	1.93E-02
Survey par. 3 dev 2004	-3.07E-02	1.94E-02
Survey par. 3 dev 2005	3.27E-02	2.65E-02
Survey par. 3 dev 2006	1.45E-01	3.76E-02
Survey par. 3 dev 2007	1.90E-01	3.70E-02
Survey par. 3 dev 2008	1.09E-01	3.81E-02
Survey par. 3 dev 2009	-5.12E-03	1.60E-02
Survey par. 3 dev 2010	-2.75E-02	3.13E-02
Survey par. 3 dev 2011	1.11E-02	2.06E-02

Table 2.1.3g—Base selectivity parameters estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Parameter	Value	SD	Value	SD	Value	SD	Value	SD
Sea. 1 fish. par. 1	6.90E+01	4.95E-01	7.07E+01	4.79E-01	7.10E+01	4.84E-01	7.25E+01	4.69E-01
Sea. 1 fish. par. 2	-9.44E+00	1.42E+01	-9.48E+00	1.35E+01	-9.46E+00	1.39E+01	-9.56E+00	1.15E+01
Sea. 1 fish. par. 3	5.70E+00	3.27E-02	5.75E+00	3.06E-02	5.75E+00	3.03E-02	5.76E+00	2.85E-02
Sea. 1 fish. par. 4	5.01E+00	2.26E-01	5.10E+00	2.98E-01	5.08E+00	3.12E-01	5.76E+00	4.48E-01
Sea. 1 fish. par. 5	-999	n/a	-999	n/a	-999	n/a	-999	n/a
Sea. 1 fish. par. 6	-2.04E-01	1.60E-01	-9.49E-02	2.11E-01	-4.92E-02	2.17E-01	-5.72E-01	5.37E-01
Sea. 2 fish. par. 1	6.92E+01	5.59E-01	7.10E+01	5.47E-01	7.14E+01	5.53E-01	7.31E+01	5.39E-01
Sea. 2 fish. par. 2	-9.43E+00	1.44E+01	-9.52E+00	1.25E+01	-9.51E+00	1.27E+01	-9.56E+00	1.15E+01
Sea. 2 fish. par. 3	5.89E+00	3.31E-02	5.94E+00	3.11E-02	5.93E+00	3.07E-02	5.94E+00	2.86E-02
Sea. 2 fish. par. 4	4.73E+00	2.89E-01	4.84E+00	4.24E-01	4.80E+00	4.42E-01	6.66E+00	6.70E-01
Sea. 2 fish. par. 5	-999	n/a	-999	n/a	-999	n/a	-999	n/a
Sea. 2 fish. par. 6	2.02E-01	1.59E-01	3.56E-01	2.22E-01	3.96E-01	2.29E-01	-1.30E+00	1.36E+00
Sea. 3 fish. par. 1	6.62E+01	7.20E-01	6.84E+01	7.14E-01	6.89E+01	7.30E-01	7.11E+01	7.21E-01
Sea. 3 fish. par. 2	10	n/a	10	n/a	10	n/a	10	n/a
Sea. 3 fish. par. 3	5.67E+00	5.19E-02	5.74E+00	4.89E-02	5.74E+00	4.86E-02	5.79E+00	4.51E-02
Sea. 3 fish. par. 4	0	n/a	0	n/a	0	n/a	0	n/a
Sea. 3 fish. par. 5	-999	n/a	-999	n/a	-999	n/a	-999	n/a
Sea. 3 fish. par. 6	10	n/a	10	n/a	10	n/a	10	n/a
Sea. 4 fish. par. 1	6.46E+01	4.14E-01	6.62E+01	4.45E-01	6.67E+01	4.61E-01	6.88E+01	4.47E-01
Sea. 4 fish. par. 2	-1.75E+00	3.36E-01	8.14E-01	3.95E-01	8.35E-01	5.01E-01	5.14E-01	3.58E-01
Sea. 4 fish. par. 3	5.09E+00	3.77E-02	5.18E+00	3.68E-02	5.20E+00	3.71E-02	5.30E+00	3.29E-02
Sea. 4 fish. par. 4	1.27E+00	2.54E+00	3.78E+00	2.70E+00	3.69E+00	3.31E+00	4.35E+00	1.53E+00
Sea. 4 fish. par. 5	-999	n/a	-999	n/a	-999	n/a	-999	n/a
Sea. 4 fish. par. 6	2.17E+00	3.49E-01	-2.80E-01	1.70E+00	-1.54E-01	1.81E+00	-1.53E+00	1.55E+00
Sea. 5 fish. par. 1	6.41E+01	5.27E-01	6.59E+01	5.25E-01	6.64E+01	5.33E-01	6.84E+01	5.28E-01
Sea. 5 fish. par. 2	-2.02E+00	4.89E-01	-1.89E+00	5.12E-01	-1.89E+00	5.76E-01	-1.93E+00	5.86E-01
Sea. 5 fish. par. 3	5.20E+00	4.66E-02	5.30E+00	4.30E-02	5.32E+00	4.25E-02	5.40E+00	3.87E-02
Sea. 5 fish. par. 4	5.09E+00	6.67E-01	5.43E+00	9.87E-01	5.46E+00	1.10E+00	7.26E+00	1.02E+00
Sea. 5 fish. par. 5	-999	n/a	-999	n/a	-999	n/a	-999	n/a
Sea. 5 fish. par. 6	2.98E-01	2.77E-01	3.27E-01	5.45E-01	3.22E-01	6.08E-01	-2.72E+00	3.67E+00
Survey par. 1	2.78E+01	6.72E-01	2.87E+01	7.17E-01	3.37E+01	6.93E-01	3.38E+01	5.72E-01
Survey par. 2	-1.36E+00	2.10E-01	-1.45E+00	2.96E-01	-8.93E+00	2.39E+01	1.00E+01	n/a
Survey par. 3	4.83E+00	5.16E-01	5.17E+00	3.91E-01	5.76E+00	3.50E-01	6.01E+00	2.86E-01
Survey par. 4	6.63E+00	3.54E-01	7.10E+00	5.81E-01	7.98E+00	4.99E-01	0.00E+00	n/a
Survey par. 5	-3.98E-01	3.41E-01	-5.57E-01	3.10E-01	-3.43E-01	2.68E-01	-1.01E+00	2.92E-01
Survey par. 6	-1.07E+00	3.50E-01	-7.63E-01	6.16E-01	-9.40E-01	7.53E-01	1.00E+01	n/a

Table 2.1.3h—Annual *dev*s for selectivity parameter #3 estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Year	Value	SD	Value	SD	Value	SD	Value	SD
1982	-3.66E+00	1.36E+00	-4.08E+00	1.32E+00	-3.48E+00	7.50E-01	-3.84E+00	6.93E-01
1983	-3.46E+00	1.14E+00	-3.55E+00	1.05E+00	-2.86E+00	7.14E-01	-3.02E+00	6.80E-01
1984	-9.98E-01	6.44E-01	-1.11E+00	5.57E-01	-7.15E-01	4.82E-01	-1.00E+00	4.07E-01
1985	-6.25E-02	4.93E-01	-2.47E-01	3.97E-01	-1.43E-01	3.79E-01	-4.08E-01	3.21E-01
1986	-2.17E+00	6.32E-01	-2.16E+00	5.33E-01	-1.45E+00	4.15E-01	-1.59E+00	3.83E-01
1987	3.46E-01	7.99E-01	-1.52E-02	6.60E-01	-3.20E-01	6.49E-01	-5.30E-01	5.10E-01
1988	-9.13E-01	7.47E-01	-1.20E+00	6.26E-01	-1.18E+00	4.81E-01	-1.41E+00	4.22E-01
1989	-3.25E+00	1.26E+00	-3.70E+00	1.13E+00	-5.26E+00	1.11E+00	-5.93E+00	1.26E+00
1990	-2.33E+00	1.08E+00	-2.53E+00	1.00E+00	-2.11E+00	7.95E-01	-2.40E+00	7.22E-01
1991	-1.53E+00	8.49E-01	-1.76E+00	7.77E-01	-1.47E+00	5.97E-01	-1.67E+00	5.27E-01
1992	1.14E+00	1.10E+00	9.13E-01	1.04E+00	9.27E-01	1.18E+00	5.80E-01	9.10E-01
1993	9.51E-01	9.38E-01	7.34E-01	8.72E-01	4.85E-01	9.46E-01	4.26E-01	7.73E-01
1994	-3.72E-01	6.12E-01	-6.05E-01	5.34E-01	-1.06E+00	5.99E-01	-8.51E-01	4.19E-01
1995	-9.48E-01	6.36E-01	-1.12E+00	5.54E-01	-1.06E+00	4.54E-01	-1.10E+00	3.86E-01
1996	-1.44E+00	7.87E-01	-1.57E+00	7.69E-01	-1.61E+00	6.01E-01	-1.52E+00	4.93E-01
1997	-8.87E-01	5.52E-01	-9.61E-01	4.88E-01	-2.99E+00	7.26E-01	-1.01E+00	4.44E-01
1998	-2.61E+00	7.42E-01	-2.52E+00	6.01E-01	-1.65E+00	4.12E-01	-1.66E+00	3.87E-01
1999	-1.95E+00	6.23E-01	-2.07E+00	5.32E-01	-1.75E+00	4.23E-01	-1.85E+00	3.77E-01
2000	-3.86E+00	1.03E+00	-3.95E+00	9.32E-01	-3.25E+00	6.52E-01	-3.38E+00	5.94E-01
2001	1.94E+00	1.12E+00	1.68E+00	1.05E+00	-3.62E+00	6.88E-01	9.41E-01	7.68E-01
2002	-3.15E+00	1.12E+00	-3.34E+00	9.67E-01	-2.40E+00	5.35E-01	-2.54E+00	4.95E-01
2003	2.37E-01	5.35E-01	1.20E-01	4.67E-01	1.76E-01	4.99E-01	-4.64E-02	4.15E-01
2004	-1.54E-01	5.74E-01	-3.06E-01	5.03E-01	-2.58E+00	7.86E-01	-6.10E-01	4.92E-01
2005	3.34E-01	5.23E-01	2.65E-01	4.66E-01	5.42E-01	5.42E-01	2.95E-01	4.72E-01
2006	1.36E+00	1.59E+00	1.32E+00	1.56E+00	-3.99E+00	1.10E+00	-4.05E+00	1.04E+00
2007	1.77E+00	1.43E+00	1.65E+00	1.44E+00	1.37E+00	1.53E+00	1.34E+00	1.52E+00
2008	-2.22E+00	8.33E-01	-2.18E+00	7.19E-01	-1.37E+00	6.25E-01	-1.60E+00	5.27E-01
2009	-2.91E+00	8.30E-01	-2.84E+00	7.18E-01	-1.83E+00	5.10E-01	-2.10E+00	4.12E-01
2010	-2.23E+00	1.08E+00	-2.19E+00	9.29E-01	-1.28E+00	7.20E-01	-1.47E+00	6.64E-01

Table 2.1.3i—Annual *dev*s for selectivity parameter #5 estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Year	Value	SD	Value	SD	Value	SD	Value	SD
1982	-6.95E-01	5.21E-01	-6.02E-01	4.95E-01	-1.00E+00	4.48E-01	-5.97E-01	4.42E-01
1983	-1.28E-01	3.97E-01	-3.09E-02	3.70E-01	-4.80E-01	3.34E-01	1.16E-01	3.42E-01
1984	-7.53E-01	6.24E-01	-7.26E-01	6.20E-01	-1.15E+00	6.85E-01	-8.87E-01	6.94E-01
1985	-1.77E+00	6.95E-01	-1.77E+00	7.13E-01	-2.15E+00	7.09E-01	-1.85E+00	7.50E-01
1986	-5.68E-01	4.37E-01	-5.03E-01	4.12E-01	-9.60E-01	3.92E-01	-3.99E-01	4.07E-01
1987	-6.90E-01	1.02E+00	-8.09E-01	9.71E-01	-9.78E-01	9.22E-01	-8.41E-01	9.42E-01
1988	-1.07E+00	7.57E-01	-1.19E+00	7.19E-01	-1.76E+00	6.67E-01	-1.43E+00	7.01E-01
1989	-1.50E+00	4.38E-01	-1.41E+00	4.15E-01	-1.52E+00	3.79E-01	-1.16E+00	3.82E-01
1990	4.91E-02	4.29E-01	7.43E-02	4.01E-01	-1.57E-01	4.04E-01	1.58E-01	3.70E-01
1991	-3.70E-01	4.57E-01	-3.47E-01	4.32E-01	-6.57E-01	4.20E-01	-2.81E-01	4.24E-01
1992	-3.82E-01	1.08E+00	-4.87E-01	1.05E+00	-5.59E-01	9.97E-01	-6.29E-01	1.01E+00
1993	-5.49E-01	1.01E+00	-6.06E-01	9.98E-01	-6.95E-01	9.48E-01	-6.39E-01	9.83E-01
1994	-1.07E+00	8.00E-01	-1.04E+00	8.05E-01	-1.13E+00	6.34E-01	-1.00E+00	8.12E-01
1995	-1.29E+00	6.47E-01	-1.24E+00	6.54E-01	-1.69E+00	6.14E-01	-1.30E+00	7.18E-01
1996	-1.55E+00	5.88E-01	-1.37E+00	6.12E-01	-1.69E+00	4.83E-01	-1.22E+00	6.33E-01
1997	-1.14E+00	4.87E-01	-1.01E+00	5.31E-01	-7.13E-01	3.14E-01	-8.06E-01	6.70E-01
1998	-9.84E-01	4.17E-01	-9.51E-01	3.92E-01	-1.52E+00	3.73E-01	-9.15E-01	4.13E-01
1999	-1.12E+00	4.11E-01	-1.06E+00	3.87E-01	-1.52E+00	3.56E-01	-9.97E-01	3.80E-01
2000	-5.26E-01	3.70E-01	-4.31E-01	3.41E-01	-8.38E-01	3.03E-01	-2.57E-01	3.19E-01
2001	-5.68E-01	9.48E-01	-7.71E-01	9.29E-01	5.52E-01	3.39E-01	-1.02E+00	9.06E-01
2002	-9.26E-02	4.27E-01	-5.00E-02	3.97E-01	-5.15E-01	3.55E-01	5.89E-03	3.65E-01
2003	-1.33E+00	8.38E-01	-1.25E+00	8.57E-01	-1.40E+00	8.32E-01	-1.17E+00	8.75E-01
2004	-1.13E+00	8.27E-01	-1.04E+00	8.56E-01	-1.55E-01	3.40E-01	-7.48E-01	9.36E-01
2005	-1.57E+00	8.30E-01	-1.45E+00	8.48E-01	-1.62E+00	8.23E-01	-1.36E+00	8.59E-01
2006	1.42E+00	8.66E-01	1.59E+00	8.28E-01	1.19E+00	4.17E-01	1.75E+00	3.91E-01
2007	2.56E+00	7.64E-01	2.76E+00	7.39E-01	2.83E+00	7.12E-01	3.09E+00	6.93E-01
2008	9.81E-01	4.72E-01	1.08E+00	4.42E-01	8.52E-01	4.33E-01	1.10E+00	3.96E-01
2009	4.67E-01	3.76E-01	6.63E-01	3.51E-01	8.73E-01	3.58E-01	8.95E-01	3.28E-01
2010	2.85E-01	5.50E-01	2.67E-01	5.15E-01	-1.26E-01	5.41E-01	1.79E-01	5.50E-01

Table 2.1.3j—Base selectivity parameters estimated by Models 6.

	Model 6	
Parameter	Value	SD
Fishery age 1 selectivity parameter	2.94E+00	3.50E-01
Fishery age 2 selectivity parameter	3.21E+00	3.01E-01
Fishery age 3 selectivity parameter	2.87E+00	1.67E-01
Fishery age 4 selectivity parameter	1.83E+00	2.19E-01
Fishery age 5 selectivity parameter	9.43E-01	9.45E-02
Fishery age 6 selectivity parameter	1.89E-01	1.31E-01
Fishery age 7 selectivity parameter	-2.34E-01	1.83E-01
Fishery age 8 selectivity parameter	-6.25E-02	2.31E-01
Fishery age 9 selectivity parameter	-1.78E-01	2.63E-01
Fishery age 10 selectivity parameter	-1.13E-01	2.79E-01
Fishery age 11 selectivity parameter	2.30E-01	3.00E-01
Fishery age 12 selectivity parameter	1.90E-01	3.25E-01
Fishery age 13 selectivity parameter	-3.03E-02	3.33E-01
Fishery age 14 selectivity parameter	-6.40E-02	3.38E-01
Fishery age 15 selectivity parameter	-8.06E-02	3.36E-01
Fishery age 16 selectivity parameter	-3.61E-02	3.41E-01
Fishery age 17 selectivity parameter	-1.71E-02	3.44E-01
Fishery age 18 selectivity parameter	-6.71E-03	3.47E-01
Fishery age 19 selectivity parameter	-3.54E-03	3.48E-01
Fishery age 20 selectivity parameter	-4.86E-03	3.49E-01
Survey age 1 selectivity parameter	5.02E+00	3.19E-01
Survey age 2 selectivity parameter	8.17E-01	1.62E-01
Survey age 3 selectivity parameter	1.75E-01	4.99E-02
Survey age 4 selectivity parameter	-1.37E-01	5.83E-02
Survey age 5 selectivity parameter	-3.36E-02	8.09E-02
Survey age 6 selectivity parameter	-9.69E-02	1.25E-01
Survey age 7 selectivity parameter	-6.74E-03	1.70E-01
Survey age 8 selectivity parameter	-1.90E-01	2.16E-01
Survey age 9 selectivity parameter	-2.22E-01	2.48E-01
Survey age 10 selectivity parameter	-9.74E-02	2.68E-01
Survey age 11 selectivity parameter	-5.86E-02	2.88E-01
Survey age 12 selectivity parameter	-5.04E-02	3.02E-01
Survey age 13 selectivity parameter	-5.94E-02	3.08E-01
Survey age 14 selectivity parameter	-3.18E-02	3.13E-01
Survey age 15 selectivity parameter	-1.65E-02	3.16E-01
Survey age 16 selectivity parameter	-1.63E-02	3.16E-01
Survey age 17 selectivity parameter	-1.58E-02	3.17E-01
Survey age 18 selectivity parameter	-1.30E-02	3.17E-01
Survey age 19 selectivity parameter	-9.47E-03	3.18E-01
Survey age 20 selectivity parameter	-6.46E-03	3.18E-01

Table 2.1.3k—Annual *dev*s for age 4 fishery selectivity parameter estimated by Model 6.

	Model 6	
Parameter	Value	SD
Fishery age 4 sel. par. dev 1977	-2.20E-02	1.46E-01
Fishery age 4 sel. par. dev 1978	3.80E-04	1.21E-01
Fishery age 4 sel. par. dev 1979	-1.44E-01	6.80E-02
Fishery age 4 sel. par. dev 1980	-1.10E-01	6.78E-02
Fishery age 4 sel. par. dev 1981	-2.08E-01	7.09E-02
Fishery age 4 sel. par. dev 1982	-2.09E-02	1.11E-01
Fishery age 4 sel. par. dev 1983	-6.88E-02	7.75E-02
Fishery age 4 sel. par. dev 1984	-1.48E-01	4.02E-02
Fishery age 4 sel. par. dev 1985	-9.72E-03	3.92E-02
Fishery age 4 sel. par. dev 1986	-1.01E-01	4.40E-02
Fishery age 4 sel. par. dev 1987	-1.58E-02	3.46E-02
Fishery age 4 sel. par. dev 1988	-2.10E-01	3.70E-02
Fishery age 4 sel. par. dev 1989	-1.78E-01	5.28E-02
Fishery age 4 sel. par. dev 1990	-9.69E-02	4.45E-02
Fishery age 4 sel. par. dev 1991	-4.26E-02	3.19E-02
Fishery age 4 sel. par. dev 1992	-3.44E-03	3.09E-02
Fishery age 4 sel. par. dev 1993	-8.80E-02	3.15E-02
Fishery age 4 sel. par. dev 1994	-8.56E-02	3.30E-02
Fishery age 4 sel. par. dev 1995	-6.22E-02	2.84E-02
Fishery age 4 sel. par. dev 1996	6.53E-04	3.90E-02
Fishery age 4 sel. par. dev 1997	-6.02E-02	3.18E-02
Fishery age 4 sel. par. dev 1998	-2.65E-02	3.35E-02
Fishery age 4 sel. par. dev 1999	-3.17E-02	2.82E-02
Fishery age 4 sel. par. dev 2000	1.10E-01	5.71E-02
Fishery age 4 sel. par. dev 2001	4.48E-02	4.75E-02
Fishery age 4 sel. par. dev 2002	-2.64E-02	2.96E-02
Fishery age 4 sel. par. dev 2003	-4.94E-03	3.66E-02
Fishery age 4 sel. par. dev 2004	1.10E-02	4.70E-02
Fishery age 4 sel. par. dev 2005	-2.40E-02	3.71E-02
Fishery age 4 sel. par. dev 2006	3.79E-02	4.73E-02
Fishery age 4 sel. par. dev 2007	6.97E-02	5.69E-02
Fishery age 4 sel. par. dev 2008	4.89E-02	3.75E-02
Fishery age 4 sel. par. dev 2009	1.64E-01	5.41E-02
Fishery age 4 sel. par. dev 2010	2.29E-01	7.96E-02
Fishery age 4 sel. par. dev 2011	1.20E-01	4.67E-02
Fishery age 4 sel. par. dev 2012	1.17E-01	8.35E-02
Fishery age 4 sel. par. dev 2013	-1.54E-02	3.90E-02

Table 2.1.3l—Annual *dev*s for age 2 survey selectivity parameter estimated by Model 6.

	Model 6	
Parameter	Value	SD
Survey age 2 sel. par. dev 1982	5.67E-02	3.41E-02
Survey age 2 sel. par. dev 1983	1.86E-03	2.09E-02
Survey age 2 sel. par. dev 1984	7.75E-02	3.91E-02
Survey age 2 sel. par. dev 1985	-2.19E-02	2.06E-02
Survey age 2 sel. par. dev 1986	3.98E-02	2.60E-02
Survey age 2 sel. par. dev 1987	-1.63E-02	2.95E-02
Survey age 2 sel. par. dev 1988	3.56E-02	4.21E-02
Survey age 2 sel. par. dev 1989	1.17E-01	2.99E-02
Survey age 2 sel. par. dev 1990	3.11E-03	2.38E-02
Survey age 2 sel. par. dev 1991	2.67E-02	2.54E-02
Survey age 2 sel. par. dev 1992	-7.25E-02	2.44E-02
Survey age 2 sel. par. dev 1993	-4.26E-02	2.08E-02
Survey age 2 sel. par. dev 1994	5.12E-02	2.38E-02
Survey age 2 sel. par. dev 1995	7.77E-02	2.80E-02
Survey age 2 sel. par. dev 1996	9.64E-02	2.74E-02
Survey age 2 sel. par. dev 1997	3.27E-02	2.01E-02
Survey age 2 sel. par. dev 1998	8.54E-02	2.52E-02
Survey age 2 sel. par. dev 1999	7.42E-02	2.42E-02
Survey age 2 sel. par. dev 2000	2.20E-02	1.96E-02
Survey age 2 sel. par. dev 2001	-7.54E-02	1.89E-02
Survey age 2 sel. par. dev 2002	2.53E-02	2.30E-02
Survey age 2 sel. par. dev 2003	-3.54E-02	1.99E-02
Survey age 2 sel. par. dev 2004	-2.35E-03	2.10E-02
Survey age 2 sel. par. dev 2005	-5.21E-02	2.02E-02
Survey age 2 sel. par. dev 2006	-5.40E-02	1.94E-02
Survey age 2 sel. par. dev 2007	-1.35E-01	1.88E-02
Survey age 2 sel. par. dev 2008	-3.72E-03	2.01E-02
Survey age 2 sel. par. dev 2009	-4.71E-02	1.84E-02
Survey age 2 sel. par. dev 2010	-2.33E-02	2.95E-02
Survey age 2 sel. par. dev 2011	-6.04E-02	1.96E-02
Survey age 2 sel. par. dev 2012	-3.79E-02	2.05E-02

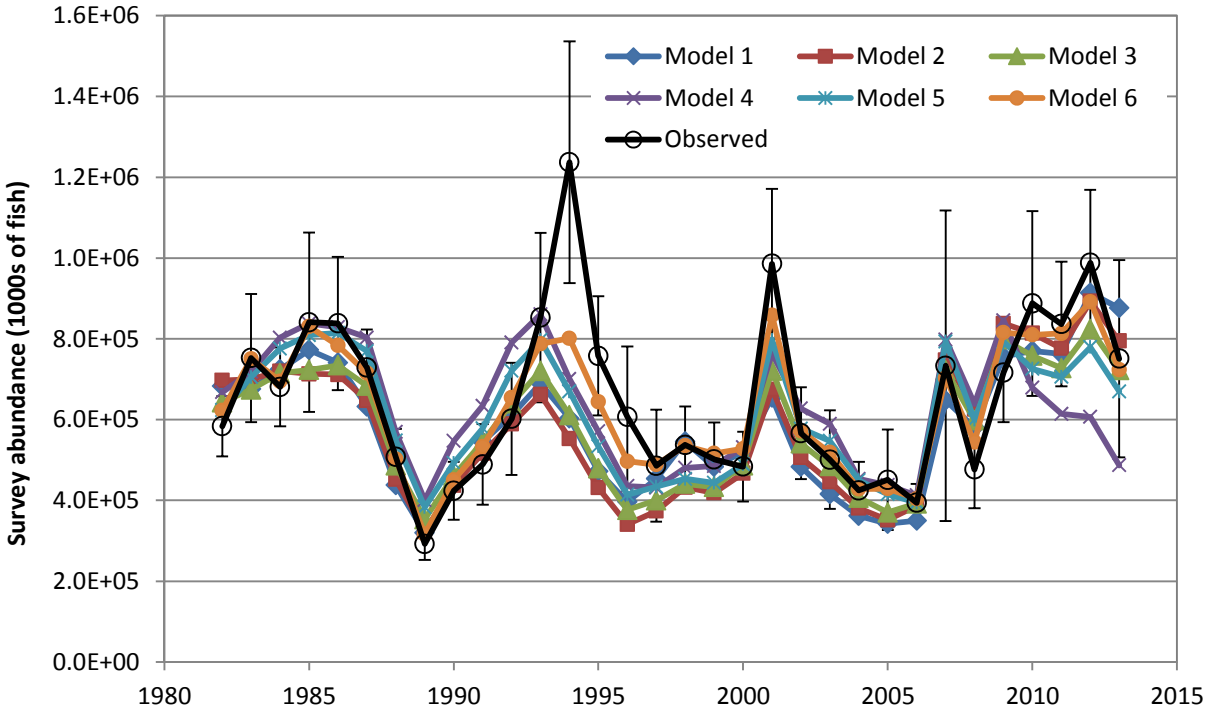


Figure 2.1.1a—Model fits to the survey abundance time series.

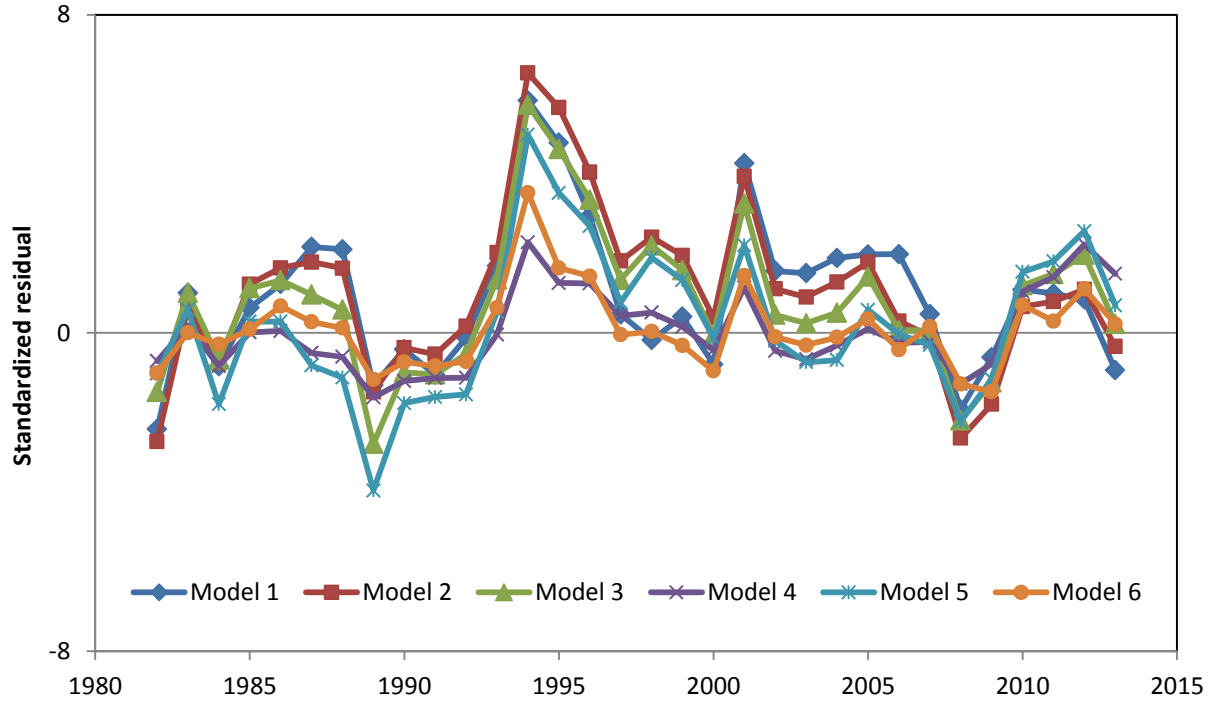


Figure 2.1.1b—Standardized residuals from the model fits to the survey abundance time series.

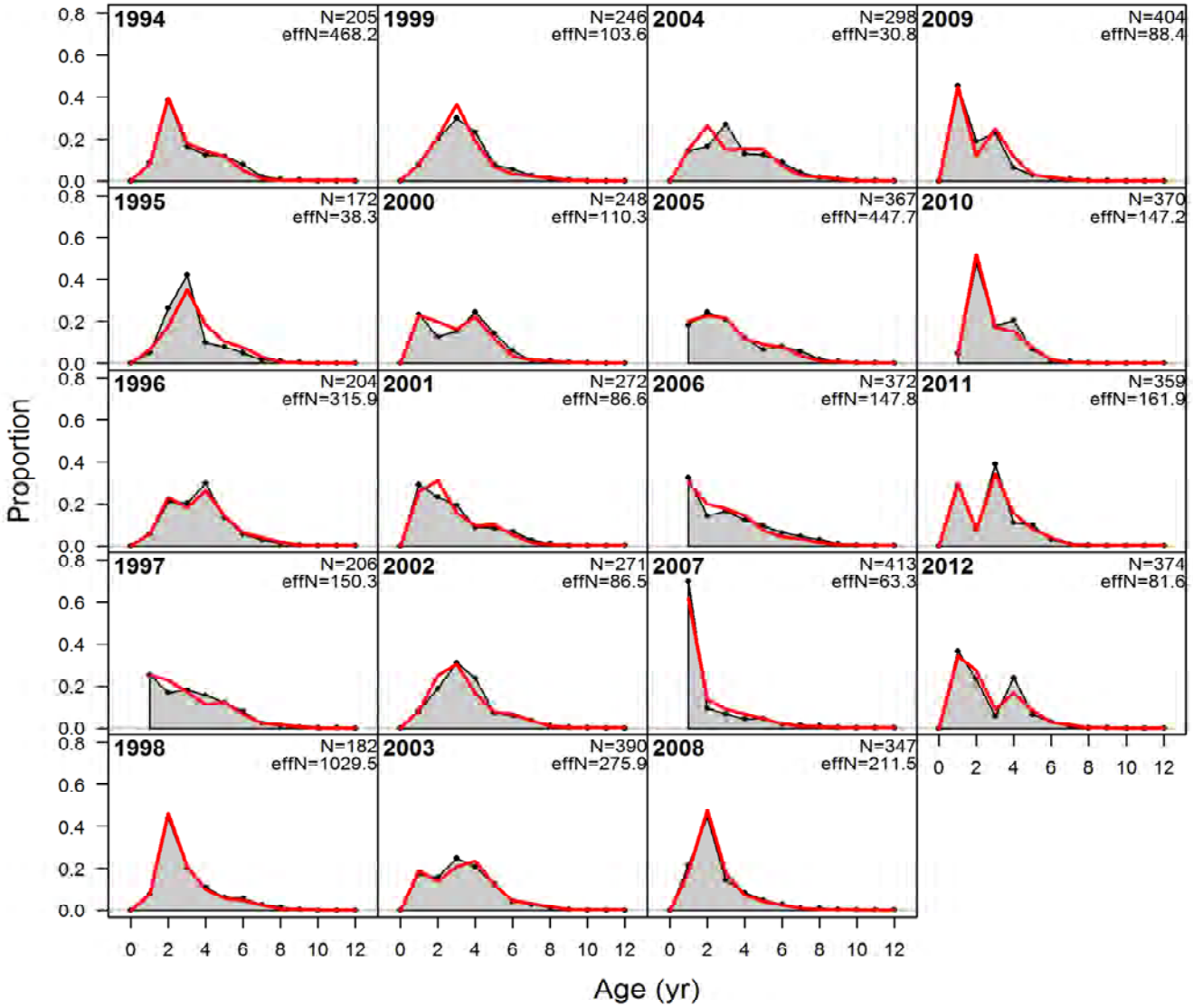


Figure 2.1.2a—Model 1 fits to the fishery age composition data.

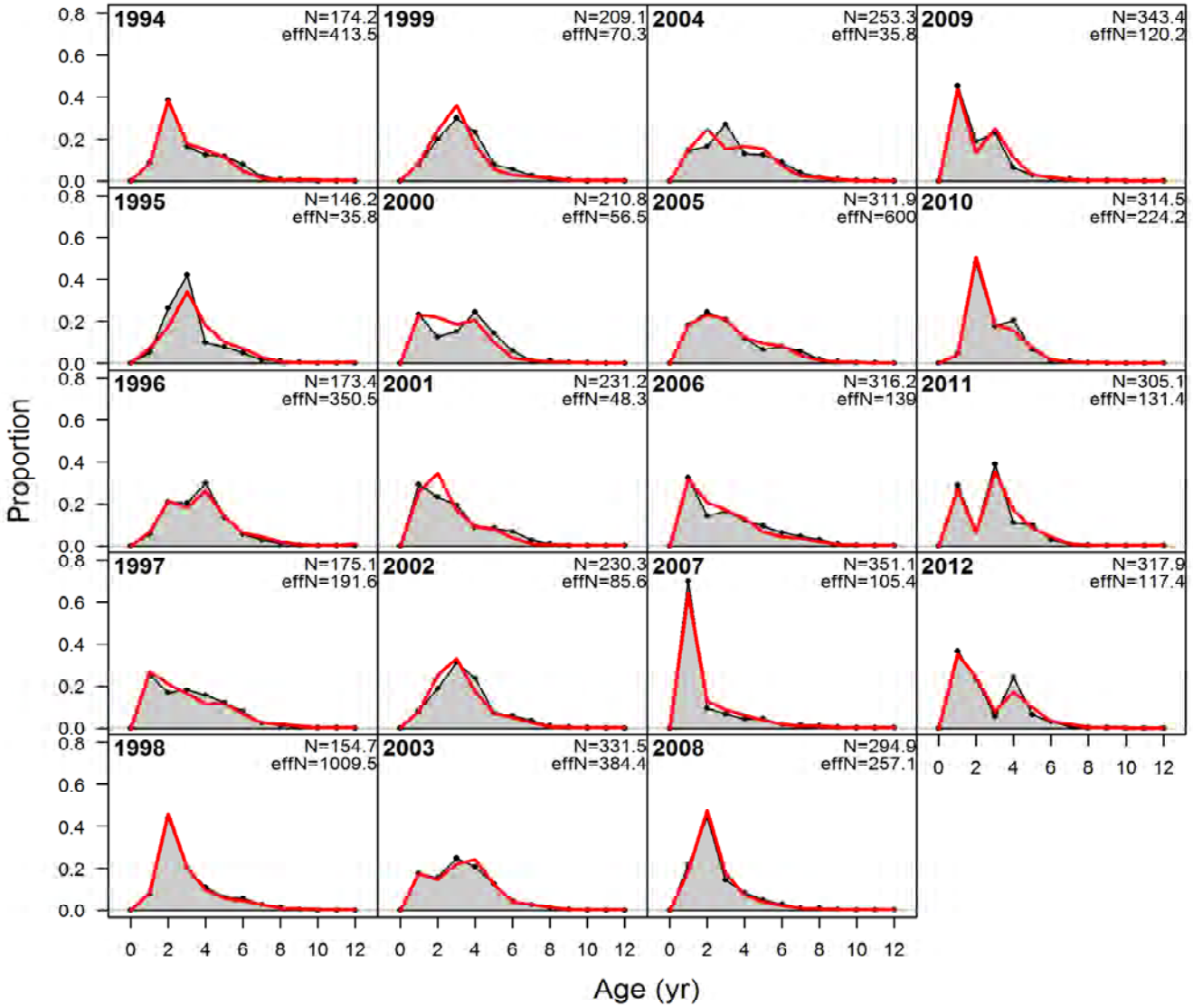


Figure 2.1.2b—Model 2 fits to the fishery age composition data.

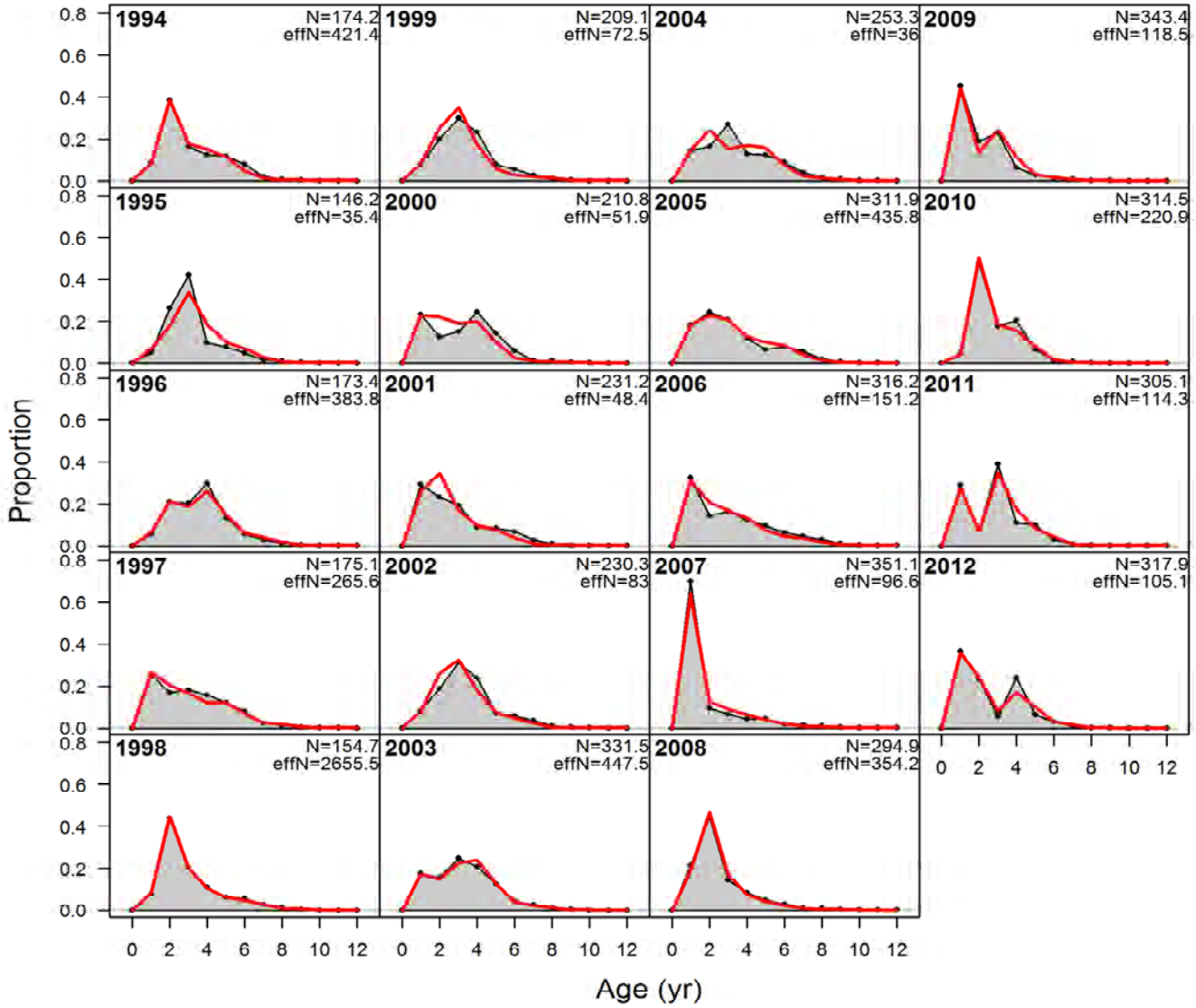


Figure 2.1.2c—Model 3 fits to the fishery age composition data.

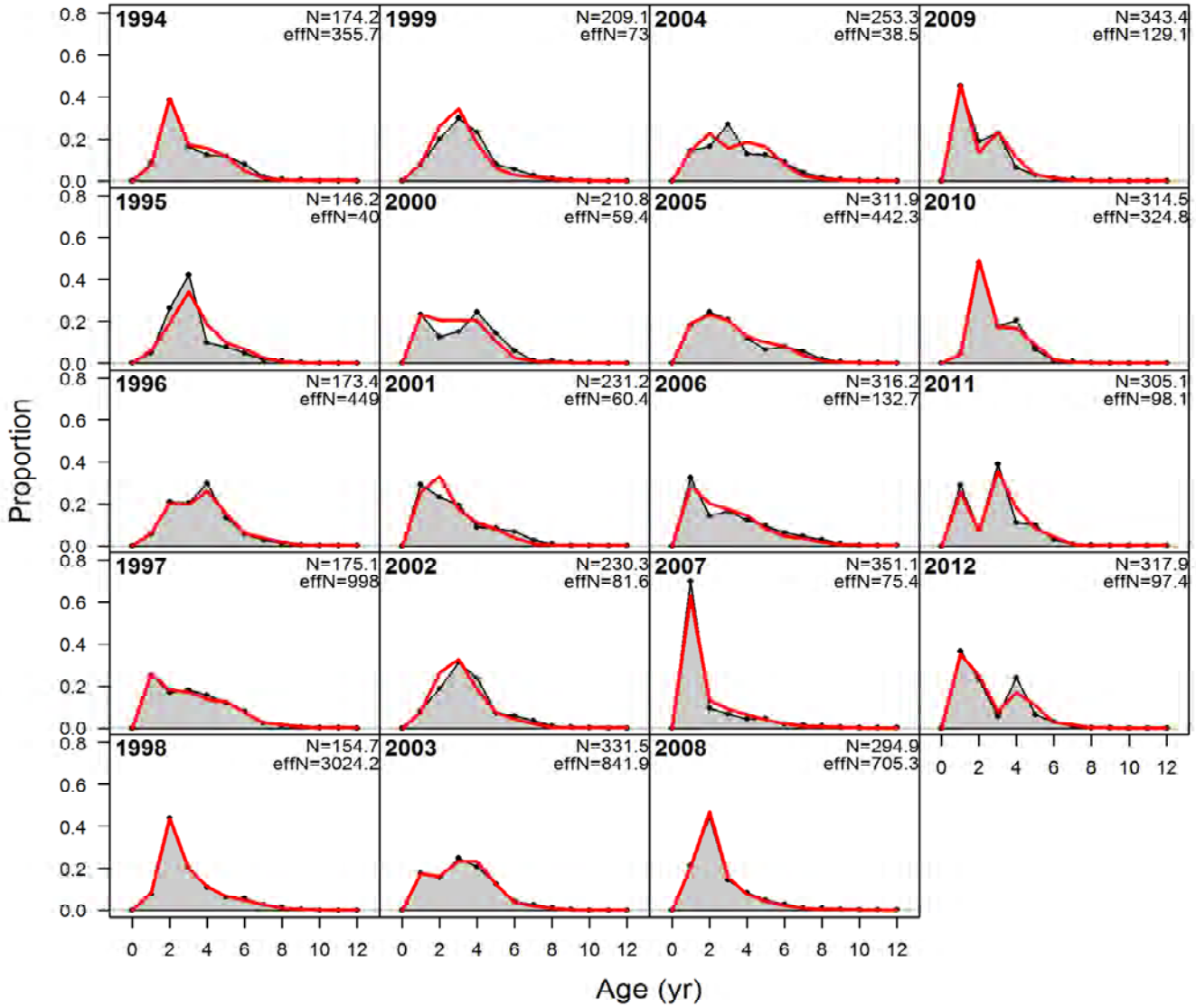


Figure 2.1.2d—Model 4 fits to the fishery age composition data.

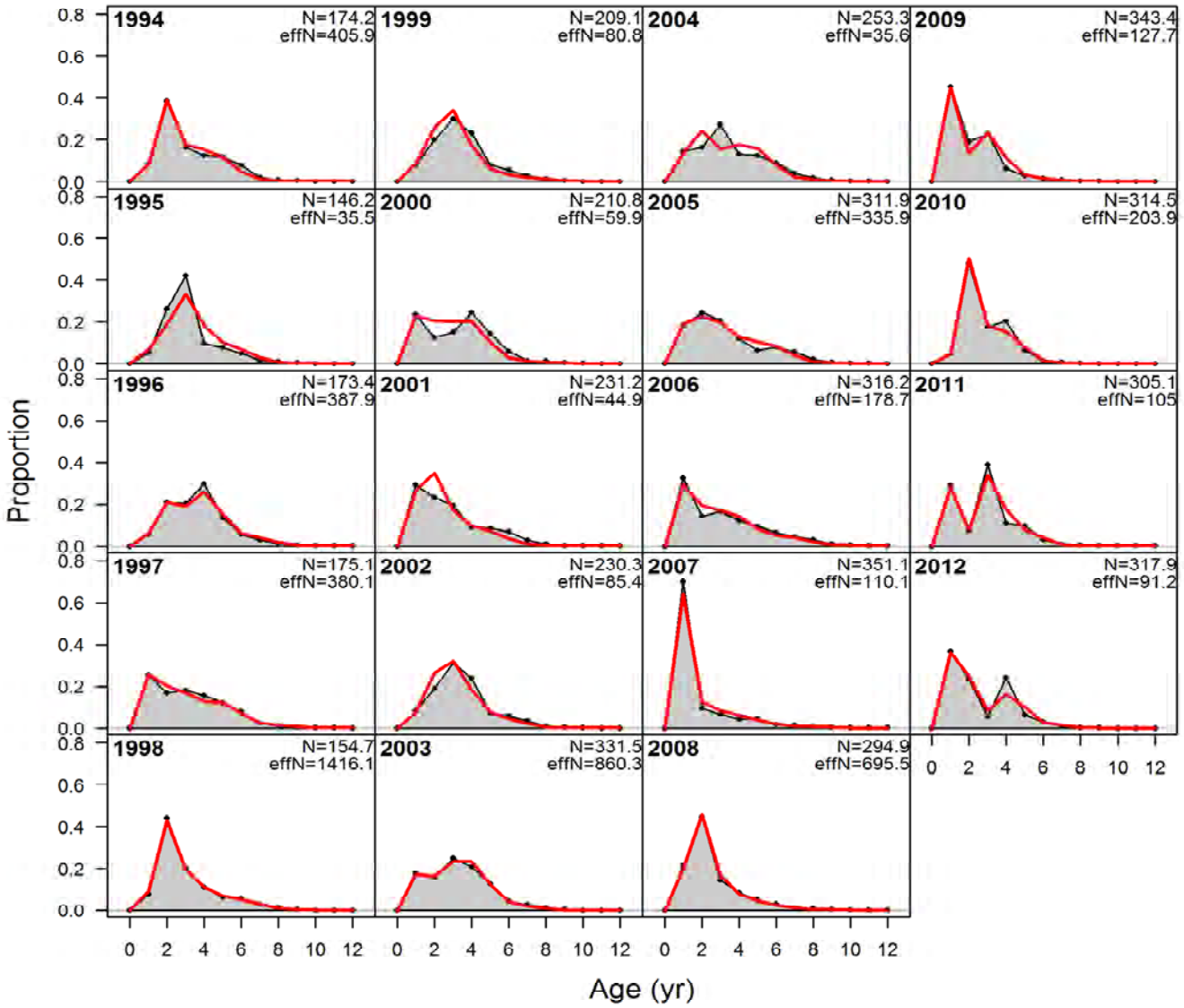


Figure 2.1.2e—Model 5 fits to the fishery age composition data.

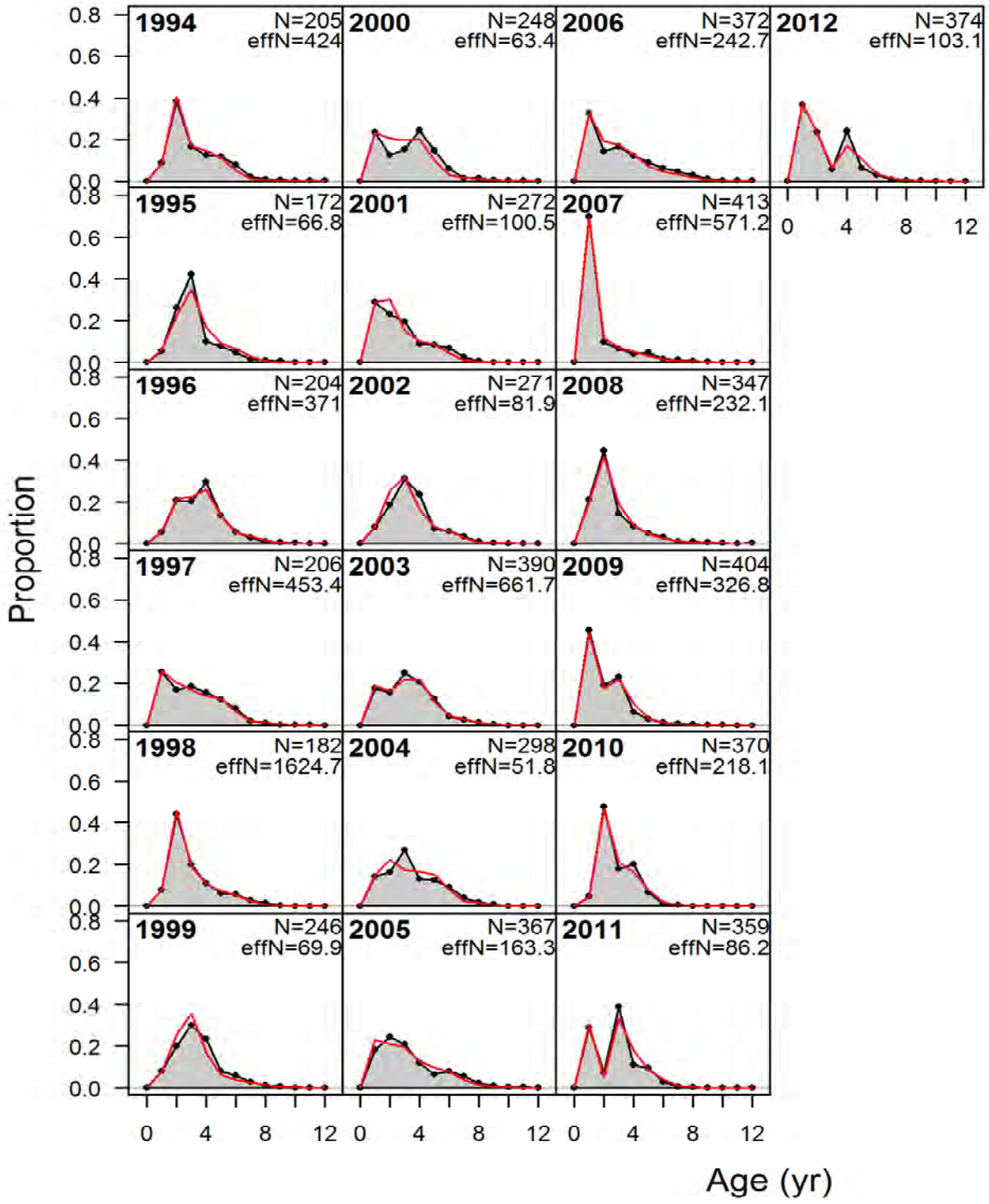
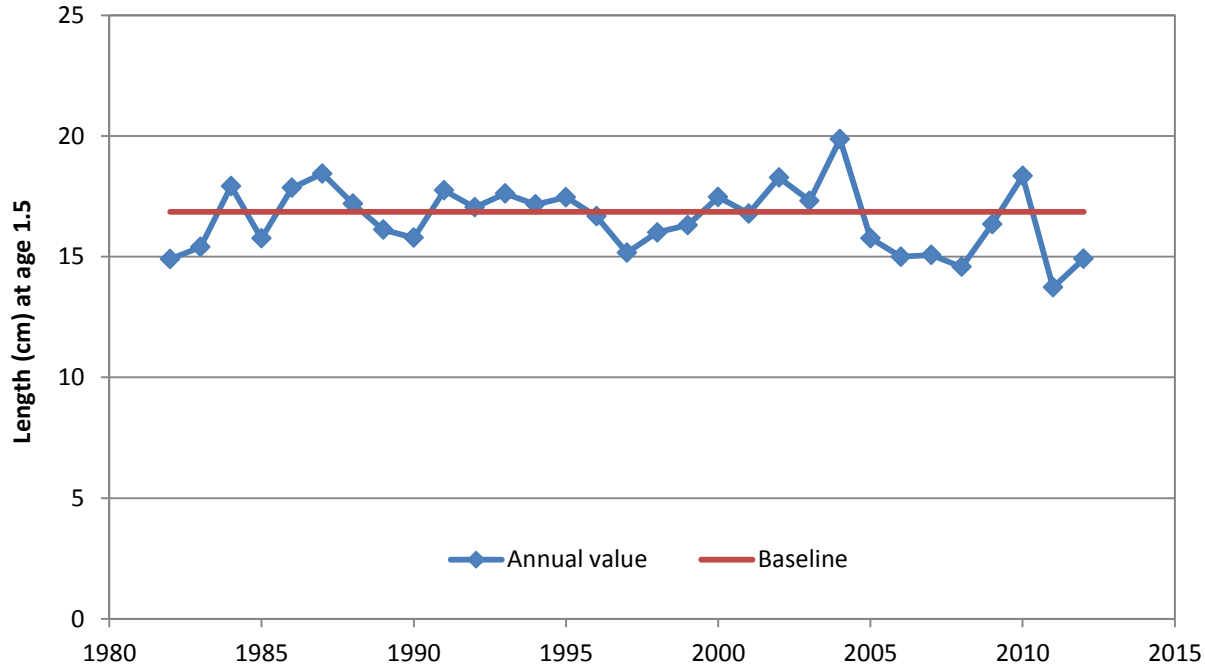


Figure 2.1.2f—Model 6 fits to the fishery age composition data.

Length at age 1.5



Catchability

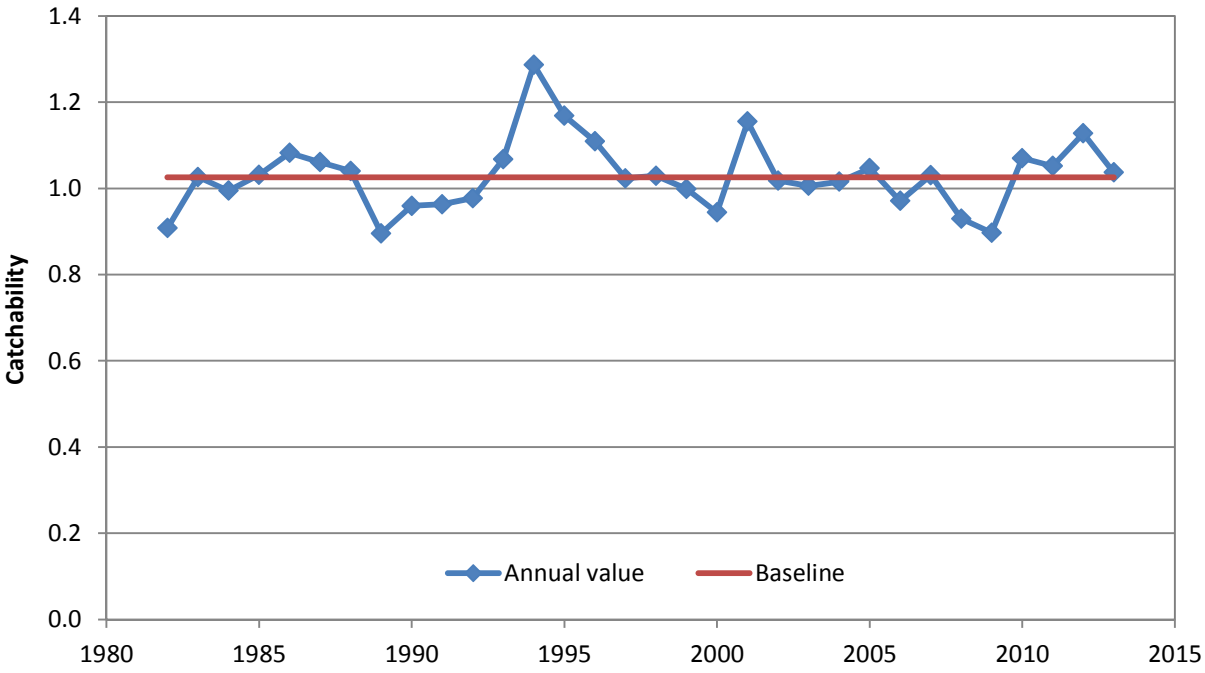


Figure 2.1.3—Time series of length at age 1.5 and survey catchability estimated by Model 6.

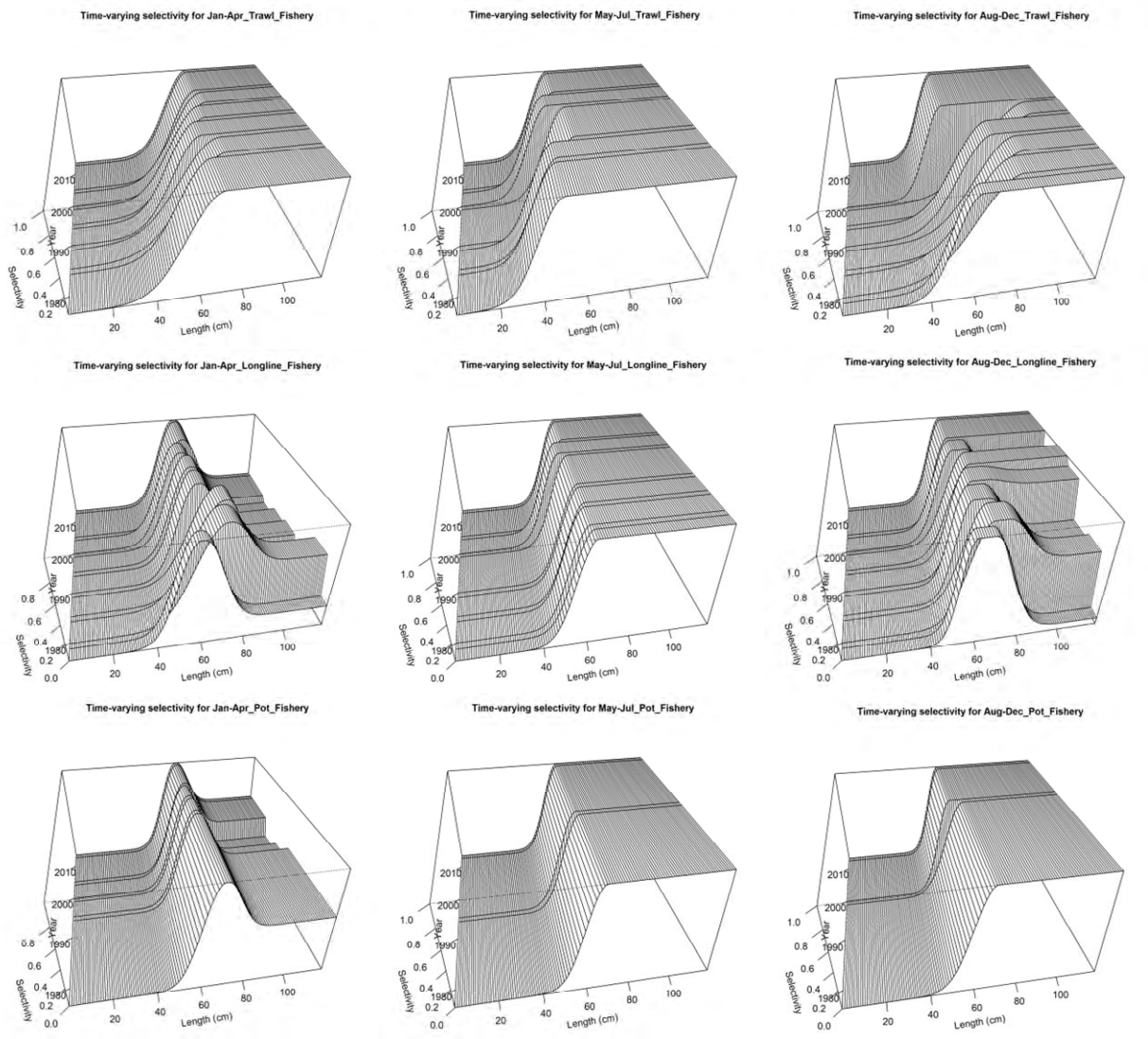


Figure 2.1.4a—Fishery selectivities estimated by Model 1.

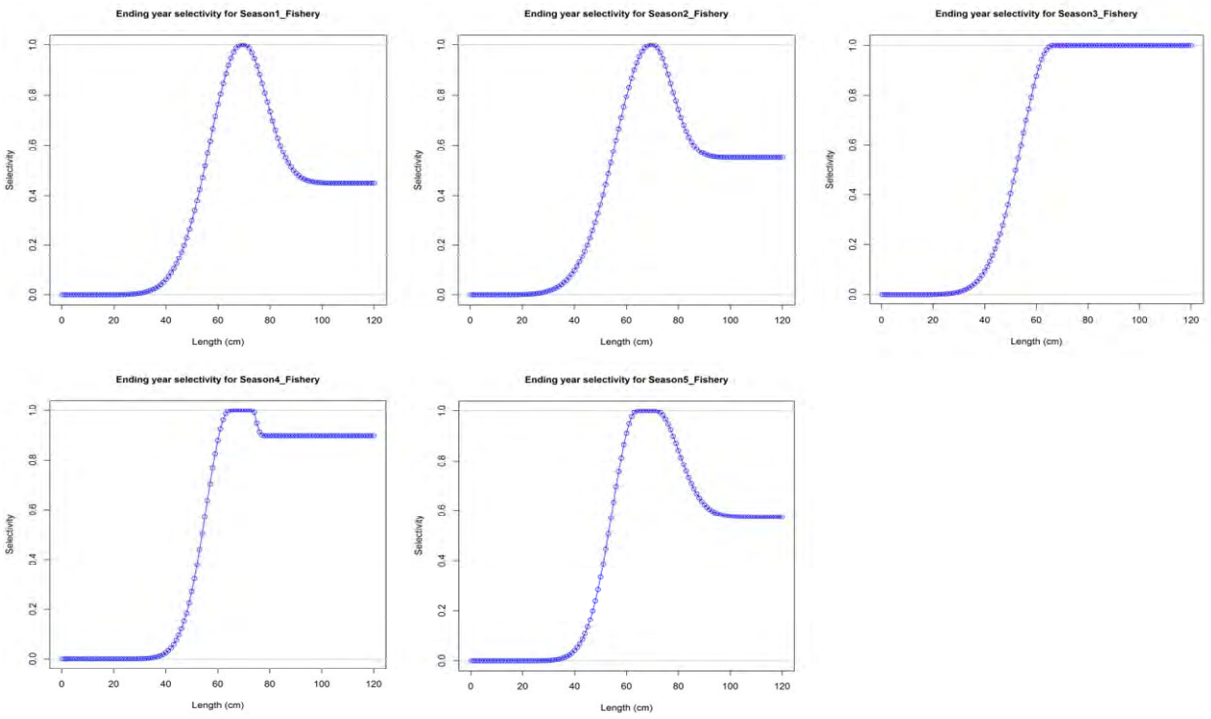


Figure 2.1.4b—Fishery selectivities estimated by Model 2.

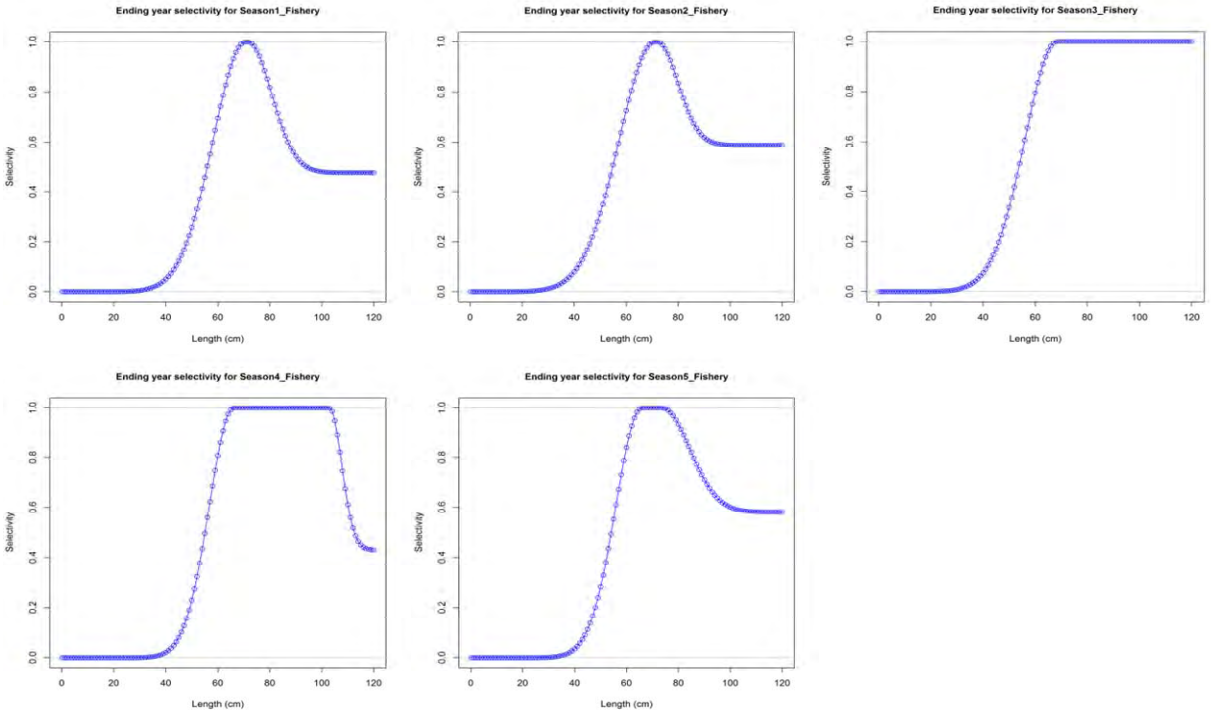


Figure 2.1.4c—Fishery selectivities estimated by Model 3.

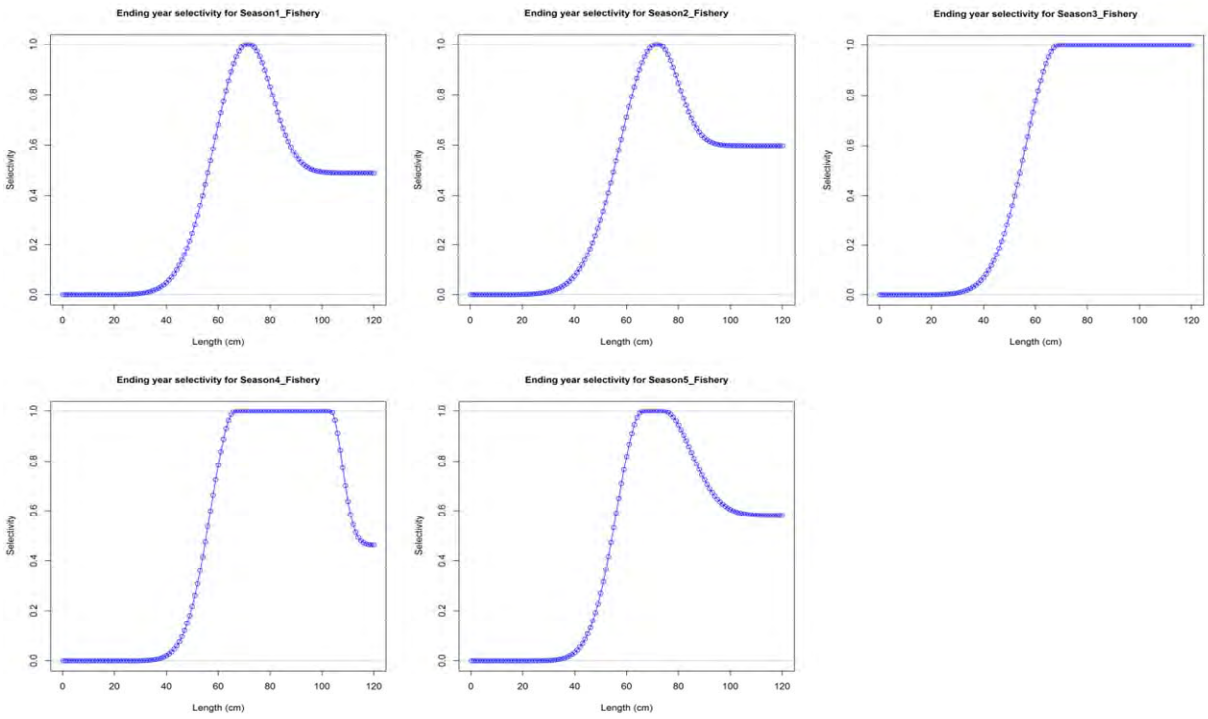


Figure 2.1.4d—Fishery selectivities estimated by Model 4.

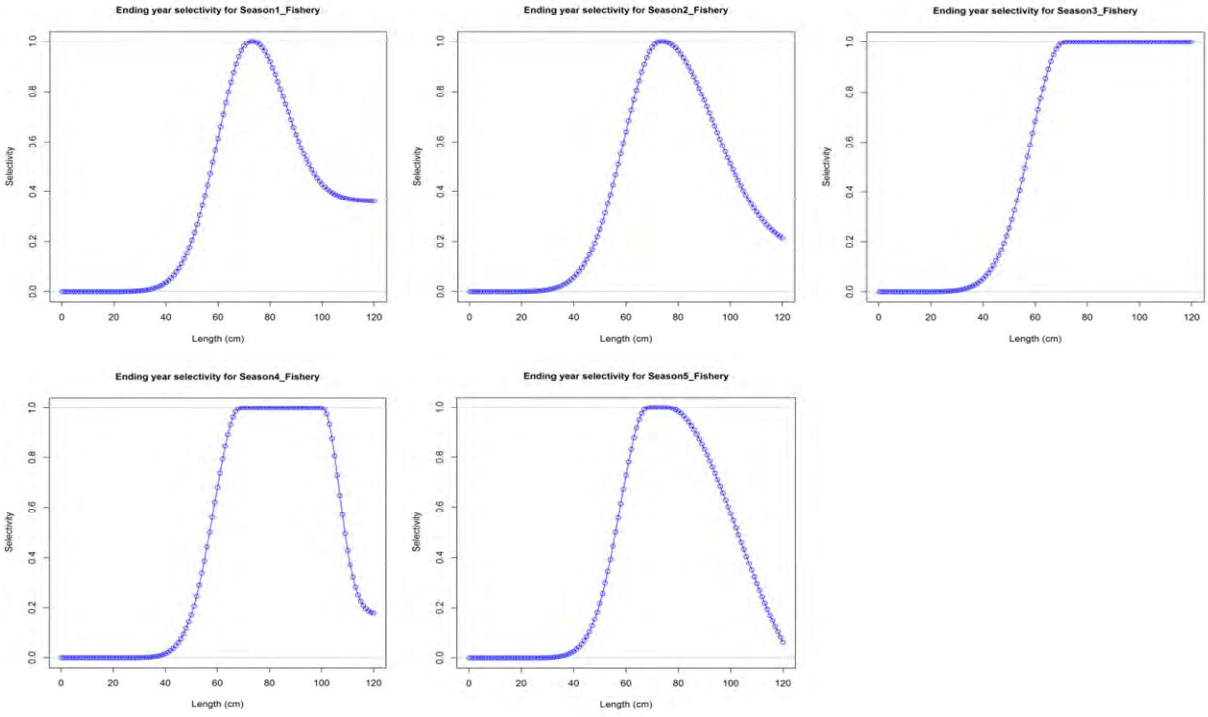


Figure 2.1.4e—Fishery selectivities estimated by Model 5.

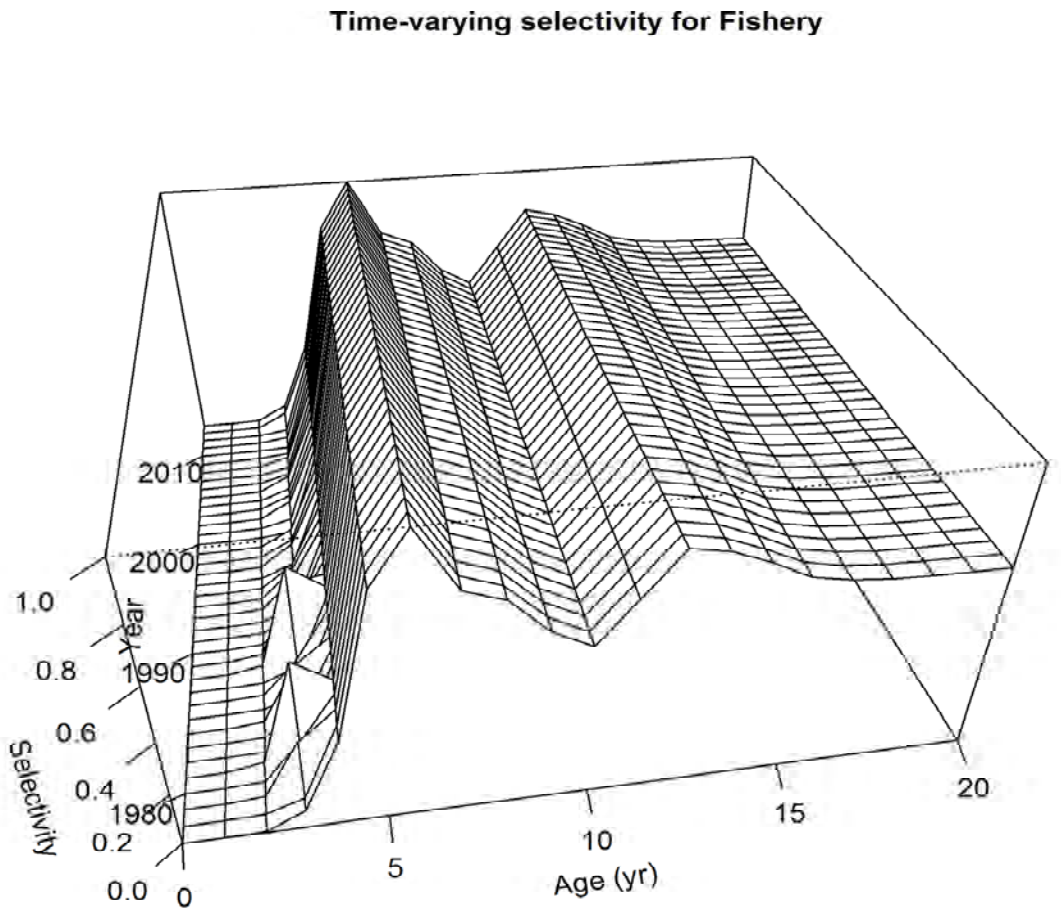
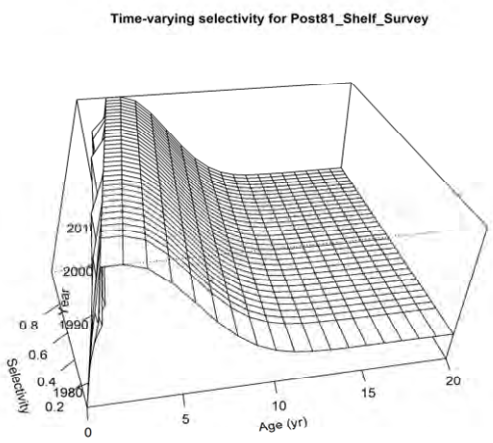
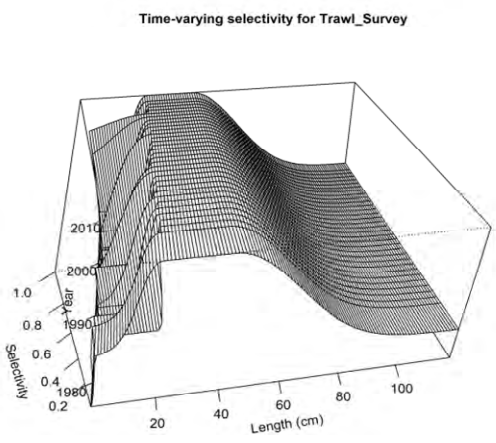


Figure 2.1.4f—Fishery selectivities estimated by Model 6.

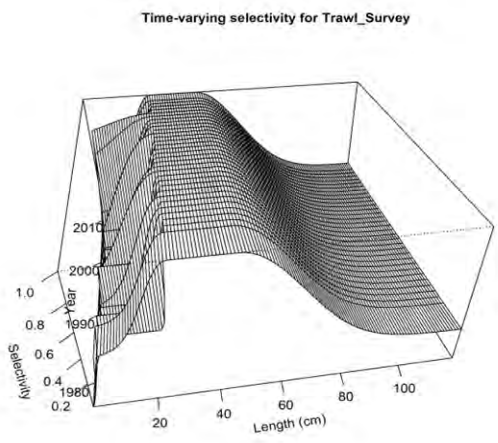
Model 1



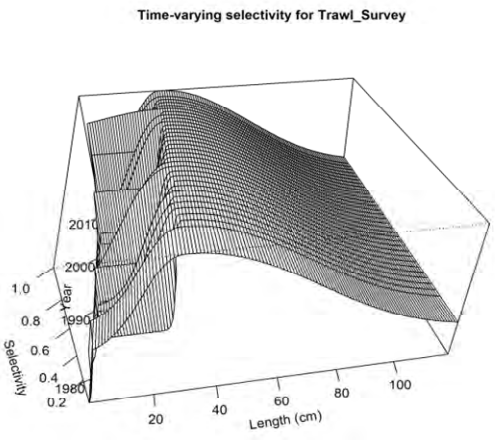
Model 2



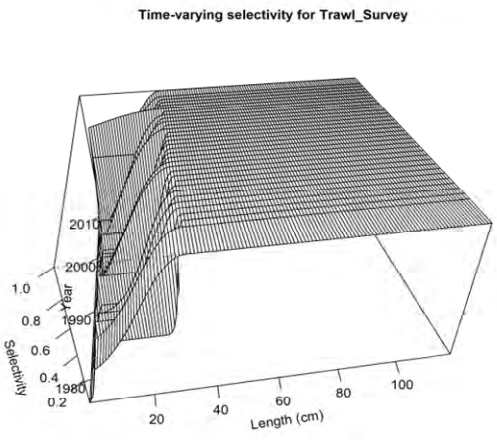
Model 3



Model 4



Model 5



Model 6

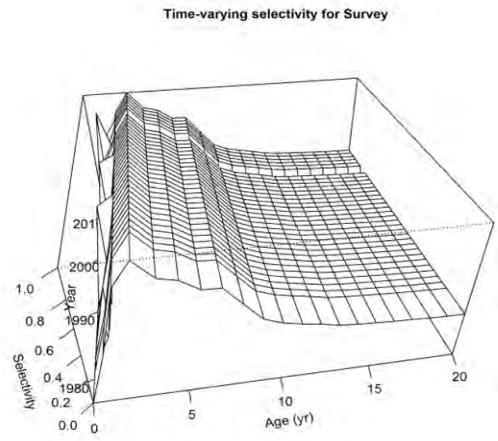


Figure 2.1.5—Survey selectivities estimated by Models 1-6.

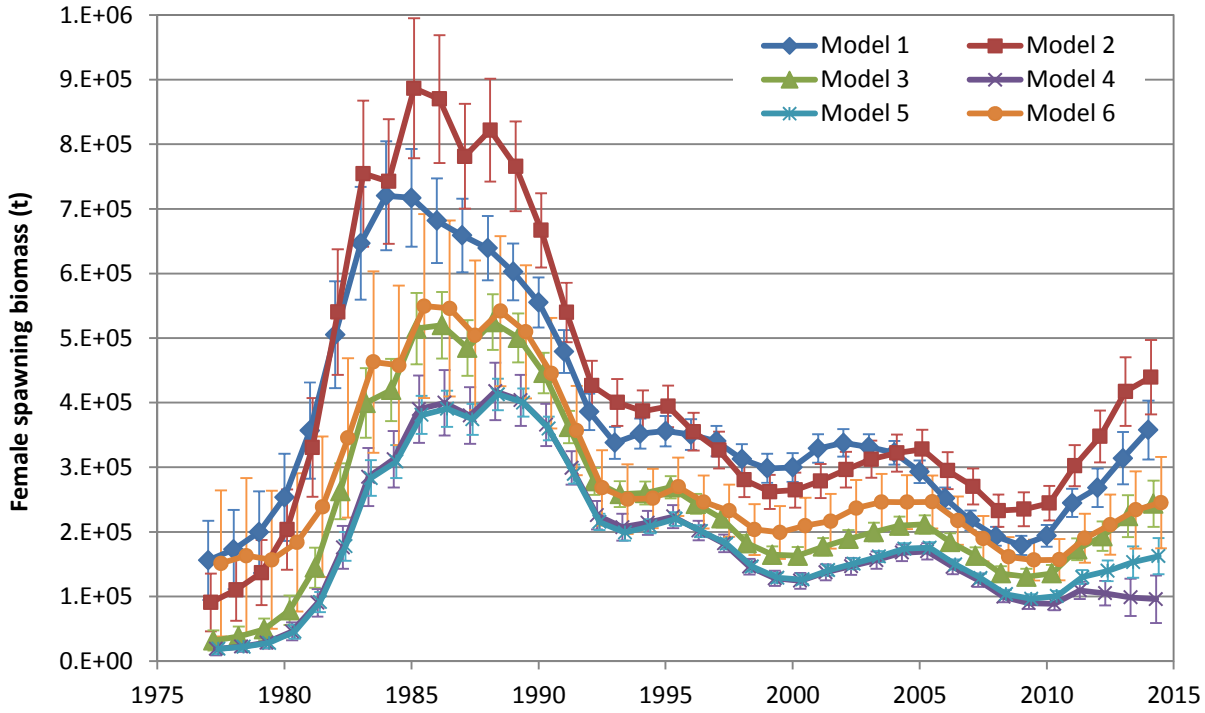


Figure 2.1.6—Model estimates of the female spawning biomass time series.

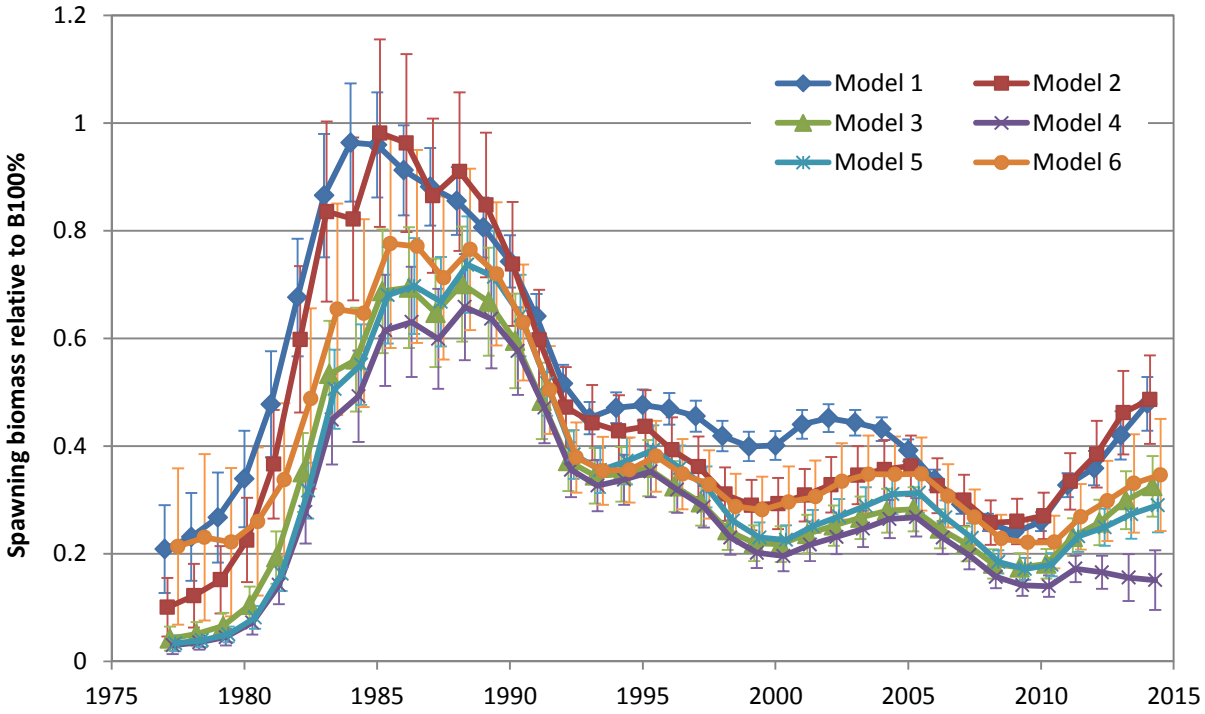


Figure 2.1.7—Model estimates of the relative female spawning biomass time series.

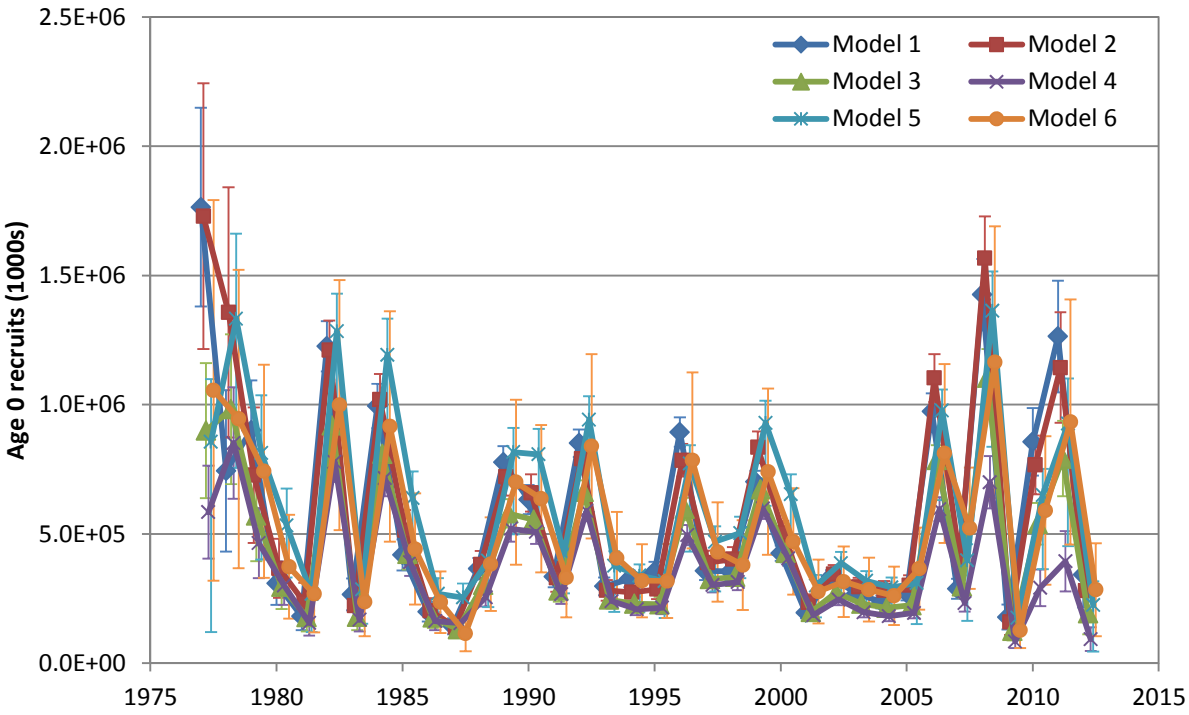


Figure 2.1.8—Model estimates of the age 0 recruitment time series.

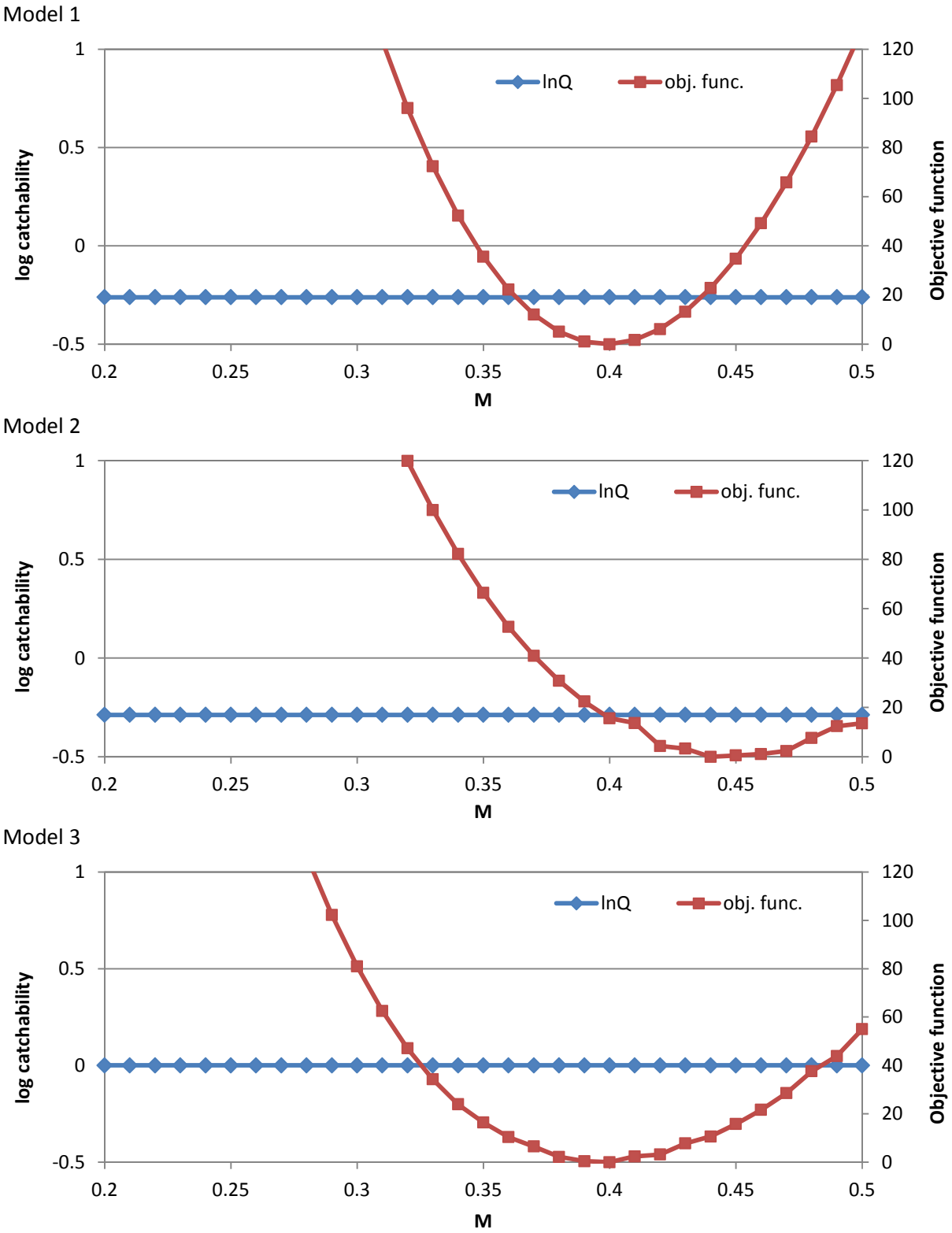


Figure 2.1.9a—Likelihood profiles with respect to the natural mortality rate for Models 1-3. Objective function minima occur at M=0.40 (Model 1), M=0.44 (Model 2), and M=0.40 (Model 3). The relationship between M and log Q is also shown.

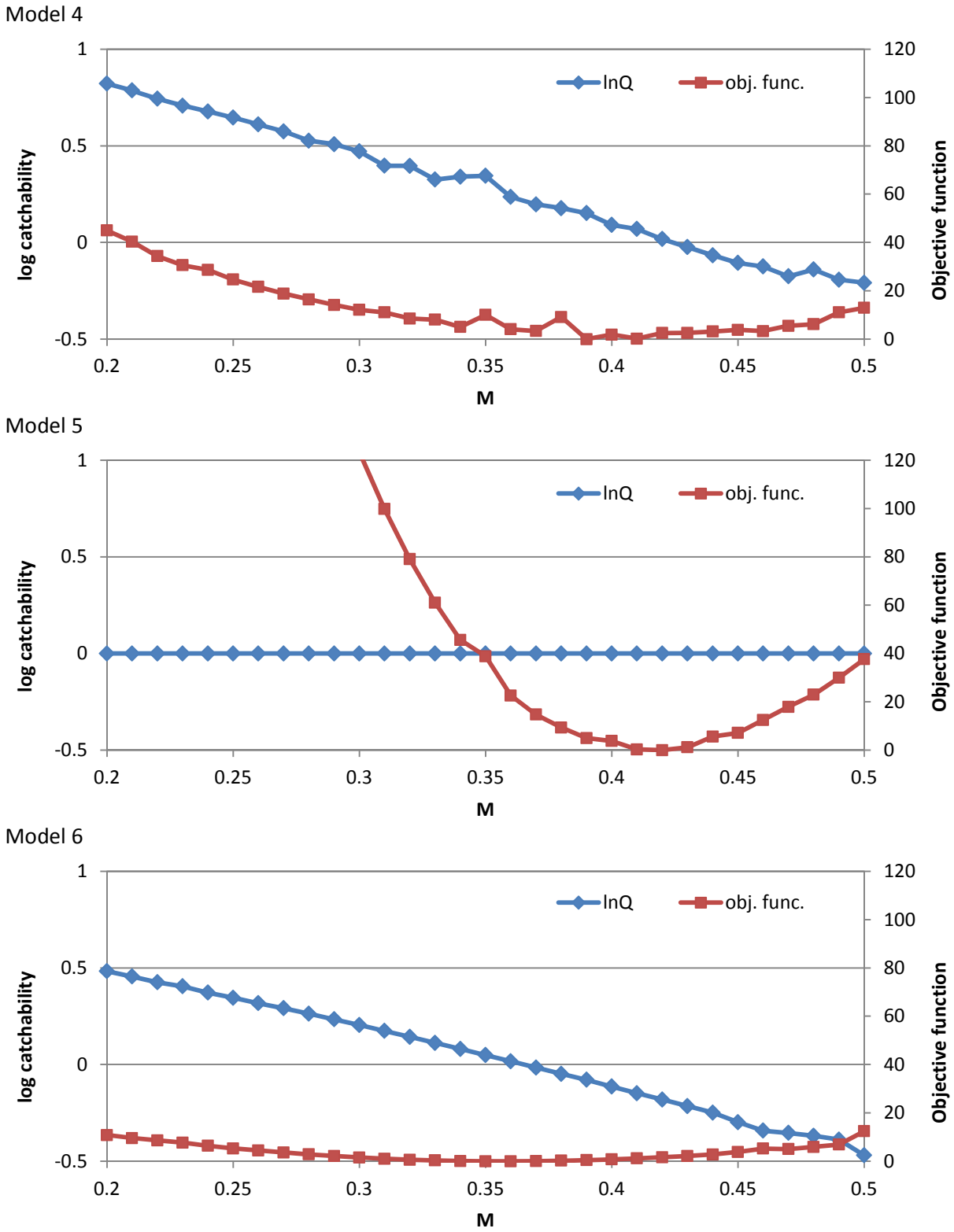


Figure 2.1.9b— Likelihood profiles with respect to the natural mortality rate for Models 4-6. Objective function minima occur at M=0.39 (Model 4), M=0.42 (Model 5), and M=0.36 (Model 3). The relationship between M and log Q is also shown. Jaggedness indicates lack of convergence in some runs.

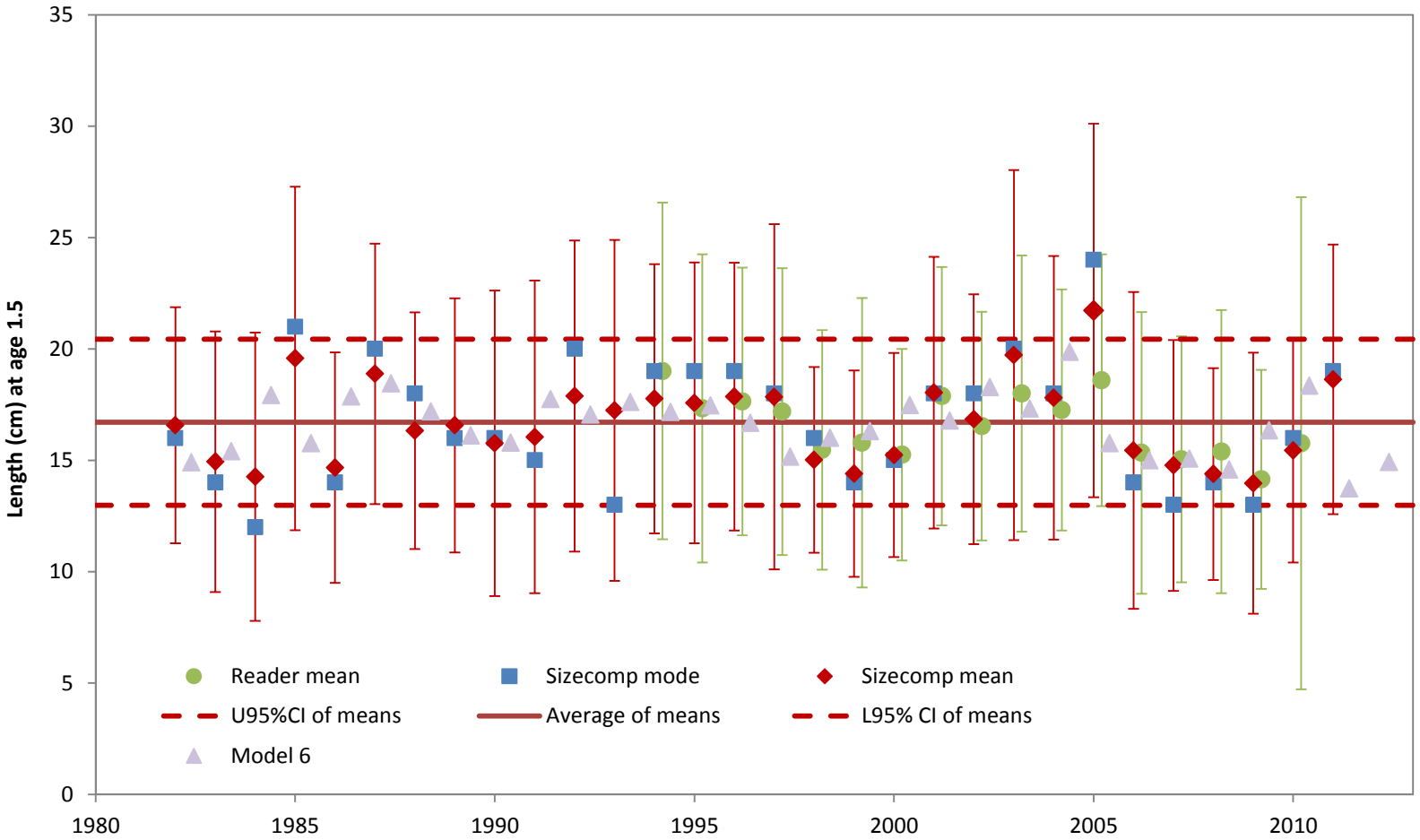


Figure 2.1.10—Various estimators of mean length (cm) at age 1.5.

APPENDIX 2.2: SUPPLEMENTAL CATCH DATA

From the minutes of the September 2013 Joint Plan Team meeting: *"The Teams recommended that SAFE chapter authors continue to include 'other' removals as an appendix. Optionally, authors could also calculate the impact of these removals on reference points and specifications, but are not required to include such calculations in final recommendations for OFL and ABC."*

This appendix is provided in response to the above recommendation. A similar compendium was provided in Attachment 2.4 of the 2012 assessment (Thompson and Lauth 2012).

NMFS Alaska Region has made substantial progress in developing a database documenting many of the removals of FMP species that have resulted from activities outside of fisheries prosecuted under the BSAI Groundfish FMP, including removals resulting from scientific research, subsistence fishing, personal use, recreational fishing, exempted fishing permit activities, and commercial fisheries other than those managed under the BSAI groundfish FMP. Estimates for EBS Pacific cod from this dataset are shown in Table 2.2.1.

Although many sources of removal are documented in Table 2.2.1, the time series is highly incomplete for many of these. Cells shaded gray represent data contained in the NMFS database. Other entries represent extrapolations for years in which the respective activity was known or presumed to have taken place, where each extrapolated value consists of the time series average of the official data for the corresponding activity. In the case of surveys, years with missing values were identified from the literature or by contacting individuals knowledgeable about the survey (the NMFS database contains names of contact persons for most activities); in the case of fisheries, it was assumed that the activity occurred every year.

In the 2012 analysis (Attachment 2.4 of Thompson and Lauth 2012), the supplemental catch data were used to provide estimates of potential impacts of these data in the event that they were included in the catch time series used in the assessment model. The results of that analysis indicated that $F_{40\%}$ increased by about 0.01 and that the one-year-ahead catch corresponding to harvesting at $F_{40\%}$ decreased by about 4,000 t. Note that this is a separate issue from the effects of taking other removals "off the top" when specifying an ABC for the groundfish fishery; the former accounts for the impact on reference points, while the latter accounts for the fact that "other" removals will continue to occur.

The average of the total removals in Table 2.2.1 for the last three complete years (2011-2013) is 6,149 t.

It should be emphasized that these calculations are provided purely for purposes of comparison and discussion, as NMFS and the Council continue to refine policy pertaining to treatment of removals from sources other than the directed groundfish fishery.

Table 2.2.1—Total removals of Pacific cod (t) from activities not related to directed fishing. Cells shaded gray represent data contained in the NMFS database. Other entries represent extrapolations for years in which the respective activity was known or presumed to have taken place.

Activity	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Aleutian Island Bottom Trawl Survey				2			2			2					2			2	
Annual Longline Survey						28	28	28	28	28	28	28	28	28	28	28	28	28	
Bait for Crab Fishery	4899	4899	4899	4899	4899	4899	4899	4899	4899	4899	4899	4899	4899	4899	4899	4899	4899	4899	4899
Bering Sea Acoustic Survey			0			0			0			0			0			0	
Bering Sea Slope Survey			1		1	1			1			1			1				
Eastern Bering Sea Bottom Trawl Survey	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
Gulf of Alaska Bottom Trawl Survey								0			0			0			0		
IPHC Annual Longline Survey																			
Large-Mesh Trawl Survey														1	1			1	1
Northern Bering Sea Bottom Trawl Survey			1		1	1			1			1			1				
Pollock EFP 11-01																			
Pribilof Islands Crab Survey																			
St. Mathews Crab Survey																			9
Subsistence Fishery	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	0	2	5	2
Summer EBS Survey with Russia																		0	

Activity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Aleutian Island Bottom Trawl Survey		2			2		2		2		2				2		1		2
Annual Longline Survey		38		30		36		30		23		25		20		24		27	
Bait for Crab Fishery	4899	4899	4899	4899	4899	4899	4899	4899	4899	4899	4899	4899	4899	4899	1737	4544	6697	6618	4899
Bering Sea Acoustic Survey	0	0		0	0		0		0		0	0	0	0	0		0		
Bering Sea Slope Survey					1		1		1				1		2		1	1	1
Eastern Bering Sea Bottom Trawl Survey	41	41	41	41	41	41	41	41	41	41	41	41	41	41	38	42	52	33	39
Gulf of Alaska Bottom Trawl Survey	0			0		0		0		0		0		0		0		0	
IPHC Annual Longline Survey			24	24	24	24	24	24	24	24	24	24	24	24	32	20	17	29	24
Large-Mesh Trawl Survey				1	1			1	1	1	1	1	1	1	1	1	2	1	1
Northern Bering Sea Bottom Trawl Survey															1				
Pollock EFP 11-01																11	307		
Pribilof Islands Crab Survey								5		5			5			5			
St. Mathews Crab Survey			9			9			9			9			9			9	
Subsistence Fishery	2	2	1	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Summer EBS Survey with Russia							0		0			0	0	0	0		0		

APPENDIX 2.3: HISTORY OF PREVIOUS EBS PACIFIC COD MODEL STRUCTURES DEVELOPED UNDER STOCK SYNTHESIS

Stock Synthesis 1 (SS1, Methot 1986, 1990, 1998, 2000) was first applied to the EBS Pacific cod stock in the 1992 assessment (Thompson 1992). This first application used age-structured data. Beginning with the 1993 SAFE report (Thompson and Methot 1993) and continuing through the 2004 SAFE report (Thompson and Dorn 2004), SS1 continued to be used, but based largely on length-structured data.

SS1 was a program that used the parameters of a set of equations governing the assumed dynamics of the stock (the "model parameters") as surrogates for the parameters of statistical distributions from which the data were assumed to be drawn (the "distribution parameters"), and varies the model parameters systematically in the direction of increasing likelihood until a maximum is reached. The overall likelihood was the product of the likelihoods for each of the model components. In part because the overall likelihood could be a very small number, SS1 used the logarithm of the likelihood as the objective function. Each likelihood component was associated with a set of data assumed to be drawn from statistical distributions of the same general form (e.g., multinomial, lognormal, etc.). Typically, likelihood components were associated with data sets such as catch size (or age) composition, survey size (or age) composition, and survey abundance (either biomass or numbers, either relative or absolute).

SS1 permitted each data time series to be divided into multiple segments, resulting in a separate set of parameter estimates for each segment. The EBS Pacific cod assessments, for example, usually divided the shelf bottom trawl survey size composition time series into pre-1982 and post-1981 segments to account for the effects of a change in the trawl survey gear instituted in 1982. Also, to account for possible differences in selectivity between the mostly foreign (also joint venture) and mostly domestic fisheries, the fishery size composition time series was split into pre-1989 and post-1988 segments during the era of SS1-based assessments.

Until 2010, each year was partitioned into three seasons defined as January-May, June-August, and September-December (these seasonal boundaries were suggested by industry participants). Four fisheries were defined during the era of SS1-based assessments: The January-May trawl fishery, the June-December trawl fishery, the longline fishery, and the pot fishery.

Following a series of modifications from 1993 through 1997, the base model for EBS Pacific cod remained completely unchanged from 1997 through 2001. During the late 1990s, a number of attempts were made to estimate the natural mortality rate M and the shelf bottom trawl survey catchability coefficient Q, but these were not particularly successful and the Plan Team and SSC always opted to retain the base model in which M and Q were fixed at traditional values of 0.37 and 1.0, respectively.

A minor modification of the base model was suggested by the SSC in 2001, namely, that consideration be given to dividing the domestic era into pre-2000 and post-1999 segments. This modification was tested in the 2002 assessment (Thompson and Dorn 2002), where it was found to result in a statistically significant improvement in the model's ability to fit the data. In the 2004 assessment (Thompson and Dorn 2004), further modifications were made to the base model. The 2004 model included a set of selectivity parameters for the EBS slope bottom trawl survey and added new likelihood components for the age compositions and length-at-age data from the 1998-2003 EBS shelf bottom trawl surveys and the size composition and biomass data from the 2002 and 2004 EBS slope bottom trawl surveys. Incorporation of age data and slope survey data had been suggested by the SSC (SSC minutes, December 2003).

A major change took place in the 2005 assessment (Thompson and Dorn 2005), as the model was migrated to the newly developed Stock Synthesis 2 program, which made use of the ADMB modeling architecture (Fournier et al. 2012) currently used in most age-structured assessments of BSAI and GOA

groundfish. The move to Stock Synthesis 2 facilitated improved estimation of model parameters as well as statistical characterization of the uncertainty associated with parameter estimates and derived quantities such as spawning biomass. Technical details of Stock Synthesis 2 were described by Methot (2005).

The 2006 assessment (Thompson et al. 2006) explored alternative functional forms for selectivity, use of Pacific cod incidental catch data from the NMFS sablefish longline survey, and the influence of prior distributions.

In 2007, SS introduced a six-parameter double normal selectivity curve. This functional form is constructed from two underlying and linearly rescaled normal distributions, with a horizontal line segment joining the two peaks. As configured in SS, the equation uses the following six parameters:

1. *beginning_of_peak_region* (where the curve first reaches a value of 1.0)
2. *width_of_peak_region* (where the curve first departs from a value of 1.0)
3. *ascending_width* (equal to twice the variance of the underlying normal distribution)
4. *descending_width* (equal to twice the variance of the underlying normal distribution)
5. *initial_selectivity* (at minimum length/age)
6. *final_selectivity* (at maximum length/age)

All but *beginning_of_peak_region* are transformed: The *ascending_width* and *descending_width* are log-transformed and the other three parameters are logit-transformed.

A technical workshop was held in April of 2007 to address possible improvements to the assessment model (Thompson and Conners 2007). Based on suggestions received at the workshop, several alternative models were considered in a preliminary 2007 assessment (Thompson et al. 2007a), and four models were advanced during the final 2007 assessment (Thompson et al. 2007b). The recommended model from the final 2007 assessment (Model 1) included a number of features that distinguished it from the model used in the 2006 assessment, including:

1. A fixed value of 0.34 was adopted for the natural mortality rate, based on life history theory.
2. The six parameter double-normal function was used for all selectivities.
3. The maturity schedule modeled as a function of age rather than length.
4. Trawl survey selectivity modeled as a function of age rather than length.
5. Fishery selectivity was assumed to be constant across all years.
6. Annual *dev*s were estimated in the *ascending_width* parameter of the trawl survey selectivity schedule, with an assumed standard deviation of 0.2.
7. The standard deviation of length at age modeled as a linear function of length at age.
8. Survey abundance was measured in numbers of fish (rather than biomass).
9. The input sample sizes for multinomial distributions were set on the basis of a scaled bootstrap harmonic mean.

Relative to the 2007 assessment, the model accepted by the Plan Team and SSC from the 2008 assessment (Thompson et al. 2008) featured two main changes:

1. An explicit algorithm was used to determine which fleets (including surveys as well as fisheries) would be forced to exhibit asymptotic selectivity.
2. An explicit algorithm was used to determine which selectivity parameters would be allowed to vary periodically in "blocks" of years, and to determine the appropriate block length for each such time-varying parameter.

The 2009 assessment (Thompson et al. 2009) featured a total of 14 models reflecting many alternative assumptions and use or non-use of certain data, particularly age composition data. Relative to the 2008 assessment, the main changes in the model accepted by the Plan Team and SSC were as follow:

1. Input standard deviations of all *dev* vectors were set iteratively by matching the standard deviations of the set of estimated *dev*s.
2. The standard deviation of length at age was estimated outside the model as a linear function of mean length at age.
3. Catchability for the post-1981 trawl survey was fixed at the value that sets the average (weighted by numbers at length) of the product of catchability and selectivity for the 60-81 cm size range equal to the point estimate of 0.47 obtained by Nichol et al. (2007).
4. Potential ageing bias was accounted for in the ageing error matrix by examining alternative bias values in increments of 0.1 for ages 2 and above, resulting in a positive bias of 0.4 years for these ages (age-specific bias values were also examined, but did not improve the fit significantly).
5. Cohort-specific growth *dev*s were estimated for all years through 2008.

Many changes were made or considered in the 2010 stock assessment (Thompson et al. 2010). Six models were presented in the preliminary assessment, as requested by the Plan Teams in May, with subsequent concurrence (given two minor modifications) by the SSC in June. Following review in September and October, three of these models, or modifications thereof, were requested by the Plan Teams or SSC to be included in the final assessment. Relative to the 2009 assessment, the main changes in the model that was ultimately accepted by the Plan Team and SSC in 2010 were as follow:

1. Relative abundance data and the two records of size composition data from the IPHC longline survey were excluded.
2. The single available record (each) of fishery age composition and mean length-at-age data was excluded.
3. A new length structure consisting of 1-cm bins was adopted, replacing the combination of 3-cm and 5-cm bins used in previous assessments.
4. A new seasonal structure was adopted, consisting of five catch seasons defined as January-February, March-April, May-July, August-October, and November-December; and three selectivity seasons defined as January-April, May-July, and August-December; with spawning identified as occurring at the beginning of the second catch season (March).
5. Cohort-specific growth rates were removed (these were introduced for the first time in the 2009 assessment).

Per request from the Plan Teams, quantities that were estimated iteratively in the 2009 assessment were not re-estimated in the 2010 assessment.

Following a review by the Center for Independent Experts earlier in the year that resulted in a total of 128 unique recommendations from the three reviewers, the 2011 stock assessment (Thompson and Lauth 2011) again considered several possible model changes. A set of seven models was requested for inclusion in the preliminary by the Plan Teams in May, with subsequent concurrence by the SSC in June. Following review in August and September, four of these models were requested by the Plan Teams or SSC to be included in the final assessment. In addition, the SSC requested one new model, which was ultimately accepted by both the BSAI Plan Team and the SSC. Relative to the 2010 assessment, the main changes in the accepted model were as follow:

1. The pre-1982 portion of the bottom trawl time series was omitted.

2. The 1977-1979 and 1980-1984 time blocks for the January-April trawl fishery selectivity parameters were combined. This change was made because the selectivity curve for the 1977-1979 time block tended to have a very difficult-to-rationalize shape (almost constant across length, even at very small sizes), which led to very high and also difficult-to-rationalize initial fishing mortality rates.
3. The age corresponding to the *L1* parameter in the length-at-age equation was increased from 0 to 1.4167, to correspond to the age of a 1-year-old fish at the time of the survey, which is when the age data are collected. This change was adopted to prevent mean size at age from going negative (as sometimes happened for age 0 fish in previous assessments, and as happened even for age 1 fish in one of the models from the 2010 assessment), and to facilitate comparison of estimated and observed length at age and variability in length at age.
4. A column for age 0 fish was added to the age composition and mean-size-at-age portions of the data file. Even though there are virtually no age 0 fish represented in these two portions of the data file, unless a column for age 0 is included, SS will interpret age 1 fish as being ages 0 and 1 combined, which can bias the estimates of year class strength.
5. Ageing bias was estimated internally.
6. The parameters governing variability in length were estimated internally.
7. All size composition records were included in the log-likelihood function.
8. The fit to the mean-size-at-age data was not included in the log-likelihood function.

It should also be noted that, consistent with the Plan Team request made in 2010, quantities that were estimated iteratively in the 2009 assessment were not re-estimated in the 2011 assessment.

Many model changes in the 2012 stock assessment (Thompson and Lauth 2012). Five primary models and nine secondary models were presented in the preliminary assessment. Of these, four of the primary models and three of the secondary models were requested by the Plan Teams, with subsequent concurrence by the SSC. Following review in September and October, four of the models from the preliminary assessment were requested by the Plan Teams or SSC to be included in the final assessment:

Model 1 was identical to the model accepted for use by the BSAI Plan Team and SSC last year, except for inclusion of new data.

Model 2 was identical to Model 1, except that the survey catchability coefficient was estimated as a free parameter.

Model 3 was also identical to Model 1, except that ageing bias was not estimated internally and the fit to the age composition data was not included in the log-likelihood function.

Model 4 was an exploratory model that differed from Model 1 in several respects:

1. A new, inter- and intra-annually varying weight-length representation developed in the preliminary assessment was used.
2. "Tail compression" was turned off. This feature aggregates size composition bins with few or zero data on a record-by-record basis, which improves computational speed, but which also makes some of the graphs in the R4SS package difficult to interpret. In Models 1-3, tail compression was turned on.
3. Fishery CPUE data were omitted. In Models 1-3, fishery CPUE data were included for purposes of comparison, but were not used in estimation.
4. A new population length bin was added for fish in the 0-0.5 cm range, which was used for extrapolating the length-at age curve below the first reference age. In Models 1-3, the lower bound of the first population length bin was 0.5 cm.

5. Mean-size-at-age data were eliminated. In Models 1-3, mean-size-at-age data were included, but not used in estimation.
6. The number of estimated year class strengths in the initial numbers-at-age vector was set at 10. In Models 1-3, only 3 elements of the initial numbers-at-age vector were estimated, which causes an automatic warning in SS.
7. The Richards growth equation (Richards 1959, Schnute 1981, Schnute and Richards 1990) was used, which adds one more parameter. In Models 1-3, the von Bertalanffy equation—a special case of the Richards equation—was used.
8. The log-scale standard deviation of recruitment was estimated internally (i.e., as a free parameter estimated by ADMB). In Models 1-3, this parameter was held constant at the value of 0.57 that was estimated in the final 2009 assessment by matching the standard deviation of the recruitment *dev*s, per Plan Team request.
9. Survey selectivity was modeled as a function of length. In Models 1-3, survey selectivity was modeled as a function of age.
10. Fisheries were defined with respect to each of the five seasons, but not with respect to gear. In Models 1-3, fisheries were defined with respect to both season and gear.
11. Fishery selectivity curves were defined for each of the five seasons, but were not stratified by gear type. In Models 1-3, seasons 1-2 and 4-5 were lumped into a pair of "super" seasons for the purpose of defining fishery selectivity curves, and fishery selectivities were also *gear*-specific (3 super-seasons × 3 gears = 9 selectivity curves).
12. The selectivity curve for the fishery that came closest to being asymptotic on its own (in this case, the season 3 fishery) was forced to be asymptotic by fixing both *width_of_peak_region* and *final_selectivity* at a value of 10.0 and *descending_width* at a value of 0.0. In Models 1-3, six of the nine super-season × gear fisheries were forced to exhibit asymptotic selectivity.
13. Survey catchability was tuned iteratively to set the average of the product of catchability and survey selectivity across the 60-81 cm range equal to 0.47, corresponding to the Nichol et al. (2007) estimate. In Models 1-3, Q was left at the value of 0.77 estimated by a similar procedure in the final 2009 assessment, per Plan Team request.
14. The age composition sample size multiplier was tuned iteratively to set the mean of the ratio of effective sample size to input sample size equal to 1.0. In Models 1-3, the variance adjustment was fixed at 1.0.
15. The two parameters governing the ascending limb of the survey selectivity schedule were given annual additive *dev*s with each σ_{dev} tuned to match the estimate that would be appropriate for a univariate linear-normal model with random effects integrated out. In Models 1-3, no *dev* vector corresponding to the *initial_selectivity* parameter was used, because it was "tuned out" in the 2009 final assessment; and σ_{dev} for the *ascending_width* parameter was left at the value of 0.07 estimated iteratively in the final 2009 assessment, per Plan Team request.

Following review of the 2012 final assessment, Model 1 (the same model used in 2011) was accepted by both the BSAI Plan Team and the SSC.

An updated description of the SS framework was published by Methot and Wetzel (2013).

Many changes were considered in the 2013 assessment. Four models were presented in that year's preliminary assessment, as requested in May and June by the Plan Team and SSC. After reviewing the preliminary assessment, the Plan Team requested six models for inclusion in the final assessment. The SSC agreed with this suggestion, and asked for an additional two models, bringing the total number of models requested for inclusion in the final assessment to eight.

However, due to a government shutdown in October 2013, the only model presented in the final assessment was the same model used in 2011 and 2012. This model was accepted by both the BSAI Plan Team and the SSC.

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Chapter 2A: Assessment of the Pacific Cod Stock in the Aleutian Islands

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EXECUTIVE SUMMARY

Summary of Changes in Assessment Inputs

Relative to the November edition of last year's BSAI SAFE report, the following substantive changes have been made in the AI Pacific cod stock assessment.

Changes in the Input Data

1) Catch data for 1991-2013 were updated, and preliminary catch data for 2014 were incorporated.
2) Commercial fishery size composition data for 2013 were updated, and preliminary size composition data from the 2014 commercial fisheries were incorporated.
3) All fishery data (catch and size composition) from years prior to 1991 were removed.
4) The numeric abundance estimate from the 2014 AI bottom trawl survey was incorporated (the 2014 estimate of 20.8 million fish was up about 8% from the 2012 estimate).
5) Age composition data from the 2010 AI bottom trawl survey were incorporated.

Changes in the Assessment Methodology

Although harvest specifications for AI Pacific cod, which began in 2014, have been based on Tier 5 methods, age-structured models of this stock have been explored in the preliminary and final 2012 BSAI Pacific cod assessments (Thompson and Lauth 2012), the preliminary and final 2013 AI Pacific cod assessments (Thompson and Palsson 2013), and this year's preliminary assessment (Appendix 2A.1). Three age-structured models were presented in this year's preliminary assessment. After reviewing this year's preliminary assessment, the Plan Team and SSC requested three models for inclusion in the final assessment: Model 1 is the Tier 5 random effects model accepted for use by the Team and SSC last year. Model 2 is identical to age-structured Model 1 from the preliminary assessment. Model 3 is also identical to age-structured Model 1 from the preliminary assessment, except that the prior distributions for survey selectivity parameters are tightened so that the resulting selectivity curve is less dome-shaped.

Tier 5 management based on the random effects model is the authors' recommendation for setting 2015-2016 harvest specifications.

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Summary of Results

The principal results of the present assessment, based on the current model, are listed in the table below (biomass and catch figures are in units of t) and compared with the corresponding quantities from last year's assessment as specified by the SSC:

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2014	2015	2015	2016
M (natural mortality rate)	0.34	0.34	0.34	0.34
Tier	5	5	5	5
Biomass (t)	59,000	59,000	68,900	68,900
F_{OFL}	0.34	0.34	0.34	0.34
$maxF_{ABC}$	0.26	0.26	0.26	0.26
F_{ABC}	0.26	0.26	0.26	0.26
OFL (t)	20,100	20,100	23,400	23,400
maxABC (t)	15,100	15,100	17,600	17,600
ABC (t)	15,100	15,100	17,600	17,600
Status	As determined *last* year for:		As determined *this* year for:	
	2012	2013	2013	2014
Overfishing	No	n/a	No	n/a

Responses to SSC and Plan Team Comments on Assessments in General

JPT1 (9/13 minutes): *"The Teams recommended that SAFE chapter authors continue to include 'other' removals as an appendix. Optionally, authors could also calculate the impact of these removals on reference points and specifications, but are not required to include such calculations in final recommendations for OFL and ABC."* "Other" removals are presented in Appendix 2A.2.

JPT2 (9/13 minutes): *"In conformity with the main recommendations of the working group, the Teams recommended the following:*

1. *Assessment authors should routinely do retrospective analyses extending back 10 years, plot spawning biomass estimates and error bars, plot relative differences, and report Mohn's rho (revised).*
2. *If a model exhibits a retrospective pattern, try to investigate possible causes.*
3. *Communicate the uncertainty implied by retrospective variability in biomass estimates.*
4. *For the time being, do not disqualify a model on the grounds of poor retrospective performance alone.*
5. *Do consider retrospective performance as one factor in model selection."*

This comment is addressed in the "Results" section, under "Model Evaluation" and also in a new subsection entitled "Retrospective Analysis," located under "Time Series Results."

JPT3 (9/13 minutes): *"The Teams recommended that each stock assessment model incorporate the best possible estimate of the current year's removals. The Teams plan to inventory how their respective authors address and calculate total current year removals. Following analysis of this inventory, the Teams will provide advice to authors on the appropriate methodology for calculating current year removals to ensure consistency across assessments and FMPs."* This comment is addressed under the

"Standard Harvest Scenarios, Projection Methodology, and Projection Results" subsection of the "Results" section.

SSC1 (10/13 minutes): *"We agree with the recommendations of the Plan Team that retrospective analyses extending back 10 years and including Mohn's revised ρ, should routinely be presented in the assessments, and that retrospective patterns should be taken into consideration when selecting a model and when communicating uncertainties associated with biomass estimates. The SSC also notes that a strong retrospective bias should be one of the criteria considered when setting ABCs and could provide justification for recommending a higher or lower ABC."* See response to comment JPT2. Consideration of retrospective bias in the context of ABC is addressed in the "Harvest Recommendations" subsection of the "Results" section.

SSC2 (12/13): *"During public testimony, it was proposed that assessment authors should consider projecting the reference points for the future two years (e.g., 2014 and 2015) on the phase diagrams. It was suggested that this forecast would be useful to the public. The SSC agrees. The SSC appreciated this suggestion and asks the assessment authors to do so in the next assessment."* Figure 2A.17 includes projected values for the next two years.

JPT4 (9/14): Regarding catch projections, *"the Teams recommend that authors choose a method that appears to be appropriate for their stock, and this method be clearly documented. The Teams recommend authors establish their best available estimate of catch in the current year and the next two years. The Teams recommend that authors should also document how those projected catches were determined in the Harvest Recommendations section (ideally Scenario 2)."* See response to comment JPT3. Estimation of projected catches is addressed in the same subsection, and those estimated catches are used in Scenario 2.

SSC3 (10/14): Regarding comment JPT4, *"The SSC supports these recommendations."* See response to comments JPT3 and JPT4.

Responses to SSC and Plan Team Comments Specific to this Assessment

Eleven comments specific to this assessment were addressed in the preliminary assessment. In the interest of efficiency, they are not repeated in this section. BSAI Plan Team (BPT) and SSC comments that were developed following completion of the preliminary assessment are shown below.

BPT1 (9/14): *"For November, the Team recommends that Grant supply three candidate models, all based on data from 1991 onward, which means that there is no need to estimate a recruitment offset (because the data do not span an environmental regime shift):*

1. *Model 1 from this meeting (same as Model 2 when the recruitment offset is disregarded).*
2. *A variant of Model 1 with the priors tightened enough that the survey selectivity schedule is smoother and more like a logistic curve.*
3. *Tier 5."*

All of the Team's requested models are included in this assessment, although re-numbered so that last year's model (Tier 5 random effects) is designated Model 1.

SSC4 (10/14): *"The SSC agrees with the Plan Team and recommendations including limiting the data to post-1990 and three candidate models be brought forward to the November plan team meeting."* See response to Comment BPT1. Data are limited to the post-1990 period (see discussion under "Catch Size Composition" in the "Fishery" subsection of the "Data" section).

INTRODUCTION

General

Pacific cod (*Gadus macrocephalus*) is a transoceanic species, occurring at depths from shoreline to 500 m. The southern limit of the species' distribution is about 34° N latitude, with a northern limit of about 63° N latitude. Pacific cod is distributed widely over the eastern Bering Sea (EBS) as well as in the Aleutian Islands (AI) area. Tagging studies (e.g., Shimada and Kimura 1994) have demonstrated significant migration both within and between the EBS, AI, and Gulf of Alaska (GOA). However, recent research indicates the existence of discrete stocks in the EBS and AI (Canino et al. 2005, Cunningham et al. 2009, Canino et al. 2010, Spies 2012). Although the resource in the combined EBS and AI (BSAI) region had been managed as a single unit since 1977, last year separate 2014-2015 harvest specifications were set for the two areas.

Pacific cod is not known to exhibit any special life history characteristics that would require it to be assessed or managed differently from other groundfish stocks in the EBS or AI areas.

Review of Life History

Pacific cod eggs are demersal and adhesive. Eggs hatch in about 15 to 20 days. Spawning takes place in the sublittoral-bathyal zone (40 to 290 m) near bottom. Eggs sink to the bottom after fertilization and are somewhat adhesive. Optimal temperature for incubation is 3° to 6°C, optimal salinity is 13 to 23 parts per thousand (ppt), and optimal oxygen concentration is from 2 to 3 ppm to saturation. Little is known about the optimal substrate type for egg incubation.

Little is known about the distribution of Pacific cod larvae, which undergo metamorphosis at about 25 to 35 mm. Larvae are epipelagic, occurring primarily in the upper 45 m of the water column shortly after hatching, moving downward in the water column as they grow.

Juveniles occur mostly over the inner continental shelf at depths of 60 to 150 m. Adults occur in depths from the shoreline to 500 m, although occurrence in depths greater than 300 m is fairly rare. Preferred substrate is soft sediment, from mud and clay to sand. Average depth of occurrence tends to vary directly with age for at least the first few years of life.

It is conceivable that mortality rates, both fishing and natural, may vary with age in Pacific cod. In particular, very young fish likely have higher natural mortality rates than older fish (note that this may not be particularly important from the perspective of single-species stock assessment, so long as these higher natural mortality rates do not occur at ages or sizes that are present in substantial numbers in the data). For example, Leslie matrix analysis of a Pacific cod stock occurring off Korea estimated the instantaneous natural mortality rate of 0-year-olds at 2.49% per day (Jung et al. 2009). This may be compared to a mean estimate for age 0 Atlantic cod (*Gadus morhua*) in Newfoundland of 4.17% per day, with a 95% confidence interval ranging from about 3.31% to 5.03% (Gregory et al. in prep.); and age 0 Greenland cod (*Gadus ogac*) of 2.12% per day, with a 95% confidence interval ranging from about 1.56% to 2.68% (Robert Gregory and Corey Morris, *pers. commun.*).

Although little is known about the likelihood of age-dependent natural mortality in adult Pacific cod, it has been suggested that Atlantic cod may exhibit increasing natural mortality with age (Greer-Walker 1970).

At least one study (Ueda et al. 2006) indicates that age 2 Pacific cod may congregate more, relative to age 1 Pacific cod, in areas where trawling efficiency is reduced (e.g., areas of rough substrate), causing their

selectivity to decrease. Also, Atlantic cod have been shown to dive in response to a passing vessel (Ona and Godø 1990), which may complicate attempts to estimate catchability (Q) or selectivity. It is not known whether Pacific cod exhibit a similar response.

As noted above, Pacific cod are known to undertake seasonal migrations, the timing and duration of which may be variable (Savin 2008).

FISHERY

Description of the Directed Fishery

During the early 1960s, Japanese vessels began harvesting Pacific cod in the AI. However, these catches were not particularly large, and by the time that the Magnuson Fishery Conservation and Management Act went into effect in 1977, foreign catches of Pacific cod in the AI had never exceeded 4,200 t. Joint venture fisheries began operations in the AI in 1981, and peaked in 1987, with catches totaling over 10,000 t. Foreign fishing for AI Pacific cod ended in 1986, followed by an end to joint venture fishing in 1990. Domestic fishing for AI Pacific cod began in 1981, with a peak catch of over 43,000 t in 1992.

Presently, the Pacific cod stock is exploited by a multiple-gear fishery, including trawl, longline, pot, and jig components (although catches by jig gear are very small in comparison to the other three main gear types, with an average annual catch of less than 30 t since 1992). The breakdown of catch by gear during the most recent complete five-year period (2009-2013) is as follows: trawl gear accounted for an average of 75% of the catch, longline gear accounted for an average of 23%, and pot gear accounted for an average of 2%.

Historically, Pacific cod were caught throughout the AI. For the last five years prior to enactment of additional Steller sea lion (*Eumetopias jubatus*) protective regulations in 2011, the proportions of Pacific cod catch in NMFS statistical areas 541 (Eastern AI), 542 (Central AI), and 543 (Western AI) averaged 58%, 19%, and 23%, respectively. For the period 2011-2014, the average distribution has been 84%, 16%, and 0%, respectively (bearing in mind that 2014 data are not yet complete).

Catches of Pacific cod taken in the AI for the periods 1964-1980, 1981-1990, and 1991-2014 are shown in Tables 2A.1a, 2A.1b, and 2A.1c, respectively. The catches in Tables 2A.1a and 2A.1b are broken down by fleet sector (foreign, joint venture, domestic annual processing). The catches in Table 2A.1b are also broken down by gear to the extent possible. The catches in Table 2A.1c are broken down by gear. Table 2A.1d breaks down catches from 1994-2014 by NMFS 3-digit statistical area (area breakdowns not available prior to 1994), both in absolute terms and as proportions of the yearly totals.

Effort and CPUE

Figure 2A.1 shows, subject to confidentiality restrictions, the approximate locations in which trawl hauls or longline sets sampled during 2013 and 2014 contained Pacific cod. To create these figures, the areas managed under the FMP were divided into 20 km × 20 km squares. For each gear type, a square is shaded if hauls/sets containing Pacific cod from more than two distinct vessels were sampled in it during the respective gear/season/year.

Gear-specific time series of fishery catch per unit effort (CPUE) are plotted, along with linear regression lines, in Figure 2A.2. Both CPUE time series appear to be decreasing overall, although the negative slope of the regression for trawl gear is not statistically significant at the 5% level (P=0.06).

Discards

The catches shown in Tables 2A.1b and 2A.1c include estimated discards. Discard rates of Pacific cod in the AI Pacific cod fisheries are shown for each year 1991-2014 in Table 2A.2. Amendment 49, which mandated increased retention and utilization of Pacific cod, was implemented in 1998. From 1991-1997, discard rates in the Pacific cod fishery averaged about 7.5%. Since then, they have averaged about 1.0%.

Management History

The history of acceptable biological catch (ABC), overfishing level (OFL), and total allowable catch (TAC) levels is summarized and compared with the time series of aggregate (i.e., all-gear, combined area) commercial catches in Table 2A.3. Note that, with the exception of 2014, this time series pertains to the combined BSAI region, so the catch time series differs from that shown in Table 2.1, which pertains to the AI only.

From 1980 through 2013, TAC averaged about 83% of ABC (ABC was not specified prior to 1980), and from 1980 through 2013 aggregate commercial catch averaged about 92% of TAC. In 10 of these 34 years, TAC equaled ABC exactly, and in 8 of these 34 years (24%), catch exceeded TAC (by an average of 3%). However, three of those overages occurred in 2007, 2008, and 2010, when TAC was reduced by 3% to account for a small, State-managed fishery inside State of Alaska waters within the AI subarea (similar reductions have been made in all years since 2006); thus, while the combined Federal and State catch exceeded the Federal TAC in 2007, 2008, and 2010 by 2% or less, the overall target catch (Federal TAC plus State GHL) was *not* exceeded.

Total catch has been less than OFL in every year since 1993.

Changes in ABC over time are typically attributable to three factors: 1) changes in resource abundance, 2) changes in management strategy, and 3) changes in the stock assessment model. Because ABC for all years through 2013 were based on the EBS assessment model (with an expansion factor for the AI), readers are referred to Chapter 2 for a history of changes in that model.

Beginning with the 2014 fishery, the Board of Fisheries for the State of Alaska established a guideline harvest level (GHL) in State waters between 164 and 167 degrees west longitude in the EBS subarea (this supplemented a GHL that had been set aside for the Aleutian Islands subarea since 2006). The State's procedure for setting GHLs for the two subareas is to sum the subarea ABCs, then set a GHL in each subarea equal to 3% of the total.

The final rule for the 2015 Steller sea lion protection measures is anticipated to remove the prohibition of retention for Pacific cod in Area 543 (Western AI). A harvest limit for Area 543 will be determined by subtracting the State GHL from the AI Pacific cod ABC, then multiplying the result by the proportion of the AI Pacific cod biomass in Area 543 (see "Area Allocation of ABC," under the "Harvest Recommendations" subsection of the "Results" section).

Table 2A.4 lists all amendments to the BSAI Groundfish FMP that reference Pacific cod explicitly.

DATA

This section describes data used in the models presented in this stock assessment, of which one is of the Tier 5 variety, and two are of the Tier 3 (age-structured) variety. This section does not attempt to summarize all available data pertaining to Pacific cod in the AI.

The following table summarizes the sources, types, and years of data included in the data file for the Tier 5 model:

Source	Type	Years
AI bottom trawl survey	Biomass	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014

The following table summarizes the sources, types, and years of data included in the data file for the two Tier 3 models:

Source	Type	Years
Fishery	Catch biomass	1991-2014
Fishery	Size composition	1991-2014
AI bottom trawl survey	Numerical abundance	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014
AI bottom trawl survey	Size composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014
AI bottom trawl survey	Age composition	2010, 2012

As indicated in both of the above tables, the data time series used in the models for this year's assessment all begin no earlier than 1991. Beginning with last year's AI assessments, the SSC recommended that survey data prior to 1991 not be included in any of the models, due to lack of standardization between the gears and vessels used in the pre-1990 portion of the time series. For this year's AI Pacific cod assessment, the exclusion was extended to include fishery data as well as survey data. This is discussed further below, under "Catch Size Composition" in the "Fishery" subsection.

Fishery

Catch Biomass

The catch data used in the model consist of the totals for 1977-2014 shown in Tables 2A.1. Catches for the August-December portion of 2014 were estimated by the method described under Scenario 2 in the "Harvest recommendations" subsection of the "Results" section. With this one exception, the catches shown in Table 2.5 consist of "official" data from the NMFS Alaska Region. However, other removals of Pacific cod are known to have occurred over the years, including removals due to subsistence fishing, scientific research, and fisheries managed under other FMPs. Estimates of such other removals are shown in Appendix 2A.2.

Catch Size Composition

Fishery size compositions with at least 400 observations are presently available for nearly every year from 1977 through the first part of 2014 (the exceptions are the periods 1980-1981 and 1986-1989).

The data from the pre-1991 portion of the time series consistently show a much smaller proportion of large fish than the post-1990 portion. Figure 2A.3 shows cumulative distribution functions of the average (across years) size compositions, binned in 10-cm intervals, together with 95% confidence intervals (the confidence intervals were generated by both parametric and non-parametric bootstraps; because the results were nearly identical, only the non-parametric bootstrap results are shown). Not only are the curves representing the means very different, the confidence intervals do not come close to overlapping anywhere within the 40-90 cm range.

Some possible reasons for the difference are: 1) the samples collected during one or both time periods were not representative, 2) fishery selectivity at age was dramatically different between the two periods, 3) recruitment was consistently higher during the earlier period, and 4) fishing mortality was consistently higher during the earlier time period.

The first hypothesis in the above list has not yet been explored. However, Model 2 in last year's assessment allowed for all three of the other hypotheses, and last year's Model 1 allowed for the last two. The results of those models did not corroborate either the selectivity hypothesis or the recruitment hypothesis. Fishery selectivity at age in last year's Model 2 was, on average, about the same between the two time periods; and recruitment was, on average, either about the same during the two periods (last year's Model 1) or much higher during the later time period (last year's Model 2).

Both of last year's age-structured models did estimate, though, that fishing mortality was consistently much higher during the earlier time period. However, this finding was viewed with skepticism by the authors, in part because both models also estimated that biomass was very low during the first part of the time series, which, taken together with the estimates of very high fishing mortality during that period, implies that fishermen were expending very large amounts of effort in pursuit of very few fish, which did not seem to fit with the history of the fishery's development. Moreover, the survey biomass index has declined fairly consistently during the post-1990 period (see next subsection), which the models could not reconcile with a decreasing fishing mortality trend and a level or increasing recruitment trend.

Given the inability of last year's models to reconcile the pre-1991 fishery size composition data with the post-1990 data, the models presented in this year's preliminary assessment (Appendix 2A.1) omitted the pre-1991 fishery size composition data and, given the resulting lack of any ability to estimate fishery selectivity for the pre-1991 period, the pre-1991 catch data were eliminated as well. After reviewing the preliminary assessment, both the Plan Team and SSC recommended omitting all pre-1991 data for this year's final assessment (see Comments BPT1 and SSC4).

For use in the age-structured models, size composition data are grouped into 1-cm bins ranging from 4 to 120 cm, as shown in Table 2A.5.

The actual sample sizes for the fishery size composition data are shown below:

Year:	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
N:	22653	102653	46775	29716	30870	42610	23762	74286	34027	52435	57750	23442
Year:	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
N:	23690	23990	20754	20446	27543	26282	21954	34329	8879	11789	8590	4265

Survey

Biomass and Numerical Abundance

The time series of trawl survey biomass and numerical abundance are shown for Areas 541-543 (Eastern, Central, and Western AI, respectively), together with their respective coefficients of variation, in Table 2A.6. These estimates pertain to the Aleutian *management* area, and so are smaller than the estimates pertaining to the Aleutian *survey* area that have been reported in BSAI Pacific cod stock assessments prior to 2013.

Both the biomass and numerical abundance data indicate very consistent declines throughout the time series. Simple linear regressions on both time series estimate negative slope coefficients that are statistically significant at the 1% level.

As in recent assessments of Pacific cod in the EBS, the Tier 3 models developed here use survey estimates of population size measured in units of individual fish rather than biomass. The Tier 5 model, on the other hand, uses survey biomass.

Survey Size Composition

Table 2A.7 shows the total number of fish measured at each 1 cm interval from 4-120+ cm, by year, in the survey.

The actual sample sizes for the survey size composition data are shown below:

Year:	1991	1994	1997	2000	2002	2004	2006	2010	2012	2014
N:	7125	7497	4635	5178	3914	3721	2784	3521	3278	4549

Survey Age Composition

Age data from the 2010 AI trawl survey became available in time for use in this year's final assessment, supplementing the single year (2012) of age data available for last year's assessment. Actual sample sizes and the proportions of fish in ages 0 through 12+ are shown for each year below:

Year	N	0	1	2	3	4	5
2010	673	0.0000	0.0071	0.0659	0.2130	0.3360	0.2698
2012	599	0.0000	0.0721	0.0893	0.0901	0.2515	0.2834

Year	6	7	8	9	10	11	12+
2010	0.0609	0.0236	0.0074	0.0122	0.0021	0.0012	0.0009
2012	0.1544	0.0412	0.0120	0.0021	0.0026	0.0013	0.0000

ANALYTIC APPROACH

Tier 5 Model Structure

Model 1 is the random effects model recommended by the Survey Averaging Working Group (http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/2013/Sept/SAWG_2013_draft.pdf), which was accepted by the Plan Team and SSC in 2013 for the purpose of setting AI Pacific cod harvest specifications. The model is programmed using the ADMB software package (Fournier et al. 2012).

This is a very simple, state-space model of the "random walk" variety. The only parameter in the model is the log of the log-scale process error standard deviation. When used to implement the Tier 5 harvest control rules, the model also requires an estimate of the natural mortality rate.

The Tier 5 model assumes that the observation error variances are equal to the sampling variances estimated from the haul-by-haul survey data. The log-scale process errors and observations are both assumed to be normally distributed.

Tier 3 Model Structures: General

Two Tier 3 models are presented in this assessment: Model 2 is identical to age-structured Model 1 from the preliminary assessment (Appendix 2A.1). Model 3 is also identical to age-structured Model 1 from the preliminary assessment, except "with the priors tightened enough that the survey selectivity schedule is smoother and more like a logistic curve" (Comment BPT1). Specifically, the standard deviation of the selectivity prior distributions (constant across age) was reduced until survey selectivity at age 20 was mid-way between the value estimated by Model 1 and unity.

The two Tier 3 models were developed using the Stock Synthesis (SS) program (Methot and Wetzel 2013). Version 3.24s (compiled on 07/24/13) of SS was used to run the models in this assessment. SS is programmed using the ADMB software package (Fournier et al. 2012). The current SS user manual is available at:
https://drive.google.com/a/noaa.gov/?tab=mo#folders/0Bz1UsDoLaOMLN2FiOTI3MWQtZDQwOS00YWZkLThmNmEtMTk2NTA2M2FjYWVh

The Tier 3 models bear some similarities to the model that has been accepted for use in management of the EBS Pacific cod stock since 2011 (Thompson 2013). Some of the main differences between the Tier Tier 3 AI models and the 2011-2013 EBS model are as follow:

1. In the data file, length bins (1 cm each) were extended out to 150 cm instead of 120 cm, because of the higher proportion of large fish observed in the AI.
2. Each year consisted of a single season instead of five.
3. A single fishery was defined instead of nine season-and-gear-specific fisheries.
4. The survey was assumed to sample age 1 fish at true age 1.5 instead of 1.41667.
5. Initial abundances were estimated for the first ten age groups instead of the first three.
6. Selectivity for both the fishery and survey was modeled using a random walk with respect to age (SS selectivity-at-age pattern #17) instead of the usual double normal. Selectivity-at-age pattern #17 in SS has one parameter for each age in the model. Except for age 0, the parameter for any given age represents the logarithm of the ratio of selectivity at that age to selectivity at the previous age (i.e., the backward first difference on the log scale). Age 0 fish are often expected to have a selectivity of zero, which can be achieved in this selectivity pattern by setting the parameter for age 0 equal to -1000, as was done for all three models presented here. As with other parameters in SS, each parameter in this selectivity pattern is associated with a prior distribution (see "Loop #1" under "Tier 3 Model Structures: Iterative Tuning Procedures," below).
7. The logarithm of survey catchability, $\ln(Q)$, was treated as a free parameter, with a normal prior distribution whose parameters were derived by averaging those used in other age-structured assessments of AI groundfish (similar to Model 2 in last year's preliminary and final AI assessments).
8. A normal prior distribution for each selectivity parameter was used, tuned so that the schedule of prior means (across age) was consistent with logistic selectivity, with a constant (across age) prior standard deviation.
9. Potentially, each selectivity parameter was allowed to be time-varying with annual additive *dev*s (normally distributed random deviations added to the base value of their respective parameter) where the sigma term was tuned according to the method described Thompson and Lauth (2012, Annex 2.1.1).

In most substantive respects, the two Tier 3 AI models are very similar to Model 2 in this year's EBS Pacific cod assessment.

Except for the ln(Q) parameter and the selectivity and *dev* parameters in both models, all parameters were estimated with uniform prior distributions.

Development of the final versions of both models included calculation of the Hessian matrix. These models also passed a "jitter" test of 50 runs with a jitter parameter (equal to half the standard deviation of the logit-scale distribution from which initial values are drawn) of 0.10 (or 0.01, in the event that too few runs converged when the jitter parameter was set at 0.10). In the event that a jitter run produced a better value for the objective function than the base run, then: 1) the model was re-run starting from the final parameter file from the best jitter run, 2) the resulting new control file became the new base run, and 3) the entire process (starting with a new set of jitter runs) was repeated until no jitter run produced a better value for the objective function than the most recent base run.

Tier 3 Model Structures: Iterative Tuning Procedures

The quantities governing age-to-age and year-to-year changes in selectivity (both fishery and survey) were tuned iteratively during the development of Model 2 during this year's preliminary assessment (Appendix 2A.1, where it was labeled Model 1). Because this type of iterative tuning is time-consuming, it was not possible to redo the analysis for the final assessment; instead, the values resulting from the tuning procedure in the preliminary assessment were retained here, with the exception of the standard deviation for the prior distributions associated with the survey selectivity parameters in Model 3 (see also Comment SSC4 in this year's EBS Pacific cod assessment).

Three main loops were involved in the iterative tuning procedure:

1. Tuning the means of the prior distributions for the selectivity parameters.
2. Estimating "unconstrained" values of the standard deviations of the selectivity *dev*s.
3. Estimating "iterated" values of the standard deviations for the selectivity *dev*s.

Following the iterative procedure, the model was run with final estimates of the standard deviations for the selectivity *dev*s, which were estimated from a formula involving the results of loops #2 and #3.

The loops are described in more detail below.

Loop #1: tuning the parameters of the prior distributions for the selectivity parameters

Initially, the model was run with recruitment as the only time-varying quantity, with the standard deviation of log-scale recruitment estimated internally (i.e., as a free parameter), and with large standard deviations in the prior distributions for all selectivity parameters.

Once the initial model converged, a pair of transformed logistic curves was fit to the point estimates of the fishery and survey selectivity schedules (a *transformed* logistic curve was used because the selectivity parameters in pattern #17 consist of the backward first differences of selectivity on the log scale, rather than selectivity itself ; Thompson and Palsson 2013). The respective transformed logistic curve (fishery or survey) was then used to specify a new set of means for the selectivity prior distributions (one for each age). A constant (across age) prior standard deviation was then computed such that no age had a prior CV (on the selectivity scale, not the transformed scale) less than 50%.

The model was then run with the new set of prior means and constant prior standard deviations (one for the fishery, one for the survey), then a new pair of transformed logistic curves was fit to the results, and the process was repeated until convergence was achieved. The converged set of prior means (on the

transformed scale, not the selectivity scale) was as follows (ages 7+ all had prior means of 0 for both the fishery and the survey):

Age:	1	2	3	4	5	6
Fishery:	3.290	3.280	3.049	1.380	0.117	0.005
Survey:	5.295	0.846	0.004	0.000	0.000	0.000

The converged prior standard deviations were 0.342 for the fishery and 0.319 for the survey (both constant across age). For Model 3 in the final assessment, the prior standard deviation for the survey was reduced until survey selectivity at age 20 was mid-way between the value estimated by Model 2 and unity. This was achieved by setting the prior standard deviation equal to 0.078.

Loop #2: Estimating "unconstrained" values of the standard deviations of the selectivity devs

Loops #2 and #3 were designed to produce the quantities needed in order to use the method of Thompson and Lauth (2012, Annex 2.1.1) for estimating the standard deviation of a *dev* vector. The purpose of Loop #2 was to determine the value of the selectivity *dev* vector (for either the fishery or the survey) that would be obtained if the *dev*s were completely unconstrained by their respective σs. This was not always a straightforward process, as estimating a large matrix of age×year *dev*s is difficult if the *dev*s are unconstrained. In general, though, the procedure was to focus on one fleet (fishery or survey) at a time; begin with a small, constant (across age) value of σ; calculate the standard deviation of the estimated *dev*s; then increase the value of σ gradually until the standard deviation of the estimated *dev*s reached an asymptote.

Loop #3: Estimating "iterated" values of the standard deviations for the selectivity devs

Again proceeding one fleet (fishery or survey) at a time, this loop began with age-specific σs set at the unconstrained values estimated in Loop #2. The standard deviations of the estimated *dev*s then became the age-specific σs for the next run, and the process was repeated until the σs converged.

It is common for some ages to be "tuned" out during Loop #3 (i.e., the σs converge on zero). In the present case, all ages were tuned out except the following (these are final values of σ, after application of the algorithm described by Thompson and Lauth (2012, Annex 2.1.1), shown in parentheses):

Fishery: age 4 (0.092), age 6 (0.237)
Survey: age 2 (0.194), age 3 (0.078), age 7 (0.442).

Parameters Estimated Outside the Assessment Model

Natural Mortality (Tier 3 and Tier 5)

A value of 0.34 has been used for the natural mortality rate *M* in all BSAI Pacific cod stock assessments since 2007 (Thompson et al. 2007). This value was based on Equation 7 of Jensen (1996) and an age at maturity of 4.9 years (Stark 2007). In response to a request from the SSC, the 2008 assessment included a discussion of alternative values and a justification for the value chosen (Thompson et al. 2008). However, it should be emphasized that, even if Jensen's Equation 7 is exactly right, variability in the estimate of the age at maturity implies that the point of estimate of 0.34 is accompanied by some level of uncertainty. Using the variance for the age at 50% maturity published by Stark (0.0663), the 95% confidence interval for *M* extends from about 0.30 to 0.38.

The value of 0.34 adopted in 2007 replaced the value of 0.37 that had been used in all BSAI Pacific cod stock assessments from 1993 through 2006.

For historical completeness, some other published estimates of *M* for Pacific cod are shown below:

Area	Author	Year	Value
Eastern Bering Sea	Low	1974	0.30-0.45
	Wespestad et al.	1982	0.70
	Bakkala and Wespestad	1985	0.45
	Thompson and Shimada	1990	0.29
	Thompson and Methot	1993	0.37
Gulf of Alaska	Thompson and Zenger	1993	0.27
	Thompson and Zenger	1995	0.50
British Columbia	Ketchen	1964	0.83-0.99
	Fournier	1983	0.65

All of the models in this assessment (both Tier 3 and Tier 5) fix *M* at the value of 0.34 used for BSAI Pacific cod since 2007.

Variability in Estimated Age (Tier 3 Only)

Variability in estimated age in SS is based on the standard deviation of estimated age between "reader" and "tester" age determinations. The same weighted least squares regression that has been used in the past several assessments of EBS Pacific cod was used here to estimate a proportional relationship between standard deviation and age. The regression for the small reader-tester sample (n=581) of AI Pacific cod age data yielded an estimated slope of 0.08550 (i.e, the standard deviation of estimated age was modeled as 0.0898 × age) and a weighted R^2 of 0.69. This regression corresponds to a standard deviation at age 1 of 0.090 and a standard deviation at age 20 of 1.796. These parameter estimates, which are very close to those estimated for the EBS stock, were used for the Tier 3 models in the present assessment.

Weight at Length (Tier 3 Only)

In both Tier 3 models, weight (kg) at length (cm) was assumed to follow the usual form $\text{weight}=A\times\text{length}^B$ and to be constant across the time series, with *A* and *B* estimated at 5.683×10^{-6} and 3.18, respectively, based on 8,126 samples collected from the AI fishery between 1974 and 2011.

Maturity (Tier 3 Only)

A detailed history and evaluation of parameter values used to describe the maturity schedule for BSAI Pacific cod was presented in the 2005 assessment (Thompson and Dorn 2005). A length-based maturity schedule was used for many years. The parameter values used for this schedule in the 2005 and 2006 assessments were set on the basis of a study by Stark (2007) at the following values: length at 50% maturity = 58 cm and slope of linearized logistic equation = –0.132. However, in 2007, changes in SS allowed for use of either a length-based or an age-based maturity schedule. Beginning with the 2007 assessment, the accepted model has used an age-based schedule with intercept = 4.88 years and slope = –0.965 (Stark 2007). The use of an age-based rather than a length-based schedule follows a recommendation from the maturity study's author (James Stark, Alaska Fisheries Science Center, personal communication). The age-based parameters from the EBS Pacific cod assessment were retained for the Tier 3 models in the present assessment.

Catchability (Tier 3 Only)

As noted above, *Q* was estimated internally in both Tier 3 models, using a prior distribution based on a meta-analysis of prior distributions for *Q* in other AI groundfish stock assessments. The prior distribution was assumed to be normal (*Q* is estimate on a log scale in SS), with mean 0 and standard deviation 0.11.

Parameters Estimated Inside the Assessment Model (Tier 3 Only)

Parameters estimated inside SS for the models used in this assessment include:

1. all three von Bertalanffy growth parameters
2. standard deviation of length at ages 1 and 20
3. mean ageing bias at ages 1 and 20
4. log mean recruitment
5. standard deviation of log recruitment
6. *dev*s for log-scale initial (i.e., 1991) abundance at ages 1 through 10
7. annual log-scale recruitment *dev*s for 1991-2011
8. initial (equilibrium) fishing mortality
9. log survey catchability
10. base values of fishery selectivity parameters for ages 1 through 20
11. base values of survey selectivity parameters for ages 1 through 20
12. annual *dev*s for the fishery selectivity parameters corresponding to ages 4 and 6
13. annual *dev*s for the survey selectivity parameters corresponding to ages 2, 3, and 7

Uniform prior distributions are used for all parameters, except that *dev* vectors are constrained by input standard deviations ("sigma"), which are somewhat analogous to a joint prior distribution.

For all parameters estimated within individual SS runs, the estimator used is the mode of the logarithm of the joint posterior distribution, which is in turn calculated as the sum of the logarithms of the parameter-specific prior distributions and the logarithm of the likelihood function.

In addition to the above, the full set of year-, season-, and gear-specific fishing mortality rates were also estimated internally, but not in the same sense as the above parameters. The fishing mortality rates are determined (almost) exactly as functions of other model parameters, because SS assumes that the input total catch data are true values rather than estimates, so the fishing mortality rates can be computed algebraically given the other parameter values and the input catch data. An option does exist in SS for treating the fishing mortality rates as full parameters, but previous explorations have indicated that adding these parameters has almost no effect on other model output (Methot and Wetzell 2013).

Objective Function (Tier 5)

Model 1 incorporates both process error and observation error in the likelihood. Both are assumed to be lognormal. As a random effects model, the states (i.e, the individual points in the biomass time series) are "integrated out," leaving a marginal likelihood that is a function of just the one parameter (the log of the log-scale process error standard deviation).

Objective Function (Tier 3)

The Tier 3 models in this assessment include objective function components for initial (equilibrium) catch, trawl survey relative abundance, fishery and survey size composition, survey age composition,

recruitment, prior distributions, "softbounds" (equivalent to an extremely weak prior distribution used to keep parameters from hitting bounds), and parameter deviations.

In SS, emphasis factors are specified to determine which likelihood components receive the greatest attention during the parameter estimation process. All likelihood components were given an emphasis of 1.0 here.

Use of Size Composition Data in Parameter Estimation

Size composition data are assumed to be drawn from a multinomial distribution specific to a particular fleet (fishery or survey) and year. In the parameter estimation process, SS weights a given size composition observation according to the emphasis associated with the respective likelihood component and the sample size specified for the multinomial distribution from which the data are assumed to be drawn. The steps used to scale the sample sizes here were similar to those used in the EBS Pacific cod assessment (Thompson 2013): 1) Records with fewer than 400 observations were omitted. 2) The sample sizes for fishery length compositions from years prior to 1999 were tentatively set at 16% of the actual sample size, and the sample sizes for fishery length compositions after 1998 and all survey length compositions were tentatively set at 34% of the actual sample size. 3) All sample sizes were adjusted proportionally to achieve a within-fleet average sample size of 300 (i.e., the fishery sample sizes average 300, as do the survey sample sizes).

The resulting input sample sizes for *fishery* length composition data are shown below:

Year:	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
N:	133	604	275	175	182	251	140	437	425	656	722	293

Year:	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
N:	296	300	259	256	344	329	274	429	111	147	107	53

The resulting input sample sizes for *survey* length composition data are shown below:

Year:	1991	1994	1997	2000	2002	2004	2006	2010	2012	2014
N:	463	487	301	336	254	242	181	229	213	295

Use of Age Composition Data in Parameter Estimation

Like the size composition data, the age composition data are assumed to be drawn from a multinomial distribution specific to a particular year and gear. To date, only two years of age composition data are available, namely the 2010 and 2012 surveys. As in the EBS Pacific cod assessment, the average input sample size for the age composition data was fixed at 300. The actual sample sizes of 673 and 599 for 2010 and 2012 thus translate into input sample sizes of 317 and 283, respectively.

Use of Survey Relative Abundance Data in Parameter Estimation

Each year's survey abundance estimate is assumed to be drawn from a lognormal distribution specific to that year. The model's estimate of survey abundance in a given year serves as the geometric mean for that year's lognormal distribution, and the ratio of the survey abundance estimate's standard error to the survey abundance estimate itself serves as the distribution's coefficient of variation, which is then transformed into the "sigma" parameter for the lognormal distribution.

Use of Recruitment Deviation "Data" in Parameter Estimation

The likelihood component for recruitment is different from traditional likelihoods because it does not involve "data" in the same sense that traditional likelihoods do. Instead, the log-scale recruitment *dev* plays the role of the datum in a normal distribution with mean zero and specified (or estimated) standard deviation; but, of course, the *dev*s are parameters, not data.

RESULTS

Model Evaluation

The models used in this assessment are described under "Analytic Approach" above.

Goodness of Fit (Tier 5)

Statistics related to Model 1's goodness of fit with respect to the survey biomass data are shown below:

Statistic	Value
Correlation (observed:expected)	0.98
Root mean squared error	0.11
Mean normalized residual	0.06
Standard deviation of normalized residuals	0.63

The above values are similar to those from last year's assessment.

Figure 2A.4 shows the fit of Model 1 to the trawl survey biomass data (note that the Tier 3 models use numbers of fish as the survey index, while Model 1 uses biomass).

Goodness of Fit (Tier 3)

The values for the objective function components for Models 2 and 3 are directly comparable, because the two models have identical numbers of parameters:

Parameter counts	Model 2	Model 3
Unconstrained parameters	10	10
Parameters with priors	41	41
Constrained deviations	152	152
Total	203	203

Objective function values are shown for Models 2 and 3 below (lower values are better, all else being equal; objective function components with a value less than 0.001 for all models are omitted for brevity; color scale extends from red (minimum) to green (maximum)):

Objective function component	Model 2	Model 3
Equilibrium catch	0.001	0.002
Survey abundance	-11.619	-9.270
Fishery size composition	102.218	101.117
Survey size composition	211.073	208.984
Age composition	11.519	15.943
Recruitment	-4.511	-0.174
Priors	17.680	20.262
"Softbounds"	0.001	0.001
Parameter *dev*s	12.039	20.438
Total	338.400	357.302

Model 3 has a better (lower) value for the two size composition components and a negligibly better value for the "softbounds" component, but Model 2 has a better value for all other components and a much better value for the overall objective function.

The table below shows the number of size composition records (Nrec) that are available for the fishery and survey, and it also shows how the output "effective" sample sizes (Neff, McAllister and Ianelli 1997) of the Tier 3 models compare to the input sample sizes (Ninp) for these data. Two sets of ratios are provided, with the arithmetic mean input sample size used as the denominator for both sets. The *arithmetic* mean effective sample size is used as the numerator for the first set, and the *harmonic* mean effective sample size is used for the second (values greater than unity are preferred in both measures, all else being equal).

			Mean(Neff)/mean(Ninp)		Harm(Neff)/mean(Ninp)	
Fleet	Nrec	Mean(Ninp)	Model 2	Model 3	Model 2	Model 3
Fishery	24	300	14.62	15.19	8.77	8.01
Survey	10	300	3.50	3.55	2.29	2.31

Both Tier 3 models give ratios much greater than unity for all cases, with Model 3's ratios greater than those of Model 2 in three out of four cases.

Figures 2A.5 and 2A.6 show the Tier 3 models' fits to the fishery size composition and survey size composition data, respectively.

The table below shows the Tier 3 models' ratios of effective sample size to input sample size for the two years of age composition data:

			Mean(Neff)/mean(Ninp)		Harm(Neff)/mean(Ninp)	
Fleet	Nrec	Mean(Ninp)	Model 2	Model 3	Model 2	Model 3
Survey	2	300	1.05	0.69	0.79	0.52

Model 2 gives a ratio greater than 1.0 when the arithmetic mean is used in the numerator, but otherwise all of the ratios are less than unity.

Figure 2A.7 shows the Tier 3 models' fits to the one available year of survey age composition data.

The table below shows four statistics related to the Tier 3 models' goodness of fit with respect to the survey abundance data (color scale extends from red (minimum) to green (maximum)). Relative values of the four statistics can be interpreted as follows: correlation—higher values indicate a better fit, root mean squared error— values closer to the average log-scale standard error in the data (0.18) indicate a fit more consistent with the sampling variability in the data, mean normalized residual—values closer to zero indicate a better fit, standard deviation of normalized residuals—values closer to unity indicate a fit more consistent with the sampling variability in the data.

Statistic	Model 2	Model 3
Correlation (observed:expected)	0.95	0.96
Root mean squared error	0.17	0.21
Mean normalized residual	-0.56	-0.79
Standard deviation of normalized residuals	0.98	1.07

Model 2 fits these data slightly better than Model 3 in terms of all of the above measures except correlation, although the differences between models is fairly small for all measures.

Figure 2A.8 shows the fits of the Tier 3 models to the trawl survey abundance data. Model 3's estimates are higher (although sometimes just slightly) than the observed values in all years prior to 2012. Model 2 has a slightly better residual pattern than Model 3, although, as the above text table indicates, it is not ideal, either. The point estimates from both of the Tier 3 models fall within the 95% confidence intervals of the observations in 9 of the 10 years.

Parameter Estimates (Tier 5)

Model 1 has a single internally estimated parameter, the log of the log-scale process error standard deviation. The point estimate and standard deviation of this parameter were -1.762 and 0.671, respectively. Exponentiating the point estimate gives a log-scale process error standard deviation of 0.172.

Parameter Estimates (Tier 3)

Table 2A.8 displays some of the more important constants and all of the parameters (except fishing mortality rates) estimated internally in either of the Tier 3 models, along with the standard deviations of those estimates. Table 2A.8a shows selected constants. Table 2A.8b shows growth, ageing bias, recruitment (except annual *dev*s), initial fishing mortality, log catchability, and initial age composition parameters; Table 2A.8c shows annual log-scale recruitment *dev*s (these are plotted in Figure 2A.9); Table 2A.8d shows baseline selectivity parameters; Table 2A.8e shows fishery selectivity *dev*s; and Table 2A.8f shows survey selectivity *dev*s.

The estimates of log catchability in Table 2A.8b translate into Q values of 0.647 and 0.566 for Models 2 and 3, respectively.

Table 2A.9 shows estimates of fishing mortality. Two measures of annual fishing mortality are shown for each model. The first is an "average" fishing mortality rate across ages 8-18. This age range was determined in the 2013 assessment as the set of ages for which fishery selectivity was at least 90% on average across years (ages 19-20 also met this criterion, but SS generates a warning if the last two age groups are included in the average). The second measure of fishing mortality ("Apical F") is the rate corresponding to the length of full selection.

Other Derived Quantities

Figure 2A.10 shows the time series of spawning biomass relative to $B_{100\%}$ as estimated by the Tier 3 models.

Figure 2A.11 shows the time series of total (age 0+) biomass as estimated by the Tier 3 models, with the survey biomass time series included for comparison. Models 2 and 3 estimate very similar time series. Both are consistently much higher than the survey biomass time series, by factors of about 3.3 (on average) in both cases.

Figure 2A.12 shows trawl survey selectivity as estimated by the Tier 3 models. Selectivity for Model 2 is sharply peaked at age 4, with a secondary mode at age 7 in some years. In Model 2, average (across years) selectivity is less than 0.2 for all ages greater than 11, with selectivity dropping to an average value of 0.09 at age 20. Selectivity for Model 3 also peaks at age 4, but declines much less steeply than in Model 2. In Model 3, average selectivity is greater than 0.5 at all ages beyond age 4. As noted previously, the prior distributions for the selectivity parameters in Model 3 were tuned so that selectivity at age 20 would be mid-way between selectivity at age 20 in Model 2 and unity. This criterion turned out to be fairly effective in increasing Model 3 selectivity by an average of about 50% (relative to Model 2) at all ages greater than 4.

Figure 2A.13 shows fishery selectivity as estimated by the Tier 3 models. The profiles for the two models are broadly similar through the peak at age 11, but Model 2 selectivity declines by a greater amount than Model 3 selectivity at ages greater than 11.

Per request of the SSC (see Comment SSC4 in Appendix 2A.1), Figure 2A.14 shows likelihood profiles with respect to *M* for each Tier 3 model. The value of survey catchability is also shown. Both models assume a value of 0.34 for *M*, but the likelihood profiles indicate that a much lower value of M would minimize the objective function (0.11 in Model 2 and 0.18 in Model 3).

Table 2A.10 contains selected management reference points. For Models 2 and 3, the values in the first upper portion of this table (everything above the probabilities shown in the last seven rows) come from the standard projection model, based on parameter estimates from the respective SS model. The last seven rows (Models 2 and 3 only) come directly from SS rather than the standard projection model. The entries in these rows show the probability that the maximum permissible ABC in each of the next two years will exceed the corresponding true-but-unknown OFL and the probability that the stock will fall below $B_{20\%}$ in each of the next five years.

Evaluation Criteria

The following criteria were considered in evaluating the model:

1. Does the model contain new features that merit further evaluation before being adopted?
2. Would use of the model for setting 2015-2016 harvest specifications pose a significant risk to the stock?

In the context of the first criterion, one new feature of Models 2 and 3 that stands out is their use of SS selectivity pattern #17, which treats selectivity as a random walk with respect to age. Although this pattern has several benefits (see "Discussion" section in Appendix 2A.1), some aspects could benefit from further evaluation, specifically:

- Selectivity pattern #17 involves internal rescaling so that selectivity reaches a peak value of unity at some integer age. Restricting peak selectivity to occur at an integer age means that the function is not entirely differentiable, which is potentially problematic in ADMB.
- Although a substantial improvement in goodness of fit can sometimes be achieved by allowing annual *dev*s at the age of peak selectivity, this is sometimes accompanied by a large final gradient in the objective function (most likely related to the item in the previous bullet), which is usually considered to be symptomatic of a problem with the model.
- In some situations, a substantial improvement in goodness of fit can be achieved by estimating selectivity at unrealistically low values for all ages except for a few that are very close to the age-plus group.

A second new feature that may merit further investigation is the absence of the pre-1991 fishery data in Models 2 and 3. While removing these data resulted in much better fits to the remaining data, there is some possibility that the resulting estimates of reference points such as $B_{40\%}$ may be biased. This would be the case if mean recruitment in the pre-1991 portion of the time series were substantially different from mean recruitment in the post-1990 period. As noted previously, it might be possible to reconcile the difference in size compositions between the two parts of the time series (Figure 2A.3) with the other data in the model if fishery selectivity were sufficiently different between the two periods. Unfortunately, although one of last year's age-structured models allowed for time-varying fishery selectivity, it failed to find substantial differences between the two periods. However, the method used for determining the appropriate amount of time variability (Thompson and Lauth 2012, Annex 2.1.1) can tend to underestimate this amount under certain conditions. An alternative for future exploration might be to specify period-specific fisheries, and then allow for an appropriate amount of time-variability within each period. If this is successful, then perhaps the pre-1991 fishery data could be restored.

With regard to the second criterion, a formal risk analysis has not been undertaken in this assessment, but one feature of Models 2 and 3 that merits attention in this context is the difference between these models' estimates of total biomass and the biomass estimated by the survey (Figure 2A.11). As noted above, the ratio of model biomass to survey biomass has an average (across the time series) value of about 3.3 for both models. While it is not inconceivable that the survey misses so many fish, it does not seem wise to accept such an enormous discrepancy without first examining other hypotheses more fully.

On the basis of the above, Model 1 is recommended for use in setting final harvest specifications for 2015 and preliminary harvest specifications for 2016, with two caveats: First, it should be noted that use of trawl survey data for a Tier 5 assessment was criticized in the 2013 CIE review of assessments for non-target species, primarily because catchability (and selectivity for recruited ages) may not equal unity. Second, it is important to understand that the design of the AI trawl survey is not entirely random. The sampling frame for the AI survey is the list of stations that were successfully sampled from all previous surveys dating back to 1980. The 1980 survey was a systematic survey with sampling stations set approximately every 20 nautical miles. Over time more stations were added, but the systematic nature of the survey is still evident. As such, the survey design is a stratified random survey of previously and successfully towed stations that were originally based on a systematic design. This approach was taken because experience showed that much of the AI area is untrawlable. However, area swept estimates of density are still expanded over all habitat regardless of whether it is deemed trawlable or not.

Final Parameter Estimates and Associated Schedules

For typical stock assessments, this subsection of the chapter would summarize the parameter estimates and associated schedules associated with the final model. However, given the ongoing interest in development of age-structured models for AI Pacific cod, an attempt will be made to present information

for *all* of the models, thereby giving the Plan Team and SSC maximum flexibility in developing their own recommended harvest specifications.

As noted previously, estimates of all statistically estimated parameters in the Tier 3 models are shown in Table 2A.8. Estimates of fishing mortality rates from the Tier 3 models are shown in Table 2A.9. Estimates of the only statistically estimated parameter in the Tier 5 mode is shown in the main text, under "Parameter Estimates (Tier 5)."

Schedules of selectivity at length for the fishery from the Tier 3 models are shown in Table 2A.11, and schedules of selectivity at age for the trawl surveys from the Tier 3 models are shown in Table 2A.12. The survey selectivity schedule and the fishery selectivity schedule for the Tier 3 models are plotted in Figures 2A.12 and 2A.13, respectively.

Schedules of length at age and weight at age for the population, fishery, and survey are shown in Table 2A.13.

Time Series Results

As in the previous subsection, results for all three models (Tiers 3 and 5) will be presented here to the extent possible.

Definitions

The biomass estimates presented here will be defined in three ways for the Tier 3 models: 1) age 0+ biomass, consisting of the biomass of all fish aged 0 years or greater in January of a given year; 2) age 3+ biomass, consisting of the biomass of all fish aged 3 years or greater in January of a given year; and 3) spawning biomass, consisting of the biomass of all spawning females in a given year. For the Tier 5 models, biomass will be defined as the model estimate of survey biomass (as distinguished from observed survey biomass).

For the remaining quantities (recruitment and fishing mortality), Tier 5 estimates do not exist, so only Tier 3 estimates will be given. The recruitment estimates presented here will be defined as numbers of age 0 fish in a given year. To supplement the full-selection fishing mortality rates already shown in Table 2A.9, an alternative "effective" fishing mortality rate will be provided here, defined for each age and year as $-\ln(N_{a+1,t+1}/N_{a,t})-M$, where N = number of fish, a = age measured in years, t = time measured in years, and M = instantaneous natural mortality rate. In addition, the ratio of full-selection fishing mortality to $F_{35\%}$ will be shown.

Biomass

Table 2A.14a shows the time series of age 0+, age 3+, and female spawning biomass for the years 1977-2014 as estimated by the Tier 3 models (projections through 2015 are also shown for this year's assessment). The estimated spawning biomass time series are accompanied by their respective standard deviations. Table 2A.14b shows the time series of survey biomass with 95% confidence intervals as estimated last year and this year by Model 1 (because this is a random walk model, projected biomass for 2015 is the same as estimated biomass for 2014).

As noted previously, the time series of total (age 0+) biomass as estimated by the Tier 3 models are shown, together with the observed time series of trawl survey biomass, in Figure 2A.11, and the time series of survey biomass as estimated by the Tier 5 model is shown in Figure 2A.4. The time series of

female spawning biomass as estimated by the Tier 3 models are shown, together with the observed time series of trawl survey biomass, in Figure 2A.15.

Recruitment and Numbers at Age

Table 2A.15 shows the time series of age 0 recruitment (1000s of fish) for the years 1977-2013 as estimated by the Tier 3 models. Both estimated time series are accompanied by their respective standard deviations.

For the time series as a whole, both Tier 3 models estimate that 1996 was the largest cohort. Of the last ten cohorts, Model 2 estimates that only the 2007 year class was above average, and Model 3 estimates that none were above average. The recruitment time series for Models 2 and 3 had autocorrelation coefficients of 0.29 and 0.25, respectively.

Tier 3 model estimates of recruitment for the entire time series (1977-2013) are shown in Figure 2A.16, along with their respective 95% confidence intervals.

The time series of numbers at age as estimated by the Tier 3 models are shown in Table 2A.16.

Fishing Mortality

Table 2A.17 shows "effective" fishing mortality by age and year for ages 1-19 and years 1977-2014 as estimated by the Tier 3 models.

For each of the Tier 3 models, Figure 2A.17 plots the estimated trajectory of relative fishing mortality and relative female spawning biomass from 1977 through 2016 based on full-selection fishing mortality, overlaid with the current harvest control rules (projected values for 2015 and 2016 are from Scenario 2 under "Harvest Recommendations," below). It should be noted that, except for the projection years, this trajectory is based on SS output, which may not match the estimates obtained by the standard projection program exactly.

Retrospective Analysis

Figure 2A.18 shows the retrospective behavior of Models 2 and 3 with respect to female spawning biomass over the years 2004-2014. This figure was obtained by conducting ten additional model runs, dropping the 2014 data to create the run labeled "2013," dropping the 2013-2014 data to create the run labeled "2012," and so forth (the run labeled "2014" is this year's model run). In an attempt to quantify the results of this type of retrospective analysis, Mohn (1999) introduced a statistic labeled ρ, which has since been redefined to represent the average relative bias in terminal year estimates of a given quantity (in this case, female spawning biomass) across retrospective runs. For Model 2, $\rho = -0.384$, indicating that Model 2 tends to underestimate spawning biomass in the current year by nearly 40%. Model 3 produced a similar ρ value of -0.431. Both of these ρ values are higher (in absolute terms) than 18 of the 20 examples of BSAI and GOA groundfish stocks reported in the 2013 report of the Retrospective Working Group. Not only are the retrospective biases of Model 2 and 3 high and negative on average, they are negative in all runs shown in Figure 2A.18.

Determining the cause of a retrospective bias can be difficult. One oft-considered possibility is that certain parameters are constrained in the model to be constant over time, whereas the model would behave better if those parameters were allowed to vary over time. Examining the correlation between estimated parameter values and the number of "peels" (i.e., the number of data years dropped in each sequential run) in a retrospective analysis has been suggested as an appropriate diagnostic tool. For all

estimated parameters in Models 2 and 3 (except those that get eliminated from the model during the peeling process, leaving a total of 119), correlation coefficients with respect to number of peels were computed.

The results are shown in Figure 2A.18, in the form of a cumulative distribution function. For example, 38 and 28 parameters (32% and 24% of the total) in Models 2 and 3, respectively, had a correlation (in absolute value) of at least 0.90 with respect to number of peels.

For Model 2, the parameters with correlations of at least 0.90 in absolute value were:

Length at age 1 (cm)	Fishery selparm age 3	Survey selparm age 14
Asymptotic length (cm)	Fishery selparm age 13	Survey selparm age 15
Brody growth coefficient	Fishery selparm age 14	Survey selparm age 16
ln(catchability)	Fishery selparm age 15	Survey selparm age 17
Initial age 6 ln(abundance) dev	Fishery selparm age 16	Survey selparm age 18
Initial age 8 ln(abundance) dev	Fishery selparm age 17	Survey selparm age 19
Initial age 9 ln(abundance) dev	Fishery selparm age 18	Survey selparm age 20
Initial age 10 ln(abundance) dev	Fishery selparm age 19	Fishery seldev age 4 year 1995
Recruitment dev for 1994	Fishery selparm age 20	Fishery seldev age 4 year 2003
Recruitment dev for 1997	Survey selparm age 3	Survey seldev age 6 year 1995
Recruitment dev for 1998	Survey selparm age 11	Survey seldev age 3 year 2002
Recruitment dev for 1999	Survey selparm age 12	Survey seldev age 3 year 2004
Fishery selparm age 2	Survey selparm age 13	

For Model 3, the parameters with correlations of at least 0.90 in absolute value were:

Length at age 1 (cm)	Recruitment dev for 1999	Survey selparm age 3
ln(catchability)	Fishery selparm age 2	Survey selparm age 5
ln(mean recruitment)	Fishery selparm age 3	Fishery seldev age 4 year 1994
Initial age 5 ln(abundance) dev	Fishery selparm age 14	Fishery seldev age 6 year 1992
Initial age 8 ln(abundance) dev	Fishery selparm age 15	Fishery seldev age 6 year 2003
Initial age 9 ln(abundance) dev	Fishery selparm age 16	Survey seldev age 2 year 1991
Initial age 10 ln(abundance) dev	Fishery selparm age 17	Survey seldev age 7 year 1997
Recruitment dev for 1994	Fishery selparm age 18	Survey seldev age 7 year 2000
Recruitment dev for 1997	Fishery selparm age 19	
Recruitment dev for 1998	Fishery selparm age 20	

Most of the parameters in the above lists already pertain to a specific year in the time series, so it is not clear that adding time variability to an existing estimated parameter will solve the problem. The non-time-varying parameters are the growth parameters, catchability, and mean recruitment. Adding time-variabililty to one or more of these parameters may help to address the retrospective bias. For example, Model 2 in this year's EBS Pacific cod assessment included time-varying catchability, and its value of rho was only -0.049. However, there was not sufficient time to investigate such modifications in the present assessment.

It should be noted that only one model run was conducted for each peel in the retrospective analysis (i.e., no "jitter" analysis was conducted), meaning it is possible that some of the retrospective runs may not have converged to the true minimum of the objective function.

Harvest Recommendations

As in the previous two subsections, results for all three models (Tiers 3 and 5) will be presented here to the extent possible.

Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines the "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater.

Tier 3 of the Amendment 56 control rules uses the following reference points: $B_{40\%}$, equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing; $F_{35\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 35% of the level that would be obtained in the absence of fishing; and $F_{40\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 40% of the level that would be obtained in the absence of fishing. The only parameter used in the Tier 5 reference points is M.

If the SSC determines that the estimates of 2015-16 spawning biomass and the Tier 3 reference points from either of the Tier 3 models are all reliable, then AI Pacific cod will be managed under Tier 3. If the SSC determines that neither of the Tier 3 models produces reliable estimates of all of these quantities, then AI Pacific cod will continue to be managed under Tier 5.

The following formulae apply under Tier 3:

3a) Stock status: $B/B_{40\%} > 1$

$F_{OFL} = F_{35\%}$

$F_{ABC} \leq F_{40\%}$

3b) Stock status: $0.05 < B/B_{40\%} \leq 1$

$F_{OFL} = F_{35\%} \times (B/B_{40\%} - 0.05) \times 1/0.95$

$F_{ABC} \leq F_{40\%} \times (B/B_{40\%} - 0.05) \times 1/0.95$

3c) Stock status: $B/B_{40\%} \leq 0.05$

$F_{OFL} = 0$

$F_{ABC} = 0$

The following formulae apply under Tier 5:

$F_{OFL} = M$

$F_{ABC} \leq 0.75 \times M$

Estimates of projected biomass and all Tier 3 and Tier 5 reference points are shown for the respective models in Table 2A.10. For the authors' recommended model (Tier 5, Model 1), the estimates are as follow:

Quantity	2015	2016
Biomass (t)	68,900	68,900
M	0.34	0.34

The 95% confidence interval for the above Tier 5 biomass estimate extends from 50,100-93,800 t.

Specification of OFL and Maximum Permissible ABC

As shown in Table 2A.10, of the two Tier 3 models, Model 2 projects that female spawning biomass will be above $B_{40\%}$ in both 2015 (Tier 3a) but below in 2016 (Tier 3b), while Model 3 projects that it will be below in both years (Tier 3b). Tier 5 has no sub-tiers.

Estimates of OFL, maximum permissible ABC, and the associated fishing mortality rates for 2015 and 2016 are shown for the respective models in Table 2A.10. For the authors' recommended model (Tier 5, Model 1), the estimates are as follow:

Quantity	2015	2016
OFL (t)	23,400	23,400
maxABC (t)	17,900	17,900
F_{OFL}	0.34	0.34
$maxF_{ABC}$	0.26	0.26

The age 0+ biomass projections for 2015 and 2016 from the Tier 3 models (using SS rather than the standard projection model) are 170,000 t and 151,000 t, respectively (Model 2); and 151,000 t and 132,000 t, respectively (Model 3).

Standard Harvest Scenarios, Projection Methodology, and Projection Results (Tier 3 Only)

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with an estimated vector of numbers at age for January 1, 2015. This requires an appropriate estimate of total catch for 2014. Because each year's stock assessment is finalized before complete (i.e., year-long) catch data are available for that year, it is necessary to extrapolate the available catch data through the end of the year.

Twelve estimators were evaluated to determine the best method of estimating total current-year catch as a function of previous intra-annual fishery performance, which parallel the set of estimators used in this year's EBS Pacific cod assessment. Typically, current-year catch data are available through the beginning of October. In the seasonal structure used by the base model for the EBS stock, the last two "catch seasons" span the months August-October and November-December, meaning that current-year catch data are missing for part of season 4 and all of season 5. All 12 estimators therefore involved extrapolating the catch for seasons 1-3 through the end of the year. The estimators consisted of two groups of six each. One group was based on the average *absolute* amounts of catch taken in some number of previous years during seasons 4-5, and the other was based on the average *relative* amounts of catch taken in some number of previous years during seasons 4-5. For both groups, averages were taken over a range of previous years spanning 1 to 6. The results of this analysis are shown in Figure 2A.20. Although it may be difficult to identify the best estimator by eye, it turned out that all of the "relative" estimators performed better than any of the "absolute" estimators (the opposite was the case in the EBS assessment), and the best "relative" estimator was based on the average January-July catch proportion from the preceding 5 years.

Because management of the Pacific cod fisheries has a very strong track record of keeping catch below ABC, however, this estimator was used only in the event that it did not result in a current-year catch

greater than current-year ABC. In the case of the 2014 fishery, the estimator resulted in a catch of 11,852 t, which is less than the 2014 ABC of 15,100 t, so final 2014 catch was estimated at a value of 11,852 t.

In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Except for the first two projection years under Scenario 2 (see paragraph below), total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

For the first two projection years under Scenario 2, total catch was computed based on two factors: 1) the relationship between previous ABCs and previous catches, and 2) the fact that neither BSAI or AI Pacific cod catch has ever exceeded BSAI or AI Pacific cod ABC in the last 20 years. Computation of an appropriate estimator is complicated by the fact that, prior to 2014, the Pacific cod ABC applied to the EBS and AI combined, but, as in 2014, future ABCs are anticipated to apply to the AI only. To adjust for this, a series of "pseudo-ABCs" was computed for the years 1995-2013 by multiplying each BSAI ABC by the corresponding ratio of AI catch to BSAI catch. Catch for the AI was then regressed against the AI pseudo-ABC, giving an intercept of about -900 t and a slope of about 0.95. This regression implies that catch will be less than ABC for all values of ABC. The data, the catch=ABC line, the regression line, and the estimator are shown in Figure 2A.21.

Five of the seven standard scenarios are sometimes used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TACs for 2015 and 2016, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

> *Scenario 1*: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
>
> *Scenario 2*: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2015 recommended in the assessment to the *max* F_{ABC} for 2015. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)
>
> *Scenario 3*: In all future years, F is set equal to the 2009-2013 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
>
> *Scenario 4*: In all future years, the upper bound on F_{ABC} is set at $F_{60\%}$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)
>
> *Scenario 5*: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is 1) above its MSY level in 2014 or 2) above 1/2 of its MSY level in 2014 and expected to be above its MSY level in 2024 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its MSY level in 2016 or 2) above 1/2 of its MSY level in 2016 and expected to be above its MSY level in 2026 under this scenario, then the stock is not approaching an overfished condition.)

Projections corresponding to the standard scenarios are shown for the Tier 3 models in Tables 2A.18-2A.24. Each of these tables consists of two pages, with the first corresponding to Model 2 and the second corresponding to Model 3.

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2015, it does not provide the best estimate of OFL for 2016, because the mean 2016 catch under Scenario 6 is predicated on the 2015 catch being equal to the 2015 OFL, whereas the actual 2015 catch will likely be less than the 2015 OFL. Table 2A.10 contains the appropriate one- and two-year ahead projections for both ABC and OFL under Model 1.

ABC Recommendation

The authors' recommended ABCs for 2015 and 2016 are the maximum permissible values from the Tier 5 random effects model: 17,600 t in both years.

Area Allocation of Harvests

As noted in the "Management History" subsection of the "Fishery" section, the anticipated final rule for the 2015 Steller sea lion protection measures requires an estimate of the proportion of the AI Pacific cod stock residing in Area 543, which will be used to set the harvest limit in 543 after subtraction of the State GHL from the overall AI ABC. The Area 543 proportion could be computed on the basis of the survey observations themselves, or by running the Tier 5 random effects model for Area 543 and then computing the ratios of the resulting estimates to those of Model 1. More specifically, some possible estimators of this proportion are: 1) the 1991-2014 average proportion from the survey (26.5%), 2) the most recent proportion from the survey (24.6%), 3) the 1991-2014 average proportion from the random effects model (25.6%), and 4) the most recent proportion from the random effects model (26.3%). All of these estimates are quite close to one another, with an average value of 25.7%. If the random effects model is used to set the 2015 ABC based on the model's most recent estimate of biomass, it seems reasonable to estimate the biomass proportion in Area 543 accordingly, by using the most recent estimate from the random effects model (26.3%).

Status Determination

Under the MSFCMA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing. This report involves the answers to three questions: 1) Is the stock being subjected to overfishing? 2) Is the stock currently overfished? 3) Is the stock approaching an overfished condition?

Is the stock being subjected to overfishing? The official BSAI catch estimate for the most recent complete year (2013) is 250,274 t. This is less than the 2013 BSAI OFL of 359,000 t. Therefore, the combined BSAI stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest Scenarios #6 and #7 are used in these determinations as follows:

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2014:

a. If spawning biomass for 2014 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2014 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c. If spawning biomass for 2014 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 2.33). If the mean spawning biomass for 2024 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario #7 (Table 2.25):

a. If the mean spawning biomass for 2016 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2016 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2016 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2026. If the mean spawning biomass for 2026 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

Based on the above criteria and Tables 2A.23 and 2A.24, if either of the Tier 3 models is accepted for use in status determination, the stock is not overfished and is not approaching an overfished condition.

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the Stock

A primary ecosystem phenomenon affecting the Pacific cod stock seems to be the occurrence of periodic "regime shifts," in which central tendencies of key variables in the physical environment change on a scale spanning several years to a few decades (Zador, 2011). One well-documented example of such a regime shift occurred in 1977, and shifts occurring in 1989 and 1999 have also been suggested (e.g., Hare and Mantua 2000). Because the data time series in the models presented in this assessment do not begin until 1991, the 1977 regime shift should not be a factor in any of the quantities presented here, although it may indeed have had an impact on the stock.

The prey and predators of Pacific cod have been described or reviewed by Albers and Anderson (1985), Livingston (1989, 1991), Lang et al. (2003), Westrheim (1996), and Yang (2004). The composition of Pacific cod prey varies to some extent by time and area. In terms of percent occurrence, some of the most important items in the diet of Pacific cod in the BSAI and GOA have been polychaetes, amphipods, and

crangonid shrimp. In terms of numbers of individual organisms consumed, some of the most important dietary items have been euphausids, miscellaneous fishes, and amphipods. In terms of weight of organisms consumed, some of the most important dietary items have been walleye pollock, fishery offal, yellowfin sole, and crustaceans. Small Pacific cod feed mostly on invertebrates, while large Pacific cod are mainly piscivorous. Predators of Pacific cod include Pacific cod, halibut, salmon shark, northern fur seals, Steller sea lions, harbor porpoises, various whale species, and tufted puffin. Major trends in the most important prey or predator species could be expected to affect the dynamics of Pacific cod to some extent.

Fishery Effects on the Ecosystem

Potentially, fisheries for Pacific cod can have effects on other species in the ecosystem through a variety of mechanisms, for example by relieving predation pressure on shared prey species (i.e., species which serve as prey for both Pacific cod and other species), by reducing prey availability for predators of Pacific cod, by altering habitat, by imposing bycatch mortality, or by "ghost fishing" caused by lost fishing gear.

Incidental Catch Taken in the Pacific Cod Fisheries

Incidental catches taken in the Pacific cod fisheries are summarized in Tables 2A.25-2A.28. Catches for 2014 in each of these tables are incomplete. Table 2A.25 shows incidental catch of FMP species, other than squid and the members of the former "other species" complex, taken from 1991-2014 by trawl gear and longline gear (incidental catch of these species by pot gear in the AI Pacific cod fishery is typically negligible). Table 2A.26 shows incidental catch of squid and the members of the former "other species" complex taken from 2003-2014, aggregated across gear types. Table 2A.27 shows incidental catch of prohibited species taken from 1991-2014, plus mortality estimates for halibut, aggregated across gear types. Table 2A.28 shows incidental catch of non-target species groups taken from 2003-2014, aggregated across gear types.

Steller Sea Lions

Sinclair and Zeppelin (2002) showed that Pacific cod was one of the four most important prey items of Steller sea lions in terms of frequency of occurrence averaged over years, seasons, and sites, and was especially important in winter. Pitcher (1981) and Calkins (1998) also showed Pacific cod to be an important winter prey item in the GOA and BSAI, respectively. Furthermore, the size ranges of Pacific cod harvested by the fisheries and consumed by Steller sea lions overlap, and the fishery operates to some extent in the same geographic areas used by Steller sea lion as foraging grounds (Livingston (ed.), 2002).

The Fisheries Interaction Team of the Alaska Fisheries Science Center has been engaged in research to determine the effectiveness of recent management measures designed to mitigate the impacts of the Pacific cod fisheries (among others) on Steller sea lions. Results from studies conducted in 2002-2003 were summarized by Conners et al. (2004). These studies included a tagging feasibility study, which may evolve into an ongoing research effort capable of providing information on the extent and rate to which Pacific cod move in and out of various portions of Steller sea lion critical habitat. Nearly 6,000 cod with spaghetti tags were released, of which approximately 1,000 had been returned as of September, 2003.

Seabirds

The following is a summary of information provided by Livingston (ed., 2002): In both the BSAI and GOA, the northern fulmar (*Fulmarus glacialis*) comprises the majority of seabird bycatch, which occurs primarily in the longline fisheries, including the hook and line fishery for Pacific cod (Tables 2.33b and 2.36b). Shearwater (*Puffinus* spp.) distribution overlaps with the Pacific cod longline fishery in the

Bering Sea, and with trawl fisheries in general in both the Bering Sea and GOA. Black-footed albatross (*Phoebastria nigripes*) is taken in much greater numbers in the GOA longline fisheries than the Bering Sea longline fisheries, but is not taken in the trawl fisheries. The distribution of Laysan albatross (*Phoebastria immutabilis*) appears to overlap with the longline fisheries in the central and western Aleutians. The distribution of short-tailed albatross (*Phoebastria albatrus*) also overlaps with the Pacific cod longline fishery along the Aleutian chain, although the majority of the bycatch has taken place along the northern portion of the Bering Sea shelf edge (in contrast, only two takes have been recorded in the GOA). Some success has been obtained in devising measures to mitigate fishery-seabird interactions. For example, on vessels larger than 60 ft. LOA, paired streamer lines of specified performance and material standards have been found to reduce seabird incidental take significantly.

Fishery Usage of Habitat

The following is a summary of information provided by Livingston (ed., 2002): The longline and trawl fisheries for Pacific cod each comprise an important component of the combined fisheries associated with the respective gear type in each of the three major management regions (EBS, AI, and GOA). Looking at each gear type in each region as a whole (i.e., aggregating across all target species) during the period 1998-2001, the total number of observed sets was as follows:

Gear	EBS	AI	GOA
Trawl	240,347	43,585	68,436
Longline	65,286	13,462	7,139

In the EBS, both longline and trawl effort was concentrated north of False Pass (Unimak Island) and along the shelf edge represented by the boundary of areas 513, 517 (in addition, longline effort was concentrated along the shelf edge represented by the boundary of areas 521-533). In the AI, both longline and trawl effort were dispersed over a wide area along the shelf edge. The catcher vessel longline fishery in the AI occurred primarily over mud bottoms. Longline catcher-processors in the AI tended to fish more over rocky bottoms. In the GOA, fishing effort was also dispersed over a wide area along the shelf, though pockets of trawl effort were located near Chirikof, Cape Barnabus, Cape Chiniak and Marmot Flats. The GOA longline fishery for Pacific cod generally took place over gravel, cobble, mud, sand, and rocky bottoms, in depths of 25 fathoms to 140 fathoms.

Impacts of the Pacific cod fisheries on essential fish habitat were further analyzed in an environmental impact statement by NMFS (2005)), followed by a 5-year review in 2010 (NMFS 2010). A second 5-year review is currently in progress.

DATA GAPS AND RESEARCH PRIORITIES

Significant improvements in the quality of this assessment could be made if future research were directed toward closing certain data gaps. At this point, the most critical needs pertain to trawl survey catchability and selectivity, specifically: 1) to understand the factors determining these characteristics, 2) to understand whether/how these characteristics change over time, and 3) to obtain accurate estimates of these characteristics. Ageing also continues to be an issue, as the assessment models consistently estimate a positive ageing bias. Longer-term research needs include improved understanding of: 1) the ecology of Pacific cod in the AI, including spatial dynamics, trophic and other interspecific relationships, and the relationship between climate and recruitment; 2) ecology of species taken as bycatch in the Pacific cod fisheries, including estimation of biomass, carrying capacity, and resilience; and 3) ecology of species that interact with Pacific cod, including estimation of interaction strengths, biomass, carrying capacity, and resilience.

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TABLES

Table 2A.1a—Summary of 1964-1980 catches (t) of Pacific cod in the AI by fleet sector. "For." = foreign, "JV" = joint venture processing, "Dom." = domestic annual processing. Catches by gear are not available for these years. Catches may not always include discards.

	Aleutian Islands			
Year	For.	JV	Dom.	Total
1964	241	0	0	241
1965	451	0	0	451
1966	154	0	0	154
1967	293	0	0	293
1968	289	0	0	289
1969	220	0	0	220
1970	283	0	0	283
1971	2,078	0	0	2,078
1972	435	0	0	435
1973	977	0	0	977
1974	1,379	0	0	1,379
1975	2,838	0	0	2,838
1976	4,190	0	0	4,190
1977	3,262	0	0	3,262
1978	3,295	0	0	3,295
1979	5,593	0	0	5,593
1980	5,788	0	0	5,788

Table 2A.1b—Summary of 1981-1990 catches (t) of Pacific cod in the AI by area, fleet sector, and gear type. All catches include discards. "LLine" = longline, "Subt." = sector subtotal. Breakdown of domestic annual processing by gear is not available prior to 1988.

	Foreign			Joint Venture		Domestic Annual Processing			
Year	Trawl	LLine	Subt.	Trawl	Subt.	Trawl	LL+pot	Subt.	Total
1981	2,680	235	2,915	1,749	1,749	n/a	n/a	2,770	7,434
1982	1,520	476	1,996	4,280	4,280	n/a	n/a	2,121	8,397
1983	1,869	402	2,271	4,700	4,700	n/a	n/a	1,459	8,430
1984	473	804	1,277	6,390	6,390	n/a	n/a	314	7,981
1985	10	829	839	5,638	5,638	n/a	n/a	460	6,937
1986	5	0	5	6,115	6,115	n/a	n/a	786	6,906
1987	0	0	0	10,435	10,435	n/a	n/a	2,772	13,207
1988	0	0	0	3,300	3,300	1,698	167	1,865	5,165
1989	0	0	0	6	6	4,233	303	4,536	4,542
1990	0	0	0	0	0	6,932	609	7,541	7,541

Table 2A.1c—Summary of 1991-2014 catches (t) of Pacific cod in the AI. To avoid confidentiality problems, longline and pot catches have been combined. The small catches taken by "other" gear types have been merged proportionally with the catches of the gear types shown. Catches for 2014 are through October 13.

	Federal			State	
Year	Trawl	Long.+pot	Subtotal	Subtotal	Total
1991	3,414	6,383	9,798		9,798
1992	14,587	28,481	43,068		43,068
1993	17,328	16,876	34,205		34,205
1994	14,383	7,156	21,539		21,539
1995	10,574	5,960	16,534		16,534
1996	21,179	10,430	31,609		31,609
1997	17,411	7,753	25,164		25,164
1998	20,531	14,196	34,726		34,726
1999	16,478	11,653	28,130		28,130
2000	20,379	19,306	39,685		39,685
2001	15,836	18,372	34,207		34,207
2002	27,929	2,872	30,801		30,801
2003	31,478	977	32,456		32,456
2004	25,770	3,103	28,873		28,873
2005	19,624	3,075	22,699		22,699
2006	16,963	3,535	20,498	3,714	24,211
2007	25,714	4,497	30,211	4,146	34,357
2008	19,404	7,507	26,910	4,319	31,229
2009	20,277	6,245	26,522	2,060	28,582
2010	16,757	8,277	25,034	3,967	29,001
2011	9,359	1,233	10,592	266	10,858
2012	9,789	3,201	12,991	5,232	18,223
2013	6,966	1,812	8,778	4,793	13,572
2014	5,656	429	6,085	4,451	10,536

Table 2A.1d—Summary of 1994-2014 catches (t) of Pacific cod in the AI, by NMFS 3-digit statistical area (area breakdowns not available prior to 1994). Catches for 2014 are through October 20.

	Amount			Proportion		
Year	Western	Central	Eastern	Western	Central	Eastern
1994	2,059	7,441	12,039	0.096	0.345	0.559
1995	1,713	5,086	9,735	0.104	0.308	0.589
1996	4,023	4,509	23,077	0.127	0.143	0.730
1997	894	4,440	19,830	0.036	0.176	0.788
1998	3,487	9,299	21,940	0.100	0.268	0.632
1999	2,322	5,276	20,532	0.083	0.188	0.730
2000	9,073	8,799	21,812	0.229	0.222	0.550
2001	12,767	7,358	14,082	0.373	0.215	0.412
2002	2,259	7,133	21,408	0.073	0.232	0.695
2003	2,997	6,713	22,746	0.092	0.207	0.701
2004	3,657	6,825	18,391	0.127	0.236	0.637
2005	4,268	3,552	14,879	0.188	0.157	0.655
2006	4,583	4,662	14,967	0.189	0.193	0.618
2007	5,008	4,660	24,688	0.146	0.136	0.719
2008	7,319	5,555	18,355	0.234	0.178	0.588
2009	7,929	6,899	13,754	0.277	0.241	0.481
2010	8,213	6,291	14,497	0.283	0.217	0.500
2011	24	1,768	9,066	0.002	0.163	0.835
2012	29	2,816	15,377	0.002	0.155	0.844
2013	53	2,875	10,644	0.004	0.212	0.784
2014	30	1,041	9,485	0.003	0.099	0.899

Table 2A.2—Discards (t) of Pacific cod in the AI Pacific cod fishery, by gear and year for the period 1991-2014 (2014 data are current through October 20). To avoid confidentiality problems, longline and pot catches have been combined. The small amounts of discards taken by other gear types have been merged proportionally into the gear types shown. Note that Amendment 49, which mandated increased retention and utilization, was implemented in 1998. Note also that the version of this table in the 2012 and 2013 assessments inadvertently included discards of Pacific cod in *all* fisheries, not just the Pacific cod fishery.

Year	Trawl	Long.+pot	Total
1991	21	84	105
1992	633	452	1,085
1993	1,371	2,156	3,527
1994	1,091	211	1,302
1995	115	345	460
1996	343	516	859
1997	580	639	1,220
1998	140	473	613
1999	225	196	420
2000	138	466	605
2001	213	243	455
2002	526	79	604
2003	187	29	216
2004	181	57	238
2005	101	38	139
2006	100	113	214
2007	352	131	483
2008	30	113	143
2009	33	115	149
2010	38	154	192
2011	20	24	45
2012	14	70	84
2013	87	38	126
2014	22	5	27

Table 2A.3—History of **BSAI** Pacific cod catch, TAC, ABC, and OFL (t). Catch for 2013 is through October 12. Note that specifications through 2013 were for the combined BSAI region, so BSAI catch is shown rather than the AI catches from Table 2A.1 for the period 1977-2013. Source for historical specifications: NPFMC staff.

Year	Catch	TAC	ABC	OFL
1977	36,597	58,000	-	-
1978	45,838	70,500	-	-
1979	39,354	70,500	-	-
1980	51,649	70,700	148,000	-
1981	63,941	78,700	160,000	-
1982	69,501	78,700	168,000	-
1983	103,231	120,000	298,200	-
1984	133,084	210,000	291,300	-
1985	150,384	220,000	347,400	-
1986	142,511	229,000	249,300	-
1987	163,110	280,000	400,000	-
1988	208,236	200,000	385,300	-
1989	182,865	230,681	370,600	-
1990	179,608	227,000	417,000	-
1991	220,038	229,000	229,000	-
1992	207,278	182,000	182,000	188,000
1993	167,391	164,500	164,500	192,000
1994	193,802	191,000	191,000	228,000
1995	245,033	250,000	328,000	390,000
1996	240,676	270,000	305,000	420,000
1997	257,765	270,000	306,000	418,000
1998	193,256	210,000	210,000	336,000
1999	173,998	177,000	177,000	264,000
2000	191,060	193,000	193,000	240,000
2001	176,749	188,000	188,000	248,000
2002	197,356	200,000	223,000	294,000
2003	207,907	207,500	223,000	324,000
2004	212,618	215,500	223,000	350,000
2005	205,635	206,000	206,000	265,000
2006	193,025	194,000	194,000	230,000
2007	174,486	170,720	176,000	207,000
2008	171,277	170,720	176,000	207,000
2009	175,756	176,540	182,000	212,000
2010	171,875	168,780	174,000	205,000
2011	220,109	227,950	235,000	272,000
2012	251,055	261,000	314,000	369,000
2013	250,274	260,000	307,000	359,000
2014	6,085	6,997	15,100	20,100

Table 2A.4—Amendments to the BSAI Fishery Management Plan (FMP) that reference Pacific cod explicitly (excerpted from Appendix A of the FMP).

Amendment 2, implemented January 12, 1982:

For Pacific cod, decreased maximum sustainable yield to 55,000 t from 58,700 t, increased equilibrium yield to 160,000 t from 58,700 t, increased acceptable biological catch to 160,000 t from 58,700 t, increased optimum yield to 78,700 t from 58,700 t, increased reserves to 3,935 t from 2,935 t, increased domestic annual processing (DAP) to 26,000 t from 7,000 t, and increased DAH to 43,265 t from 24,265 t.

Amendment 4, implemented May 9, 1983, supersedes Amendment 2:

For Pacific Cod, increased equilibrium yield and acceptable biological catch to 168,000 t from 160,000 t, increased optimum yield to 120,000 t from 78,700 t, increased reserves to 6,000 t from 3,935 t, and increased TALFF to 70,735 t from 31,500 t.

Amendment 10, implemented March 16, 1987:

Established Bycatch Limitation Zones for domestic and foreign fisheries for yellowfin sole and other flatfish (including rock sole); an area closed to all trawling within Zone 1; red king crab, C. bairdi Tanner crab, and Pacific halibut PSC limits for DAH yellowfin sole and other flatfish fisheries; a C. bairdi PSC limit for foreign fisheries; and a red king crab PSC limit and scientific data collection requirement for U.S. vessels fishing for Pacific cod in Zone 1 waters shallower than 25 fathoms.

Amendment 24, implemented February 28, 1994, and effective through December 31, 1996:

1. Established the following gear allocations of BSAI Pacific cod TAC as follows: 2 percent to vessels using jig gear; 44.1 percent to vessels using hook-and-line or pot gear, and 53.9 percent to vessels using trawl gear.
2. Authorized the seasonal apportionment of the amount of Pacific cod allocated to gear groups. Criteria for seasonal apportionments and the seasons authorized to receive separate apportionments will be set forth in regulations.

Amendment 46, implemented January 1, 1997, superseded Amendment 24:

Replaced the three year Pacific cod allocation established with Amendment 24, with the following gear allocations in BSAI Pacific cod: 2 percent to vessels using jig gear; 51 percent to vessels using hook-and-line or pot gear; and 47 percent to vessels using trawl gear. The trawl apportionment will be divided 50 percent to catcher vessels and 50 percent to catcher processors. These allocations as well as the seasonal apportionment authority established in Amendment 24 will remain in effect until amended.

Amendment 49, implemented January 3, 1998:

Implemented an Increased Retention/Increased Utilization Program for pollock and Pacific cod beginning January 1, 1998 and rock sole and yellowfin sole beginning January 1, 2003.

Amendment 64, implemented September 1, 2000, revised Amendment 46:

Allocated the Pacific cod Total Allowable Catch to the jig gear (2 percent), fixed gear (51 percent), and trawl gear (47 percent) sectors.

Amendment 67, implemented May 15, 2002, revised Amendment 39:

Established participation and harvest requirements to qualify for a BSAI Pacific cod fishery endorsement for fixed gear vessels.

Amendment 77, implemented January 1, 2004, revised Amendment 64:

Implemented a Pacific cod fixed gear allocation between hook and line catcher processors (80 percent), hook and line catcher vessels (0.3 percent), pot catcher processors (3.3 percent), pot catcher vessels (15 percent), and catcher vessels (pot or hook and line) less than 60 feet (1.4 percent).

Amendment 85, partially implemented on March 5, 2007, superseded Amendments 46 and 77:

Implemented a gear allocation among all non-CDQ fishery sectors participating in the directed fishery for Pacific cod. After deduction of the CDQ allocation, the Pacific cod TAC is apportioned to vessels using jig gear (1.4 percent); catcher processors using trawl gear listed in Section 208(e)(1)-(20) of the AFA (2.3 percent); catcher processors using trawl gear as defined in Section 219(a)(7) of the Consolidated Appropriations Act, 2005 (Public Law 108-447) (13.4 percent); catcher vessels using trawl gear (22.1 percent); catcher processors using hook-and-line gear (48.7 percent); catcher vessels ≥60’ LOA using hook-and-line gear (0.2 percent); catcher processors using pot gear (1.5 percent); catcher vessels ≥60’ LOA using pot gear (8.4 percent); and catcher vessels <60’ LOA that use either hook-and-line gear or pot gear (2.0 percent).

Table 2A.5 (page 1 of 3)—Fishery size composition, by year and cm.

Year	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	1	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	1	5
1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1999	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	4	5	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
2003	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
2004	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
2005	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
2007	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Year	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
1991	0	0	0	2	0	0	1	2	8	2	4	9	13	11	15	7	9	21	28	39
1992	0	0	0	0	0	0	0	3	4	4	9	21	27	46	40	62	116	153	226	310
1993	0	0	0	0	1	4	7	11	9	12	17	20	30	29	33	39	45	67	76	113
1994	0	0	0	0	1	2	4	7	5	3	8	3	14	8	19	19	26	33	52	73
1995	14	22	34	38	59	51	49	54	66	56	51	33	22	19	11	12	11	23	20	30
1996	0	2	0	2	5	15	6	9	8	14	18	15	12	29	39	39	50	63	108	136
1997	0	0	0	0	2	2	0	7	4	5	9	12	6	9	17	22	17	25	25	32
1998	1	1	4	1	8	9	25	28	43	51	47	88	92	94	87	122	183	200	212	296
1999	0	1	1	3	0	1	3	3	7	6	8	25	21	19	30	32	38	62	75	131
2000	0	1	0	0	0	4	6	5	6	13	7	6	7	20	30	52	62	98	140	169
2001	0	0	0	1	3	10	5	11	12	15	15	23	34	64	72	93	130	163	211	230
2002	0	1	0	1	2	5	3	9	11	12	8	24	22	33	37	48	71	65	68	65
2003	0	1	0	0	1	3	5	5	12	16	22	15	21	25	21	17	33	50	53	64
2004	1	0	1	1	2	2	5	5	14	22	17	44	43	49	69	71	81	94	81	86
2005	0	0	0	0	3	2	1	1	2	5	2	6	12	4	7	11	16	20	30	30
2006	0	1	0	1	0	0	1	3	4	0	4	3	5	0	3	6	14	11	31	33
2007	3	0	1	0	5	3	5	7	12	12	12	20	15	19	17	20	27	31	31	50
2008	0	1	1	2	0	1	3	0	3	2	7	5	10	9	19	21	43	41	47	67
2009	0	0	0	3	0	0	1	4	3	4	10	14	15	20	20	39	52	53	67	86
2010	1	0	0	2	0	0	2	1	0	6	12	14	13	22	40	45	72	87	120	143
2011	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	1	2	3	15
2012	0	0	0	0	0	0	0	0	2	2	1	3	2	4	5	1	12	4	2	7
2013	0	0	0	0	0	0	0	0	0	1	1	1	2	1	2	1	3	6	10	10
2014	0	0	0	0	0	0	0	1	0	0	0	0	3	1	0	2	0	4	2	6

Table 2A.5 (page 2 of 3)—Fishery size composition, by year and cm.

Year	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
1991	24	36	56	63	62	76	62	92	103	141	140	186	214	255	252	312	285	324	359	360
1992	463	550	587	621	705	792	820	872	826	886	898	962	990	1025	1183	1297	1328	1454	1522	1752
1993	121	218	240	274	321	433	573	674	751	827	861	957	985	937	846	857	793	754	764	775
1994	101	83	139	160	161	223	233	257	291	297	333	359	389	466	512	572	632	654	720	750
1995	26	29	33	55	83	81	83	107	137	181	186	195	254	269	308	318	385	404	430	451
1996	168	197	268	249	296	334	335	362	416	423	508	453	502	583	534	558	572	685	800	926
1997	43	56	83	78	110	103	165	147	191	227	248	298	348	351	329	366	440	426	397	371
1998	359	455	483	523	639	629	793	723	718	804	822	798	867	808	882	931	1092	1143	1176	1298
1999	118	173	183	215	305	292	317	366	374	380	400	436	471	464	541	516	516	595	592	646
2000	170	246	286	291	362	375	367	462	488	559	582	658	752	825	841	855	875	946	971	968
2001	296	321	347	424	466	495	563	643	741	772	762	851	951	948	1041	1078	1195	1312	1324	1493
2002	74	89	102	110	122	152	164	179	156	147	154	174	165	139	172	164	198	218	224	255
2003	62	110	105	141	140	164	199	228	232	229	229	253	271	290	239	239	311	279	274	304
2004	84	82	112	116	145	174	186	237	264	307	320	362	381	348	398	371	367	405	399	439
2005	51	51	79	67	79	87	118	127	145	154	193	172	229	253	249	258	297	309	334	340
2006	41	49	70	108	121	137	154	163	199	186	215	211	261	298	315	314	395	395	378	388
2007	30	65	56	64	71	92	112	153	197	201	229	271	331	352	409	468	483	491	496	544
2008	88	96	128	172	209	235	299	308	341	323	316	338	300	310	331	301	308	335	316	358
2009	65	90	78	100	104	121	133	154	167	167	190	234	318	324	359	337	407	414	482	485
2010	184	226	232	307	370	399	444	490	459	519	530	496	490	499	504	531	502	493	509	531
2011	16	18	31	37	47	61	49	72	72	94	102	93	118	132	150	145	187	168	191	212
2012	5	11	10	15	19	32	28	26	51	45	56	76	100	115	126	174	168	214	256	292
2013	13	17	26	37	51	42	55	48	44	53	62	64	48	41	64	65	94	87	85	116
2014	1	7	6	10	20	21	31	27	31	50	42	42	46	51	57	39	55	55	54	70

Year	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83
1991	380	428	463	565	575	544	698	648	732	801	852	829	852	827	753	829	856	703	774	707
1992	1800	2141	2134	2337	2558	2797	2940	2871	3149	3267	3427	3578	3478	3549	3297	3289	3169	2878	2726	2644
1993	783	828	829	856	775	903	891	866	922	938	992	1035	972	1105	1007	1162	1105	1184	1208	1162
1994	762	853	800	865	828	881	827	808	780	804	766	730	617	655	598	545	550	520	535	498
1995	554	556	590	642	635	686	782	748	735	733	782	890	778	857	837	864	880	821	776	736
1996	914	1040	1158	1030	1056	965	1062	977	992	1071	1042	1125	1010	933	926	931	1037	954	1006	982
1997	363	352	349	317	362	371	351	355	402	383	407	489	458	445	513	582	608	572	548	531
1998	1407	1664	1689	1616	1766	1826	2306	1998	1888	1881	1781	2067	1667	1564	1513	1483	1604	1368	1262	1249
1999	621	616	628	560	717	715	702	664	735	783	829	797	773	808	906	800	836	826	820	808
2000	972	991	977	1054	1028	1040	1124	1002	1133	1112	1053	1053	1012	1050	990	1002	1053	972	1084	988
2001	1383	1452	1495	1607	1693	1659	1697	1651	1631	1558	1564	1361	1349	1263	1122	1076	973	962	898	924
2002	279	324	370	451	447	481	571	637	744	718	738	768	809	790	814	779	757	702	726	671
2003	277	272	357	337	307	366	408	415	372	398	349	420	418	432	469	500	547	580	593	688
2004	416	437	460	483	496	481	530	552	515	491	578	510	552	591	523	537	544	518	532	537
2005	340	366	319	362	408	405	464	454	460	518	534	561	559	561	563	637	685	632	623	598
2006	440	429	364	392	449	361	377	368	389	394	447	411	435	411	479	477	500	457	503	472
2007	461	498	466	532	488	493	456	453	428	440	473	458	491	472	519	502	523	532	531	539
2008	408	460	438	427	481	493	521	515	473	524	498	468	471	437	429	403	422	438	425	372
2009	491	452	486	447	486	404	475	406	414	453	434	457	413	451	413	390	379	400	359	363
2010	577	618	531	583	634	668	821	620	695	775	809	822	825	759	764	763	770	687	618	605
2011	210	210	208	228	195	214	217	155	162	147	145	172	135	179	155	161	221	182	184	201
2012	330	327	307	315	351	386	407	384	427	374	391	345	376	343	354	293	297	261	272	208
2013	103	129	158	147	172	187	171	200	231	204	198	196	209	254	227	259	248	217	247	234
2014	61	63	51	56	77	68	72	90	74	56	74	74	81	74	70	87	92	109	95	95

Table 2A.5 (page 3 of 3)—Fishery size composition, by year and cm.

Year	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
1991	642	619	600	515	463	393	311	263	259	212	174	171	115	133	103	72	60	28	42	29
1992	2441	2466	2071	1887	1768	1679	1534	1265	1227	1047	982	879	750	690	635	592	406	314	270	237
1993	1165	1170	1104	1048	955	913	780	728	713	609	548	567	498	423	407	364	298	279	252	213
1994	533	480	480	516	499	564	573	423	391	388	344	395	293	255	276	271	269	178	143	145
1995	741	736	683	646	580	525	629	499	552	620	709	623	496	383	334	330	403	236	263	253
1996	936	903	876	791	761	750	747	524	607	522	564	459	427	428	376	392	409	299	273	267
1997	511	563	509	484	523	492	611	491	480	528	476	465	408	429	394	335	361	287	264	239
1998	1122	1276	1163	1043	1227	1098	1286	1038	910	1028	1066	1076	969	903	924	846	964	726	640	618
1999	775	747	738	655	640	581	569	514	473	413	382	354	362	330	357	328	360	300	287	249
2000	1066	1006	1139	991	1064	1102	1210	1008	1027	906	890	760	769	636	624	566	574	520	468	458
2001	834	722	678	662	653	677	655	611	543	546	525	509	534	481	460	492	527	408	371	384
2002	648	603	574	496	495	412	377	322	328	309	280	257	237	197	182	143	224	165	153	142
2003	669	748	731	710	685	675	699	604	560	556	485	430	406	362	319	282	320	201	213	160
2004	472	439	415	408	366	351	394	347	359	361	329	327	313	321	317	233	269	245	216	178
2005	485	516	466	445	387	421	408	336	311	340	296	261	240	238	202	205	188	182	158	155
2006	478	461	525	468	492	457	442	406	366	362	325	279	249	233	210	190	197	168	170	131
2007	596	559	634	593	662	659	689	640	611	662	585	606	544	550	518	474	418	363	357	315
2008	447	431	449	433	445	485	480	470	484	516	454	518	505	497	503	445	515	470	412	459
2009	346	322	322	279	322	301	304	342	336	318	342	341	309	314	320	323	343	286	318	326
2010	580	480	457	502	427	433	429	388	383	396	354	340	398	392	353	383	436	364	446	458
2011	210	216	213	198	182	179	157	164	152	153	125	116	123	113	97	97	87	80	72	55
2012	186	188	202	156	171	128	165	145	159	118	140	128	131	107	97	102	104	84	99	81
2013	228	227	223	225	202	210	196	164	176	152	153	112	124	126	107	104	103	108	89	86
2014	127	99	111	113	97	127	115	94	111	117	119	96	85	82	75	60	51	51	43	40

Year	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120+
1991	22	16	9	5	2	1	2	0	0	1	1	1	0	0	0	0	0
1992	211	147	128	115	82	59	67	49	26	16	14	5	3	0	6	1	1
1993	172	142	120	70	78	41	40	29	20	14	7	3	4	2	1	0	1
1994	107	81	59	40	34	27	44	18	11	16	5	9	5	4	3	1	1
1995	218	203	113	90	82	66	112	40	47	26	11	25	9	3	0	1	2
1996	239	247	191	166	120	98	123	50	55	18	18	6	4	5	1	0	5
1997	210	196	145	137	120	99	77	51	37	28	22	26	14	4	6	2	9
1998	586	619	419	331	299	250	244	134	99	74	50	48	24	14	4	9	24
1999	260	223	188	144	124	88	86	49	42	33	24	12	2	6	2	5	13
2000	406	384	343	338	244	177	194	126	93	46	27	29	17	8	3	3	14
2001	306	294	254	224	218	167	193	81	86	54	33	42	16	14	12	16	21
2002	140	111	102	81	64	53	46	27	29	12	5	1	4	1	1	1	0
2003	153	108	98	84	73	49	48	25	29	13	6	4	6	0	5	2	2
2004	193	128	117	98	78	72	64	30	29	16	10	4	4	1	5	3	2
2005	136	126	100	92	70	46	46	26	24	17	9	5	6	3	1	4	9
2006	130	115	94	94	79	65	57	34	26	25	15	12	1	2	4	2	6
2007	263	209	196	171	145	113	86	50	36	28	19	11	10	3	3	2	0
2008	357	328	287	231	209	169	156	89	63	35	21	18	15	10	7	5	67
2009	280	273	261	251	222	151	130	95	74	40	30	24	9	3	0	2	2
2010	387	391	343	316	306	257	218	148	117	62	51	47	20	13	4	1	8
2011	72	58	55	42	41	27	24	26	12	10	3	6	4	3	1	2	4
2012	74	73	61	37	48	37	38	25	27	12	15	12	6	6	3	4	8
2013	65	56	45	51	39	27	18	16	4	6	4	0	2	0	0	1	0
2014	37	28	38	24	18	16	12	10	9	3	3	0	0	1	0	0	0

Table 2A.6— Total biomass and abundance (absolute and relative), with coefficients of variation, as estimated by AI shelf bottom trawl surveys, 1991-2014.

	Biomass (t)				Population (1000s)			
Year	Western	Central	Eastern	All	Western	Central	Eastern	All
1991	75,514	39,729	64,926	180,170	18,679	13,138	33,669	65,486
1994	23,797	51,538	78,081	153,416	4,491	12,425	37,284	54,201
1997	14,357	30,252	28,239	72,848	4,000	12,014	8,859	24,873
2000	44,261	36,456	47,117	127,834	13,899	10,661	18,819	43,379
2002	23,623	24,687	25,241	73,551	6,840	6,704	12,579	26,123
2004	9,637	20,731	51,851	82,219	3,220	5,755	13,040	22,016
2006	19,734	21,823	43,348	84,905	6,521	6,243	8,882	21,646
2010	21,341	11,207	23,277	55,826	5,323	5,169	9,577	20,068
2012	13,514	14,804	30,592	58,911	4,100	5,596	9,480	19,176
2014	18,088	8,488	47,032	73,608	5,090	2,705	12,994	20,789

	Biomass proportions				Population proportions			
Year	Western	Central	Eastern	All	Western	Central	Eastern	All
1991	0.419	0.221	0.360	1.000	0.285	0.201	0.514	1.000
1994	0.155	0.336	0.509	1.000	0.083	0.229	0.688	1.000
1997	0.197	0.415	0.388	1.000	0.161	0.483	0.356	1.000
2000	0.346	0.285	0.369	1.000	0.320	0.246	0.434	1.000
2002	0.321	0.336	0.343	1.000	0.262	0.257	0.482	1.000
2004	0.117	0.252	0.631	1.000	0.146	0.261	0.592	1.000
2006	0.232	0.257	0.511	1.000	0.301	0.288	0.410	1.000
2010	0.382	0.201	0.417	1.000	0.265	0.258	0.477	1.000
2012	0.229	0.251	0.519	1.000	0.214	0.292	0.494	1.000
2014	0.246	0.115	0.639	1.000	0.245	0.130	0.625	1.000

	Biomass coefficient of variation				Population coefficient of variation			
Year	Western	Central	Eastern	All	Western	Central	Eastern	All
1991	0.092	0.112	0.370	0.141	0.149	0.128	0.439	0.231
1994	0.292	0.390	0.301	0.206	0.245	0.202	0.444	0.310
1997	0.261	0.208	0.230	0.134	0.249	0.281	0.163	0.153
2000	0.423	0.270	0.222	0.185	0.544	0.305	0.291	0.228
2002	0.245	0.264	0.329	0.164	0.297	0.168	0.277	0.160
2004	0.169	0.207	0.304	0.200	0.166	0.173	0.241	0.152
2006	0.230	0.194	0.545	0.288	0.317	0.165	0.332	0.173
2010	0.409	0.257	0.223	0.189	0.338	0.173	0.216	0.144
2012	0.264	0.203	0.241	0.148	0.136	0.199	0.208	0.122
2014	0.236	0.276	0.275	0.187	0.153	0.216	0.220	0.145

Table 2A.7—Trawl survey size composition, by year and cm.

Year	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	11	1	0	1	3	2	4	9	26	81	114	147	216
1994	0	0	0	0	0	0	0	0	0	62	254	398	595	528	236	211	167	63	12	16	7	4	4	4	3	3	9	18	24
1997	0	0	0	0	0	0	0	0	0	0	0	0	3	12	5	19	35	87	81	111	102	82	42	19	2	12	7	15	27
2000	0	0	0	0	0	0	0	0	0	0	5	38	33	37	51	20	2	6	0	2	1	4	7	4	3	14	10	13	13
2002	0	0	0	0	0	1	0	0	0	0	6	6	12	16	25	9	13	12	13	5	19	9	9	21	22	28	22	37	45
2004	0	0	0	0	0	0	0	0	0	0	5	0	1	3	6	2	14	14	8	8	5	1	1	1	0	0	0	3	1
2006	0	0	0	0	0	0	0	0	0	5	11	13	42	71	69	57	22	21	18	16	23	13	3	2	1	2	0	1	6
2010	0	0	0	0	0	0	0	0	0	0	6	16	12	14	15	23	17	10	3	0	0	3	1	1	2	10	15	26	22
2012	0	0	0	0	0	0	0	0	0	0	1	5	19	24	50	44	50	31	24	8	9	5	1	0	3	2	2	11	7
2014	0	0	0	0	0	0	0	0	0	6	0	7	16	27	18	45	28	24	30	27	14	10	5	11	10	14	12	24	33

Year	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61
1991	249	293	322	299	242	224	150	139	85	92	54	80	52	64	72	73	68	54	76	63	58	68	60	98	94	82	115	116	110
1994	34	40	44	48	43	47	38	30	44	59	46	60	63	90	90	102	83	102	67	68	66	72	62	53	93	78	76	84	93
1997	32	36	51	61	60	60	58	45	32	31	34	34	25	35	47	52	59	82	70	73	79	96	103	106	127	150	125	172	165
2000	15	26	12	32	14	17	4	27	24	21	52	96	134	93	117	110	132	123	154	131	136	125	119	130	125	175	183	165	187
2002	99	92	103	134	142	119	93	85	63	52	62	56	59	62	77	81	87	63	62	76	68	94	69	97	72	74	61	64	41
2004	5	6	17	25	30	24	28	26	40	41	38	32	48	56	60	84	83	97	86	84	91	67	98	81	92	83	66	109	80
2006	1	5	3	8	13	11	20	12	19	14	9	21	27	38	39	44	62	63	69	75	57	61	49	49	56	29	45	37	35
2010	27	23	23	27	16	23	28	25	28	35	44	63	84	92	114	117	126	113	121	138	146	135	118	112	116	93	69	93	81
2012	32	23	18	32	55	38	18	41	29	31	20	26	30	34	31	32	42	44	64	58	49	70	56	66	62	86	90	88	86
2014	43	23	29	47	48	30	26	39	11	21	19	19	23	36	42	71	57	104	84	111	125	125	128	120	127	106	113	93	95

Year	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1991	121	139	86	119	163	157	162	131	136	119	136	117	119	99	89	109	115	81	84	75	63	61	65	46	56	50	22	31	30
1994	95	123	118	124	102	125	114	128	108	118	124	111	133	77	79	86	78	50	71	47	72	62	52	72	46	59	44	54	93
1997	121	148	135	106	85	103	112	80	63	50	59	50	49	58	49	34	27	27	33	31	31	23	25	19	23	24	23	18	22
2000	156	151	154	148	168	115	112	97	84	86	77	86	70	82	88	59	46	49	42	28	27	36	19	27	18	26	22	15	12
2002	39	40	44	33	33	34	31	34	34	33	36	34	42	45	47	42	34	39	49	49	50	55	39	44	38	38	32	15	30
2004	60	89	102	90	89	101	92	83	84	83	88	61	82	68	72	65	62	48	38	55	52	40	35	40	37	38	11	18	21
2006	51	45	35	39	54	29	42	39	44	30	47	47	39	35	41	34	38	42	47	46	46	30	54	32	28	41	37	39	47
2010	65	45	54	56	56	69	78	58	47	43	35	35	31	33	33	24	23	13	9	23	19	19	12	4	16	12	10	15	9
2012	79	104	157	105	97	85	95	80	63	47	56	50	67	59	43	40	39	49	37	36	32	19	20	11	14	13	15	7	10
2014	103	76	99	117	81	84	77	87	113	84	87	86	62	71	74	85	46	59	55	42	46	42	39	44	37	38	39	40	56

Year	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119+
1991	43	30	20	11	14	6	12	4	12	4	1	5	0	3	3	1	6	0	1	0	0	0	0	0	1	0	0	0	0
1994	60	66	48	38	42	50	27	18	27	9	10	8	8	7	5	5	2	0	2	0	0	0	2	2	0	0	0	0	0
1997	31	26	9	25	8	20	13	16	20	9	10	22	7	3	10	8	1	3	3	2	0	0	0	0	0	0	0	0	0
2000	17	13	6	12	10	8	6	10	8	5	2	4	5	3	4	6	1	11	2	1	2	0	0	0	1	0	0	0	0
2002	29	10	21	16	12	9	7	8	4	5	3	6	13	1	6	2	2	2	0	1	0	3	0	0	1	0	0	0	0
2004	15	21	17	14	15	11	8	9	15	7	2	8	8	5	6	3	2	3	1	0	1	0	0	0	0	0	0	0	0
2006	28	17	17	13	28	19	15	10	14	13	5	9	4	15	3	3	6	8	3	0	1	3	2	1	0	1	0	0	0
2010	11	9	8	10	6	7	9	5	7	10	15	5	6	3	8	3	6	6	4	3	5	1	1	0	1	0	0	0	0
2012	8	7	9	5	16	9	5	4	5	6	6	5	4	7	1	1	1	1	1	0	1	0	0	0	0	1	0	0	0
2014	32	29	37	22	32	29	27	22	14	10	4	12	5	10	4	5	2	3	2	1	0	2	0	0	0	0	0	0	0

Table 2A.8a—Selected constants used in the SS control files for Models 2 and 3.

Parameter	Model 2	Model 3
Natural mortality rate	3.40E-01	3.40E-01
Weight-length α (proportionality)	5.68E-06	5.68E-06
Weight-length β (exponent)	3.18E+00	3.18E+00
Age at 50% maturity	4.88E+00	4.88E+00
Maturity slope	-9.65E-01	-9.65E-01
Std. dev. of ageing error at age 1	9.30E-02	9.30E-02
Std. dev. of ageing error at age 12	1.86E+00	1.86E+00
Stock-recruitment "steepness"	1.00E+00	1.00E+00

Table 2A.8b—Growth, ageing bias, recruitment (except annual *dev*s), catchability, initial fishing mortality, and initial age composition parameters, as estimated internally by Models 2 and 3.

	Model 2		Model 3	
Parameter	Estimate	St. dev.	Estimate	St. dev.
Length at age 1 (cm)	1.80E+01	1.93E-01	1.80E+01	1.92E-01
Asymptotic length (cm)	1.10E+02	1.91E+00	1.07E+02	1.28E+00
Brody growth coefficient	2.17E-01	6.94E-03	2.26E-01	5.52E-03
SD of length at age 1 (cm)	3.16E+00	1.37E-01	3.16E+00	1.37E-01
SD of length at age 20 (cm)	8.11E+00	4.03E-01	8.02E+00	3.76E-01
Ageing bias at age 1 (years)	4.81E-01	3.14E-02	4.83E-01	3.04E-02
Ageing bias at age 20 (years)	1.14E+00	4.41E-01	9.46E-01	4.68E-01
ln(mean recruitment)	1.10E+01	8.13E-02	1.10E+01	7.57E-02
σ(recruitment)	4.94E-01	6.73E-02	5.47E-01	7.09E-02
Initial fishing mortality rate	4.24E-02	1.06E-02	4.74E-02	1.15E-02
ln(catchability)	-4.35E-01	8.67E-02	-5.69E-01	7.79E-02
Initial age 1 ln(abundance) dev	2.83E-01	1.74E-01	4.82E-01	1.72E-01
Initial age 2 ln(abundance) dev	-7.35E-01	3.91E-01	-6.76E-01	4.35E-01
Initial age 3 ln(abundance) dev	1.03E+00	1.48E-01	1.12E+00	1.50E-01
Initial age 4 ln(abundance) dev	-1.74E-01	1.84E-01	-1.32E-01	1.91E-01
Initial age 5 ln(abundance) dev	4.90E-01	1.69E-01	7.66E-01	1.76E-01
Initial age 6 ln(abundance) dev	1.13E+00	1.98E-01	1.09E+00	2.37E-01
Initial age 7 ln(abundance) dev	8.69E-01	3.27E-01	1.24E+00	2.71E-01
Initial age 8 ln(abundance) dev	7.77E-03	4.36E-01	2.93E-02	5.28E-01
Initial age 9 ln(abundance) dev	-4.99E-01	4.05E-01	-3.41E-01	4.64E-01
Initial age 10 ln(abundance) dev	-6.91E-01	3.93E-01	-5.64E-01	4.43E-01

Table 2A.8c—Annual log-scale recruitment *dev*s estimated by Models 2 and 3. Color scale extends from red (low) to green (high) in each **column**.

	Model 2		Model 3	
Year	Estimate	St. dev.	Estimate	St. dev.
1991	2.51E-01	1.40E-01	2.73E-01	1.40E-01
1992	-2.51E-01	2.21E-01	-3.18E-01	2.48E-01
1993	7.78E-01	1.24E-01	1.02E+00	1.18E-01
1994	-1.32E-01	1.51E-01	-1.44E-01	1.65E-01
1995	4.26E-01	1.58E-01	6.06E-01	1.72E-01
1996	8.85E-01	1.19E-01	1.07E+00	1.16E-01
1997	6.45E-01	1.12E-01	6.74E-01	1.16E-01
1998	6.20E-02	1.81E-01	1.02E-01	1.85E-01
1999	7.93E-01	1.17E-01	7.86E-01	1.20E-01
2000	6.62E-02	1.52E-01	-9.24E-02	1.37E-01
2001	-1.24E-01	1.29E-01	-1.28E-01	1.29E-01
2002	-5.25E-01	1.53E-01	-5.04E-01	1.61E-01
2003	-2.04E-01	1.33E-01	-2.12E-01	1.35E-01
2004	-5.33E-01	1.76E-01	-6.15E-01	1.80E-01
2005	-1.57E-01	1.51E-01	-1.69E-01	1.61E-01
2006	-1.87E-01	1.28E-01	-1.20E-01	1.27E-01
2007	2.45E-01	1.08E-01	1.27E-01	1.03E-01
2008	-1.22E-01	1.36E-01	1.01E-02	1.33E-01
2009	-7.19E-01	1.85E-01	-8.68E-01	1.88E-01
2010	-1.60E-01	1.74E-01	-2.87E-02	1.77E-01
2011	-4.91E-01	1.94E-01	-5.68E-01	1.89E-01
2012	-3.32E-01	3.51E-01	-4.79E-01	3.70E-01
2013	-2.13E-01	3.68E-01	-4.27E-01	3.77E-01

Table 2A.8d—Base selectivity parameters as estimated by Models 2 and 3.

		Model 2		Model 3	
Fleet	Age	Estimate	St. dev.	Estimate	St. dev.
Fishery	1	3.29E+00	3.42E-01	3.29E+00	3.42E-01
Fishery	2	3.41E+00	3.18E-01	3.41E+00	3.19E-01
Fishery	3	3.22E+00	1.86E-01	3.22E+00	1.87E-01
Fishery	4	1.23E+00	1.80E-01	1.22E+00	1.80E-01
Fishery	5	3.34E-01	1.13E-01	2.78E-01	1.20E-01
Fishery	6	1.49E-01	2.84E-01	1.64E-01	2.84E-01
Fishery	7	-1.01E-01	1.97E-01	-9.93E-02	1.94E-01
Fishery	8	6.94E-02	2.53E-01	-9.21E-03	2.48E-01
Fishery	9	1.71E-01	2.70E-01	8.16E-02	2.70E-01
Fishery	10	2.72E-01	2.90E-01	3.50E-01	2.85E-01
Fishery	11	4.68E-02	3.28E-01	2.15E-01	2.91E-01
Fishery	12	-3.03E-01	3.52E-01	-4.79E-02	3.18E-01
Fishery	13	-4.78E-01	3.18E-01	-2.58E-01	3.16E-01
Fishery	14	-3.56E-01	3.18E-01	-1.86E-01	3.23E-01
Fishery	15	-2.49E-01	3.23E-01	-1.43E-01	3.28E-01
Fishery	16	-2.09E-01	3.24E-01	-1.52E-01	3.27E-01
Fishery	17	-1.60E-01	3.27E-01	-1.37E-01	3.27E-01
Fishery	18	-1.19E-01	3.29E-01	-1.06E-01	3.29E-01
Fishery	19	-8.45E-02	3.32E-01	-7.21E-02	3.32E-01
Fishery	20	-6.52E-02	3.34E-01	-5.70E-02	3.34E-01
Survey	1	5.29E+00	3.19E-01	5.29E+00	7.80E-02
Survey	2	9.46E-01	2.67E-01	8.58E-01	7.71E-02
Survey	3	6.55E-01	2.10E-01	1.01E-01	7.50E-02
Survey	4	4.47E-01	1.06E-01	1.43E-01	6.12E-02
Survey	5	-4.33E-01	1.26E-01	-1.40E-01	6.10E-02
Survey	6	-2.68E-01	2.18E-01	-6.60E-02	7.15E-02
Survey	7	1.23E-02	3.11E-01	-1.75E-03	7.79E-02
Survey	8	-3.14E-01	2.36E-01	-8.03E-03	7.68E-02
Survey	9	-3.03E-01	2.69E-01	-2.38E-02	7.64E-02
Survey	10	-1.79E-01	2.89E-01	-2.98E-02	7.64E-02
Survey	11	-1.92E-01	2.98E-01	-2.82E-02	7.68E-02
Survey	12	-2.00E-01	3.03E-01	-2.45E-02	7.71E-02
Survey	13	-1.65E-01	3.04E-01	-2.13E-02	7.73E-02
Survey	14	-1.26E-01	3.07E-01	-1.65E-02	7.75E-02
Survey	15	-1.03E-01	3.09E-01	-1.30E-02	7.76E-02
Survey	16	-7.81E-02	3.10E-01	-9.66E-03	7.77E-02
Survey	17	-5.32E-02	3.13E-01	-7.09E-03	7.78E-02
Survey	18	-3.69E-02	3.14E-01	-4.86E-03	7.78E-02
Survey	19	-2.59E-02	3.16E-01	-3.54E-03	7.79E-02
Survey	20	-1.86E-02	3.16E-01	-2.51E-03	7.79E-02

Table 2A.8e—Fishery selectivity *dev*s as estimated by Models 2 and 3.

			Model 2		Model 3			Model 2		Model 3	
Fleet	Year	Age	Estimate	St. dev.	Estimate	St. dev.	Age	Estimate	St. dev.	Estimate	St. dev.
Fishery	1991	4	-4.21E-04	5.37E-02	-5.83E-03	5.54E-02	6	5.37E-02	4.05E-02	5.96E-02	4.08E-02
Fishery	1992	4	7.77E-02	3.19E-02	7.05E-02	3.19E-02	6	-4.16E-02	3.50E-02	-3.54E-02	3.48E-02
Fishery	1993	4	-7.31E-02	3.59E-02	-6.76E-02	3.66E-02	6	3.43E-02	3.81E-02	3.60E-02	3.85E-02
Fishery	1994	4	-9.90E-03	3.90E-02	-1.44E-02	3.95E-02	6	-2.47E-02	3.77E-02	-1.89E-02	3.78E-02
Fishery	1995	4	-8.12E-03	4.65E-02	-1.76E-02	4.68E-02	6	1.64E-02	3.87E-02	1.91E-02	3.87E-02
Fishery	1996	4	7.04E-02	3.51E-02	9.45E-02	3.55E-02	6	-6.62E-02	3.69E-02	-7.67E-02	3.75E-02
Fishery	1997	4	-2.94E-02	4.99E-02	-3.84E-02	5.15E-02	6	5.94E-02	3.91E-02	6.91E-02	3.92E-02
Fishery	1998	4	-1.50E-02	2.93E-02	-1.14E-02	3.01E-02	6	1.16E-03	3.33E-02	5.64E-03	3.32E-02
Fishery	1999	4	3.30E-02	3.11E-02	3.36E-02	3.21E-02	6	1.98E-02	3.52E-02	2.67E-02	3.60E-02
Fishery	2000	4	-1.35E-02	2.75E-02	-2.70E-02	2.76E-02	6	8.15E-02	3.40E-02	8.64E-02	3.42E-02
Fishery	2001	4	-6.62E-02	2.89E-02	-7.42E-02	2.95E-02	6	1.15E-02	3.28E-02	6.25E-03	3.27E-02
Fishery	2002	4	6.27E-03	3.61E-02	-2.13E-03	3.66E-02	6	6.81E-02	3.81E-02	6.22E-02	3.89E-02
Fishery	2003	4	-1.17E-01	3.67E-02	-1.28E-01	3.65E-02	6	1.20E-01	3.76E-02	1.08E-01	3.78E-02
Fishery	2004	4	-1.02E-01	3.10E-02	-9.50E-02	3.10E-02	6	2.94E-02	3.55E-02	1.27E-02	3.53E-02
Fishery	2005	4	-1.93E-02	4.07E-02	-6.04E-03	4.14E-02	6	-5.30E-03	3.63E-02	-1.34E-02	3.67E-02
Fishery	2006	4	2.74E-02	3.72E-02	3.24E-02	3.74E-02	6	-5.30E-02	3.57E-02	-5.31E-02	3.58E-02
Fishery	2007	4	3.37E-02	4.02E-02	2.96E-02	4.06E-02	6	-7.79E-03	3.53E-02	-5.31E-03	3.53E-02
Fishery	2008	4	-1.75E-02	3.32E-02	-1.27E-02	3.37E-02	6	1.79E-02	3.54E-02	1.81E-02	3.53E-02
Fishery	2009	4	3.42E-02	3.53E-02	4.45E-02	3.58E-02	6	1.60E-02	3.62E-02	1.99E-02	3.66E-02
Fishery	2010	4	-1.43E-02	2.82E-02	-2.43E-02	2.82E-02	6	5.92E-02	3.63E-02	7.29E-02	3.64E-02
Fishery	2011	4	2.03E-02	5.16E-02	3.29E-02	5.07E-02	6	8.84E-02	4.01E-02	9.28E-02	4.04E-02
Fishery	2012	4	7.67E-02	5.70E-02	7.09E-02	5.86E-02	6	4.31E-02	3.91E-02	6.10E-02	3.97E-02
Fishery	2013	4	9.38E-03	5.29E-02	1.48E-02	5.26E-02	6	8.77E-02	4.56E-02	1.06E-01	4.66E-02
Fishery	2014	4	-7.95E-03	6.73E-02	-1.62E-02	6.94E-02	6	8.47E-02	5.12E-02	1.04E-01	5.19E-02

Table 2A.8f—Survey selectivity *dev*s as estimated by Models 2 and 3.

			Model 2		Model 3	
Fleet	Year	Age	Estimate	St. dev.	Estimate	St. dev.
Survey	1991	2	3.43E-01	8.46E-02	3.61E-01	8.13E-02
Survey	1994	2	-1.31E-01	4.25E-02	-8.79E-02	3.58E-02
Survey	1997	2	-2.65E-03	4.09E-02	1.06E-02	3.30E-02
Survey	2000	2	2.99E-02	5.05E-02	4.11E-02	4.40E-02
Survey	2002	2	1.37E-01	5.00E-02	1.77E-01	4.15E-02
Survey	2004	2	8.26E-02	6.35E-02	9.58E-02	5.87E-02
Survey	2006	2	-1.37E-01	5.22E-02	-1.11E-01	4.56E-02
Survey	2010	2	1.17E-02	5.24E-02	-4.94E-03	4.59E-02
Survey	2012	2	-1.04E-01	4.54E-02	-1.11E-01	3.72E-02
Survey	2014	2	n/a	n/a	n/a	n/a
Survey	1991	3	-5.39E-02	2.71E-02	6.40E-03	2.07E-02
Survey	1994	3	3.07E-03	3.55E-02	4.83E-02	3.32E-02
Survey	1997	3	4.87E-02	3.03E-02	1.23E-01	2.60E-02
Survey	2000	3	9.76E-02	3.66E-02	1.52E-01	3.31E-02
Survey	2002	3	-1.22E-01	2.98E-02	-9.23E-02	1.92E-02
Survey	2004	3	7.15E-02	3.74E-02	1.35E-01	3.35E-02
Survey	2006	3	1.08E-01	4.23E-02	1.55E-01	3.88E-02
Survey	2010	3	7.94E-02	3.02E-02	1.61E-01	2.40E-02
Survey	2012	3	8.85E-02	3.33E-02	1.65E-01	2.82E-02
Survey	2014	3	6.73E-02	4.15E-02	1.17E-01	4.06E-02
Survey	1991	7	4.85E-02	5.40E-02	-4.99E-02	4.36E-02
Survey	1994	7	7.39E-02	4.34E-02	8.09E-04	2.46E-02
Survey	1997	7	-7.70E-03	4.72E-02	-8.91E-02	2.97E-02
Survey	2000	7	-5.34E-03	4.94E-02	-8.56E-02	3.50E-02
Survey	2002	7	1.37E-01	4.08E-02	1.22E-02	3.54E-02
Survey	2004	7	-2.13E-02	4.81E-02	-1.10E-01	3.34E-02
Survey	2006	7	3.76E-02	4.48E-02	-2.86E-02	2.69E-02
Survey	2010	7	-2.36E-02	4.85E-02	-9.54E-02	3.22E-02
Survey	2012	7	-5.98E-02	5.34E-02	-1.26E-01	4.10E-02
Survey	2014	7	5.78E-02	4.64E-02	9.52E-03	3.00E-02

Table 2A.9— Annual fishing mortality rates as estimated by Models 2 and 3. "F averaged over 8-18" represents an average rate across the specified age range; "Apical F" represents the fishing mortality rate at the length of peak selectivity. Color scale extends from red (low) to green (high) in each **column**.

	Model 2				Model 3			
	F averaged over 8-18		Apical F		F averaged over 8-18		Apical F	
Year	Estimate	St. dev.	Estimate	St. dev.	Estimate	St. dev.	Estimate	St. dev.
1991	3.781E-02	6.937E-03	5.620E-02	1.541E-02	3.744E-02	6.964E-03	5.436E-02	1.600E-02
1992	1.214E-01	2.050E-02	1.907E-01	5.417E-02	1.216E-01	2.156E-02	1.900E-01	5.715E-02
1993	1.149E-01	2.112E-02	1.815E-01	5.338E-02	1.038E-01	1.794E-02	1.797E-01	5.646E-02
1994	6.267E-02	1.160E-02	9.476E-02	3.013E-02	5.794E-02	1.028E-02	9.884E-02	3.207E-02
1995	5.820E-02	9.693E-03	7.996E-02	2.342E-02	5.304E-02	8.234E-03	8.241E-02	2.396E-02
1996	1.073E-01	1.851E-02	1.432E-01	2.913E-02	9.941E-02	1.632E-02	1.457E-01	3.034E-02
1997	1.061E-01	1.670E-02	1.482E-01	3.817E-02	1.008E-01	1.463E-02	1.484E-01	3.965E-02
1998	1.395E-01	2.260E-02	1.992E-01	5.594E-02	1.315E-01	1.931E-02	1.995E-01	5.693E-02
1999	1.251E-01	2.001E-02	1.750E-01	4.821E-02	1.168E-01	1.699E-02	1.715E-01	4.848E-02
2000	2.132E-01	3.647E-02	2.967E-01	7.450E-02	2.041E-01	3.279E-02	2.850E-01	7.512E-02
2001	1.356E-01	2.258E-02	2.046E-01	5.577E-02	1.223E-01	1.821E-02	1.920E-01	5.536E-02
2002	1.434E-01	2.427E-02	2.135E-01	5.862E-02	1.297E-01	1.935E-02	2.039E-01	5.848E-02
2003	1.598E-01	2.690E-02	2.345E-01	6.310E-02	1.469E-01	2.190E-02	2.290E-01	6.395E-02
2004	1.238E-01	2.028E-02	1.842E-01	4.968E-02	1.140E-01	1.581E-02	1.852E-01	4.975E-02
2005	9.600E-02	1.357E-02	1.386E-01	3.912E-02	9.436E-02	1.118E-02	1.506E-01	4.060E-02
2006	1.094E-01	1.538E-02	1.484E-01	4.017E-02	1.125E-01	1.361E-02	1.663E-01	4.145E-02
2007	1.906E-01	2.369E-02	2.683E-01	7.009E-02	2.016E-01	2.103E-02	3.038E-01	7.200E-02
2008	2.224E-01	3.035E-02	3.095E-01	8.450E-02	2.420E-01	2.839E-02	3.587E-01	9.023E-02
2009	2.447E-01	3.854E-02	3.338E-01	9.320E-02	2.774E-01	3.803E-02	3.975E-01	1.037E-01
2010	3.164E-01	5.978E-02	4.391E-01	1.188E-01	3.826E-01	6.492E-02	5.417E-01	1.425E-01
2011	1.223E-01	2.516E-02	1.820E-01	5.336E-02	1.488E-01	2.851E-02	2.230E-01	6.608E-02
2012	1.701E-01	3.651E-02	2.586E-01	7.863E-02	2.129E-01	4.218E-02	3.276E-01	9.737E-02
2013	1.296E-01	2.617E-02	1.984E-01	6.026E-02	1.577E-01	3.060E-02	2.547E-01	7.503E-02
2014	1.122E-01	2.222E-02	1.682E-01	5.087E-02	1.262E-01	2.389E-02	2.086E-01	6.048E-02

Table 2A.10—Summary of key management reference points. Values for Models 2 and 3 come from the standard projection algorithm (except the last seven rows, which come from SS). All biomass figures are in t. Color scale extends from red (low) to green (high) in each **row**.

Quantity	Model 1	Model 2	Model 3
B100%	n/a	127,000	121,000
B40%	n/a	50,800	48,400
B35%	n/a	44,500	42,400
B(2015)	68,900	52,800	46,600
B(2016)	68,900	45,700	40,900
B(2015)/B100%	n/a	0.42	0.38
B(2016)/B100%	n/a	0.36	0.34
F40%	n/a	0.54	0.63
F35%	n/a	0.66	0.79
maxFABC(2015)	0.26	0.54	0.61
maxFABC(2016)	0.26	0.48	0.53
maxABC(2015)	17,600	33,400	29,300
maxABC(2016)	17,600	26,300	23,500
FOFL(2015)	0.34	0.66	0.76
FOFL(2016)	0.34	0.59	0.66
OFL(2015)	23,400	40,000	34,900
OFL(2016)	23,400	32,600	29,200
Pr(maxABC(2015)>truOFL(2015))	n/a	0.13	0.12
Pr(maxABC(2016)>truOFL(2016))	n/a	0.38	0.38
Pr(B(2015)<B20%)	n/a	0.00	0.00
Pr(B(2016)<B20%)	n/a	0.00	0.00
Pr(B(2017)<B20%)	n/a	0.00	0.00
Pr(B(2018)<B20%)	n/a	0.00	0.00
Pr(B(2019)<B20%)	n/a	0.00	0.00

Legend:
B100% = equilibrium unfished spawning biomass
B40% = 40% of B100% (the inflection point of the harvest control rules in Tier 3)
B35% = 35% of B100% (the BMSY proxy for Tier 3)
B(year) = projected survey biomass (Model 1) or spawning biomass (Models 2 and 3) for year
B(year)/B100% = ratio of spawning biomass to B100%
F40% = fishing mortality that reduces equilibrium spawning per recruit to 40% of unfished
F35% = fishing mortality that reduces equilibrium spawning per recruit to 35% of unfished
maxFABC(year) = maximum permissible ABC fishing mortality rate under Tier 3
maxABC(year) = maximum permissible ABC under Tier 3
FOFL(year) = OFL fishing mortality rate under Tier 3
OFL(year) = OFL under Tier 3
Pr(maxABC(year)>truOFL(year)) = probability that maxABC is greater than the "true" OFL
Pr(B(year)<B20%) = probability that spawning biomass is less than 20% of unfished

Table 2A.11a—Fishery selectivity as estimated by Model 2.

	Age																				
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1991	0.000	0.000	0.003	0.067	0.228	0.319	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
1992	0.000	0.000	0.003	0.081	0.592	0.827	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
1993	0.000	0.000	0.007	0.167	0.277	0.387	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
1994	0.000	0.000	0.006	0.160	0.500	0.698	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
1995	0.000	0.000	0.004	0.105	0.331	0.463	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
1996	0.000	0.000	0.004	0.105	0.716	1.000	0.599	0.542	0.581	0.689	0.903	0.947	0.699	0.434	0.304	0.237	0.192	0.164	0.145	0.134	0.125
1997	0.000	0.000	0.003	0.084	0.216	0.302	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
1998	0.000	0.000	0.005	0.130	0.386	0.539	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
1999	0.000	0.000	0.003	0.067	0.320	0.447	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2000	0.000	0.000	0.002	0.058	0.173	0.242	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2001	0.000	0.000	0.008	0.195	0.348	0.486	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2002	0.000	0.000	0.002	0.054	0.198	0.276	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2003	0.000	0.000	0.004	0.110	0.118	0.165	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2004	0.000	0.000	0.009	0.233	0.291	0.407	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2005	0.000	0.000	0.006	0.145	0.412	0.575	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2006	0.000	0.000	0.006	0.148	0.663	0.926	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2007	0.000	0.000	0.004	0.088	0.422	0.589	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2008	0.000	0.000	0.004	0.113	0.326	0.456	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2009	0.000	0.000	0.003	0.069	0.333	0.465	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2010	0.000	0.000	0.003	0.073	0.216	0.302	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2011	0.000	0.000	0.002	0.039	0.162	0.226	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2012	0.000	0.000	0.001	0.035	0.254	0.355	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2013	0.000	0.000	0.002	0.043	0.163	0.228	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2014	0.000	0.000	0.002	0.053	0.168	0.235	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132

Table 2A.11b—Fishery selectivity as estimated by Model 3.

	Age																				
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1991	0.000	0.000	0.003	0.065	0.207	0.274	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
1992	0.000	0.000	0.003	0.080	0.535	0.707	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
1993	0.000	0.000	0.006	0.152	0.262	0.346	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
1994	0.000	0.000	0.006	0.155	0.454	0.599	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
1995	0.000	0.000	0.004	0.109	0.310	0.410	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
1996	0.000	0.000	0.004	0.090	0.757	1.000	0.547	0.495	0.491	0.533	0.756	0.937	0.893	0.690	0.573	0.496	0.426	0.372	0.334	0.311	0.294
1997	0.000	0.000	0.003	0.082	0.189	0.249	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
1998	0.000	0.000	0.005	0.118	0.355	0.469	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
1999	0.000	0.000	0.002	0.061	0.288	0.380	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2000	0.000	0.000	0.002	0.062	0.159	0.210	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2001	0.000	0.000	0.009	0.218	0.353	0.466	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2002	0.000	0.000	0.002	0.061	0.202	0.267	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2003	0.000	0.000	0.005	0.136	0.128	0.169	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2004	0.000	0.000	0.010	0.252	0.331	0.437	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2005	0.000	0.000	0.005	0.135	0.430	0.567	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2006	0.000	0.000	0.005	0.138	0.639	0.843	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2007	0.000	0.000	0.004	0.088	0.396	0.523	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2008	0.000	0.000	0.004	0.105	0.313	0.414	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2009	0.000	0.000	0.002	0.059	0.308	0.406	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2010	0.000	0.000	0.003	0.068	0.182	0.240	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2011	0.000	0.000	0.001	0.032	0.149	0.197	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2012	0.000	0.000	0.001	0.030	0.204	0.270	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2013	0.000	0.000	0.001	0.034	0.131	0.173	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2014	0.000	0.000	0.002	0.047	0.134	0.177	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314

Table 2A.12—Survey selectivity as estimated by Models 2 and 3.

Model 2

	Age																				
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1991	0.000	0.009	0.569	0.639	1.000	0.649	0.496	0.816	0.596	0.440	0.368	0.304	0.249	0.211	0.186	0.168	0.155	0.147	0.142	0.138	0.136
1994	0.000	0.440	0.306	0.608	0.951	0.617	0.472	1.000	0.731	0.540	0.451	0.372	0.305	0.259	0.228	0.206	0.190	0.180	0.174	0.170	0.166
1997	0.000	0.082	0.205	0.639	1.000	0.649	0.496	0.465	0.340	0.251	0.210	0.173	0.142	0.120	0.106	0.096	0.089	0.084	0.081	0.079	0.077
2000	0.000	0.037	0.127	0.639	1.000	0.649	0.496	0.476	0.348	0.257	0.215	0.177	0.145	0.123	0.109	0.098	0.091	0.086	0.083	0.081	0.079
2002	0.000	0.059	0.577	0.328	0.513	0.333	0.254	1.000	0.731	0.540	0.451	0.372	0.305	0.259	0.228	0.206	0.190	0.180	0.174	0.170	0.166
2004	0.000	0.028	0.164	0.639	1.000	0.649	0.496	0.406	0.297	0.219	0.183	0.151	0.124	0.105	0.093	0.084	0.077	0.073	0.071	0.069	0.068
2006	0.000	0.175	0.115	0.639	1.000	0.649	0.496	0.732	0.535	0.395	0.330	0.272	0.223	0.189	0.167	0.151	0.139	0.132	0.127	0.124	0.122
2010	0.000	0.052	0.151	0.639	1.000	0.649	0.496	0.397	0.290	0.214	0.179	0.148	0.121	0.103	0.091	0.082	0.076	0.072	0.069	0.067	0.066
2012	0.000	0.152	0.139	0.639	1.000	0.649	0.496	0.276	0.202	0.149	0.125	0.103	0.084	0.071	0.063	0.057	0.053	0.050	0.048	0.047	0.046
2014	0.000	0.066	0.171	0.639	1.000	0.649	0.496	0.895	0.654	0.483	0.404	0.333	0.273	0.231	0.204	0.184	0.170	0.162	0.156	0.152	0.149

Model 3

	Age																				
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1991	0.000	0.011	0.735	0.866	1.000	0.870	0.814	0.494	0.490	0.478	0.464	0.451	0.440	0.431	0.424	0.419	0.415	0.412	0.410	0.408	0.407
1994	0.000	0.492	0.483	0.866	1.000	0.870	0.814	0.819	0.813	0.794	0.770	0.749	0.731	0.715	0.704	0.695	0.688	0.683	0.680	0.677	0.676
1997	0.000	0.088	0.230	0.866	1.000	0.870	0.814	0.334	0.332	0.324	0.314	0.306	0.298	0.292	0.287	0.283	0.281	0.279	0.277	0.276	0.276
2000	0.000	0.049	0.174	0.866	1.000	0.870	0.814	0.346	0.343	0.335	0.325	0.316	0.309	0.302	0.297	0.293	0.291	0.289	0.287	0.286	0.285
2002	0.000	0.077	1.000	0.440	0.508	0.442	0.414	0.466	0.463	0.452	0.439	0.426	0.416	0.407	0.401	0.395	0.392	0.389	0.387	0.386	0.385
2004	0.000	0.034	0.206	0.866	1.000	0.870	0.814	0.272	0.270	0.263	0.256	0.249	0.242	0.237	0.233	0.230	0.228	0.227	0.226	0.225	0.224
2006	0.000	0.217	0.169	0.866	1.000	0.870	0.814	0.611	0.606	0.592	0.574	0.558	0.545	0.533	0.525	0.518	0.513	0.509	0.507	0.505	0.504
2010	0.000	0.071	0.159	0.866	1.000	0.870	0.814	0.314	0.311	0.304	0.295	0.287	0.280	0.274	0.270	0.266	0.264	0.262	0.260	0.260	0.259
2012	0.000	0.196	0.153	0.866	1.000	0.870	0.814	0.232	0.230	0.224	0.218	0.212	0.207	0.202	0.199	0.196	0.195	0.193	0.192	0.192	0.191
2014	0.000	0.104	0.245	0.866	1.000	0.870	0.814	0.894	0.887	0.866	0.840	0.817	0.797	0.780	0.768	0.758	0.751	0.745	0.742	0.739	0.737

Table 2A.13—Schedules of population length (cm) and weight (kg) by age as estimated by Models 2 and 3. Lengths and weights correspond to mid-point of the year.

	Population				Fishery				Survey			
	Length		Weight		Length		Weight		Length		Weight	
Age	Model 2	Model 3	Model 2	Model 3	Model 2	Model 3	Model 2	Model 3	Model 2	Model 3	Model 2	Model 3
0	6.34	6.34	0.00	0.00	6.40	6.39	0.00	0.00	6.40	6.39	0.00	0.00
1	18.02	18.01	0.06	0.06	18.02	18.01	0.06	0.06	18.02	18.01	0.06	0.06
2	35.97	36.09	0.53	0.53	35.97	36.09	0.53	0.53	35.97	36.09	0.53	0.53
3	50.42	50.52	1.52	1.53	50.42	50.52	1.52	1.53	50.42	50.52	1.52	1.53
4	62.06	62.02	2.93	2.93	62.06	62.02	2.93	2.93	62.06	62.02	2.93	2.93
5	71.43	71.20	4.58	4.53	71.43	71.20	4.58	4.53	71.43	71.20	4.58	4.53
6	78.97	78.53	6.29	6.18	78.97	78.53	6.29	6.18	78.97	78.53	6.29	6.18
7	85.04	84.37	7.95	7.75	85.04	84.37	7.95	7.75	85.04	84.37	7.95	7.75
8	89.92	89.02	9.48	9.19	89.92	89.02	9.48	9.19	89.92	89.02	9.48	9.19
9	93.85	92.74	10.86	10.46	93.85	92.74	10.86	10.46	93.85	92.74	10.86	10.46
10	97.02	95.71	12.06	11.56	97.02	95.71	12.06	11.56	97.02	95.71	12.06	11.56
11	99.57	98.07	13.10	12.49	99.57	98.07	13.10	12.49	99.57	98.07	13.10	12.49
12	101.62	99.96	13.97	13.26	101.62	99.96	13.97	13.26	101.62	99.96	13.97	13.26
13	103.27	101.46	14.70	13.91	103.27	101.46	14.70	13.91	103.27	101.46	14.70	13.91
14	104.60	102.66	15.31	14.43	104.60	102.66	15.31	14.43	104.60	102.66	15.31	14.43
15	105.67	103.62	15.81	14.87	105.67	103.62	15.81	14.87	105.67	103.62	15.81	14.87
16	106.53	104.38	16.23	15.22	106.53	104.38	16.23	15.22	106.53	104.38	16.23	15.22
17	107.23	104.99	16.56	15.50	107.23	104.99	16.56	15.50	107.23	104.99	16.56	15.50
18	107.79	105.48	16.84	15.73	107.79	105.48	16.84	15.73	107.79	105.48	16.84	15.73
19	108.24	105.87	17.06	15.91	108.24	105.87	17.06	15.91	108.24	105.87	17.06	15.91
20	108.91	106.43	17.41	16.19	108.91	106.43	17.41	16.19	108.91	106.43	17.41	16.19

Table 2A.14a—Time series of age 0+ biomass, age 3+ biomass, female spawning biomass (t), and standard deviation of spawning biomass ("SB SD") as estimated by Models 2 and 3. Spawning biomass for 2015 represents output from the standard projection model.

	Model 2				Model 3			
Year	Age 0+	Age 3+	Spawn.	SB SD	Age 0+	Age 3+	Spawn.	SB SD
1991	410,220	391,878	132,484	16,598	437,490	418,181	140,115	17,078
1992	436,601	427,408	148,960	18,414	465,346	454,854	158,363	18,890
1993	420,158	411,589	146,101	18,928	448,803	440,501	156,045	19,338
1994	401,801	395,323	143,200	18,787	427,931	421,643	153,071	18,964
1995	389,415	375,267	143,175	18,249	412,706	395,717	152,402	18,117
1996	383,077	376,461	140,819	17,310	405,967	399,511	148,945	16,928
1997	361,938	350,604	130,739	16,160	385,137	372,210	137,938	15,631
1998	355,401	338,950	124,136	15,135	380,786	362,107	131,384	14,573
1999	352,256	339,628	116,927	14,365	380,902	368,513	124,999	13,843
2000	360,366	352,091	115,887	13,945	389,621	381,511	125,116	13,449
2001	355,770	341,284	114,326	13,849	381,739	368,134	124,470	13,289
2002	355,006	347,718	117,517	13,794	373,818	367,806	127,271	13,000
2003	348,363	342,437	118,801	13,410	357,565	351,935	126,307	12,243
2004	328,325	324,038	116,904	12,647	328,407	324,259	120,810	11,082
2005	301,279	295,778	113,341	11,629	294,329	289,163	113,274	9,767
2006	274,518	270,227	106,675	10,519	262,630	258,824	103,353	8,498
2007	244,891	238,956	95,467	9,479	229,701	224,071	90,132	7,418
2008	210,002	203,888	78,785	8,643	193,055	187,001	72,403	6,621
2009	187,201	178,617	65,395	8,085	169,302	161,884	58,529	6,142
2010	176,102	170,245	56,588	7,851	157,236	150,968	49,493	5,998
2011	167,437	163,768	51,289	7,975	148,450	145,271	44,027	6,195
2012	174,123	168,377	55,885	8,364	155,532	149,391	48,402	6,615
2013	170,629	166,288	57,280	8,706	153,114	149,322	49,705	6,993
2014	169,493	164,424	58,215	8,808	152,324	148,191	50,938	7,197
2015	169,768	163,894	52,817	8,764	151,184	146,489	46,601	7,303

Table 2A.14b—Time series of survey biomass (t) and 95% confidence intervals as estimated last year and this year under Model 1. Values for projection years (not shown) are equal to the last year in the series.

	Last year's assessment			This year's assessment		
Year	Mean	U95%CI	L95%CI	Mean	U95%CI	L95%CI
1991	172,531	225,071	132,255	171,637	223,879	131,586
1992	159,866	232,627	109,863	158,994	228,499	110,631
1993	148,130	218,510	100,419	147,282	214,304	101,221
1994	137,256	188,877	99,743	136,433	186,588	99,759
1995	115,954	169,205	79,462	115,818	166,577	80,527
1996	97,958	140,742	68,180	98,318	139,333	69,377
1997	82,755	107,292	63,829	83,463	108,004	64,498
1998	89,490	127,817	62,656	89,714	126,385	63,684
1999	96,773	140,031	66,879	96,434	137,482	67,642
2000	104,649	142,608	76,794	103,657	140,250	76,612
2001	92,040	128,873	65,734	91,773	126,968	66,335
2002	80,949	105,138	62,325	81,252	105,080	62,827
2003	80,706	113,231	57,524	80,844	112,097	58,305
2004	80,463	107,900	60,003	80,439	107,284	60,311
2005	78,706	114,554	54,076	78,661	113,007	54,753
2006	76,987	111,145	53,326	76,921	109,895	53,841
2007	72,158	111,310	46,778	72,373	109,719	47,738
2008	67,632	105,507	43,354	68,093	104,268	44,469
2009	63,390	95,090	42,258	64,067	94,673	43,355
2010	59,414	79,927	44,166	60,278	80,818	44,959
2011	59,222	83,284	42,112	60,701	84,052	43,837
2012	59,031	76,711	45,425	61,126	77,817	48,014
2013				64,887	90,035	46,763
2014				68,880	93,757	50,604

Table 2A.15—Time series of EBS Pacific cod age 0 recruitment (1000s of fish), with standard deviations, as estimated by Models 2 and 3. Color scale extends from red (low) to green (high) in each **column**.

	Model 2		Model 3	
Year	Recruits	Std. dev.	Recruits	Std. dev.
1991	68,961	10,694	66,564	9,949
1992	41,759	9,962	36,860	9,797
1993	116,830	15,089	140,502	16,759
1994	47,021	7,682	43,861	7,611
1995	82,148	14,284	92,857	16,909
1996	130,073	16,491	148,358	17,309
1997	102,302	12,249	99,436	11,339
1998	57,108	10,946	56,080	10,767
1999	118,571	14,024	111,239	12,070
2000	57,350	8,497	46,195	6,382
2001	47,428	6,357	44,582	5,587
2002	31,756	5,188	30,612	5,141
2003	43,763	6,409	40,982	5,779
2004	31,499	6,192	27,403	5,322
2005	45,879	7,832	42,803	7,412
2006	44,526	6,807	44,930	6,662
2007	68,602	9,645	57,500	7,354
2008	47,514	7,233	51,177	7,640
2009	26,146	5,458	21,277	4,404
2010	45,746	8,790	49,234	9,535
2011	32,838	7,133	28,707	5,967
2012	38,520	14,957	31,372	12,867
2013	43,383	17,555	33,069	13,807
Average	59,553		58,504	

Table 2A.16a—Numbers (1000s) at age at the beginning of the year as estimated by Model 2.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1991	68961	50690	76135	16267	22421	29867	16212	4748	1986	1137	751	1210	825	569	397	279	196	139	98	69	168
1992	41759	49084	36080	54183	11535	15755	20881	11136	3272	1366	777	507	814	563	395	278	196	138	98	69	167
1993	116830	29723	34936	25665	37975	7334	9579	13172	7107	2072	846	461	298	503	368	264	189	134	95	68	164
1994	47021	83156	21155	24837	17723	25704	4866	6078	8451	4526	1293	507	274	185	330	247	180	129	92	66	161
1995	82148	33468	59187	15048	17411	12032	17124	3262	4098	5676	3007	840	328	182	126	228	172	126	91	65	159
1996	130073	58470	23821	42113	10622	12069	8252	11587	2218	2777	3811	1983	552	220	125	88	159	120	88	64	158
1997	102302	92582	41617	16945	29528	6823	7444	5391	7632	1453	1791	2384	1232	356	147	85	60	110	84	61	155
1998	57108	72816	65896	29607	11912	20355	4644	4824	3525	4960	928	1107	1463	786	236	100	58	42	76	58	151
1999	118571	40648	51826	46854	20533	7851	13013	2914	3064	2220	3054	546	645	899	511	158	68	40	29	53	145
2000	57350	84395	28932	36871	32958	13818	5167	8291	1877	1959	1392	1840	326	404	590	344	108	46	27	20	137
2001	47428	40820	60069	20579	25799	22283	9154	3048	4980	1113	1124	746	973	187	251	382	227	72	31	19	108
2002	31756	33758	29053	42687	14074	17101	14359	5724	1930	3127	683	658	433	596	121	167	258	155	50	22	87
2003	43763	22603	24028	20670	30034	9603	11474	8928	3606	1205	1905	397	378	263	384	80	113	176	106	34	75
2004	31499	31149	16088	17085	14338	20793	6576	7040	5557	2223	723	1084	223	226	168	254	54	77	120	73	76
2005	45879	22420	22170	11431	11649	9673	13732	4165	4510	3533	1384	432	642	139	148	113	172	37	53	83	103
2006	44526	32656	15957	15767	7974	7831	6358	8953	2739	2948	2273	863	268	412	93	101	78	119	26	37	130
2007	68602	31693	23243	11348	10980	5144	4858	4119	5854	1780	1884	1404	529	171	274	63	69	54	83	18	117
2008	47514	48829	22557	16528	7888	6978	3126	2918	2515	3534	1042	1038	764	309	107	179	42	47	36	57	92
2009	26146	33819	34753	16033	11360	5075	4313	1829	1740	1481	2009	552	542	433	191	69	118	28	31	25	102
2010	45746	18610	24071	24714	11151	7236	3093	2485	1075	1009	827	1040	281	302	264	122	45	78	19	21	86
2011	32838	32561	13245	17111	17039	7218	4510	1667	1376	585	522	387	477	145	176	163	78	30	52	13	72
2012	38520	23373	23176	9425	12094	11776	4930	2861	1069	876	365	312	230	297	95	118	111	53	20	36	59
2013	43383	27417	16636	16490	6648	8061	7647	2979	1756	650	517	203	172	135	188	62	79	75	36	14	65
2014	60649	30879	19514	11837	11637	4581	5484	4801	1893	1107	400	304	118	105	88	125	42	54	52	25	55

Table 2A.16b—Numbers (1000s) at age at the beginning of the year as estimated by Model 3.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1991	66564	58377	78964	16016	27882	27124	22276	4576	2194	1219	755	1181	802	545	375	259	180	125	88	61	144
1992	36860	47378	41551	56197	11359	19624	19021	15360	3165	1518	841	514	796	542	373	258	179	125	87	61	143
1993	140502	26236	33722	29557	39397	7303	12212	12117	9888	2039	970	514	303	473	335	236	166	117	82	58	137
1994	43861	100005	18673	23976	20471	26751	4885	7826	7842	6405	1310	597	305	182	295	214	153	109	78	55	131
1995	92857	31219	71179	13283	16806	13931	17946	3282	5287	5300	4310	861	385	198	120	198	144	104	75	53	128
1996	148358	66093	22220	50645	9369	11660	9587	12173	2236	3604	3600	2870	565	253	133	81	135	99	72	52	126
1997	99436	105597	47042	15808	35580	5972	7174	6300	8061	1482	2374	2295	1782	353	163	87	54	90	67	49	121
1998	56080	70776	75160	33467	11116	24626	4096	4682	4146	5308	969	1499	1408	1101	225	106	57	36	60	45	115
1999	111239	39916	50374	53446	23267	7371	15963	2595	2999	2658	3373	587	874	829	677	142	68	37	24	40	107
2000	46195	79177	28411	35840	37643	15764	4915	10279	1687	1951	1716	2091	352	528	520	434	92	45	25	16	99
2001	44582	32880	56355	20208	25066	25607	10569	2962	6292	1034	1181	971	1119	191	305	311	265	58	28	16	75
2002	30612	31732	23402	40044	13792	16673	16666	6724	1905	4050	660	720	570	663	118	193	200	173	38	19	61
2003	40982	21788	22586	16648	28149	9421	11239	10531	4297	1218	2567	398	418	334	406	74	123	130	114	25	53
2004	27403	29170	15508	16056	11487	19456	6451	6998	6641	2713	761	1519	226	239	201	251	47	79	84	75	52
2005	42803	19504	20761	11017	10907	7690	12773	4121	4516	4289	1738	467	898	135	149	128	162	31	52	56	85
2006	44930	30466	13882	14765	7684	7277	5026	8325	2708	2971	2802	1095	286	554	86	96	84	108	21	35	95
2007	57500	31980	21684	9872	10271	4918	4502	3246	5427	1767	1924	1744	660	174	349	55	63	55	72	14	88
2008	51177	40927	22761	15418	6842	6482	2986	2683	1967	3294	1058	1072	916	352	99	206	33	39	35	46	66
2009	21277	36426	29129	16177	10567	4352	3977	1724	1580	1160	1912	564	533	463	192	56	121	20	24	22	71
2010	49234	15144	25926	20714	11247	6655	2635	2244	994	913	659	988	270	260	246	107	33	72	12	15	58
2011	28707	35043	10779	18426	14206	7255	4160	1367	1200	533	478	303	409	115	124	126	57	18	41	7	44
2012	31372	20433	24942	7670	13022	9781	4942	2599	865	760	334	284	173	235	69	77	80	37	12	27	34
2013	33069	22330	14543	17746	5405	8668	6373	2905	1556	518	449	183	146	90	132	40	46	49	23	7	39
2014	58856	23538	15894	10348	12523	3721	5903	3909	1807	969	319	260	101	81	53	80	25	29	31	15	31

Table 2A.17a—"Effective" fishing mortality (= -ln($N_{a+1,t+1}/N_{a,t}$)-M) at age and year, as estimated by Model 2.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1991	0.000	0.000	0.004	0.013	0.018	0.036	0.032	0.034	0.041	0.054	0.056	0.042	0.026	0.018	0.014	0.011	0.010	0.009	0.008
1992	0.000	0.001	0.015	0.113	0.158	0.121	0.109	0.117	0.139	0.182	0.191	0.141	0.087	0.061	0.048	0.039	0.033	0.029	0.026
1993	0.000	0.001	0.030	0.050	0.070	0.115	0.104	0.111	0.132	0.173	0.182	0.134	0.083	0.058	0.045	0.037	0.031	0.028	0.024
1994	0.000	0.001	0.015	0.047	0.066	0.060	0.054	0.058	0.069	0.090	0.095	0.070	0.043	0.030	0.024	0.019	0.016	0.015	0.013
1995	0.000	0.000	0.008	0.026	0.037	0.051	0.046	0.049	0.058	0.076	0.080	0.059	0.037	0.026	0.020	0.016	0.014	0.012	0.011
1996	0.000	0.001	0.015	0.103	0.143	0.086	0.078	0.083	0.099	0.129	0.136	0.100	0.062	0.044	0.034	0.028	0.023	0.021	0.018
1997	0.000	0.000	0.012	0.032	0.045	0.094	0.085	0.091	0.108	0.141	0.148	0.109	0.068	0.048	0.037	0.030	0.026	0.023	0.020
1998	0.000	0.001	0.026	0.077	0.107	0.126	0.114	0.122	0.145	0.190	0.199	0.147	0.091	0.064	0.050	0.040	0.034	0.031	0.027
1999	0.000	0.000	0.012	0.056	0.078	0.111	0.100	0.107	0.127	0.167	0.175	0.129	0.080	0.056	0.044	0.036	0.030	0.027	0.024
2000	0.000	0.001	0.017	0.051	0.072	0.188	0.170	0.182	0.216	0.283	0.297	0.219	0.136	0.095	0.074	0.060	0.051	0.046	0.040
2001	0.000	0.002	0.040	0.071	0.099	0.130	0.117	0.125	0.149	0.195	0.205	0.151	0.094	0.066	0.051	0.042	0.035	0.031	0.027
2002	0.000	0.000	0.012	0.042	0.059	0.135	0.122	0.131	0.155	0.204	0.214	0.158	0.098	0.069	0.053	0.043	0.037	0.033	0.029
2003	0.000	0.001	0.026	0.028	0.039	0.148	0.134	0.144	0.171	0.224	0.235	0.173	0.107	0.075	0.059	0.048	0.041	0.036	0.032
2004	0.000	0.002	0.043	0.054	0.075	0.117	0.105	0.113	0.134	0.176	0.184	0.136	0.084	0.059	0.046	0.037	0.032	0.028	0.025
2005	0.000	0.001	0.020	0.057	0.080	0.088	0.079	0.085	0.101	0.132	0.139	0.102	0.063	0.044	0.035	0.028	0.024	0.021	0.019
2006	0.000	0.001	0.022	0.098	0.137	0.094	0.085	0.091	0.108	0.142	0.148	0.110	0.068	0.048	0.037	0.030	0.026	0.023	0.020
2007	0.000	0.001	0.024	0.113	0.158	0.170	0.154	0.165	0.195	0.256	0.268	0.198	0.123	0.086	0.067	0.054	0.046	0.041	0.036
2008	0.000	0.001	0.035	0.101	0.141	0.196	0.177	0.190	0.225	0.295	0.310	0.229	0.142	0.099	0.077	0.063	0.054	0.048	0.042
2009	0.000	0.001	0.023	0.111	0.155	0.211	0.191	0.205	0.243	0.319	0.334	0.247	0.153	0.107	0.084	0.068	0.058	0.051	0.045
2010	0.000	0.001	0.032	0.095	0.133	0.278	0.251	0.269	0.319	0.419	0.439	0.324	0.201	0.141	0.110	0.089	0.076	0.067	0.059
2011	0.000	0.000	0.007	0.029	0.041	0.115	0.104	0.112	0.132	0.174	0.182	0.134	0.083	0.058	0.046	0.037	0.031	0.028	0.024
2012	0.000	0.000	0.009	0.066	0.092	0.164	0.148	0.159	0.188	0.247	0.259	0.191	0.118	0.083	0.065	0.052	0.045	0.040	0.035
2013	0.000	0.000	0.009	0.032	0.045	0.126	0.113	0.122	0.144	0.189	0.198	0.147	0.091	0.064	0.050	0.040	0.034	0.030	0.027
2014	0.000	0.000	0.009	0.028	0.039	0.106	0.096	0.103	0.122	0.160	0.168	0.124	0.077	0.054	0.042	0.034	0.029	0.026	0.023

Table 2A.17b—"Effective" fishing mortality (= -ln($N_{a+1,t+1}/N_{a,t}$)-M) at age and year, as estimated by Model 3.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1991	0.000	0.000	0.004	0.011	0.015	0.032	0.029	0.028	0.031	0.044	0.054	0.052	0.040	0.033	0.029	0.025	0.022	0.019	0.017
1992	0.000	0.001	0.015	0.102	0.134	0.111	0.100	0.100	0.108	0.153	0.190	0.181	0.140	0.116	0.101	0.086	0.075	0.068	0.061
1993	0.000	0.001	0.027	0.047	0.062	0.105	0.095	0.094	0.102	0.145	0.180	0.171	0.132	0.110	0.095	0.082	0.071	0.064	0.057
1994	0.000	0.001	0.015	0.045	0.059	0.058	0.052	0.052	0.056	0.080	0.099	0.094	0.073	0.060	0.052	0.045	0.039	0.035	0.032
1995	0.000	0.000	0.009	0.026	0.034	0.048	0.044	0.043	0.047	0.066	0.082	0.079	0.061	0.050	0.044	0.038	0.033	0.029	0.026
1996	0.000	0.001	0.013	0.110	0.146	0.080	0.072	0.072	0.078	0.110	0.137	0.130	0.101	0.083	0.072	0.062	0.054	0.049	0.044
1997	0.000	0.000	0.012	0.028	0.037	0.087	0.078	0.078	0.084	0.120	0.148	0.141	0.109	0.091	0.079	0.068	0.059	0.053	0.047
1998	0.000	0.001	0.024	0.071	0.094	0.117	0.106	0.105	0.113	0.161	0.200	0.190	0.147	0.122	0.106	0.091	0.079	0.071	0.064
1999	0.000	0.000	0.011	0.049	0.065	0.100	0.091	0.090	0.098	0.138	0.172	0.164	0.126	0.105	0.091	0.078	0.068	0.061	0.055
2000	0.000	0.001	0.018	0.045	0.060	0.166	0.151	0.149	0.162	0.230	0.285	0.272	0.210	0.174	0.151	0.130	0.113	0.102	0.090
2001	0.000	0.002	0.042	0.068	0.089	0.112	0.102	0.101	0.109	0.155	0.192	0.183	0.141	0.117	0.102	0.087	0.076	0.069	0.061
2002	0.000	0.000	0.012	0.041	0.054	0.119	0.108	0.107	0.116	0.164	0.204	0.194	0.150	0.125	0.108	0.093	0.081	0.073	0.065
2003	0.000	0.001	0.031	0.029	0.039	0.134	0.121	0.120	0.130	0.185	0.229	0.218	0.169	0.140	0.121	0.104	0.091	0.082	0.073
2004	0.000	0.002	0.047	0.061	0.081	0.108	0.098	0.097	0.105	0.149	0.185	0.177	0.136	0.113	0.098	0.084	0.073	0.066	0.060
2005	0.000	0.001	0.020	0.065	0.085	0.088	0.080	0.079	0.086	0.121	0.151	0.144	0.111	0.092	0.080	0.069	0.060	0.054	0.048
2006	0.000	0.001	0.023	0.106	0.140	0.097	0.088	0.087	0.095	0.134	0.166	0.159	0.122	0.102	0.088	0.076	0.066	0.059	0.053
2007	0.000	0.001	0.027	0.120	0.159	0.177	0.161	0.159	0.173	0.245	0.304	0.290	0.224	0.186	0.161	0.138	0.121	0.108	0.096
2008	0.000	0.002	0.038	0.112	0.148	0.209	0.190	0.188	0.204	0.289	0.359	0.342	0.264	0.219	0.190	0.163	0.142	0.128	0.115
2009	0.000	0.001	0.023	0.122	0.162	0.232	0.210	0.208	0.226	0.321	0.398	0.379	0.293	0.243	0.211	0.181	0.158	0.142	0.126
2010	0.000	0.001	0.037	0.098	0.130	0.316	0.287	0.284	0.308	0.437	0.542	0.516	0.399	0.331	0.287	0.247	0.215	0.193	0.172
2011	0.000	0.000	0.007	0.033	0.044	0.130	0.118	0.117	0.127	0.180	0.223	0.213	0.164	0.136	0.118	0.101	0.088	0.080	0.070
2012	0.000	0.000	0.010	0.067	0.088	0.191	0.173	0.172	0.186	0.264	0.328	0.312	0.241	0.200	0.174	0.149	0.130	0.117	0.105
2013	0.000	0.000	0.009	0.033	0.044	0.149	0.135	0.133	0.145	0.205	0.255	0.243	0.188	0.156	0.135	0.116	0.101	0.091	0.081
2014	0.000	0.000	0.010	0.028	0.037	0.122	0.110	0.109	0.119	0.168	0.209	0.199	0.154	0.128	0.111	0.095	0.083	0.074	0.067

Table 2A.18a—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in 2015-2027 (Scenario 1), with random variability in future recruitment, based on Model 2.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	33,400	33,400	33,400	33,400	0
2016	26,300	26,300	26,300	26,300	0
2017	21,800	21,800	21,800	21,800	2
2018	21,700	21,700	21,700	21,800	49
2019	23,300	24,000	24,100	25,300	628
2020	25,300	28,000	28,500	33,200	2,443
2021	25,200	30,500	30,800	36,800	3,672
2022	23,000	31,900	32,000	42,600	6,054
2023	22,500	32,900	32,800	43,600	6,756
2024	22,400	33,800	33,300	45,000	7,000
2025	22,400	33,600	33,700	46,100	7,200
2026	22,200	33,500	33,600	45,200	7,199
2027	22,500	33,800	33,400	45,300	7,060

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	52,600	52,600	52,600	52,600	0
2016	44,700	44,700	44,700	44,700	0
2017	40,800	40,800	40,800	40,800	4
2018	40,600	40,700	40,700	40,900	85
2019	42,400	43,100	43,200	44,300	609
2020	43,900	46,100	46,500	50,200	2,041
2021	43,300	48,200	48,800	56,900	4,224
2022	42,100	49,400	50,400	62,300	6,280
2023	41,400	50,100	51,300	64,300	7,374
2024	41,300	50,500	51,800	67,300	7,907
2025	40,900	50,500	52,000	67,700	8,137
2026	41,000	50,500	51,900	66,400	8,085
2027	41,200	50,600	51,800	66,600	7,875

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.54	0.54	0.54	0.54	0.00
2016	0.47	0.47	0.47	0.47	0.00
2017	0.43	0.43	0.43	0.43	0.00
2018	0.42	0.42	0.42	0.43	0.00
2019	0.44	0.45	0.45	0.46	0.01
2020	0.46	0.48	0.49	0.53	0.02
2021	0.45	0.51	0.50	0.54	0.03
2022	0.44	0.52	0.51	0.54	0.03
2023	0.43	0.53	0.51	0.54	0.04
2024	0.43	0.53	0.51	0.54	0.04
2025	0.43	0.53	0.51	0.54	0.04
2026	0.43	0.53	0.51	0.54	0.04
2027	0.43	0.53	0.51	0.54	0.04

Table 2A.18b—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in 2015-2027 (Scenario 1), with random variability in future recruitment, based on Model 3.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	29,300	29,300	29,300	29,300	0
2016	23,500	23,500	23,500	23,500	0
2017	18,900	18,900	18,900	18,900	2
2018	18,500	18,600	18,600	18,700	55
2019	19,700	20,400	20,500	21,800	706
2020	22,800	25,500	26,100	31,400	2,711
2021	23,300	28,600	29,100	35,900	4,010
2022	20,500	30,000	30,600	43,600	7,129
2023	19,900	31,300	31,400	44,500	7,851
2024	19,900	32,300	32,200	46,200	8,203
2025	19,800	32,300	32,700	47,700	8,435
2026	19,800	32,300	32,600	46,400	8,443
2027	20,100	32,400	32,400	46,900	8,296

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	46,400	46,400	46,400	46,400	0
2016	39,900	39,900	39,900	39,900	0
2017	36,100	36,100	36,100	36,100	5
2018	35,700	35,800	35,800	36,000	99
2019	37,600	38,300	38,500	39,800	708
2020	39,600	42,000	42,500	46,900	2,358
2021	39,400	44,600	45,500	54,700	4,849
2022	38,300	46,200	47,400	61,400	7,167
2023	37,400	47,200	48,600	63,300	8,350
2024	37,500	47,700	49,300	66,200	9,021
2025	37,300	47,800	49,600	67,700	9,349
2026	37,000	47,900	49,500	66,400	9,308
2027	37,600	48,000	49,400	66,700	9,029

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.61	0.61	0.61	0.61	0.00
2016	0.52	0.52	0.52	0.52	0.00
2017	0.46	0.46	0.46	0.46	0.00
2018	0.46	0.46	0.46	0.46	0.00
2019	0.48	0.49	0.50	0.51	0.01
2020	0.51	0.55	0.55	0.61	0.03
2021	0.51	0.58	0.58	0.63	0.04
2022	0.49	0.60	0.59	0.63	0.05
2023	0.48	0.62	0.59	0.63	0.05
2024	0.48	0.62	0.59	0.63	0.05
2025	0.48	0.62	0.59	0.63	0.05
2026	0.48	0.63	0.59	0.63	0.05
2027	0.48	0.63	0.59	0.63	0.05

Table 2A.19a—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the authors' best estimates of 2015-2016 catches given ABC = maxABC in 2015-2016, with $F = max\ F_{ABC}$ thereafter (Scenario 2), and with random variability in future recruitment, based on Model 2.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	30,900	30,900	30,900	30,900	0
2016	25,200	25,200	25,200	25,200	0
2017	23,100	23,100	23,100	23,100	2
2018	22,300	22,400	22,400	22,500	49
2019	23,600	24,200	24,400	25,500	631
2020	25,400	28,100	28,600	33,300	2,440
2021	25,200	30,500	30,800	36,800	3,669
2022	22,900	31,900	32,000	42,600	6,054
2023	22,500	32,900	32,800	43,600	6,757
2024	22,400	33,800	33,300	45,000	6,999
2025	22,400	33,600	33,700	46,100	7,199
2026	22,200	33,500	33,600	45,200	7,198
2027	22,500	33,800	33,400	45,300	7,060

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	52,800	52,800	52,800	52,800	0
2016	45,700	45,700	45,700	45,700	0
2017	41,900	41,900	41,900	41,900	4
2018	41,200	41,300	41,300	41,400	85
2019	42,700	43,300	43,400	44,500	609
2020	43,900	46,200	46,500	50,300	2,041
2021	43,300	48,200	48,900	56,900	4,224
2022	42,100	49,400	50,300	62,300	6,281
2023	41,400	50,100	51,200	64,300	7,374
2024	41,300	50,500	51,800	67,300	7,908
2025	40,900	50,500	52,000	67,700	8,138
2026	41,000	50,500	51,900	66,400	8,085
2027	41,200	50,600	51,800	66,600	7,876

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.49	0.49	0.49	0.49	0.00
2016	0.43	0.43	0.43	0.43	0.00
2017	0.44	0.44	0.44	0.44	0.00
2018	0.43	0.43	0.43	0.43	0.00
2019	0.45	0.45	0.45	0.47	0.01
2020	0.46	0.49	0.49	0.53	0.02
2021	0.45	0.51	0.50	0.54	0.03
2022	0.44	0.52	0.51	0.54	0.03
2023	0.43	0.53	0.51	0.54	0.04
2024	0.43	0.53	0.51	0.54	0.04
2025	0.43	0.53	0.51	0.54	0.04
2026	0.43	0.53	0.51	0.54	0.04
2027	0.43	0.53	0.51	0.54	0.04

Table 2A.19b—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the authors' best estimates of 2015-2016 catches given ABC = maxABC in 2015-2016, with $F = max\ F_{ABC}$ thereafter (Scenario 2), and with random variability in future recruitment, based on Model 3.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	27,000	27,000	27,000	27,000	0
2016	22,300	22,300	22,300	22,300	0
2017	20,100	20,100	20,100	20,100	2
2018	19,100	19,100	19,200	19,300	56
2019	20,000	20,600	20,800	22,100	709
2020	22,900	25,600	26,200	31,500	2,710
2021	23,300	28,600	29,100	35,900	4,009
2022	20,500	30,000	30,600	43,600	7,130
2023	19,900	31,300	31,400	44,500	7,852
2024	19,900	32,200	32,200	46,200	8,203
2025	19,800	32,300	32,700	47,700	8,435
2026	19,800	32,300	32,600	46,400	8,442
2027	20,100	32,400	32,400	46,900	8,296

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	46,600	46,600	46,600	46,600	0
2016	40,900	40,900	40,900	40,900	0
2017	37,200	37,300	37,300	37,300	5
2018	36,200	36,300	36,400	36,500	99
2019	37,900	38,600	38,700	40,000	708
2020	39,700	42,100	42,600	47,000	2,357
2021	39,400	44,600	45,500	54,700	4,848
2022	38,300	46,200	47,400	61,400	7,166
2023	37,400	47,200	48,600	63,300	8,349
2024	37,500	47,700	49,300	66,200	9,020
2025	37,300	47,800	49,600	67,700	9,348
2026	37,000	47,900	49,500	66,400	9,307
2027	37,600	48,000	49,400	66,700	9,029

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.55	0.55	0.55	0.55	0.00
2016	0.47	0.47	0.47	0.47	0.00
2017	0.48	0.48	0.48	0.48	0.00
2018	0.47	0.47	0.47	0.47	0.00
2019	0.49	0.50	0.50	0.52	0.01
2020	0.51	0.55	0.55	0.61	0.03
2021	0.51	0.58	0.58	0.63	0.04
2022	0.49	0.60	0.59	0.63	0.05
2023	0.48	0.62	0.59	0.63	0.05
2024	0.48	0.62	0.59	0.63	0.05
2025	0.48	0.62	0.59	0.63	0.05
2026	0.48	0.63	0.59	0.63	0.05
2027	0.48	0.63	0.59	0.63	0.05

Table 2A.20a—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that the upper bound on F_{ABC} is set the most recent five-year average fishing mortality rate in 2015-2027 (Scenario 3), with random variability in future recruitment, based on Model 2.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	13,400	13,400	13,400	13,400	0
2016	14,000	14,000	14,000	14,000	0
2017	13,800	13,800	13,800	13,800	0
2018	14,200	14,200	14,200	14,200	3
2019	14,600	14,700	14,700	15,000	136
2020	15,400	16,100	16,200	17,300	594
2021	15,900	17,200	17,400	19,300	1,049
2022	15,300	18,100	18,500	22,900	2,349
2023	15,400	19,000	19,400	24,300	2,839
2024	15,700	19,800	20,200	25,600	3,116
2025	16,000	20,300	20,700	27,000	3,348
2026	15,800	20,600	21,000	27,500	3,474
2027	15,900	20,700	21,000	27,000	3,464

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	54,300	54,300	54,300	54,300	0
2016	53,400	53,400	53,400	53,400	0
2017	53,000	53,000	53,000	53,000	4
2018	54,200	54,300	54,300	54,500	89
2019	57,000	57,700	57,800	59,000	650
2020	59,800	62,300	62,700	66,900	2,289
2021	60,900	66,800	67,600	77,300	5,099
2022	60,900	70,800	71,800	86,700	8,127
2023	60,500	74,000	75,100	93,500	10,322
2024	61,000	76,400	77,600	98,100	11,708
2025	61,100	77,700	79,200	103,000	12,480
2026	61,100	78,800	80,200	103,000	12,761
2027	61,700	79,600	80,700	104,000	12,694

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.20	0.20	0.20	0.20	0.00
2016	0.20	0.20	0.20	0.20	0.00
2017	0.20	0.20	0.20	0.20	0.00
2018	0.20	0.20	0.20	0.20	0.00
2019	0.20	0.20	0.20	0.20	0.00
2020	0.20	0.20	0.20	0.20	0.00
2021	0.20	0.20	0.20	0.20	0.00
2022	0.20	0.20	0.20	0.20	0.00
2023	0.20	0.20	0.20	0.20	0.00
2024	0.20	0.20	0.20	0.20	0.00
2025	0.20	0.20	0.20	0.20	0.00
2026	0.20	0.20	0.20	0.20	0.00
2027	0.20	0.20	0.20	0.20	0.00

Table 2A.20b—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that the upper bound on F_{ABC} is set the most recent five-year average fishing mortality rate in 2015-2027 (Scenario 3), with random variability in future recruitment, based on Model 3.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	12,500	12,500	12,500	12,500	0
2016	13,400	13,400	13,400	13,400	0
2017	12,900	12,900	12,900	12,900	0
2018	13,100	13,100	13,100	13,200	3
2019	13,300	13,500	13,500	13,800	167
2020	14,600	15,300	15,400	16,600	656
2021	15,400	16,600	16,800	19,000	1,102
2022	14,300	17,400	17,900	23,200	2,847
2023	14,300	18,300	18,800	25,100	3,412
2024	14,500	19,300	19,700	26,600	3,755
2025	15,100	19,900	20,500	27,700	3,996
2026	15,000	20,500	20,900	28,500	4,155
2027	15,200	20,700	21,100	28,400	4,148

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	47,800	47,800	47,800	47,800	0
2016	47,200	47,200	47,200	47,200	0
2017	46,200	46,200	46,200	46,200	5
2018	46,600	46,700	46,700	46,900	104
2019	48,900	49,700	49,800	51,300	755
2020	51,700	54,400	55,000	59,900	2,636
2021	53,000	59,300	60,300	71,300	5,828
2022	53,000	63,500	65,000	82,500	9,229
2023	52,700	67,400	68,800	90,400	11,635
2024	52,300	70,100	71,700	95,200	13,206
2025	53,500	71,900	73,700	100,000	14,127
2026	54,000	73,000	74,700	101,000	14,468
2027	54,200	73,800	75,300	101,000	14,341

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.24	0.24	0.24	0.24	0.00
2016	0.24	0.24	0.24	0.24	0.00
2017	0.24	0.24	0.24	0.24	0.00
2018	0.24	0.24	0.24	0.24	0.00
2019	0.24	0.24	0.24	0.24	0.00
2020	0.24	0.24	0.24	0.24	0.00
2021	0.24	0.24	0.24	0.24	0.00
2022	0.24	0.24	0.24	0.24	0.00
2023	0.24	0.24	0.24	0.24	0.00
2024	0.24	0.24	0.24	0.24	0.00
2025	0.24	0.24	0.24	0.24	0.00
2026	0.24	0.24	0.24	0.24	0.00
2027	0.24	0.24	0.24	0.24	0.00

Table 2A.21a—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that the upper bound on F_{ABC} is set at $F_{60\%}$ in 2015-2027 (Scenario 4), with random variability in future recruitment, based on Model 2.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	16,400	16,400	16,400	16,400	0
2016	16,700	16,700	16,700	16,700	0
2017	16,200	16,200	16,200	16,200	0
2018	16,400	16,400	16,400	16,400	3
2019	16,800	17,000	17,000	17,300	168
2020	17,800	18,600	18,700	20,000	730
2021	18,300	19,800	20,000	22,400	1,280
2022	17,400	20,800	21,200	26,500	2,816
2023	17,500	21,800	22,200	28,200	3,373
2024	17,800	22,700	23,000	29,400	3,673
2025	18,100	23,000	23,600	30,900	3,918
2026	17,900	23,300	23,800	31,300	4,033
2027	18,100	23,400	23,900	30,900	3,999

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	54,000	54,000	54,000	54,000	0
2016	52,000	52,000	52,000	52,000	0
2017	50,700	50,700	50,700	50,700	4
2018	51,300	51,400	51,400	51,600	89
2019	53,700	54,400	54,500	55,700	650
2020	56,100	58,600	59,000	63,200	2,281
2021	56,900	62,700	63,500	73,100	5,047
2022	56,500	66,200	67,200	81,800	7,970
2023	56,100	69,100	70,200	88,000	9,998
2024	56,400	71,100	72,200	92,000	11,232
2025	56,200	72,200	73,600	96,000	11,890
2026	56,300	73,100	74,300	96,500	12,093
2027	56,800	73,700	74,700	96,300	11,983

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.24	0.24	0.24	0.24	0.00
2016	0.24	0.24	0.24	0.24	0.00
2017	0.24	0.24	0.24	0.24	0.00
2018	0.24	0.24	0.24	0.24	0.00
2019	0.24	0.24	0.24	0.24	0.00
2020	0.24	0.24	0.24	0.24	0.00
2021	0.24	0.24	0.24	0.24	0.00
2022	0.24	0.24	0.24	0.24	0.00
2023	0.24	0.24	0.24	0.24	0.00
2024	0.24	0.24	0.24	0.24	0.00
2025	0.24	0.24	0.24	0.24	0.00
2026	0.24	0.24	0.24	0.24	0.00
2027	0.24	0.24	0.24	0.24	0.00

Table 2A.21b—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that the upper bound on F_{ABC} is set at $F_{60\%}$ in 2015-2027 (Scenario 4), with random variability in future recruitment, based on Model 3.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	14,500	14,500	14,500	14,500	0
2016	15,300	15,300	15,300	15,300	0
2017	14,600	14,600	14,600	14,600	0
2018	14,700	14,700	14,700	14,700	4
2019	14,800	14,900	15,000	15,300	196
2020	16,200	17,000	17,100	18,600	769
2021	17,000	18,400	18,600	21,200	1,285
2022	15,800	19,200	19,900	26,000	3,274
2023	15,600	20,300	20,800	28,000	3,894
2024	15,800	21,300	21,800	29,500	4,263
2025	16,500	22,000	22,700	31,000	4,518
2026	16,400	22,500	23,000	31,500	4,669
2027	16,600	22,700	23,200	31,400	4,639

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	47,600	47,600	47,600	47,600	0
2016	46,300	46,300	46,300	46,300	0
2017	44,600	44,600	44,600	44,600	5
2018	44,600	44,700	44,700	44,900	104
2019	46,700	47,400	47,600	49,000	755
2020	49,300	51,900	52,500	57,400	2,629
2021	50,300	56,500	57,500	68,500	5,784
2022	50,000	60,500	61,900	79,300	9,097
2023	49,700	64,100	65,400	86,200	11,358
2024	49,200	66,400	68,000	90,800	12,798
2025	50,400	67,900	69,700	95,100	13,619
2026	50,700	69,000	70,600	95,800	13,887
2027	51,200	69,600	71,000	95,800	13,721

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.28	0.28	0.28	0.28	0.00
2016	0.28	0.28	0.28	0.28	0.00
2017	0.28	0.28	0.28	0.28	0.00
2018	0.28	0.28	0.28	0.28	0.00
2019	0.28	0.28	0.28	0.28	0.00
2020	0.28	0.28	0.28	0.28	0.00
2021	0.28	0.28	0.28	0.28	0.00
2022	0.28	0.28	0.28	0.28	0.00
2023	0.28	0.28	0.28	0.28	0.00
2024	0.28	0.28	0.28	0.28	0.00
2025	0.28	0.28	0.28	0.28	0.00
2026	0.28	0.28	0.28	0.28	0.00
2027	0.28	0.28	0.28	0.28	0.00

Table 2A.22a—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = 0$ in 2015-2027 (Scenario 5), with random variability in future recruitment, based on Model 2.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0	0	0	0	0
2016	0	0	0	0	0
2017	0	0	0	0	0
2018	0	0	0	0	0
2019	0	0	0	0	0
2020	0	0	0	0	0
2021	0	0	0	0	0
2022	0	0	0	0	0
2023	0	0	0	0	0
2024	0	0	0	0	0
2025	0	0	0	0	0
2026	0	0	0	0	0
2027	0	0	0	0	0

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	55,200	55,200	55,200	55,200	0
2016	59,700	59,700	59,700	59,700	0
2017	64,100	64,100	64,100	64,200	4
2018	69,400	69,500	69,500	69,600	89
2019	75,500	76,200	76,300	77,500	652
2020	81,200	83,800	84,200	88,500	2,324
2021	85,300	91,400	92,200	102,000	5,331
2022	87,700	98,200	99,500	116,000	8,846
2023	89,100	104,000	106,000	127,000	11,904
2024	90,600	109,000	111,000	136,000	14,166
2025	92,000	113,000	115,000	143,000	15,681
2026	93,000	116,000	118,000	148,000	16,556
2027	94,600	119,000	120,000	150,000	16,909

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00
2017	0.00	0.00	0.00	0.00	0.00
2018	0.00	0.00	0.00	0.00	0.00
2019	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00
2023	0.00	0.00	0.00	0.00	0.00
2024	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00
2026	0.00	0.00	0.00	0.00	0.00
2027	0.00	0.00	0.00	0.00	0.00

Table 2A.22b—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = 0$ in 2015-2027 (Scenario 5), with random variability in future recruitment, based on Model 3.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0	0	0	0	0
2016	0	0	0	0	0
2017	0	0	0	0	0
2018	0	0	0	0	0
2019	0	0	0	0	0
2020	0	0	0	0	0
2021	0	0	0	0	0
2022	0	0	0	0	0
2023	0	0	0	0	0
2024	0	0	0	0	0
2025	0	0	0	0	0
2026	0	0	0	0	0
2027	0	0	0	0	0

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	48,700	48,700	48,700	48,700	0
2016	53,100	53,100	53,100	53,100	0
2017	56,700	56,700	56,700	56,800	5
2018	60,800	60,900	60,900	61,100	104
2019	66,100	66,800	67,000	68,400	757
2020	71,400	74,200	74,700	79,700	2,678
2021	75,300	81,900	82,900	94,400	6,086
2022	77,700	89,000	90,600	110,000	10,022
2023	78,900	95,700	97,400	123,000	13,436
2024	80,300	101,000	103,000	132,000	16,013
2025	82,000	106,000	107,000	141,000	17,794
2026	83,200	109,000	111,000	146,000	18,831
2027	84,300	111,000	113,000	148,000	19,205

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00
2017	0.00	0.00	0.00	0.00	0.00
2018	0.00	0.00	0.00	0.00	0.00
2019	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00
2023	0.00	0.00	0.00	0.00	0.00
2024	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00
2026	0.00	0.00	0.00	0.00	0.00
2027	0.00	0.00	0.00	0.00	0.00

Table 2A.23a—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = F_{OFL}$ in 2016-2027 (Scenario 6), with random variability in future recruitment, based on Model 2.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	40,000	40,000	40,000	40,000	0
2016	28,300	28,300	28,300	28,300	0
2017	22,700	22,700	22,700	22,700	2
2018	22,700	22,700	22,700	22,800	54
2019	24,600	25,400	25,500	26,800	710
2020	26,700	29,700	30,300	35,600	2,875
2021	26,400	32,200	33,000	41,800	4,709
2022	23,900	33,500	34,300	47,400	7,336
2023	23,400	34,400	34,900	47,900	7,980
2024	23,400	34,500	35,300	48,900	8,122
2025	23,200	34,500	35,400	49,700	8,300
2026	23,100	34,400	35,300	48,800	8,243
2027	23,300	34,200	35,100	48,900	8,082

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	52,000	52,000	52,000	52,000	0
2016	42,000	42,000	42,000	42,000	0
2017	37,700	37,700	37,700	37,800	4
2018	37,600	37,700	37,700	37,900	85
2019	39,500	40,200	40,300	41,400	604
2020	40,800	43,000	43,400	47,100	2,000
2021	40,100	44,800	45,500	53,200	4,007
2022	38,900	45,900	46,500	57,100	5,676
2023	38,200	46,300	47,000	58,400	6,422
2024	38,200	46,200	47,200	60,200	6,742
2025	37,700	46,100	47,300	60,400	6,860
2026	37,700	46,200	47,100	59,100	6,752
2027	38,000	46,100	47,000	59,000	6,556

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.66	0.66	0.66	0.66	0.00
2016	0.54	0.54	0.54	0.54	0.00
2017	0.48	0.48	0.48	0.48	0.00
2018	0.48	0.48	0.48	0.49	0.00
2019	0.51	0.52	0.52	0.53	0.01
2020	0.53	0.56	0.56	0.61	0.03
2021	0.52	0.58	0.59	0.66	0.05
2022	0.50	0.60	0.59	0.66	0.06
2023	0.49	0.60	0.60	0.66	0.06
2024	0.49	0.60	0.60	0.66	0.06
2025	0.48	0.60	0.60	0.66	0.06
2026	0.48	0.60	0.60	0.66	0.06
2027	0.49	0.60	0.59	0.66	0.06

Table 2A.23b—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = F_{OFL}$ in 2015-2027 (Scenario 6), with random variability in future recruitment, based on Model 3.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	34,900	34,900	34,900	34,900	0
2016	25,500	25,500	25,500	25,500	0
2017	19,700	19,700	19,700	19,700	3
2018	19,300	19,400	19,400	19,500	62
2019	20,800	21,600	21,800	23,200	802
2020	24,300	27,300	28,000	34,000	3,174
2021	24,600	30,400	31,300	41,000	5,044
2022	21,400	31,700	33,000	49,000	8,519
2023	20,700	32,800	33,600	49,000	9,165
2024	20,600	33,400	34,200	50,500	9,449
2025	20,800	33,100	34,500	51,400	9,660
2026	20,200	33,000	34,200	50,400	9,584
2027	20,600	32,900	34,000	50,900	9,413

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	45,900	45,900	45,900	45,900	0
2016	37,600	37,600	37,600	37,600	0
2017	33,400	33,400	33,400	33,400	5
2018	33,100	33,100	33,200	33,300	99
2019	35,100	35,800	35,900	37,200	703
2020	37,000	39,300	39,800	44,100	2,312
2021	36,500	41,600	42,400	51,300	4,623
2022	35,300	43,000	43,800	56,500	6,543
2023	34,400	43,500	44,600	57,200	7,360
2024	34,700	43,700	45,000	59,700	7,809
2025	34,500	43,500	45,000	60,100	8,008
2026	34,300	43,700	44,900	59,000	7,901
2027	34,700	43,600	44,700	59,400	7,639

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.75	0.75	0.75	0.75	0.00
2016	0.60	0.60	0.60	0.60	0.00
2017	0.53	0.53	0.53	0.53	0.00
2018	0.53	0.53	0.53	0.53	0.00
2019	0.56	0.57	0.57	0.60	0.01
2020	0.59	0.63	0.64	0.72	0.04
2021	0.59	0.67	0.68	0.79	0.06
2022	0.56	0.70	0.69	0.79	0.08
2023	0.55	0.70	0.70	0.79	0.08
2024	0.55	0.71	0.70	0.79	0.08
2025	0.55	0.71	0.70	0.79	0.08
2026	0.55	0.71	0.70	0.79	0.08
2027	0.55	0.71	0.70	0.79	0.08

Table 2A.24a—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in each year 2015-2016 and $F = F_{OFL}$ thereafter (Scenario 7), with random variability in future recruitment, based on Model 2.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	33,400	33,400	33,400	33,400	0
2016	26,300	26,300	26,300	26,300	0
2017	26,000	26,000	26,000	26,000	2
2018	24,100	24,200	24,200	24,300	56
2019	25,200	25,900	26,000	27,400	715
2020	26,800	29,900	30,400	35,800	2,875
2021	26,400	32,200	32,900	41,700	4,706
2022	23,800	33,500	34,300	47,400	7,335
2023	23,300	34,300	34,900	47,900	7,979
2024	23,400	34,500	35,200	48,900	8,121
2025	23,200	34,500	35,400	49,700	8,299
2026	23,100	34,400	35,300	48,800	8,242
2027	23,300	34,200	35,100	48,900	8,082

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	52,600	52,600	52,600	52,600	0
2016	44,700	44,700	44,700	44,700	0
2017	40,400	40,400	40,400	40,400	4
2018	38,800	38,900	38,900	39,100	85
2019	39,900	40,600	40,700	41,800	604
2020	40,900	43,100	43,500	47,200	1,998
2021	40,100	44,800	45,400	53,200	4,006
2022	38,900	45,900	46,500	57,100	5,675
2023	38,200	46,200	47,000	58,400	6,422
2024	38,200	46,200	47,200	60,200	6,742
2025	37,700	46,100	47,300	60,400	6,860
2026	37,700	46,200	47,100	59,100	6,753
2027	38,000	46,100	47,000	59,000	6,557

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.54	0.54	0.54	0.54	0.00
2016	0.47	0.47	0.47	0.47	0.00
2017	0.52	0.52	0.52	0.52	0.00
2018	0.50	0.50	0.50	0.50	0.00
2019	0.51	0.52	0.53	0.54	0.01
2020	0.53	0.56	0.56	0.61	0.03
2021	0.52	0.58	0.59	0.66	0.05
2022	0.50	0.60	0.59	0.66	0.06
2023	0.49	0.60	0.60	0.66	0.06
2024	0.49	0.60	0.60	0.66	0.06
2025	0.48	0.60	0.60	0.66	0.06
2026	0.48	0.60	0.60	0.66	0.06
2027	0.49	0.60	0.59	0.66	0.06

Table 2A.24b—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in each year 2015-2017 and $F = F_{OFL}$ thereafter (Scenario 7), with random variability in future recruitment, based on Model 3.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	29,300	29,300	29,300	29,300	0
2016	23,500	23,500	23,500	23,500	0
2017	22,700	22,700	22,700	22,700	3
2018	20,600	20,700	20,700	20,800	63
2019	21,300	22,100	22,300	23,700	809
2020	24,400	27,400	28,100	34,200	3,174
2021	24,600	30,400	31,300	41,000	5,042
2022	21,300	31,600	32,900	49,000	8,519
2023	20,600	32,700	33,600	48,900	9,166
2024	20,600	33,400	34,200	50,500	9,449
2025	20,800	33,100	34,400	51,400	9,659
2026	20,200	33,000	34,200	50,400	9,583
2027	20,600	32,900	34,000	50,900	9,413

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	46,400	46,400	46,400	46,400	0
2016	39,900	39,900	39,900	39,900	0
2017	35,800	35,800	35,800	35,800	5
2018	34,100	34,200	34,200	34,400	98
2019	35,500	36,100	36,300	37,600	702
2020	37,100	39,400	39,900	44,200	2,310
2021	36,500	41,500	42,400	51,300	4,621
2022	35,300	43,000	43,800	56,500	6,541
2023	34,400	43,500	44,500	57,200	7,358
2024	34,700	43,700	45,000	59,700	7,808
2025	34,500	43,500	45,000	60,100	8,007
2026	34,300	43,700	44,900	59,000	7,900
2027	34,700	43,600	44,700	59,400	7,639

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.61	0.61	0.61	0.61	0.00
2016	0.52	0.52	0.52	0.52	0.00
2017	0.57	0.57	0.57	0.57	0.00
2018	0.54	0.54	0.55	0.55	0.00
2019	0.57	0.58	0.58	0.60	0.01
2020	0.59	0.63	0.64	0.72	0.04
2021	0.58	0.67	0.68	0.79	0.06
2022	0.56	0.70	0.69	0.79	0.08
2023	0.55	0.70	0.70	0.79	0.08
2024	0.55	0.71	0.70	0.79	0.08
2025	0.55	0.71	0.70	0.79	0.08
2026	0.55	0.71	0.70	0.79	0.08
2027	0.55	0.71	0.70	0.79	0.08

Table 2.25a (page 1 of 2)—Incidental catch (t) of FMP species, other than squid and members of the former "other species" complex, taken in the Aleutian Islands trawl fishery for Pacific cod, 1991-2014 (2014 data current through October 20).

Trawl fishery

Species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Pollock	26	205	135	164	12	29	279	270	482	778	312	719
Pacific Cod	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sablefish								6				1
Yellowfin Sole												
Greenland Turbot	1	5	11	15				16	1	8	6	7
Arrowtooth Flounder	5	72	95	58	6	97	47	76	72	95	130	225
Kamchatka Flounder												
Rock Sole	19	161	178	116	185	204	193	380	540	456	462	1080
Flathead Sole					7	4	17	17	31	71	37	105
Alaska Plaice												
Other Flatfish						0	0	25	9	15	8	20
Flounder		26	27	19								
Pacific Ocean Perch	24	235	366	88	22	50	99	234	48	102	72	63
Northern Rockfish												117
Rougheye Rockfish												
Shortraker Rockfish												
Sharpchin/Northern Rockfish		195	313	132	37	157	88	158	191	274	182	
Shortraker/Rougheye Rockfish		28	9	2		1	2	3	1	3	4	1
Shortraker/Rougheye/Sharpchin/Northern Rockfish	13											
Other Rockfish	0	17	7	2	3	11	76	48	29	18	12	19
Atka Mackerel	164	2981	3176	239	124	579	94	567	499	260	842	378
Squid		0	2	0			1	1	0	0	2	0

Table 2.25a (page 2 of 2)—Incidental catch (t) of FMP species, other than squid and members of the former "other species" complex, taken in the Aleutian Islands trawl fishery for Pacific cod, 1991-2014 (2014 data current through October 20).

Trawl fishery

Species/group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Pollock	785	537	669	314	395	54	51	18	57	78	23	11
Pacific Cod	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sablefish	1	1	0	1	1							
Yellowfin Sole	0	9		3	0	0						
Greenland Turbot	8	6	5		7	1	1					
Arrowtooth Flounder	230	199	244	206	134	24	35	35	16	19	17	5
Kamchatka Flounder									3	2	2	
Rock Sole	802	699	437	449	585	258	432	427	196	217	146	101
Flathead Sole	39	34	24	33	22	10	14	17	3	9	5	2
Alaska Plaice					0	0						
Other Flatfish	8	10	6	11	9	13	3	2	0	7	3	8
Flounder												
Pacific Ocean Perch	185	160	180	134	96	105	32	5	2	43	33	1
Northern Rockfish	215	129	210	185	89	51	59	29	21	9	11	14
Rougheye Rockfish		1	3	1	0	0		0	1			
Shortraker Rockfish		3		2	0						0	
Sharpchin/Northern Rockfish												
Shortraker/Rougheye Rockfish	7											
Shortraker/Rougheye/Sharpchin/Northern Rockfish												
Other Rockfish	13	12	8	7	9	9	7	4	4	9	3	1
Atka Mackerel	1075	549	482	447	361	456	359	124	101	384		
Squid	3	2	1	1	0	0	0	0		0	0	

Table 2.25b (page 1 of 2)—Incidental catch (t) of FMP species, other than squid and members of the former "other species" complex, taken in the Aleutian Islands longline fishery for Pacific cod, 1991-2014 (2014 data current through October 20).

Longline fishery

Species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Pollock	7	15	41	5	19	9	41	35	12	44	72	5
Pacific Cod	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sablefish	94	71	56	66	10	67	32	12	14	24	37	62
Yellowfin Sole												
Greenland Turbot	71	78	57	32	13	14	24	30	30	30	26	6
Arrowtooth Flounder	32	137	61	37	15	21	44	59	49	152	214	35
Kamchatka Flounder												
Rock Sole	0	2	7	5	5	15	5	12	3	3	7	4
Flathead Sole					0	1	2	2	0	5	8	1
Alaska plaice												
Other Flatfish						0	1	2	1	4	13	1
Flounder		3	4	1								
Pacific Ocean Perch		120	2	1	0	1	0	0	0	9	3	0
Northern Rockfish												28
Rougheye Rockfish												
Shortraker Rockfish												
Sharpchin/Northern Rockfish		45	19	10	4	20	17	54	35	75	132	
Shortraker/Rougheye Rockfish		454	191	104	14	117	61	201	107	147	166	36
Shortraker/Rougheye/Sharpchin/Northern Rockfish	132											
Other Rockfish	34	163	36	33	4	21	36	92	61	68	97	30
Atka Mackerel		55	20	40	41	31	40	90	71	151	273	41
Squid												

Table 2.25b (page 2 of 2)—Incidental catch (t) of FMP species, other than squid and members of the former "other species" complex, taken in the Aleutian Islands longline fishery for Pacific cod, 1991-2014 (2014 data current through October 20).

Longline fishery

Species/group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Pollock	9	15	3	8	6	9	29	47	6	8	0	
Pacific Cod	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sablefish	14	2		37	22	23	3	30	6	15	1	
Yellowfin Sole												
Greenland Turbot	12	3		11	15	4	5	5	1	2		
Arrowtooth Flounder	14	18	34	36	66	42	45	65	8	10	2	
Kamchatka Flounder										4	3	
Rock Sole	1	2	4	3	3	2	2	3		2	0	
Flathead Sole	0	0	0	1	2	2	3	3		1		
Alaska Plaice												
Other Flatfish		10		0		0	16	2				
Flounder												
Pacific Ocean Perch	1	0	2	1	4	3	1	1		1		
Northern Rockfish	18	27	19	8	33	54	56	119		12	34	
Rougheye Rockfish		26	1	3	28	46	23	30		27	11	
Shortraker Rockfish		3	5	8	12	6	6	28	2	6	4	
Sharpchin/Northern Rockfish												
Shortraker/Rougheye Rockfish	12											
Shortraker/Rougheye/Sharpchin/Northern Rockfish												
Other Rockfish	12	55	12	20	50	45	77	81	14	20	15	
Atka Mackerel	14	12	19	9	25	47	89	93		19	23	
Squid												

Table 2A.26—Incidental catch (t) of squid and members of the former "other species" complex taken in the Aleutian Islands fisheries for Pacific cod, 2003-2014 (2014 data are current through October 8).

Species/group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Octopus	14	14	12	64	26	19	20	48	10	8	38	8
Sculpins, Large	107	294	207	307	378	375	402	523	99	366	298	88
Sculpins, Other	153	64	7	69	29	26	91	201	6	13	9	4
Shark, Other		0										
Shark, Pacific Sleeper	0	2	2	0	0	0	0	0				
Shark, Salmon							0		0			
Shark, Spiny Dogfish	0	0	0	1	0	3	1	1	0	0	0	0
Skate, Alaska								207	39	64	38	9
Skate, Aleutian									6	25	6	3
Skate, Big		0	0	5	0	0	0	0		2	0	0
Skate, Longnose		0	0	0		0	0	0		0	0	0
Skate, Other	200	486	405	411	647	576	748	602	116	251	148	22
Skate, Whiteblotched									2	4	8	3
Squid	3	2	1	1	0	0	0	0	0	0	0	0

Table 2A.27—Catches of prohibited species by Aleutian Islands fisheries for Pacific cod, 1991-2014 (2014 data are current through October 13). Herring and halibut catches (and halibut mortality totals) are in t, salmon and crab are in 1000s of individuals.

Species	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Bairdi Tanner Crab	2	2	1	1	1	7	3	1	6	48	5	14
Opilio Tanner (Snow) Crab	2	1	1	0	0	0	0	0	0	0	0	1
Red King Crab	0	0	0	0	0	0	0	1	0	1	1	8
Blue King Crab												
Golden (Brown) King Crab												
Other King Crab	2	5	1	2	0	1	0	1	7	1	1	1
Herring												
Chinook Salmon	0	0	0	0	1	0	1	1	0	1	0	2
Non-Chinook Salmon		0			0		0	0		0	0	0

Species	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Bairdi Tanner Crab	11	8	3	7	28	199	41	11	1	11	16	
Opilio Tanner (Snow) Crab	0	0	0	12	73	108	126	34	1	2	1	
Red King Crab	7	1	3	0	3	6	1	1	1	1	8	
Blue King Crab	0	0	0	0	9	0	0	18	0	0	0	
Golden (Brown) King Crab	0	0	0	0	1	2	1	0	1	0	0	
Other King Crab												
Herring	0	0	0	0	0	0	0	0	0	0	0	
Chinook Salmon	2	1	1	1	1	1	1	1	0	0	0	
Non-Chinook Salmon	0	0	0	0	1	0	0	0	0	0	0	

Halibut quantity	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Catch	313	1626	531	423	386	546	438	1023	457	643	1486	261
Mortality				62	48	122	75	190	86	111	172	50

Halibut quantity	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Catch	175	328	306	331	936	698	718	711	211	245	81	51
Mortality	58	60	79	82	148	89	102	74	35	56	24	19

Table 2A.28—Incidental catch (t) of non-target species groups by Aleutian Islands Pacific cod fisheries, 2003-2014 (2014 data are current through October 8), sorted in order of descending average.

Species/group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Ave.
Giant Grenadier	0	0	1	95	31	26	10	189	18	51	1	23	37
Misc fish	29	18	20	17	26	17	18	17	9	9	7	5	16
Grenadier	46	13	1	26	10	0	2	70	0	4	1		16
Sponge unidentified	25	23	26	28	19	4	15	9	3	7	2	1	13
Corals Bryozoans	25	13	12	12	16	11	11	10	6	4	4	1	10
Sea star	6	9	6	7	9	11	21	18	2	8	5	3	9
Invertebrate unidentified	0	1	0	14	2	4	0	10	0	0	0	0	3
Bivalves	15	1	1	3	2	1	0	0	0	0	0	0	2
Dark Rockfish						2	4	4	0	0	0	0	1
Scypho jellies	0	0	1	2	0	0	0	0	0	3	6	2	1
Snails	1	1	0	1	1	2	3	1	0	1	1	0	1
Greenlings	1	0	0	4	1	1	0	1	0	0	0	0	1
Urchins dollars cucumbers	1	1	0	1	1	0	1	0	0	0	0	0	1
Sea anemone unidentified	0	0	1	1	1	0	1	1	0	1	0	0	1
Sea pens whips	0	0	0	0	0	0	1	1	0	0	0		0
Eelpouts	0	1	0	0	0	0	0	0	0	0	0	0	0
Benthic urochordata	0	0	0	0	1	0	0	0	0	0	0	0	0
Misc crustaceans	0	0	0	0	0	0	0	0	0	0	0	0	0
Hermit crab unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0
Brittle star unidentified	0	0	0	0	1	0	0	0	0	0	0	0	0
Pandalid shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaete unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0
Pacific Sand lance	0		0	0	0	0		0					0
Eulachon			0	0	0	0				0			0
Misc inverts (worms etc)		0	0	0	0	0	0	0	0	0	0	0	0
Capelin					0	0				0	0	0	0
Stichaeidae	0		0	0	0		0						0
Other osmerids			0	0	0					0	0		0
Gunnels		0	0		0								0
Birds	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc crabs	1	1	0	1	2	1	1	1	0	0	2	1	1

FIGURES

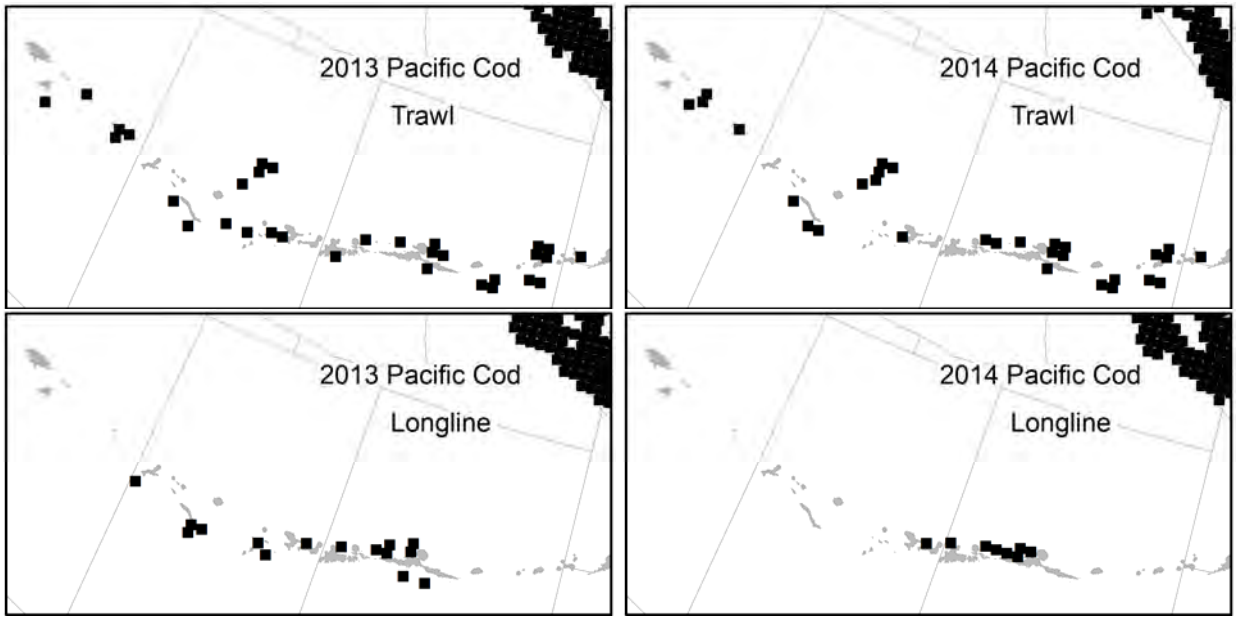


Figure 2A.1--AI maps showing each 400 square km cell with trawl hauls or longline sets containing Pacific cod from at least 3 distinct vessels in 2013-2014, overlaid against NMFS 3-digit statistical areas.

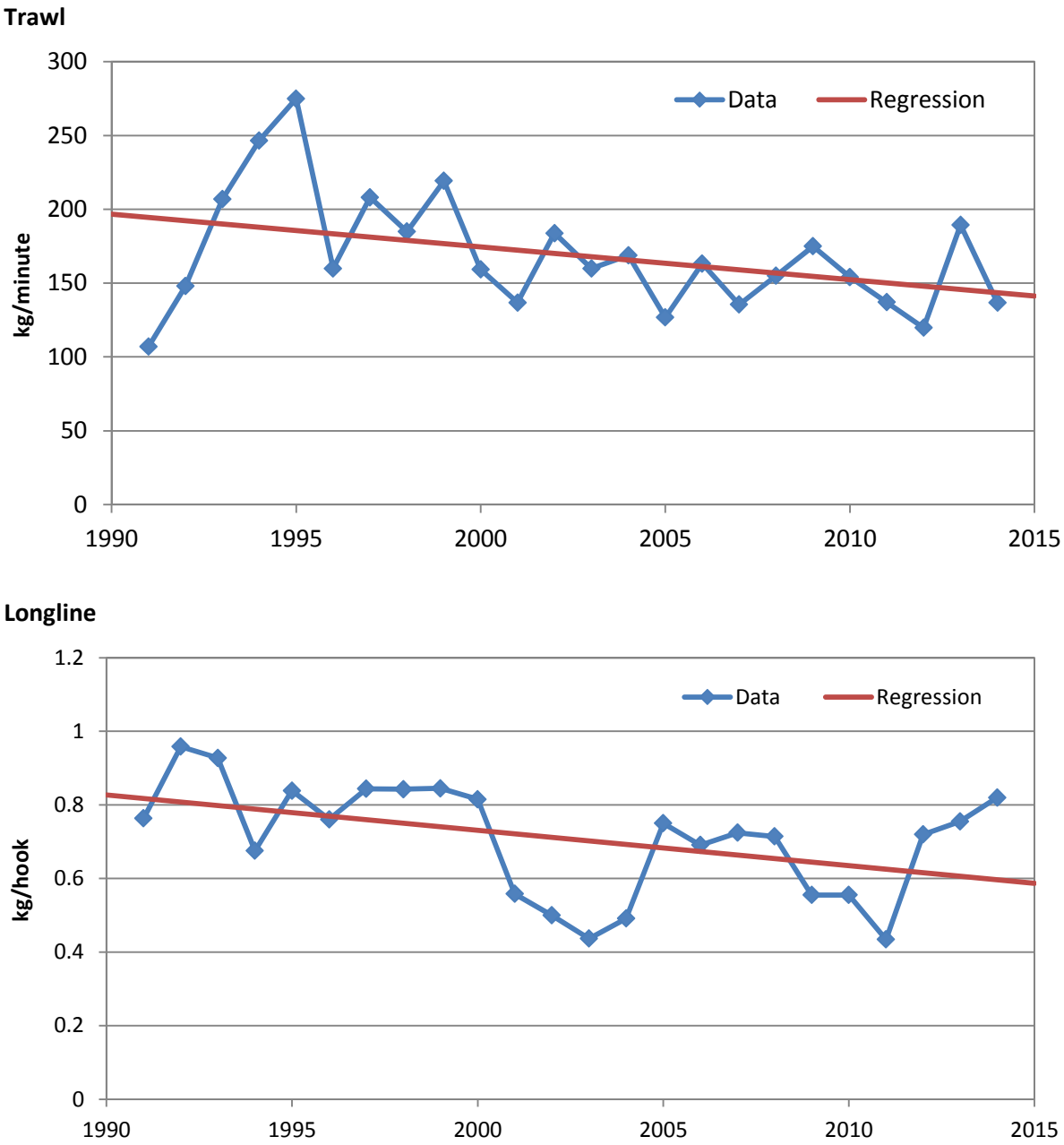


Figure 2A.2—Catch per unit effort for the trawl and longline fisheries, 1991-2014 (2014 data are partial).

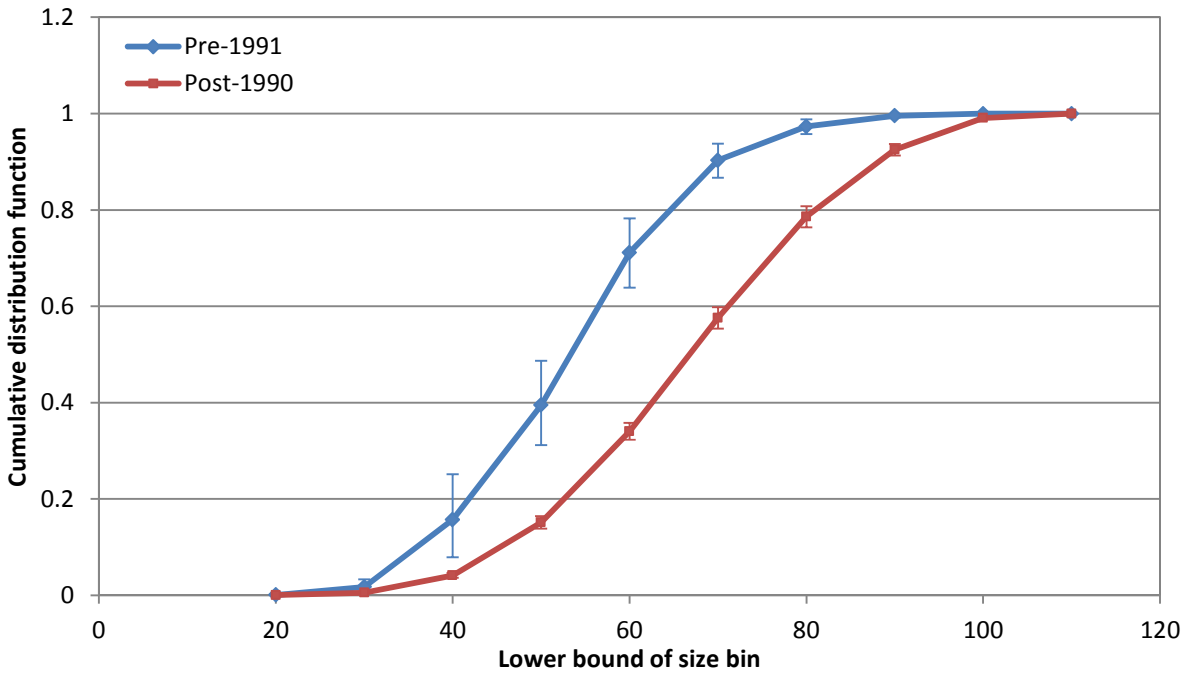


Figure 2A.3—Cumulative distribution functions of mean (across years) fishery size compositions during the 1977-1990 and 1991-2014 periods, with bootstrapped 95% confidence intervals.

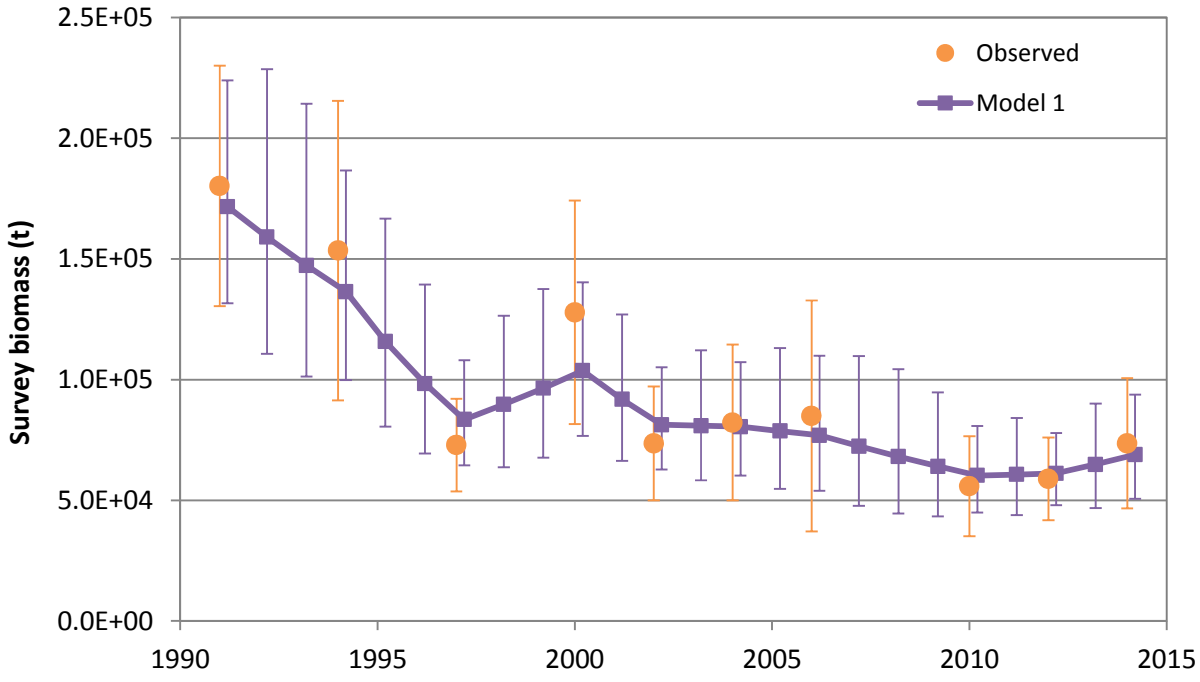


Figure 2A.4—Fit of Model 1 (Tier 5 random effects model) to survey biomass time series, with 95% confidence intervals for the observations and the estimates.

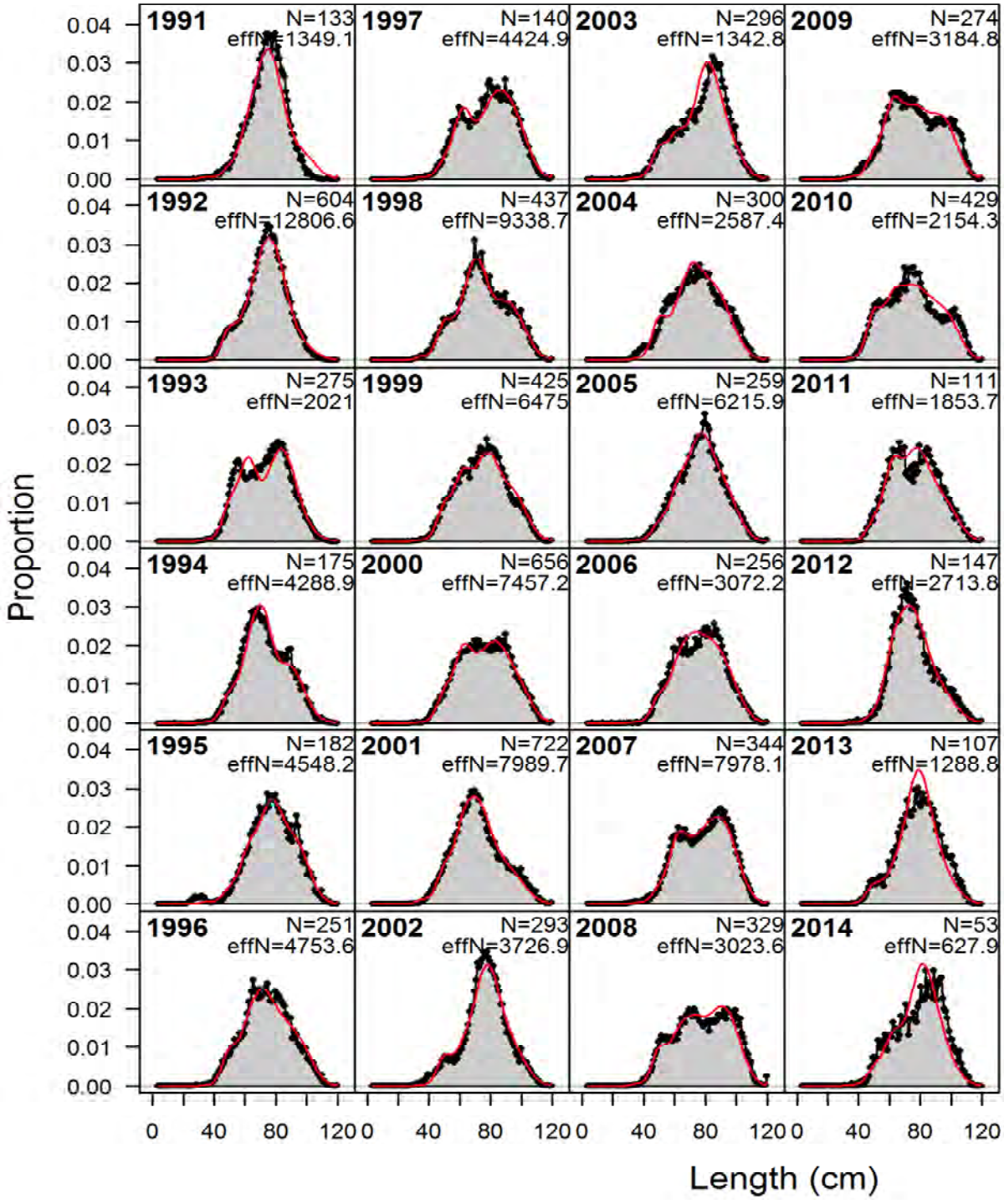


Figure 2A.5a—Fit to fishery size composition data obtained by Model 2 (grey = observed, red = estimated).

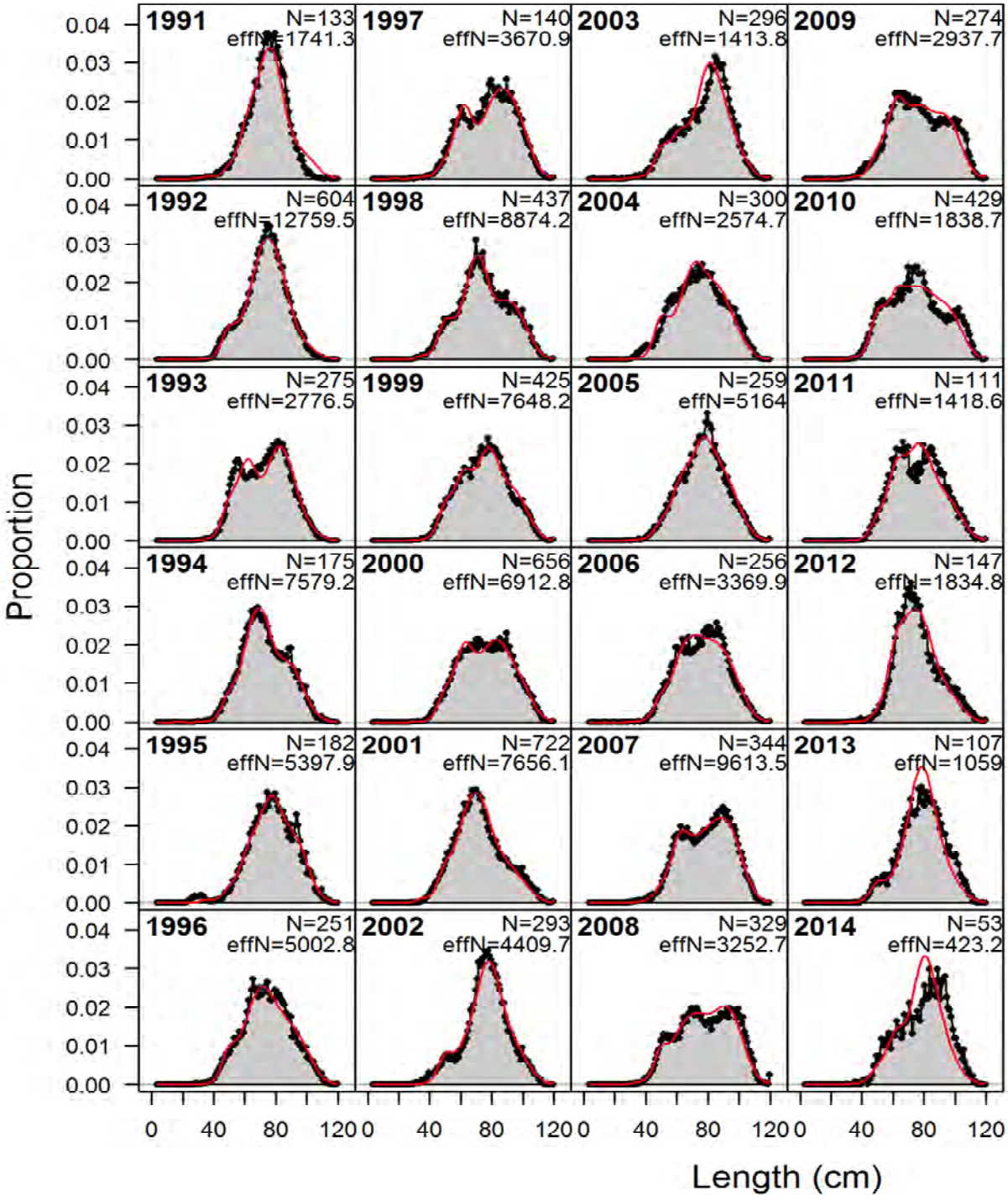


Figure 2A.5b—Fit to fishery size composition data obtained by Model 3 (grey = observed, red = estimated).

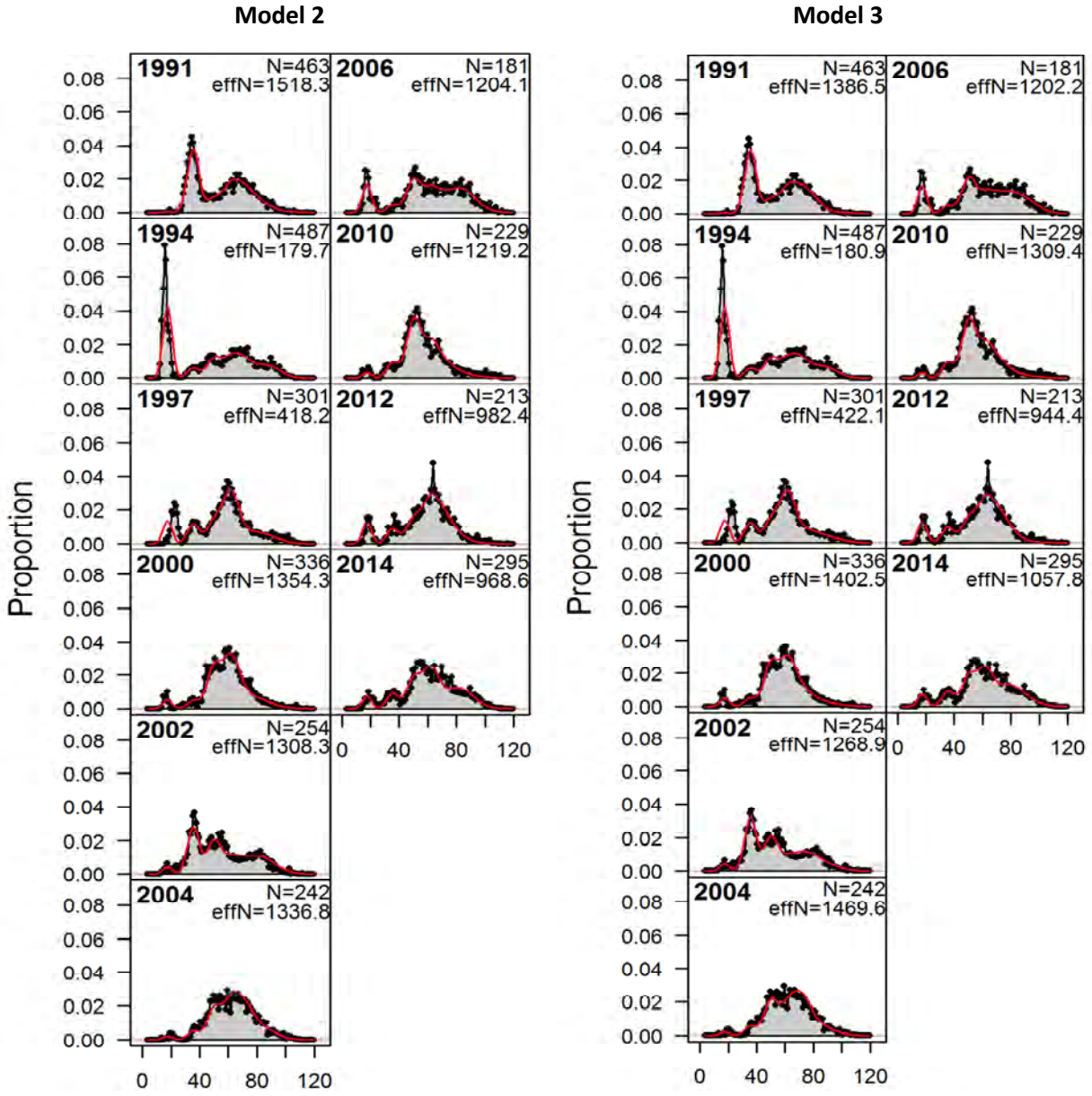


Figure 2A.6—Fits to survey size composition data obtained by Models 2 and 3 (grey = observed, red = estimated).

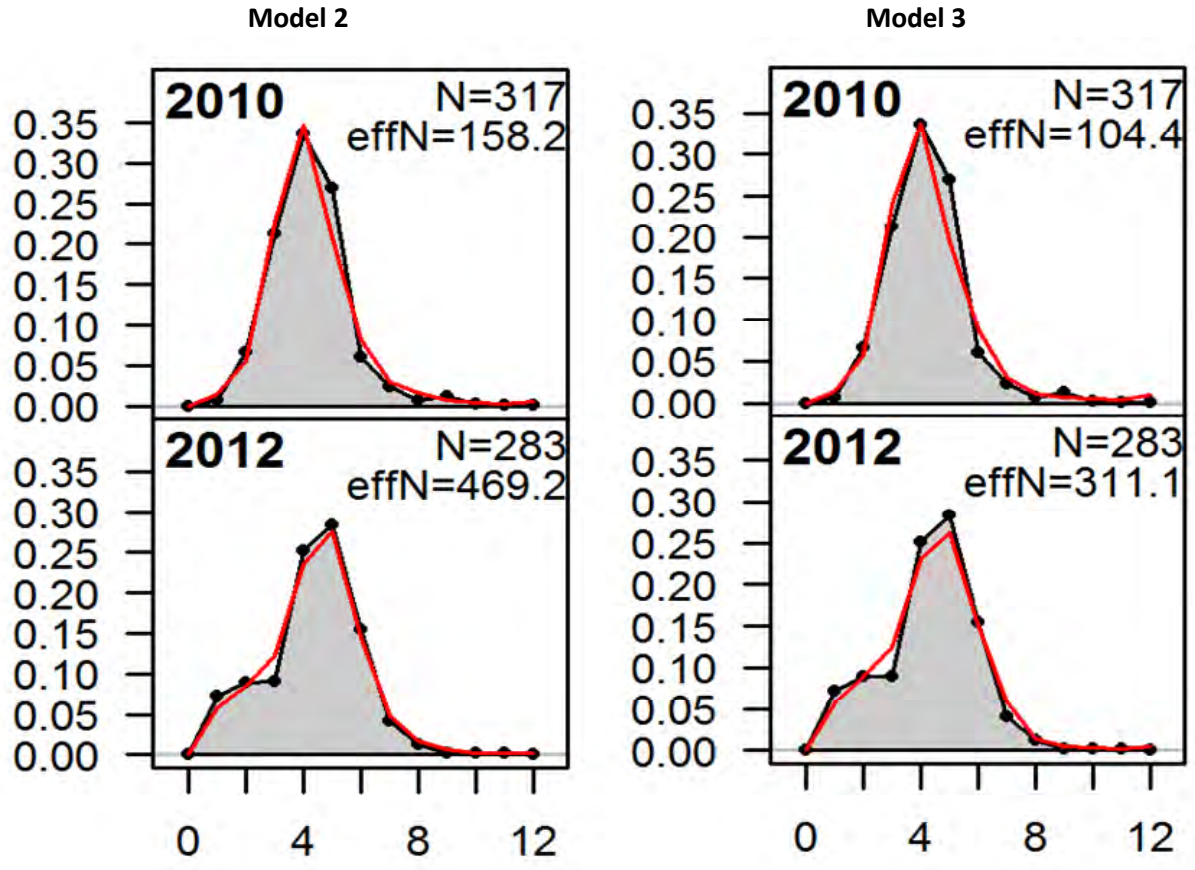


Figure 2A.7—Fits to age composition data obtained by Models 2 and 3 (grey = observed, red = estimated).

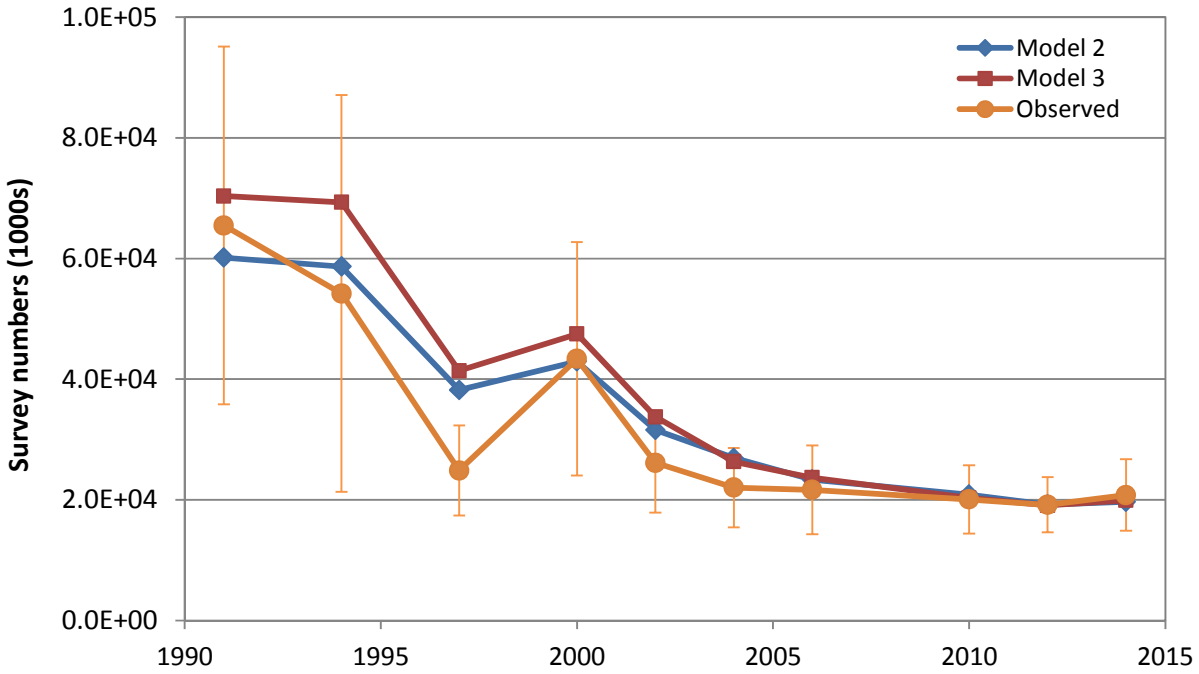


Figure 2A.8—Tier 3 model fits to the survey abundance time series, with 95% confidence intervals for the observations.

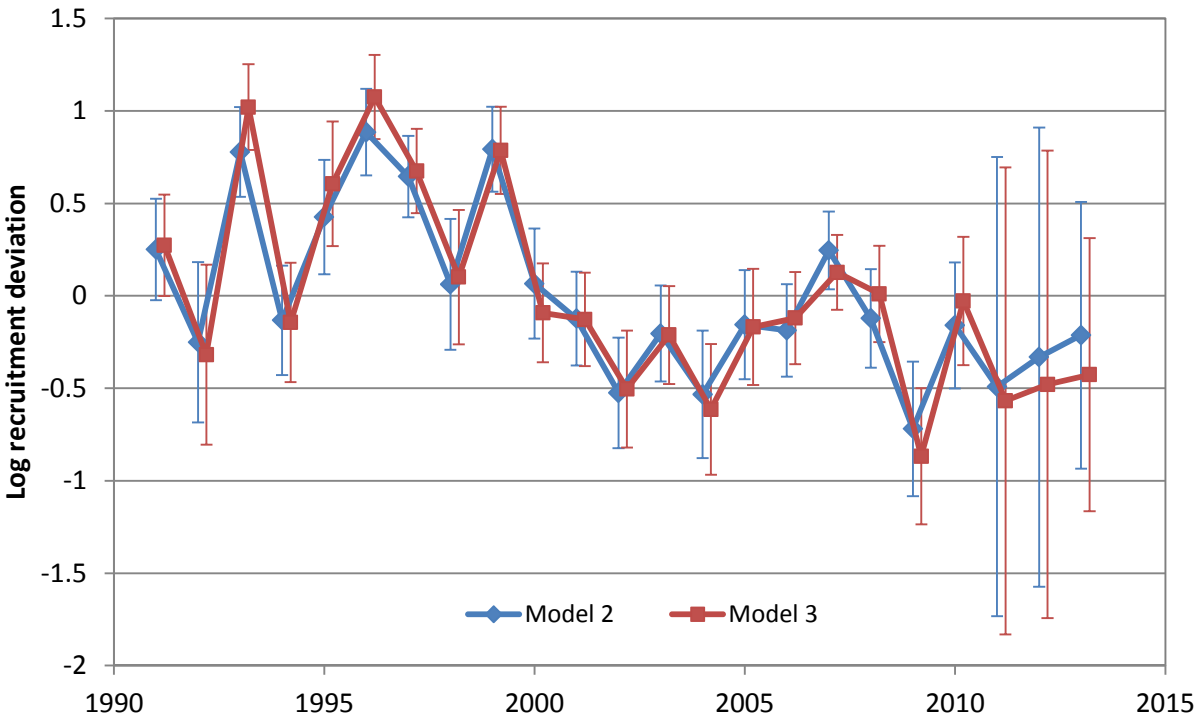


Figure 2A.9—Time series of estimated log recruitment deviations from Models 2 and 3, with 95% confidence intervals (horizontal axis values have been offset slightly to prevent over-plotting).

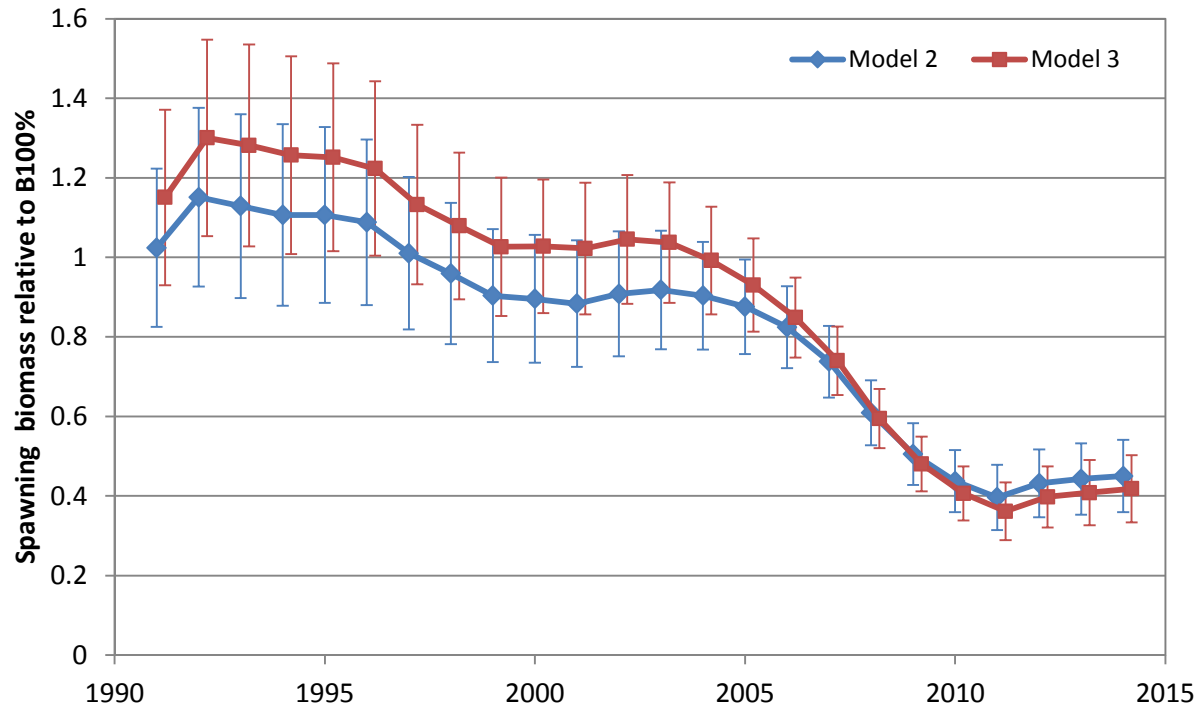


Figure 2A.10—Time series of spawning biomass relative to $B_{100\%}$ as estimated by Models 2 and 3.

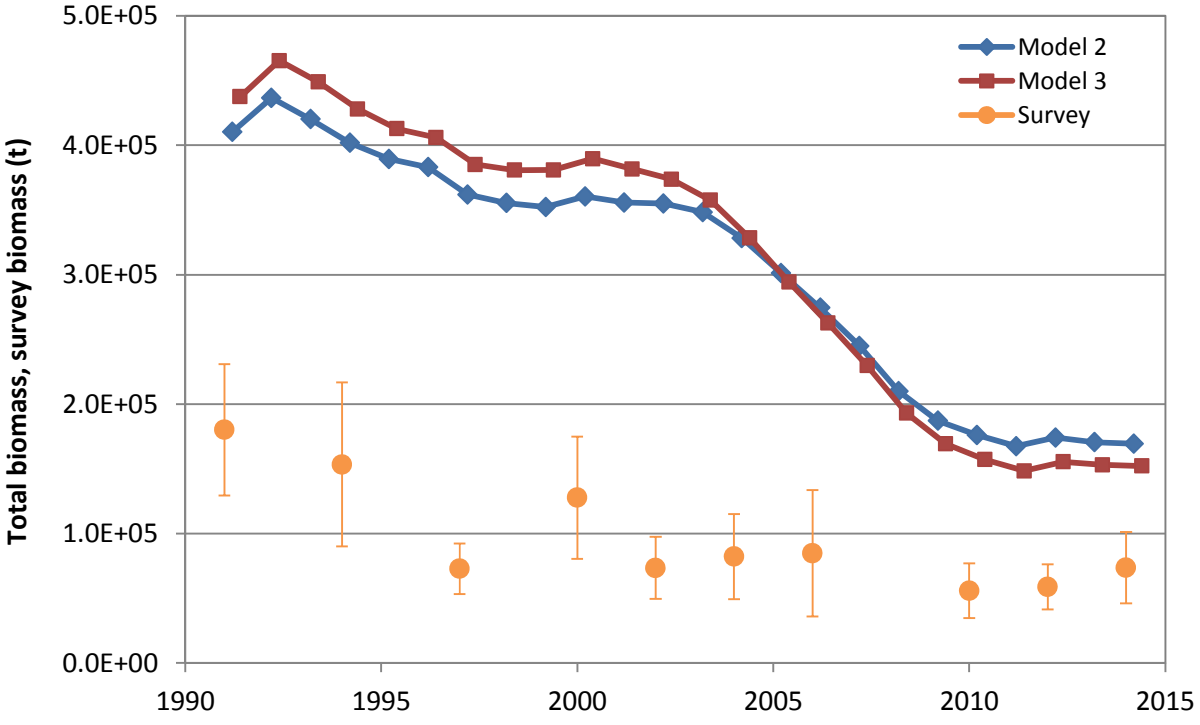
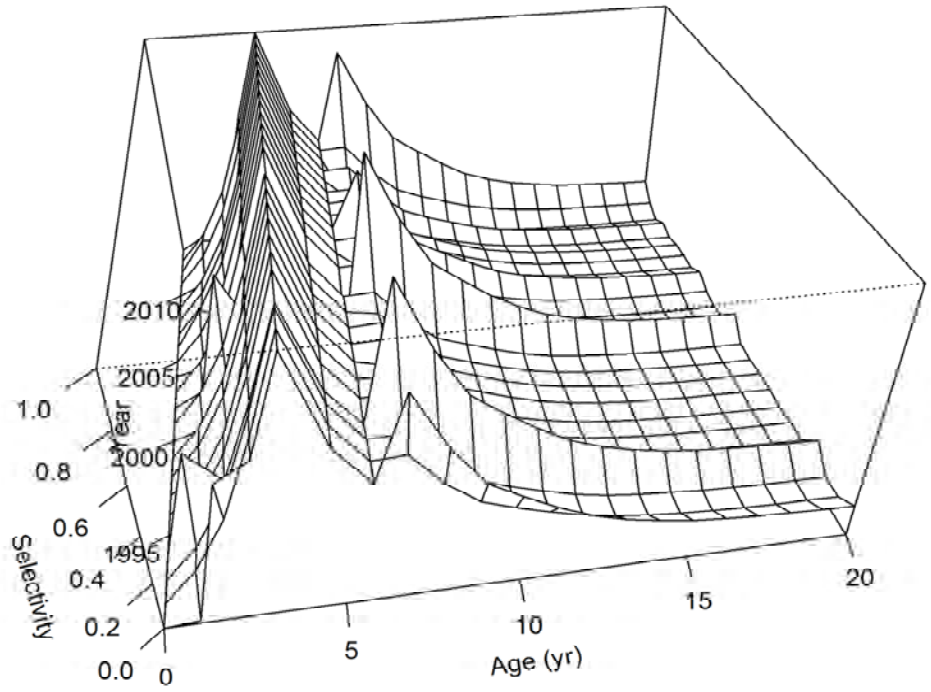


Figure 2A.11—Time series of total (age 0+) biomass as estimated by Models 1 and 2, together with survey biomass observations (horizontal axis values have been offset slightly to prevent over-plotting).

Model 2



Model 3

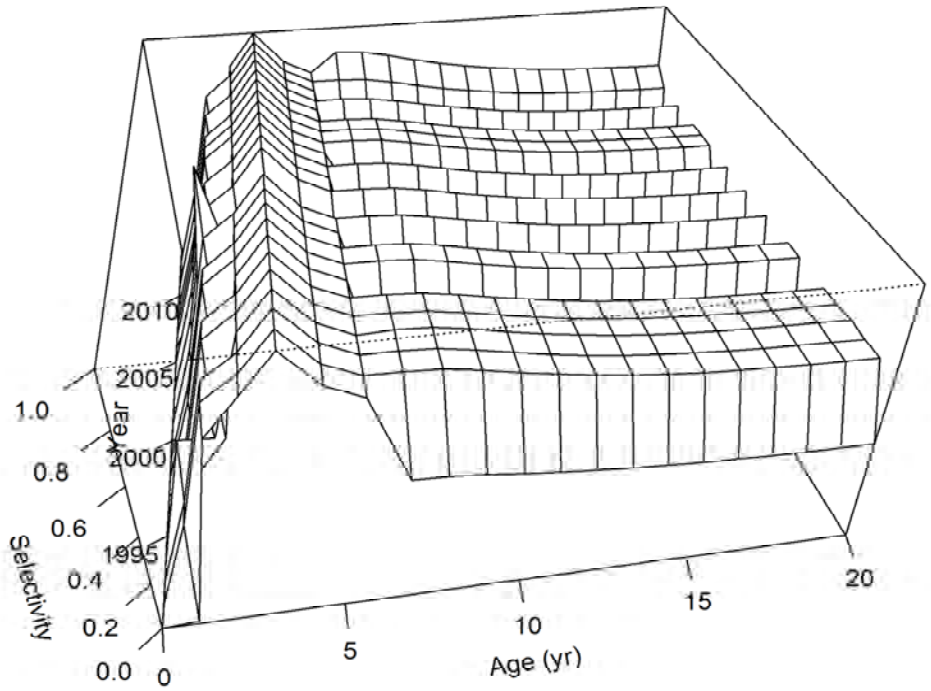
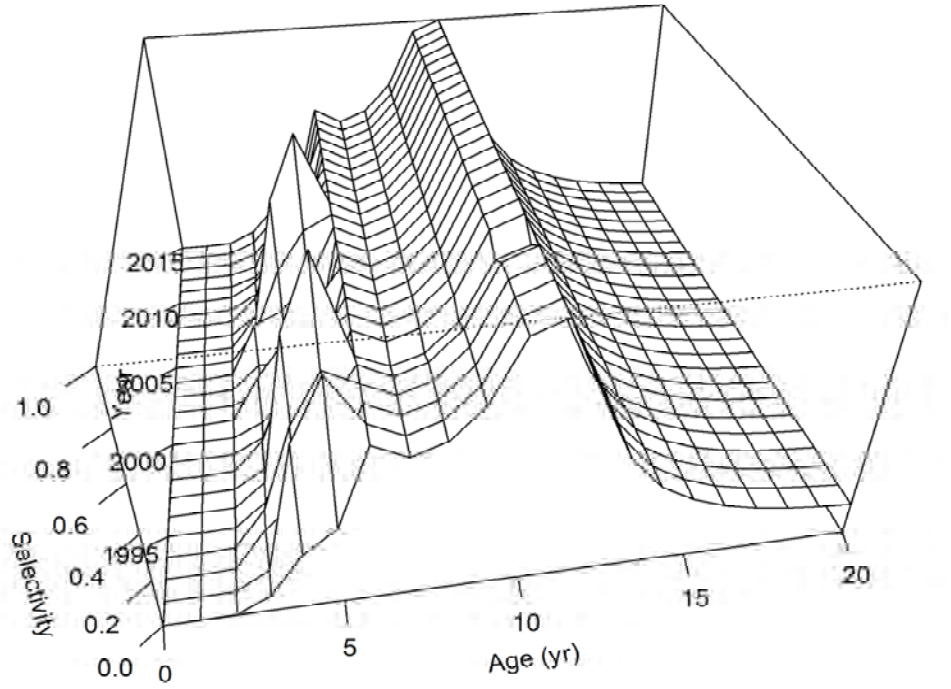


Figure 2A.12—Survey selectivity at age as estimated by Models 2 and 3.

Model 2



Model 3

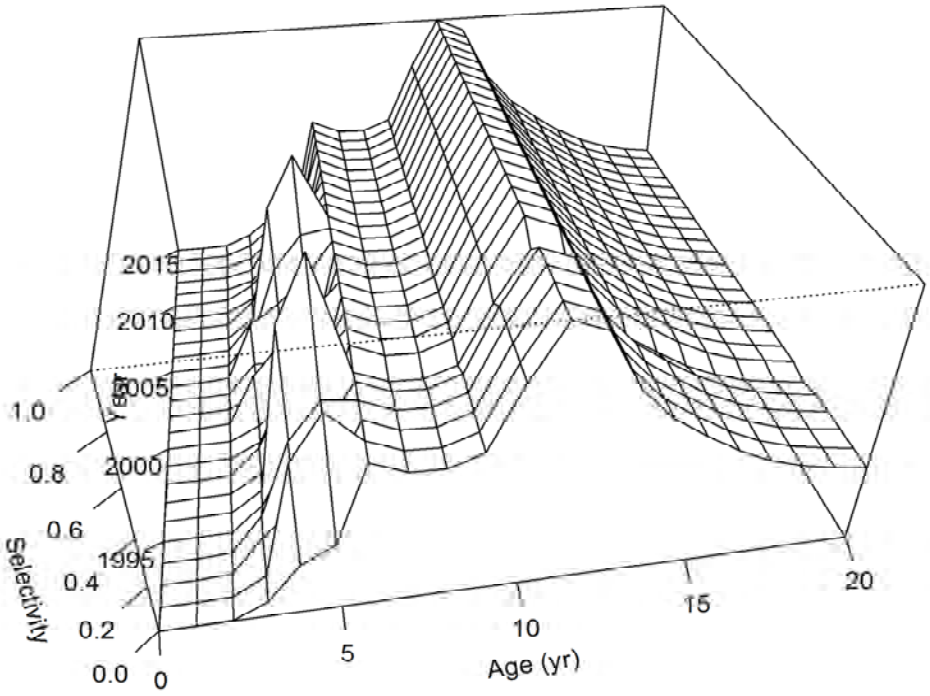


Figure 2A.13—Fishery selectivity at age as estimated by Models 2 and 3.

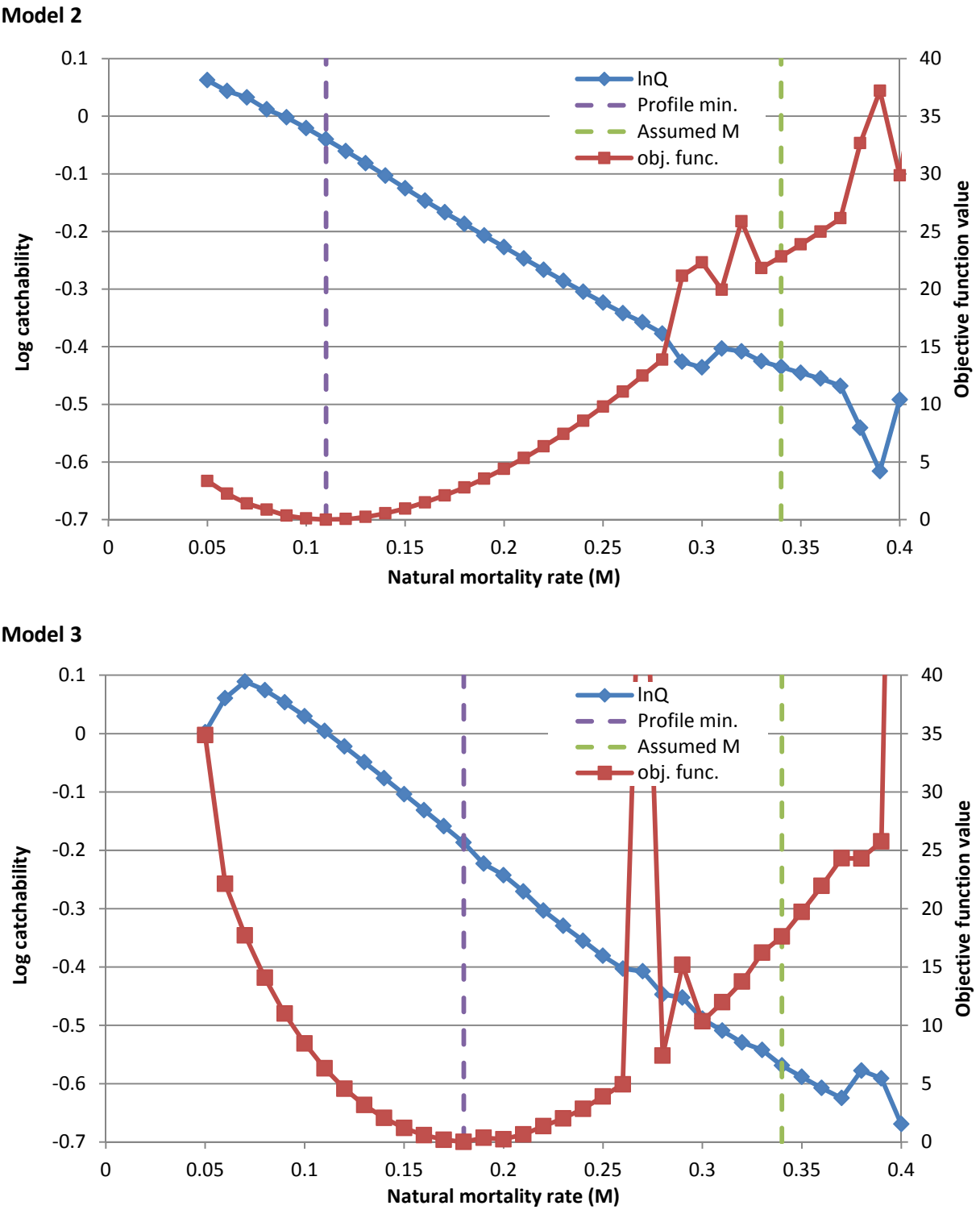


Figure 2A.14— Likelihood profiles with respect to the natural mortality rate for Models 2 and 3. Objective function minima occur at M=0.11 (Model 2) and M=0.18 (Model 3). The relationship between M and log Q is also shown. The jagged shapes for high values of M are likely due to lack of convergence in some runs.

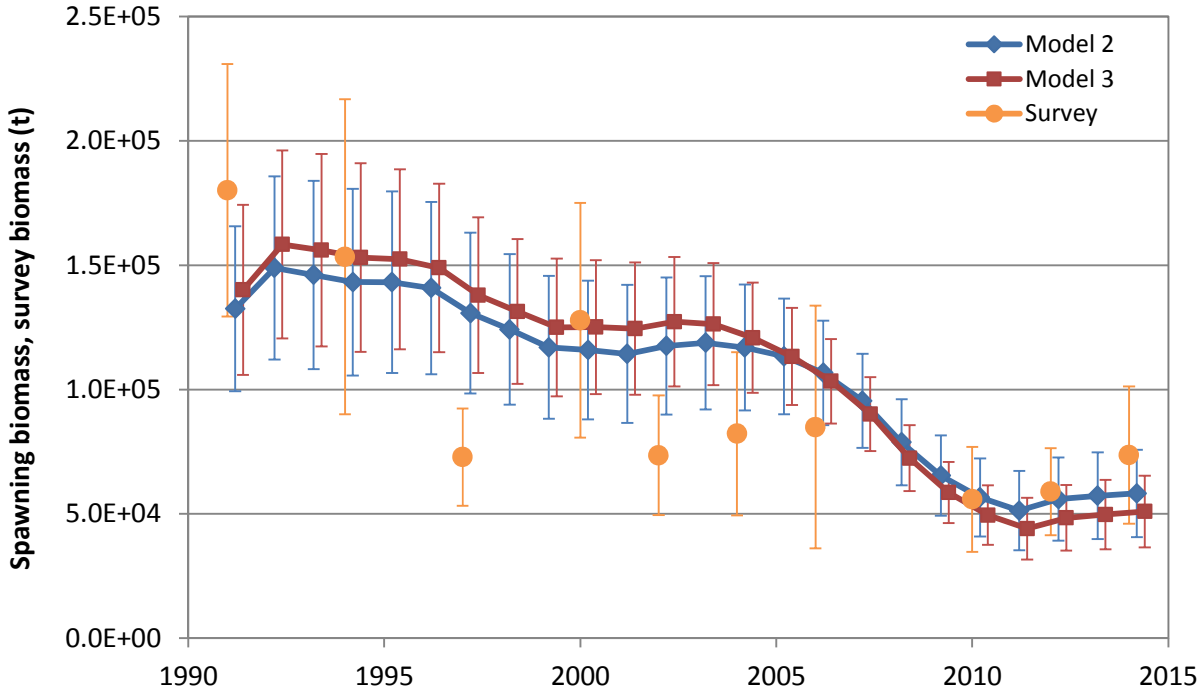


Figure 2A.15—Time series of female spawning biomass as estimated by Models 2 and 3, with 95% confidence intervals. Survey biomass is shown for comparison.

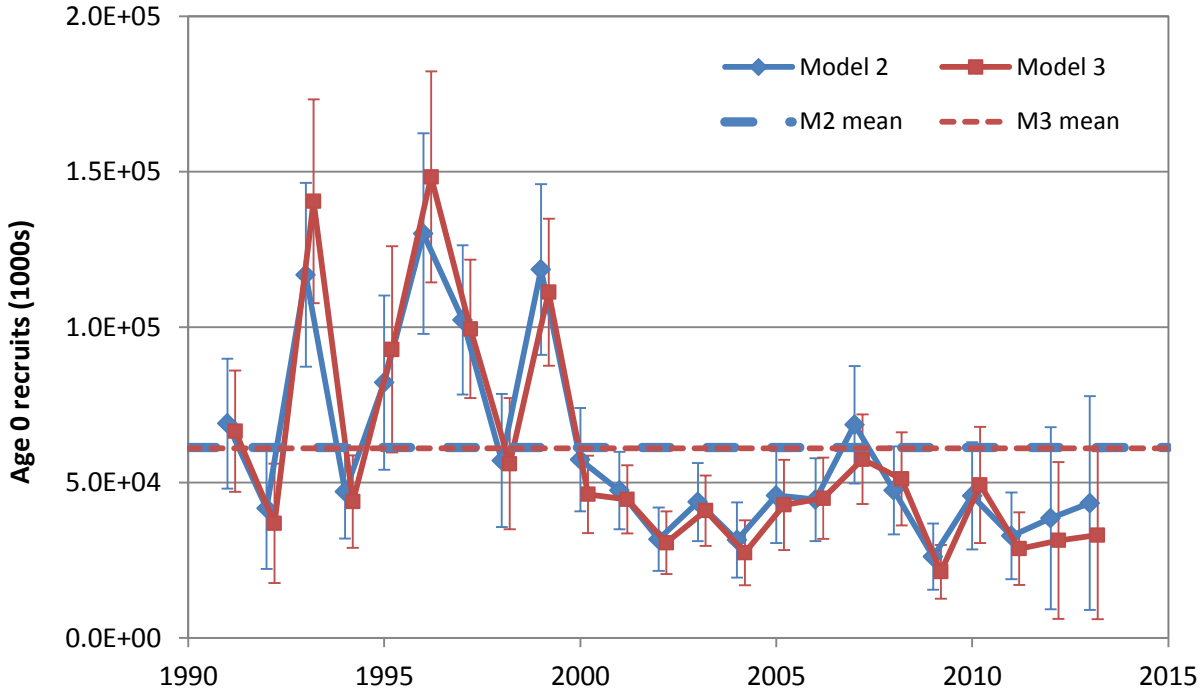


Figure 2A.16—Time series of recruitment at age 0 as estimated by the stock assessment model (horizontal axis values have been offset slightly to prevent over-plotting).

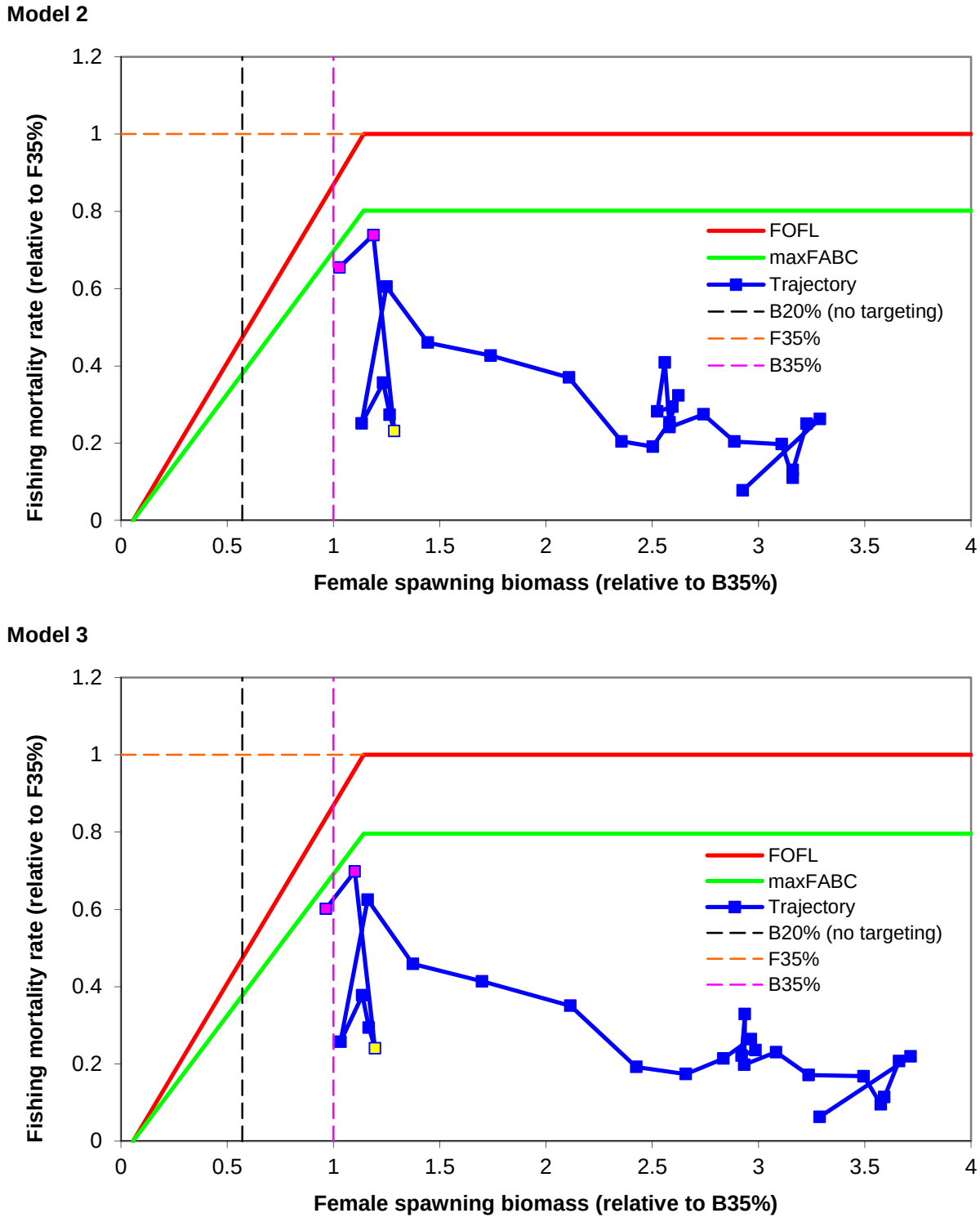


Figure 2A.17—Trajectory of AI Pacific cod fishing mortality and female spawning biomass as estimated by Models 2 and 3, 1991-present (yellow square = 2014, magenta squares = first two projection years).

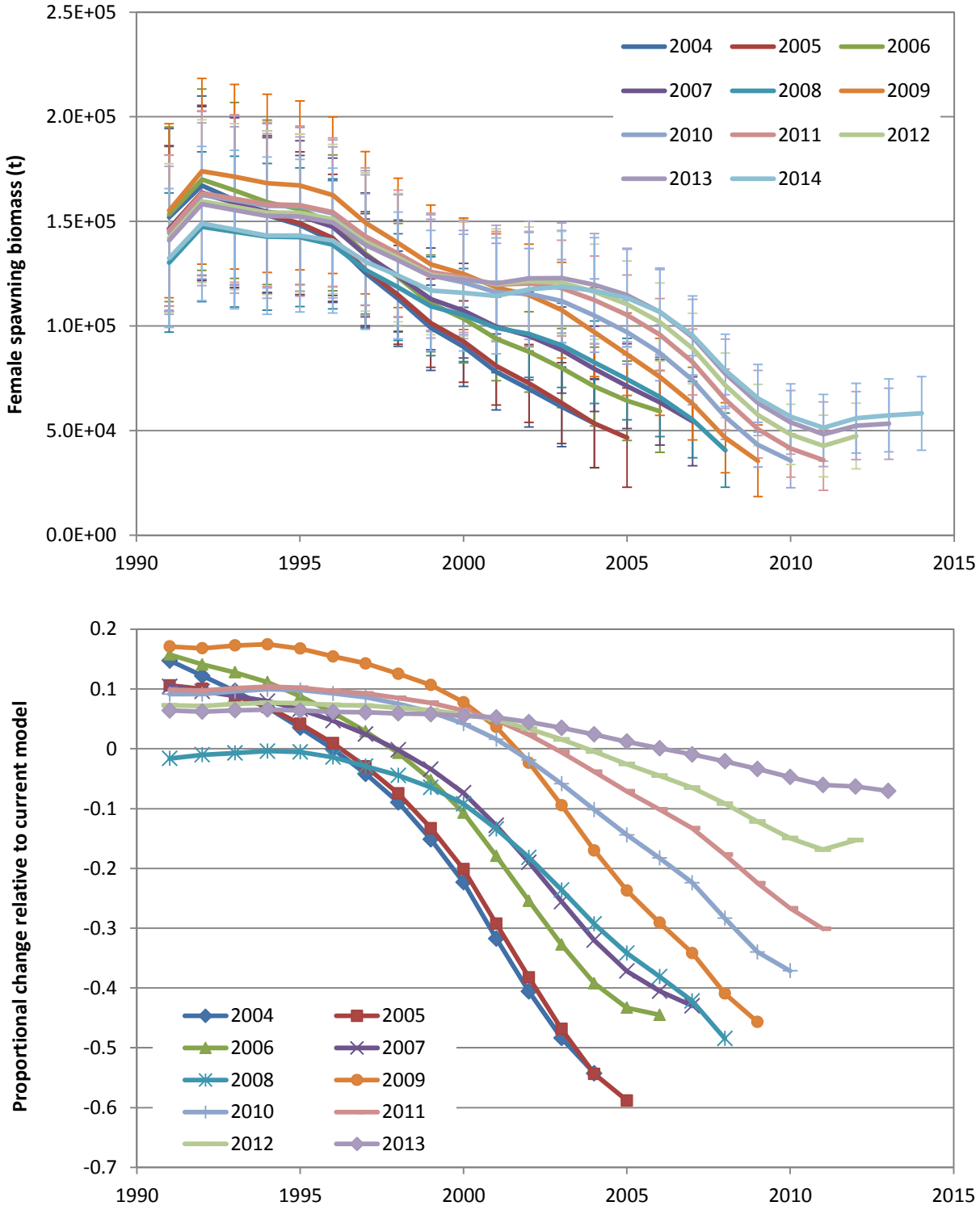


Figure 2A.18a—Retrospective analysis of spawning biomass estimates from Model 2. Top panel: spawning biomass time series with 95% confidence intervals from the current version of Model 2 (2014) and 10 retrospective runs (2004-2013) obtained by dropping one year of data at a time. Bottom panel: change in spawning biomass relative to the current version of Model 2 for each of 10 retrospective runs.

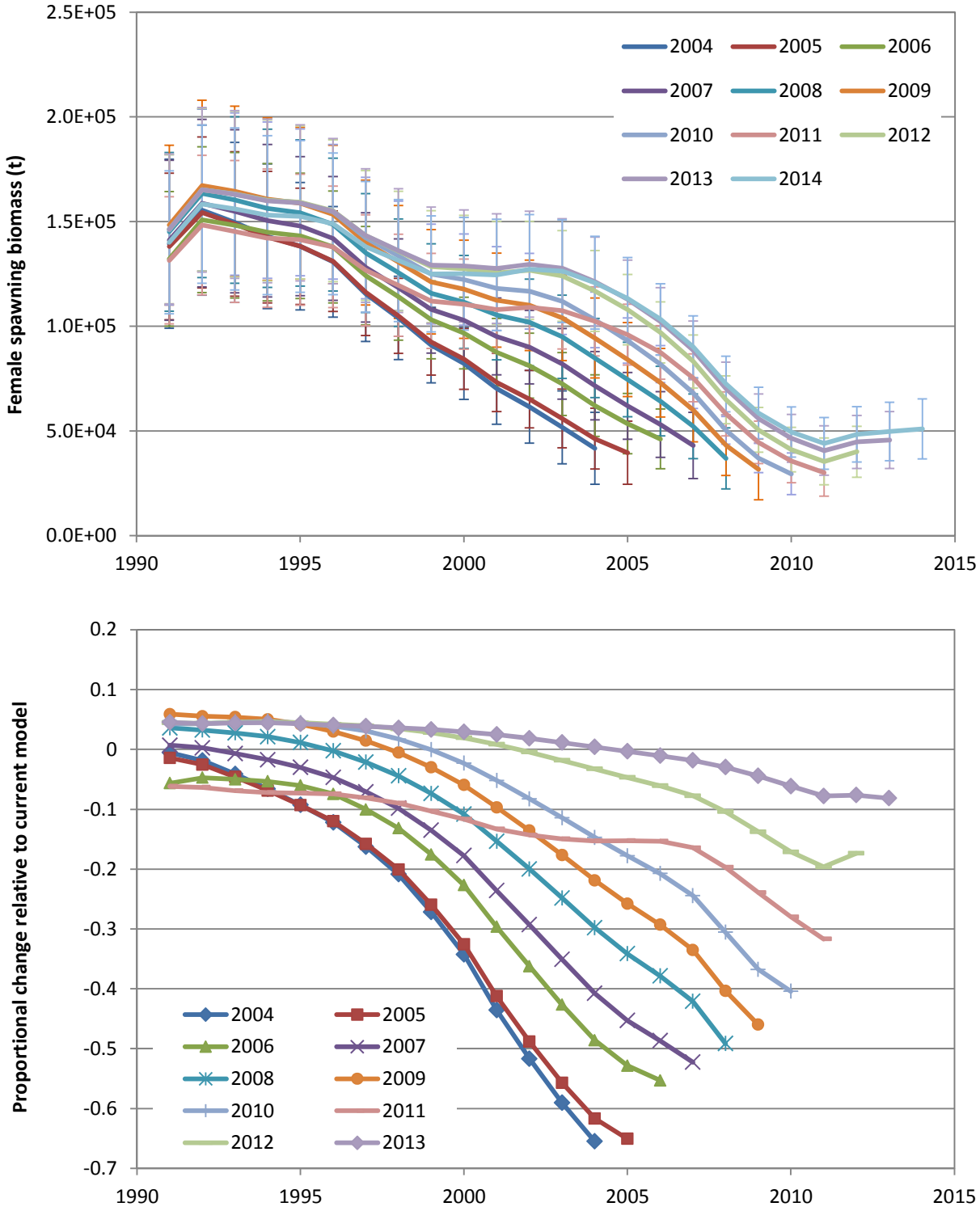


Figure 2A.18b—Retrospective analysis of spawning biomass estimates from Model 3. Top panel: spawning biomass time series with 95% confidence intervals from the current version of Model 3 (2014) and 10 retrospective runs (2004-2013) obtained by dropping one year of data at a time. Bottom panel: change in spawning biomass relative to the current version of Model 3 for each of 10 retrospective runs.

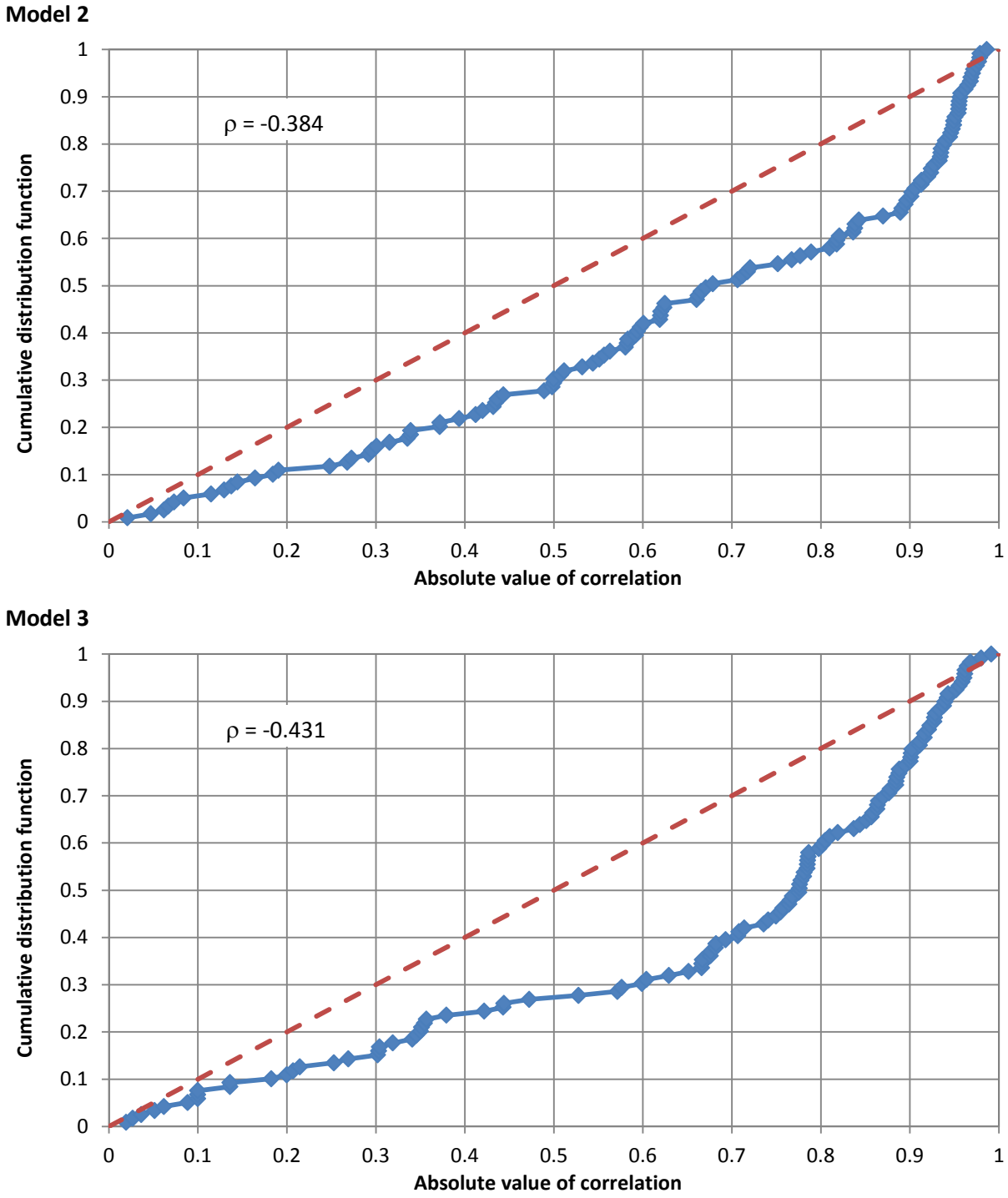


Figure 2A.19—Cumulative distribution function (cdf) of correlations (absolute value) between parameters and number of "peels" in retrospective runs in Models 2 and 3. The diagonal dashed line represents the cdf that would be obtained from a uniform distribution. The statistic ρ represents the average (across peels) relative bias in terminal year estimates of spawning biomass.

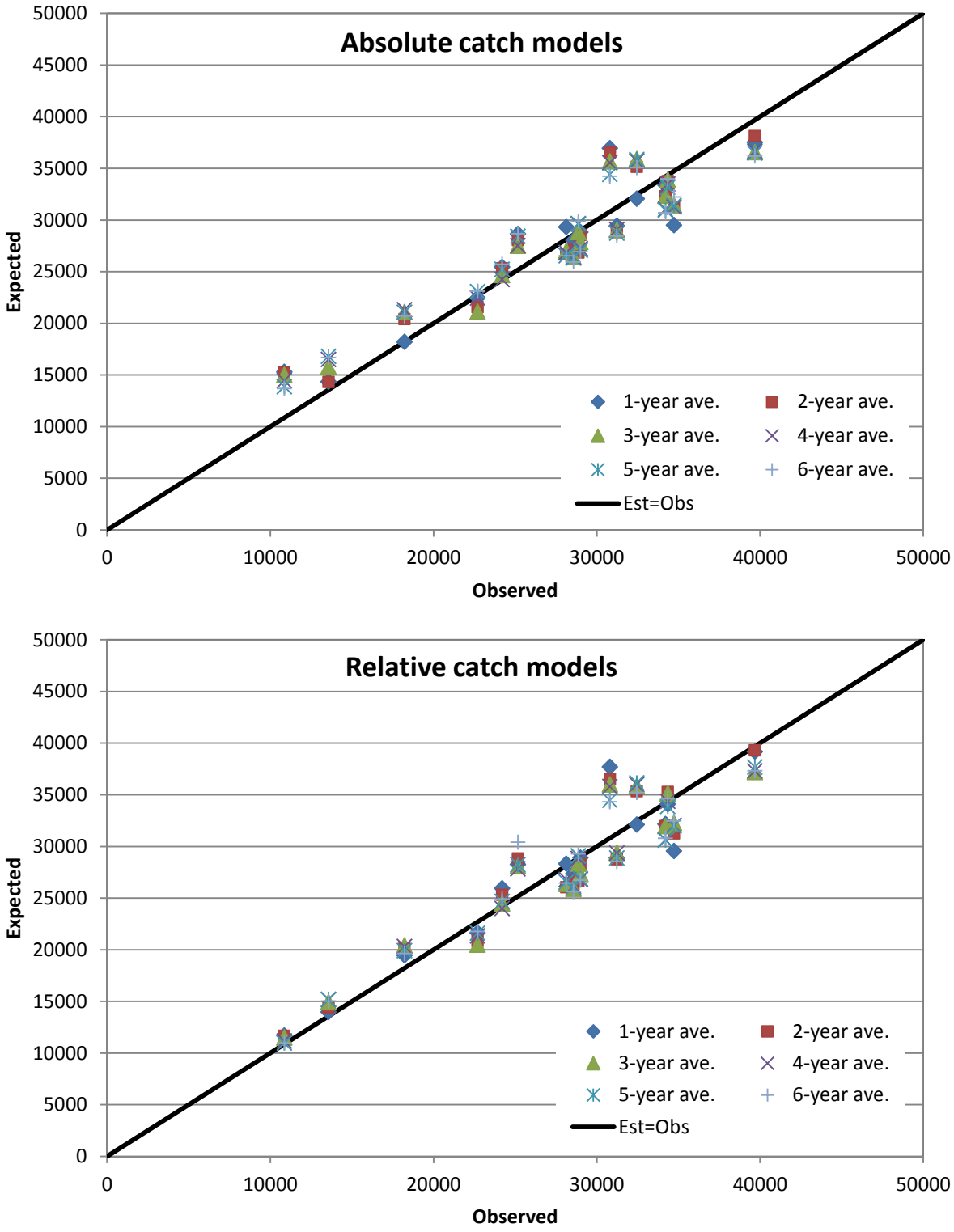


Figure 2A.20—Estimators of current-year catch as a function of either absolute or relative August-December catch in some number (1-6) of previous years. Estimators with symbols closer to the diagonal line are better than others.

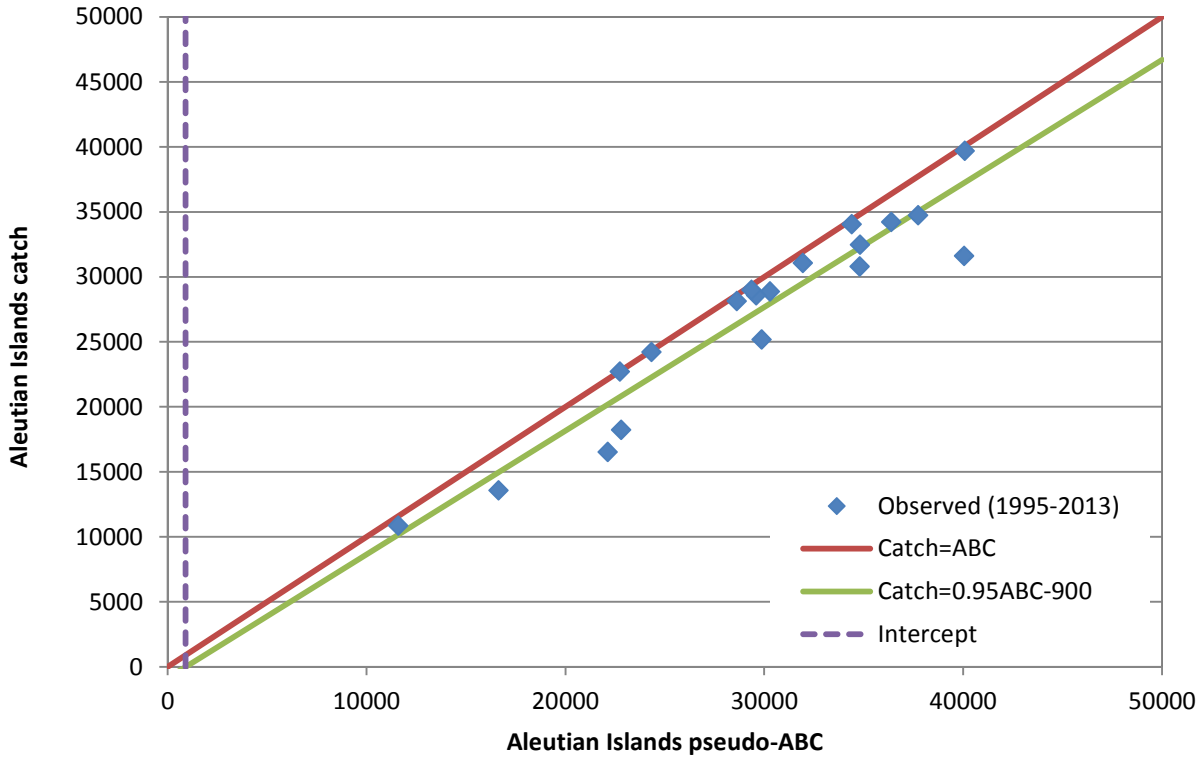


Figure 2A.21—Estimation of catch as a function of ABC. Because Pacific cod ABCs through 2013 were specified for the entire BSAI region, "pseudo-ABCs" are shown here, computed by multiplying the overall ABC by the proportion of BSAI catch taken in the AI. The estimator represented by the green line was used to project 2015 and 2016 catch for Models 2 and 3.

APPENDIX 2A.1: PRELIMINARY ASSESSMENT OF THE PACIFIC COD STOCK IN THE ALEUTIAN ISLANDS

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Introduction

This document represents an effort to respond to comments made by the BSAI Plan Team, the joint BSAI and GOA Plan Teams, and the SSC regarding the need to develop an age-structured model of the Pacific cod (*Gadus macrocephalus*) stock in the Aleutian Islands (AI). The age-structured models presented in last year's stock assessment (Thompson and Palsson 2013) were not accepted for use by the BSAI Plan Team or SSC.

Responses to SSC and Plan Team Comments on Assessments in General

Because last year's SSC and Plan Team comments pertaining to assessments in general all dealt with features of the final SAFE chapters, they will be addressed in this year's final assessment.

Responses to SSC and Plan Team Comments Specific to Aleutian Islands Pacific Cod

Note: In previous years, the full Joint Plan Teams have met in the spring to consider recommendations for models to be included in that year's Pacific cod assessments. In 2014, this task was delegated to a Joint Team Subcommittee (JTS) on Pacific Cod Models. All comments specific to AI Pacific cod from the September 2013 BPT and October 2013 SSC meetings were addressed in the 2013 final assessment.

BPT1 (11/13 minutes): *"For continued development of a Tier 3 assessment, the Team recommended:*

a. *forcing the regime change recruitment offset to zero*
b. *examining the usefulness of IPHC longline survey data, and*
c. *continuing to monitor commercial CPUE."*

Subsequent conversation with Team members clarified that only item (a) in the above list was a model proposal; the other two items were comments not directly related to development of a new model. For item (a), see comment JTS1. No progress has been made on items (b) or (c).

SSC1 (12/13 minutes): *"The SSC encourages further work on the age-structured models. Some of the issues are very similar to those in the Bering Sea, in particular the appropriate shape of the selectivity function. The SSC notes that selectivity was modeled differently in the AI model using an empirical and more flexible approach, although the model with asymptotic selectivity (and estimated Q) produced a better fit."* Further work on the age-structured models is described in this preliminary assessment. The empirical and more flexible approach described in this comment was retained, with some modification, in this preliminary assessment. One of the models described here imposes asymptotic selectivity, and all three models estimated survey catchability (Q) internally. See also response to comment JTS1.

SSC2 (12/13 minutes): *"At this still early stage of model development, the SSC does not want to be overly prescriptive, but suggests bringing forward models that:*

a. focus on exploring the effects of different shapes of selectivity-at-age,
b. including a model with asymptotic selectivity."

Different shapes of the selectivity-at-age schedule are explored in the models presented in this preliminary assessment, and a model with forced asymptotic selectivity is included. See also response to comment JTS1.

JTS1 (3/14 minutes): *"For the AI, the subcommittee recommended that the following models be developed for this year's preliminary assessment:*

- *Model 1: A new model (author's choice) with the regime change recruitment offset fixed at 0.0*
- *Model 2: A new model (author's choice) with alternative selectivity specification(s)*
- *Model 3: A new model (author's choice) with forced asymptotic selectivity*

The subcommittee noted that the above list includes both of the model proposals contained in the SSC's December 2013 minutes. The subcommittee also suggested that obtaining a much larger supply of age data from the AI is more important than development of additional models at this point." This preliminary assessment includes all of the models requested in this comment. Additional age data are expected to be available in time for use in this year's final assessment.

SSC3 (4/14 minutes): *"The process for developing and refining appropriate models for Pacific cod still needs to mature and the SSC recommends that the assessment authors continue to work with the subcommittee to refine this process."* The authors will continue to work with the subcommittee to refine the process of developing appropriate models for Pacific cod. The next meeting of the subcommittee is anticipated to take place in the spring of 2015.

SSC4 (4/14 minutes): *"For 2014, the SSC recommends as an alternative model the use of the time-varying, non-parametric selectivity function described above"* (the reference to "above" in this comment pertains to a recommendation for modeling selectivity as a random walk with respect to age in the GOA Pacific cod assessment). Given the lack of any language to the contrary, it will be assumed that the SSC accepts the list of models recommended by the JTS, with the understanding that random walk selectivity is included in the "alternative selectivity specification(s)" requested for Model 2 in comment JTS1.

SSC5 (4/14 minutes): *"Additionally, profiling over the natural mortality rate should be conducted to gain a better understanding of the relationship between global scaling (Q and its associated priors) and natural mortality rate. The mode of the M-profile should not be used as a basis for setting the natural mortality rate in the model as it is conditional on other structural assumptions in the model."* Likelihood profiles with respect to the natural mortality rate are included for all models in this preliminary assessment. The mode is not used for setting the natural mortality rate in any of the models.

SSC6 (4/14 minutes): *"Lastly, the SSC recommends that as an overarching goal for these three areas, a common model structure be explored and based on the biology of Pacific cod and not devolve over time to address area-specific outliers or retrospective biases"* (the "three areas" referred to in this comment are the EBS, AI, and GOA). The model structures for all three areas already share several features in common. As further steps toward developing a common model structure, all models in this preliminary assessment of the AI stock and Model 6 in the preliminary assessment of the EBS stock use the same fleet structure and the same approach to selectivity.

SSC7 (4/14 minutes): *"The SSC clarified its intent regarding the use of the base model ('base' being used here to identify the model accepted by the SSC in the previous year) for 'several' years. While the SSC cannot be prescriptive about the exact length of time this would be, the idea is to continue the use of the model until there is general agreement by the stock assessment authors, the Plan Team, and the SSC on discontinuing its use."* This comment was directed primarily toward the EBS and GOA Pacific cod assessments, where age-structured models have been in use for several years. In the case of the AI Pacific cod stock, no age-structured model has yet been accepted for use. The existing management approach is based on Tier 5, applying a random effects model to the survey biomass time series in order to obtain the best estimate of current biomass. The authors understand that this approach will continue to be used until such time as the SSC adopts a different approach.

SSC8 (4/14 minutes): *"The SSC discussed the use of model averaging to ameliorate some of the problems of choosing among competing models with substantially different estimates. Essentially, the SSC agrees with the analyst that this approach should not be used until progress is made regarding issues about the selection of the competing models and averaging over models with nonlinearities in population and fishery processes."* Model averaging is not used in this preliminary assessment.

SSC9 (4/14 minutes): *"The SSC also discussed the nomenclature used to specify models in a historical context (when introduced and the model designator). While the SSC understands that this was useful for the historical presentation, it also notes that the nomenclature is confusing and probably not useful for the assessment in a given year. Furthermore, the use of "base model" to denote any model that is proposed seems overly inclusive and perhaps should be restricted to the chosen model in a previous assessment year."* Use of the term "base model" will henceforth be restricted to denoting the chosen model in a previous assessment year.

Data

The data file used for all three models presented here is identical to that used in last year's final assessment, with two exceptions:

1. Data prior to 1991 were removed, because last year's models had difficulty giving reasonable estimates of biomass and fishing mortality during the early years of the time series. Note that survey data from prior to 1991 had already been removed from last year's file.
2. Weighting of size composition data was adjusted so that the average (across years) was 300 for the fishery and 300 for the survey (in last year's assessment, the weighting achieved an average of 300 for the fishery and survey combined; the new adjustment results in more weight being given to the survey than before).

The following table summarizes the sources, types, and years of data included in the data file for one or more of the stock assessment models:

Source	Type	Years
Fishery	Catch biomass	1991-2012
Fishery	Catch size composition	1991-2012
AI bottom trawl survey	Numerical abundance	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012
AI bottom trawl survey	Size composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012

Analytic Approach

Model Structure

Per request of the Joint Team Subcommittee on Pacific Cod Models and the SSC, the following three models are presented in this preliminary assessment, all of which are estimated using Stock Synthesis (SS, Methot and Wetzel 2013):

- Model 1: A new model (author's choice) with the regime change recruitment offset fixed at 0.0
- Model 2: A new model (author's choice) with alternative selectivity specification(s)
- Model 3: A new model (author's choice) with forced asymptotic selectivity

All three are based on the models from last year's final AI assessment, which in turn were based on the accepted EBS model for 2012 (Thompson and Lauth 2012). Some of the main differences between last year's AI models and the 2012 EBS model were as follow:

1. In the data file, length bins (1 cm each) were extended out to 150 cm instead of 120 cm, because of the higher proportion of large fish observed in the AI.
2. Each year consisted of a single season instead of five.
3. A single fishery was defined instead of nine season-and-gear-specific fisheries.
4. The survey was assumed to sample age 1 fish at true age 1.5 instead of 1.41667.
5. Initial abundances were estimated for the first ten age groups instead of the first three.
6. Selectivity for both the fishery and survey was modeled using a random walk with respect to age (SS selectivity-at-age pattern #17) instead of the usual double normal. Selectivity-at-age pattern #17 in SS has one parameter for each age in the model. Except for age 0, the parameter for any given age represents the logarithm of the ratio of selectivity at that age to selectivity at the previous age (i.e., the backward first difference on the log scale). Age 0 fish are often expected to have a selectivity of zero, which can be achieved in this selectivity pattern by setting the parameter for age 0 equal to -1000, as was done for all three models presented here. As with other parameters in SS, each parameter in this selectivity pattern is associated with a prior distribution (see "Loop #1" under "Iterative Tuning Procedures Used for Model 2," below).

The three models presented in this preliminary assessment all include the following features, which represent additional departures from the 2012 EBS model:

1. The logarithm of survey catchability, ln(Q), was treated as a free parameter, with a normal prior distribution whose parameters were derived by averaging those used in other age-structured assessments of AI groundfish (similar to Model 2 in last year's preliminary and final assessments).
2. A normal prior distribution for each selectivity parameter was used, tuned so that the schedule of prior means (across age) was consistent with logistic selectivity, with a constant (across age) prior standard deviation.
3. Potentially, each selectivity parameter was allowed to be time-varying with annual additive *dev*s (normally distributed random deviations added to the base value of their respective parameter) where the sigma term was tuned according to the method described Thompson and Lauth (2012, Annex 2.1.1).

Except for the ln(Q) parameter and the selectivity and *dev* parameters in all models, all parameters were estimated with uniform prior distributions.

Model nomenclature follows that suggested in comment JTS1. Chronologically, model development proceeded as follows:

- Model 2 was developed first, with no constraint on the shape of the selectivity schedule other than that imposed by the prior distributions. For the vector of numbers at age in the initial year, SS allows the user to specify how many age groups to estimate as individual parameters, with the understanding that the remaining age groups are in equilibrium under an initial catch and mean recruitment level. The mean recruitment used to compute the equilibrium portion of the initial vector can be forced to equal the mean recruitment used for the remainder of the time series, or it can be allowed to differ, which is done by estimating a "recruitment offset" parameter. As in the EBS model, the recruitment offset parameter was estimated freely in Model 2.
- Model 1 was based on Model 2. The only change from Model 2 was that the recruitment offset parameter was fixed at a value of 0 in Model 1.
- Model 3 was also based on Model 2. The only changes from Model 2 were that survey selectivity first-differences were forced to equal zero after the age at which survey selectivity peaked in Model 2, and the lower bound on survey selectivity first-differences at all earlier ages was set at 0 (the combination of these two changes forced survey selectivity to increase monotonically until the age at which it peaked in Model 2, after which survey selectivity was constant at unity).

Development of the final versions of all models included calculation of the Hessian matrix. These models also passed a "jitter" test of 50 runs with a jitter parameter (equal to half the standard deviation of the logit-scale distribution from which initial values are drawn) of 0.01. In the event that a jitter run produced a better value for the objective function than the base run, then: 1) the model was re-run starting from the final parameter file from the best jitter run, 2) the resulting new control file became the new base run, and 3) the entire process (starting with a new set of jitter runs) was repeated until no jitter run produced a better value for the objective function than the most recent base run.

Except for the ln(Q) parameter and the selectivity and *dev* parameters in all models, all parameters were estimated with uniform prior distributions. Bounds were non-constraining in all cases.

The software used to run all models was SS V3.24s, as compiled on 7/24/2013 (Methot 2013). Stock Synthesis is programmed using the ADMB software package (Fournier et al. 2012).

Iterative Tuning Procedures Used for Model 2

Because this preliminary assessment is only an exploration of alternative models, and in the interest of time, the following procedures were applied to Model 2 only (i.e., Models 1 and 3 used the tuned quantities from Model 2, rather than retuning these quantities individually for Models 1 and 3).

Three main loops were involved in the iterative tuning procedure:

4. Tuning the means of the prior distributions for the selectivity parameters.
5. Estimating "unconstrained" values of the standard deviations of the selectivity *dev*s.
6. Estimating "iterated" values of the standard deviations for the selectivity *dev*s.

Following the iterative procedure, the model was run with final estimates of the standard deviations for the selectivity *dev*s, which were estimated from a formula involving the results of loops #2 and #3.

The loops are described in more detail below.

Loop #1: tuning the parameters of the prior distributions for the selectivity parameters

Initially, the model was run with recruitment as the only time-varying quantity, with the standard deviation of log-scale recruitment estimated internally (i.e., as a free parameter), and with large standard deviations in the prior distributions for all selectivity parameters.

Once the initial model converged, a pair of transformed logistic curves was fit to the point estimates of the fishery and survey selectivity schedules (a *transformed* logistic curve was used because the selectivity parameters in pattern #17 consist of the backward first differences of selectivity on the log scale, rather than selectivity itself ; Thompson and Palsson 2013). The respective transformed logistic curve (fishery or survey) was then used to specify a new set of means for the selectivity prior distributions (one for each age). A constant (across age) prior standard deviation was then computed such that no age had a prior CV (on the selectivity scale, not the transformed scale) less than 50%.

The model was then run with the new set of prior means and constant prior standard deviations (one for the fishery, one for the survey), then a new pair of transformed logistic curves was fit to the results, and the process was repeated until convergence was achieved. The converged set of prior means (on the transformed scale, not the selectivity scale) was as follows (ages 7+ all had prior means of 0 for both the fishery and the survey):

Age:	1	2	3	4	5	6
Fishery:	3.290	3.280	3.049	1.380	0.117	0.005
Survey:	5.295	0.846	0.004	0.000	0.000	0.000

The converged prior standard deviations were 0.342 for the fishery and 0.319 for the survey (both constant across age).

Loop #2: Estimating "unconstrained" values of the standard deviations of the selectivity devs

Loops #2 and #3 were designed to produce the quantities needed to use the method of Thompson and Lauth (2012, Annex 2.1.1) for estimating the standard deviation of a *dev* vector. The purpose of Loop #2 was to determine the value of the selectivity *dev* vector (for either the fishery or the survey) that would be obtained if the *dev*s were completely unconstrained by their respective σs. This was not always a straightforward process, as estimating a large matrix of age×year *dev*s is difficult if the *dev*s are unconstrained. In general, though, the procedure was to focus on one fleet (fishery or survey) at a time; begin with a small, constant (across age) value of σ; calculate the standard deviation of the estimated *dev*s; then increase the value of σ gradually until the standard deviation of the estimated *dev*s reached an asymptote.

Loop #3: Estimating "iterated" values of the standard deviations for the selectivity devs

Again proceeding one fleet (fishery or survey) at a time, this loop began with age-specific σs set at the unconstrained values estimated in Loop #2. The standard deviations of the estimated *dev*s then became the age-specific σs for the next run, and the process was repeated until the σs converged.

It is common for some ages to be "tuned" out during Loop #3 (i.e., the σs converge on zero). For Model 2, all ages were tuned out except the following (these are final values of σ, after application of the algorithm described by Thompson and Lauth (2013, Annex 2.1.1), shown in parentheses):

Fishery: age 4 (0.092), age 6 (0.237)
Survey: age 2 (0.194), age 3 (0.078), age 7 (0.442).

Because survey selectivity for Model 2 peaked at age 4, survey selectivity *dev*s were turned off for age 7 in Model 3 (because it required asymptotic selectivity).

Parameters Estimated Outside the Assessment Model

Some parameters were fixed externally at values borrowed from the EBS Pacific cod model:

1. The natural mortality rate was fixed at 0.34.
2. The parameters of the logistic maturity-at-age relationship were set at values of 4.88 years (age at 50% maturity) and –0.965 (slope) in all models.

In all three models, weight (kg) at length (cm) was assumed to follow the usual form weight=$A\times$length^B and to be constant across the time series, with A and B estimated at 5.683×10^{-6} and 3.18, respectively, based on 8,126 samples collected from the AI fishery between 1974 and 2011.

Parameters Estimated Inside the Assessment Model

Parameters estimated inside SS for all models include the von Bertalanffy growth parameters; standard deviation of length at ages 1 and 20; ageing bias at ages 1 and 20; log mean recruitment since the beginning of the time series; offset for log mean recruitment prior to the beginning of the time series (Models 2 and 3 only); *dev*s for log-scale initial (i.e., 1991) abundance at ages 1 through 10; annual log-scale recruitment *dev*s for 1991-2011; initial (equilibrium) fishing mortality; base values for all fishery and survey selectivity parameters; and annual *dev*s for the selectivity parameters corresponding to ages 4 and 6 in the fishery, and ages 2, 3, and 7 (Models 1 and 2 only for age 7) in the survey.

For all parameters estimated within individual SS runs, the estimator used is the mode of the logarithm of the joint posterior distribution, which is in turn calculated as the sum of the logarithms of the parameter-specific prior distributions and the logarithm of the likelihood function.

In addition to the above, the full set of annual fishing mortality rates are also estimated internally, but not in the same sense as the above parameters. The fishing mortality rates are determined (almost) exactly rather than estimated statistically because SS assumes that the input total catch data are true values rather than estimates, so the fishing mortality rates can be computed algebraically given the other parameter values and the input catch data. An option does exist in SS for treating the fishing mortality rates as full parameters, but previous explorations have indicated that adding these parameters has almost no effect on other model output (Methot and Wetzell 2013).

Likelihood Components

All three models include likelihood components for initial (equilibrium) catch, trawl survey relative abundance, fishery and survey size composition, survey age composition, recruitment, prior distributions, "softbounds" (equivalent to an extremely weak prior distribution used to keep parameters from hitting bounds), and parameter deviations.

In SS, emphasis factors are specified to determine which likelihood components receive the greatest attention during the parameter estimation process. As in the EBS Pacific cod assessment, all likelihood components were given an emphasis of 1.0 here.

Results

Overview

The following table summarizes the status of the stock as estimated by the three models ("Value" is the point estimate, "SD" is the standard deviation to the point estimate, "FSB 2014" is female spawning biomass in 2014 (t), and "Bratio 2014" is the ratio of FSB 2014 to $B_{100\%}$:

	Model 1		Model 2		Model 3	
Quantity	Value	SD	Value	SD	Value	SD
FSB 2014	52,229	8,748	51,751	8,753	31,922	4,996
Bratio 2014	0.395	0.047	0.387	0.049	0.254	0.046

For these two quantities, the estimates from Models 1 and 2 are fairly similar, with the estimates from Model 3 being substantially lower.

Goodness of Fit

Objective function values are shown for each model below (lower values are better, all else being equal; objective function components with a value less than 0.0005 for all models are omitted for brevity; color scale extends from red (minimum) to green (maximum); note that the parameter counts include constrained deviations):

Component	Model 1	Model 2	Model 3
Survey index	-8.838	-9.129	-1.972
Size composition (fishery)	93.943	92.256	108.043
Size composition (survey)	190.720	190.479	217.886
Age composition	2.967	2.849	5.462
Recruitment	-0.303	2.171	21.367
Priors	17.463	16.606	17.808
"Softbounds"	0.001	0.001	0.006
Parameter devs	11.621	11.557	19.990
Total	307.574	306.789	388.591
Number of parameters	196	197	158
AIC	1007.148	1007.578	1093.182

Model 1 has one fewer parameter than Model 2 (the initial recruitment offset), and Model 3 has 39 fewer parameters than Model 2 (all selectivity parameters, although most of them are constrained deviations, and so should not be counted as full parameters).

Figure 2A.1.1 shows the fits of the three models to the trawl survey abundance data. All three models estimate a 2012 survey biomass close to the observed value. Models 1 and 2 tend to overestimate the survey abundance, although usually not by much. Model 3 has the best mix of positive and negative residuals, but does not perform as well as the other models by most other measures, as shown below (for comparison to the root mean squared residual, the average log-scale standard error in the data is 0.184; color scale extends from red (minimum) to green (maximum)):

Quantity	Model 1	Model 2	Model 3
Correlation (observed:expected)	0.959	0.954	0.695
Root mean squared residual	0.190	0.184	0.303
Mean standardized residual	-0.701	-0.656	-0.582
Root mean squared standardized residual	1.225	1.198	1.740

Models 1 and 2 do better than Model 3 by all of the above measures except mean standardized residual.

Figure 2A.1.2 shows the models' fits to the fishery size composition data, and Figure 2A.1.3 shows the models' fits to the survey size composition data. Effective sample sizes and negative log likelihoods for the size composition data are shown in Table 2A.1.1. All three models give effective sample sizes far above the mean input sample sizes for both the fishery and the survey. The performances of Models 1 and 2 are very similar, giving slightly higher effective sample sizes and slightly lower (better) negative log likelihoods than Model 1.

Figure 2A.1.4 shows the models' fits to the single available year of survey age composition data. Effective sample sizes and negative log likelihoods are shown below. Models 1 and 2 both give effective sample sizes far above the input sample size, while the effective sample size given by Model 1 is slightly below the input sample size. Again, Models 1 and 2 give slightly lower (better) negative log likelihoods than Model 1.

			Effective sample size			Negative log likelihood		
Fleet	Year	N	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Survey	2012	300	730	769	286	2.967	2.849	5.462

Parameters, Schedules, and Time Series Estimates

Table 2A.1.2 lists the constants and parameters listed in the SS control files for the three models, along with standard deviations ("SD") for all estimated parameters. Constants are listed in Table 2A.1.2a, main parameters (except selectivity) are listed in Table 2A.1.2b, base selectivity parameters are listed in Table 2A.1.2c, deviations (*dev*s) for fishery selectivity parameters are listed in Table 2A.1.2d, and deviations for survey selectivity parameters are listed in Table 2A.1.2e. Quantities with "n/a" listed under "SD" were fixed rather than estimated.

Selectivity schedules (fishery and survey) for Models 1, 2, and 3 are shown in Figures 2A.1.5a, 2A.1.5b, and 2A.1.5c, respectively. The schedules for Models 1 and 2 are very similar. The main difference between Model 3's selectivity schedules and those of Models 1 and 2 is the asymptotic nature of Model 3's survey selectivity (which was a design feature of Model 3).

Time series estimated by the three models are shown for female spawning biomass, relative (to $B_{100\%}$) female spawning biomass, and age 0 recruitment in Figures 2A.1.6, 2A.1.7, and 2A.1.8, respectively. Figures 2A.1.6 and 2A.1.7 are very similar except for scale. In these two figures, the values estimated by Model 1 are higher than those estimated by Model 2 for the early portion of the time series, but the two models converge by the end of the time series; both Models 1 and 2 estimate values that are higher than those estimated by Model 3 throughout the time series. In Figure 2A.1.8, the recruitments estimated by Models 1 and 2 are very similar, and again are consistently higher than those estimated by Model 3 throughout the time series.

Discussion

The structural differences between the three models presented in this preliminary assessment are simple: Models 2 and 3 estimate a recruitment offset which allows the average recruitment in the years preceding the start of the time series to differ from the average recruitment during the time series, whereas Model 1 forces the average recruitment to be the same during both periods. Models 1 and 2 allow survey selectivity to vary freely, except to the extent that they are constrained by their respective prior distributions, whereas Model 3 forces survey selectivity to be asymptotic.

In general, the differences between the estimates produced by Models 1 and 2 are small. However, some of the differences between Models 1 and 2 and Model 3 are substantial. For example, as reported in the "Overview" subsection of the "Results" section, Model 3's estimates of female spawning biomass in 2014 are 38-39% lower than those obtained by Models 1 and 2. The estimates of ln(Q), on the other hand, are fairly similar for all three models, with a range of -0.485 to -0.453, corresponding to a Q range of 0.616 to 0.636. These values imply that the survey misses at least 36-38% of even the most-selected age group.

Although the natural mortality rate M is not estimated internally in any of the models, Figure 2A.1.9 shows the likelihood profiles with respect to M for each of the models. If M were estimated internally, Models 1 and 2 would give an estimate (0.11) much lower than the value (0.34) that has been used in the EBS Pacific cod assessment for the last several years. This may indicate structural deficiencies in Models 1 and 2.

The three models presented here generally provide good-to-excellent fits to all three types of data (survey abundance index, size compostion, and age composition).

For all three models, data prior to 1991 were removed, because last year's models had difficulty giving reasonable estimates of biomass and fishing mortality during the early years of the time series (note that survey data from prior to 1991 had already been removed from last year's file). Although the problematic estimates are now gone, it may be worth considering further whether removal of all pre-1991 data is an appropriate way to address the issue.

Additional age data from the AI bottom trawl survey are expected to become available in time for use in this year's final assessment. Given that only a single year of age data was available for this preliminary assessment, it is possible that these additional data will affect the results of the models substantially.

Last year's preliminary assessment provided the first exploration of SS selectivity-at-age pattern #17 (random walk with age) for Pacific cod, and use of this pattern has been retained here. Some advantages of pattern #17 are the following:

1. Pattern #17 allows for use of prior distributions that are consistent with a logistic functional form without actually forcing the resulting selectivity schedule to be logistic.
2. Pattern #17 provides an alternative to the somewhat complicated parameterization of the double normal selectivity curve (which has been used in the EBS Pacific cod models for the last several years), in which the effects of some parameters are conditional on the values of other parameters, thus making it difficult to specify appropriate prior distributions.
3. The iterative tuning procedure used here for the means of the prior distributions provides a way to specify these quantities objectively and uniquely for each age.
4. Estimation of individual selectivities at age avoids the problem of mis-specifying a functional form *a priori*, which can have significant consequences (e.g., Kimura 1990, Clark 1999).

This preliminary assessment also emphasized the potential time variability of both fishery and survey selectivity. Although a scientific consensus on how (or whether) to address this phenomenon has yet to be achieved, some of the presentations at the 2013 CAPAM selectivity workshop (Crone et al., 2013) seemed to favor allowing selectivity to vary over time.

It should be emphasized that iterative tuning of the selectivity prior distributions and the sigma parameters for time-varying selectivity was applied only to Model 2, with Models 1 and 3 simply "borrowing" the resulting tuned quantities. If these iterative tuning procedures were also applied to Models 1 and 3, the performance of the latter models would likely change somewhat.

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Table 2A.1.1—Effective sample sizes for size composition fits.

			Effective sample size			Negative log likelihood		
Fleet	Year	N	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Fishery	1991	129	1540	1704	1710	6.121	5.852	6.334
Fishery	1992	586	13269	14622	17131	4.592	4.276	3.910
Fishery	1993	267	2034	2054	2285	4.759	4.669	4.272
Fishery	1994	170	4838	4675	2276	1.352	1.355	2.465
Fishery	1995	176	4794	4694	3894	5.416	5.408	4.957
Fishery	1996	243	5221	5342	5157	2.210	2.169	2.715
Fishery	1997	136	4350	4430	2109	1.281	1.258	2.394
Fishery	1998	424	9331	9337	7858	2.282	2.271	3.069
Fishery	1999	412	6641	6893	14991	3.063	2.971	2.479
Fishery	2000	636	6923	6938	4411	4.887	4.857	7.319
Fishery	2001	700	7972	7825	5376	6.902	7.033	11.226
Fishery	2002	284	3956	3905	4415	4.884	4.878	3.523
Fishery	2003	287	1280	1305	2458	6.308	6.198	4.443
Fishery	2004	291	2654	2688	2895	7.364	7.301	6.670
Fishery	2005	252	6135	6038	2856	1.550	1.556	2.742
Fishery	2006	248	3320	3287	1976	2.707	2.733	4.153
Fishery	2007	334	8089	8716	4439	2.621	2.572	4.078
Fishery	2008	319	3038	3161	1962	4.938	4.778	6.956
Fishery	2009	266	3213	3281	1882	5.297	5.198	7.216
Fishery	2010	416	2566	2553	2116	8.116	8.057	9.597
Fishery	2011	108	1886	2008	2364	1.915	1.835	1.767
Fishery	2012	143	2609	2730	2146	2.204	2.085	2.874
Fishery	2013	76	715	776	951	3.173	2.944	2.887
Fishery	Ave/sum	300	4625	4737	4246	93.943	92.256	108.043
Survey	1991	462	1620	1637	1145	12.828	12.835	18.038
Survey	1994	486	187	188	187	57.723	57.567	56.682
Survey	1997	300	413	413	381	54.466	54.430	58.205
Survey	2000	336	1395	1400	1025	14.436	14.411	19.027
Survey	2002	254	1294	1292	816	10.687	10.657	12.388
Survey	2004	241	1433	1430	1196	10.675	10.665	13.098
Survey	2006	181	1233	1235	895	9.664	9.638	12.268
Survey	2010	228	1768	1754	827	7.548	7.584	13.074
Survey	2012	213	958	948	573	12.694	12.692	15.106
Survey	Ave/sum	300	1144	1144	783	190.720	190.479	217.886

Table 2A.1.2a—Constants (not estimated internally) in the SS control file.

Parameter	Model 1	Model 2	Model 3
Natural mortality rate	3.40E-01	3.40E-01	3.40E-01
Weight-length a (proportionality)	5.68E-06	5.68E-06	5.68E-06
Weight-length b (exponent)	3.18E+00	3.18E+00	3.18E+00
Age at 50% maturity	4.88E+00	4.88E+00	4.88E+00
Maturity slope	-9.65E-01	-9.65E-01	-9.65E-01
Std. dev. of ageing error at age 1	9.30E-02	9.30E-02	9.30E-02
Std. dev. of ageing error at age 12	1.86E+00	1.86E+00	1.86E+00
Stock-recruitment "steepness"	1.00E+00	1.00E+00	1.00E+00

Table 2A.1.2b—Main parameters (except selectivity) parameters estimated by the models.

	Model 1		Model 2		Model 3	
Parameter	Value	SD	Value	SD	Value	SD
Length at age 1 (cm)	1.79E+01	1.98E-01	1.79E+01	1.98E-01	1.79E+01	1.91E-01
Asymptotic length (cm)	1.09E+02	1.78E+00	1.09E+02	1.77E+00	1.11E+02	1.96E+00
Brody growth coefficient	2.19E-01	6.74E-03	2.19E-01	6.73E-03	2.18E-01	6.78E-03
SD of length at age 1 (cm)	3.15E+00	1.41E-01	3.14E+00	1.41E-01	2.97E+00	1.35E-01
SD of length at age 20 (cm)	7.98E+00	4.05E-01	8.02E+00	4.07E-01	9.81E+00	4.92E-01
Ageing bias at age 1 (years)	2.99E-01	1.74E-01	3.01E-01	1.79E-01	4.20E-01	7.58E-02
Ageing bias at age 20 (years)	1.47E+00	1.09E+00	1.40E+00	1.11E+00	-1.72E-01	6.10E-01
ln(mean post-1990 recruitment)	1.10E+01	8.40E-02	1.11E+01	8.81E-02	1.10E+01	1.36E-01
σ(recruitment)	5.56E-01	7.60E-02	5.99E-01	9.27E-02	9.56E-01	1.43E-01
ln(pre-1991 recruitment offset)	0.00E+00	n/a	-2.37E-01	2.03E-01	-1.29E+00	3.14E-01
Initial fishing mortality rate	5.82E-03	1.36E-03	7.67E-03	2.51E-03	3.07E-02	9.26E-03
ln(catchability)	-4.68E-01	8.59E-02	-4.53E-01	8.69E-02	-4.85E-01	8.20E-02
Initial age 1 ln(abundance) dev	3.69E-01	1.80E-01	5.55E-01	2.49E-01	1.30E+00	3.77E-01
Initial age 2 ln(abundance) dev	1.13E+00	1.53E-01	1.33E+00	2.36E-01	2.46E+00	3.18E-01
Initial age 3 ln(abundance) dev	-1.41E-01	1.91E-01	3.20E-02	2.49E-01	6.92E-01	3.68E-01
Initial age 4 ln(abundance) dev	5.98E-01	1.76E-01	7.80E-01	2.43E-01	1.91E+00	3.68E-01
Initial age 5 ln(abundance) dev	1.17E+00	2.16E-01	1.33E+00	2.64E-01	2.00E+00	3.68E-01
Initial age 6 ln(abundance) dev	1.06E+00	3.26E-01	1.22E+00	3.68E-01	2.07E+00	4.22E-01
Initial age 7 ln(abundance) dev	1.04E-01	5.08E-01	2.08E-01	5.69E-01	-3.35E-01	8.18E-01
Initial age 8 ln(abundance) dev	-4.42E-01	4.60E-01	-4.01E-01	4.99E-01	-7.50E-01	7.24E-01
Initial age 9 ln(abundance) dev	-6.61E-01	4.42E-01	-6.43E-01	4.74E-01	-9.98E-01	6.86E-01
Initial age 10 ln(abundance) dev	-7.43E-01	4.36E-01	-7.44E-01	4.65E-01	-1.07E+00	6.75E-01
Log-scale recruit. dev for 1991	2.85E-01	1.45E-01	2.59E-01	1.46E-01	8.19E-02	1.38E-01
Log-scale recruit. dev for 1992	-2.28E-01	2.34E-01	-2.51E-01	2.37E-01	-6.63E-01	1.85E-01
Log-scale recruit. dev for 1993	8.52E-01	1.26E-01	8.38E-01	1.26E-01	1.17E+00	9.67E-02
Log-scale recruit. dev for 1994	-1.43E-01	1.58E-01	-1.59E-01	1.60E-01	-3.19E-01	1.93E-01
Log-scale recruit. dev for 1995	4.95E-01	1.62E-01	4.83E-01	1.62E-01	2.15E-01	1.61E-01
Log-scale recruit. dev for 1996	9.39E-01	1.21E-01	9.30E-01	1.21E-01	1.15E+00	1.18E-01
Log-scale recruit. dev for 1997	6.33E-01	1.15E-01	6.28E-01	1.16E-01	6.87E-01	1.11E-01
Log-scale recruit. dev for 1998	9.86E-02	1.82E-01	9.45E-02	1.83E-01	-3.21E-01	2.05E-01
Log-scale recruit. dev for 1999	7.55E-01	1.21E-01	7.61E-01	1.21E-01	7.47E-01	1.21E-01
Log-scale recruit. dev for 2000	5.17E-02	1.54E-01	5.93E-02	1.55E-01	8.05E-01	1.13E-01
Log-scale recruit. dev for 2001	-1.92E-01	1.33E-01	-1.79E-01	1.34E-01	1.34E-02	1.54E-01
Log-scale recruit. dev for 2002	-5.86E-01	1.56E-01	-5.76E-01	1.59E-01	-5.20E-01	1.85E-01
Log-scale recruit. dev for 2003	-2.94E-01	1.36E-01	-2.75E-01	1.38E-01	-6.45E-03	1.39E-01
Log-scale recruit. dev for 2004	-6.21E-01	1.87E-01	-6.09E-01	1.91E-01	-1.01E+00	2.51E-01
Log-scale recruit. dev for 2005	-1.88E-01	1.59E-01	-1.70E-01	1.61E-01	1.08E-01	1.32E-01
Log-scale recruit. dev for 2006	-4.61E-01	1.60E-01	-4.58E-01	1.62E-01	-5.24E-01	2.15E-01
Log-scale recruit. dev for 2007	3.00E-01	1.24E-01	3.12E-01	1.25E-01	5.53E-01	1.16E-01
Log-scale recruit. dev for 2008	-9.69E-02	1.52E-01	-9.89E-02	1.54E-01	-3.89E-02	1.54E-01
Log-scale recruit. dev for 2009	-9.96E-01	2.06E-01	-1.00E+00	2.08E-01	-9.35E-01	2.00E-01
Log-scale recruit. dev for 2010	-4.38E-01	4.06E-01	-4.42E-01	4.22E-01	-8.68E-01	2.44E-01
Log-scale recruit. dev for 2011	-1.65E-01	5.09E-01	-1.44E-01	5.42E-01	-3.33E-01	4.31E-01

Table 2A.1.2c—Base selectivity parameters estimated by the models.

	Model 1		Model 2		Model 3	
Parameter	Value	SD	Value	SD	Value	SD
Fishery age 1 selectivity parameter	3.29E+00	3.42E-01	3.29E+00	3.42E-01	3.29E+00	3.42E-01
Fishery age 2 selectivity parameter	3.41E+00	3.19E-01	3.41E+00	3.19E-01	3.42E+00	3.18E-01
Fishery age 3 selectivity parameter	3.20E+00	1.88E-01	3.20E+00	1.89E-01	3.41E+00	2.05E-01
Fishery age 4 selectivity parameter	1.24E+00	1.82E-01	1.25E+00	1.82E-01	1.28E+00	1.88E-01
Fishery age 5 selectivity parameter	2.92E-01	1.16E-01	2.95E-01	1.16E-01	2.60E-01	1.42E-01
Fishery age 6 selectivity parameter	1.51E-01	2.86E-01	1.54E-01	2.86E-01	1.77E-01	2.87E-01
Fishery age 7 selectivity parameter	-9.38E-02	1.99E-01	-8.94E-02	1.98E-01	-1.79E-03	2.07E-01
Fishery age 8 selectivity parameter	-4.88E-03	2.52E-01	1.71E-02	2.52E-01	4.23E-01	2.90E-01
Fishery age 9 selectivity parameter	1.02E-01	2.71E-01	1.23E-01	2.72E-01	3.73E-01	2.64E-01
Fishery age 10 selectivity parameter	2.79E-01	2.84E-01	2.93E-01	2.85E-01	2.30E-01	3.13E-01
Fishery age 11 selectivity parameter	1.14E-01	3.13E-01	1.26E-01	3.13E-01	-1.21E-01	3.21E-01
Fishery age 12 selectivity parameter	-2.21E-01	3.46E-01	-2.02E-01	3.45E-01	-2.73E-01	3.42E-01
Fishery age 13 selectivity parameter	-4.43E-01	3.20E-01	-4.35E-01	3.20E-01	-3.74E-01	3.19E-01
Fishery age 14 selectivity parameter	-3.35E-01	3.20E-01	-3.32E-01	3.20E-01	-2.80E-01	3.24E-01
Fishery age 15 selectivity parameter	-2.40E-01	3.23E-01	-2.38E-01	3.24E-01	-2.11E-01	3.27E-01
Fishery age 16 selectivity parameter	-2.06E-01	3.24E-01	-2.04E-01	3.24E-01	-1.68E-01	3.29E-01
Fishery age 17 selectivity parameter	-1.62E-01	3.26E-01	-1.60E-01	3.27E-01	-1.33E-01	3.30E-01
Fishery age 18 selectivity parameter	-1.22E-01	3.29E-01	-1.21E-01	3.29E-01	-9.80E-02	3.33E-01
Fishery age 19 selectivity parameter	-8.58E-02	3.32E-01	-8.52E-02	3.32E-01	-7.01E-02	3.35E-01
Fishery age 20 selectivity parameter	-6.74E-02	3.34E-01	-6.67E-02	3.34E-01	-5.22E-02	3.36E-01
Survey age 1 selectivity parameter	5.29E+00	3.19E-01	5.29E+00	3.19E-01	5.29E+00	3.19E-01
Survey age 2 selectivity parameter	9.25E-01	2.88E-01	9.26E-01	2.88E-01	1.26E+00	1.69E-01
Survey age 3 selectivity parameter	6.20E-01	2.17E-01	6.21E-01	2.17E-01	7.82E-01	1.26E-01
Survey age 4 selectivity parameter	3.45E-01	1.12E-01	3.53E-01	1.13E-01	6.05E-02	9.56E-02
Survey age 5 selectivity parameter	-3.95E-01	1.30E-01	-3.91E-01	1.30E-01	0.00E+00	n/a
Survey age 6 selectivity parameter	-1.95E-01	2.25E-01	-1.81E-01	2.26E-01	0.00E+00	n/a
Survey age 7 selectivity parameter	9.20E-03	3.12E-01	8.62E-03	3.12E-01	0.00E+00	n/a
Survey age 8 selectivity parameter	-4.12E-01	2.38E-01	-3.74E-01	2.41E-01	0.00E+00	n/a
Survey age 9 selectivity parameter	-2.97E-01	2.67E-01	-2.79E-01	2.68E-01	0.00E+00	n/a
Survey age 10 selectivity parameter	-1.14E-01	2.88E-01	-1.02E-01	2.88E-01	0.00E+00	n/a
Survey age 11 selectivity parameter	-1.35E-01	3.00E-01	-1.26E-01	3.00E-01	0.00E+00	n/a
Survey age 12 selectivity parameter	-1.77E-01	3.04E-01	-1.70E-01	3.05E-01	0.00E+00	n/a
Survey age 13 selectivity parameter	-1.54E-01	3.05E-01	-1.48E-01	3.05E-01	0.00E+00	n/a
Survey age 14 selectivity parameter	-1.18E-01	3.08E-01	-1.13E-01	3.08E-01	0.00E+00	n/a
Survey age 15 selectivity parameter	-1.02E-01	3.09E-01	-9.75E-02	3.09E-01	0.00E+00	n/a
Survey age 16 selectivity parameter	-7.96E-02	3.10E-01	-7.62E-02	3.11E-01	0.00E+00	n/a
Survey age 17 selectivity parameter	-5.27E-02	3.13E-01	-5.07E-02	3.13E-01	0.00E+00	n/a
Survey age 18 selectivity parameter	-3.64E-02	3.14E-01	-3.50E-02	3.14E-01	0.00E+00	n/a
Survey age 19 selectivity parameter	-2.55E-02	3.16E-01	-2.46E-02	3.16E-01	0.00E+00	n/a
Survey age 20 selectivity parameter	-1.81E-02	3.16E-01	-1.75E-02	3.17E-01	0.00E+00	n/a

Table 2A.1.2d—Deviations (*dev*s) for fishery selectivity parameters estimated by the models.

	Model 1		Model 2		Model 3	
Parameter	Value	SD	Value	SD	Value	SD
Fishery age 4 sel. dev for 1991	-2.66E-03	5.47E-02	-2.89E-03	5.49E-02	-3.57E-03	6.16E-02
Fishery age 4 sel. dev for 1992	8.03E-02	3.24E-02	8.19E-02	3.25E-02	1.02E-01	3.06E-02
Fishery age 4 sel. dev for 1993	-7.38E-02	3.66E-02	-7.47E-02	3.68E-02	-1.01E-01	4.05E-02
Fishery age 4 sel. dev for 1994	-1.33E-02	3.96E-02	-1.24E-02	3.96E-02	-2.46E-02	4.05E-02
Fishery age 4 sel. dev for 1995	-1.13E-02	4.72E-02	-1.09E-02	4.73E-02	-1.35E-02	4.81E-02
Fishery age 4 sel. dev for 1996	7.47E-02	3.58E-02	7.55E-02	3.59E-02	1.41E-01	3.66E-02
Fishery age 4 sel. dev for 1997	-3.29E-02	5.08E-02	-3.28E-02	5.10E-02	-4.66E-02	5.81E-02
Fishery age 4 sel. dev for 1998	-1.20E-02	2.99E-02	-1.20E-02	2.99E-02	-4.79E-02	2.95E-02
Fishery age 4 sel. dev for 1999	3.20E-02	3.18E-02	3.22E-02	3.19E-02	7.01E-02	3.41E-02
Fishery age 4 sel. dev for 2000	-1.92E-02	2.79E-02	-1.89E-02	2.79E-02	-1.92E-02	3.01E-02
Fishery age 4 sel. dev for 2001	-6.54E-02	2.94E-02	-6.51E-02	2.94E-02	-1.08E-01	3.02E-02
Fishery age 4 sel. dev for 2002	1.90E-04	3.68E-02	8.66E-04	3.68E-02	1.72E-02	3.85E-02
Fishery age 4 sel. dev for 2003	-1.15E-01	3.70E-02	-1.15E-01	3.70E-02	-4.95E-02	3.83E-02
Fishery age 4 sel. dev for 2004	-1.03E-01	3.15E-02	-1.03E-01	3.15E-02	-9.98E-02	3.38E-02
Fishery age 4 sel. dev for 2005	-1.99E-02	4.12E-02	-1.98E-02	4.13E-02	-5.07E-02	4.28E-02
Fishery age 4 sel. dev for 2006	2.77E-02	3.77E-02	2.83E-02	3.78E-02	3.08E-02	4.01E-02
Fishery age 4 sel. dev for 2007	3.59E-02	4.08E-02	3.56E-02	4.10E-02	-1.11E-04	4.55E-02
Fishery age 4 sel. dev for 2008	-1.06E-02	3.41E-02	-1.07E-02	3.41E-02	1.25E-02	3.44E-02
Fishery age 4 sel. dev for 2009	1.96E-02	3.71E-02	1.86E-02	3.72E-02	1.94E-02	4.15E-02
Fishery age 4 sel. dev for 2010	7.23E-03	2.96E-02	7.31E-03	2.97E-02	3.40E-02	2.97E-02
Fishery age 4 sel. dev for 2011	2.58E-02	5.30E-02	2.54E-02	5.32E-02	2.40E-02	5.80E-02
Fishery age 4 sel. dev for 2012	5.64E-02	5.95E-02	5.61E-02	5.96E-02	5.15E-02	6.25E-02
Fishery age 4 sel. dev for 2013	2.14E-02	6.58E-02	2.20E-02	6.60E-02	-5.61E-03	6.87E-02
Fishery age 6 sel. dev for 1991	5.24E-02	4.10E-02	5.81E-02	4.14E-02	9.57E-02	4.40E-02
Fishery age 6 sel. dev for 1992	-4.31E-02	3.54E-02	-3.90E-02	3.56E-02	-1.92E-02	3.68E-02
Fishery age 6 sel. dev for 1993	3.71E-02	3.86E-02	4.23E-02	3.88E-02	7.66E-02	3.84E-02
Fishery age 6 sel. dev for 1994	-2.05E-02	3.80E-02	-1.65E-02	3.81E-02	-1.03E-02	3.87E-02
Fishery age 6 sel. dev for 1995	1.90E-02	3.90E-02	2.21E-02	3.91E-02	8.58E-03	4.06E-02
Fishery age 6 sel. dev for 1996	-6.73E-02	3.75E-02	-6.46E-02	3.76E-02	-9.09E-02	3.88E-02
Fishery age 6 sel. dev for 1997	6.24E-02	3.95E-02	6.51E-02	3.96E-02	9.64E-02	4.10E-02
Fishery age 6 sel. dev for 1998	2.44E-03	3.36E-02	4.46E-03	3.37E-02	1.84E-02	3.45E-02
Fishery age 6 sel. dev for 1999	2.49E-02	3.57E-02	2.60E-02	3.57E-02	1.78E-03	3.67E-02
Fishery age 6 sel. dev for 2000	8.45E-02	3.45E-02	8.58E-02	3.45E-02	1.12E-01	3.68E-02
Fishery age 6 sel. dev for 2001	1.11E-02	3.31E-02	1.20E-02	3.32E-02	2.64E-02	3.46E-02
Fishery age 6 sel. dev for 2002	7.02E-02	3.87E-02	7.07E-02	3.88E-02	4.62E-02	4.06E-02
Fishery age 6 sel. dev for 2003	1.18E-01	3.81E-02	1.19E-01	3.81E-02	1.22E-01	4.07E-02
Fishery age 6 sel. dev for 2004	2.72E-02	3.59E-02	2.76E-02	3.58E-02	6.12E-02	3.75E-02
Fishery age 6 sel. dev for 2005	-4.87E-03	3.66E-02	-5.07E-03	3.66E-02	2.04E-02	3.75E-02
Fishery age 6 sel. dev for 2006	-5.35E-02	3.61E-02	-5.44E-02	3.61E-02	-6.62E-02	3.76E-02
Fishery age 6 sel. dev for 2007	-7.58E-03	3.56E-02	-8.82E-03	3.56E-02	-1.99E-02	3.72E-02
Fishery age 6 sel. dev for 2008	2.00E-02	3.57E-02	1.77E-02	3.58E-02	-2.60E-02	3.76E-02
Fishery age 6 sel. dev for 2009	2.62E-02	3.67E-02	2.35E-02	3.68E-02	3.84E-03	3.90E-02
Fishery age 6 sel. dev for 2010	5.78E-02	3.69E-02	5.39E-02	3.71E-02	4.71E-02	3.82E-02
Fishery age 6 sel. dev for 2011	1.08E-01	4.15E-02	1.04E-01	4.16E-02	1.31E-01	4.20E-02
Fishery age 6 sel. dev for 2012	7.31E-02	4.13E-02	6.87E-02	4.15E-02	9.20E-02	4.23E-02
Fishery age 6 sel. dev for 2013	1.07E-01	5.26E-02	1.03E-01	5.27E-02	1.01E-01	5.59E-02

Table 2A.1.2e—Deviations (*dev*s) for survey selectivity parameters estimated by the models.

	Model 1		Model 2		Model 3	
Parameter	Value	SD	Value	SD	Value	SD
Survey age 2 sel. dev for 1991	3.43E-01	8.51E-02	3.42E-01	8.52E-02	5.12E-01	1.29E-01
Survey age 2 sel. dev for 1994	-1.24E-01	4.45E-02	-1.24E-01	4.46E-02	-5.08E-01	1.21E-01
Survey age 2 sel. dev for 1997	-6.81E-04	4.26E-02	-3.87E-04	4.26E-02	1.10E-01	1.05E-01
Survey age 2 sel. dev for 2000	2.55E-02	5.16E-02	2.62E-02	5.17E-02	2.06E-01	1.14E-01
Survey age 2 sel. dev for 2002	1.34E-01	5.12E-02	1.34E-01	5.12E-02	9.60E-02	1.30E-01
Survey age 2 sel. dev for 2004	8.21E-02	6.44E-02	8.24E-02	6.45E-02	2.44E-01	1.31E-01
Survey age 2 sel. dev for 2006	-1.29E-01	5.37E-02	-1.29E-01	5.38E-02	-2.30E-01	1.33E-01
Survey age 2 sel. dev for 2010	-5.10E-02	5.49E-02	-5.17E-02	5.49E-02	-8.11E-02	1.50E-01
Survey age 2 sel. dev for 2012	9.20E-03	7.16E-02	1.26E-02	7.45E-02	-1.58E-02	1.76E-01
Survey age 3 sel. dev for 1991	-4.29E-02	2.79E-02	-4.11E-02	2.79E-02	-9.77E-02	6.75E-02
Survey age 3 sel. dev for 1994	6.66E-03	3.64E-02	8.08E-03	3.66E-02	-1.03E-01	6.74E-02
Survey age 3 sel. dev for 1997	6.11E-02	3.11E-02	6.06E-02	3.11E-02	3.12E-02	7.28E-02
Survey age 3 sel. dev for 2000	1.07E-01	3.71E-02	1.07E-01	3.71E-02	8.56E-02	7.83E-02
Survey age 3 sel. dev for 2002	-1.16E-01	3.02E-02	-1.16E-01	3.02E-02	-6.81E-02	6.95E-02
Survey age 3 sel. dev for 2004	7.72E-02	3.77E-02	7.73E-02	3.78E-02	6.44E-02	7.70E-02
Survey age 3 sel. dev for 2006	1.12E-01	4.27E-02	1.12E-01	4.28E-02	7.86E-03	7.34E-02
Survey age 3 sel. dev for 2010	1.03E-01	3.44E-02	1.02E-01	3.45E-02	1.41E-01	7.54E-02
Survey age 3 sel. dev for 2012	5.95E-02	4.64E-02	5.82E-02	4.76E-02	5.68E-03	7.72E-02
Survey age 7 sel. dev for 1991	3.07E-02	5.58E-02	3.74E-02	5.64E-02	n/a	n/a
Survey age 7 sel. dev for 1994	6.88E-02	4.39E-02	6.93E-02	4.40E-02	n/a	n/a
Survey age 7 sel. dev for 1997	-1.94E-02	4.77E-02	-1.82E-02	4.78E-02	n/a	n/a
Survey age 7 sel. dev for 2000	-1.62E-02	5.00E-02	-1.66E-02	5.01E-02	n/a	n/a
Survey age 7 sel. dev for 2002	1.27E-01	4.11E-02	1.26E-01	4.12E-02	n/a	n/a
Survey age 7 sel. dev for 2004	-3.18E-02	4.89E-02	-3.37E-02	4.91E-02	n/a	n/a
Survey age 7 sel. dev for 2006	3.04E-02	4.56E-02	2.72E-02	4.58E-02	n/a	n/a
Survey age 7 sel. dev for 2010	3.32E-02	5.25E-02	2.68E-02	5.28E-02	n/a	n/a
Survey age 7 sel. dev for 2012	-4.62E-02	5.47E-02	-5.23E-02	5.51E-02	n/a	n/a

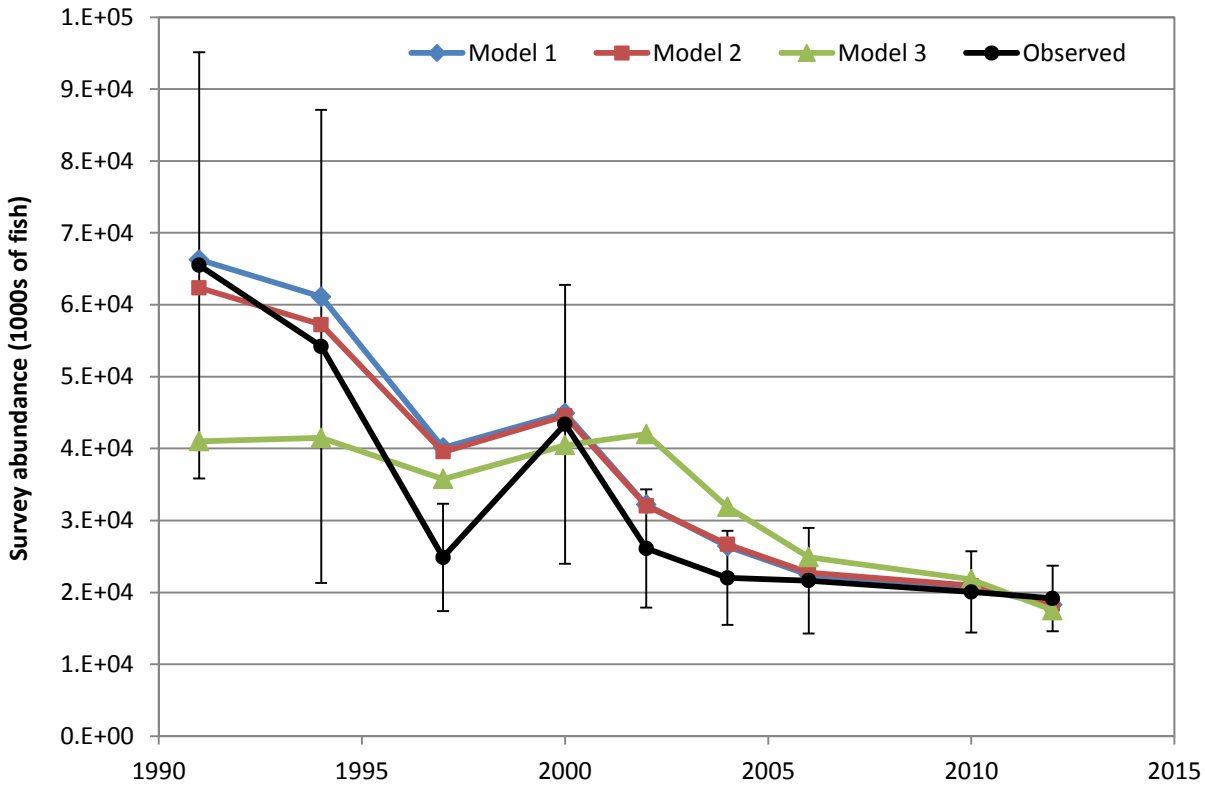


Figure 2A.1.1—Model fits to the survey abundance time series.

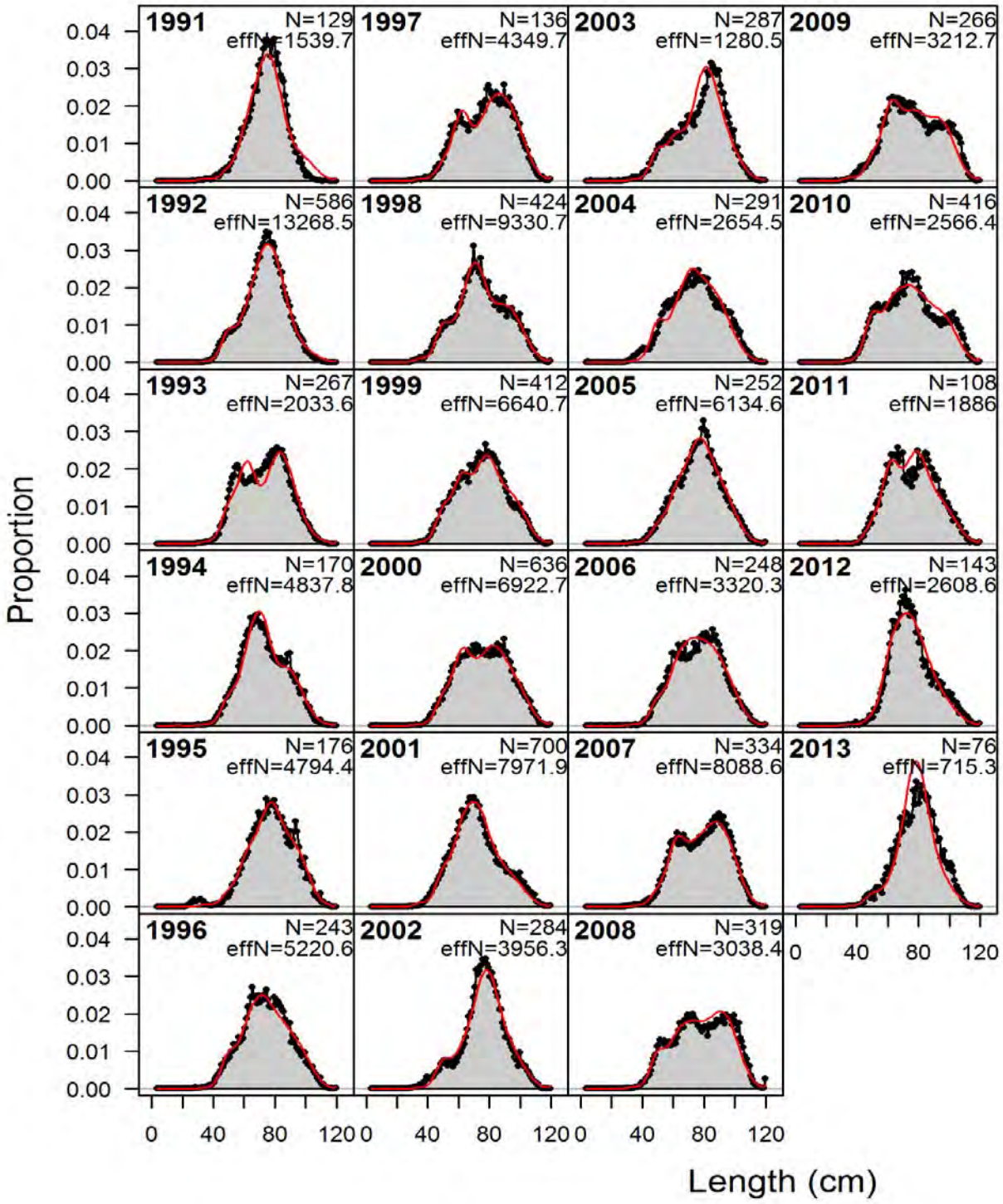


Figure 2.A.1.2a—Model 1 fits to the fishery size composition data.

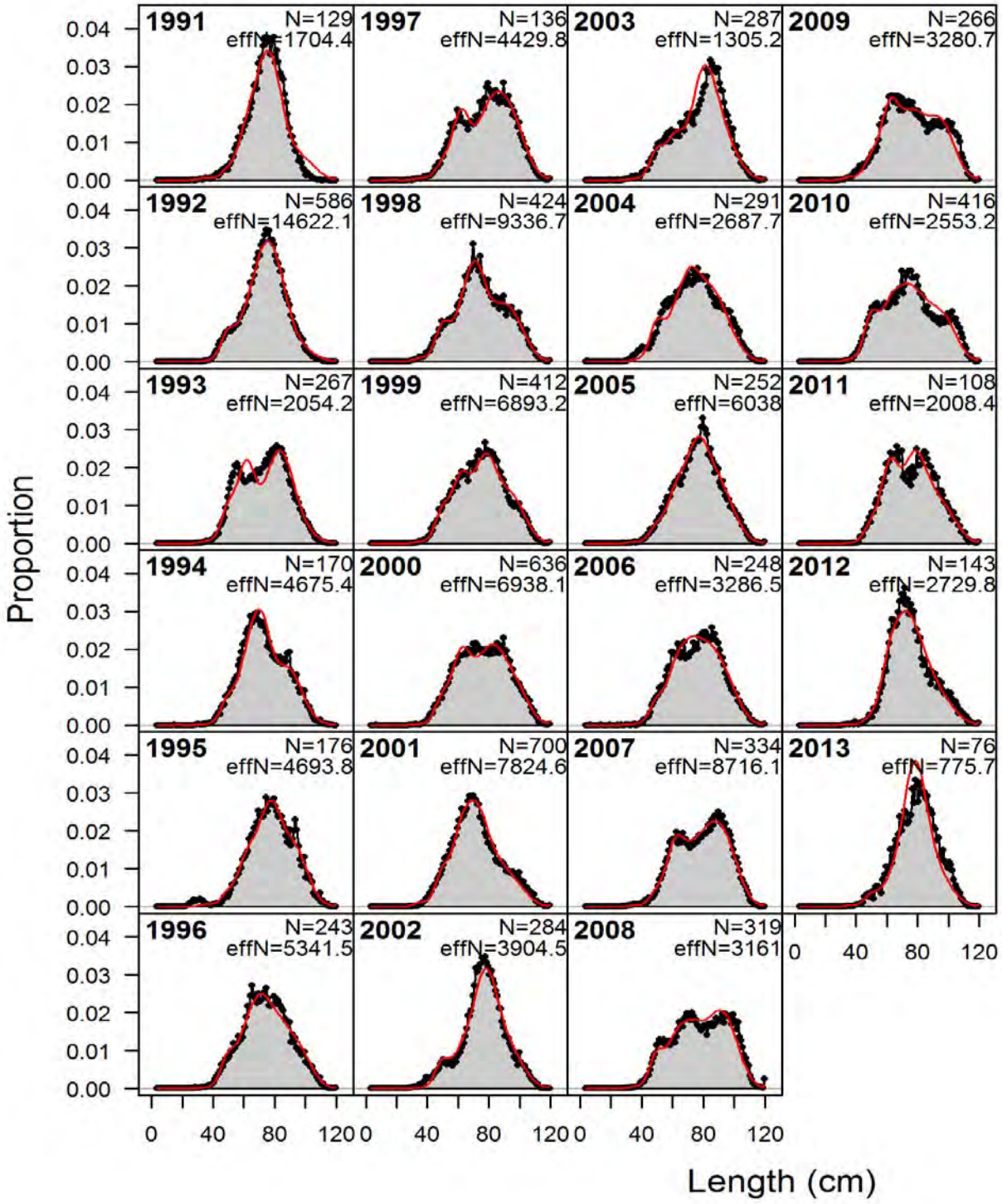


Figure 2A.1.2b—Model 2 fits to the fishery size composition data.

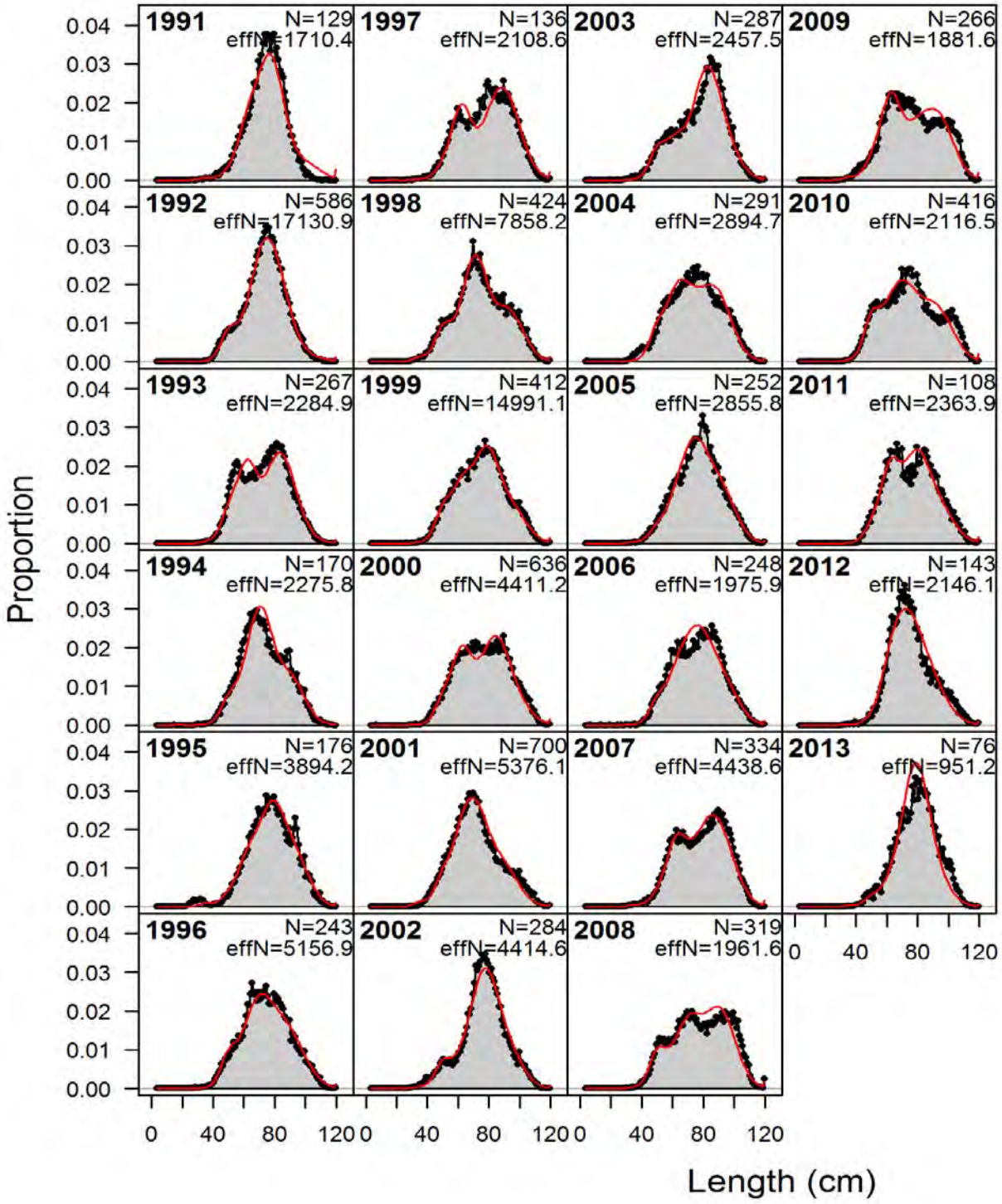


Figure 2A.1.2c—Model 3 fits to the fishery size composition data.

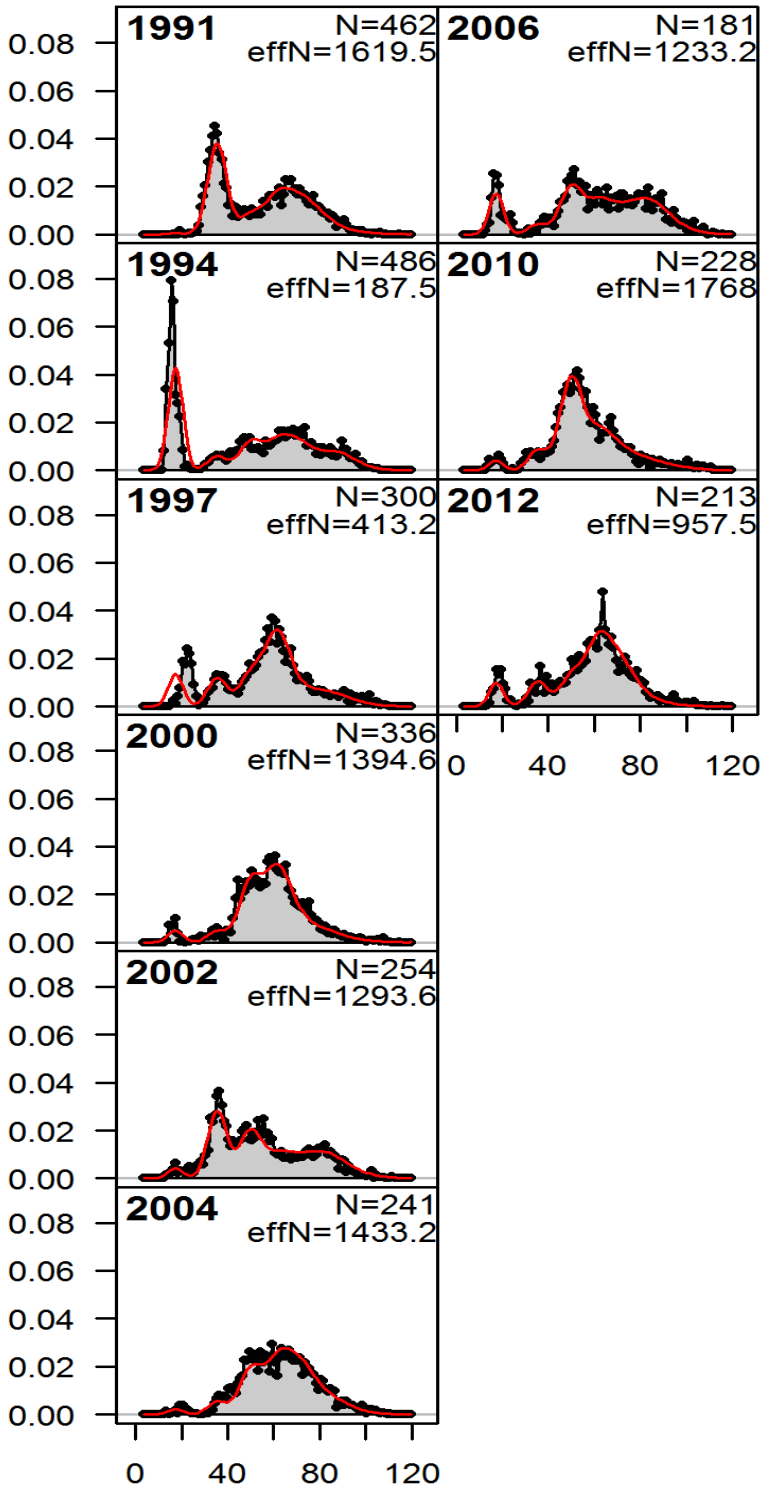


Figure 2A.1.3a—Model 1 fits to the survey size composition data.

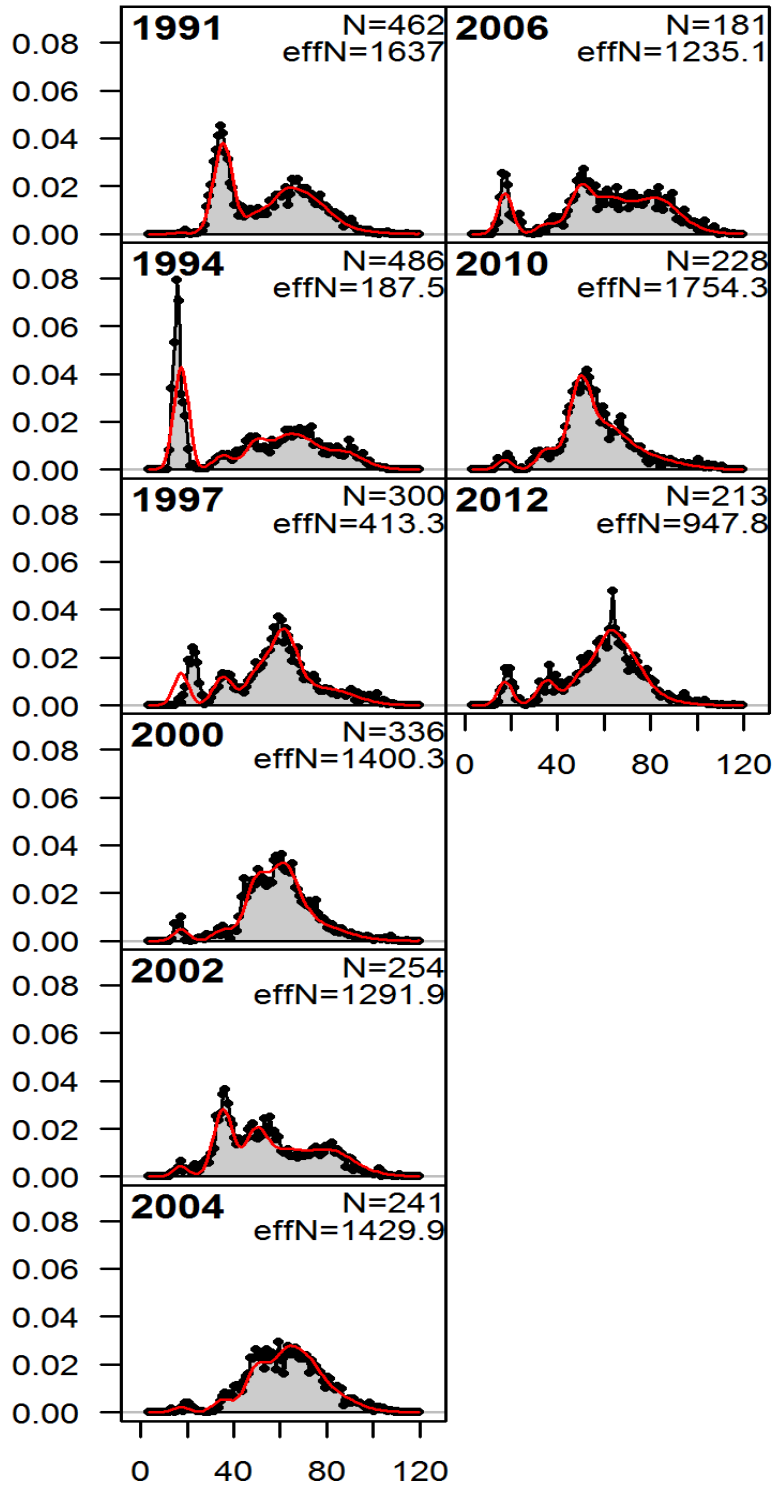


Figure 2A.1.3b—Model 2 fits to the survey size composition data.

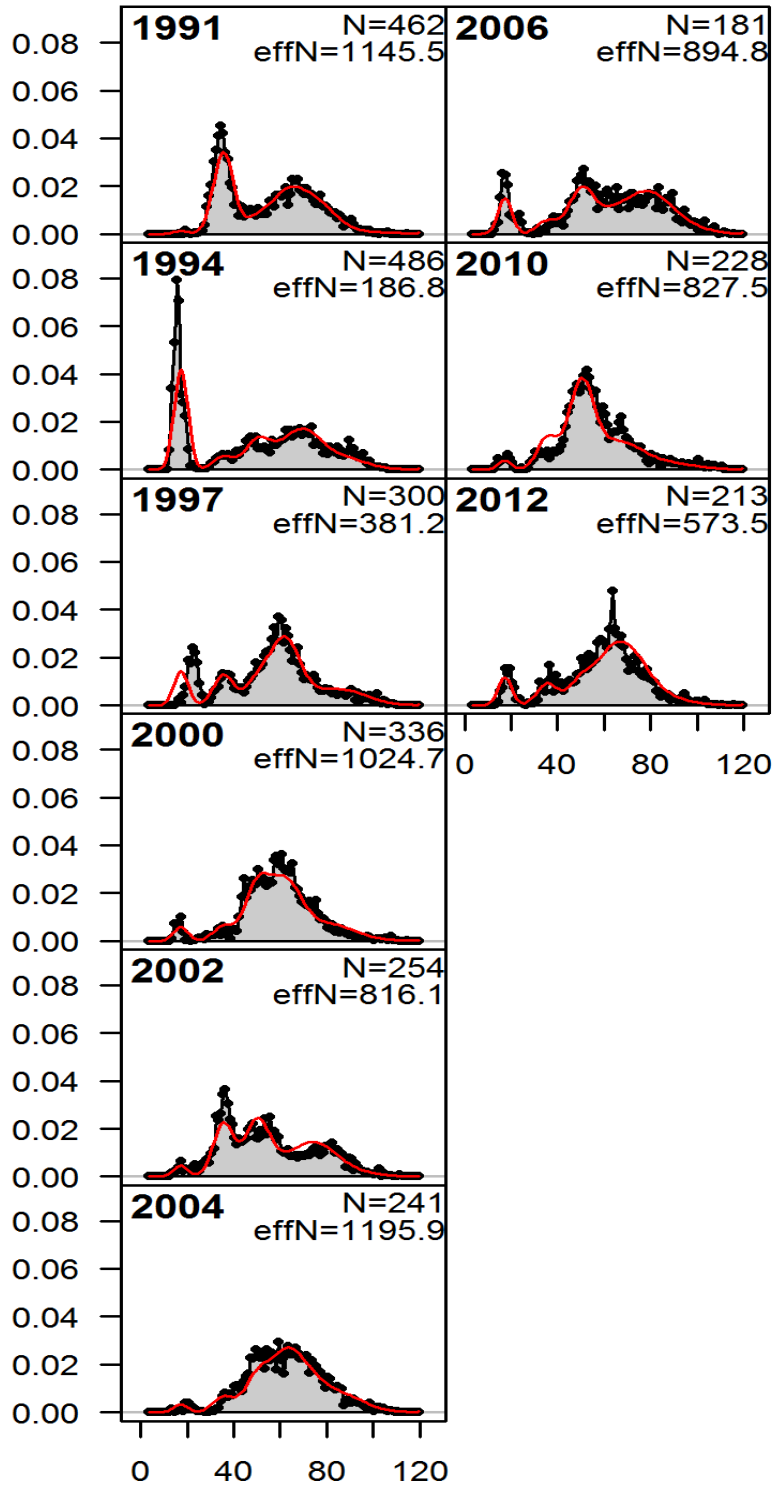
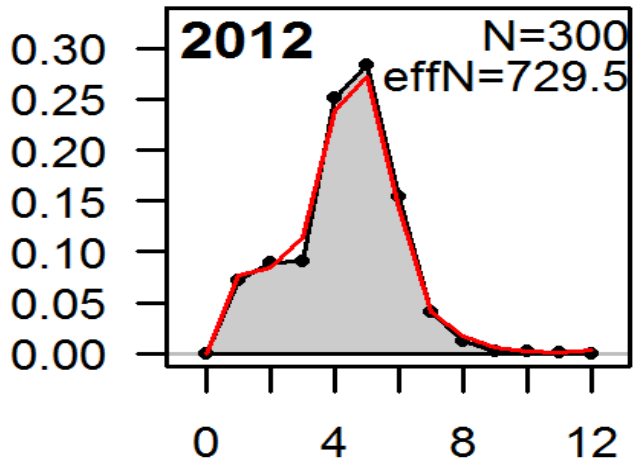
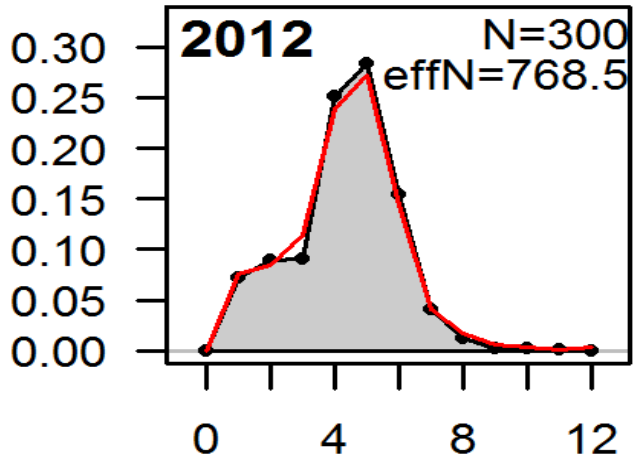


Figure 2A.1.3c—Model 3 fits to the survey size composition data.

Model 1



Model 2



Model 3

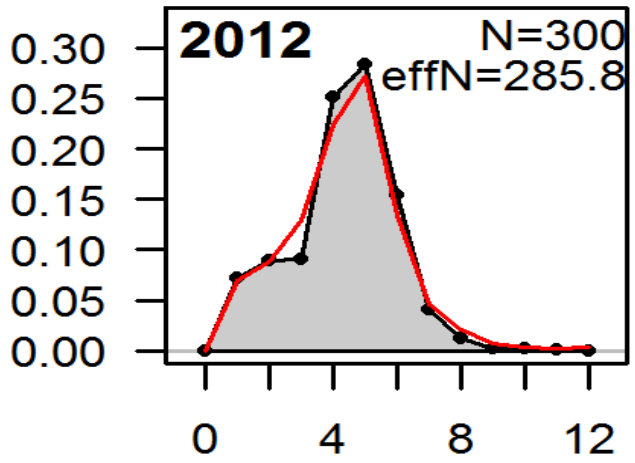
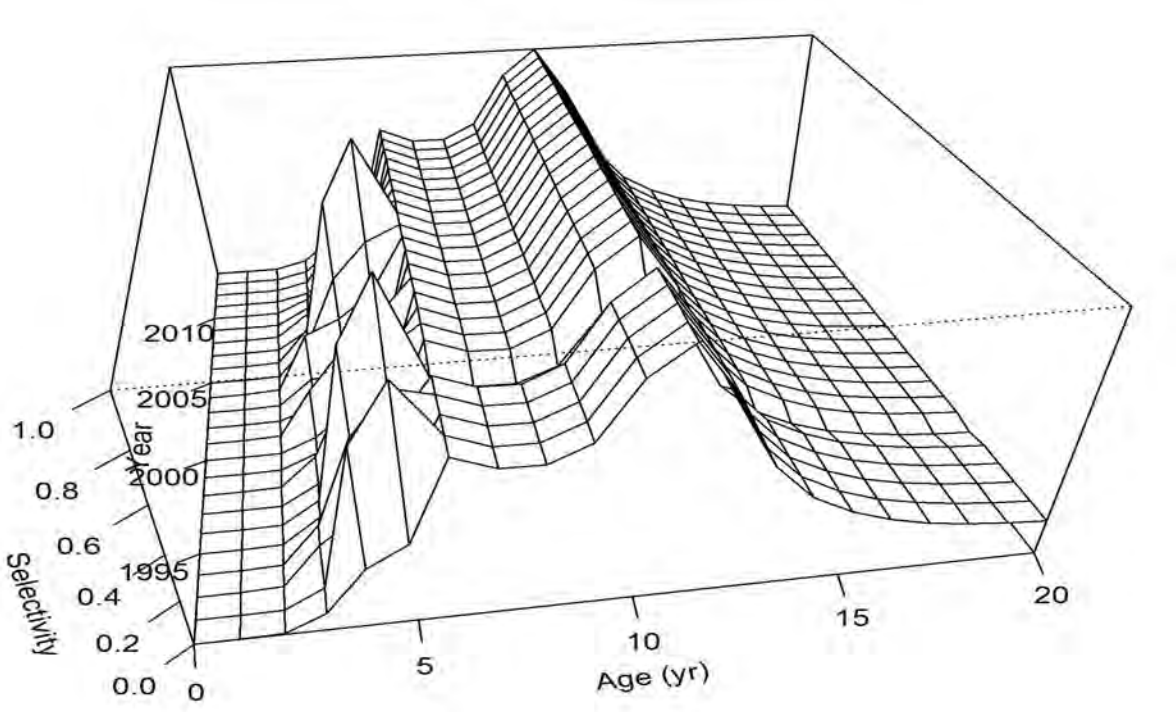


Figure 2A.1.4—Model fits to the single year of age data.

Fishery



Survey

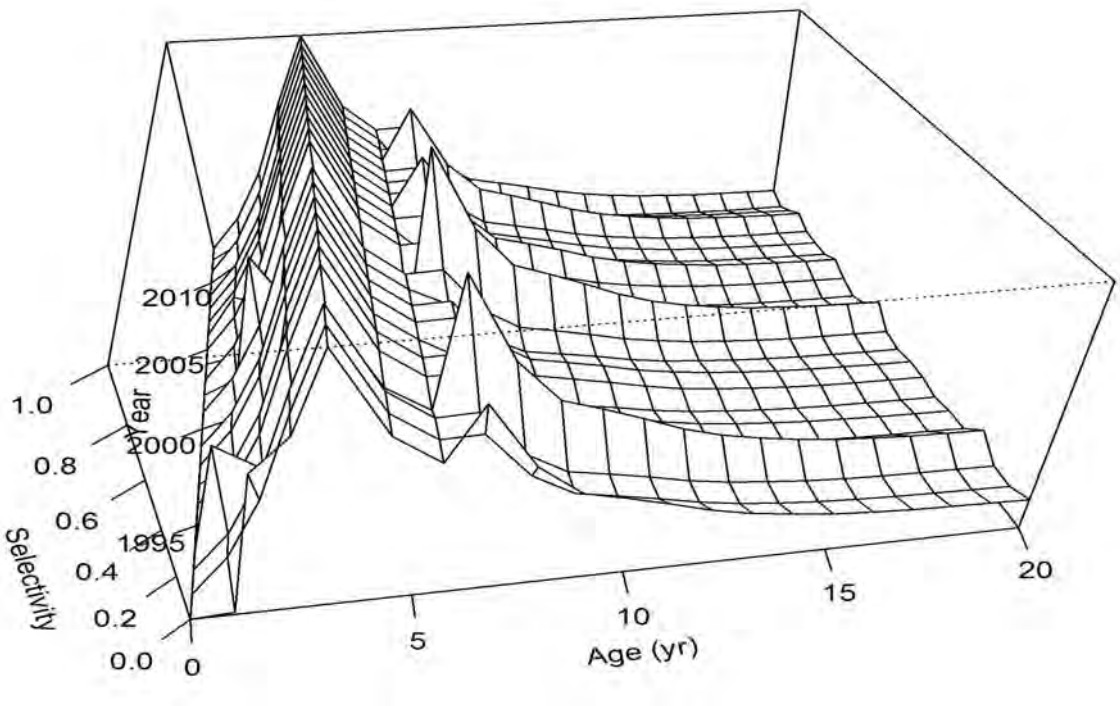
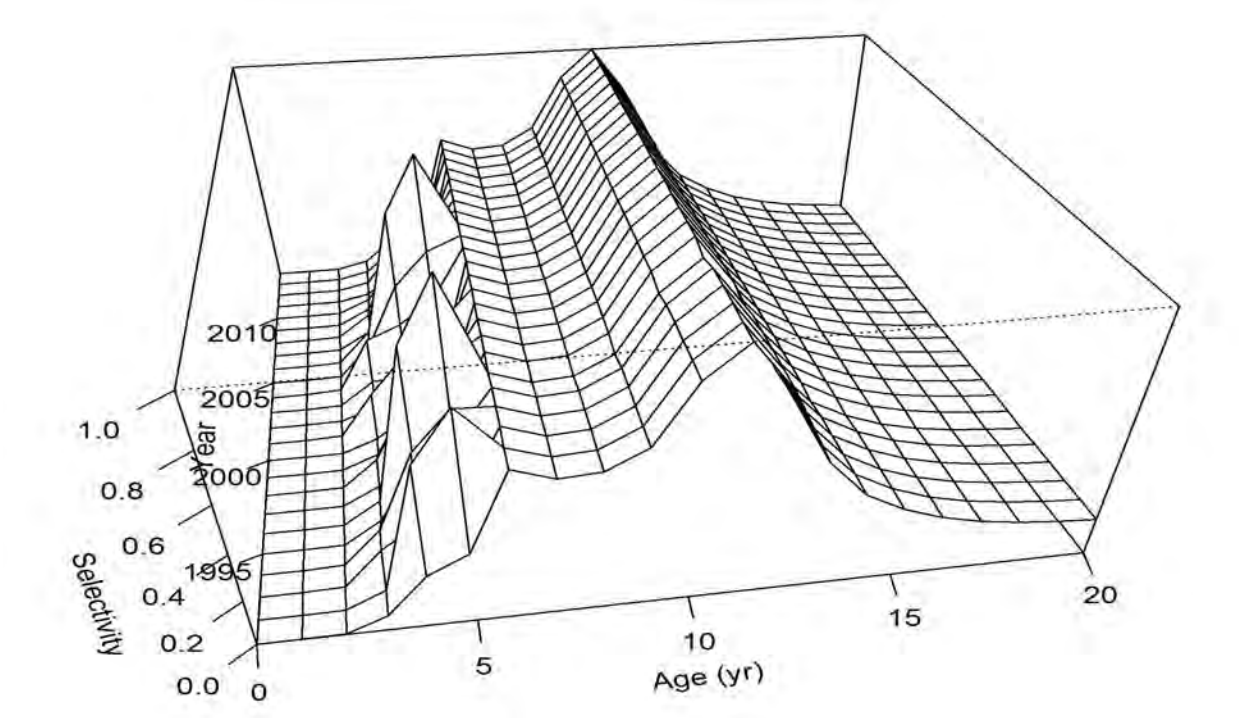


Figure 2A.1.5a—Model 1 selectivities.

Fishery



Survey

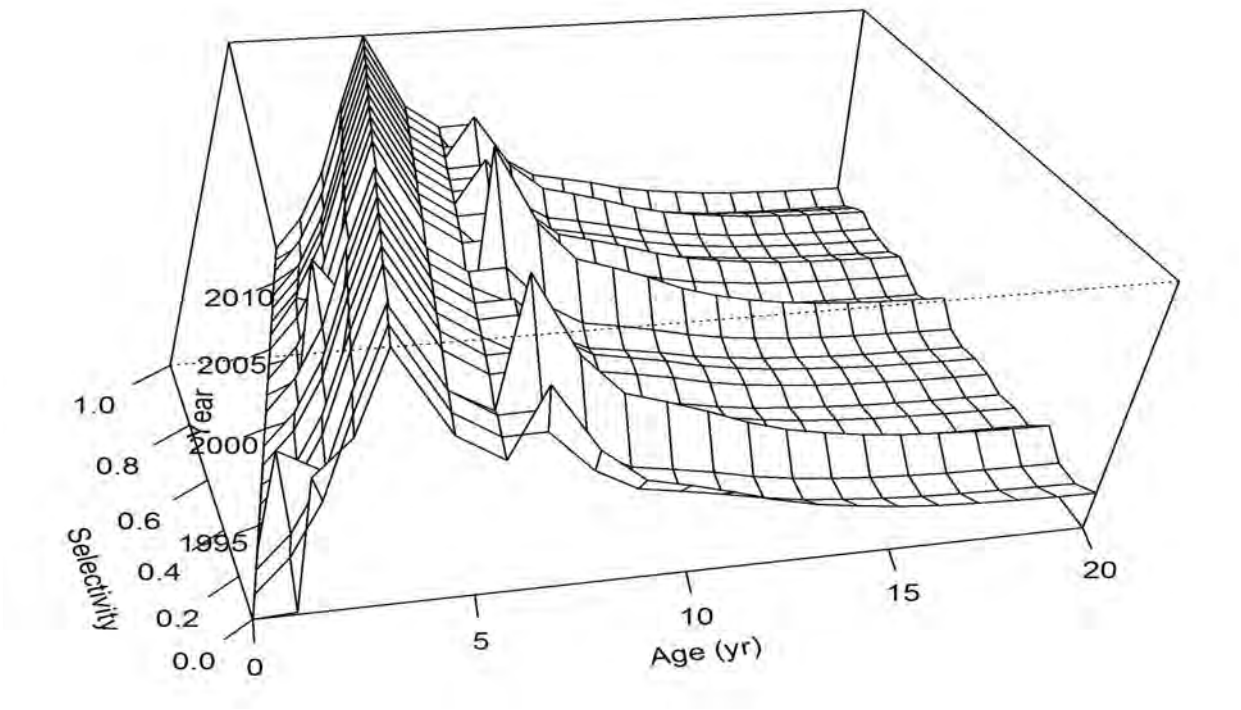
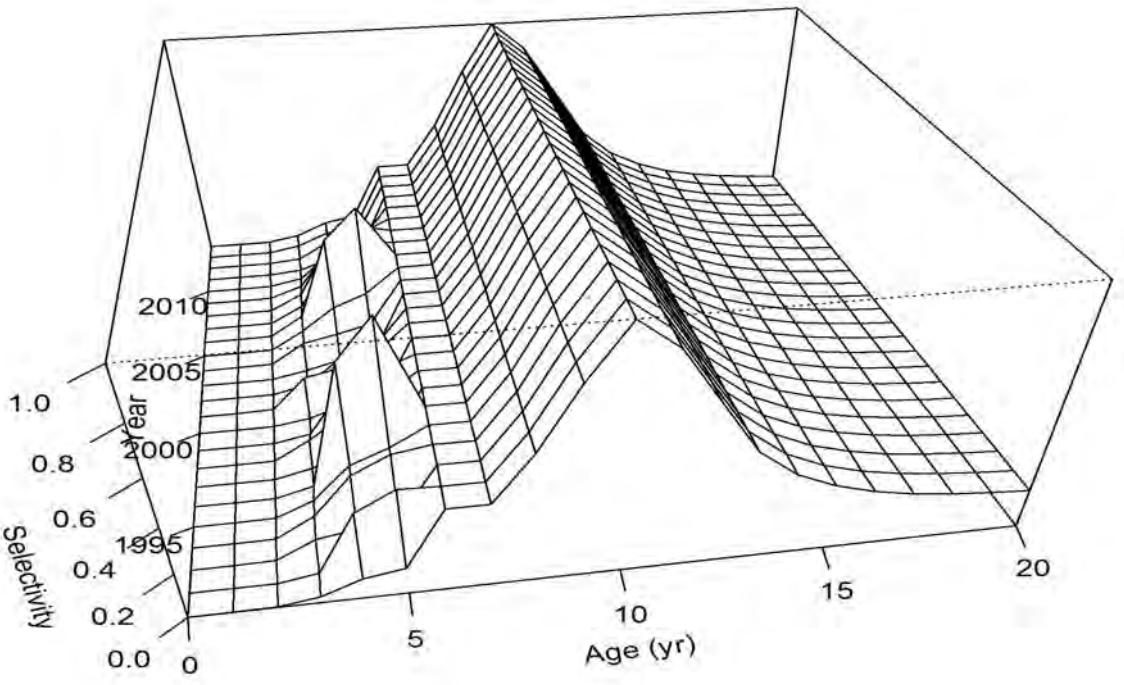


Figure 2A.1.5b—Model 2 selectivities.

Fishery



Survey

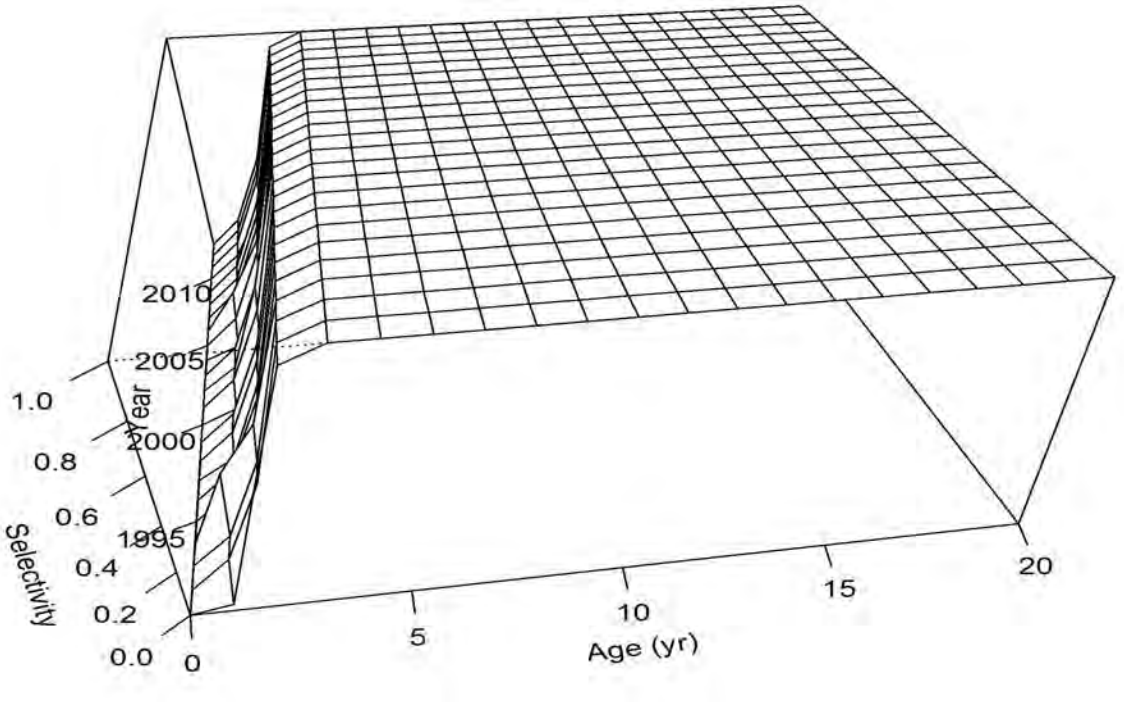


Figure 2A.1.5c—Model 3 selectivities.

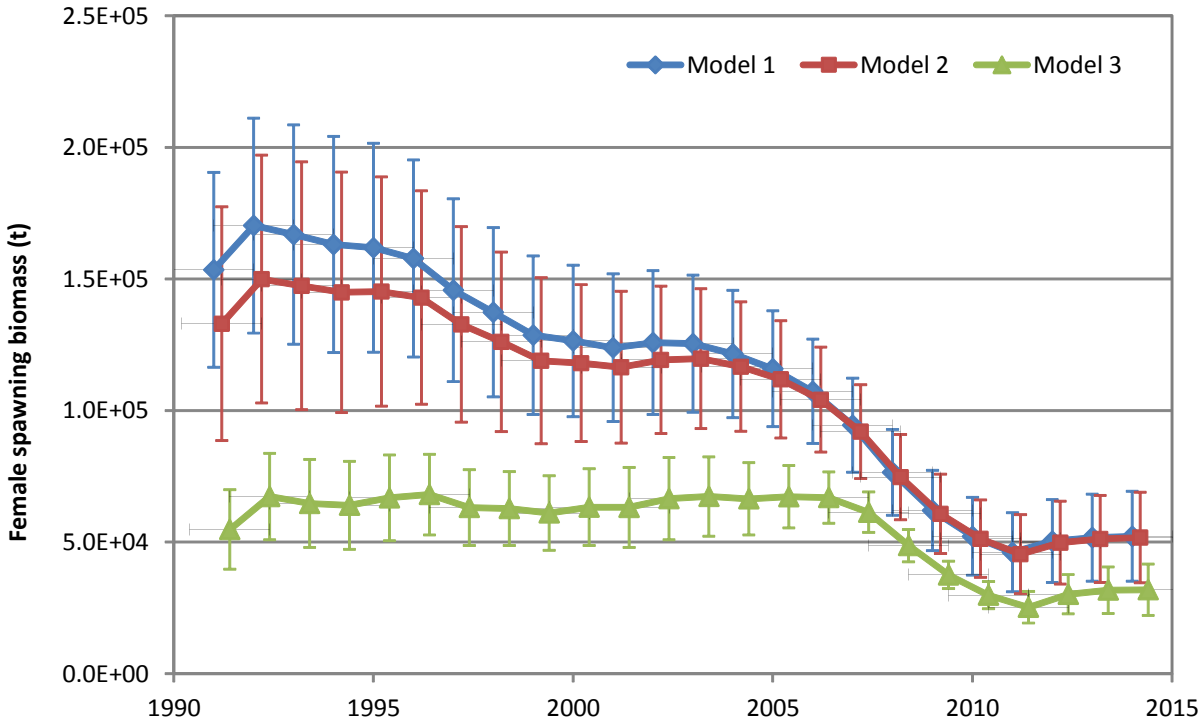


Figure 2A.1.6—Model estimates of the female spawning biomass time series.

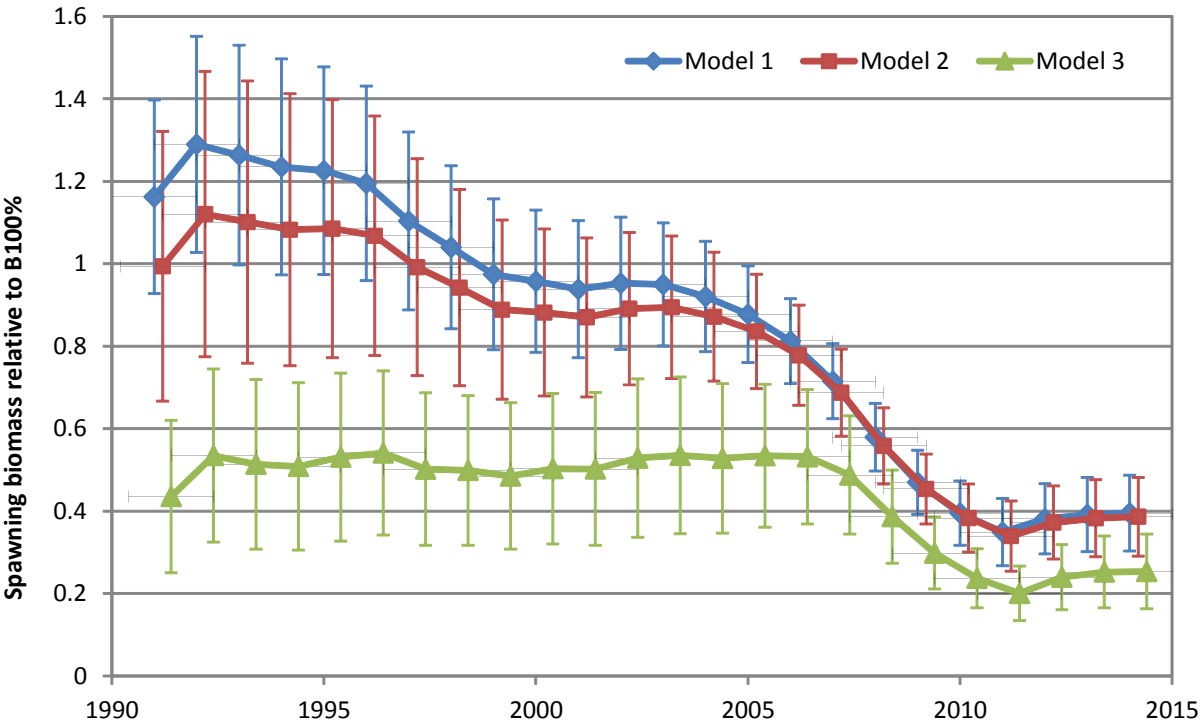


Figure 2A.1.7—Model estimates of the relative female spawning biomass time series.

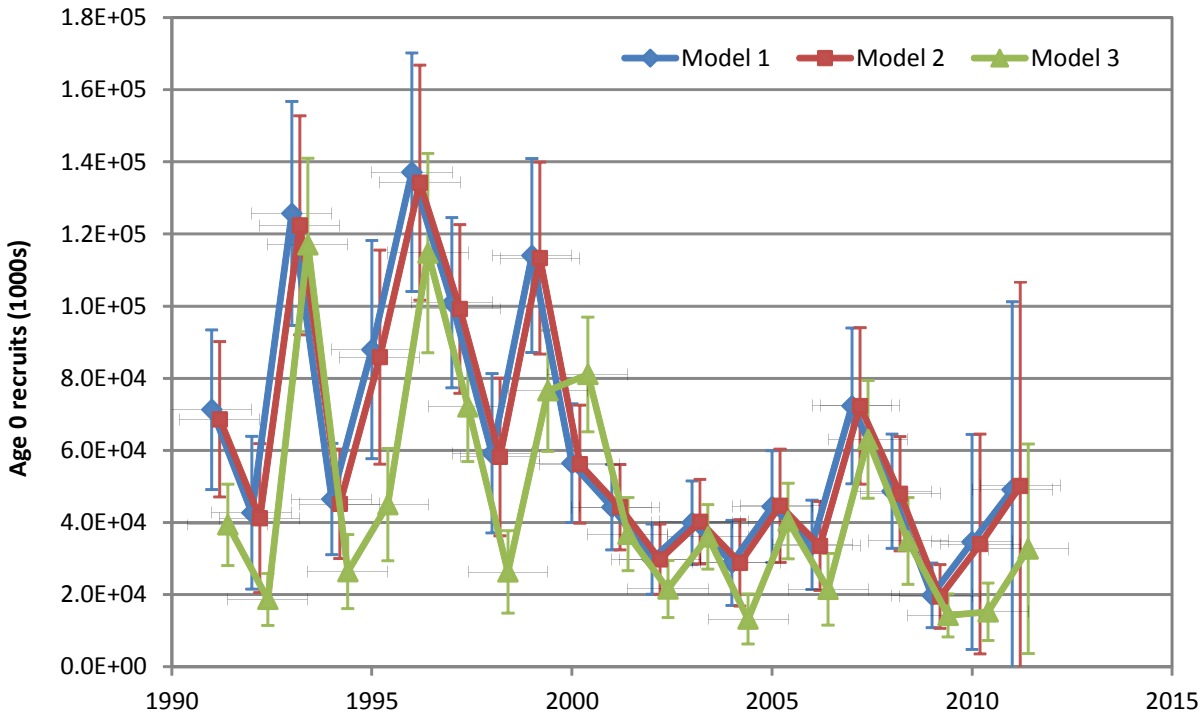


Figure 2A.1.8—Model estimates of the age 0 recruitment time series.

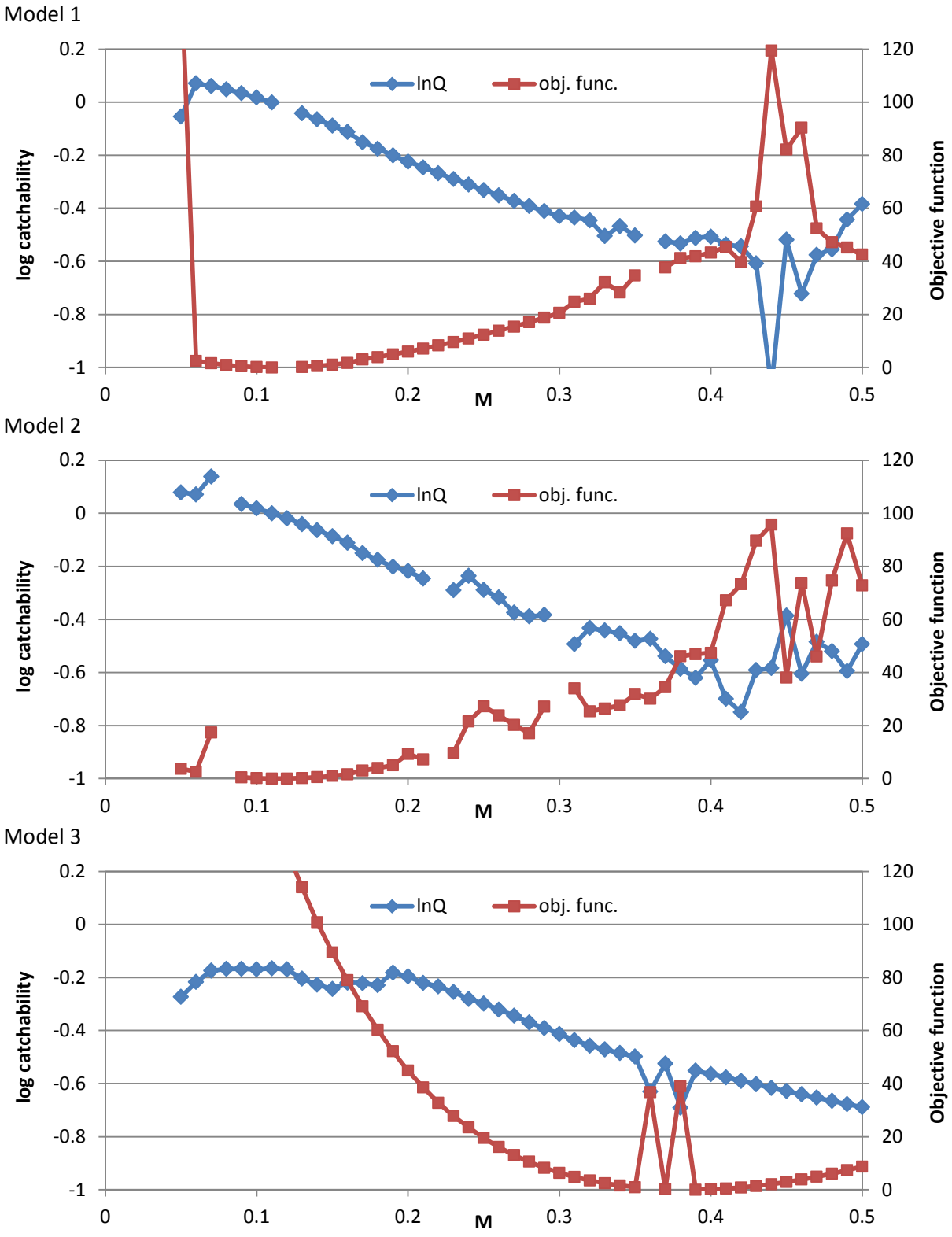


Figure 2A.1.9—Likelihood profiles with respect to the natural mortality rate. Objective function minima occur at M=0.11 (Model 1 and Model 2), and M=0.39 (Model 3). The relationship between M and log catchability is also shown for each model. Jaggedness indicates lack of convergence in some runs.

APPENDIX 2A.2: SUPPLEMENTAL CATCH DATA

From the minutes of the September 2013 Joint Plan Team meeting: *"The Teams recommended that SAFE chapter authors continue to include 'other' removals as an appendix. Optionally, authors could also calculate the impact of these removals on reference points and specifications, but are not required to include such calculations in final recommendations for OFL and ABC."*

This appendix is provided in response to the above recommendation. A similar compendium was provided for the combined BSAI Pacific cod stock in Attachment 2.4 of the 2012 assessment (Thompson and Lauth 2012).

NMFS Alaska Region has made substantial progress in developing a database documenting many of the removals of FMP species that have resulted from activities outside of fisheries prosecuted under the BSAI Groundfish FMP, including removals resulting from scientific research, subsistence fishing, personal use, recreational fishing, exempted fishing permit activities, and commercial fisheries other than those managed under the BSAI groundfish FMP. Estimates for AI Pacific cod from this dataset are shown in Table 2A.2.1.

Although many sources of removal are documented in Table 2A.2.1, the time series is highly incomplete for many of these. Cells shaded gray represent data contained in the NMFS database. Other entries represent extrapolations for years in which the respective activity was known or presumed to have taken place, where each extrapolated value consists of the time series average of the official data for the corresponding activity. In the case of surveys, years with missing values were identified from the literature or by contacting individuals knowledgeable about the survey (the NMFS database contains names of contact persons for most activities); in the case of fisheries, it was assumed that the activity occurred every year.

In the 2012 analysis of the combined BSAI Pacific cod stock (Attachment 2.4 of Thompson and Lauth 2012), the supplemental catch data were used to provide estimates of potential impacts of these data in the event that they were included in the catch time series used in the assessment model. The results of that analysis indicated that $F_{40\%}$ increased by about 0.01 and that the one-year-ahead catch corresponding to harvesting at $F_{40\%}$ decreased by about 4,000 t. Note that this is a separate issue from the effects of taking other removals "off the top" when specifying an ABC for the groundfish fishery; the former accounts for the impact on reference points, while the latter accounts for the fact that "other" removals will continue to occur.

The average of the total removals in Table 2A.2.1 for the last three complete years (2011-2013) is 92 t.

It should be emphasized that these calculations are provided purely for purposes of comparison and discussion, as NMFS and the Council continue to refine policy pertaining to treatment of removals from sources other than the directed groundfish fishery.

Table 2A.2.1—Total removals of Pacific cod (t) from activities not related to directed fishing. Cells shaded gray represent data contained in the NMFS database. Other entries represent extrapolations for years in which the respective activity was known or presumed to have taken place.

Activity	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Aleutian Island Bottom Trawl Survey				13			13			13					13			13	
Aleutian Islands Coop. Acoustic Survey																			
Annual Longline Survey			19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	
Atka Tagging Survey																			
Bait for Crab Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IPHC Annual Longline Survey																			
Subsistence Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Activity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Aleutian Island Bottom Trawl Survey		13			13		13		13		13				12		12		16
Aleutian Islands Coop. Acoustic Survey													1						
Annual Longline Survey	17		27		25		19		13		25		13		16		18		
Atka Tagging Survey					100	100	100	100	100		100	100				100	100		
Bait for Crab Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IPHC Annual Longline Survey			13	13	13	13	13	13	13	13	13	13	13	13	9	23	9	13	13
Subsistence Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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3. Assessment of the sablefish stock in Alaska

by
Dana H. Hanselman, Chris R. Lunsford, and Cara J. Rodgveller

Executive Summary

Summary of changes in assessment inputs

Relative to last year's assessment, we made the following substantive changes in the current assessment.

Changes in the input data: New data included in the assessment model were relative abundance and length data from the 2014 longline survey, relative abundance and length data from the 2013 longline fishery, length data from the 2013 trawl fisheries, age data from the 2013 longline survey and 2013 fixed gear fishery, updated historical catches from 2006 – 2013, and projected 2014- 2016 catches.

Changes in the assessment methodology: There are no model changes.

Summary of results

	As estimated or specified *last* year for:		As estimated or recommended *this* year for:	
Quantity/Status	2014	2015	2015*	2016*
M (natural mortality rate)	0.10	0.10	0.10	0.10
Tier	3b	3b	3b	3b
Projected total (age 2+) biomass (t)	215,446	221,212	219,997	227,042
Projected female spawning biomass (t)	91,212	88,793	91,183	88,345
$B_{100\%}$	265,903	265,903	262,269	262,269
$B_{40\%}$	106,361	106,361	104,908	104,908
$B_{35\%}$	93,066	93,066	91,794	91,794
F_{OFL}	0.095	0.090	0.098	0.091
$maxF_{ABC}$	0.080	0.077	0.082	0.078
F_{ABC}	0.080	0.077	0.082	0.078
OFL (t)	16,225	14,667	16,128	14,658
max ABC (t)	13,722	12,400	13,657	12,406
ABC (t)	13,722	12,400	**13,657**	12,406
Status	As determined *last* year for:		As determined *this* year for:	
	2012	2013	2013	2014
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

* Projections are based on estimated catches of 11,172 t and 9,862 t used in place of maximum permissible ABC for 2015 and 2016. This was done in response to management requests for a more accurate two-year projection.

Assessment results

The fishery abundance index decreased 13% from 2012 to 2013 (the 2014 data are not available yet). The longline survey abundance index increased 15% from 2013 to 2014 following a 25% decrease from 2011 to 2013. Spawning biomass is projected to decrease from 2015 to 2018, and then stabilize.

Sablefish are managed under Tier 3 of NPFMC harvest rules. Reference points are calculated using recruitments from 1979-2012. The updated point estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ from this assessment

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are 104,908 t (combined across the EBS, AI, and GOA), 0.095, and 0.112, respectively. Projected female spawning biomass (combined areas) for 2015 is 91,183 t (88% of $B_{40\%}$), placing sablefish in sub-tier "b" of Tier 3. The maximum permissible value of F_{ABC} under Tier 3b is 0.082, which translates into a 2015 ABC (combined areas) of 13,657 t. The OFL fishing mortality rate is 0.098 which translates into a 2015 OFL (combined areas) of 16,128 t. Model projections indicate that this stock is not subject to overfishing, overfished, nor approaching an overfished condition.

We recommend a 2015 ABC of 13,657 t. The maximum permissible ABC for 2015 from a Tier 3b adjusted $F_{40\%}$ strategy is 13,657 t. The maximum permissible ABC for 2015 is very similar to the 2014 ABC of 13,722 t. The 2013 assessment projected a 10% decrease in ABC for 2015 from 2014. This smaller decrease is supported by a moderate increase in the domestic longline survey index from the all-time low in 2013 that offset the lowest value of the fishery abundance index seen in 2013. The fishery abundance index has been trending down since 2007. The 2013 IPHC GOA sablefish index was not used in the model, but also declined 21% from 2012. The 2008 year class showed potential to be above average in previous assessments based on patterns in the age and length compositions. However the estimate in this year's assessment is only average because it is heavily influenced by the recent large overall decrease in the longline survey and trawl indices. Spawning biomass is projected to decline through 2018, and then is expected to increase; assuming average recruitment is achieved in the future. ABCs are projected to decrease in 2016 to 12,406 t and 12,292 t in 2017 (see Table 3.18).

Projected 2015 spawning biomass is 35% of unfished spawning biomass. Spawning biomass has increased from a low of 32% of unfished biomass in 2002 to 35% of unfished biomass projected for 2015 but is trending downward in projections for the near future. The 1997 year class has been an important contributor to the population; however, it has been reduced and is predicted to comprise less than 7% of the 2015 spawning biomass. The 2000 year class is still the largest contributor, with 16% of the spawning biomass in 2015. The 2008 year class is average and will comprise 10% of spawning biomass in 2015 even though it is only 60% mature.

Apportionment

In December 1999, the Council apportioned the 2000 ABC and OFL based on a 5-year exponential weighting of the survey and fishery abundance indices. We have used the same algorithm to apportion the ABC and OFL since 2000. Following the standard apportionment scheme, we have observed that the objective to reduce variability in apportionment was not being achieved. Since 2007, the average change in apportionment by area has increased annually (Figure 3.36A). While some of these changes may actually reflect interannual changes in regional abundance, they most likely reflect the high movement rates of the population and the high variability of our estimates of abundance in the Bering Sea and Aleutian Islands. For example, the apportionment for the Bering Sea has varied drastically since 2007, attributable to high variability in both survey abundance and fishery CPUE estimates in the Bering Sea (Figure 3.36B). These large annual changes in apportionment result in increased variability of ABCs by area, including areas other than the Bering Sea (Figure 3.36C). Because of the high variability in apportionment seen in recent years, we do not believe the standard method is meeting the goal of reducing the magnitude of interannual changes in the apportionment. Because of these reasons, we recommended fixing the apportionment at the proportions from the 2013 assessment until the apportionment scheme is thoroughly reevaluated and reviewed. A Ph.D. student with the University of Alaska-Fairbanks began a project in 2012 with the objectives of re-examining the apportionment strategy and conducting management strategy evaluations. A spatial sablefish model has been developed, but management strategy evaluations have not begun yet. Meanwhile, it seems imprudent to move to an interim apportionment or return to the former scheme until more satisfactory methods have been identified and evaluated. **Therefore**, **for 2015, we recommend keeping the apportionment fixed at the proportions used in 2014.**

Area	2014 ABC	Standard apportionment for 2015 ABC	**Recommended fixed apportionment for 2015 ABC***	**Difference from 2014**
Total	13,722	13,657	**13,657**	-0.5%
Bering Sea	1,339	2,210	**1,333**	-0.5%
Aleutians	1,811	1,840	**1,802**	-0.5%
Gulf of Alaska (subtotal)	10,572	9,607	**10,522**	-0.5%
Western	1,480	1,445	**1,473**	-0.5%
Central	4,681	3,975	**4,658**	-0.5%
W. Yakutat**	1,574	1,428	**1,567**	-0.5%
E. Yak. / Southeast**	2,837	2,759	**2,823**	-0.5%

* Fixed at the 2012 assessment apportionment proportions (Hanselman et al. 2012). ** Before 95:5 hook and line: trawl split shown below.

Adjusted for 95:5 hook-and-line: trawl split in EGOA	Year	W. Yakutat	E. Yakutat/Southeast
	2015	1,708 t	2,682 t
	2016	1,552 t	2,436 t

Plan team summaries

Area	Year	Biomass (4+)	OFL	ABC	TAC	Catch
GOA	2013	167,000	14,780	12,510	12,510	11,945
	2014	149,000	12,500	10,572	10,572	10,391
	2015	130,000	12,425	10,522		
	2016	127,000	11,293	9,558		
BS	2013	19,000	1,870	1,580	1,580	634
	2014	21,000	1,584	1,339	1,339	328
	2015	34,000	1,575	1,333		
	2016	33,000	1,431	1,211		
AI	2013	28,000	2,530	2,140	2,140	1,062
	2014	28,000	2,141	1,811	1,811	757
	2015	24,000	2,128	1,802		
	2016	23,000	1,934	1,637		

Year	2014				2015		2016	
Region	OFL	ABC	TAC	Catch*	OFL	ABC	OFL	ABC
BS	1,584	1,339	1,339	328	1,575	1,333	1,431	1,211
AI	2,141	1,811	1,811	757	2,128	1,802	1,934	1,637
GOA	12,500	10,572	10,572	10,391	12,425	10,522	11,293	9,558
W	--	1,480	1,480	1,090	--	1,474	--	1,338
C	--	4,681	4,681	4,737	--	4,658	--	4,232
**WYAK	--	1,574	1,574	1,707	--	1,708	--	1,552
SEO	--	2,837	2,837	2,857	--	2,682	--	2,436
Total	16,225	13,722	13,722	11,476	16,128	13,657	14,658	12,406

*Extrapolated from October 1, 2014 Alaska Fisheries Information Network, (www.akfin.org). **After 95:5 trawl split shown above.

Responses to SSC and Plan Team Comments on Assessments in General

The Teams recommended that each stock assessment model incorporate the best possible estimate of the current year's removals. The Teams plan to inventory how their respective authors address and calculate total current year removals. Following analysis of this inventory, the Teams will provide advice to authors on the appropriate methodology for calculating current year removals to ensure consistency across assessments and FMPs. (September 2013, Plan Team)

The Joint Plan Teams in September 2014 examined the compilation of current methods for estimating current year's removals and recognized that the best method was stock specific and encouraged authors to choose the best method for their stocks and document them. We estimated current year's removals by multiplying the official catch as of October 1, 2014, by an expansion factor that represents the average additional catch taken between October 1 and December 31 in the last three complete years (2011-2013). (See *Specified catch estimation* section).

During public testimony, it was proposed that assessment authors should consider projecting the reference points for the future two years (e.g., 2014 and 2015) on the phase diagrams. It was suggested that this forecast would be useful to the public. The SSC agrees. The SSC appreciated this suggestion and asks the assessment authors to do so in the next assessment. (December 2013, SSC)

These projections are available in the executive summary table and have been added to the phase-plane plots in this assessment. (See *Figure 3.30*)

Responses to SSC and Plan Team Comments Specific to this Assessment

The Teams recommend establishment of an ecosystem/assessment committee to help set up an example report card that is designed to allow the authors to fill in the blanks as an update rather than develop new conceptual models and to have in-house discussion on this topic before future presentations to the Plan Teams.(November 2012, Plan Team)

In September 2014, a document and presentation was made to the joint Plan Teams by the ecosystem/assessment committee with sablefish as an example species. The Plan Team and SSC encouraged development of stock-specific ecosystem consideration sections that have ecosystem indicators specific to particular stocks. We hope to include sablefish as an example stock as this effort moves forward.

The Teams recommend that the authors investigate time-varying selectivity in relation to some of the issues seen in the retrospective pattern. (November 2012, Plan Team)

Selectivity for the longline survey and longline fishery are currently time-varying, but not annually. The time blocks are related to specific changes in the survey (transition from cooperative to domestic) and the fishery (transition from derby to IFQ). The lack of retrospective trend in recent years (see Figure 3.31) does not warrant a change to fishery selectivity. However, the most recent fishery age data in 2013 show a shift to older fish driven by catches in the Aleutian Islands. These data may warrant exploration of annual varying selectivity for the 2015 assessment.

The SSC continues to encourage the development of a spatial assessment model for research purposes and supports the additional collection and analysis of biological samples needed to support a movement model.(December 2012, SSC)

A study on sablefish movement and mortality has been accepted for publication (Hanselman et al. 2014). Additionally, there is a UAF Ph.D. student working on a spatial assessment model for sablefish. We continue to evaluate and progress towards spatially explicit modeling of sablefish.

The Teams recommended following the authors' approach for apportionment as an interim measure (-15% across all areas). The Teams also recommended that the standard approach (used in previous year's assessments) be presented to the SSC and Council and noted that work is underway to select an improved apportionment approach. (November 2013, Plan Team)

For this year we continue to recommend the interim apportionment approach which is explained in detail in the apportionment Section (See Section *Apportionment*).

The SSC reviewed the recommended alteration to the usual algorithm of spatial apportionment. The SSC approves the alternative apportionment for next year. However, the SSC is concerned about removing a data point (2013) without strong justification. The SSC recommends re-examining the method for spatially allocating the sablefish ABC in the next year. To the extent practicable, the SSC requests that the authors try to include preliminary results of the spatial MSE in the 2014 assessment.(December 2013, SSC)

The spatial MSE is not completed at this time. However, we are working closely with a graduate student who has made significant progress toward a spatial assessment model which will be the foundation of the management strategy evaluations.

The SSC reiterates its concern that the current assessment model exhibits a strong retrospective pattern and encourages further exploration of the factors underlying the slow response of the model to shifts in stock status. (December 2013, SSC)

The sablefish model had a period of retrospective bias between 2004-2008, (see *Retrospective Analysis* section) but that bias appears to have dissipated in the last 5 years. In the Plan Team retrospective investigations group report, sablefish had one of the lowest rankings in terms of retrospective problems (17 out of 20). For 2014, the retrospective pattern has lessened further. In previous examinations of the retrospective pattern for sablefish (Hanselman et al. 2011), it was shown that longline survey catchability had a systematic pattern of change relative to the number of retrospective peels. For 2014, there was a substantial increase in past catch estimates during the period with high retrospective bias (see *Catch* section under ***Data***). This increase in catch increased our current estimates of spawning biomass during that historically low period which contributed to the reduction in Mohn's revised rho (see *Retrospective Analysis* section for further details).

Introduction

Distribution

Sablefish (*Anoplopoma fimbria*) inhabit the northeastern Pacific Ocean from northern Mexico to the Gulf of Alaska (GOA), westward to the Aleutian Islands (AI), and into the Bering Sea (BS) (Wolotira et al. 1993). Adult sablefish occur along the continental slope, shelf gullies, and in deep fjords, generally at depths greater than 200 m. Sablefish observed from a manned submersible were found on or within 1 m of the bottom (Krieger 1997). In contrast to the adult distribution, juvenile sablefish spend their first two to three years on the continental shelf of the GOA, and occasionally on the shelf of the southeast BS. The BS shelf is utilized significantly in some years and seldom used during other years (Shotwell et al. 2012).

Early life history

Spawning is pelagic at depths of 300-500 m near the edges of the continental slope (Mason et al. 1983, McFarlane and Nagata 1988), with eggs developing at depth and larvae developing near the surface as far offshore as 180 miles (Wing 1997). Along the Canadian coast (Mason et al. 1983) and off Southeast Alaska (Jennifer Stahl, February, 2010, ADF&G, pers. comm.) sablefish spawn from January-April with a peak in February. In a survey near Kodiak Island in December, 2011 that targeted sablefish preparing to spawn, spawning appeared to be imminent, but spent fish were not found. It is likely that they would spawn in January or February (Katy Echave, October 2012, AFSC, pers. comm.). Farther down the coast off of central California sablefish spawn earlier, from October-February (Hunter et al. 1989). An analysis of larval otoliths showed that spawning in the Gulf of Alaska may be a month later than southern sablefish (Sigler et al. 2001). Sablefish in spawning condition were also noted as far west as Kamchatka in November and December (Orlov and Biryukov 2005). In gill nets set at night for several years on the AFSC longline survey, most young-of-the-year sablefish were caught in the central and eastern GOA (Sigler et al. 2001). Near the end of the first summer, pelagic juveniles less than 20 cm move inshore and spend the winter and following summer in inshore waters, reaching 30-40 cm by the end of their second summer (Rutecki and Varosi 1997). After their second summer, they begin moving offshore to deeper water, typically reaching their adult habitat, the upper continental slope at 4 to 5 years. This corresponds to the age range when sablefish start becoming reproductively viable (Mason et al. 1983).

Movement

A movement model for Alaskan sablefish was developed for Alaskan sablefish by Heifetz and Fujioka (1991) based on 10 years of tagging data. The model has been updated by incorporating data from 1979-2009 in an AD Model Builder program, with time-varying reporting rates, and tag recovery data from ADF&G for State inside waters (Southern Southeast Inside and Northern Southeast Inside). In addition, the study estimated mortality rates from the tagging data (Hanselman et al. *in press*). Annual movement probabilities were high, ranging from 10-88% depending on area of occupancy at each time step, and size group. Overall, movement probabilities were very different between areas of occupancy and moderately different between size groups. Estimated annual movement of small sablefish from the central Gulf of Alaska had the reverse pattern of a previous study, with 29% moving westward and 39% moving eastward. Movement probabilities also varied annually with decreasing movement until the late 1990s and increasing movement until 2009. Year specific magnitude in movement probability of large fish was highly negatively correlated with female spawning biomass estimates from the federal stock assessment. Average mortality estimates from time at liberty were similar to the stock assessment.

Stock structure

Sablefish form two populations based on differences in growth rate, size at maturity, and tagging studies (McDevitt 1990, Saunders et al. 1996, Kimura et al. 1998). A northern population inhabits Alaska and northern British Columbia waters and a southern population inhabits southern British Columbia, Washington, Oregon, and California waters, with mixing of the two populations occurring off southwest Vancouver Island and northwest Washington. Significant stock structure among the federal Alaska population is unlikely given extremely high movement rates throughout their lives (Heifetz and Fujioka 1991, Maloney and Heifetz 1997, Kimura et al. 1998).

Fishery

Early U.S. fishery, 1957 and earlier

Sablefish have been exploited since the end of the 19th century by U.S. and Canadian fishermen. The North American fishery on sablefish developed as a secondary activity of the halibut fishery of the United States and Canada. Initial fishing grounds were off Washington and British Columbia and then spread to Oregon, California, and Alaska during the 1920's. Until 1957, the sablefish fishery was exclusively a U.S. and Canadian fishery, ranging from off northern California northward to Kodiak Island in the GOA; catches were relatively small, averaging 1,666 t from 1930 to 1957, and generally limited to areas near fishing ports (Low et al. 1976).

Foreign fisheries, 1958 to 1987

Japanese longliners began operations in the eastern BS in 1958. The fishery expanded rapidly in this area and catches peaked at 25,989 t in 1962 (Table 3.1, Figures 3.1, 3.2). As the fishing grounds in the eastern Bering were preempted by expanding Japanese trawl fisheries, the Japanese longline fleet expanded to the AI region and the GOA. In the GOA, sablefish catches increased rapidly as the Japanese longline fishery expanded, peaking at 36,776 t overall in 1972. Catches in the AI region remained at low levels with Japan harvesting the largest portion of the sablefish catch. Most sablefish harvests were taken from the eastern Being Sea until 1968, and then from the GOA until 1977. Heavy fishing by foreign vessels during the 1970's led to a substantial population decline and fishery regulations in Alaska, which sharply reduced catches. Catch in the late 1970's was restricted to about one-fifth of the peak catch in 1972, due to the passage of the Fishery Conservation and Management Act (FCMA).

Japanese trawlers caught sablefish mostly as bycatch in fisheries targeting other species. In the BS, the trawlers were mainly targeting rockfishes, Greenland turbot, and Pacific cod, and only a few vessels targeted sablefish. In the GOA, sablefish were mainly caught as bycatch in the directed Pacific Ocean perch fishery until 1972, when some vessels started targeting sablefish in 1972 (Sasaki 1985).

Other foreign nations besides Japan also caught sablefish. Substantial Soviet Union catches were reported from 1967-73 in the BS (McDevitt 1986). Substantial Korean catches were reported from 1974-1983 scattered throughout Alaska. Other countries reporting minor sablefish catches were Republic of Poland, Taiwan, Mexico, Bulgaria, Federal Republic of Germany, and Portugal. The Soviet gear was factory-type stern trawl and the Korean gears were longlines and pots (Low et al. 1976).

Recent U.S. fishery, 1977 to present

The U.S. longline fishery began expanding in 1982 in the GOA, and by 1988, the U.S. harvested all sablefish taken in Alaska, except minor joint venture catches. Following domestication of the fishery, the previously year-round season in the GOA began to shorten in 1984 from 12 months in 1983 to 10 days in 1994, warranting the label “derby” fishery.

In 1995, Individual Fishery Quotas (IFQ) were implemented for hook-and-line vessels along with an 8-month season. The IFQ Program is a catch share fishery that issued quota shares to individuals based on sablefish and halibut landings made from 1988-1990. Since the implementation of IFQ’s, the number of longline vessels with sablefish IFQ harvests has experienced a substantial anticipated decline from 616 in 1995 to 362 in 2011 (NOAA 2012). This decrease was expected as shareholders have consolidated their holdings and fish them off fewer vessels to reduce costs (Fina 2011). The sablefish fishery has historically been a small boat fishery; the median vessel length in the 2011 fishery was 56ft. In recent years, approximately 30% of vessels eligible to fish in the IFQ fishery participate in both the halibut and sablefish fisheries and approximately 40% of vessels fish in more than one management area. The season dates have varied by several weeks since 1995, but the monthly pattern has been from March to

November with the majority of landings occurring in May - June. The number of landings fluctuates with quota size, but in 2011 there were 1,726 landings recorded in the Alaska fishery (NOAA 2012).

Pot fishing in the IFQ fishery is not allowed in the GOA but is legal in the BSAI regions. In 2000, the pot fishery accounted for less than ten percent of the fixed gear sablefish catch in these areas but effort has increased substantially in response to killer whale depredation. Pots are longlined with approximately 40-135 pots per set. Since 2004, pot gear has accounted for over 50% of the BS fixed gear IFQ catch and up to 34% of the fixed gear catch in the AI.

Sablefish also are caught incidentally during directed trawl fisheries for other species groups such as rockfish and deepwater flatfish. Allocation of the TAC by gear group varies by management region and influences the amount of catch in each region (Table 3.1, Figures 3.1, 3.2). Five State of Alaska fisheries land sablefish outside the IFQ program; the major State fisheries occur in the Prince William Sound, Chatham Strait, and Clarence Strait and the minor fisheries in the northern GOA and AI. The minor state fisheries were established by the State of Alaska in 1995, the same time as the Federal Government established the IFQ fishery, primarily to provide open-access fisheries to fishermen who could not participate in the IFQ fishery.

IFQ management has increased fishery catch rates and decreased the harvest of immature fish (Sigler and Lunsford 2001). Catching efficiency (the average catch rate per hook for sablefish) increased 1.8 times with the change from an open-access to an IFQ fishery. The change to IFQ also decreased harvest and discard of immature fish which improved the chance that these fish will reproduce at least once. Thus, the stock can provide a greater yield under IFQ at the same target fishing rate because of the selection of older fish (Sigler and Lunsford 2001).

Longline gear in Alaska is fished on-bottom. Since the inception of the IFQ system, average set length in the directed fishery for sablefish has been near 9 km and average hook spacing near1.2 m. The gear is baited by hand or by machine, with smaller boats generally baiting by hand and larger boats generally baiting by machine. Circle hooks are usually used, except for modified J-hooks on some boats with machine baiters. The gear usually is deployed from the vessel stern with the vessel traveling at 5-7 knots. Some vessels attach weights to the longline, especially on rough or steep bottom, so that the longline stays in place on bottom.

Management measures/units

A summary of historical catch and management measures pertinent to sablefish in Alaska are shown in Table 3.7. Influential management actions regarding sablefish include:

Management units

Sablefish are assessed as a single population in Federal waters off Alaska because of their high movement rates. Sablefish are managed by discrete regions to distribute exploitation throughout their wide geographical range. There are four management areas in the GOA: Western, Central, West Yakutat, and East Yakutat/Southeast Outside; and two management areas in the Bering Sea/Aleutian Islands (BSAI): the BS and the AI regions. Amendment 8 to the GOA Fishery Management Plan established the West and East Yakutat management areas for sablefish, effective 1980.

Quota allocation

Amendment 14 to the GOA Fishery Management Plan allocated the sablefish quota by gear type: 80% to fixed gear (including pots) and 20% to trawl in the Western and Central GOA, and 95% to fixed gear and 5% to trawl in the Eastern GOA, effective 1985. Amendment 15 to the BS/AI Fishery Management Plan, allocated the sablefish quota by gear type, 50% to fixed gear and 50% to trawl in the eastern BS, and 75% to fixed gear and 25% to trawl gear in the Aleutians, effective 1990.

IFQ management

Amendment 20 to the GOA Fishery Management Plan and 15 to the BS/AI Fishery Management Plan established IFQ management for sablefish beginning in 1995. These amendments also allocated 20% of the fixed gear allocation of sablefish to a CDQ reserve for the BS and AI.

Maximum retainable allowances

Maximum retainable allowances for sablefish were revised in the GOA by a regulatory amendment, effective April, 1997. The percentage depends on the basis species: 1% for pollock, Pacific cod, Atka mackerel, "other species", and aggregated amount of non-groundfish species. Fisheries targeting deep flatfish, rex sole, flathead sole, shallow flatfish, Pacific ocean perch, northern rockfish, dusky rockfish, and demersal shelf rockfish in the Southeast Outside district, and thornyheads are allowed 7%. Arrowtooth flounder fisheries are not allowed to retain any sablefish.

Allowable gear

Amendment 14 to the GOA Fishery Management Plan banned the use of pots for fishing for sablefish in the GOA, effective 18 November 1985, starting in the Eastern area in 1986, in the Central area in 1987, and in the Western area in 1989. An earlier regulatory amendment was approved in 1985 for 3 months (27 March - 25 June 1985) until Amendment 14 was effective. A later regulatory amendment in 1992 prohibited longline pot gear in the BS (57 FR 37906). The prohibition on sablefish longline pot gear use was removed for the BS, except from 1 to 30 June to prevent gear conflicts with trawlers during that month, effective 12 September 1996. Sablefish longline pot gear is allowed in the AI.

Catch

Annual catches in Alaska averaged about 1,700 t from 1930 to 1957 and exploitation rates remained low until Japanese vessels began fishing for sablefish in the BS in 1958 and the GOA in 1963. Catches rapidly escalated during the mid-1960s. Annual catches in Alaska reached peaks in 1962, 1972, and 1988 (Table 3.1, Figure 3.2). The 1972 catch was the all-time high, at 53,080 t, and the 1962 and 1988 catches were 50% and 72% of the 1972 catch. Evidence of declining stock abundance and passage of the MSFCMA led to significant fishery restrictions from 1978 to 1985, and total catches were reduced substantially.

Exceptional recruitment fueled increased abundance and increased catches during the late 1980's, which coincided with the domestic fishery expansion. Catches declined during the 1990's, increased in the early 2000s, and have since declined to near 12,000 t (Figure 3.1). TACs in the GOA are nearly fully utilized, while TACs in the BS and AI are rarely fully utilized.

Bycatch and discards

Sablefish discards by target fisheries are available for hook-and-line gear and other gear combined (Table 3.3). From 1994 to 2004 discards averaged 1,357 t for the GOA and BSAI combined (Hanselman et al. 2008). Since then, discards have been lower, averaging 614 t between 2007 and 2013. The highest discard amounts occur in hook-and-line fisheries in the GOA (Table 3.3).

Table 3.4 shows the average bycatch of Fishery Management Plans' (FMP) groundfish species in the sablefish target fishery from 2009-2013. The largest bycatch group is GOA thornyhead rockfish (520 t/year, 151 t discarded). Arrowtooth flounder and shark are the 2nd and 3rd most caught species at 348 t/year and 331 t/year. Arrowtooth is the only species that has substantial catch in non-longline gear. The next three groups are GOA Shortraker, GOA Other rockfish, and GOA longnose skate which total 435 t/year.

Giant grenadiers, a non-target species that is soon entering both FMPs as an Ecosystem Component, make up the bulk of the nontarget species bycatch, with 2013 the highest in the last five years at 8,083 t (Table

3.5). Other nontarget taxa that have catches over one ton per year are corals, snails, sponges, sea stars, and miscellaneous fishes and crabs.

Prohibited species catches (PSC) in the targeted sablefish fisheries are dominated by halibut (1,224 t/year on average) and golden king crab (66,000 individuals/year on average). Halibut and golden king crab catches are highly variable from year to year, probably as a result of relatively low observer sampling effort in sablefish fisheries (Table 3.6).

Data

The following table summarizes the data used for this assessment:

Source	Data	Years
Fixed gear fisheries	Catch	1960-2014
Trawl fisheries	Catch	1960-2014
Japanese longline fishery	Catch-per-unit-effort (CPUE)	1964-1981
U.S. fixed gear fishery	CPUE, length	1990-2013
	Age	1999-2013
U.S. trawl fisheries	Length	1990,1991,1999, 2005-2013
Japan-U.S. cooperative longline survey	CPUE, length	1979-1994
	Age	1981, 1983, 1985, 1987, 1989, 1991, 1993
Domestic longline survey	CPUE, length	1990-2014
	Age	1996-2013
NMFS GOA trawl survey	Abundance index	1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003, 2005, 2007, 2009, 2011, 2013
	Lengths	1984, 1987, 1990, 1993, 1996, 1999, 2003, 2005, 2007, 2009, 2011, 2013

Fishery

Length, catch, and effort data were historically collected from the Japanese and U.S. longline and trawl fisheries, and are now collected from U.S. longline, trawl, and pot fisheries (Table 3.8). The Japanese data were collected by fishermen trained by Japanese scientists (L. L. Low, August 25, 1999, Alaska Fisheries Science Center, pers. comm.). The U.S. fishery length and age data were collected by at-sea and plant observers. No age data were systematically collected from the fisheries until 1999 because of the difficulty of obtaining representative samples from the fishery and because only a small number of sablefish can be aged each year. The equations used to compile the fishery and survey data used in the assessment are shown in Appendix A of the 2002 SAFE (Sigler et al. 2002).

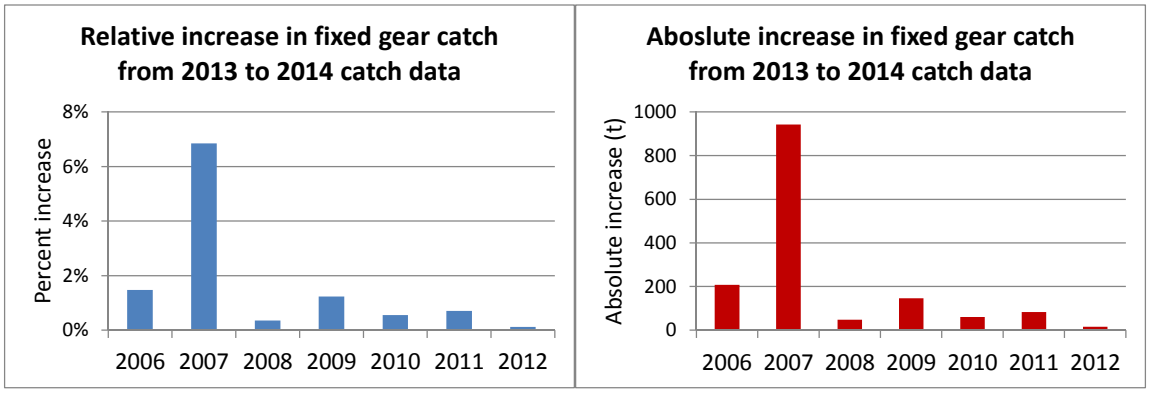
Catch

The catches used in this assessment (Table 3.1) include catches from minor State-managed fisheries in the northern GOA and in the AI region because fish caught in these State waters are reported using the area code of the adjacent Federal waters in the Alaska Regional Office catch reporting system (G. Tromble, July 12, 1999, Alaska Regional Office, pers. comm.), the source of the catch data used in this assessment. Minor State fisheries catches averaged 180 t from 1995-1998, about 1% of the average total catch. Most of the catch (80%) is from the AI region. The effect of including these State waters catches in the assessment is to overestimate biomass by about 1%, a negligible error considering statistical variation in other data used in this assessment. Catches from state areas that conduct their own assessments and set Guideline Harvest levels (e.g., Prince William Sound, Chatham Strait, and Clarence Strait), are not included in this assessment.

Some catches probably were not reported during the late 1980's (Kinoshita et al. 1995). Unreported catches could account for the Japan-U.S. cooperative longline survey index's sharp drop from 1989-90 (Table 3.8, Figures 3.3). We tried to estimate the amount of unreported catches by comparing reported catch to another measure of sablefish catch, sablefish imports to Japan, the primary buyer of sablefish. However the trends of reported catch and imports were similar, so we decided to change our approach for catch reporting in the 1999 assessment (Sigler et al. 1999). We assumed that non-reporting is due to at-sea discards, and apply discard estimates from 1994 to 1997 to inflate U.S. reported catches before 1994 (2.9% for hook-and-line and 26.6% for trawl).

In response to Annual Catch Limit (ACL) requirements, assessments now document all removals including catch that are not associated with a directed fishery. Research catches of sablefish have been reported in previous stock assessments (Hanselman et al. 2009). Estimates of all removals not associated with a directed fishery including research catches are available and are presented in Appendix 3B. The sablefish research removals are small relative to the fishery catch, but substantial compared to the research removals for many other species. These research removals support a dedicated longline survey. Additional sources of significant removals are bottom trawl surveys and the International Pacific Halibut Commission's longline survey. Other removals are relatively minor for sablefish but the sport fishery catch has been increasing in recent years, but occurs primarily in State waters. Total removals from activities other than directed fishery have been between 239-359 t since 2006. These catches are not included in the stock assessment model. These removal estimates equate to approximately 2% of the recommended ABC and represent a relatively low risk to the sablefish stock.

For the 2014 assessment, sablefish catches since 2006 have been altered substantively in the Alaska Regional Office Catch Accounting System (CAS) revisions. The years 2006-2009 were particularly different than reported in the 2013 SAFE. These estimates of catch have been updated and corrected to account for selected landings and associated catch that were inadvertently not being counted against the Federal ABC. The missing records were a result of the transition to the eLandings system and the fact that not all processors were using the system in those years. During that time, there were paper fish tickets generated from processors who were not using eLandings. Those data were entered into the eLandings system by Alaska Department of Fish and Game, but were missing federal permit information and thus did not get properly captured by the CAS. Recently, changes were made to CAS to enable accounting of groundfish landings with missing federal permit information and CAS has been re-run for the historical years. This resulted in a net total increase of about 1,500 t to the sablefish catch in since 2005, with the biggest relative increase in 2007 (see figures below).



Lengths

We use length compositions from the U.S. fixed gear (longline and pot) and U.S. trawl fisheries which are both measured by sex. The fixed gear fishery has large sample sizes and has annual data since 1990. The trawl fishery had low levels of observer sampling in much of the 1990s and early 2000s, and has a much smaller sample size than the fixed gear fishery. We only use years for the trawl fishery that have sample

sizes of at least 300 per sex. The length compositions are weighted by catch in each FMP management area to obtain a representative estimate of catch-at-length.

Ages

We use age compositions from the U.S. fixed gear fishery since 1999. Sample sizes are similar to the longline survey with about 1,000 otoliths aged every year. The age compositions are weighted by the catch in each area to obtain a representative estimate of catch-at-age.

Longline fishery catch rate index

Fishery information is available from longline sets which target sablefish in the IFQ fishery. Records of catch and effort for these vessels are collected by observers and by vessel captains in voluntary and required logbooks. Fishery data from the Observer Program is available since 1990. Logbooks are required for vessels over 60 feet beginning in 1999. Since 2000, a longline fishery catch rate index has been derived from observed sets and logbook data for use in the model and in apportionment. The mean CPUE is scaled to a relative population weight by the total area size in each area. In the years that logbook and observer CPUEs are available, the average of the two sources is computed by weighting with the inverse of the coefficient of variation.

Longline sample sizes

The total weight of all sets recorded by observers determined to be targeting sablefish represent on average 14% of the annual IFQ hook and line catch; in 2013 they comprised 12% of the catch (1,389 mt). On average, the percent of the IFQ catch observed is lowest in the EY/SE (5%), highest in WY and AI (~22%), and moderate in the BS, CGOA, and WGOA (10-14%). In 2013 coverage in the BS was only 2% and only 10% in WY. The AI had higher coverage than average (35%). This may partially be due to observer restructuring. Low longline fishery sample sizes in the BS are likely a result of poor observer coverage for sablefish directed trips (Table 3.9). Because of confidentiality concerns, the catch rates with less than three vessels cannot be shown.

Killer whales impact sablefish catch rates in the BS, AI and WGOA and these sets are excluded from catch rate analyses. Since 2009, there has been an increase in killer whale depredation in the WGOA (average 6% from 2010-2013); however, this is only 7-18 sets per year. In the AI and BS, killer whale depredation has been variable, ranging from 0-12 sets per year in each area. Sperm whale depredation occurs in the CGOA, EY/SE, WY, and sometimes in the WGOA. The percent of sets in each area depredated by sperm whales varies greatly and determining if sperm whales are depredating can be subjective because whales do not take the great majority of the catch, like killer whales do. Therefore, measures of depredation in the fishery may not be accurate.

Logbook sample sizes are substantially higher than observer samples sizes, especially since 2004, and have continued to rise annually in many management areas (WGOA, WY, CGOA) (Table 3.9). Logbook participation increased sharply in 2004 in all areas primarily because the International Pacific Halibut Commission (IPHC) was used to collect, edit, and enter logbooks electronically. This increasing trend is likely due to the strong working relationship the IPHC has with fishermen, their diligence in collecting logbooks dockside, and because many vessels <60 feet are now participating in the program voluntarily. There were 5% more sets used for catch rate analyses in 2013 than in 2012. Like in 2012, the number of sets submitted by vessels <60 ft was approximately equal to the number from vessels >60 ft. There is a higher proportion of the catch documented by logbooks than by observers; 54% of the catch was documented in logbooks that were used in calculations of catch rates in 2013, compared to 12% for observer data in 2013. Some data is included in both data sets if logbooks are required and an observer was onboard.

Longline catch rates

Killer whale depredation data is excluded for catch rate calculations in observer data, but whale depredation is not documented in logbooks and so no data is excluded. In general, catch rates are highest in the EY/SE and WY areas and are lowest in the BS and AI (Table 3.9, Figures 3.5 and 3.6). Recently, catch rate trends in the observer and logbook data have been similar in the EBS, CGOA, WGOA, and AI. In 2013 catch rates decreased substantially in both fishery data sets in the WGOA and CGOA. The decrease was larger in the logbook data set (30% drop in WGOA and 39% in CGOA in logbook data; 11% drop in WGOA and 31% in CGOA in observer data). Catch rates in the AI have been pretty stable since 2009 in both data sets. In 2013, WY logbook CPUE was down, while the observer data was up from 2012. EY/SE CPUE decreased in both data sets, but more in logbook data than observer data (14% versus 2%).

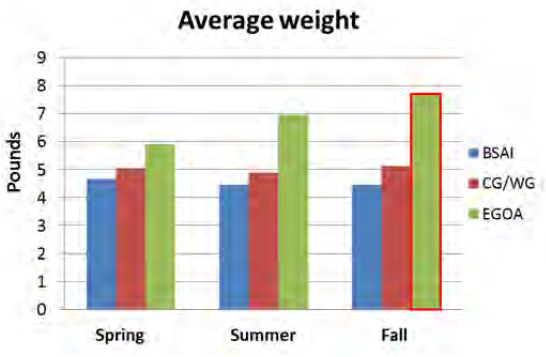
Longline spatial and temporal patterns

Changes in spatial or temporal patterns of the fishery may cause fishery catch rates to be unrepresentative of abundance. For example, fishers sometimes target concentrations of fish, even as geographic distribution shrinks when abundance declines (Crecco and Overholtz 1990). This could lead to an incorrect interpretation of fishery catch rates, which could remain stable while the area occupied by the stock was diminishing (Rose and Kulka 1999).

We examined fishery longline data for seasonal and annual differences in effort and catch rate (CPUE, lbs/hook). Such changes may cause fishery catch rates to be unrepresentative of abundance. In the observed longline data since 2000, the majority of effort occurs in the spring and less in the summer and fall. Since 1998, catch rates are also highest in the spring, moderate in the summer, and variable in the fall (due to lower sample sizes in the fall). No significant spatial or temporal changes have emerged in the logbook or observer data.

Seasonal changes in fish size

In 2012 and 2013 there was an increase in the quantity of logbook data providing estimates of catch in weight and estimated numbers per set. This enables us to examine change in average weight of fish caught by season. Data from 2012 and 2013 were combined to increase sample sizes. To further increase sample size, areas were aggregated into BS/AI, CG/WGOA, and WY/EY/SE (EGOA). Data were included unless there was missing weight or count information. There were very small differences between spring, summer, and fall in all areas except the EGOA (see figure below). However, this may be a sample size issue as there were very few sets available in the fall in EGOA compared to all other areas/seasons (78 sets; highlighted in red below). In EGOA, weight in spring was 5.9 lbs, 7 lbs in summer, and 7.7 lbs in fall. More data is needed to determine if there actually is an increasing trend in weight in the fall in the EGOA.



Count of logbook sets used for calculations of average sablefish weight by area and season.

Area	Spring	Summer	Fall	Total
BS/AI	560	614	157	1,331
CG/WG	1,563	1,409	403	3,375
EGOA	783	297	78	1,158

Pot fishery catch rate analysis

Pot catch rates: Because pot data is sparser than longline data, and in some years is confidential due to fewer than 3 vessels participating, specific annual data is not presented. In addition, it is difficult to discern trends, since pot catch rates have wider confidence intervals than longline data due to smaller sample sizes. Overall, there are more vessels in both the logbook and observer data from the sablefish pot fishery in the BS than the AI.

Since 2006, in the BS there have been from 5 to 9 vessels in logbook data and 5 to 8 vessels in observer data. In the AI, there have been from 1 to 5 vessels in logbooks and 1 to 4 in observer data. In 2013, CPUE remained stable in logbook data but fewer total pots and sets were recorded during the year, especially in the AI. From 2006-2013 the average catch rate in logbook data was 29 lbs/pot in the AI (number sets (n) = 809) and 24 lbs/pot in the BS (n = 6,164). Pot CPUE has been stable in observer data as well. Average catch rate in the observer data from 2006-2013 was 11 lbs/pot (n = 1,156) in the AI and 18 lbs/pot (n = 2,970) in the BS. Effort is approximately equal throughout the fishing season.

The composition of bycatch species caught in observed pots that retained sablefish in the BS and AI is comprised mostly of arrowtooth/Kamchatka flounder, golden king crab, Greenland turbot, Pacific halibut, and giant grenadier. Almost all of the golden king crab is caught in the AI (Hanselman et al. 2010).

Surveys

A number of fishery independent surveys catch sablefish. The survey indices included in the model for this assessment are the AFSC longline survey and the AFSC GOA bottom trawl survey. For other surveys that occur in the same or adjacent geographical areas, but are not included as separate indices in the model, we provide trends and comparative analyses to the AFSC longline survey. Research catch removals including survey removals are documented in Appendix 3B.

AFSC Surveys

Longline survey

Overview: Catch, effort, age, length, weight, and maturity data are collected during sablefish longline surveys. These longline surveys likely provide an accurate index of sablefish abundance (Sigler 2000). Japan and the United States conducted a cooperative longline survey for sablefish in the GOA annually from 1978 to 1994, adding the AI region in 1980 and the eastern BS in 1982 (Sasaki 1985, Sigler and Fujioka 1988). Since 1987, the Alaska Fisheries Science Center has conducted annual longline surveys of the upper continental slope, referred to as domestic longline surveys, designed to continue the time series of the Japan-U.S. cooperative survey (Sigler and Zenger 1989). The domestic longline survey began annual sampling of the GOA in 1987, biennial sampling of the AI in 1996, and biennial sampling of the eastern BS in 1997 (Rutecki et al. 1997). The domestic survey also samples major gullies of the GOA in addition to sampling the upper continental slope. The order in which areas are surveyed was changed in 1998 to reduce interactions between survey sampling and short, intense fisheries. Before 1998, the order was AI and/or BS, Western Gulf, Central Gulf, Eastern Gulf. Starting in 1998, the Eastern Gulf area was surveyed before the Central Gulf area.

Specimen collections: Sablefish length data were randomly collected for all survey years. Otoliths were collected for age determination for most survey years. From 1979-1994 otolith collections were length-stratified; since 1994 otoliths have been collected randomly. Prior to 1996, otolith collections were aged but not consistently from year to year. Since 1996, a sample of otoliths collected during each survey have been aged in the years they were collected. Approximately one-half of the otoliths collected (~1,000) are aged annually. This sample size for age compositions should be large enough to get a precise age composition for the whole survey area, but may be too small to estimate the age composition in smaller areas by sex (P. Hulson, unpublished manuscript).

Standardization: Kimura and Zenger (1997) compared the performance of the two surveys from 1988 to

1994 in detail, including experiments comparing hook and gangion types used in the two surveys. The abundance index for both longline surveys decreased from 1988 to 1989, the cooperative survey decreased from 1989 to 1990, while the domestic survey increased (Table 3.9). Kimura and Zenger (1997) attributed the difference to the domestic longline survey not being standardized until 1990.

Survey Trends: Relative population abundance indices are computed annually using survey catch rates from stations sampled on the continental slope. Highest sablefish abundance indices occurred during the Japan-U.S. cooperative survey in the mid-1980's, in response to exceptional recruitment in the late 1970's (Figure 3.7). Relative population numbers declined through the 1990's in most areas during the domestic longline survey. Survey catches and abundance estimates trended down through 2009. Three of the lowest overall abundance estimates in the domestic survey occurred from 2007-2009. Survey estimates in the Eastern Gulf increased in 2010 and in 2011 the high Central Gulf estimate increased the entire index. Survey abundance estimates in 2010 and 2011 were unexpectedly high, while the 2012 and 2013 estimates were below expectations.

The 2013 survey estimate of relative abundance in numbers (RPN) was at the lowest point in the domestic time series; however, in 2014 there was an overall increase of 15% from 2013. The individual areas that contributed to the increase were WGOA (67%), WY (21%), and EY/SE (13%). Although there were modest increases, the index is still below average because of recent weak recruitment.

Whale Depredation: Killer whale depredation of the survey's sablefish catches has been a problem in the BS since the beginning of the survey (Sasaki 1987). Killer whale depredation primarily occurs in the BS, AI, WGOA, and to a lesser extent in recent years in the CGOA (Table 3.11). Depredation is easily identified by reduced sablefish catch and the presence of lips or jaws and bent, straightened, or broken hooks. Since 1990, portions of the gear at stations affected by killer whale depredation during the domestic longline survey have been excluded from the analysis of catch rates, RPNs, and RPWs. The AI and the BS were added to the domestic longline survey in 1996 and this is when killer whale depredation increased. In 2009, 10 BS stations were depredated, which significantly impacted catch and biased the abundance index leading to using the 2007 BS RPN estimate to interpolate the 2009 and 2010 BS RPNs (Hanselman et al. 2009). In 2011, depredation levels in the BS were similar to previous years with catches at 7 of 16 stations affected. In 2013, a new high of 11 stations were depredated, although fewer skates were impacted and therefore removed from the analysis in comparison to what occurred in 2009.

In 2014 there were 3 stations depredated by killer whales in the AI, down from the all time high of 5 in 2012 (Table 3.11). There were 4 stations with killer whale depredation in the WGOA. This is within the normal range of 1 to 5 stations. Although there has been some killer whale depredation in the CGOA in the past (1 - 2 stations), this year there was none. Overall the number of skates affected by killer whale depredation was 2/3 of what it was in 2012 (when the AI was last sampled). In total, there were 7 stations in 2014 with killer whale depredation and 10 in 2012.

Sperm whale depredation affects longline catches, but evidence of depredation is not accompanied by obvious decreases in sablefish catch or common occurrence of lips and jaws or bent and broken hooks. Data on sperm whale depredation have been collected since the 1998 longline survey (Table 3.11). Sperm whales are often observed from the survey vessel during haulback but do not appear to be depredating on the catch. Sperm whale depredation and presence is recorded during the longline survey at the station level, not the skate level like killer whales. Depredation is defined as sperm whales being present during haulback with the occurrence of damaged sablefish in the catch.

Sperm whale depredation has been variable since 1998. Whales are most common in the EGOA (WY and EY/SE). There are 65 stations sampled that are used in calculations of population indices in a year when the AI is sampled. In 2014 there were sperm whales depredating at 15 stations (Table 3.11). The number of stations with sperm whale depredation was typical of the range since 2007 (10-19 per year). In 2014, there were whales depredating at 10 stations in the EGOA (out of a total of 25) and 4 in the CGOA (out of 16). Depredation occurred at one station in the AI, which is rare, but has happened in the past. There were

no sperm whales depredating in the WGOA in 2014.

Multiple studies have attempted to quantify sperm whale depredation rates. An early study using data collected by fisheries observers in Alaskan waters found no significant effect on the commercial fishery catch (Hill et al. 1999). Another study using data collected from commercial vessels in southeast Alaska, found a small, significant effect comparing longline fishery catches between sets with sperm whales present and sets with sperm whales absent (3% reduction, 95% CI of (0.4 – 5.5%), t-test, $p = 0.02$, Straley et al. 2005).

A general linear model fit to longline survey data from 1998-2004 found neither sperm whale presence ($p = 0.71$) nor depredation rate ($p = 0.78$) increased significantly from 1998 to 2004. Catch rates were about 2% less at locations where depredation occurred, but the effect was not significant ($p = 0.34$). This analysis was updated through 2009 and now shows a significant effect of approximately four kilograms per hundred hooks in the Central and Eastern Gulf regions, which translates into approximately a 2% decrease in overall catch in those areas (J. Liddle, October, 2009, pers. comm.). A retrospective analysis of this data indicates the effect is not significant until the 2009 data is added, indicating the increasing depredation effect has combined with accumulating survey data to give increased power to detect this small reduction in CPUE.

Longline survey catch rates are not adjusted for sperm whale depredation because we do not know when measureable depredation began during the survey time series, because past studies of depredation on the longline survey showed no significant effect, and because sperm whale depredation is difficult to detect (Sigler et al. 2007). Because of recent increases in sperm whale presence and depredation at survey stations, as indicated by whale observations and significant results of recent studies, we evaluated a statistical adjustment to survey catch rates using a general linear modeling approach (Appendix 3C, Hanselman et al. 2010). This approach had promise but had issues with variance estimation and autocorrelation between samples. A new approach has been developed using a generalized linear mixed model (see Appendix 3C).

Gully Stations: In addition to the continental slope stations sampled during the survey, twenty-seven stations are sampled in gullies at the rate of one to two stations per day. The sampled gullies are Shelikof Trough, Amatuli Gully, W-grounds, Yakutat Valley, Spencer Gully, Ommaney Trench, Dixon Entrance, and one station on the continental shelf off Baranof Island. The majority of these stations are located in deep gully entrances to the continental shelf in depths from 150-300 m in areas where the commercial fishery targets sablefish. No gullies are currently sampled in the Western GOA, AI, or BS.

Previous analyses have shown that on average gully stations catch fewer large fish and more small fish than adjacent slope stations (Rutecki et al. 1997, Zenger et al. 1994). Compared with the adjacent regions of the slope, sablefish catch rates for gully stations have been mixed with no significant trend (Zenger et al. 1994). Gully catches may indicate recruitment signals before slope areas because of their shallow depth, where younger, smaller sablefish typically inhabit. Catch rates from these stations have not been included in the historical abundance index calculations because preferred habitat of adult sablefish is on the slope.

These areas do support significant numbers of sablefish, however, and are important areas sampled by the survey. We compared the RPNs of gully stations to the RPNs of slope stations in the GOA to see if catches were comparable, or more importantly, if they portrayed different trends than the RPNs used in this assessment.

To compare trends, we computed Student's-*t* normalized residuals for all GOA gullies and slope stations and plotted them for the time series. If the indices were correlated, then the residuals would track one another over time (Figure 3.8). Overall, gully catches in the GOA from 1990-2014 are moderately correlated with slope catches ($r = 0.51$). There is no evidence of major differences in trends. In regards to gully catches being a recruitment indicator, the increase in the gully RPNs in 1999 and 2001-2002 may be

in response to the above average 1997 and 2000 year classes. Both the 2001 and 2002 RPNs for the gully stations are higher than in 1999, which supports the current model estimate that the 2000 year class was larger than 1997. Both gully and slope trends were down in 2012 and 2013, consistent with the overall decrease in survey catch. However, the slope stations increased in 2014, while the gullies continued to decline. In the future, we will continue to explore sablefish catch rates in gullies and explore their usefulness for indicating recruitment; they may also be useful for quantifying depredation, since sperm whales have rarely depredated on catches from gully stations.

Interactions between the fishery and survey are described in Appendix 3A.

Trawl surveys

Trawl surveys of the upper continental slope that adult sablefish inhabit have been conducted biennially or triennially since 1980 in the AI, and 1984 in the GOA, always to 500 m and occasionally to 700-1000 m. Trawl surveys of the BS slope were conducted biennially from 1979-1991 and redesigned and standardized for 2002, 2004, 2008, 2010, and 2012. Trawl surveys of the BS shelf are conducted annually but generally catch no sablefish. Trawl survey abundance indices were not used in the assessment model prior to 2007 in the sablefish assessment because they were not considered good indicators of the sablefish relative abundance. However, there is a long time series of data available and given the trawl survey's ability to sample smaller fish, it may be a better indicator of recruitment than the longline survey. There is some difficulty with combining estimates from the BS and AI with the GOA estimates since they occur on alternating years. A method could be developed to combine these indices, but it leaves the problem of how to use the length data to predict recruitment since the data could give mixed signals on year class strength. At this time we are using only the GOA trawl survey biomass estimates (<500 m depth, Figure 3.4) and length data (<500 m depth) as a recruitment index for the whole population. The largest proportion of sablefish biomass is in the GOA so it should be indicative of the overall population. Biomass estimates used in the assessment for 1984-2013 are shown in Table 3.10. The GOA trawl survey index was at its lowest level of the time series in 2013, down 29% from 2011.

AI and BS Slope survey biomass estimates are not used in the assessment model but are tracked in Figure 3.9. Estimates in the two areas have decreased slowly since 2000.

Other surveys/areas not used in the assessment model

IPHC Longline Surveys

The IPHC conducts a longline survey each year to assess Pacific halibut. This survey differs from the AFSC longline survey in gear configuration and sampling design, but catches substantial numbers of sablefish. More information on this survey can be found in Soderlund et al. (2009). A major difference between the two surveys is that the IPHC survey samples the shelf consistently from ~ 10-500 meters, whereas the AFSC survey samples the slope and select gullies from 200-1000 meters. Because the majority of effort occurs on the shelf in shallower depths, the IPHC survey may catch smaller and younger sablefish than the AFSC survey; however, lengths of sablefish are not taken on the IPHC survey.

For comparison to the AFSC survey, IPHC relative population number's (RPN) were calculated using the same methods as the AFSC survey values, the only difference being the depth stratum increments. First, an average CPUE was calculated by depth stratum for each region. The CPUE was then multiplied by the area size of that stratum. A region RPN was calculated by summing the RPNs for all strata in the region. Area sizes used to calculate biomass in the RACE trawl surveys were utilized for IPHC RPN calculations. Area sizes differ between the IPHC and AFSC longline surveys because the IPHC surveys the shelf while the AFSC survey samples the slope.

We do not obtain IPHC survey estimates for the current year until the following year. We compared the IPHC and the AFSC RPNs for the GOA (Figure 3.10). The two series track well, but the IPHC survey RPN has more variability. This is likely because it surveys shallower water on the shelf where younger sablefish reside and are more patchily distributed. Since the abundance of younger sablefish will be more

variable as year classes pass through, the survey should more closely resemble the NMFS GOA trawl survey index described above (Figure 3.4).

While the two surveys have shown consistent patterns for most years, they diverged in 2010 and 2011, but the 2013 estimates both show the lowest point in the time series for each index (Figure 3.10). The IPHC estimate for the Gulf of Alaska for 2013 was a 21% decline from 2012. IPHC trends by region were similar, but IPHC data was more variable for most areas. We will continue to examine trends in each region and at each depth interval for evidence of recruiting year classes and for comparison to the AFSC longline survey. There is some effort in depths shallower than 200 meters on the AFSC longline survey, and we recently have computed RPNs for these depths for future comparisons with the IPHC RPNs.

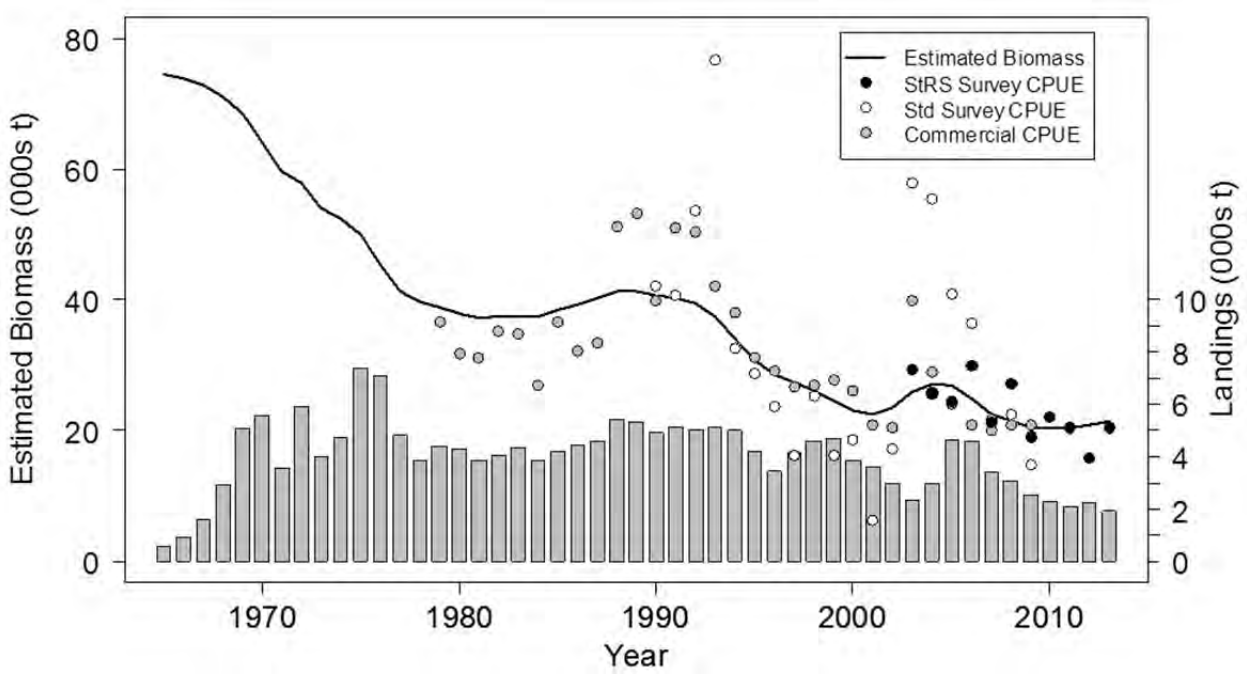
Alaska Department of Fish and Game

The Alaska Department of Fish and Game conducts mark-recapture and a longline survey in Northern Southeast Alaska Inside (NSEI) waters. Sablefish in this area are treated as a separate population, but some migration into and out of Inside waters has been confirmed with tagging studies (Hanselman et al. 2014). Estimates of exploitable population biomass based on mark-recapture estimates show a stable to slightly declining trend. This population seems to be stabilizing from previous steep declines. Their longline survey CPUE estimates (Figure 3.11a) and fishery CPUE estimates (Figure 3.11b) had been slowly increasing since 2000, confirming the lows in 1999/2000 estimated in our assessment. Like the AFSC longline survey, there was a sharp decline in the 2013 longline CPUE estimate for NSEI.

Department of Fish and Oceans of Canada

In a 2011 Science Advisory Report, DFO reported : *"Stock reconstructions suggest that stock status is currently below B_{MSY} for all scenarios, with the stock currently positioned in the mid-Cautious to low-Healthy zones."* Under these scenarios, recent harvest rates on adult sablefish potentially have been between 0.06 – 0.15[1].

The stratified random trap survey was up approximately 29% from 2012 to 2013 after a time series low in 2012. The estimated biomass trend in B.C. is similar to the trend in Alaska (see figure below)[2]. The similarly low abundance south of Alaska concerns us, and points to the need to better understand the contribution to Alaska sablefish productivity from B.C. sablefish. Some potential ideas are to conduct an area-wide study of sablefish tag recoveries, and to attempt to model the population to include B.C. sablefish.



Overall abundance trends

Relative abundance has cycled through three valleys and two peaks near 1970 and 1985 (Table 3.10, Figures 3.3 and 3.4). The post-1970 decrease likely is due to heavy fishing. The 1985 peak likely is due to the exceptionally large late 1970's year classes. Since 1988, relative abundance has decreased substantially. Regionally, abundance decreased faster in the BS, AI, and western GOA and more slowly in the central and eastern GOA (Figure 3.7). The majority of the surveys show that sablefish were at their lowest levels in the early 2000s, with current abundance reaching these lows again.

[1] Science Advisory Report 2011/25: http://www.dfo-mpo.gc.ca/Csas-sccs/publications/sar-as/2011/2011_025-eng.pdf

[2] DFO. 2014. Performance of a revised management procedure for Sablefish in British Columbia. DFO Can. Sci. Advis. Sec. Sci. Resp. 2014 /025.

Analytic approach

Model Structure

The sablefish population is assessed with an age-structured model. The analysis presented here extends earlier age structured models developed by Kimura (1990) and Sigler (1999), which all stem from the work by Fournier and Archibald (1982). The current model configuration follows a more complex version of the GOA Pacific ocean perch model (Hanselman et al. 2005a); it includes split sexes and many more data sources to attempt to more realistically represent the underlying population dynamics of sablefish. The current configuration was accepted by the Groundfish Plan Team and NPFMC in 2010 (Hanselman et al. 2010). The population dynamics and likelihood equations are described in Box 1. The analysis was completed using AD Model Builder software, a C++ based software for development and fitting of general nonlinear statistical models (Fournier et al. 2012).

Parameters Estimated Outside the Assessment Model

The following table lists the parameters estimated independently:

Parameter name	Value	Value	Source
Time period	1960-1995	1996-current	
Natural mortality	0.1	0.1	Johnson and Quinn (1988)
Female maturity-at-age	$m_a = 1/(1+e^{-0.84(a-6.60)})$		Sasaki (1985)
Length-at-age - females	$\bar{L}_a = 75.6(1-e^{-0.208(a+3.63)})$	$\bar{L}_a = 80.2(1-e^{-0.222(a+1.95)})$	Hanselman et al. (2007)
Length-at-age - males	$\bar{L}_a = 65.3(1-e^{-0.227(a+4.09)})$	$\bar{L}_a = 67.8(1-e^{-0.290(a+2.27)})$	Hanselman et al. (2007)
Weight-at-age - females	$\ln \hat{W}_a = \ln(5.47) + 3.02\ln(1-e^{-0.238(a+1.39)})$		Hanselman et al. (2007)
Weight-at-age - males	$\ln \hat{W}_a = \ln(3.16) + 2.96\ln(1-e^{-0.356(a+1.13)})$		Hanselman et al. (2007)
Ageing error matrix	From known-age tag releases, extrapolated for older ages		Heifetz et al. (1999)
Recruitment variability (σ_r)	1.2	1.2	Sigler et al. (2002)

Age and Size of Recruitment: Juvenile sablefish rear in nearshore and continental shelf waters, moving to the upper continental slope as adults. Fish first appear on the upper continental slope, where the longline survey and longline fishery occur, at age 2, and a fork length of about 45 cm. A higher proportion of young fish are susceptible to trawl gear compared to longline gear because trawl fisheries usually occur on the continental shelf and shelf break inhabited by younger fish, and catching small sablefish may be hindered by the large bait and hooks on longline gear.

Sablefish are difficult to age, especially those older than eight years (Kimura and Lyons 1991). To compensate, we use an ageing error matrix based on known-age otoliths (Heifetz et al. 1999; Hanselman et al. 2012).

Growth and maturity: Sablefish grow rapidly in early life, growing 1.2 mm d^{-1} during their first spring and summer (Sigler et al. 2001). Within 100 days after first increment (first daily otolith mark for larvae) formation, they average 120 mm. Sablefish are currently estimated to reach average maximum lengths and weights of 68 cm and 3.2 kg for males and 80 cm and 5.5 kg for females (Echave et al. 2012).

New growth relationships were estimated in 2007 because many more age data were available (Hanselman et al. 2007); this analysis was accepted by the Plan Team in November 2007 and published in 2012 (Echave et al. 2012). We divided the data into two time periods based on the change in sampling

design that occurred in 1995. It appears that sablefish maximum length and weight has increased slightly over time. New age-length conversion matrices were constructed using these curves with normal error fit to the standard deviations of the collected lengths at age (Figure 3.12). These new matrices provided for a superior fit to the data. Therefore, we use a bias-corrected and updated growth curve for the older data (1981-1993) and a new growth curve describing recent randomly collected data (1996-2004).

Fifty percent of females are mature at 65 cm, while 50 percent of males are mature at 57 cm (Sasaki 1985), corresponding to ages 6.6 for females and 5 for males (Table 3.12). Maturity parameters were estimated independently of the assessment model and then incorporated into the assessment model as fixed values. The maturity - length function is $m_l = 1 / (1 + e^{-0.40 (L - 57)})$ for males and $m_l = 1 / (1 + e^{-0.40 (L - 65)})$ for females. Maturity at age was computed using logistic equations fit to the length-maturity relationships shown in Sasaki (1985, Figure 23, GOA). Prior to the 2006 assessment, average male and female maturity was used to compute spawning biomass. Beginning with the 2006 assessment, female-only maturity has been used to compute spawning biomass. Female maturity-at-age from Sasaki (1985) is described by the logistic fit of $m_a = 1/(1+e^{-0.84(a-6.60)})$. In 2011, the AFSC conducted a winter cruise out of Kodiak to sample sablefish when they are preparing to spawn. Ovaries were examined histologically to determine maturity for a study of the age at maturity and fecundity. Skipped spawning was documented for the first time in sablefish. These winter samples provided a similar age at 50% maturity estimate (6.8 years) as the mean of visual observations taken during summer surveys from 1996-2012 (mean = 7.0 years) and the estimate currently used in the assessment (mean =6.6 years), when skipped spawners were classified as mature. Funding for more winter sampling in the same area is being sought for sampling in 2015 to examine the annual variability in skipped spawning rates at age. Future analyses will aim to develop and evaluate methods to incorporate skipped spawning into maturity ogives.

Maximum age and natural mortality: Sablefish are long-lived; ages over 40 years are regularly recorded (Kimura et al. 1993). Reported maximum age for Alaska is 94 years (Kimura et al. 1998). Canadian researchers report age determinations up to 113 years[1]. A natural mortality rate of M=0.10 has been assumed for previous sablefish assessments, compared to M=0.112 assumed by Funk and Bracken (1984). Johnson and Quinn (1988) used values of 0.10 and 0.20 in a catch-at-age analysis and found that estimated abundance trends agreed better with survey results when M=0.10 was used. Natural mortality has been modeled in a variety of ways in previous assessments. For sablefish assessments before 1999, natural mortality was assumed to equal 0.10. For assessments from 1999 to 2003, natural mortality was estimated rather than assumed to equal 0.10; the estimated value was about 0.10 but only with a precise prior imposed. For the 2004 assessment, a more detailed analysis of the posterior probability showed that natural mortality was not well-estimated by the available data (Sigler et al. 2004). Therefore in 2006, we returned to fixing the parameter at 0.10.

Variance and effective sample sizes: Several quantities were computed in order to compare the variance of the residuals to the assumed input variances. The standardized deviation of normalized residuals (SDNR) is closely related to the root mean squared error (RMSE) or effective sample size; values of SDNR of approximately 1 indicate that the model is fitting a data component as well as would be expected for a given specified input variance. The normalized residuals for a given year i of the abundance index was computed as

$$\delta_i = \frac{\ln(I_i) - \ln(\hat{I}_i)}{\sigma_i}$$

[1]Fisheries and Oceans Canada; http://www.pac.dfo-mpo.gc.ca/fm-gp/commercial/ground-fond/sable-charbon/bio-eng.htm

where σ_i is the input sampling log standard deviation of the estimated abundance index. For age or length composition data assumed to follow a multinomial distribution, the normalized residuals for age/length group *a* in year *i* were computed as

$$\delta_{i,a} = \frac{(y_{i,a} - \hat{y}_{i,a})}{\sqrt{\hat{y}_{i,a}(1-\hat{y}_{i,a})/n_i}}$$

where *y* and $\hat{y}$ are the observed and estimated proportion, respectively, and *n* is the input assumed sample size for the multinomial distribution. The effective sample size was also computed for the age and length compositions modeled with a multinomial distribution, and for a given year *i* was computed as

$$E_i = \frac{\sum_a \hat{y}_a * (1 - \hat{y}_a)}{\sum_a (\hat{y}_a - y_a)^2}.$$

An effective sample size that is nearly equal to the input sample size can be interpreted as having a model fit that is consistent with the input sample size.

For the 2010 recommended assessment model, we used average SDNR as a criterion to help reweight the age and length compositions. SDNR is a common metric used for goodness of fit in other fisheries, particularly in New Zealand (e.g. Langley and Maunder 2009) and has been recommended for use in fisheries models in Alaska during multiple CIE reviews, such as Atka mackerel and rockfish. We iteratively reweighted the model by setting an objective function penalty to reduce the deviations of average SDNR of a data component from one. Initially, we tried to fit all multinomial components this way, but due to tradeoffs in fit, it was found that the input sample sizes became too large and masked the influence of important data such as abundance indices. Given that we have age and length samples from nearly all years of the longline surveys, we chose to eliminate the attempt to fit the length data well enough to achieve an average SDNR of one, and reweighted all age components and only length components where no age data exists (e.g. domestic trawl fishery). The abundance index SDNRs were calculated, but no attempt was made to adjust their input variance because we have *a priori* knowledge about their sampling variances. This process was completed before the 2010 data were added into the assessment and endorsed by the Plan Teams and SSC in 2010. We continue to use these weightings. The table below shows the input CVs/sample sizes for the data sources and their associated output SDNR for the recommended model. This reweighting is intended to remain fixed for at least several years. The data weights in general continue to do well by these objectives (Table 3.13).

Parameters Estimated Inside the Assessment Model

Below is a summary of the parameters estimated within the recommended assessment model:

Parameter name	Symbol	Number of
Catchability	q	6
Log-mean-recruitment	μ_r	1
Spawners-per-recruit levels	F_{35}, F_{40}, F_{50}	3
Recruitment deviations	τ_y	82
Average fishing mortality	μ_f	2
Fishing mortality deviations	ϕ_y	110
Fishery selectivity	fs_a	8
Survey selectivity	ss_a	7
Total		219

Catchability is separately estimated for the Japanese longline fishery, the cooperative longline survey, the domestic longline survey, U.S. longline derby fishery, U.S. longline IFQ fishery, and the NMFS GOA trawl survey. Information is available to link these estimates of catchability. Kimura and Zenger (1997) analyzed the relationship between the cooperative and domestic longline surveys. For assessments through 2006, we used their results to create a prior distribution which linked catchability estimates for the two surveys. For 2007, we estimated new catchability prior distributions based on the ratio of the various abundance indices to a combined Alaskan trawl index. This resulted in similar mean estimates of catchability to those previously used, but allowed us to estimate a prior variance to be used in the model. This also facilitates linking the relative catchabilities between indices. These priors were used in the recommended model for 2008. This analysis was presented at the September 2007 Plan Team and is presented in its entirety in Hanselman et al. (2007). Lognormal prior distributions were used with the parameters shown below:

Index	U.S. LL Survey	Jap. LL Survey	Fisheries	GOA Trawl
Mean	7.857	4.693	4.967	0.692
CV	33%	24%	33%	30%

Recruitment is not estimated with a stock-recruit relationship, but is estimated with a level of average recruitment with deviations from average recruitment for the years 1933-2013.

Fishing mortality is estimated with two average fishing mortality parameters for the two fisheries (fixed gear and trawl) and deviations from the average for years 1960-2014 for each fishery.

Selectivity is represented using a function and is separately estimated by sex for the longline survey, fixed-gear fishery (pot and longlines combined), and the trawl survey. Selectivity for the longline surveys and fixed-gear fishery is restricted to be asymptotic by using the logistic function. Selectivity for the trawl fishery and trawl survey are dome-shaped (right descending limb) and estimated with a two-parameter gamma-function and a power function respectively (see Box 1 for equations). This right-descending limb is allowed because we do not expect that the trawl survey and fishery will catch older aged fish as frequently because they fish shallower than the fixed-gear fishery. Selectivity for the fixed-gear fishery is estimated separately for the "derby" fishery prior to 1995 and the IFQ fishery from 1995 thereafter. Fishers may choose where they fish in the IFQ fishery, compared to the crowded fishing grounds during the 1985-1994 "derby" fishery, when fishers reportedly often fished in less productive depths due to crowding (Sigler and Lunsford 2001). In choosing their ground, they presumably target bigger, older fish, and depths that produce the most abundant catches.

Bayesian analysis of reference points

Since the 1999 assessment, we have conducted a limited Bayesian analysis of assessment uncertainty. The posterior distribution was computed based on 10 million MCMC simulations drawn from the posterior distribution. A burn-in of 1 million draws was removed from the beginning of the chain and then thinned to 4,000 parameter draws to remove serial correlation between successive draws. This was determined to be sufficient through simple chain plots, and comparing the means and standard deviations of the first half of the chain with the second half.

In previous assessments, we estimated the posterior probability that projected abundance will fall below the decision analysis thresholds based on Mace and Sissenwine (1993). However, in the North Pacific Fishery Management Council setting we have thresholds that are defined in the Council harvest rules. These are when the spawning biomass falls below $B_{40\%}$, $B_{35\%}$, and when the spawning biomass falls below ½ MSY or $B_{17.5\%}$ which calls for a rebuilding plan under the Magnuson-Stevens Act. For the previous analysis based on Mace and Sissenwine (1993), see Hanselman et al. 2005b. To examine the posterior probability, we project spawning biomass into the future with recruitments varied as random draws from a lognormal distribution with the mean and standard deviation of 1979-2012 age-2 recruitments. The fishing mortality used is the current yield ratio described in the *Catch specification* section multiplied by maxABC for each year.

Box 1	Model Description
Y	Year, $y=1, 2, \ldots T$
T	Terminal year of the model
A	Model age class, $a = a_0, a_0+1, \ldots, a_+$
a_0	Age at recruitment to the model
a_+	Plus-group age class (oldest age considered plus all older ages)
L	Length class
Ω	Number of length bins (for length composition data)
G	Gear-type (g = longline surveys, longline fisheries, or trawl fisheries)
X	Index for likelihood component
$w_{a,s}$	Average weight at age a and sex s
φ_a	Proportion of females mature at age a
μ_r	Average log-recruitment
μ_f	Average log-fishing mortality
$\phi_{y,g}$	Annual fishing mortality deviation
τ_y	Annual recruitment deviation ~ $\ln(0, \sigma_r)$
σ_r	Recruitment standard deviation
$N_{y,a,s}$	Numbers of fish at age a in year y of sex s
M	Natural mortality
$F_{y,a,g}$	Fishing mortality for year y, age class a and gear g
$Z_{y,a}$	Total mortality for year y and age class a ($=\sum_g F_{y,a,g} + M$)
R_y	Recruitment in year y
B_y	Spawning biomass in year y
$s^g_{a,s}$	Selectivity at age a for gear type g and sex s
$A_{50\%}, d_{50\%}$	Age at 50% selection for ascending limb, age at 50% deselection for descending limb
δ	Slope/shape parameters for different logistic curves
$\mathbf{A}$	Ageing-error matrix dimensioned $a_+ \times a_+$
$\mathbf{A}^l_s$	Age to length conversion matrix by sex s dimensioned $a_+ \times \Omega$
q_g	Abundance index catchability coefficient by gear
λ_x	Statistical weight (penalty) for component x
$I_y, \hat{I}_y$	Observed and predicted survey index in year y
$P^g_{y,l,s}, \hat{P}^g_{y,l,s}$	Observed and predicted proportion at length l for gear g in year y and sex s
$P^g_{y,a,s}, \hat{P}^g_{y,a,s}$	Observed and predicted proportion at observed age a for gear g in year y and sex s
ψ^g_y	Sample size assumed for gear g in year y (for multinomial likelihood)
n_g	Number of years that age (or length) composition is available for gear g
$q_{\mu,g}, \sigma_{q,g}$	Prior mean, standard deviation for catchability coefficient for gear g
M_μ, σ_M	Prior mean, standard deviation for natural mortality
$\sigma_{r_\mu}, \sigma_{\sigma_r}$	Prior mean, standard deviation for recruitment variability

Equations describing state dynamics

Model Description (continued)

$$N_{1,a} = \begin{cases} R_1, & a = a_0 \\ e^{\left(\mu_r + \tau_{a_0 - a + 1}\right)} e^{-(a-a_0)M}, & a_0 < a < a_+ \\ e^{(\mu_r)} e^{-(a-a_0)M} \left(1 - e^{-M}\right)^{-1}, & a = a_+ \end{cases}$$

Initial year recruitment and numbers at ages.

$$N_{y,a} = \begin{cases} R_y, & a = a_0 \\ N_{y-1,a-1} e^{-Z_{y-1,a-1}}, & a_0 < a < a_+ \\ N_{y-1,a-1} e^{-Z_{y-1,a-1}} + N_{y-1,a} e^{-Z_{y-1,a}}, & a = a_+ \end{cases}$$

Subsequent years recruitment and numbers at ages

$$R_y = e^{\left(\mu_r + \tau_y\right)}$$

Recruitment

Selectivity equations

$$s^g_{a,s} = \left(1 + e^{\left(-\delta_{g,s}(a - a_{50\%,g,s})\right)}\right)^{-1}$$

Logistic selectivity

$$s^g_{a,s} = \frac{a^{\delta_{g,s}}}{\max\left(s^g_{a,s}\right)}$$

Inverse power family

$$s^g_{a,s} = \left(\frac{a}{a_{\max}}\right)^{a_{\max,g,s}/p} e^{(a_{\max,g,s} - a)/p}$$

$$p = 0.5\left[\sqrt{a_{\max,g,s}{}^2 + 4\delta_{g,s}{}^2} - a_{\max,g,s}\right]$$

Reparameterized gamma distribution

$$s^g_{a,s} = \left(1 - \varphi^g_s\right)^{-1} \left(\frac{\left(1 - \varphi^g_s\right)}{\varphi^g_s}\right)^{\varphi^g_s} \frac{\left(e^{(\delta_{g,s}\varphi^g_s(a_{50\%,g,s} - a))}\right)}{\left(1 + e^{(\delta_{g,s}(a_{50\%,g,s} - a))}\right)}$$

Exponential-logistic selectivity

Observation equations

$$\hat{C}_{y,g} = \sum_1^g \sum_1^s w_{a,s} N_{y,a,g,s} F_{y,a,g,s} \left(1 - e^{-Z_{y,a,g,s}}\right) Z^{-1}_{y,a,g,s}$$

Catch biomass in year *y*

$$\hat{I}_{y,g} = q^g \sum_{a_0}^{a_+} \sum_1^s N_{y,a,s} \frac{s^g_{a,s}}{\max\left(s^g_{a,s}\right)} w_{a,s}$$

Survey biomass index (weight)

$$\hat{I}_{y,g} = q^g \sum_{a_0}^{a_+} \sum_1^s N_{y,a,s} \frac{s^g_{a,s}}{\max\left(s^g_{a,s}\right)}$$

Survey abundance index (numbers)

$$\hat{P}^g_{y,a,s} = N_{y,a,s} s^g \left(\sum_{a_0}^{a_+} N_{y,a,s} s^g_{a,s}\right)^{-1} \mathbf{A}_s$$

Vector of fishery or survey predicted proportions at age

$$\hat{P}^g_{y,a,s} = N_{y,\cdot,s} s^g_s \left(\sum_{a_0}^{a_+} N_{y,a,s} s^g_{a,s}\right)^{-1} \mathbf{A}^l_s$$

Vector of fishery or survey predicted proportions at length

Posterior distribution components	**Model Description** (continued)
$L_C = \lambda_c \sum_{1}^{g} \sum_{y} \left(\ln C_{g,y} - \ln \hat{C}_{g,y} \right)^2 / \left(2\sigma_C^2 \right)$	Catch likelihood
$L_I = \lambda_I \sum_{1}^{g} \sum_{y} \left(\ln I_{g,y} - \ln \hat{I}_{g,y} \right)^2 / \left(2\sigma_I^2 \right)$	Survey biomass index likelihood
$L_{age} = \lambda_{age} \sum_{i=1}^{n_g} -\psi_y^g \sum_{a_0}^{a_+} \left(P_{i,a}^g + v \right) \ln\left(\hat{P}_{i,a}^g + v \right)$	Age composition likelihood
$L_{length} = \lambda_{length} \sum_{1}^{s} \sum_{i=1}^{n_g} -\psi_y^g \sum_{l=1}^{\Omega} \left(P_{i,l,s}^g + v \right) \ln\left(\hat{P}_{i,l,s}^g + v \right)$	Length composition likelihood (ψ_y^g=sample size, n_g = number of years of data for gear g, i = year of data availability, v is a constant set at 0.001)
$L_q = \left(\ln \hat{q}^g - \ln q_\mu^g \right)^2 / 2\sigma_q^2$	Prior on survey catchability coefficient for gear g
$L_M = \left(\ln \hat{M} - \ln M_\mu \right)^2 / 2\sigma_M^2$	Prior for natural mortality
$L_{\sigma_r} = \left(\ln \hat{\sigma}_r - \ln \sigma_{r_\mu} \right)^2 / 2\sigma_{\sigma_r}^2$	Prior distribution for σ_r
$L_\tau = 0.1 \sum_{y=1}^{T} \frac{\tau_y^2}{2\hat{\sigma}_r^2} + n \ln \hat{\sigma}_r$	Prior on recruitment deviations
$L_f = \lambda_f \sum_{1}^{g} \sum_{y=1}^{T} \phi_{y,g}^2$	Regularity penalty on fishing mortality
$L_{Total} = \sum_{x} L_x$	Total objective function value

Results

Model Evaluation

For this assessment, we present last year's model updated for 2013 with no model changes. A comparison of the model likelihood components and key parameter estimates from 2013 are compared with the 2014 updated model.

Box 2: Model comparison of the 2013 and 2014 models by contribution to the objective function (negative log-likelihood values) and key parameters.

Model Likelihood Components (Data)	2013	2014
Catch	8	7
Domestic LL survey RPN	46	47
Japanese LL survey RPN	18	18
Domestic LL fishery RPW	7	10
Japanese LL fishery RPW	12	13
NMFS GOA trawl survey	19	19
Domestic LL survey ages	169	180
Domestic LL fishery ages	192	238
Domestic LL survey lengths	55	59
Japanese LL survey ages	144	144
Japanese LL survey lengths	46	46
NMFS trawl survey lengths	290	286
Domestic LL fishery lengths	198	207
Domestic trawl fishery lengths	186	194
Data likelihood	1391	1469
Total objective function value	1415	1489
Key parameters		
Number of parameters	216	219
$B_{next\ year}$ (Female spawning (kt) biomass for next year)	91	92
$B_{40\%}$ (Female spawning biomass (kt))	106	105
B_{1960} (Female spawning biomass (kt))	161	161
$B_{0\%}$ (Female spawning biomass (kt))	266	262
SPR% current	34.3%	35.1%
$F_{40\%}$	0.094	0.094
$F_{40\%}$ (Tier 3b adjusted)	0.080	0.082
*ABC(*kt*)*	13.7	13.7
$q_{Domestic\ LL\ survey}$	7.7	7.6
$q_{Japanese\ LL\ survey}$	6.3	6.2
$q_{Domestic\ LL\ fishery}$	4.1	4.0
$q_{Trawl\ Survey}$	1.4	1.3
$a_{50\%}$ (domestic LL survey selectivity)	3.8	3.8
$a_{50\%}$ (LL fishery selectivity)	3.9	3.9
μ_r (average recruitment)	17.8	18.0
σ_r (recruitment variability)	1.20	1.20

The two models are identical in all aspects except for inclusion of new data. Our usual criteria for choosing a superior model are: (1) the best overall fit to the data (in terms of negative log-likelihood), (2) biologically reasonable patterns of estimated recruitment, catchabilities, and selectivities, (3) a good visual fit to length and age compositions, and (4) parsimony.

Because the models presented have different amounts of data and different data weightings, it is not reasonable to compare their negative log likelihoods so we cannot compare them by the first criterion above. In general we can only evaluate the 2014 model based on changes in results from 2013 and it is unlikely we would reject the model that included the most recent data. The model generally produces good visual fits to the data, and biologically reasonable patterns of recruitment, abundance, and selectivities. An exception to the generally good fits to the data is the fit to the 2013 fishery age composition, which fits poorly (see further discussion in ***Goodness of fit*** below). The 2014 update shows a slight increase in spawning and total biomass from previous projections. Therefore the 2014 model is utilizing the new information effectively, and we use it to recommend 2015 ABC and OFL.

Time Series Results

Definitions

Spawning biomass is the biomass estimate of mature females. Total biomass is the estimate of all sablefish age-two and greater. Recruitment is measured as the number of age-two sablefish. Fishing mortality is fully-selected F, meaning the mortality at the age the fishery has fully selected the fish.

Abundance trends

Sablefish abundance increased during the mid-1960's (Table 3.15, Figure 3.13) due to strong year classes in the early 1960's. Abundance subsequently dropped during the 1970's due to heavy fishing and relatively low recruitment; catches peaked at 53,080 t in 1972. The population recovered due to a series of strong year classes from the late 1970's (Figure 3.14, Table 3.14) and also recovered at different rates in different areas (Table 3.15); spawning abundance peaked again in 1987. The population then decreased because these strong year classes expired. The model suggested an increasing trend in spawning biomass since the all-time low in 2002, which changed directions again in 2008 (Figure 3.13). The low 2012-2013 longline survey RPN values changed what was a stable trend in 2011 to a downward trajectory in 2014.

Projected 2015 spawning biomass is 35% of unfished spawning biomass. Spawning biomass has increased from a low of 32% of unfished biomass in 2002 to 35% of unfished biomass projected for 2015 but is trending downward in projections for the near future. The 1997 year class has been an important contributor to the population; however, it has been reduced and is predicted to comprise less than 7% of the 2015 spawning biomass. The 2000 year class is still the largest contributor, with 16% of the spawning biomass in 2015. The 2008 year class is average and will comprise 10% of spawning biomass in 2015 even though it is only 60% mature. Figure 3.15 shows the relative contribution of each year class to next year's spawning biomass.

Recruitment trends

Annual estimated recruitment varies widely (Figure 3.14b). The two recent strong year classes in 1997 and 2000 are evident in all data sources. After 2000, few strong year classes are apparent, but the 2008 year class is currently estimated to be the largest since 2000. Few small fish were caught in the 2005 through 2009 trawl surveys, but the 2008 year class appeared in the 2011 trawl survey length composition (Figures 3.16, 3.17). The 2010 and 2011 longline survey age compositions show the 2008 year class appearing relatively strong in all three areas for lightly selected 2 and 3 year old fish (Figures 3.18-3.20). The 2013 survey age composition is dominated by 2005-2008 year classes where the 2005 and 2006 year classes are larger than model predictions. Large year classes often appear in the western areas first and then in subsequent years in the Central and Eastern GOA. While this was true for the 1997 and 2000 year classes, the 2008 year class is appearing in all areas at approximately the same magnitude at the same

time (Figure 3.18).

Average recruitment during 1979-2013 was 17.8 million 2-year-old sablefish per year, which is similar to the average recruitment during 1958-2012. Estimates of recruitment strength during the 1960s are less certain because they depend on age data from the 1980s with older aged fish that are subject to more ageing error. In addition the size of the early recruitments is based on an abundance index during the 1960s based only on the Japanese fishery catch rate, which may be a weak measure of abundance. The 2008 year class is being estimated at about average in this year's model. Because of the very low survey abundance indices in 2012 and 2013, the 2008 year class thus far is only just above average. If the 2008 year class is actually strong, the estimate will increase if the survey abundance estimates become stronger in future years.

Juvenile sablefish are pelagic and at least part of the population inhabits shallow near-shore areas for their first one to two years of life (Rutecki and Varosi 1997). In most years, juveniles have been found only in a few places such as Saint John Baptist Bay near Sitka, Alaska. Widespread, abundant age-1 juveniles likely indicate a strong year class. Abundant age-1 juveniles were reported for the 1960 (J. Fujioka & H. Zenger, 1995, NOAA, pers. comm.), 1977 (Bracken 1983), 1980, 1984, and 1998 year classes in southeast Alaska, the 1997 and 1998 year classes in Prince William Sound (W. Bechtol, 2004, ADFG, pers. comm.), the 1998 year class near Kodiak Island (D. Jackson, 2004, ADFG, pers. comm.), and the 2008 year class in Uganik Bay on Kodiak Island (P. Rigby, June, 2009, NOAA, pers. comm.). Numerous reports of young of the year being caught in 2014 have been received including large catches in NOAA surface trawl surveys in the EGOA in the summer (W. Fournier, August, 2014, NOAA, pers. comm.) and in Alaska Department of Fish and Game surveys in Prince William Sound (M. Byerly, 2014, ADFG, pers. comm.). Additionally, salmon fishermen in the EGOA reported large quantities of YOY sablefish in the stomachs of troll caught coho salmon in 2014.

Sablefish recruitment varies greatly from year to year (Figure 3.14b), but shows some relationship to environmental conditions. Sablefish recruitment success is related to winter current direction and water temperature; above average recruitment is more common for years with northerly drift or above average sea surface temperature (Sigler et al. 2001). Sablefish recruitment success is also coincidental with recruitment success of other groundfish species. Strong year classes were synchronous for many northeast Pacific groundfish stocks for the 1961, 1970, 1977, and 1984 year classes (Hollowed and Wooster 1992). For sablefish in Alaska, the 1960-1961 and 1977 year classes also were strong. Some of the largest year classes of sablefish occurred when abundance was near the historic low, the 1977-1978 and 1980-1981 year classes (Figures 3.14, 3.21). These strong year classes followed the 1976/1977 North Pacific regime shift. The 1977 year class was associated with the Pacific Decadal Oscillation (PDO) phase change and the 1977 and 1981 year classes were associated with warm water and unusually strong northeast Pacific pressure index (Hollowed and Wooster 1992). Larger than average year classes were produced again in 1997-2000, when the population was low indicating that recruitment is only weakly related to spawning biomass. Some species such as walleye pollock and sablefish may exhibit increased production at the beginning of a new environmental regime, when bottom up forcing prevails and high turnover species compete for dominance, which later shifts to top down forcing once dominance is established (Bailey 2000, Hunt et al. 2002). The large year classes of sablefish indicate that the population, though low, still was able to take advantage of favorable environmental conditions and produce large year classes. Shotwell et al. (2012) used a two-stage model selection process to examine relevant environmental variables that affect recruitment and included them directly into the assessment model. The best model suggested that colder than average wintertime sea surface temperatures in the central North Pacific represent oceanic conditions that create positive recruitment events for sablefish in their early life history.

Goodness of fit

The model generally fit the data well. Abundance indices generally track through the middle of the confidence intervals of the estimates (Figures 3.3, 3.4), with the exception of the trawl survey, where

predictions are typically lower in the early years and higher in later years. This index is given less weight than the other indices based on higher sampling error so it does not fit as well. Like the trawl survey index, the fishery CPUE index is not fit well in 2013, primarily because of the increase in the 2014 longline survey index which is fit more precisely. All age compositions were predicted well, except for not quite reaching the magnitude of the 1997 and 2000 year classes in several years (Figures 3.19, 3.21, 3.24). The length frequencies from the fixed gear fishery are predicted well in most years, but the model appears to not fit the smallest fish that appear in 2011 (Figure 3.22, 3.23). The fits to the trawl survey and trawl fishery length compositions were generally mediocre, because of the small sample sizes relative to the longline survey and fishery length compositions (Figures 3.16, 3.17., 3.25). The model fit the domestic longline survey lengths poorly in the 1990s, then fit well until 2011 and 2012 where the smallest and largest fish were not fit well (Figures 3.26, 3.27). By 2014, the 2008 year class has grown large enough (in length) to be included in the main groups in the length compositions. The 2013 fixed gear fishery age composition is fit poorly, particularly in the plus group. This was due to an exceptionally high proportion of the catch caught in the AI being older than 30 years old. Examination of the origin of these older fish showed that this shift in fishery age composition was caused by a westward shift of the observed fishery into grounds that are not surveyed by the longline survey where there is an apparent abundance of older fish that are unknown to the model. We will explore methods to consider these shifts in future spatial assessment models.

Selectivities

We assume that selectivity is asymptotic for the longline survey and fisheries and dome-shaped (or descending right limb) for the trawl survey and trawl fishery (Figure 3.28). The age-of-50% selection is 3.8 years for females in the longline survey and 3.9 years in the IFQ longline fishery. Females are selected at an older age in the IFQ fishery than in the derby fishery (Figure 3.28). Males were selected at an older age than females in both the derby and IFQ fisheries, likely because they are smaller at the same age. Selection of younger fish during short open-access seasons likely was due to crowding of the fishing grounds, so that some fishers were pushed to fish shallower water that young fish inhabit (Sigler and Lunsford 2001). Relative to the longline survey, small fish are more vulnerable and older fish are less vulnerable to the trawl fishery because trawling often occurs on the continental shelf in shallower waters (< 300 m) where young sablefish reside. The trawl fishery selectivities are similar for males and females (Figure 3.28). The trawl survey selectivity curves differ between males and females, where males stay selected by the trawl survey longer (Figure 3.28). These trawl survey patterns are consistent with the idea that sablefish move out on the shelf at 2 years of age and then gradually become less available to the trawl fishery and survey as they move offshore into deeper waters.

Fishing mortality and management path

Fishing mortality was estimated to be high in the 1970s, relatively low in the early 1980s and then increased and held relatively steady in the 1990s and 2000s (Figure 3.29). Goodman et al. (2002) suggested that stock assessment authors use a "management path" graph as a way to evaluate management and assessment performance over time. In this "management path" we plot estimated fishing mortality relative to the (current) limit value and the estimated spawning biomass relative to limit spawning biomass ($B_{35\%}$). Figure 3.30 shows that recent management has generally constrained fishing mortality below the limit rate, and until recently kept the stock above the $B_{35\%}$ limit. Projected 2015 and 2016 spawning biomass is slightly below $B_{35\%}$.

Uncertainty

We compared a selection of parameter estimates from the Markov-Chain Monte Carlo (MCMC) simulations with the maximum-likelihood estimates, and compared each method's associated level of uncertainty (Table 3.16). Mean and median catchability estimates were nearly identical. The estimate of $F_{40\%}$ was lower by maximum likelihood and shows some skewness as indicated by the difference between

the MCMC mean and median values. Under both methods the variances were similar except for estimation of a large year class (2000) where the uncertainty is higher for MCMC methods. Ending female spawning biomass and the last large recruitment (2000) are estimated precisely by both methods. The more recent 2008 year class is not estimated as precisely, and the MCMC estimates are slightly higher.

Retrospective analysis

Retrospective analysis is the examination of the consistency among successive estimates of the same parameters obtained as new data are added to a model. Retrospective analysis has been applied most commonly to age-structured assessments. Retrospective biases can arise for many reasons, ranging from bias in the data (e.g., catch misreporting, non-random sampling) to different types of model misspecification such as wrong values of natural mortality, or temporal trends in values set to be invariant. Classical retrospective analysis involves starting from some time period earlier in the model and successively adding data and testing if there is a consistent bias in the outputs (NRC 1998).

For this assessment, we show the retrospective trend in spawning biomass and total biomass for ten previous assessment years (2004-2013) compared to estimates from the current preferred model. This analysis is simply removing all new data that have been added for each consecutive year to the preferred model. Each year of the assessment generally adds one year of longline fishery lengths, trawl fishery lengths, longline survey lengths, longline and fishery ages (from one year prior), fishery abundance index, and longline survey index. Every other year, a trawl survey estimate and corresponding length composition are added.

In the first four years of the retrospective plot we see that estimates of spawning biomass were consistently lower for the last few years in the next assessment year (Figure 3.31). In recent years, the retrospective plot of spawning biomass shows only small changes from year to year (e.g., Table 3.17). One common measure of the retrospective bias is Mohn's revised rho which indicates the size and direction of the bias. The revised Mohn's rho of 0.019 is very low (a small positive retrospective bias) relative to most assessments at the AFSC (Hanselman et al. 2013). The retrospective patterns are well within the posterior uncertainty of each assessment (Figure 3.31b). Recruitment estimates appear to have little trend over time with the exception of the 2002 year class which increased from a very low value to near average (Figure 3.31c). Only the 2008 year class started near average indicating low presence of 2 year olds in most of the recent data.

Examining retrospective trends can show potential biases in the model, but may not identify what their source is. Other times a retrospective trend is merely a matter of the model having too much inertia in the age-structure and other historic data to respond to the most recent data. This retrospective pattern likely to be considered mild, but at issue is the "one-way" pattern in the early part of the retrospective time series. It is difficult to isolate the cause of this pattern but several possibilities exist. For example, hypotheses could include environmental changes in catchability, time-varying natural mortality, or changes in selectivity of the fishery or survey. One other issue is that fishery abundance and lengths, and all age compositions are added into the assessment with a one year lag to the current assessment. This estimate of rho is down from 0.089 in 2013, which we attribute to two factors: 1) 2003 was dropped out of the retrospective window which had a relatively large change from the terminal year; and 2) The updated catch data that was used in 2014 added a significant amount of catch in the early part of the retrospective window, which increased the estimate of spawning biomass at the recent low point. We will monitor and explore these patterns in the future.

The 2010 Joint Plan Team requested that we examine what the current model configuration would have recommended for ABCs going back in time to see how much model and author changes has affected management advice. We examined this in the 2011 SAFE and concluded that despite many model changes, including growth updates and a split-gender model, the management advice would have been

similar (Hanselman et al. 2011).

Harvest Recommendations

Reference fishing mortality rate

Sablefish are managed under Tier 3 of NPFMC harvest rules. Reference points are calculated using recruitments from 1979-2012. The updated point estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ from this assessment are 104,908 t (combined across the EBS, AI, and GOA), 0.095, and 0.112, respectively. Projected female spawning biomass (combined areas) for 2015 is 91,183 t (88% of $B_{40\%}$), placing sablefish in sub-tier "b" of Tier 3. The maximum permissible value of F_{ABC} under Tier 3b is 0.082, which translates into a 2015 ABC (combined areas) of 13,657 t. The OFL fishing mortality rate is 0.098 which translates into a 2015 OFL (combined areas) of 16,128 t. Model projections indicate that this stock is not subject to overfishing, overfished, nor approaching an overfished condition.

Population projections

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2014 numbers at age as estimated in the assessment. This vector is then projected forward to the beginning of 2015 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2014. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch after 2014 is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2015, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In 2015 and 2016, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the realized catches in 2011-2013 to the TAC for each of those years. For the remainder of the future years, maximum permissible ABC is used. (Rationale: In many fisheries the ABC is routinely not fully utilized, so assuming an average ratio of F will yield more realistic projections.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 2009-2013 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, *F* is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, *F* is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above 1) above its MSY level in 2014 or 2) above ½ of its MSY level in 2014 and above its MSY level in 2024 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, *F* is set equal to *max* F_{ABC}, and in all subsequent years *F* is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its MSY level in 2016 or 2) above 1/2 of its MSY level in 2016 and expected to be above its MSY level in 2026 under this scenario, then the stock is not approaching an overfished condition.)

Spawning biomass, fishing mortality, and yield are tabulated for the seven standard projection scenarios (Table 3.18). The difference for this assessment for projections is in Scenario 2 (Author's F); we use pre-specified catches to increase accuracy of short-term projections in fisheries (such as sablefish) where the catch is usually less than the ABC. This was suggested to help management with setting more accurate preliminary ABCs and OFLs for 2015 and 2016. The methodology for determining these pre-specified catches is described below in ***Specified catch estimation.***

Status determination

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2015, it does not provide the best estimate of OFL for 2016, because the mean 2015 catch under Scenario 6 is predicated on the 2015 catch being equal to the 2015 OFL, whereas the actual 2015 catch will likely be less than the 2015 OFL. A better approach is to estimate catches that are more likely to occur as described below under *Specified Catch Estimation.* The executive summary contains the appropriate one- and two-year ahead projections for both ABC and OFL.

Under the MSFCMA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing. This report involves the answers to three questions: 1) Is the stock being subjected to overfishing? 2) Is the stock currently overfished? 3) Is the stock approaching an overfished condition?

Is the stock being subjected to overfishing? The official catch estimate for the most recent complete year (2013) is 13,582 t. This is less than the 2013 OFL of 20,400 t. Therefore, the stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 (Table 3.18) are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest Scenarios #6 and #7 are used in these determinations as follows:

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2014:

a. If spawning biomass for 2014 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2014 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c. If spawning biomass for 2014 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 3.18). If the mean spawning biomass for 2024 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario #7 (Table 3.18):

a. If the mean spawning biomass for 2016 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2016 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2016 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2026. If the mean spawning biomass for 2026 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

Based on the above criteria and the results of the seven scenarios in Table 3.18, the stock is not overfished and is not approaching an overfished condition.

Specified catch estimation

In response to GOA Plan Team minutes in 2010, we have established a consistent methodology for estimating current-year and future year catches in order to provide more accurate two-year projections of ABC and OFL to management. We explained the methods and gave examples in the 2011 SAFE (Hanselman et al. 2011). Going forward, for current year catch, we are applying an expansion factor to the official catch on or near October 1 by the 3-year average of catch taken between October 1 and December 31 in the last three complete catch years (e.g. 2011-2013 for this year).

For catch projections into the next two years, we are using the ratio of the last three official catches to the last three TACs multiplied against the future two years' ABCs (if TAC is normally the same as ABC). This method results in slightly higher ABCs in each of the future two years of the projection, based on both the lower catch in the first year out, and on the amount of catch taken before spawning in the projection two years out.

Bayesian analysis

The model estimates of projected spawning biomass fall near the center of the posterior distribution of spawning biomass. Most of the probability lies between 80,000 and 100,000 t (Figure 3.32). The probability changes smoothly and exhibits a relatively normal distribution. The posterior distribution clearly indicates the stock is below $B_{40\%}$.

Scatter plots of selected pairs of model parameters were produced to evaluate the shape of the posterior distribution (Figure 3.33). The plots indicate that the parameters are reasonably well defined by the data. As expected, catchabilities, $F_{40\%}$, and ending spawning biomass were confounded. The catchability of the longline survey is most confounded with ending spawning biomass because it has the most influence in the model in recent abundance predictions.

We estimated the posterior probability that projected abundance will fall, or stay below thresholds of 17.5% (MSST), and 35% (MSY), and 40% (B_{target}) of the unfished spawning biomass based on the posterior probability estimates. Abundance was projected for 14 years. For management, it is important to know the risk of falling under these thresholds. The probability that spawning biomass falls below key biological reference points was estimated based on the posterior probability distribution for spawning biomass. The probability that next year's spawning biomass was below $B_{35\%}$ was 0.89. During the next three years, the probability of falling below $B_{17.5\%}$ is near zero, the probability of falling below $B_{35\%}$ is 0.97, and the probability of staying below $B_{40\%}$ is near 100% (Figure 3.34).

Alternative Projection

We also use an alternative projection that considers uncertainty from the whole model by running projections within the model. This projection propagates uncertainty throughout the entire assessment procedure and is based on 10,000,000 MCMC (burnt-in and thinned) using the standard Tier 3 harvest rules. The projection shows wide credible intervals on future spawning biomass (Figure 3.35). The $B_{35\%}$ and $B_{40\%}$ reference points are based on the 1979-2012 recruitments, and this projection predicts that the mean and median spawning biomass will stay below $B_{35\%}$ until 2020, and then return to $B_{40\%}$ if average recruitment is attained. This projection is run with the same ratio for catch as described in Alternative 2 above, except for all future years instead of the next two.

Acceptable biological catch

We recommend a 2015 ABC of 13,657 t. The maximum permissible ABC for 2015 from a Tier 3b adjusted $F_{40\%}$ strategy is 13,657 t. The maximum permissible ABC for 2015 is very similar to the 2014 ABC of 13,722 t. The 2013 assessment projected a 10% decrease in ABC for 2015 from 2014. This smaller decrease is supported by a moderate increase in the domestic longline survey index from the all-time low in 2013 that offset the lowest value of the fishery abundance index seen in 2013. The fishery abundance index has been trending down since 2007. The 2013 IPHC GOA sablefish index was not used in the model, but also declined 21% from 2012. The 2008 year class showed potential to be above average in previous assessments based on patterns in the age and length compositions. However the estimate in this year's assessment is only average because it is heavily influenced by the recent large overall decrease in the longline survey and trawl indices. Spawning biomass is projected to decline through 2018, and then is expected to increase; assuming average recruitment is achieved in the future. ABCs are projected to decrease in 2016 to 12,406 t and 12,292 t in 2017 (see Table 3.18).

Area allocation of harvests

The combined ABC has been apportioned to regions using weighted moving average methods since 1993; these methods reduce the magnitude of inter-annual changes in the apportionment. Weighted moving average methods are robust to uncertainties about movement rates and measurement error of the biomass distribution, while adapting to current information about the biomass distribution. The 1993 TAC was apportioned using a 5 year running average with emphasis doubled for the current year survey abundance index in weight (relative population weight or RPW). Since 1995, the ABC was apportioned using an exponential weighting of regional RPWs. Exponential weighting is implied under certain conditions by the Kalman filter. The exponential factor is the measurement error variance divided by the prediction error variance (Meinhold and Singpurwalla 1983). Prediction error variance depends on the variances of the previous year's estimate, the process error, and the measurement error. When the ratio of measurement error variance to process error variance is r, the exponential factor is equal to $1-2/(\sqrt{4r+1}+1)$ (Thompson 2004). For sablefish we do not estimate these values, but instead set the exponential factor at ½, so that, except for the first year, the weight of each year's value is ½ the weight of the following year. The weights are year index 5: 0.0625; 4: 0.0625; 3: 0.1250; 2: 0.2500; 1: 0.5000. A $(1/2)^x$ weighting scheme, where x is the year index, reduced annual fluctuations in regional ABC, while keeping regional fishing rates from exceeding overfishing levels in a stochastic migratory model (J. Heifetz, 1999, NOAA, pers. comm.). Because mixing rates for sablefish are sufficiently high and fishing rates sufficiently low, moderate variations of biomass-based apportionment would not significantly change overall sablefish yield unless there are strong differences in recruitment, growth, and survival by area (Heifetz et al. 1997).

Previously, the Council approved apportionments of the ABC based on survey data alone. Starting with the 2000 ABC, the Council approved an apportionment based on survey and fishery data. The fishery and survey information were combined to apportion ABC using the following method: The RPWs based on

the fishery data were weighted with the same exponential weights used to weight the survey data (year index 5: 0.0625; 4: 0.0625; 3: 0.1250; 2: 0.2500; 1: 0.5000). The fishery and survey data were combined by computing a weighted average of the survey and fishery estimates, with the weight inversely proportional to the variability of each data source. The variance for the fishery data has typically been twice that of the survey data, so the survey data was weighted twice as much as the fishery data. Below are area-specific apportionments following the traditional apportionment scheme, which we are **not recommending for 2015:**

Apportionments are based on survey and fishery information	2014 ABC Percent	2014 Survey RPW	2013 Fishery RPW	2015 ABC Percent	2014 ABC	2015 ABC	Change
Total					13,722	**13,657**	0%
Bering Sea	10%	21%	14%	10%	1,339	**2,210**	39%
Aleutians	13%	13%	17%	13%	1,811	**1,840**	2%
Gulf of Alaska	77%	66%	69%	77%	10,572	**9,607**	-10%
Western	14%	19%	12%	14%	1,480	**1,444**	-2%
Central	44%	40%	33%	44%	4,681	**3,975**	-18%
W. Yakutat*	15%	13%	19%	15%	1,574	**1,428**	-10%
E. Yakutat / Southeast*	27%	28%	35%	27%	2,837	**2,759**	-3%

Following the standard apportionment scheme, we have observed that the objective to reduce variability in apportionment was not being achieved. Since 2007, the average change in apportionment by area has increased annually (Figure 3.36A). While some of these changes may actually reflect interannual changes in regional abundance, they most likely reflect the high movement rates of the population and the high variability of our estimates of abundance in the Bering Sea and Aleutian Islands. For example, the apportionment for the Bering Sea has varied drastically since 2007, attributable to high variability in both survey abundance and fishery CPUE estimates in the Bering Sea (Figure 3.36B). These large annual changes in apportionment result in increased variability of ABCs by area, including areas other than the Bering Sea (Figure 3.36C). Because of the high variability in apportionment seen in recent years, we do not believe the standard method is meeting the goal of reducing the magnitude of interannual changes in the apportionment. Because of these reasons, we recommended fixing the apportionment at the proportions from the 2013 assessment until the apportionment scheme is thoroughly reevaluated and reviewed. A Ph.D. student with the University of Alaska-Fairbanks began a project in 2012 with the objectives of re-examining the apportionment strategy and conducting management strategy evaluations. A spatial sablefish model has been developed, but management strategy evaluations have not begun yet. Meanwhile, it seems imprudent to move to an interim apportionment or return to the former scheme until more satisfactory methods have been identified and evaluated. **Therefore**, **for 2015, we recommend keeping the apportionment fixed at the proportions used in 2014.**
These apportionments are shown in the following table:

Area	2014 ABC	Standard apportionment for 2015 ABC	**Recommended fixed apportionment for 2015 ABC***	**Difference from 2014**
Total	13,722	13,657	**13,657**	-0.5%
Bering Sea	1,339	2,210	**1,333**	-0.5%
Aleutians	1,811	1,840	**1,802**	-0.5%
Gulf of Alaska (subtotal)	10,572	9,607	**10,522**	-0.5%
Western	1,480	1,445	**1,473**	-0.5%
Central	4,681	3,975	**4,658**	-0.5%
W. Yakutat**	1,574	1,428	**1,567**	-0.5%
E. Yak. / Southeast**	2,837	2,759	**2,823**	-0.5%

* Fixed at the 2012 assessment apportionment proportions (Hanselman et al. 2012). ** Before 95:5 hook and line: trawl split shown below.

Adjusted for 95:5 hook-and-line: trawl split in EGOA	Year	W. Yakutat	E. Yakutat/Southeast
	2015	1,708 t	2,682 t
	2016	1,552 t	2,436 t

Overfishing level (OFL)

Applying an adjusted $F_{35\%}$ as prescribed for OFL in Tier 3b, results in a value of 16,128 t for the combined stock. The OFL is apportioned by region, Bering Sea (1,575 t), AI (2,128 t), and GOA (12,425 t), by the same method as the ABC apportionment.

Ecosystem considerations

Ecosystem considerations for the Alaska sablefish fishery are summarized in Table 3.19.

Ecosystem effects on the stock

Prey population trends

Young-of-the-year sablefish prey mostly on euphausiids (Sigler et al. 2001) and copepods (Grover and Olla 1990), while juvenile and adult sablefish are opportunistic feeders. Larval sablefish abundance has been linked to copepod abundance and young-of-the-year abundance may be similarly affected by euphausiid abundance because of their apparent dependence on a single species (McFarlane and Beamish 1992). The dependence of larval and young-of-the-year sablefish on a single prey species may be the cause of the observed wide variation in annual sablefish recruitment. No time series is available for copepod and euphausiid abundance, so predictions of sablefish abundance based on this predator-prey relationship are not possible.

Juvenile and adult sablefish feed opportunistically, so diets differ throughout their range. In general, sablefish < 60 cm consume more euphausiids, shrimp, and cephalopods, while sablefish > 60 cm consume more fish (Yang and Nelson 2000). In the GOA, fish constituted 3/4 of the stomach content weight of adult sablefish with the remainder being invertebrates (Yang and Nelson 2000). Of the fish found in the diets of adult sablefish, pollock were the most abundant item while eulachon, capelin, Pacific herring, Pacific cod, Pacific sand lance, and flatfish also were found. Squid were the most important invertebrate and euphausiids and jellyfish were also present. In southeast Alaska, juvenile sablefish also consume juvenile salmon at least during the summer months (Sturdevant et al. 2009). Off the coast of Oregon and California, fish made up 76 percent of the diet (Laidig et al. 1997), while euphausiids dominated the diet off the southwest coast of Vancouver Island (Tanasichuk 1997). Off Vancouver Island, herring and other fish were increasingly important as sablefish size increased; however, the most important prey item was

euphausiids. It is unlikely that juvenile and adult sablefish are affected by availability and abundance of individual prey species because they are opportunistic feeders. The only likely way prey could affect growth or survival of juvenile and adult sablefish is by overall changes in ecosystem productivity.

Predators/Competitors: The main juvenile sablefish predators are adult coho and chinook salmon, which prey on young-of-the-year sablefish during their pelagic stage. Sablefish were the fourth most commonly reported prey species in the salmon troll logbook program from 1977 to 1984 (Wing 1985), however the effect of salmon predation on sablefish survival is unknown. The only other fish species reported to prey on sablefish in the GOA is Pacific halibut; however, sablefish comprised less than 1% of their stomach contents (M. Yang, October 14, 1999, NOAA, pers. comm.). Although juvenile sablefish may not be a prominent prey item because of their relatively low and sporadic abundance compared to other prey items, they share residence on the continental shelf with potential predators such as arrowtooth flounder, halibut, Pacific cod, bigmouth sculpin, big skate, and Bering skate, which are the main piscivorous groundfishes in the GOA (Yang et al. 2006). It seems possible that predation of sablefish by other fish is significant to the success of sablefish recruitment even though they are not a common prey item.

Sperm whales are likely a major predator of adult sablefish. Fish are an important part of sperm whale diet in some parts of the world, including the northeastern Pacific Ocean (Kawakami 1980). Fish have appeared in the diets of sperm whales in the eastern AI and GOA. Although fish species were not identified in sperm whale diets in Alaska, sablefish were found in 8.3% of sperm whale stomachs off of California (Kawakami 1980).

Sablefish distribution is typically thought to be on the upper continental slope in deeper waters than most groundfish. However, during the first two to three years of their life sablefish inhabit the continental shelf. Length samples from the NMFS bottom trawl survey suggest that the geographic range of juvenile sablefish on the shelf varies dramatically from year to year. In particular, juveniles utilize the Bering Sea shelf extensively in some years, while not at all in others (Shotwell et al. 2012). Juvenile sablefish (< 60 cm FL) prey items overlap with the diet of small arrowtooth flounder. On the continental shelf of the GOA, both species consumed euphausiids and shrimp predominantly; these prey are prominent in the diet of many other groundfish species as well. This diet overlap may cause competition for resources between small sablefish and other groundfish species.

Changes in the physical environment: Mass water movements and temperature changes appear related to recruitment success. Above-average recruitment was somewhat more likely with northerly winter currents and much less likely for years when the drift was southerly. Recruitment was above average in 61% of the years when temperature was above average, but was above average in only 25% of the years when temperature was below average. Growth rate of young-of-the-year sablefish is higher in years when recruitment is above average (Sigler et al. 2001). Shotwell et al. (2012) showed that colder than average wintertime sea surface temperatures in the central North Pacific may represent oceanic conditions that create positive recruitment events for sablefish in their early life history.

Anthropogenic changes in the physical environment: The Essential Fish Habitat Environmental Impact Statement (EFH EIS) (NMFS 2005) concluded that the effects of commercial fishing on the habitat of sablefish is minimal or temporary in the current fishery management regime primarily based on the criterion that sablefish are currently above Minimum Stock Size Threshold (MSST).

Juvenile sablefish are partly dependent on benthic prey (18% of diet by weight) and the availability of benthic prey may be adversely affected by fishing. Little is known about effects of fishing on benthic habitat or the habitat requirements for growth to maturity. Although sablefish do not appear to be directly dependent on physical structure, reduction of living structure is predicted in much of the area where juvenile sablefish reside and this may indirectly reduce juvenile survivorship by reducing prey availability or by altering the abilities of competing species to feed and avoid predation.

Fishery effects on the ecosystem

Fishery-specific contribution to bycatch of prohibited species, forage species, HAPC biota, marine mammals and birds, and other sensitive non-target species: The sablefish fishery catches significant portions of the shark and thornyhead rockfish total catch (Table 3.4). The sablefish fishery catches the majority of grenadier total catch; the annual amount is variable (Table 3.5). The trend in seabird catch is variable, but is substantially low compared to the 1990s, presumably due to widespread use of measures to reduce seabird catch. Prohibited species catches (PSC) in the targeted sablefish fisheries are dominated by halibut (1,224 t/year) and golden king crab (66,000 individuals/year). Halibut catches were low in 2013, while golden king crab catches have dropped precipitously from 210,000 individuals in 2011 to very few in 2013 (Table 3.6).

The shift from an open-access to an IFQ fishery has increased catching efficiency which has reduced the number of hooks deployed (Sigler and Lunsford 2001). Although the effects of longline gear on bottom habitat are poorly known, the reduced number of hooks deployed during the IFQ fishery must reduce the effects on benthic habitat. The IFQ fishery likely has also reduced discards of other species because of the slower pace of the fishery and the incentive to maximize value from the catch.

Fishery-specific concentration of target catch in space and time relative to predator needs in space and time (if known) and relative to spawning components: The sablefish fishery largely is dispersed in space and time. The longline fishery lasts 8-1/2 months. The quota is apportioned among six regions of Alaska.

Fishery-specific effects on amount of large size target fish: The longline fishery catches mostly medium and large-size fish which are typically mature. Length frequencies from the pot fishery in the BSAI are very similar to the longline fishery. The trawl fishery, which on average accounts for about 10% of the total catch, often catches slightly smaller fish. The trawl fishery typically occurs on the continental shelf where juvenile sablefish sometimes occur. Catching these fish as juveniles reduces the yield available from each recruit.

Fishery-specific contribution to discards and offal production: Discards of sablefish in the longline fishery are small, typically less than 5% of total catch (Table 3.3). The catch of sablefish in the longline fishery typically consists of a high proportion of sablefish, 90% or more. However, at times grenadiers may be a significant catch and they are almost always discarded.

Fishery-specific effects on age-at-maturity and fecundity of the target species: The shift from an open-access to an IFQ fishery has decreased harvest of immature fish and improved the chance that individual fish will reproduce at least once (Sigler and Lunsford 2001).

Fishery-specific effects on EFH non-living substrate: The primary fishery for sablefish is with longline gear. While it is possible that longlines could move small boulders it is unlikely fishing would persist where this would often occur. Relative to trawl gear, a significant effect of longlines on bedrock, cobbles, or sand is unlikely.

Data gaps and research priorities

There is little information on early life history of sablefish and recruitment processes. A better understanding of juvenile distribution, habitat utilization, and species interactions would improve understanding of the processes that determine the productivity of the stock. Better estimation of recruitment and year class strength would improve assessment and management of the sablefish population.

Future sablefish research is going to focus on several directions:

1) Evaluating different apportionment strategies for ABC.
2) Refine survey abundance index model for inclusion in future assessment model that accounts for

whale depredation and potentially includes gully abundance data and other covariates.

3) Refine fishery abundance index to utilize a core fleet, and identify covariates that affect catch rates.
4) Improve knowledge of sperm whale and killer whale depredation in the fishery and begin to quantify depredation effects on fishery catch rates.
5) Continue to explore the use of environmental data to aid in determining recruitment
6) An integrated GOA Ecosystem project funded by the North Pacific Research Board is underway and is looking at recruitment processes of major groundfish including sablefish. We hope to work closely with this project to help understand sablefish recruitment dynamics.
7) We are developing a spatially explicit research assessment model that includes movement, which will help in examining smaller-scale population dynamics while retaining a single stock hypothesis Alaska-wide sablefish model. This is to include management strategy evaluations of apportionment strategies.

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Tables

Table 3.1. Alaska sablefish catch (t). The values include landed catch and discard estimates. Discards were estimated for U.S. fisheries before 1993 by multiplying reported catch by 2.9% for fixed gear and 26.9% for trawl gear (1994-1997 averages) because discard estimates were unavailable. Eastern includes West Yakutat and East Yakutat / Southeast. 2014 catches are estimated for the full year (www.akfin.org).

		BY AREA								BY GEAR	
Year	Grand total	Bering Sea	Aleu-tians	Western	Central	Eastern	West Yakutat	East Yak/SEO	Un-known	Fixed	Trawl
1960	3,054	1,861	0	0	0	1,193			0	3,054	0
1961	16,078	15,627	0	0	0	451			0	16,078	0
1962	26,379	25,989	0	0	0	390			0	26,379	0
1963	16,901	13,706	664	266	1,324	941			0	10,557	6,344
1964	7,273	3,545	1,541	92	955	1,140			0	3,316	3,957
1965	8,733	4,838	1,249	764	1,449	433			0	925	7,808
1966	15,583	9,505	1,341	1,093	2,632	1,012			0	3,760	11,823
1967	19,196	11,698	1,652	523	1,955	3,368			0	3,852	15,344
1968	30,940	14,374	1,673	297	1,658	12,938			0	11,182	19,758
1969	36,831	16,009	1,673	836	4,214	14,099			0	15,439	21,392
1970	37,858	11,737	1,248	1,566	6,703	16,604			0	22,729	15,129
1971	43,468	15,106	2,936	2,047	6,996	16,382			0	22,905	20,563
1972	53,080	12,758	3,531	3,857	11,599	21,320			15	28,538	24,542
1973	36,926	5,957	2,902	3,962	9,629	14,439			37	23,211	13,715
1974	34,545	4,258	2,477	4,207	7,590	16,006			7	25,466	9,079
1975	29,979	2,766	1,747	4,240	6,566	14,659			1	23,333	6,646
1976	31,684	2,923	1,659	4,837	6,479	15,782			4	25,397	6,287
1977	21,404	2,718	1,897	2,968	4,270	9,543			8	18,859	2,545
1978	10,394	1,193	821	1,419	3,090	3,870			1	9,158	1,236
1979	11,814	1,376	782	999	3,189	5,391			76	10,350	1,463
1980	10,444	2,205	275	1,450	3,027	3,461			26	8,396	2,048
1981	12,604	2,605	533	1,595	3,425	4,425			22	10,994	1,610
1982	12,048	3,238	964	1,489	2,885	3,457			15	10,204	1,844
1983	11,715	2,712	684	1,496	2,970	3,818			35	10,155	1,560
1984	14,109	3,336	1,061	1,326	3,463	4,618			305	10,292	3,817
1985	14,465	2,454	1,551	2,152	4,209	4,098			0	13,007	1,457
1986	28,892	4,184	3,285	4,067	9,105	8,175			75	21,576	7,316
1987	35,163	4,904	4,112	4,141	11,505	10,500			2	27,595	7,568
1988	38,406	4,006	3,616	3,789	14,505	12,473			18	29,282	9,124
1989	34,829	1,516	3,704	4,533	13,224	11,852			0	27,509	7,320
1990	32,115	2,606	2,412	2,251	13,786	11,030			30	26,598	5,518
1991	27,073	1,318	2,168	1,821	11,662	10,014			89	23,124	3,950
1992	24,932	586	1,497	2,401	11,135	9,171			142	21,614	3,318
1993	25,417	669	2,078	740	11,955	9,976	4,620	5,356	0	22,912	2,506
1994	23,577	694	1,725	539	9,376	11,243	4,493	6,750	0	20,639	2,938
1995	20,692	930	1,119	1,747	7,673	9,223	3,872	5,352	0	18,079	2,613
1996	17,275	648	764	1,542	6,773	7,548	2,893	4,655	0	15,088	2,187
1997	14,607	552	781	1,374	6,234	5,666	1,930	3,735	0	12,975	1,632
1998	13,867	563	535	1,432	5,915	5,422	1,956	3,467	0	12,380	1,487
1999	13,585	675	681	1,488	5,874	4,867	1,709	3,159	0	11,601	1,985
2000	15,565	742	1,049	1,582	6,173	6,020	2,066	3,953	0	13,546	2,019
2001	14,064	864	1,074	1,588	5,518	5,021	1,737	3,284	0	12,281	1,783
2002	14,748	1,144	1,119	1,865	6,180	4,441	1,550	2,891	0	12,505	2,243
2003	16,411	1,012	1,118	2,118	6,993	5,170	1,822	3,347	0	14,351	2,060
2004	17,518	1,041	955	2,170	7,310	6,041	2,241	3,801	0	15,861	1,656
2005	16,580	1,070	1,481	1,929	6,701	5,399	1,824	3,575	0	15,024	1,556
2006	15,551	1,079	1,151	2,151	5,921	5,251	1,889	3,362	0	14,305	1,246
2007	15,957	1,182	1,168	2,101	6,003	5,502	2,074	3,429	0	14,721	1,235
2008	14,674	1,141	901	1,679	5,543	5,410	2,056	3,354	0	13,552	1,122
2009	13,128	916	1,100	1,423	5,005	4,684	1,831	2,853	0	12,071	1,057
2010	11,980	755	1,094	1,354	4,508	4,269	1,578	2,690	0	10,976	1,004
2011	12,971	705	1,024	1,402	4,919	4,921	1,896	3,024	0	11,792	1,179
2012	13,868	743	1,205	1,353	5,329	5,238	2,033	3,205	0	12,767	1,102
2013	13,642	634	1,062	1,385	5,207	5,354	2,106	3,247	0	12,604	1,038
2014	11,476	328	757	1,090	4,737	4,564	1,707	2,857	0	10,486	990

Table 3.2. Catch (t) in the Aleutian Islands and the Bering Sea by gear type from 1991-2013. Both CDQ and non-CDQ catches are included. Catches in 1991-1999 are averages. Catch as of October 24, 2014 (www.akfin.org).

Aleutian Islands				
Year	Pot	Trawl	Longline	Total
1991-1999	6	73	1,210	1,289
2000	103	33	913	1049
2001	111	39	925	1074
2002	105	39	975	1119
2003	316	42	760	1118
2004	384	32	539	955
2005	688	115	679	1481
2006	461	60	629	1151
2007	632	40	496	1168
2008	179	76	646	901
2009	78	75	947	1100
2010	59	74	961	1094
2011	141	47	836	1024
2012	77	148	979	1205
2013	87	58	917	1062
Bering Sea				
1991-1999	5	189	539	733
2000	40	283	418	741
2001	106	336	405	847
2002	382	268	467	1117
2003	363	183	417	964
2004	435	276	313	1024
2005	595	262	202	1059
2006	621	76	373	1070
2007	879	80	211	1170
2008	754	181	204	1139
2009	557	91	266	914
2010	452	30	274	755
2011	405	44	256	705
2012	432	93	218	743
2013	352	133	149	634

Table 3.3. Discarded catches of sablefish (amount [t], percent of total catch, total catch [t]) by gear (H&L=hook & line, Other = Pot, trawl, and jig, combined for confidentiality) by FMP area for 2007-2013. Source: NMFS Alaska Regional Office via AKFIN, October 24, 2014.

		BSAI			GOA			Combined		
Year	Gear	Discard	%Discard	Catch	Discard	%Discard	Catch	Discard	%Discard	Catch
2007	Total	66	2.84%	2,338	556	4.11%	13,547	622	3.92%	15,884
	H&L	16	2.25%	707	256	2.07%	12,379	272	2.08%	13,086
	Other	50	3.09%	1,631	300	25.71%	1,168	351	12.53%	2,799
2008	Total	100	4.90%	2,040	755	5.98%	12,623	855	5.83%	14,663
	H&L	93	10.99%	850	674	5.73%	11,760	768	6.09%	12,610
	Other	6	0.54%	1,189	81	9.35%	863	87	4.24%	2,052
2009	Total	24	1.19%	2,014	739	6.65%	11,112	763	5.82%	13,126
	H&L	17	1.39%	1,213	659	6.44%	10,223	675	5.91%	11,436
	Other	7	0.90%	801	499	4.53%	11,016	88	5.21%	1,690
2010	Total	43	2.31%	1,849	371	4.02%	9,231	461	3.85%	11,976
	H&L	36	2.90%	1,234	47	5.22%	896	407	3.89%	10,465
	Other	7	1.12%	614	574	5.12%	11,222	54	3.57%	1,511
2011	Total	25	1.47%	1,729	396	3.90%	10,145	599	4.63%	12,951
	H&L	18	1.63%	1,092	169	15.84%	1,068	413	3.68%	11,237
	Other	8	1.20%	637	327	2.74%	11,917	186	10.86%	1,714
2012	Total	25	1.30%	1,948	253	2.29%	11,060	343	2.48%	13,856
	H&L	13	1.10%	1,197	65	7.62%	848	266	2.17%	12,257
	Other	12	1.63%	750	626	5.24%	11,944	77	4.81%	1,598
2013	Total	30	1.79%	1,697	579	5.21%	11,099	657	4.81%	13,641
	H&L	27	2.51%	1,066	47	5.60%	845	605	4.98%	12,165
	Other	4	0.59%	630	3987	4.83%	82,482	51	3.47%	1,476
2007-2013	Total	45	2.26%	1,945	521	4.59%	11,259	614	4.48%	13,728
Mean	H&L	31	3.25%	1,051	274	6.93%	5,431	487	4.11%	11,894
	Other	13	1.29%	893	913	8.22%	18,659	128	6.38%	1,834

Table 3.4. Bycatch (t) of FMP Groundfish species in the targeted sablefish fishery averaged from 2009-2013. Other = Pot and trawl combined because of confidentiality. Source: AKFIN, October 31, 2014.

	Hook and Line			Other Gear			All Gear		
Species	Discard	Retained	Total	Discard	Retained	Total	Discard	Retained	Total
GOA Thornyhead Rockfish	147	346	493	4	23	27	151	369	520
Arrowtooth Flounder	198	40	238	106	4	110	304	44	348
Shark	330	0	331	1	0	1	331	0	331
GOA Shortraker Rockfish	127	91	219	11	9	20	138	101	239
Other Rockfish	57	95	153	2	1	3	59	96	156
GOA Skate, Longnose	133	7	139	1	0	1	134	7	140
GOA Rougheye Rockfish	55	80	135	2	3	5	57	83	140
GOA Skate, Other	133	2	136	2	0	2	135	2	137
Pacific Cod	40	46	85	1	4	5	41	50	91
Other Species	84	1	85	1	0	1	85	1	86
Greenland Turbot	23	51	74	10	1	10	33	52	85
BSAI Skate	52	0	52	0	-	0	52	0	52
GOA Deep Water Flatfish	8	0	8	16	5	22	24	5	30
Pacific Ocean Perch	1	0	1	2	15	17	2	15	18
BSAI Kamchatka Flounder	12	2	13	3	0	3	15	2	17
BSAI Shortraker Rockfish	5	8	14	0	0	0	6	8	14
BSAI Other Flatfish	11	0	11	1	0	1	12	0	12
GOA Rex Sole	0	-	0	8	4	11	8	4	11
Sculpin	10	-	10	0	0	0	10	0	10
Total	1,315	728	2,046	220	102	322	1,535	830	2,369

Table 3.5. Bycatch of nontarget species and HAPC biota in the targeted sablefish fishery. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN, October 31, 2014.

	Estimated Catch (t)				
Group Name	**2009**	**2010**	**2011**	**2012**	**2013**
Benthic urochordata	0.01	0.13	0.13	1.08	0.00
Birds	0.47	0.45	1.46	0.22	0.64
Bivalves	0.04	0.04	0.05	0.01	0.00
Brittle star unidentified	0.45	0.12	0.44	4.52	0.10
Corals Bryozoans	2.21	3.33	5.57	7.57	12.75
Dark Rockfish	0.14	0.00	0.00	0.03	0.07
Eelpouts	1.83	1.38	0.58	0.62	1.11
Giant Grenadier	6,011	4,767	6,973	6,993	8,083
Greenlings	0.07	0.00	0.02	0.00	0.00
Grenadier	1,139	864	843	1,020	1,519
Hermit crab unidentified	0.10	0.19	0.21	0.08	0.09
Invertebrate unidentified	1.53	2.08	2.02	6.81	0.18
Misc crabs	3.29	1.89	1.13	0.31	0.51
Misc crustaceans	2.36	0.00	0.00	0.00	0.00
Misc deep fish	0.00	0.00	0.00	0.00	0.00
Misc fish	5.03	6.20	8.43	10.12	28.81
Scypho jellies	0.08	0.11	0.69	0.00	0.00
Sea anemone unidentified	2.26	1.49	3.29	0.99	0.92
Sea pens whips	0.52	0.35	1.58	0.25	0.28
Sea star	2.97	3.91	3.45	2.99	18.79
Snails	10.79	11.49	20.04	12.08	8.77
Sponge unidentified	2.17	1.05	2.08	0.94	3.31
Urchins, dollars, cucumbers	1.64	0.58	0.26	0.78	0.72

Table 3.6. Prohibited Species Catch (PSC) estimates reported in tons for halibut, thousands of animals for crab, by year, and fisheries management plan (BSAI or GOA) area for the sablefish fishery. Other = Pot and trawl combined because of confidentiality. Source: NMFS AKRO Blend/Catch Accounting System PSCNQ via AKFIN, October 31, 2014.

	2010			2011			2012			2013			Mean
	BSAI	GOA	Total	BSAI	GOA	Total	BSAI	GOA	Total	BSAI	GOA	Total	
Hook and Line													
Bairdi Crab	-	0.06	0.06	-	-	-	-	-	-	-	0.09	0.09	0.04
Golden K. Crab	0.94	-	0.94	0.55	0.13	0.68	0.46	0.02	0.48	0.47	0.11	0.58	0.67
Halibut	341	992	1,333	182	889	1,071	129	1,456	1,585	86	708	794	1,196
Red K. Crab	0.01	-	0.01	0.02	-	0.02	0.01	-	0.01	-	0.03	0.03	0.01
Other													
Bairdi Crab	-	0.06	0.06	0.82	-	0.82	-	-	-	0.22	-	0.22	0.27
Golden K. Crab	32	-	32	210	0	210	17	0	17	1	-	1	65
Halibut	34	4	39	18	6	24	11	5	16	20	12	32	28
Red K. Crab	-	-	-	0.31	-	0.31	-	-	-	-	-	-	0.08

Table 3.7. Summary of management measures with time series of catch, ABC, OFL, and TAC.

Year	Catch(t)	OFL	ABC	TAC	Management measure
1980	10,444			18,000	Amendment 8 to the Gulf of Alaska Fishery Management Plan established the West and East Yakutat management areas for sablefish.
1981	12,604			19,349	
1982	12,048			17,300	
1983	11,715			14,480	
1984	14,109			14,820	
1985	14,465			13,480	Amendment 14 of the GOA FMP allocated sablefish quota by gear type: 80% to fixed gear and 20% to trawl gear in WGOA and CGOA and 95% fixed to 5% trawl in the EGOA.
1986	28,892			21,450	Pot fishing banned in Eastern GOA.
1987	35,163			27,700	Pot fishing banned in Central GOA.
1988	38,406			36,400	
1989	34,829			32,200	Pot fishing banned in Western GOA.
1990	32,115			33,200	Amendment 15 of the BSAI FMP allocated sablefish quota by gear type: 50% to fixed gear in and 50% to trawl in the EBS, and 75% fixed to 25% trawl in the Aleutian Islands.
1991	27,073			28,800	
1992	24,932			25,200	Pot fishing banned in Bering Sea (57 FR 37906).
1993	25,417			25,000	
1994	23,577			28,840	
1995	20,692			25,300	Amendment 20 to the Gulf of Alaska Fishery Management Plan and 15 to the Bering Sea/Aleutian Islands Fishery Management Plan established IFQ management for sablefish beginning in 1995. These amendments also allocated 20% of the fixed gear allocation of sablefish to a CDQ reserve for the Bering Sea and Aleutian Islands.
1996	17,275			19,380	Pot fishing ban repealed in Bering Sea except from June 1-30.
1997	14,607	27,900	19,600	17,200	Maximum retainable allowances for sablefish were revised in the Gulf of Alaska. The percentage depends on the basis species.
1998	13,867	26,500	16,800	16,800	
1999	13,585	24,700	15,900	15,900	
2000	15,565	21,400	17,300	17,300	
2001	14,064	20,700	16,900	16,900	
2002	14,748	26,100	17,300	17,300	
2003	16,411	28,900	18,400	20,900	
2004	17,518	30,800	23,000	23,000	
2005	16,580	25,400	21,000	21,000	
2006	15,551	25,300	21,000	21,000	
2007	15,957	23,750	20,100	20,100	
2008	14,674	21,310	18,030	18,030	Pot fishing ban repealed in Bering Sea for June 1-30 (74 FR 28733).
2009	13,128	19,000	16,080	16,080	
2010	11,980	21,400	15,230	15,230	
2011	12,971	20,700	16,040	16,040	
2012	13,868	20,400	17,240	17,240	
2013	13,642	19,180	16,230	16,230	
2014	11,476	16,160	13,722	13,722	

Table 3.8. Sample sizes for age and length data collected from Alaska sablefish. Japanese fishery data from Sasaki (1985), U.S. fishery data from the observer databases, and longline survey data from longline survey databases. All fish were sexed before measurement, except for the Japanese fishery data.

	LENGTH						AGE		
		Japanese fishery		U.S. fishery					
Year	U.S. NMFS trawl survey (GOA)	Trawl	Longline	Trawl	Longline	Cooperative longline survey	Domestic longline survey	Cooperative longline survey	Domestic longline survey	U.S. longline fishery
1963			30,562							
1964		3,337	11,377							
1965		6,267	9,631							
1966		27,459	13,802							
1967		31,868	12,700							
1968		17,727								
1969		3,843								
1970		3,456								
1971		5,848	19,653							
1972		1,560	8,217							
1973		1,678	16,332							
1974			3,330							
1975										
1976			7,704							
1977			1,079							
1978			9,985							
1979			1,292			19,349				
1980			1,944			40,949				
1981						34,699		1,146		
1982						65,092				
1983						66,517		889		
1984	12,964					100,029				
1985						125,129		1,294		
1986						128,718				
1987	9,610					102,639		1,057		
1988						114,239				
1989						115,067		655		
1990	4,969			1,229	32,936	78,794	101,530			
1991				721	28,182	69,653	95,364	902		
1992				0	20,929	79,210	104,786			
1993	7,282			468	21,943	80,596	94,699	1,178		
1994				89	11,914	74,153	70,431			
1995				87	17,735		80,826			
1996	4,650			239	14,416		72,247		1,176	
1997				0	20,330		82,783		1,214	
1998				35	8,932		57,773		1,191	
1999	4,408			1,268	28,070		79,451		1,186	1,141
2000				472	32,208		62,513		1,236	1,152
2001	*partial			473	30,315		83,726		1,214	1,003
2002				526	33,719		75,937		1,136	1,059
2003	5,039			503	36,077		77,678		1,128	1,185
2004				694	31,199		82,767		1,185	1,145
2005	4,956			2,306	36,213		74,433		1,074	1,164
2006				721	32,497		78,625		1,178	1,154
2007	3,804			860	29,854		73,480		1,174	1,115
2008				2,018	23,414		71,661		1,184	1,164
2009	3,975			1,837	24,674		67,978		1,197	1,126
2010				1,634	24,530		75,010		1,176	1,159
2011	2,118			1,877	22,659		87,498		1,199	1,190
2012				2,533	22,311		63,116		1,186	1,169
2013	1,561						51,586		1,190	
2014	1,561						52,290			

Table 3.9. Average catch rate (pounds/hook) for fishery data by year and region. SE = standard error, CV = coefficient of variation. C = confidential due to less than three vessels or sets. These data are still used in the combined index.

Observer Fishery Data

Aleutian Islands-Observer						Bering Sea-Observer					
Year	CPUE	SE	CV	Sets	Vessels	Year	CPUE	SE	CV	Sets	Vessels
1990	0.53	0.05	0.10	193	8	1990	0.72	0.11	0.15	42	8
1991	0.50	0.03	0.07	246	8	1991	0.28	0.06	0.20	30	7
1992	0.40	0.06	0.15	131	8	1992	0.25	0.11	0.43	7	4
1993	0.28	0.04	0.14	308	12	1993	0.09	0.03	0.36	4	3
1994	0.29	0.05	0.18	138	13	1994	C	C	C	2	2
1995	0.30	0.04	0.14	208	14	1995	0.41	0.07	0.17	38	10
1996	0.23	0.03	0.12	204	17	1996	0.63	0.19	0.30	35	15
1997	0.35	0.07	0.20	117	9	1997	C	C	C	0	0
1998	0.29	0.05	0.17	75	12	1998	0.17	0.03	0.18	28	9
1999	0.38	0.07	0.17	305	14	1999	0.29	0.09	0.32	27	10
2000	0.29	0.03	0.11	313	15	2000	0.28	0.09	0.31	21	10
2001	0.26	0.04	0.15	162	9	2001	0.31	0.02	0.07	18	10
2002	0.32	0.03	0.11	245	10	2002	0.10	0.02	0.22	8	4
2003	0.26	0.04	0.17	170	10	2003	C	C	C	8	2
2004	0.21	0.04	0.21	138	7	2004	0.17	0.05	0.31	9	4
2005	0.15	0.05	0.34	23	6	2005	0.23	0.02	0.16	9	6
2006	0.23	0.04	0.16	205	11	2006	0.17	0.05	0.21	68	15
2007	0.35	0.10	0.29	198	7	2007	0.28	0.05	0.18	34	8
2008	0.37	0.04	0.10	247	6	2008	0.38	0.22	0.58	12	5
2009	0.29	0.05	0.22	335	10	2009	0.14	0.04	0.21	24	5
2010	0.27	0.04	0.14	459	12	2010	0.17	0.03	0.19	42	8
2011	0.25	0.05	0.19	401	9	2011	0.10	0.01	0.13	12	4
2012	0.25	0.10	0.15	363	8	2012	C	C	C	6	1
2013	0.28	0.06	0.22	613	7	2013	0.21	0.10	0.46	27	5

Table 3.9 (cont.)

Western Gulf-Observer

Year	CPUE	SE	CV	Sets	Vessels
1990	0.64	0.14	0.22	178	7
1991	0.44	0.06	0.13	193	16
1992	0.38	0.05	0.14	260	12
1993	0.35	0.03	0.09	106	12
1994	0.32	0.03	0.10	52	5
1995	0.51	0.04	0.09	432	22
1996	0.57	0.05	0.10	269	20
1997	0.50	0.05	0.10	349	20
1998	0.50	0.03	0.07	351	18
1999	0.53	0.07	0.12	244	14
2000	0.49	0.06	0.13	185	12
2001	0.50	0.05	0.10	273	16
2002	0.51	0.05	0.09	348	15
2003	0.45	0.04	0.10	387	16
2004	0.47	0.08	0.17	162	10
2005	0.58	0.07	0.13	447	13
2006	0.42	0.04	0.13	306	15
2007	0.37	0.04	0.11	255	12
2008	0.46	0.07	0.16	255	11
2009	0.44	0.09	0.21	208	11
2010	0.42	0.06	0.14	198	10
2011	0.54	0.12	0.22	196	12
2012	0.38	0.04	0.11	147	13
2013	0.34	0.02	0.06	325	18

Central Gulf-Observer

Year	CPUE	SE	CV	Sets	Vessels
1990	0.54	0.04	0.07	653	32
1991	0.62	0.06	0.09	303	24
1992	0.59	0.05	0.09	335	19
1993	0.60	0.04	0.07	647	32
1994	0.65	0.06	0.09	238	15
1995	0.90	0.07	0.08	457	41
1996	1.04	0.07	0.07	441	45
1997	1.07	0.08	0.08	377	41
1998	0.90	0.06	0.06	345	32
1999	0.87	0.08	0.10	269	28
2000	0.93	0.05	0.06	319	30
2001	0.70	0.04	0.06	347	31
2002	0.84	0.07	0.08	374	29
2003	0.99	0.07	0.07	363	34
2004	1.08	0.10	0.09	327	29
2005	0.89	0.06	0.07	518	32
2006	0.82	0.06	0.08	361	33
2007	0.93	0.06	0.07	289	30
2008	0.84	0.07	0.08	207	27
2009	0.77	0.06	0.07	320	33
2010	0.80	0.05	0.07	286	31
2011	0.85	0.08	0.10	213	28
2012	0.74	0.07	0.09	298	27
2013	0.51	0.05	0.10	419	34

West Yakutat-Observer

Year	CPUE	SE	CV	Sets	Vessels
1990	0.95	0.24	0.25	75	9
1991	0.65	0.07	0.10	164	12
1992	0.64	0.18	0.27	98	6
1993	0.71	0.07	0.10	241	12
1994	0.65	0.17	0.27	81	8
1995	1.02	0.10	0.10	158	21
1996	0.97	0.07	0.07	223	28
1997	1.16	0.11	0.09	126	20
1998	1.21	0.10	0.08	145	23
1999	1.20	0.15	0.13	110	19
2000	1.28	0.10	0.08	193	32
2001	1.03	0.07	0.07	184	26
2002	1.32	0.13	0.10	155	23
2003	1.36	0.10	0.07	216	27
2004	1.23	0.09	0.08	210	24
2005	1.32	0.09	0.07	352	24
2006	0.96	0.10	0.10	257	30
2007	1.02	0.11	0.11	208	24
2008	1.40	0.12	0.08	173	23
2009	1.34	0.12	0.09	148	23
2010	1.11	0.09	0.08	136	22
2011	1.18	0.09	0.07	186	24
2012	0.97	0.09	0.10	255	24
2013	1.11	0.15	0.13	109	20

East Yakutat/SE-Observer

Year	CPUE	SE	CV	Sets	Vessels
1990	C	C	C	0	0
1991	C	C	C	17	2
1992	C	C	C	20	1
1993	C	C	C	26	2
1994	C	C	C	5	1
1995	1.45	0.20	0.14	101	19
1996	1.20	0.11	0.09	137	24
1997	1.10	0.14	0.13	84	17
1998	1.27	0.12	0.10	140	25
1999	0.94	0.12	0.13	85	11
2000	0.84	0.13	0.16	81	14
2001	0.84	0.08	0.09	110	14
2002	1.20	0.23	0.19	121	14
2003	1.29	0.13	0.10	113	19
2004	1.08	0.10	0.09	135	17
2005	1.18	0.13	0.11	181	16
2006	0.93	0.11	0.11	104	18
2007	0.92	0.15	0.17	85	16
2008	1.06	0.13	0.12	103	17
2009	0.98	0.12	0.12	94	13
2010	0.97	0.17	0.17	76	12
2011	0.98	0.09	0.10	196	16
2012	0.93	0.11	0.12	104	15
2013	0.91	0.12	0.14	165	22

Table 3.9 (cont.)

Aleutian Islands-Logbook

Year	CPUE	SE	CV	Sets	Vessels
1999	0.29	0.04	0.15	167	15
2000	0.24	0.05	0.21	265	16
2001	0.38	0.16	0.41	36	5
2002	0.48	0.19	0.39	33	5
2003	0.36	0.11	0.30	139	10
2004	0.45	0.11	0.25	102	7
2005	0.46	0.15	0.33	109	8
2006	0.51	0.16	0.31	61	5
2007	0.38	0.22	0.58	61	3
2008	0.30	0.03	0.12	119	4
2009	0.23	0.07	0.06	204	7
2010	0.25	0.05	0.20	497	9
2011	0.23	0.07	0.30	609	12
2012	0.26	0.03	0.14	893	12
2013	0.26	0.06	0.22	457	7

Bering Sea-Logbook

Year	CPUE	SE	CV	Sets	Vessels
1999	0.56	0.08	0.14	291	43
2000	0.21	0.05	0.22	169	23
2001	0.35	0.11	0.33	61	8
2002	C	C	C	5	2
2003	0.24	0.13	0.53	25	6
2004	0.38	0.09	0.24	202	8
2005	0.36	0.07	0.19	86	10
2006	0.38	0.07	0.18	106	9
2007	0.37	0.08	0.21	147	8
2008	0.52	0.20	0.39	94	7
2009	0.25	0.04	0.14	325	18
2010	0.30	0.08	0.27	766	12
2011	0.22	0.03	0.13	500	24
2012	0.30	0.04	0.15	721	21
2013	0.20	0.04	0.18	460	15

Western Gulf-Logbook

Year	CPUE	SE	CV	Sets	Vessels
1999	0.64	0.06	0.09	245	27
2000	0.60	0.05	0.09	301	32
2001	0.47	0.05	0.10	109	24
2002	0.60	0.08	0.13	78	14
2003	0.39	0.04	0.11	202	24
2004	0.65	0.06	0.09	766	26
2005	0.78	0.08	0.11	571	33
2006	0.69	0.08	0.11	1067	38
2007	0.59	0.06	0.10	891	31
2008	0.71	0.06	0.08	516	29
2009	0.53	0.06	0.11	824	33
2010	0.48	0.04	0.08	1297	46
2011	0.50	0.05	0.10	1148	46
2012	0.50	0.04	0.08	1142	37
2013	0.35	0.03	0.07	1476	32

Central Gulf-Logbook

Year	CPUE	SE	CV	Sets	Vessels
1999	0.80	0.05	0.06	817	60
2000	0.79	0.04	0.05	746	64
2001	0.74	0.06	0.08	395	52
2002	0.83	0.06	0.07	276	41
2003	0.87	0.07	0.08	399	45
2004	1.08	0.05	0.05	1676	80
2005	0.98	0.07	0.07	1154	63
2006	0.87	0.04	0.05	1358	80
2007	0.83	0.04	0.05	1190	69
2008	0.88	0.05	0.06	1039	68
2009	0.95	0.08	0.08	1081	73
2010	0.66	0.03	0.05	1171	80
2011	0.80	0.06	0.07	1065	71
2012	0.79	0.06	0.07	1599	82
2013	0.48	0.03	0.07	2102	73

Table 3.9 (cont.)

West Yakutat-Logbook						East Yakutat/SE-Logbook					
Year	CPUE	SE	CV	Sets	Vessels	Year	CPUE	SE	CV	Sets	Vessels
1999	1.08	0.08	0.08	233	36	1999	0.91	0.08	0.08	183	22
2000	1.04	0.06	0.06	270	42	2000	0.98	0.08	0.08	190	26
2001	0.89	0.09	0.11	203	29	2001	0.98	0.09	0.09	109	21
2002	0.99	0.07	0.07	148	28	2002	0.83	0.06	0.07	108	22
2003	1.26	0.10	0.08	104	23	2003	1.13	0.10	0.09	117	22
2004	1.27	0.06	0.05	527	54	2004	1.19	0.05	0.04	427	55
2005	1.13	0.05	0.04	1158	70	2005	1.15	0.05	0.05	446	77
2006	0.97	0.05	0.06	1306	84	2006	1.06	0.04	0.04	860	107
2007	0.97	0.05	0.05	1322	89	2007	1.13	0.04	0.04	972	122
2008	0.97	0.05	0.05	1118	74	2008	1.08	0.05	0.05	686	97
2009	1.23	0.07	0.06	1077	81	2009	1.12	0.05	0.05	620	87
2010	0.98	0.05	0.05	1077	85	2010	1.04	0.05	0.05	744	99
2011	0.95	0.07	0.07	1377	75	2011	1.01	0.04	0.04	877	112
2012	0.89	0.06	0.06	1634	86	2012	1.00	0.05	0.05	972	102
2013	0.74	0.06	0.07	1953	79	2013	0.86	0.05	0.06	865	88

Table 3.10. Sablefish abundance index values (1,000's) for Alaska (200-1,000 m) including deep gully habitat, from the Japan-U.S. Cooperative Longline Survey, Domestic Longline Survey, and Japanese and U.S. longline fisheries. Relative population number equals CPUE in numbers weighted by respective strata areas. Relative population weight equals CPUE measured in weight multiplied by strata areas. Indices were extrapolated for survey areas not sampled every year, including Aleutian Islands 1979, 1995, 1997, 1999, 2001, 2003, 2005, and 2007, 2009, 2011, and 2013, and Bering Sea 1979-1981, 1995, 1996, 1998, 2000, 2002, 2004, 2006, 2008, 2009, 2010, 2012, and 2014. NMFS trawl survey biomass estimates (kilotons) are from the Gulf of Alaska at depths <500 m.

	RELATIVE POPULATION NUMBER		RELATIVE POPULATION WEIGHT/BIOMASS				
Year	Coop. longline survey	Dom. longline survey	Jap. longline fishery	Coop. longline survey	Dom. longline survey	U.S. fishery	NMFS Trawl survey
1964			1,452				
1965			1,806				
1966			2,462				
1967			2,855				
1968			2,336				
1969			2,443				
1970			2,912				
1971			2,401				
1972			2,247				
1973			2,318				
1974			2,295				
1975			1,953				
1976			1,780				
1977			1,511				
1978			942				
1979	413		809	1,075			
1980	388		1,040	968			
1981	460		1,343	1,153			
1982	613			1,572			
1983	621			1,595			
1984	685			1,822			294
1985	903			2,569			
1986	838			2,456			
1987	667			2,068			271
1988	707			2,088			
1989	661			2,178			
1990	450	649		1,454	2,141	1,201	214
1991	386	593		1,321	2,071	1,066	
1992	402	511		1,390	1,758	908	
1993	395	563		1,318	1,894	904	250
1994	366	489		1,288	1,882	822	
1995		501			1,803	1,243	
1996		520			2,017	1,201	145
1997		491			1,764	1,341	
1998		477			1,662	1,130	
1999		520			1,740	1,316	104
2000		462			1,597	1,139	
2001		535			1,798	1,111	238
2002		561			1,916	1,152	
2003		532			1,759	1,218	189
2004		544			1,738	1,357	
2005		533			1,695	1,304	179
2006		580			1,848	1,206	
2007		500			1,584	1,268	111
2008		472			1,550	1,361	
2009		491			1,580	1,152	107
2010		542			1,778	1,054	
2011		556			1,683	1,048	84
2012		438			1,280	1,023	
2013		416			1,276	893	60
2014		479			1,432		

Table 3.11. Count of stations where sperm (S) or killer whale (K) depredation occurred in the six sablefish management areas. The number of stations sampled that are used for RPN calculations are in parentheses. Areas not surveyed in a given year are left blank. If there were no whale depredation data taken, it is denoted with an "n/a". Killer whale depredation did not always occur on all skates of gear, and only those skates with depredation were cut from calculations of RPNs and RPWs.

	BS (16)		**AI (14)**		**WG (10)**		**CG (16)**		**WY (8)**		**EY/SE (17)**	
Year	**S**	**K**	**S**	**K**	**S**	**K**	**S**	**K**	**S**	**K**	**S**	**K**
1996			n/a	1	n/a	0	n/a	0	n/a	0	n/a	0
1997	n/a	2			n/a	0	n/a	0	n/a	0	n/a	0
1998			0	1	0	0	0	0	4	0		0
1999	0	7			0	0	3	0	6	0	4	0
2000			0	1	0	1	0	0	4	0	2	0
2001	0	5			0	0	3	0	2	0	2	0
2002			0	1	0	4	3	0	4	0	2	0
2003	0	7			0	3	2	0	1	0	2	0
2004			0	0	0	4	3	0	4	0	6	0
2005	0	2			0	4	0	0	2	0	8	0
2006			0	1	0	3	2	1	4	0	2	0
2007	0	7			0	5	1	1	5	0	6	0
2008			0	3	0	2	2	0	8	0	9	0
2009	0	10			0	2	5	1	3	0	2	0
2010			0	3	0	1	2	1	2	0	6	0
2011	0	7			0	5	1	1	4	0	9	0
2012			1	5	1	5	2	0	4	0	3	0
2013	0	11			0	2	2	2	3	0	7	0
2014			1	3	0	4	4	0	6	0	4	0

Table 3.12. Sablefish fork length (cm), weight (kg), and proportion mature by age and sex (weights from 1996-2004 age-length data from the AFSC longline survey).

	Fork length (cm)		Weight (kg)		Fraction mature	
Age	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
2	48.1	46.8	1.0	0.9	0.059	0.006
3	53.1	53.4	1.5	1.5	0.165	0.024
4	56.8	58.8	1.9	2.1	0.343	0.077
5	59.5	63.0	2.2	2.6	0.543	0.198
6	61.6	66.4	2.5	3.1	0.704	0.394
7	63.2	69.2	2.7	3.5	0.811	0.604
8	64.3	71.4	2.8	3.9	0.876	0.765
9	65.2	73.1	2.9	4.2	0.915	0.865
10	65.8	74.5	3.0	4.4	0.939	0.921
11	66.3	75.7	3.0	4.6	0.954	0.952
12	66.7	76.6	3.1	4.8	0.964	0.969
13	67.0	77.3	3.1	4.9	0.971	0.979
14	67.2	77.9	3.1	5.1	0.976	0.986
15	67.3	78.3	3.1	5.1	0.979	0.99
16	67.4	78.7	3.1	5.2	0.982	0.992
17	67.5	79.0	3.1	5.3	0.984	0.994
18	67.6	79.3	3.2	5.3	0.985	0.995
19	67.6	79.4	3.2	5.3	0.986	0.996
20	67.7	79.6	3.2	5.4	0.987	0.997
21	67.7	79.7	3.2	5.4	0.988	0.997
22	67.7	79.8	3.2	5.4	0.988	0.998
23	67.7	79.9	3.2	5.4	0.989	0.998
24	67.7	80.0	3.2	5.4	0.989	0.998
25	67.7	80.0	3.2	5.4	0.989	0.998
26	67.8	80.1	3.2	5.4	0.999	0.998
27	67.8	80.1	3.2	5.4	0.999	0.999
28	67.8	80.1	3.2	5.4	0.999	0.999
29	67.8	80.1	3.2	5.5	0.999	0.999
30	67.8	80.2	3.2	5.5	0.999	0.999
31+	67.8	80.2	3.2	5.5	1.000	1.000

Table 3.13. Input and output sample sizes and standard deviation of normalized residuals (SDNR) for data sources in the sablefish assessment model.

Multinomial Compositions	Input N/CV	SDNR	Effective N
Domestic LL Fishery Ages	200	1.10	170
Domestic LL Fishery Lengths	120	0.83	364
Trawl Fishery Lengths	50	0.86	89
LL Survey Ages	160	0.86	199
NMFS Trawl Survey Lengths	140	0.96	149
Domestic LL Survey Lengths	20	0.29	227
Japanese/Coop LL Survey Lengths	20	0.32	197
Lognormal abundance indices			
Domestic RPN	5%	3.84	
Japanese/Coop RPN	5%	2.99	
Domestic Fishery RPW	10%	0.91	
Foreign Fishery RPW	10%	1.29	
NMFS Trawl Survey	10-20%	1.85	

Table 3.14. Sablefish recruits, total biomass (2+), and spawning biomass plus lower and upper lower 95% credible intervals (2.5%, 97.5%) from MCMC. Recruits are in millions, and biomass is in kt.

	Recruits (Age 2)			Total Biomass			Spawning Biomass		
Year	Mean	2.5%	97.5%	Mean	2.5%	97.5%	Mean	2.5%	97.5%
1960	4.6	0	52	533	468	629	173	133	236
1961	4.5	0	55	546	479	647	179	149	230
1962	90.0	12	145	614	539	710	192	167	235
1963	8.7	0	80	617	542	714	203	178	245
1964	7.4	0	72	615	539	717	218	191	261
1965	26.5	0	118	629	549	734	235	205	278
1966	74.7	0	139	685	606	770	251	220	294
1967	9.4	0	91	689	627	770	262	230	306
1968	15.0	0	57	682	626	752	268	236	311
1969	6.6	0	36	648	597	710	267	237	308
1970	2.7	0	24	595	549	653	264	236	301
1971	2.6	0	29	536	494	593	255	230	289
1972	26.5	0	60	491	446	546	237	215	268
1973	25.5	0	60	445	410	485	209	189	236
1974	2.5	0	22	401	369	436	185	167	210
1975	5.1	0	31	359	333	393	163	146	186
1976	17.9	0	29	333	310	360	147	131	166
1977	1.5	0	11	294	274	318	131	117	148
1978	2.3	0	11	264	245	286	119	108	135
1979	83.5	66	103	322	302	347	114	104	128
1980	27.5	6	48	355	336	379	109	100	122
1981	8.3	0	29	373	351	396	107	99	119
1982	48.5	29	74	417	398	447	111	103	122
1983	22.1	0	39	445	423	467	123	115	134
1984	43.3	34	58	488	468	512	139	131	150
1985	0.4	0	3	491	472	516	154	146	167
1986	23.2	11	33	502	483	524	168	160	181
1987	19.8	13	30	491	475	513	175	166	187
1988	4.0	0	12	457	443	479	174	165	187
1989	4.6	0	11	415	401	433	167	159	180
1990	5.8	3	10	373	360	389	158	150	171
1991	28.6	23	34	356	343	371	147	139	160
1992	0.3	0	2	326	314	340	136	129	148
1993	26.1	22	31	320	308	335	125	118	137
1994	3.1	0	8	297	285	312	115	108	125
1995	6.5	2	11	277	265	291	106	100	116
1996	7.5	5	10	259	247	273	101	95	111
1997	19.2	16	23	254	243	269	98	92	107
1998	1.2	0	4	240	228	253	96	90	104
1999	31.6	27	36	251	239	266	92	86	100
2000	19.6	13	29	260	248	277	89	83	96
2001	11.6	0	20	262	248	277	86	80	93
2002	43.1	36	54	292	278	310	85	80	92
2003	7.8	2	13	299	284	316	88	82	95
2004	14.5	10	19	303	287	321	91	85	98
2005	6.7	4	10	295	280	314	96	90	103
2006	11.1	7	15	289	274	307	102	96	110
2007	8.6	6	12	280	265	298	107	100	115
2008	10.6	7	14	271	256	288	109	102	117
2009	9.8	7	14	262	247	280	108	101	116
2010	17.7	13	23	263	248	281	106	99	114
2011	3.8	0	7	254	239	272	104	97	112
2012	8.4	4	14	246	231	264	101	94	109
2013	0.3	0	1	228	213	246	98	91	106
2014	11.0	4	18	218	196	229	95	88	103
2015	-	-	-	-	-	-	92	85	100
2016	-	-	-	-	-	-	88	79	96

Table 3.15. Regional estimates of sablefish total biomass (Age 2+). Partitioning was done using RPWs from Japanese LL survey from 1979-1989 and domestic LL survey from 1990-2014 using a 2 year moving average. For 1960-1978, a prospective 4:6:9 - year average of forward proportions was used.

Year	Bering Sea	Aleutian Islands	Western GOA	Central GOA	West Yakutat	EYakutat/ Southeast	Alaska
1960	98	118	51	148	46	71	533
1961	101	121	52	152	47	73	546
1962	114	136	59	171	53	82	614
1963	114	136	59	172	54	82	617
1964	114	136	59	171	53	82	615
1965	116	139	60	175	55	84	629
1966	127	151	66	191	60	91	685
1967	127	152	66	192	60	92	689
1968	126	151	65	190	59	91	682
1969	120	143	62	180	56	86	648
1970	110	132	57	166	52	79	595
1971	99	118	51	149	47	71	536
1972	91	108	47	137	43	65	491
1973	82	98	43	124	39	59	445
1974	74	89	38	112	35	53	401
1975	66	79	34	100	31	48	359
1976	62	73	32	93	29	44	333
1977	54	65	28	82	25	39	294
1978	49	60	26	72	23	36	264
1979	61	66	30	95	28	42	322
1980	64	84	34	95	31	47	355
1981	66	93	39	83	35	57	373
1982	76	87	54	101	40	60	417
1983	80	93	69	112	37	54	445
1984	92	113	77	117	35	54	488
1985	101	112	71	122	36	49	491
1986	107	105	68	125	42	53	502
1987	80	107	65	131	49	60	491
1988	48	93	61	147	47	61	457
1989	56	81	48	133	43	54	415
1990	57	61	40	114	43	57	373
1991	39	41	38	112	47	78	356
1992	23	37	25	103	51	86	326
1993	15	35	29	106	54	81	320
1994	18	34	32	98	46	69	297
1995	26	32	28	90	39	62	277
1996	25	27	28	93	33	53	259
1997	24	24	27	99	31	50	254
1998	21	30	27	84	28	50	240
1999	20	41	29	83	27	51	251
2000	20	43	34	87	27	50	260
2001	29	41	41	82	22	46	262
2002	40	45	43	95	24	45	292
2003	40	46	42	101	26	43	299
2004	40	46	38	107	28	43	303
2005	42	45	38	96	26	48	295
2006	45	40	41	87	26	49	289
2007	49	36	30	87	29	49	280
2008	52	34	27	85	26	47	271
2009	50	34	31	82	23	42	262
2010	52	29	28	77	29	49	263
2011	33	26	26	90	33	47	254
2012	14	31	28	98	28	47	246
2013	30	32	23	76	21	46	228
2014	46	27	23	62	19	41	218

Table 3.16. Key parameter estimates and their uncertainty and Bayesian credible intervals (BCI). Recruitment is in millions.

Parameter	μ (MLE)	μ (MCMC)	Median (MCMC)	σ (Hessian)	σ (MCMC)	BCI-Lower	BCI-Upper
$q_{domesticLL}$	7.56	7.55	7.55	0.11	0.22	7.13	7.97
q_{coopLL}	6.22	6.22	6.22	0.11	0.21	5.84	6.65
q_{trawl}	1.34	1.32	1.32	0.32	0.09	1.15	1.52
$F_{40\%}$	0.09	0.11	0.10	0.023	0.029	0.06	0.18
2014 SSB (kt)	95.0	95.2	95.1	3.66	3.86	87.9	103
2000 Year Class	11.6	45.0	44.9	4.26	4.87	35.6	54.5
2008 Year Class	17.7	18.3	18.3	2.30	2.48	13.5	23.1

Table 3.17. Comparison of 2013 results versus 2014 results. Biomass is in kilotons.

Year	2013 SAFE Spawning Biomass	2014 SAFE Spawning Biomass	2013 SAFE Total Biomass	2014 SAFE Total Biomass
1977	129	131	291	294
1978	117	119	261	264
1979	112	114	318	322
1980	107	109	351	355
1981	106	107	367	373
1982	109	111	412	417
1983	121	123	439	445
1984	136	139	481	488
1985	152	154	485	491
1986	165	168	495	502
1987	171	175	484	491
1988	170	174	451	457
1989	164	167	408	415
1990	154	158	367	373
1991	143	147	349	356
1992	132	136	319	326
1993	122	125	313	320
1994	111	115	291	297
1995	103	106	270	277
1996	98	101	252	259
1997	95	98	247	254
1998	92	96	233	240
1999	88	92	244	251
2000	85	89	253	260
2001	82	86	254	262
2002	81	85	284	292
2003	84	88	289	299
2004	87	91	293	303
2005	92	96	285	295
2006	98	102	279	289
2007	103	107	270	280
2008	105	109	261	271
2009	104	108	252	262
2010	102	106	255	263
2011	100	104	247	254
2012	96	101	234	246
2013	93	98	217	228

Table 3.18. Sablefish spawning biomass (kilotons), fishing mortality, and yield (kilotons) for seven harvest scenarios. Abundance projected using 1979-2012 recruitments.

Year	Maximum permissible F	Author's F* (specified catch)	Half max. F	5-year average F	No fishing	Overfished?	Approaching overfished?
			Spawning biomass (kt)				
2014	94.9	94.9	94.9	94.9	94.9	94.9	94.9
2015	92.2	92.2	92.1	92.2	92.2	92.2	92.2
2016	87.1	88.3	90.3	88.4	94.0	85.8	87.1
2017	82.5	84.9	87.8	84.7	95.6	80.4	82.5
2018	80.1	82.1	85.6	82.6	98.4	77.3	79.1
2019	80.6	82.3	84.7	83.4	104.0	77.3	78.8
2020	83.4	84.8	85.5	86.5	112.4	79.6	80.7
2021	87.2	88.3	88.3	90.8	122.3	82.8	83.7
2022	91.1	92.0	91.9	95.5	132.7	86.1	86.8
2023	94.7	95.4	95.9	100.0	143.1	89.1	89.6
2024	97.9	98.4	101.4	104.2	153.1	91.7	92.1
2025	100.6	101.0	106.4	107.9	162.5	93.9	94.2
2026	103.0	103.3	109.8	111.4	171.5	95.7	96.0
2027	105.1	105.3	113.9	114.5	179.9	97.3	97.5
			Fishing mortality				
2014	0.064	0.064	0.064	0.064	0.064	0.064	0.064
2015	0.082	0.067	0.041	0.066	-	0.098	0.098
2016	0.078	0.062	0.040	0.066	-	0.091	0.091
2017	0.073	0.075	0.039	0.066	-	0.085	0.085
2018	0.071	0.073	0.038	0.066	-	0.081	0.081
2019	0.070	0.072	0.038	0.066	-	0.080	0.080
2020	0.071	0.072	0.038	0.066	-	0.081	0.081
2021	0.072	0.072	0.039	0.066	-	0.082	0.082
2022	0.073	0.073	0.041	0.066	-	0.083	0.083
2023	0.074	0.074	0.043	0.066	-	0.084	0.084
2024	0.075	0.075	0.046	0.066	-	0.085	0.085
2025	0.076	0.076	0.047	0.066	-	0.087	0.087
2026	0.077	0.078	0.047	0.066	-	0.088	0.088
2027	0.079	0.079	0.047	0.066	-	0.090	0.090
			Yield (kt)				
2014	11.4	11.4	11.4	11.4	11.4	11.4	11.4
2015	13.7	13.7	7.0	11.0	-	16.1	13.7
2016	12.1	12.4	6.6	10.5	-	13.8	12.1
2017	11.7	12.3	6.8	10.7	-	13.1	13.8
2018	12.3	12.8	7.4	11.4	-	13.6	14.2
2019	13.3	13.7	8.1	12.2	-	14.7	15.1
2020	14.3	14.6	8.9	12.9	-	15.7	16.0
2021	15.3	15.5	9.5	13.5	-	16.8	17.0
2022	16.1	16.2	10.1	14.1	-	17.6	17.8
2023	16.8	16.9	10.7	14.6	-	18.4	18.5
2024	17.5	17.6	11.2	15.0	-	19.0	19.1
2025	18.0	18.1	11.7	15.4	-	19.6	19.7
2026	18.5	18.6	12.1	15.8	-	20.1	20.2
2027	19.1	19.1	12.5	16.1	-	20.7	20.7

* Projections in Author's F (Alternative 2) are based on estimated catches of 11,172 t and 9,862 t used in place of maximum permissible ABC for 2015 and 2016. This was done in response to management requests for a more accurate two-year projection.

Table 3.19. Analysis of ecosystem considerations for the sablefish fishery.

Indicator	*Observation*	*Interpretation*	*Evaluation*
ECOSYSTEM EFFECTS ON STOCK			
Prey availability or abundance trends			
Zooplankton	None	None	Unknown
Predator population trends			
Salmon	Decreasing	Increases the stock	No concern
Changes in habitat quality			
Temperature regime	Warm increases recruitment	Variable recruitment	No concern (can't affect)
Prevailing currents	Northerly increases recruitment	Variable recruitment	No concern (can't affect)
FISHERY EFFECTS ON ECOSYSTEM			
Fishery contribution to bycatch			
Prohibited species	Small catches	Minor contribution to mortality	No concern
Forage species	Small catches	Minor contribution to mortality	No concern
HAPC biota (seapens/whips, corals, sponges, anemones)	Small catches, except long-term reductions predicted	Long-term reductions predicted in hard corals and living structure	Possible concern
Marine mammals and birds	Bird catch about 10% total	Appears to be decreasing	Possible concern
Sensitive non-target species	Grenadier, spiny dogfish, and unidentified shark catch notable	Grenadier catch high but stable, recent shark catch is small	Possible concern for grenadiers
Fishery concentration in space and time	IFQ less concentrated	IFQ improves	No concern
Fishery effects on amount of large size target fish	IFQ reduces catch of immature	IFQ improves	No concern
Fishery contribution to discards and offal production	sablefish <5% in longline fishery, but 30% in trawl fishery	IFQ improves, but notable discards in trawl fishery	Trawl fishery discards definite concern
Fishery effects on age-at-maturity and fecundity	trawl fishery catches smaller fish, but only small part of total catch	slightly decreases	No concern

Figures

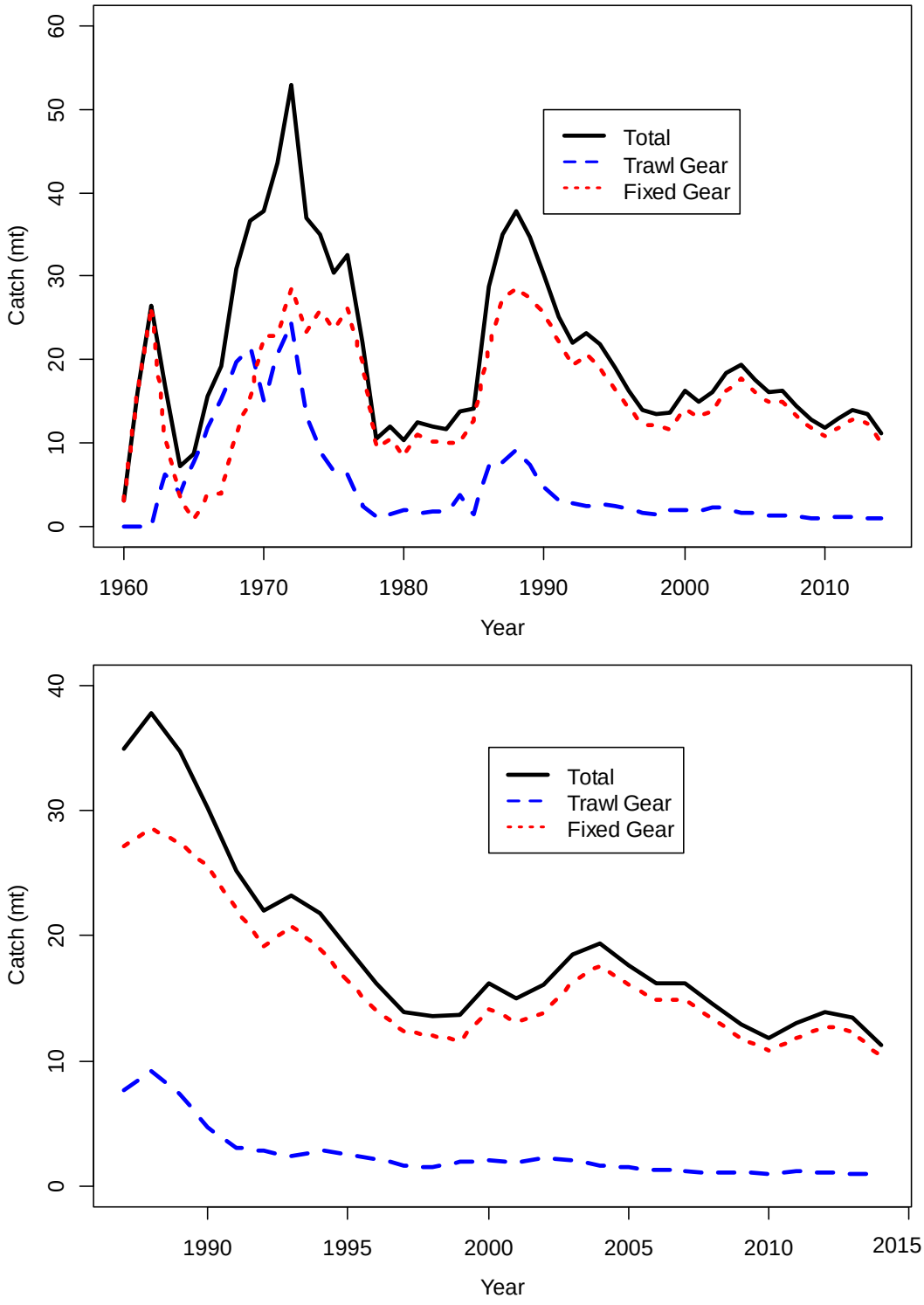

Figure 3.1. Long term and short term sablefish catch by gear type.

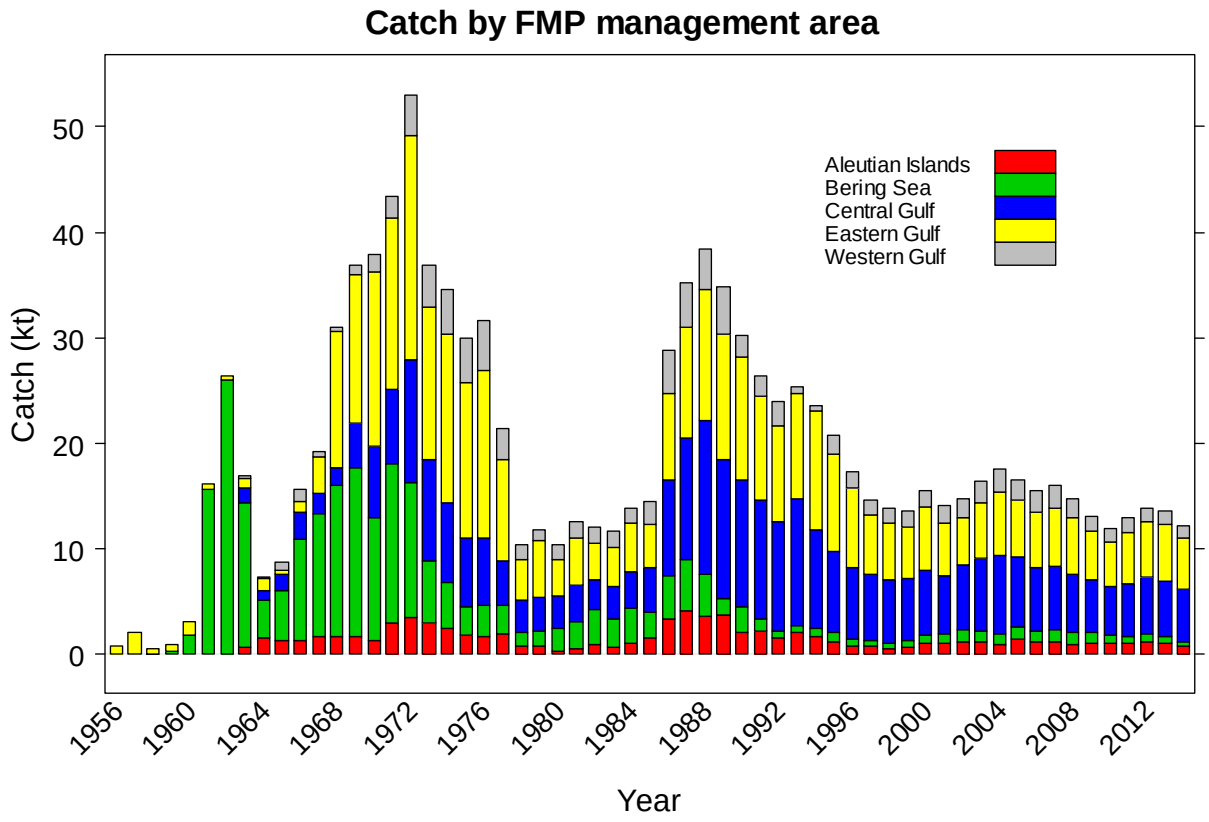

Figure 3.2. Sablefish fishery total reported catch (kt) by North Pacific Fishery Management Council area and year.

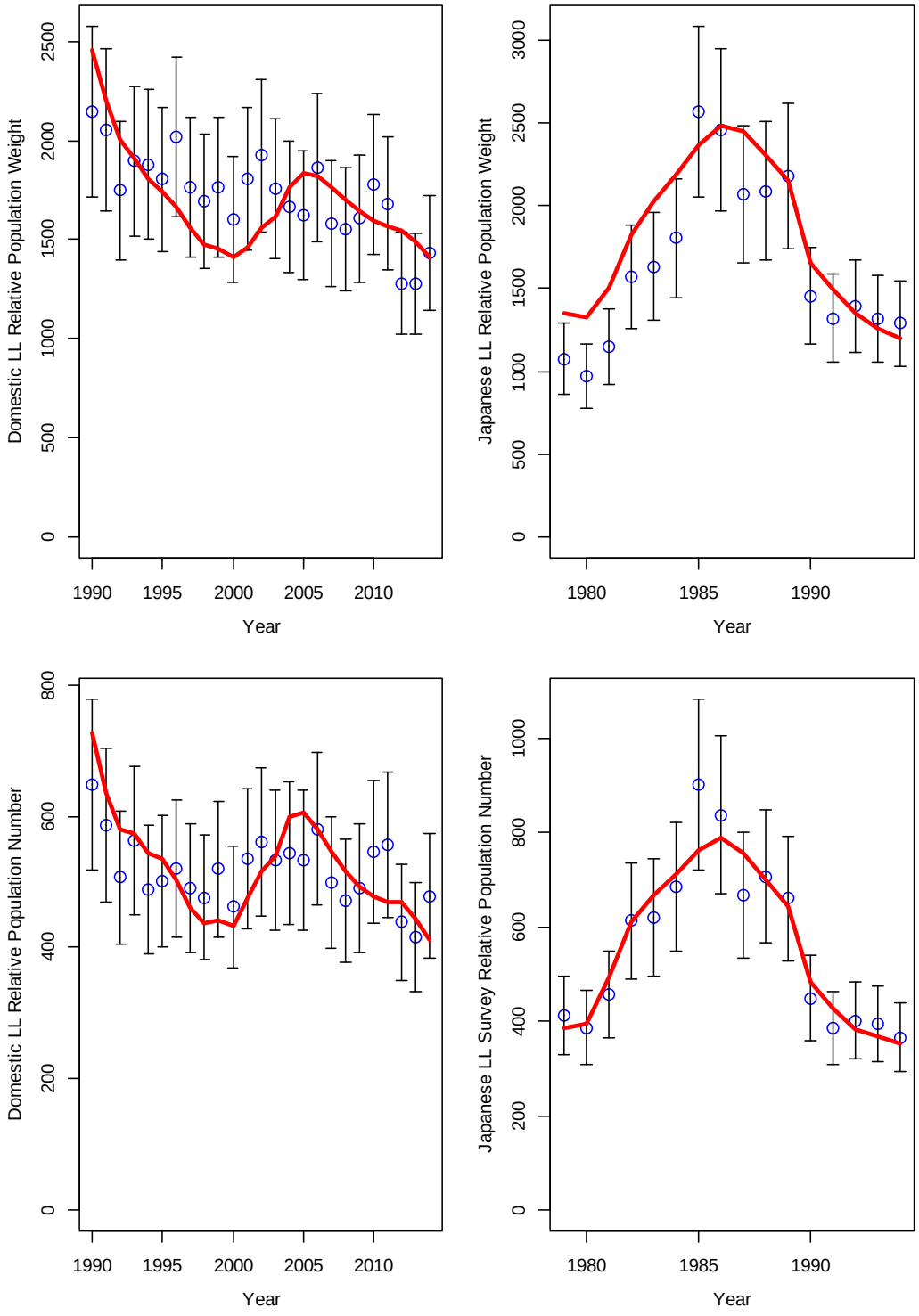

Figure 3.3. Observed and predicted sablefish relative population weight and numbers versus year. Points are observed estimates with approximate 95% confidence intervals, solid red line is model predicted. The relative population weights are not fit in the models, but are presented for comparison.

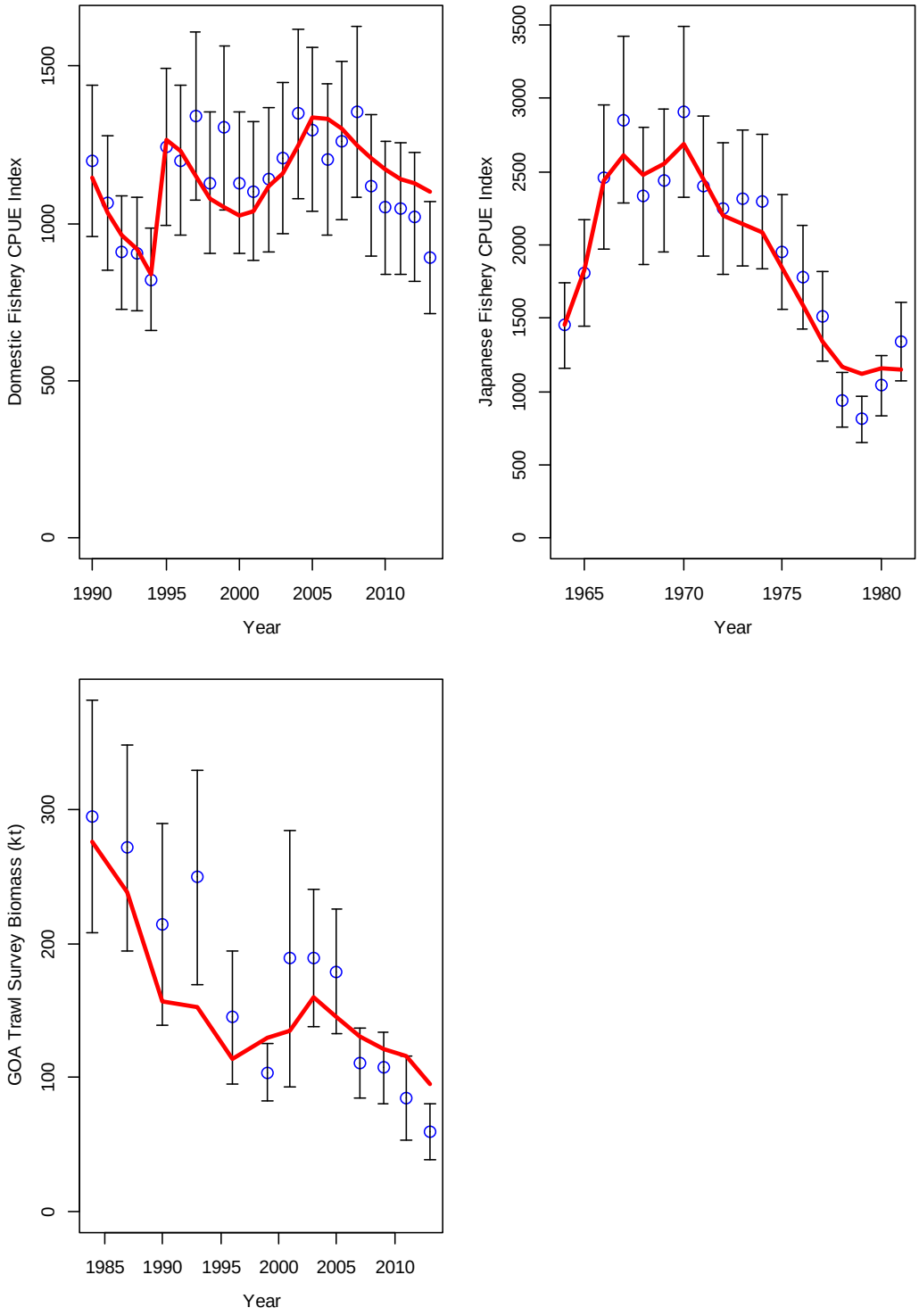

Figure 3.4. Observed and predicted sablefish abundance indices. Fishery indices are on top two panels, GOA trawl survey is on the bottom left panel. Points are observed estimates with approximate 95% confidence intervals while solid red lines are model predictions.

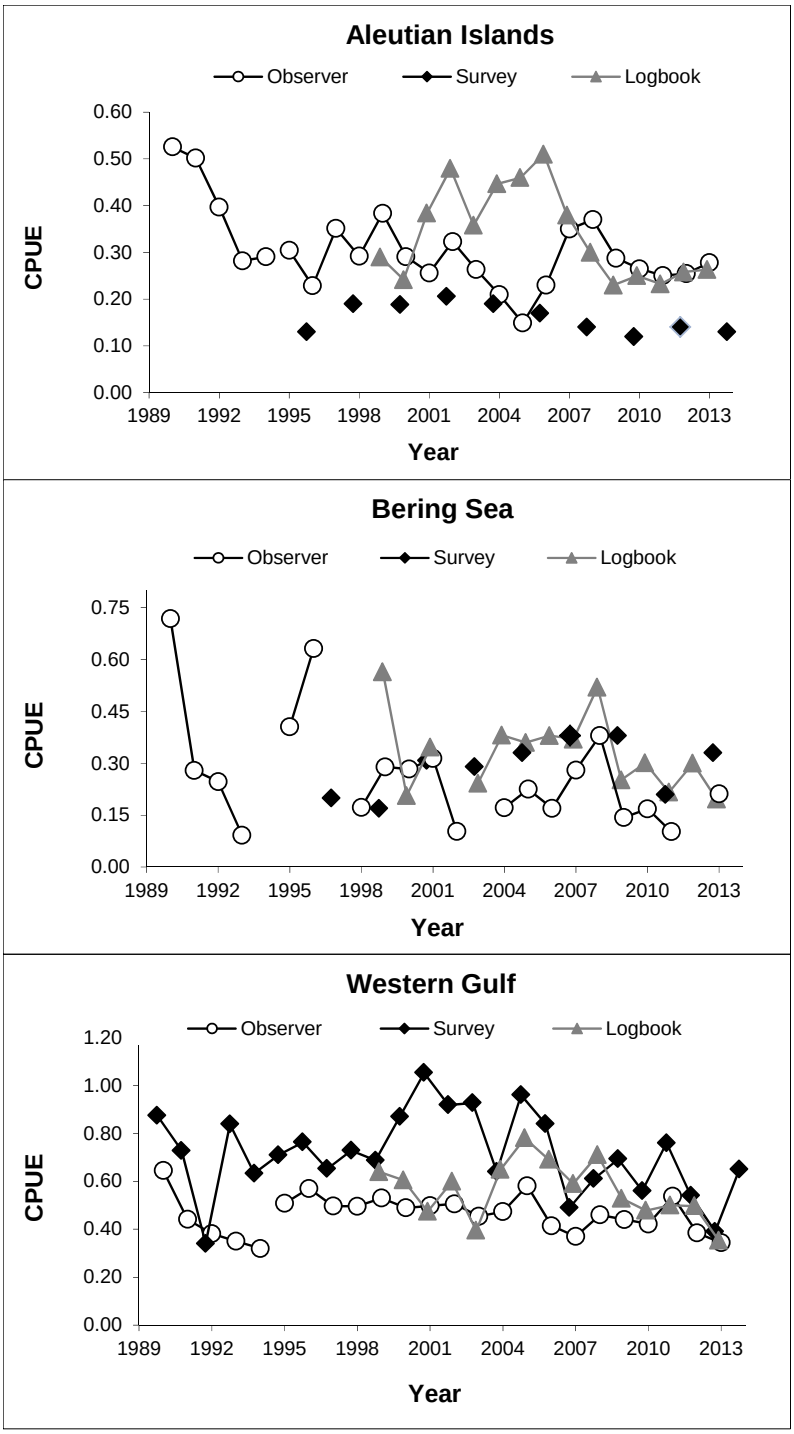

Figure 3.5. Average fishery catch rate (pounds/hook) by region and data source for longline survey and fishery data. The fishery switched from open-access to individual quota management in 1995. Data is not presented for years when there were fewer than three vessels. This occurred in observer data in the Bering Sea in 1994, 1997, 2003, and 2012, in logbook data in the Bering Sea in 2002, and in East Yakutat observer data from 1990-1994.

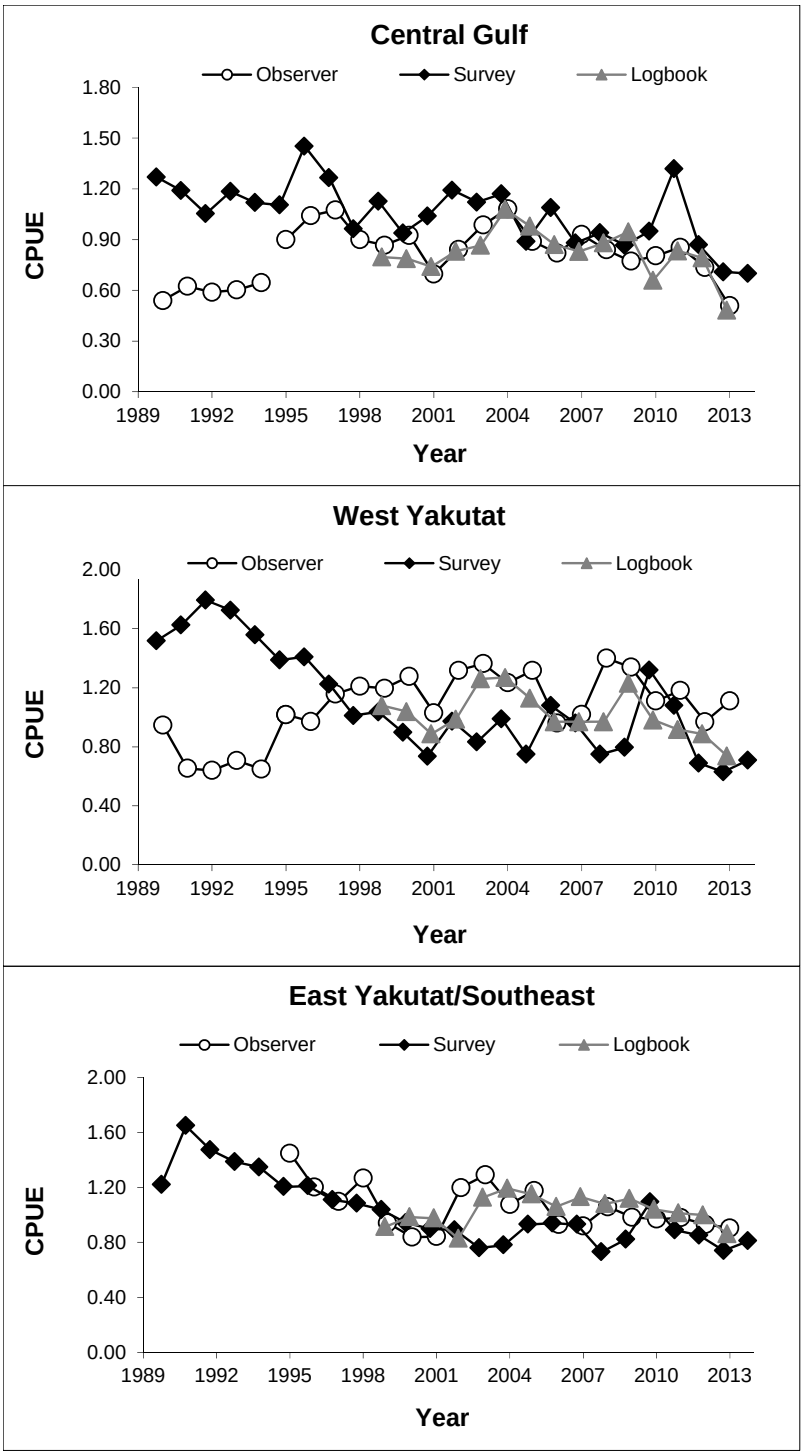

Figure 3.5. (continued)

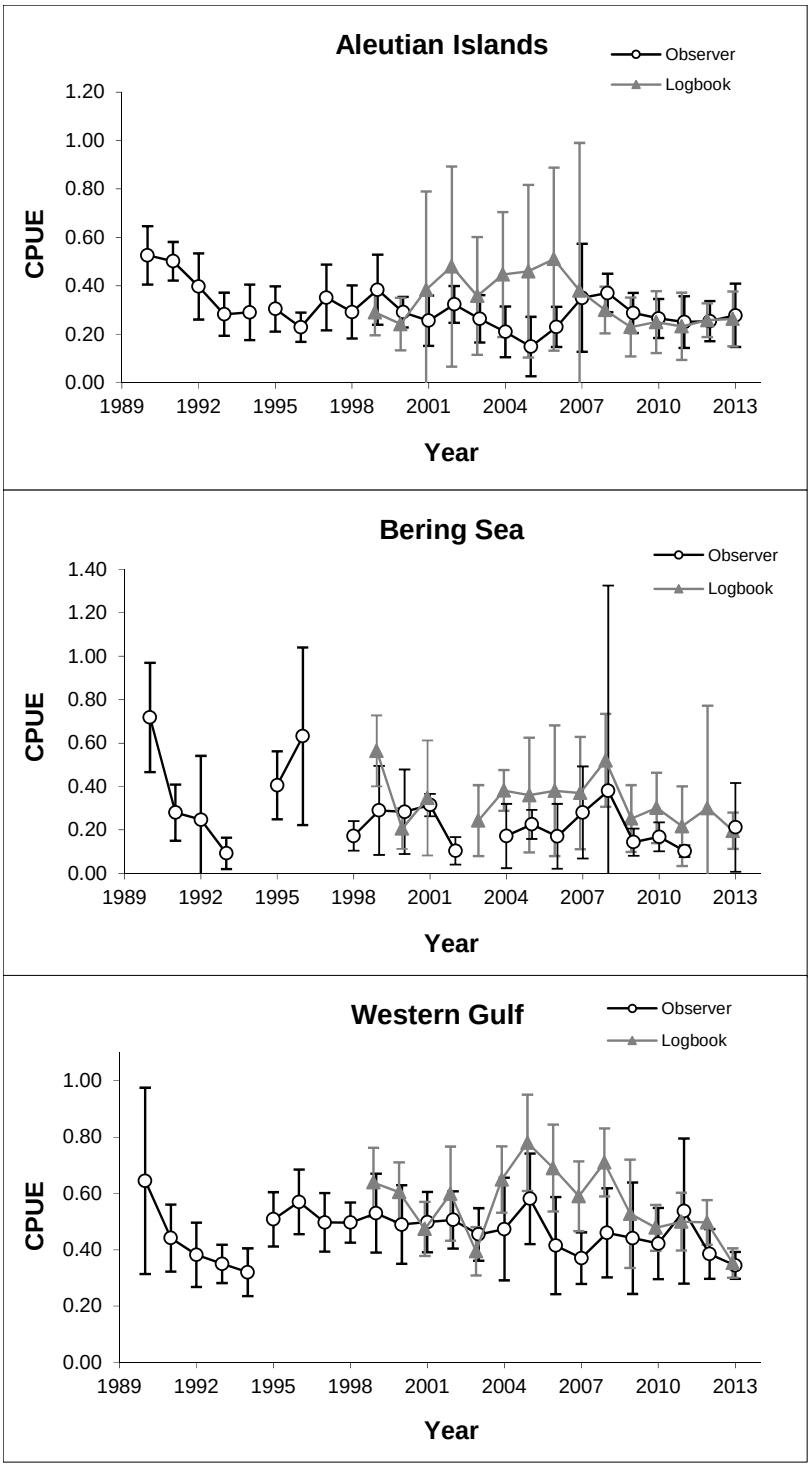

Figure 3.6. Average fishery catch rate (pounds/hook) and associated 95% confidence intervals by region and data source. The fishery switched from open-access to individual quota management in 1995. Data is not presented for years when there were fewer than three vessels. This occurred in observer data in the Bering Sea in 1994, 1997, 2003, and 2012, in logbook data in the Bering Sea in 2002, and in East Yakutat observer data from 1990-1994.

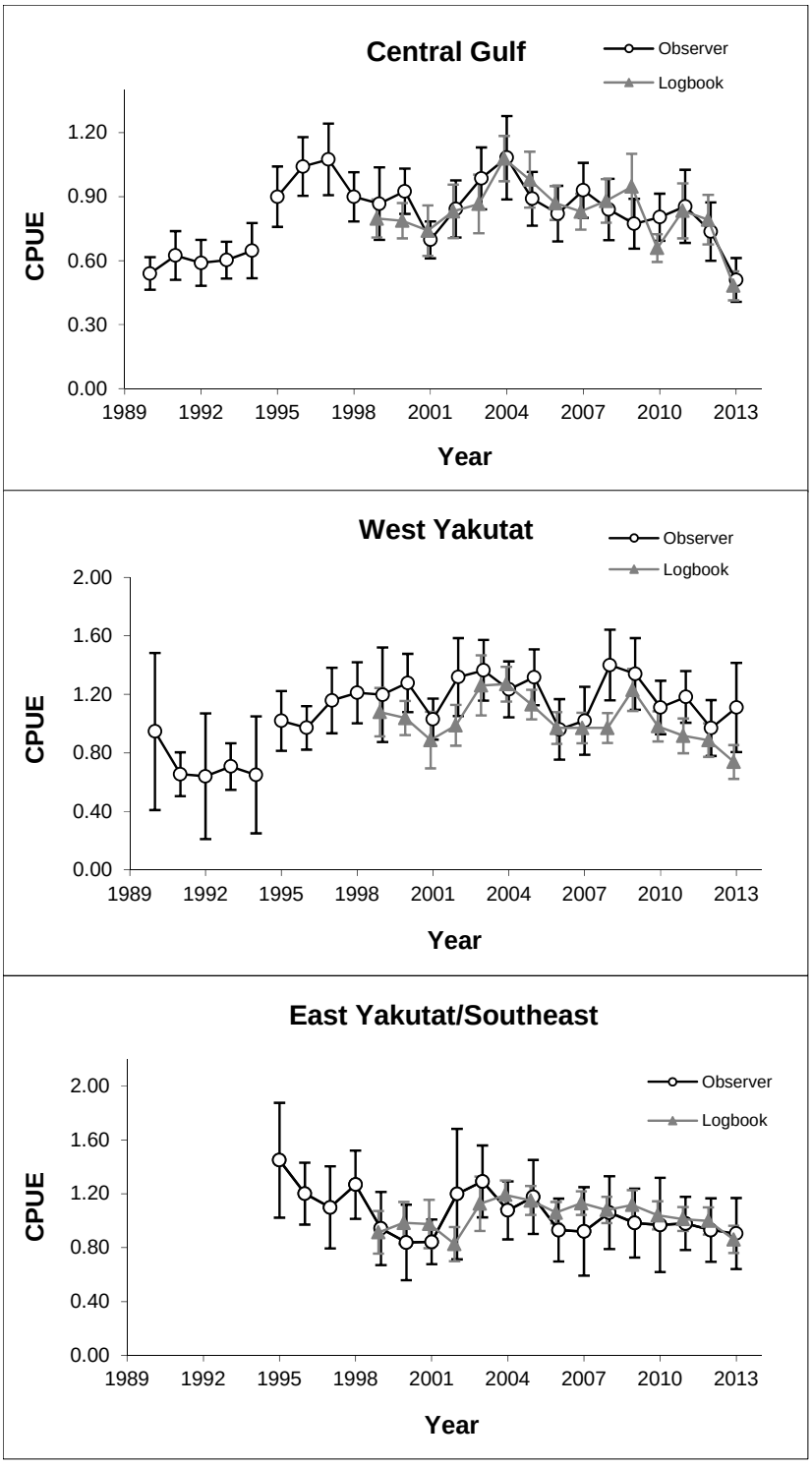

Figure 3.6. (continued)

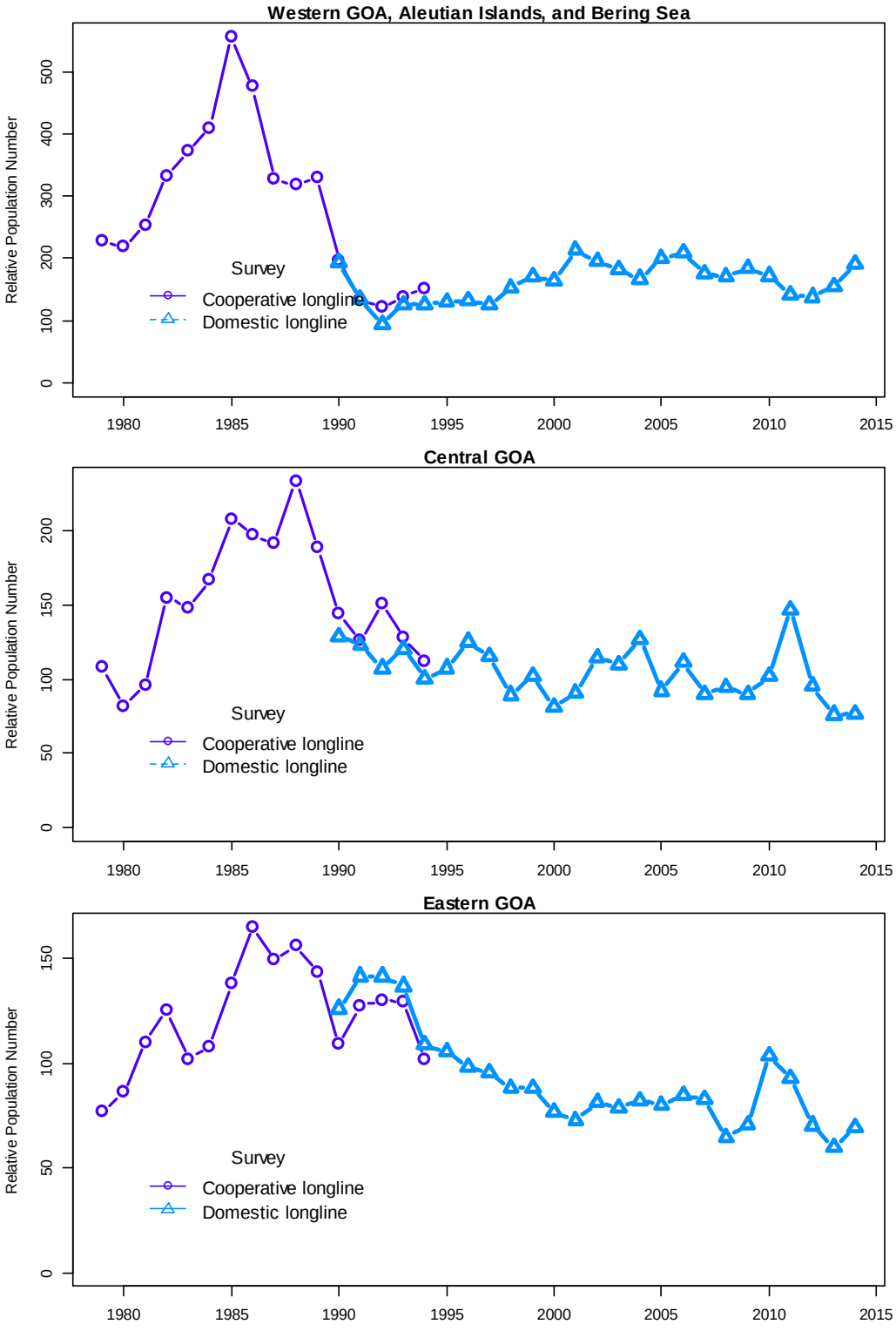

Figure 3.7. Relative abundance (numbers) by region and survey. The regions Bering Sea, Aleutians Islands, and western Gulf of Alaska are combined in the first plot. The two surveys are the Japan-U.S. cooperative longline survey and the domestic (U.S.) longline survey. In this plot, the values for the U.S. survey were adjusted to account for the higher efficiency of the U.S. survey gear.

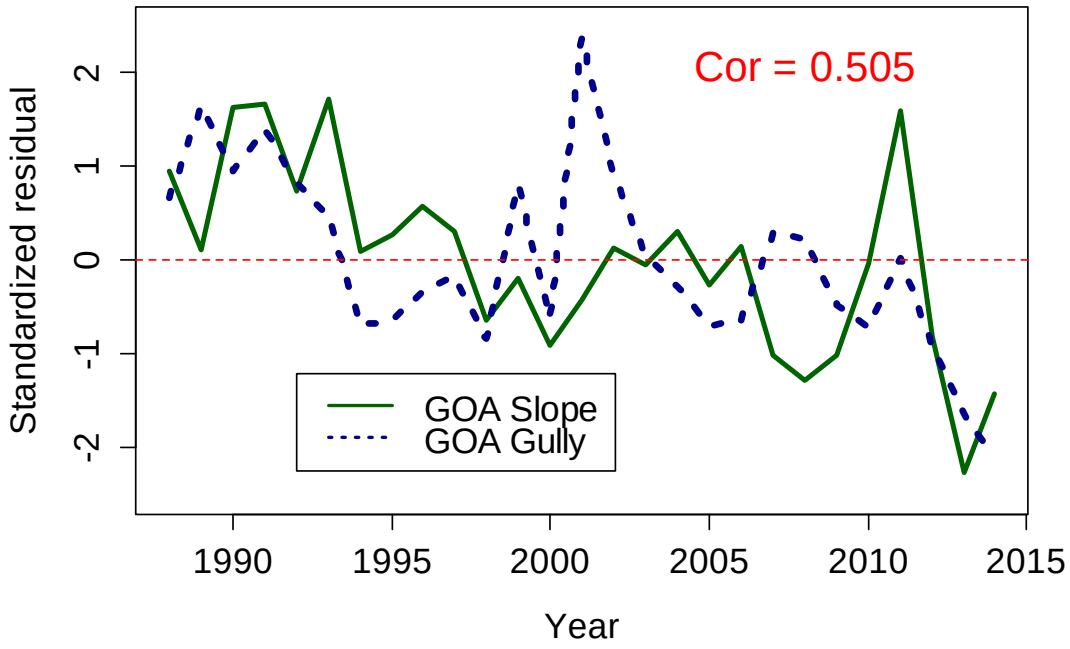

Figure 3.8 Comparison of abundance trends in GOA gully stations versus GOA slope stations.

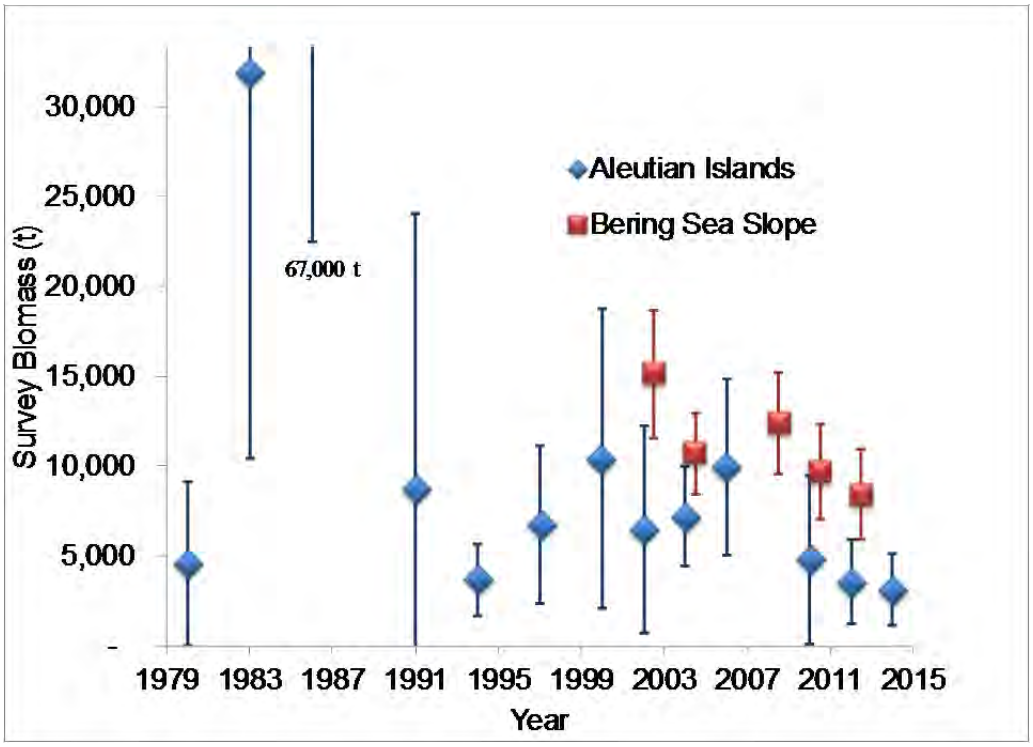

Figure 3.9. NMFS Bering Sea Slope and Aleutian Island trawl survey biomass estimates. Bering Sea Slope years are jittered so that intervals do not overlap.

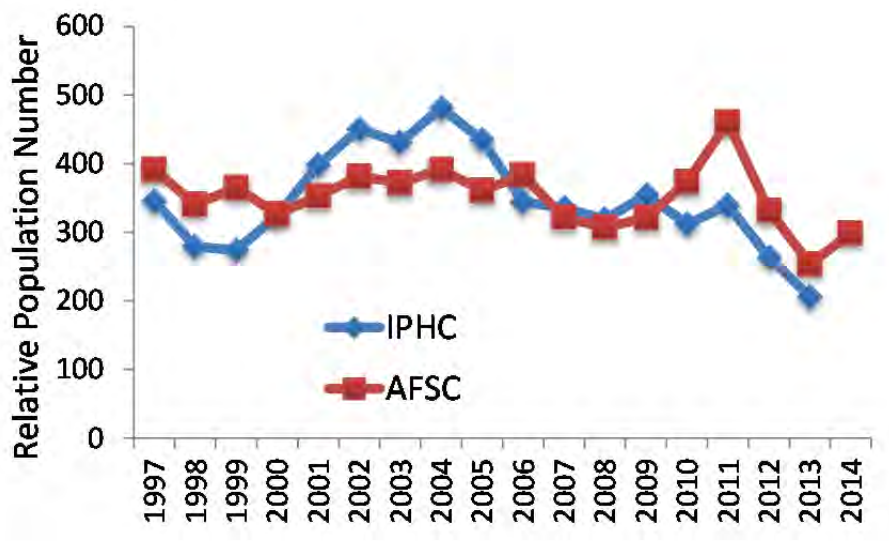

Figure 3.10. Comparisons of IPHC and AFSC longline survey trends in relative population number of sablefish in the Gulf of Alaska.

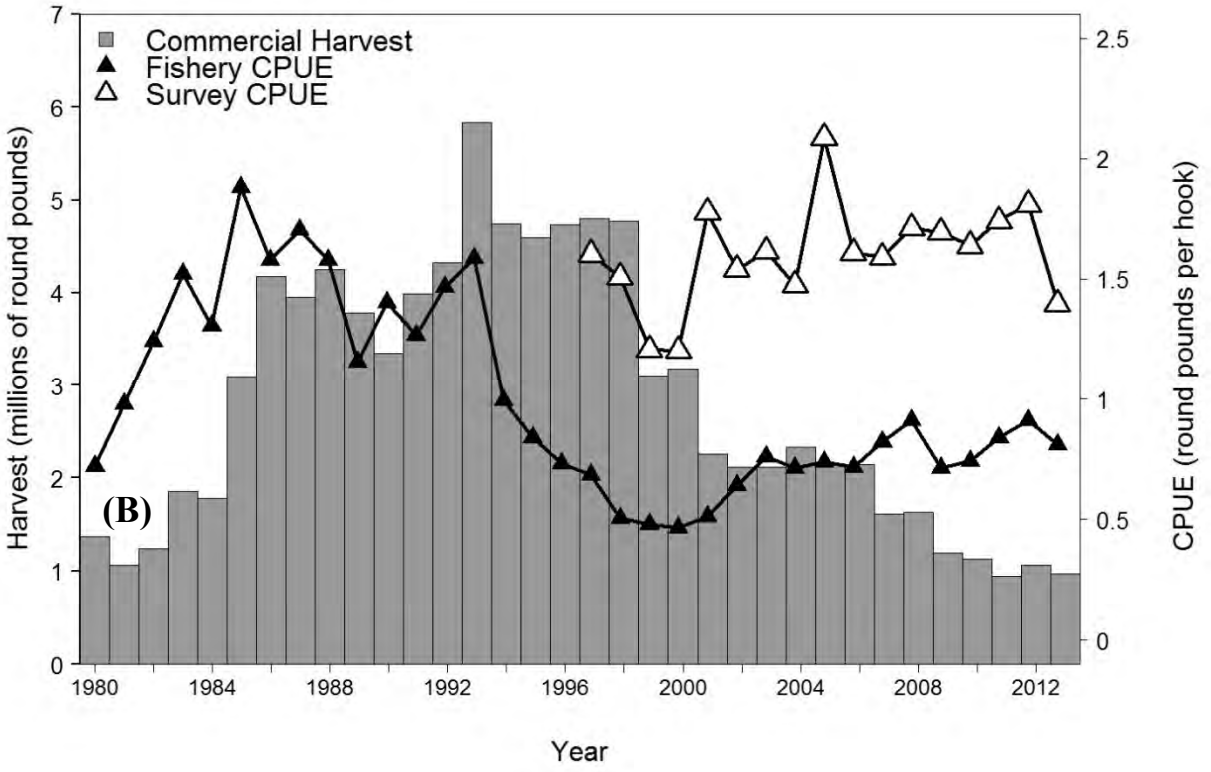

Figure 3.11a. Northern Southeast Inside sablefish long line survey and fishery catch per unit effort (round pounds per hook) and harvest over time (from J. Stahl pers. comm. November, 2014).

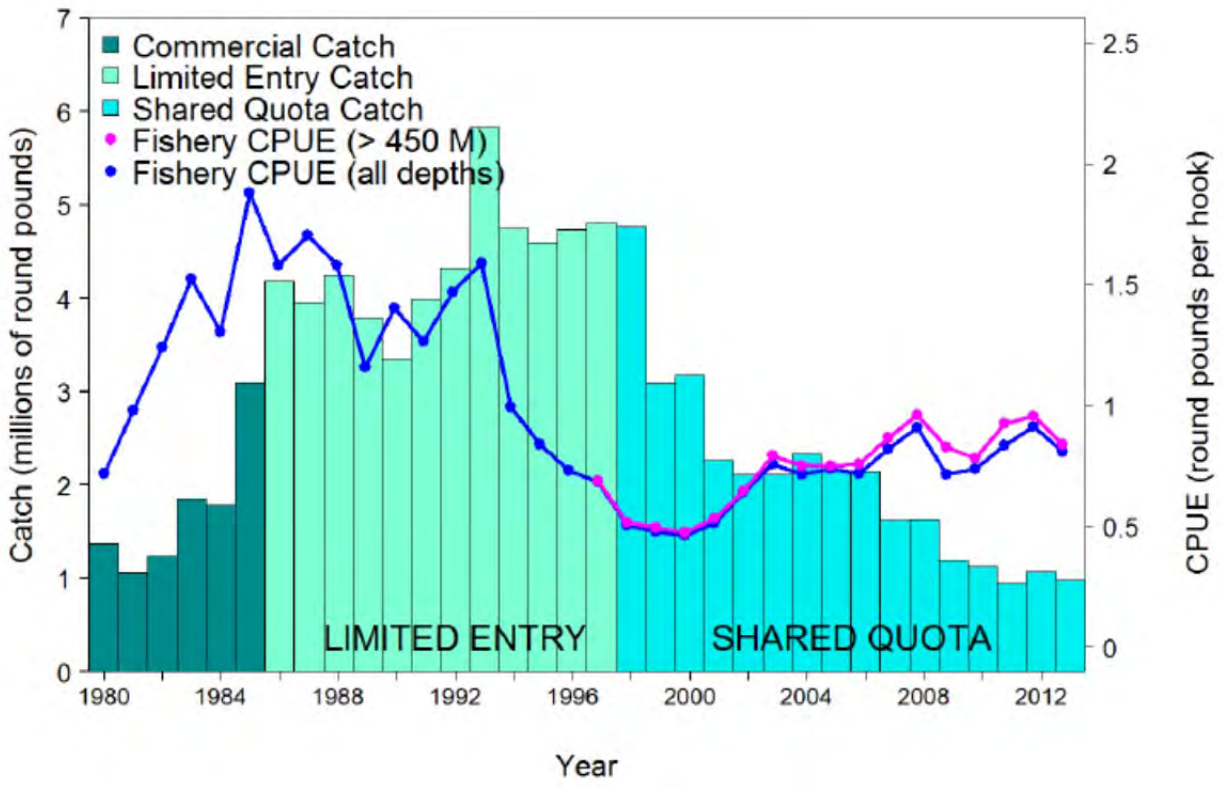

Figure 3.11b. Northern Southeast Inside sablefish long line fishery catch per unit effort (round pounds per hook) and harvest over time (from K. Green pers. comm. September, 2014).

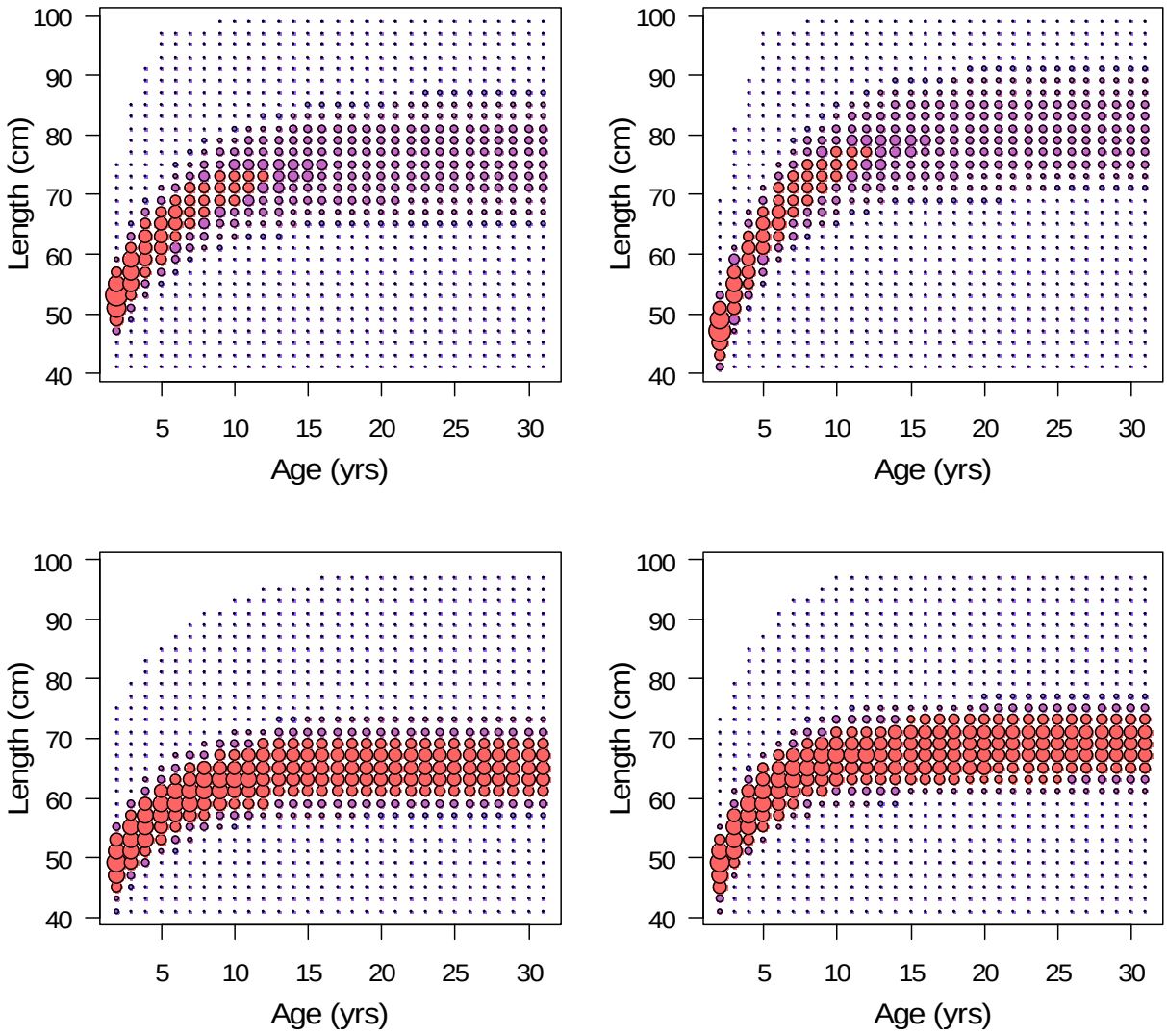

Figure 3.12. Age-length conversion matrices for sablefish. Top panels are female, bottom panel are males, left is 1960-1995, and right is 1996-2014.

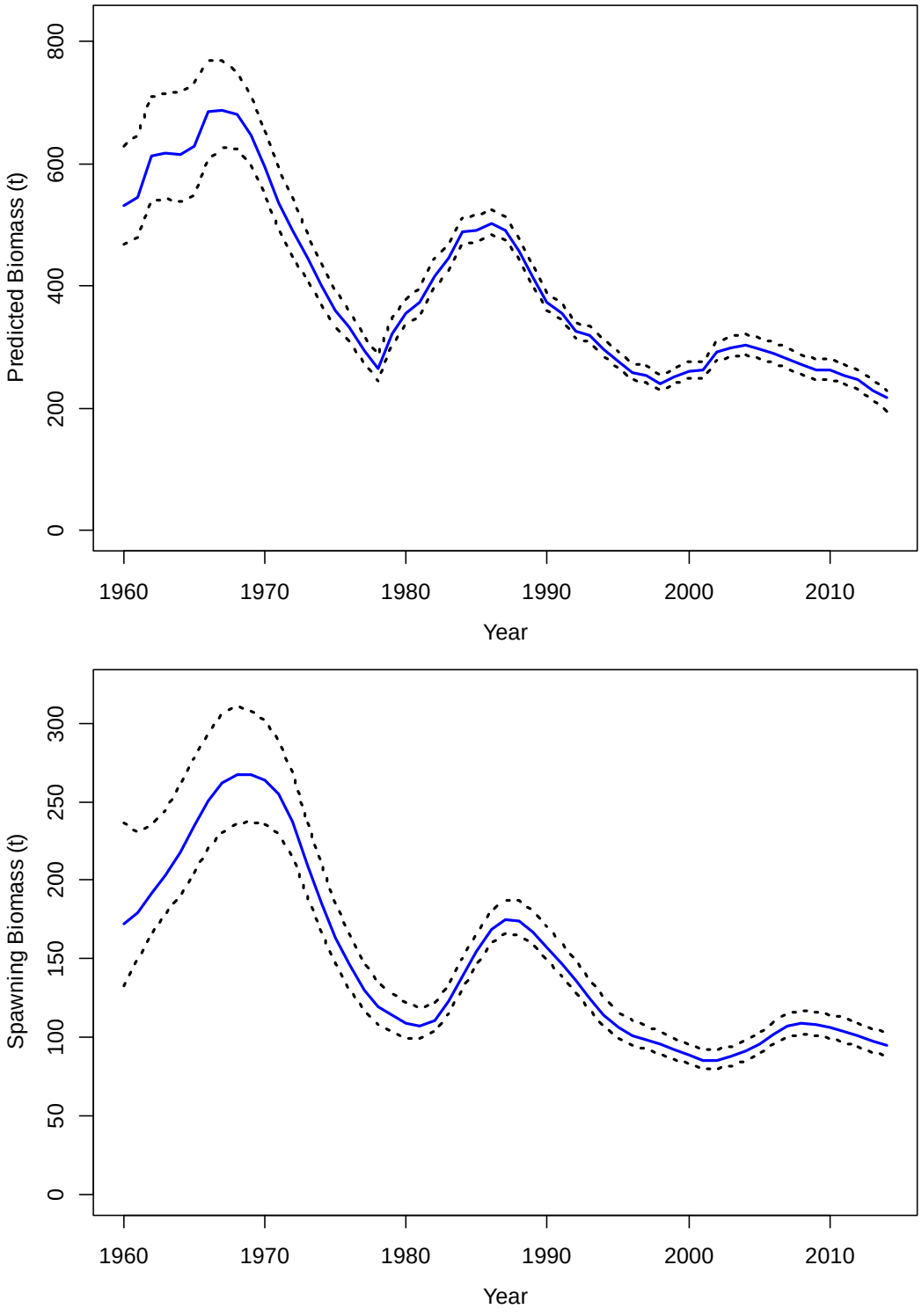

Figure 3.13.--Estimated sablefish total biomass (thousands t) and spawning biomass (bottom) with 95% MCMC credible intervals.

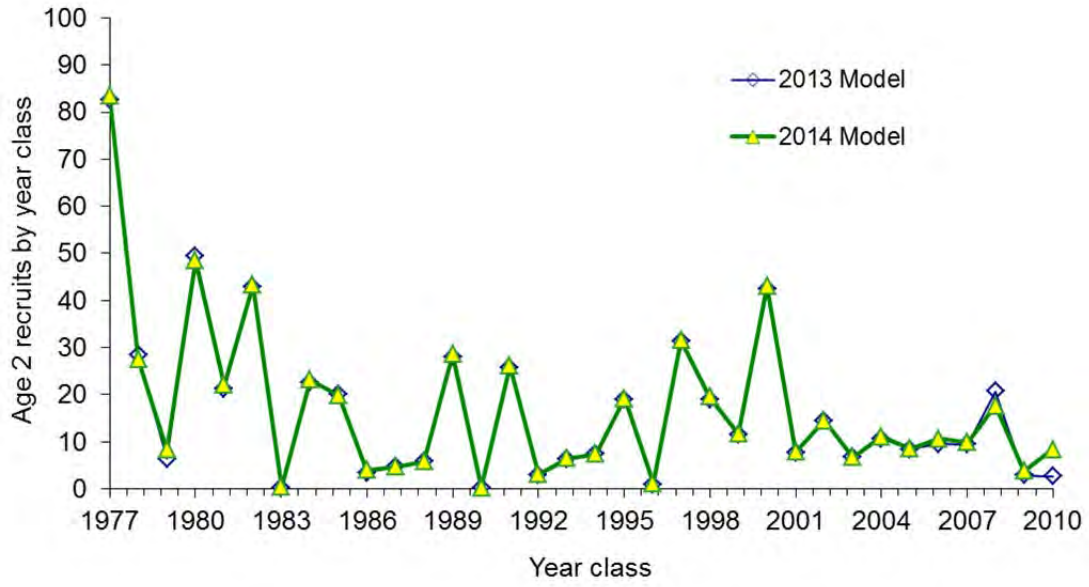

Figure 3.14a. Estimated recruitment by year class 1958-2011 (number at age 2, millions) for 2013 and 2014 models.

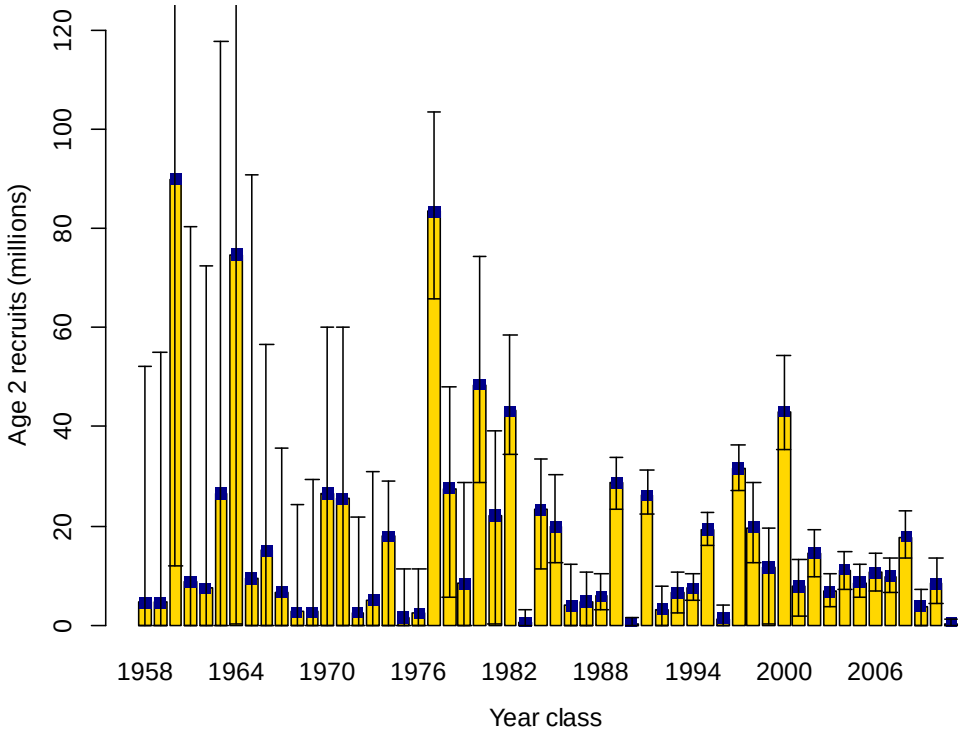

Figure 3.14b. Estimates of the number of age-2 sablefish (millions) with 95% credible intervals by year class. Credible intervals are based on MCMC posterior.

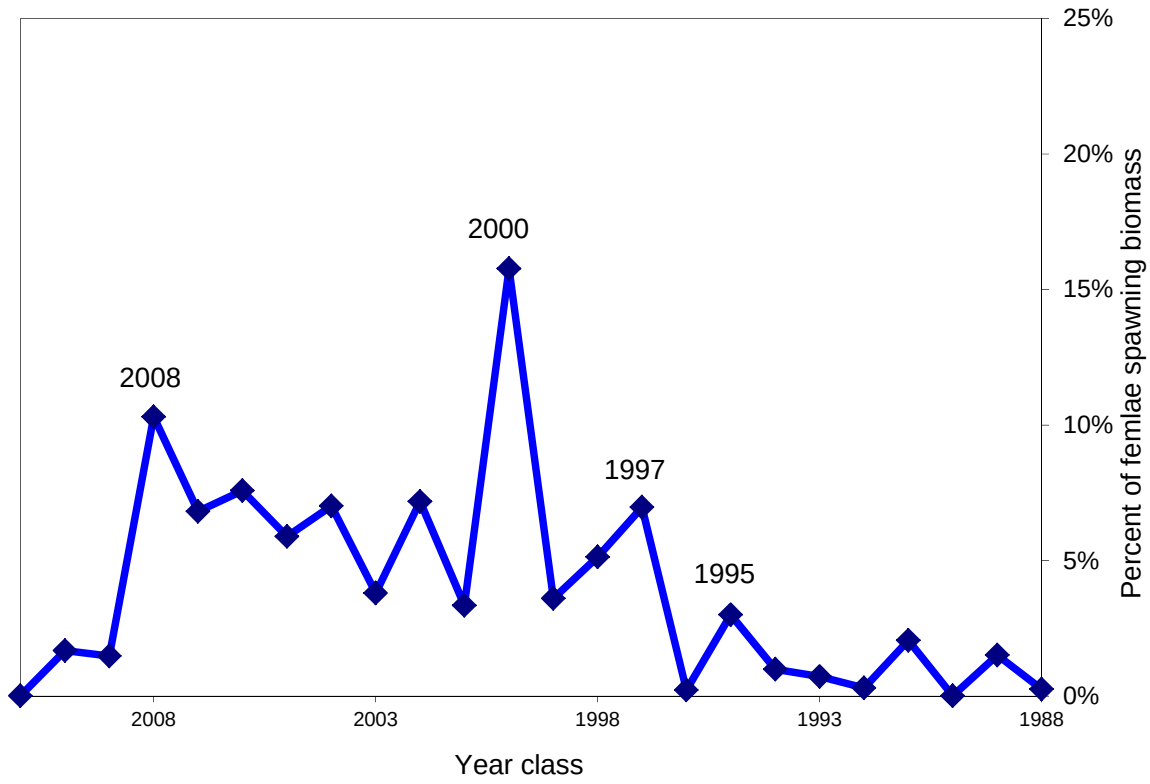

Figure 3.15. Relative contribution of the last 20 year classes to next year's female spawning biomass.

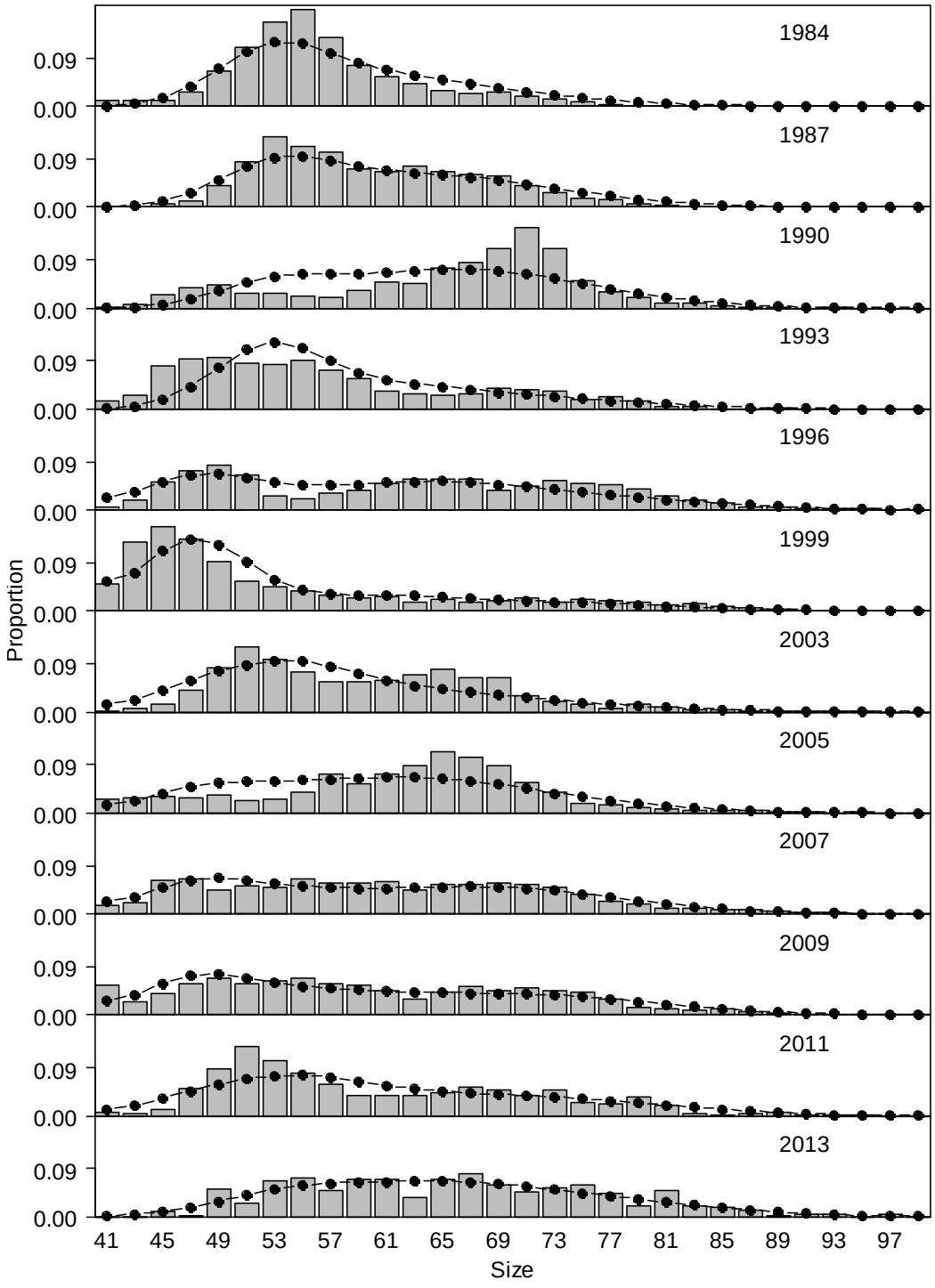

Figure 3.16. Gulf of Alaska bottom trawl survey length (cm) compositions for female sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

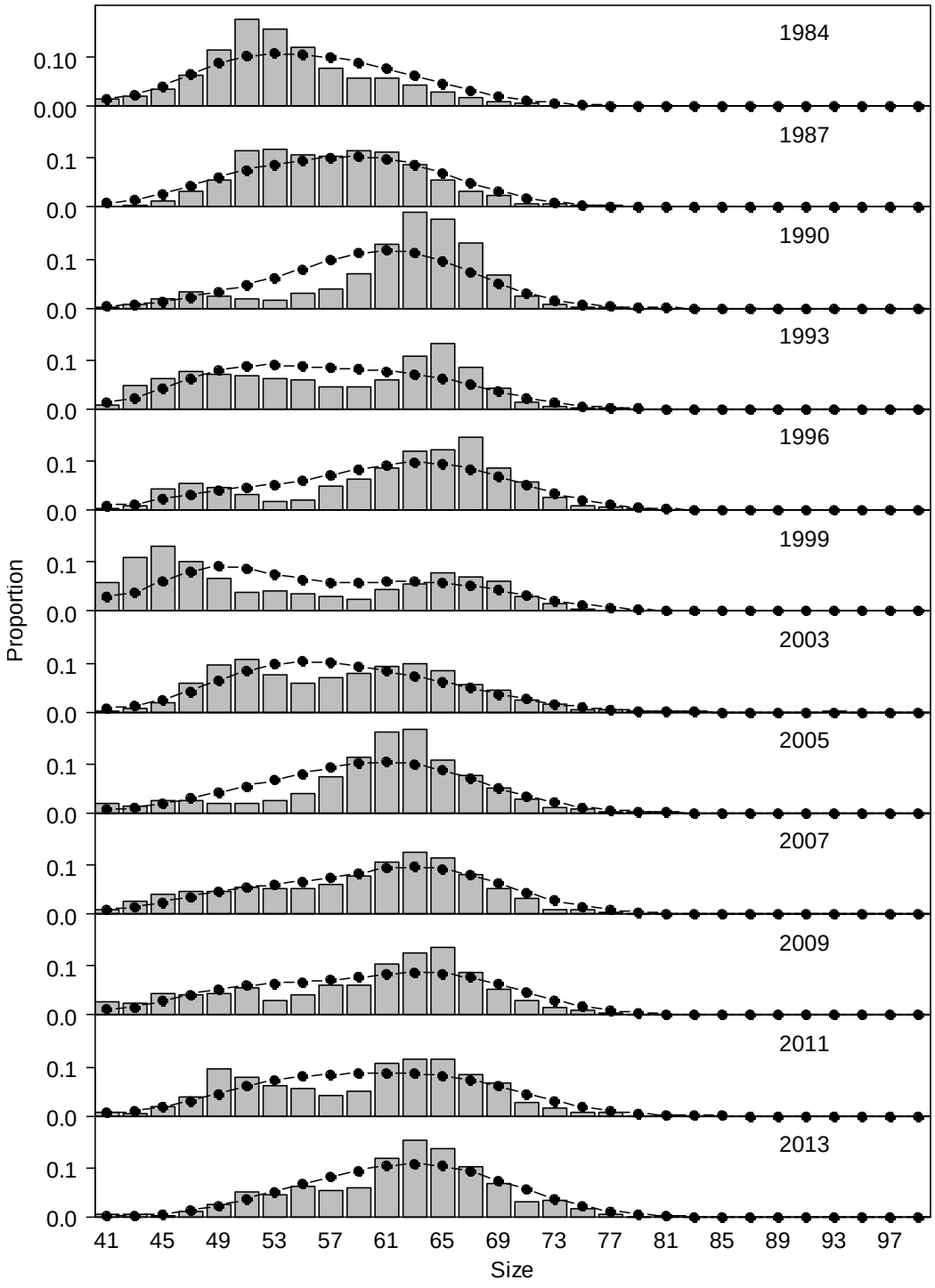

Figure 3.17. Gulf of Alaska bottom trawl survey length (cm) compositions for male sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

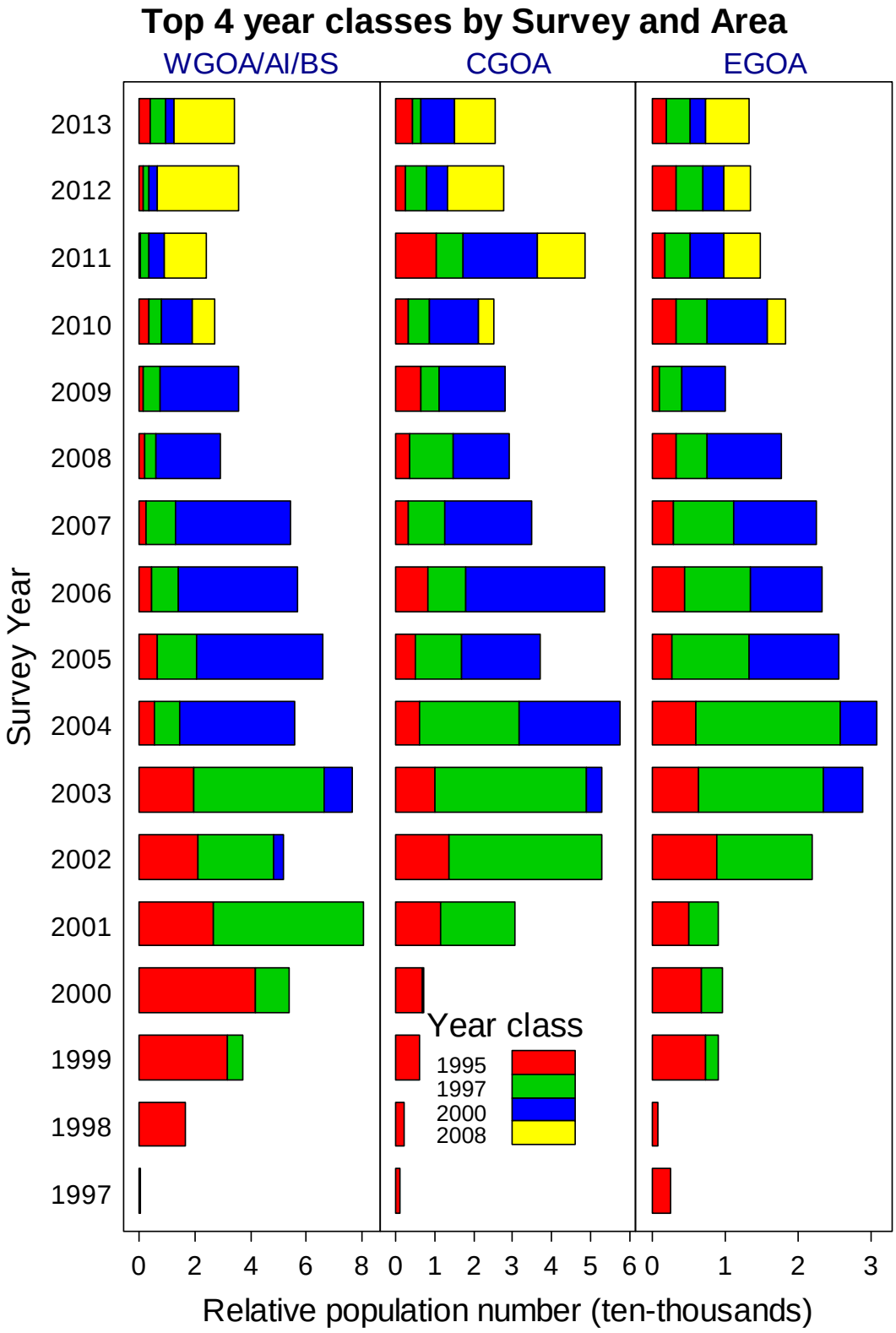

Figure 3.18. Above average 1995, 1997, 2000 and potential above-average 2008 year classes relative population abundance in each survey year and area.

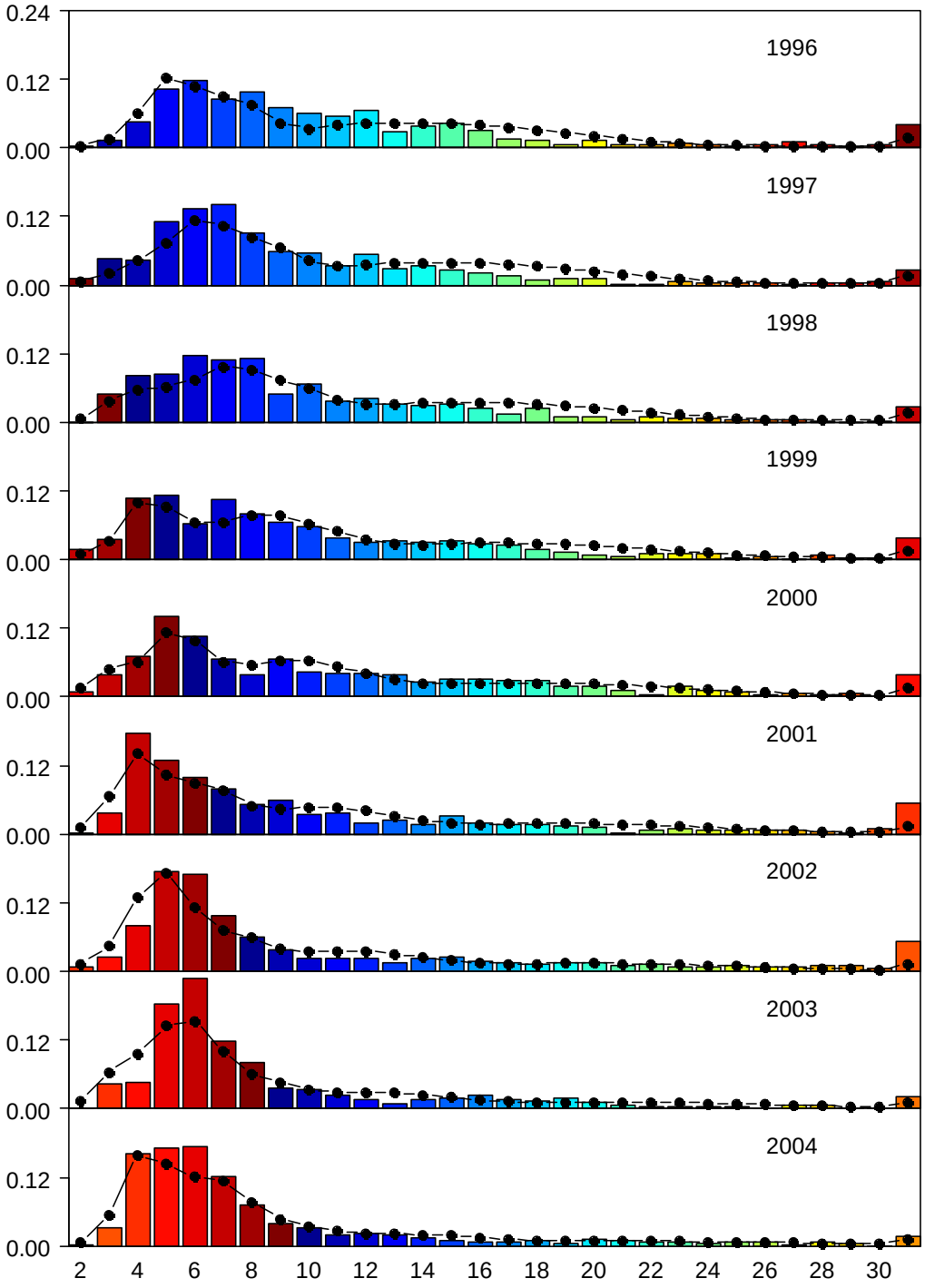

Figure 3.19. Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

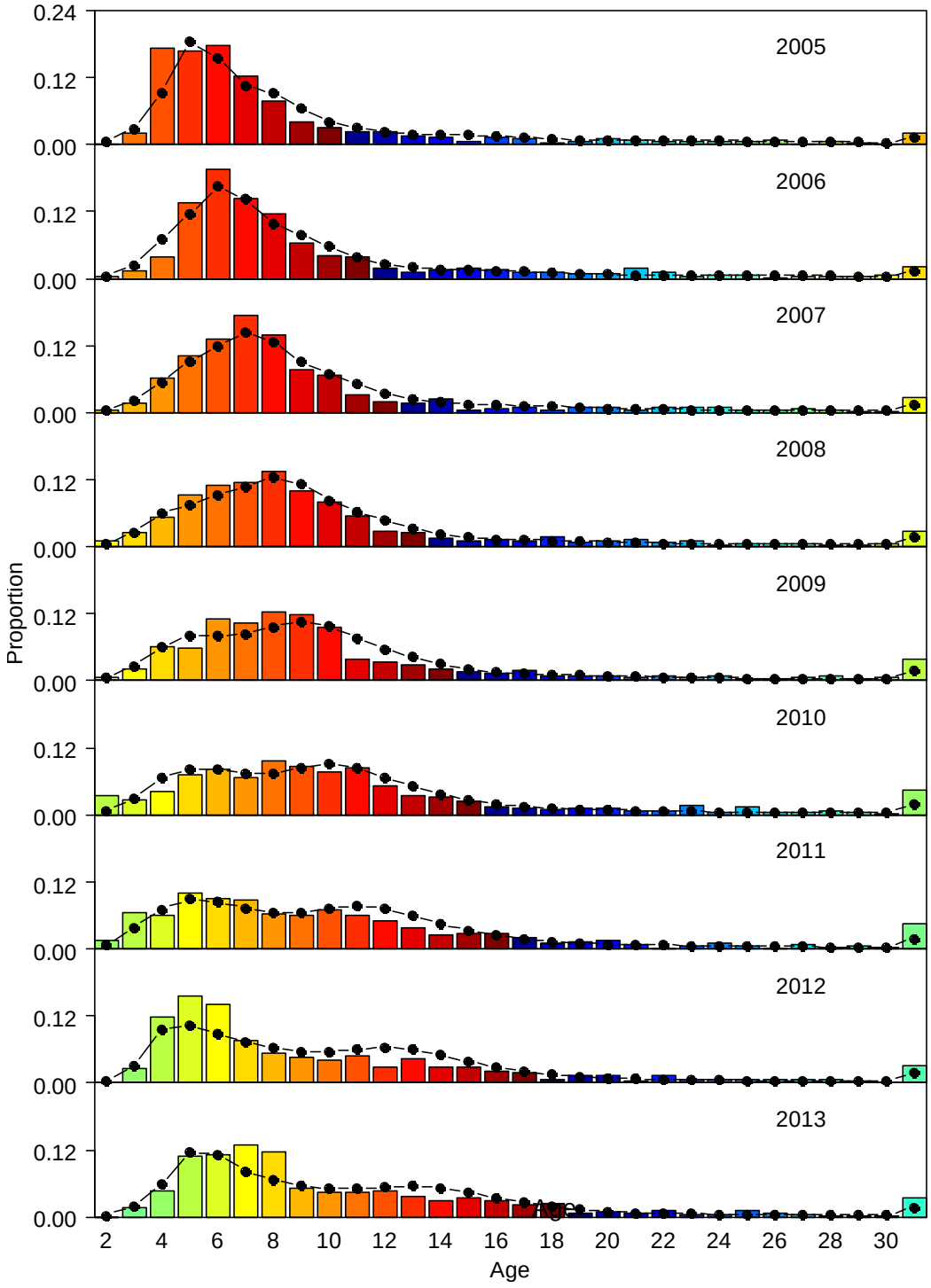

Figure 3.19 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

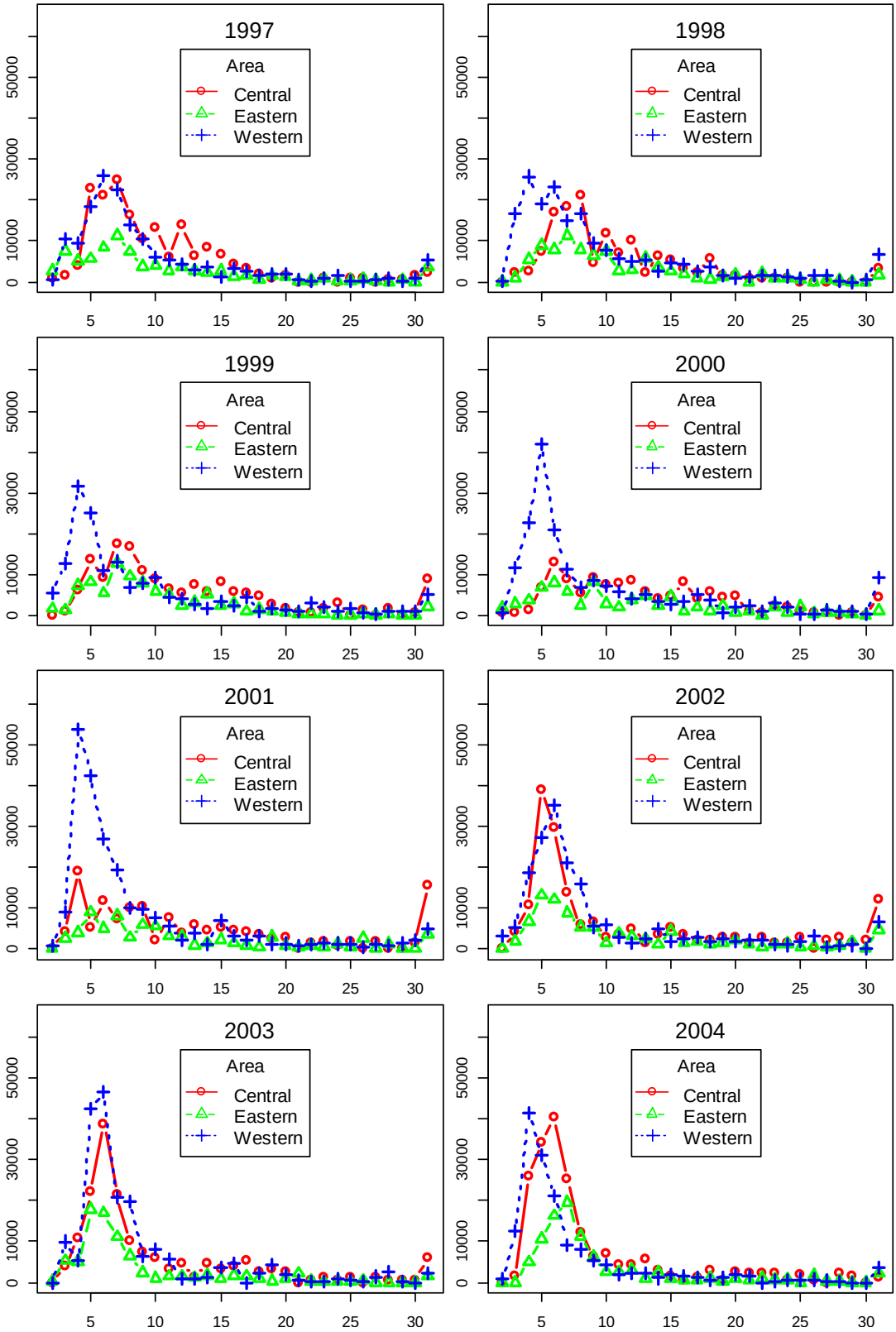

Figure 3.20. Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

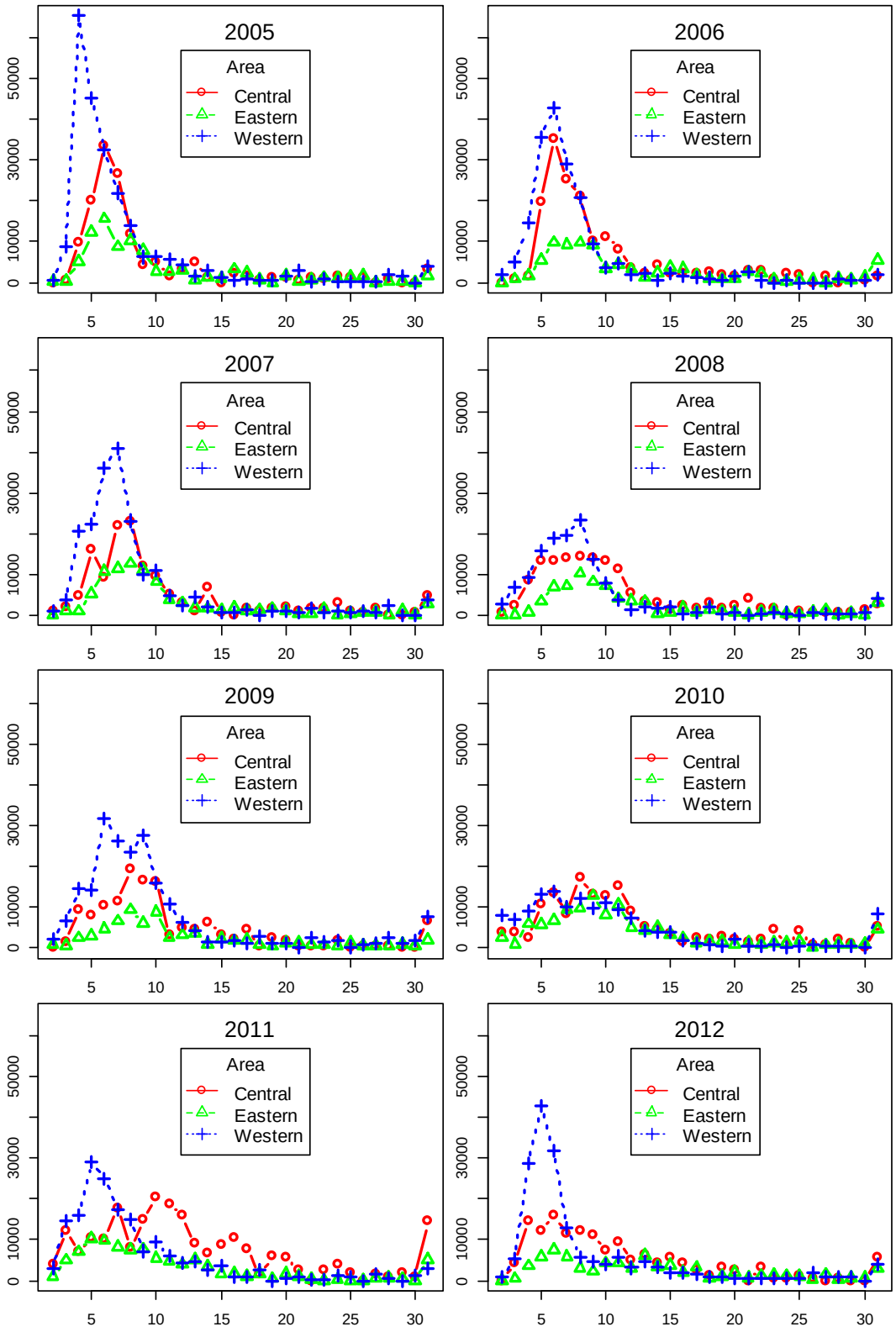

Figure 3.20 (cont.). Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

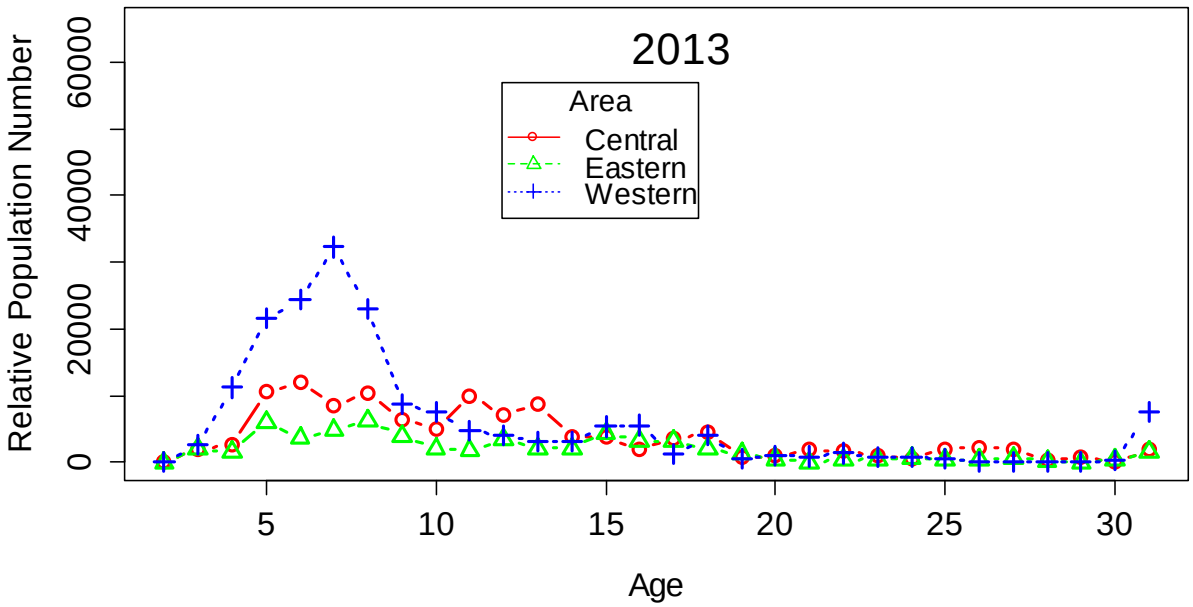

Figure 3.20 (cont.). Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

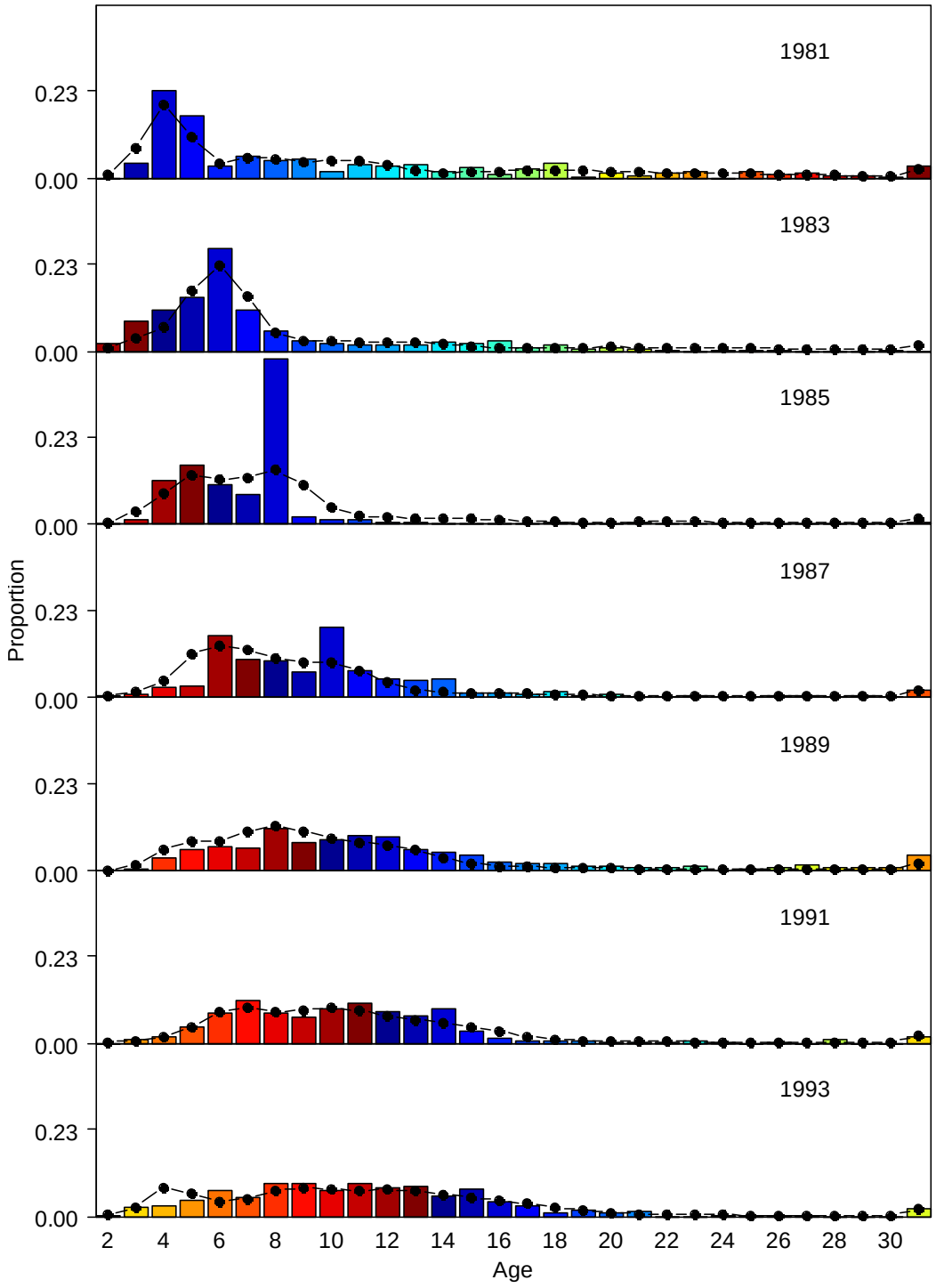

Figure 3.21. Japanese longline survey age compositions. Bars are observed frequencies and line is predicted frequencies.

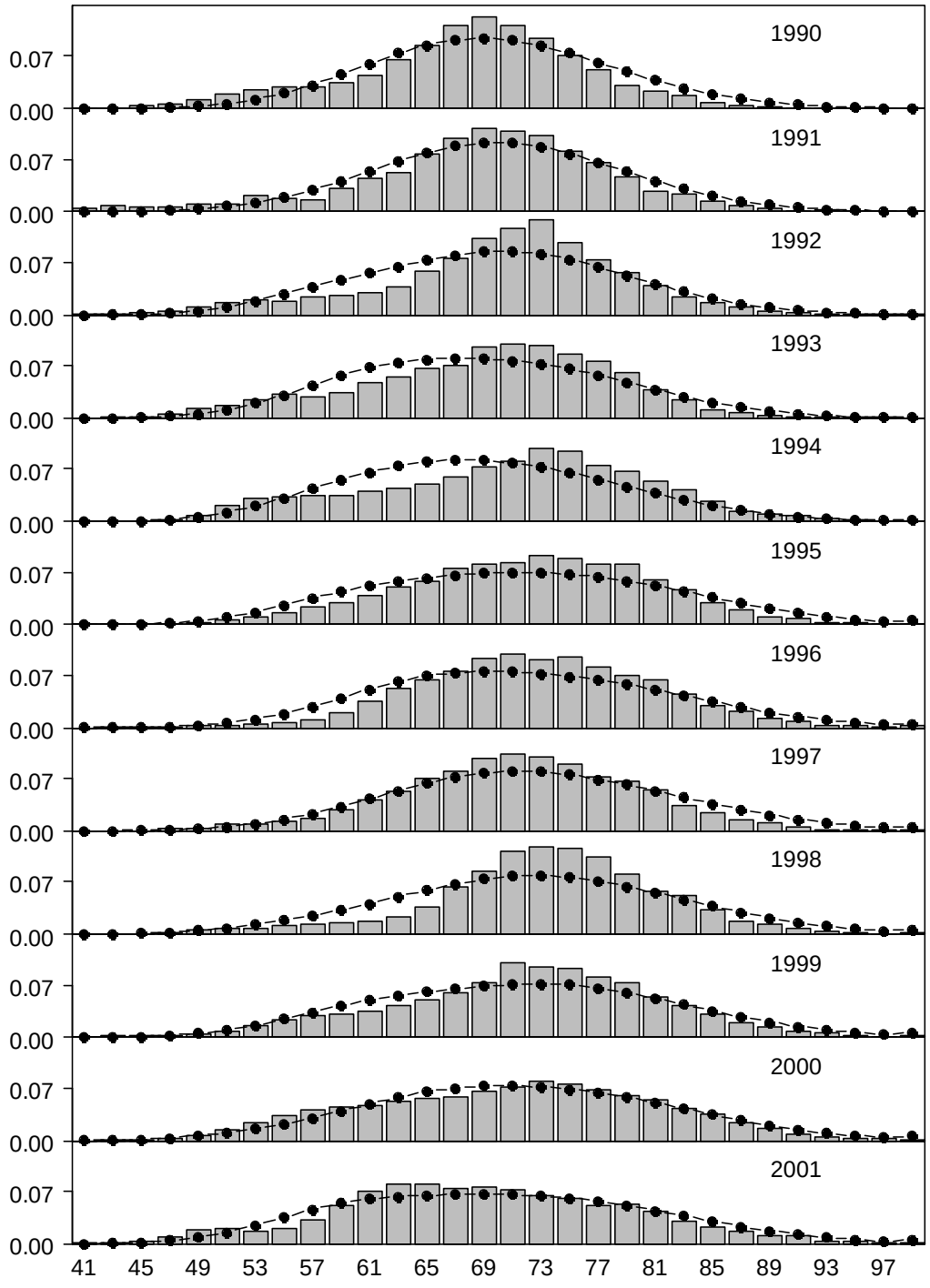

Figure 3.22. Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

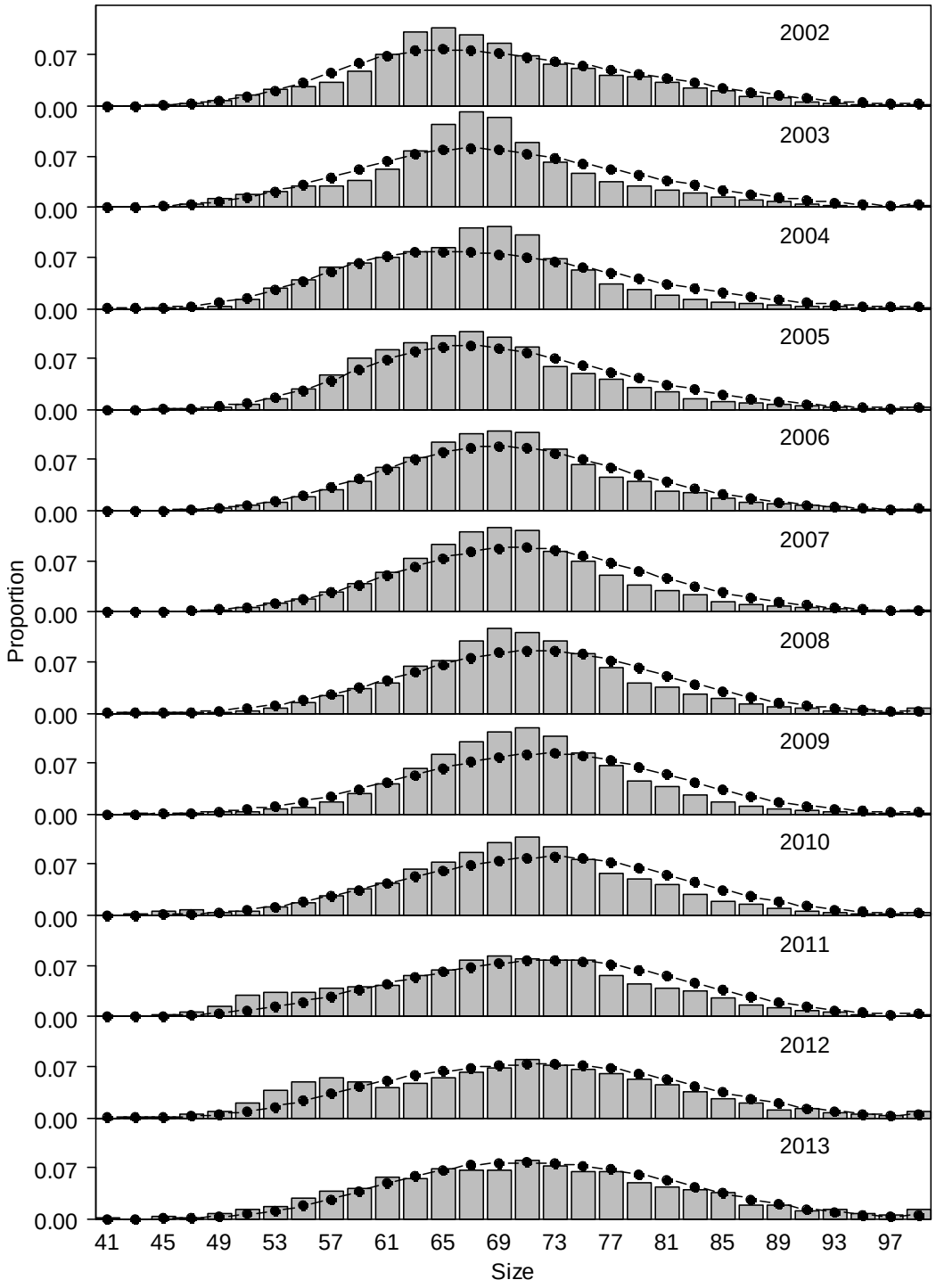

Figure 3.22 (cont.). Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

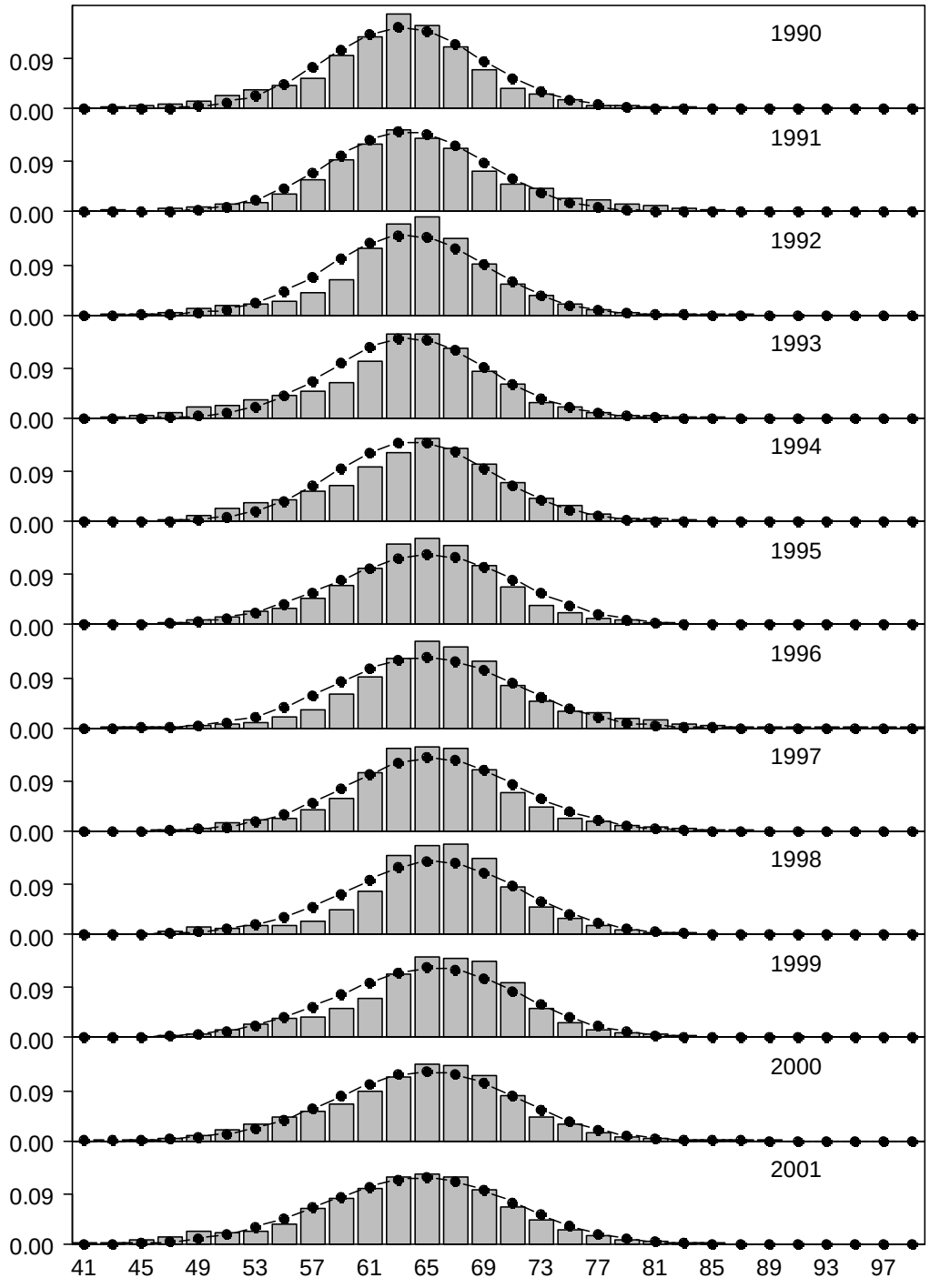

Figure 3.23. Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

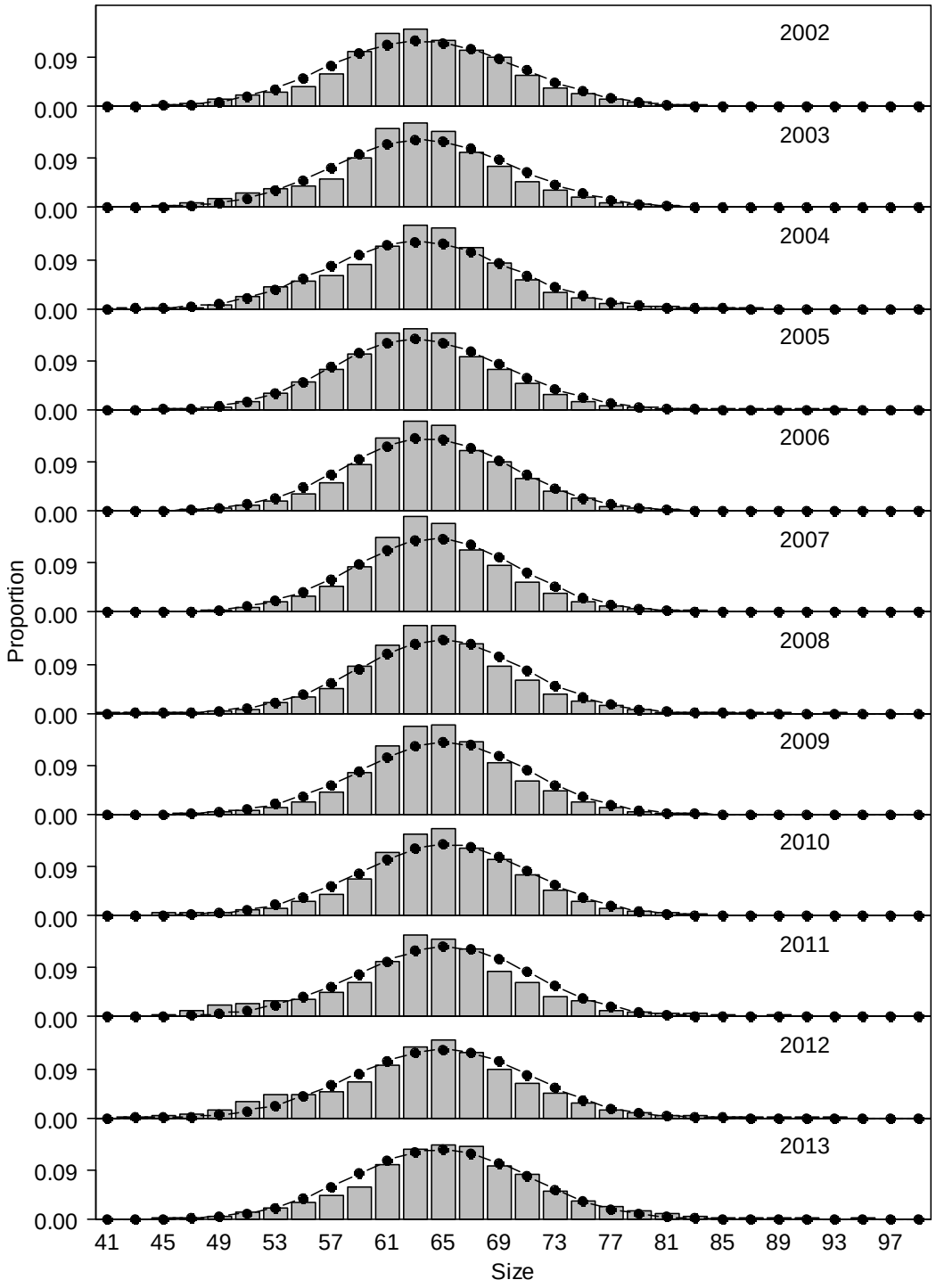

Figure 3.23 (cont.). Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

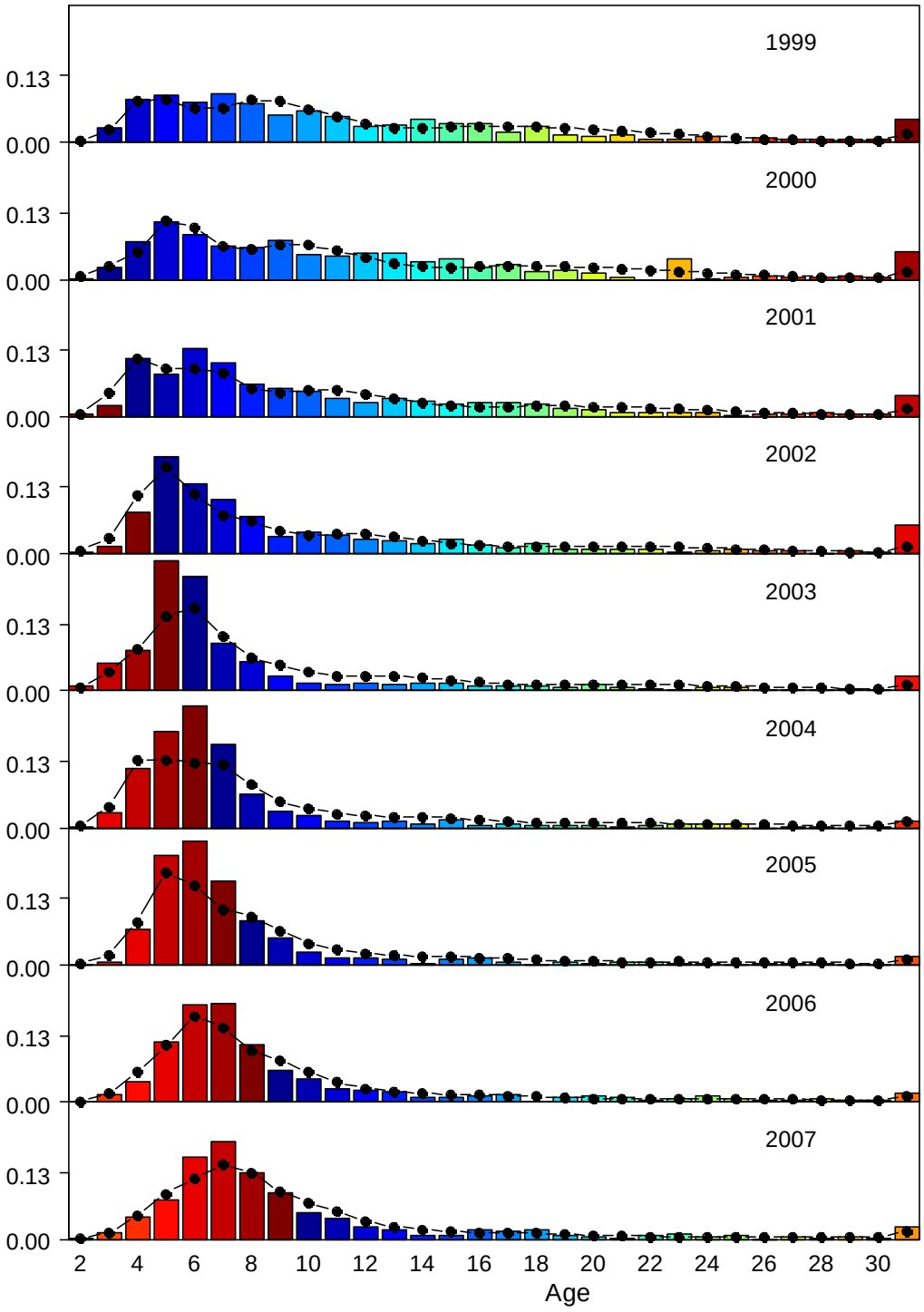

Figure 3.24. Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

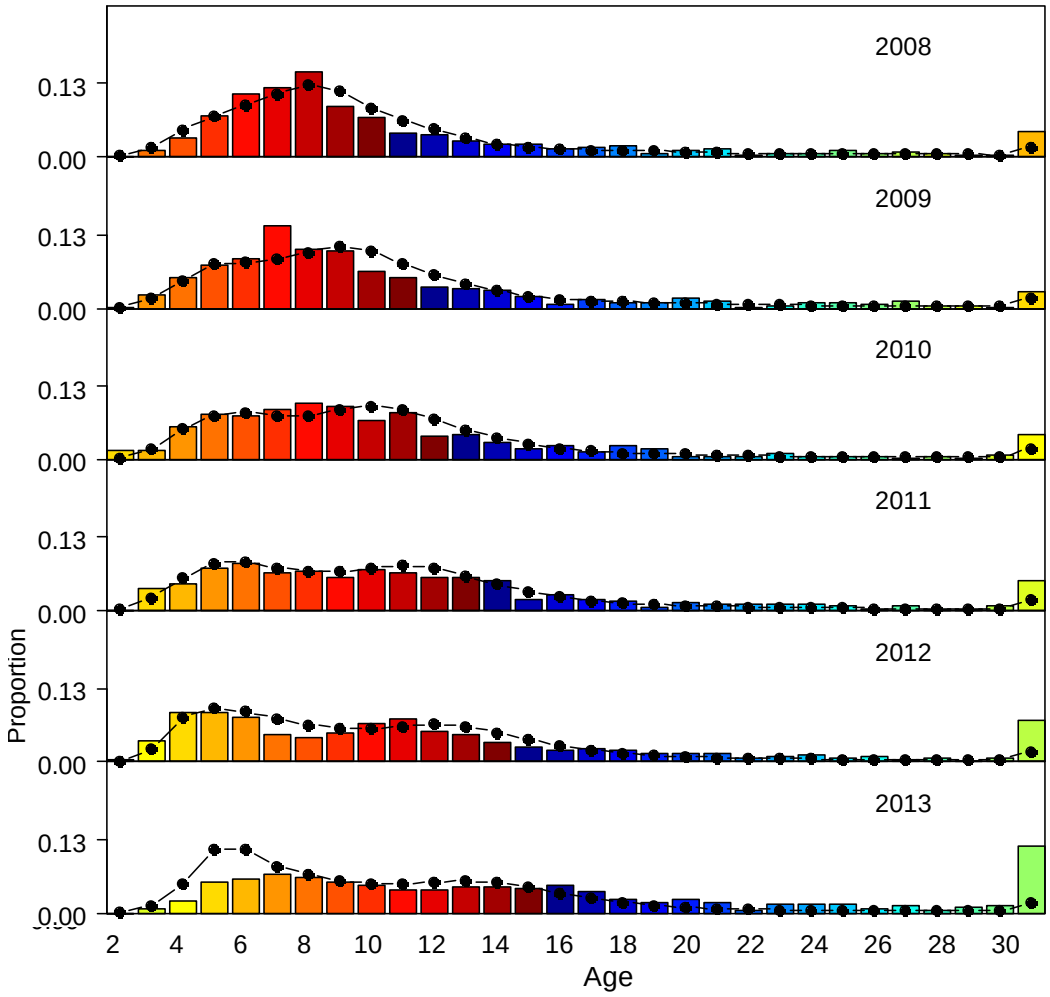

Figure 3.24 (cont.). Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

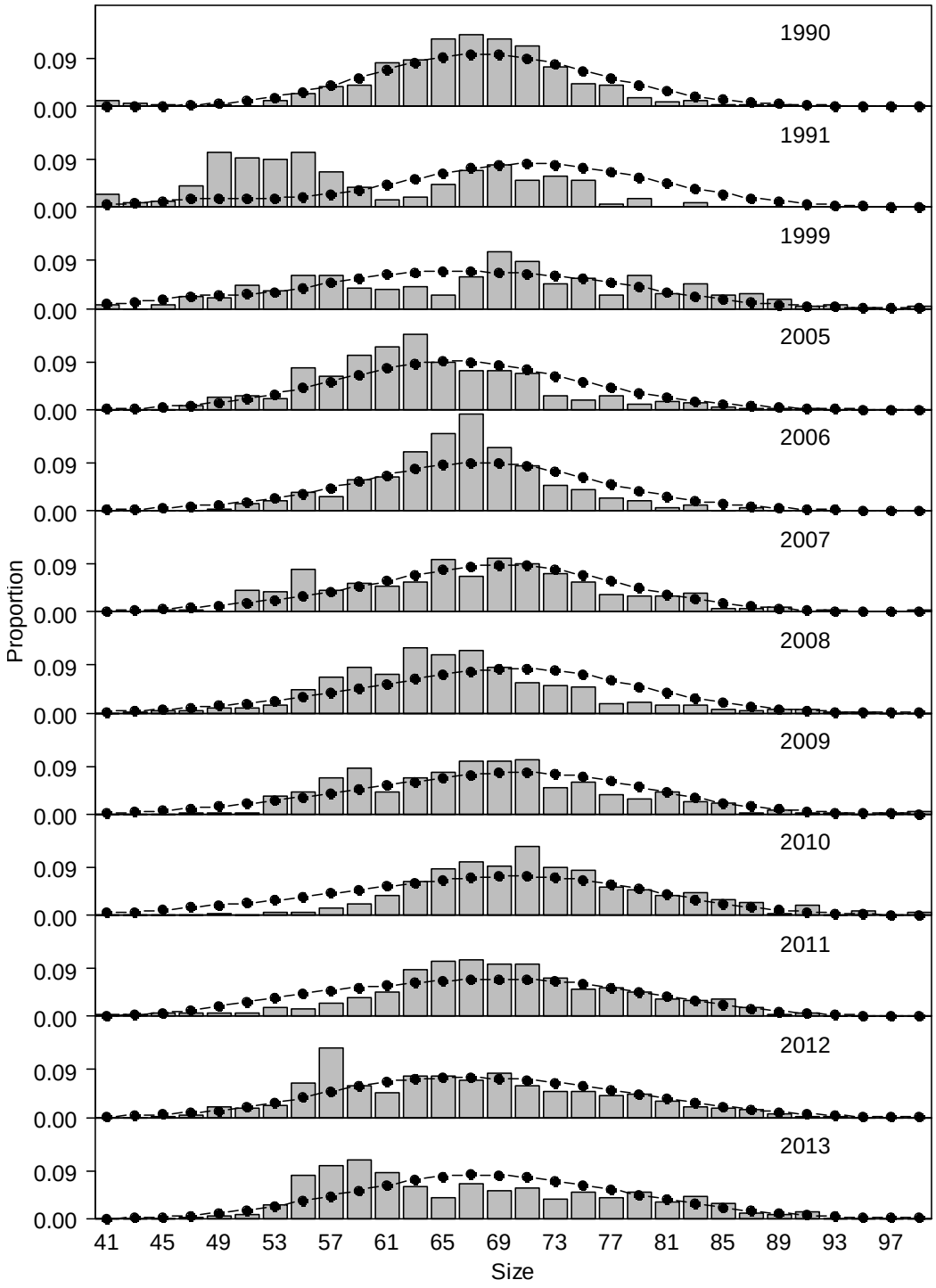

Figure 3.25a. Domestic trawl gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

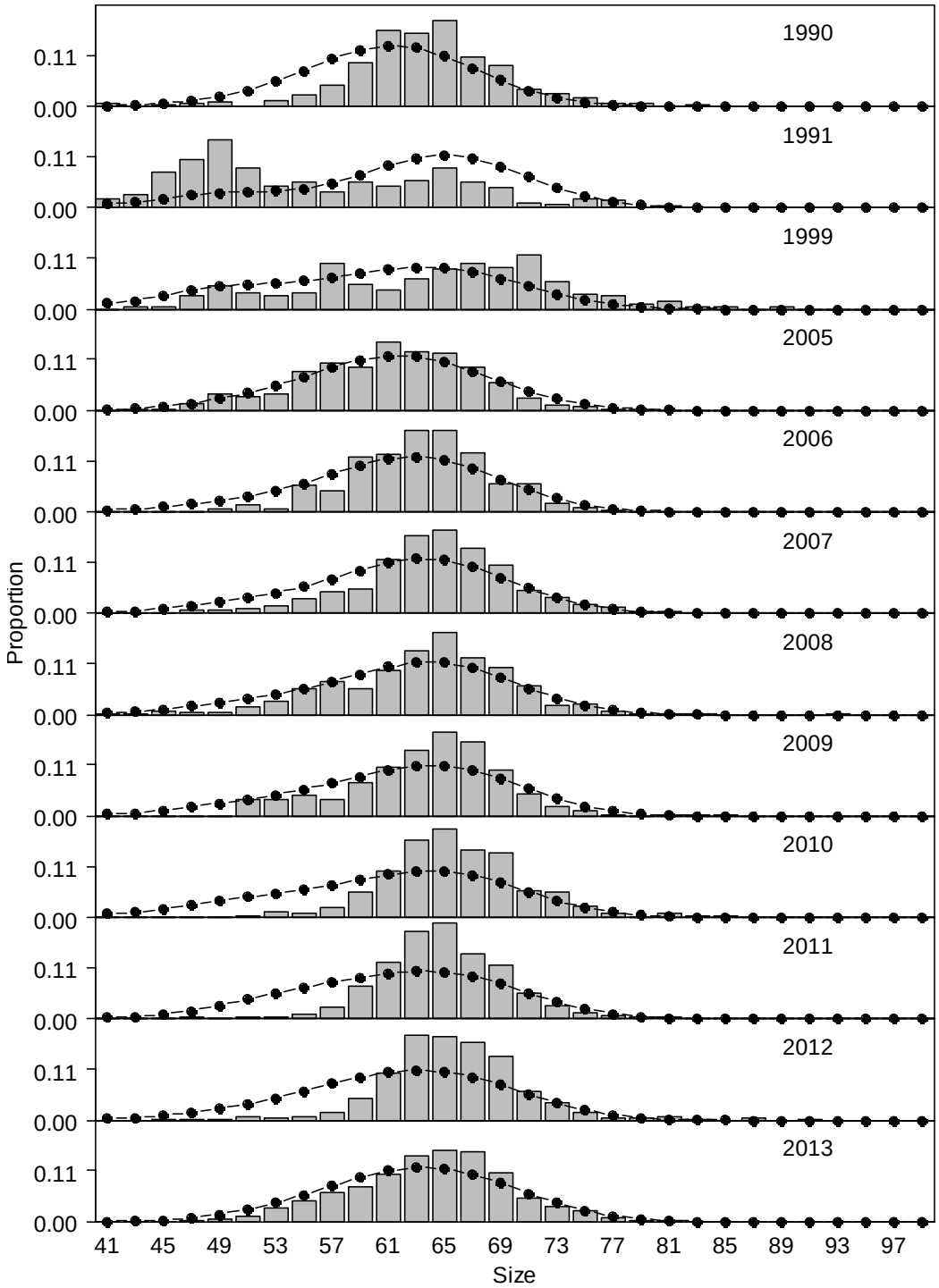

Figure 3.25b. Domestic trawl gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

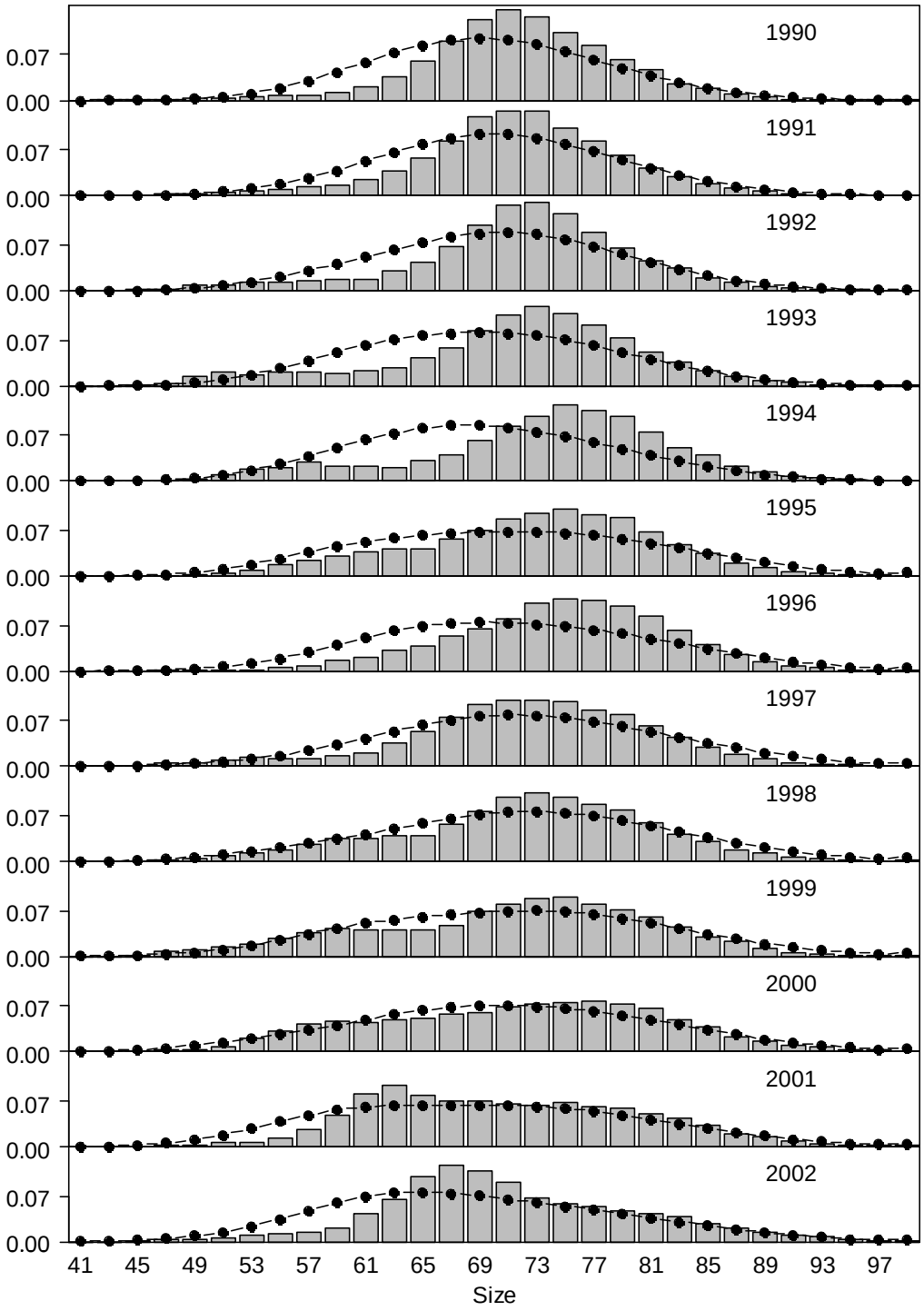

Figure 3.26. Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

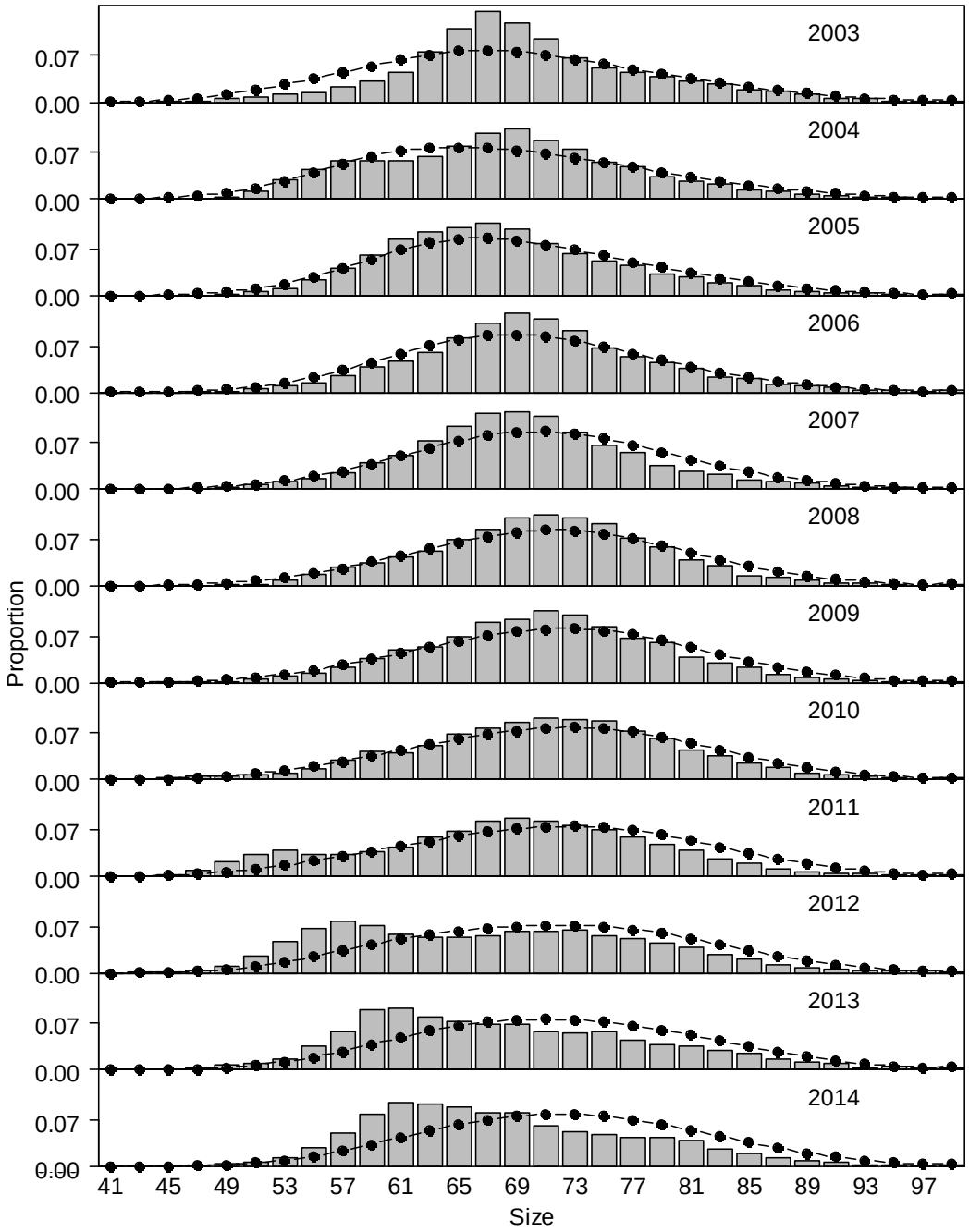

Figure 3.26 (cont.). Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

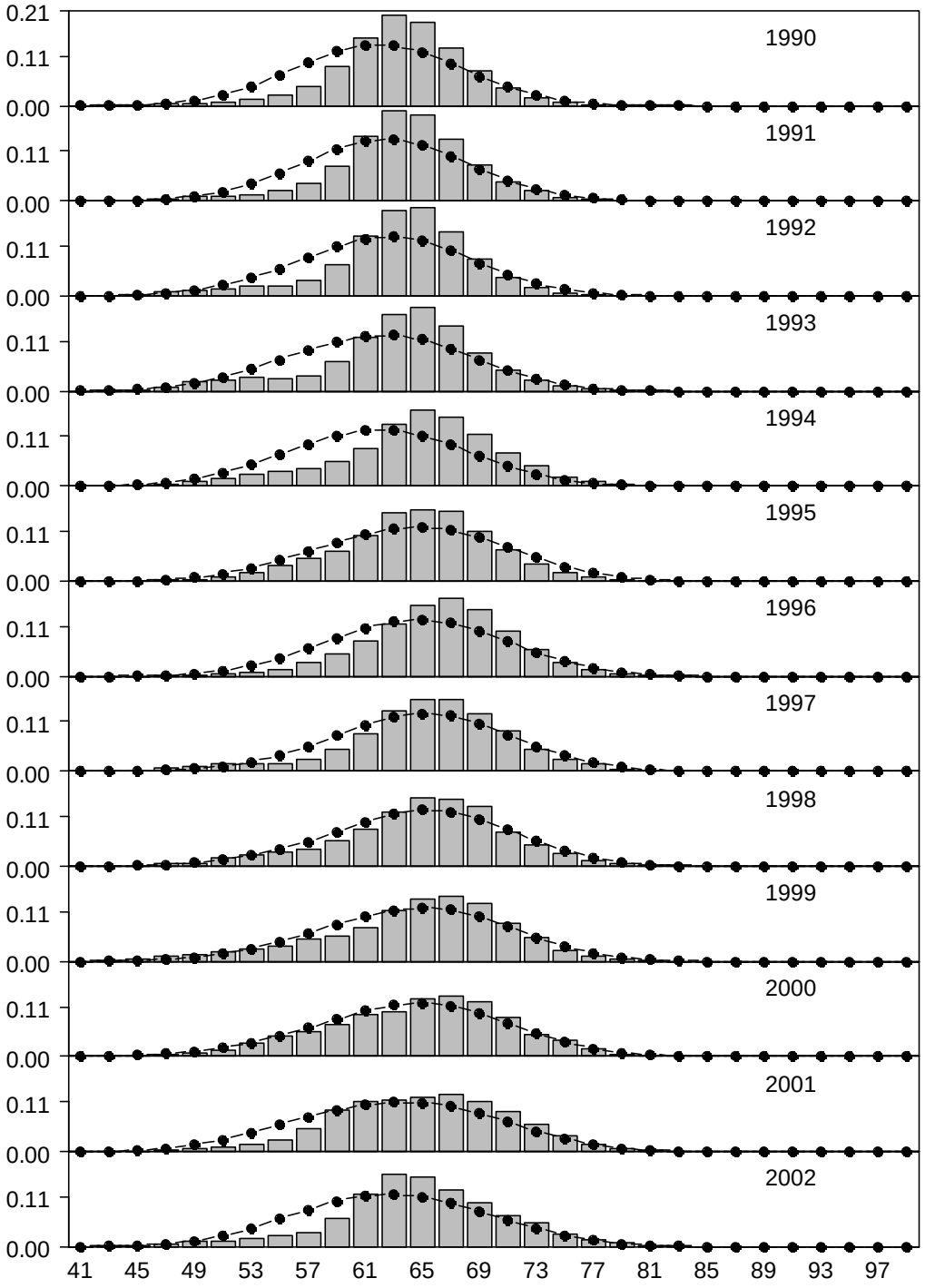

Figure 3.27. Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

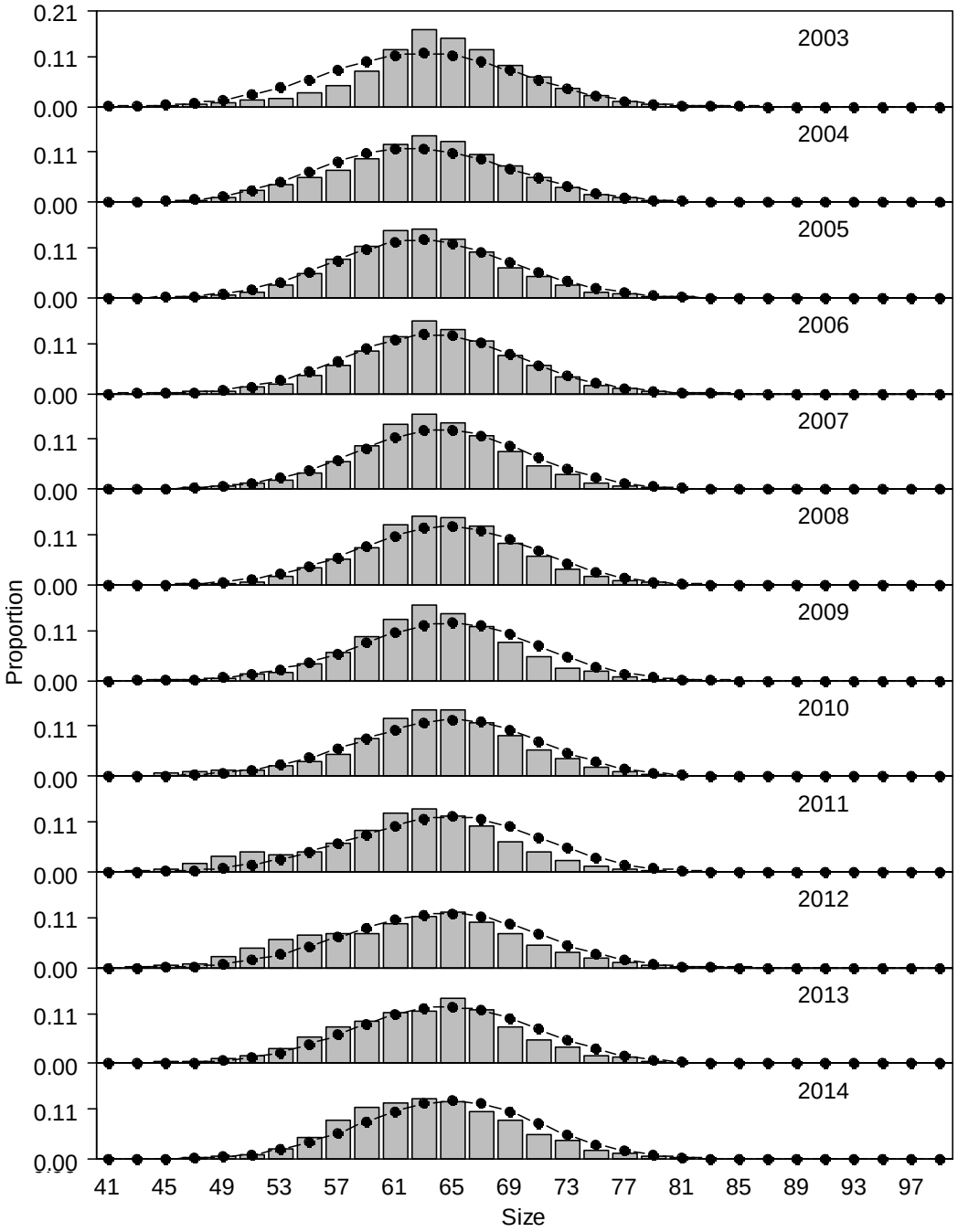

Figure 3.27.(cont.). Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

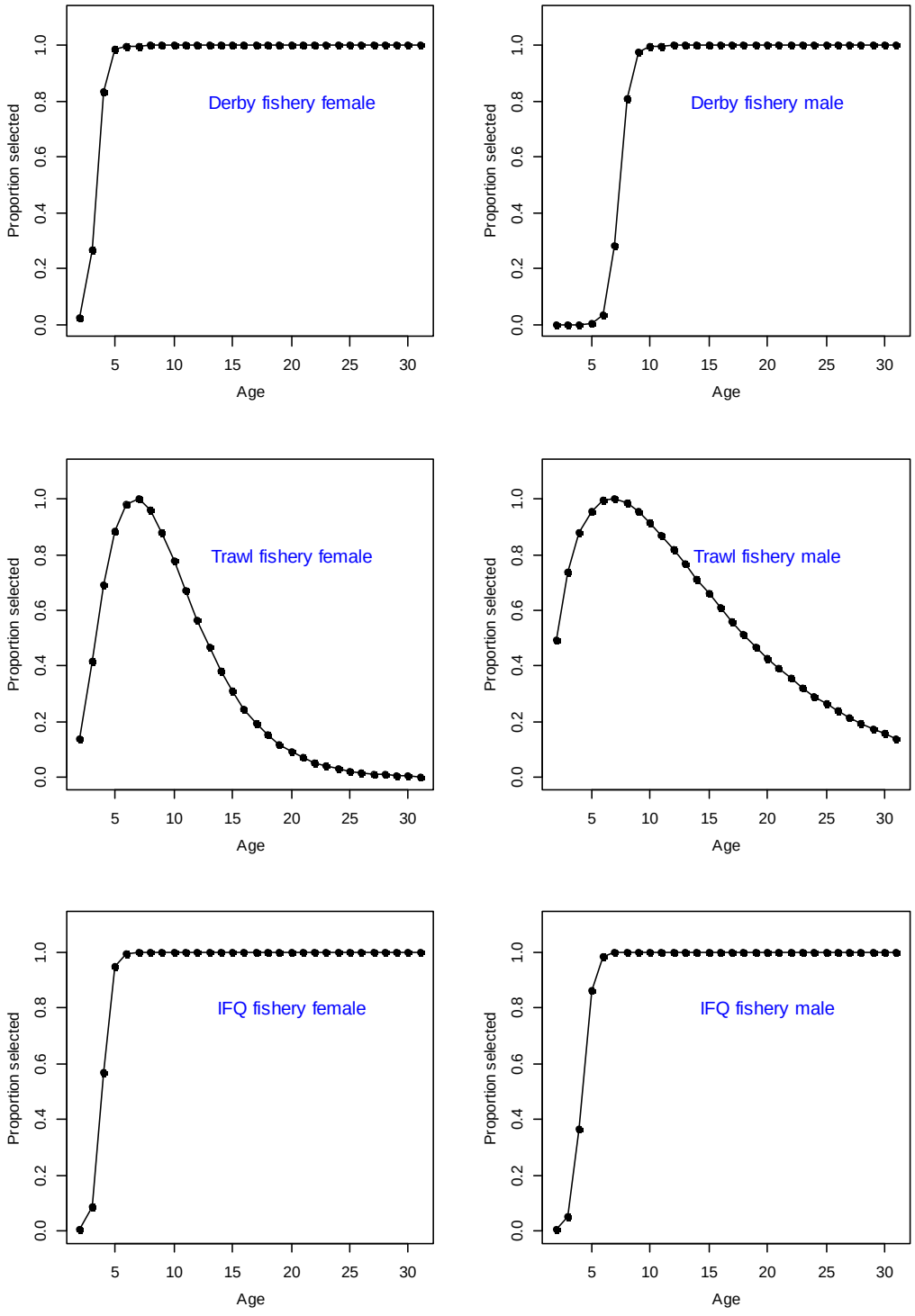

Figure 3.28. Sablefish selectivities for fisheries.

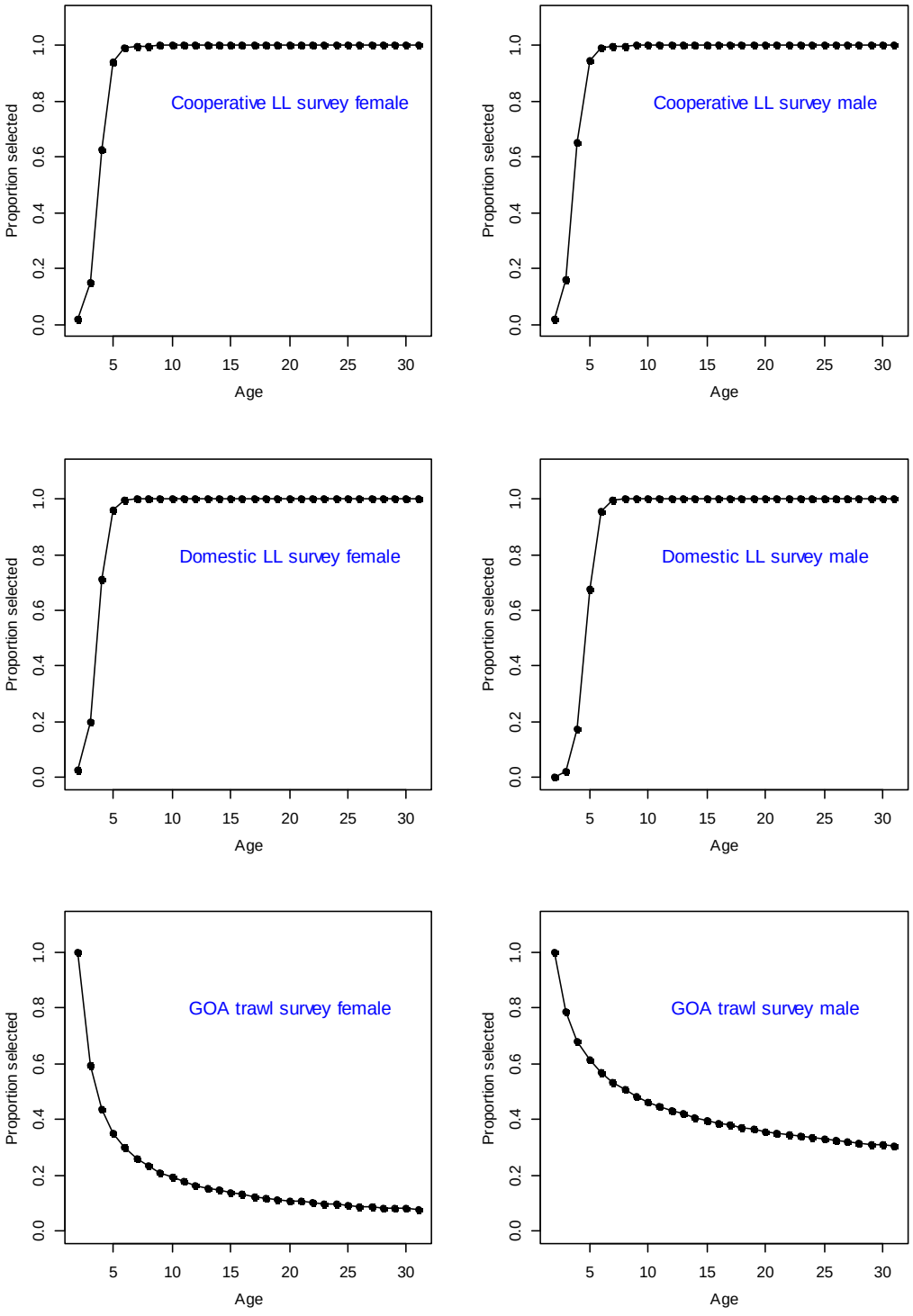

Figure 3.28 (cont.). Sablefish selectivities for surveys.

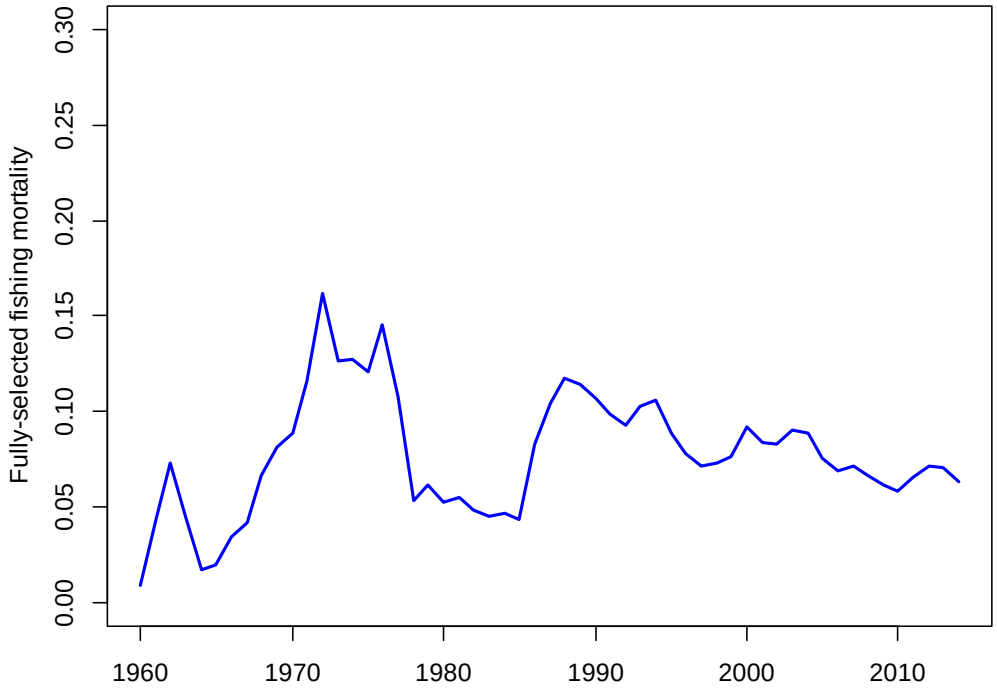

Figure 3.29. Time series of combined fully-selected fishing mortality for fixed and trawl gear for sablefish.

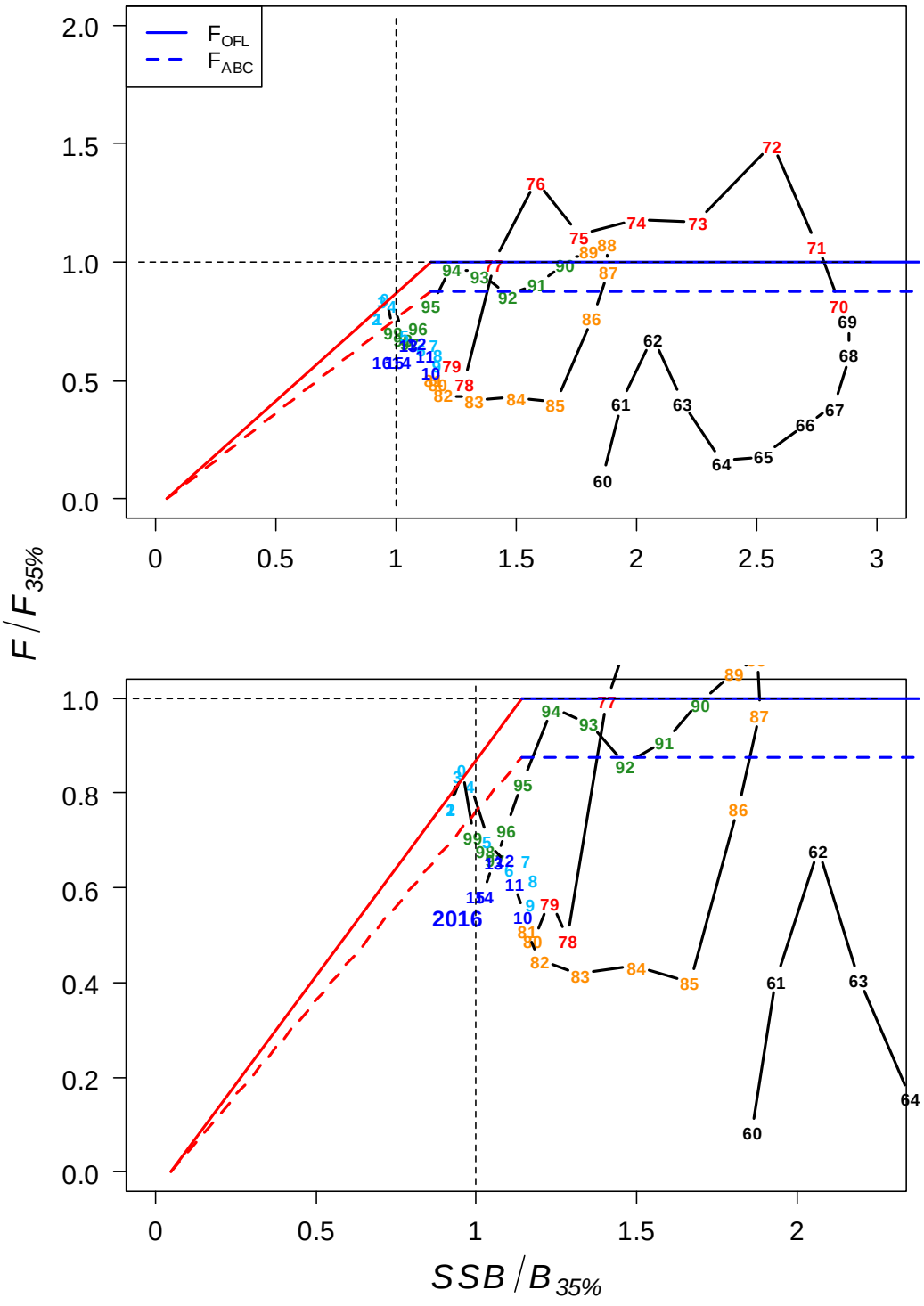

Figure 3.30. Phase-plane diagram of time series of sablefish estimated spawning biomass relative to the unfished level and fishing mortality relative to F_{OFL} for author recommended model. Bottom is zoomed in to examine more recent years.

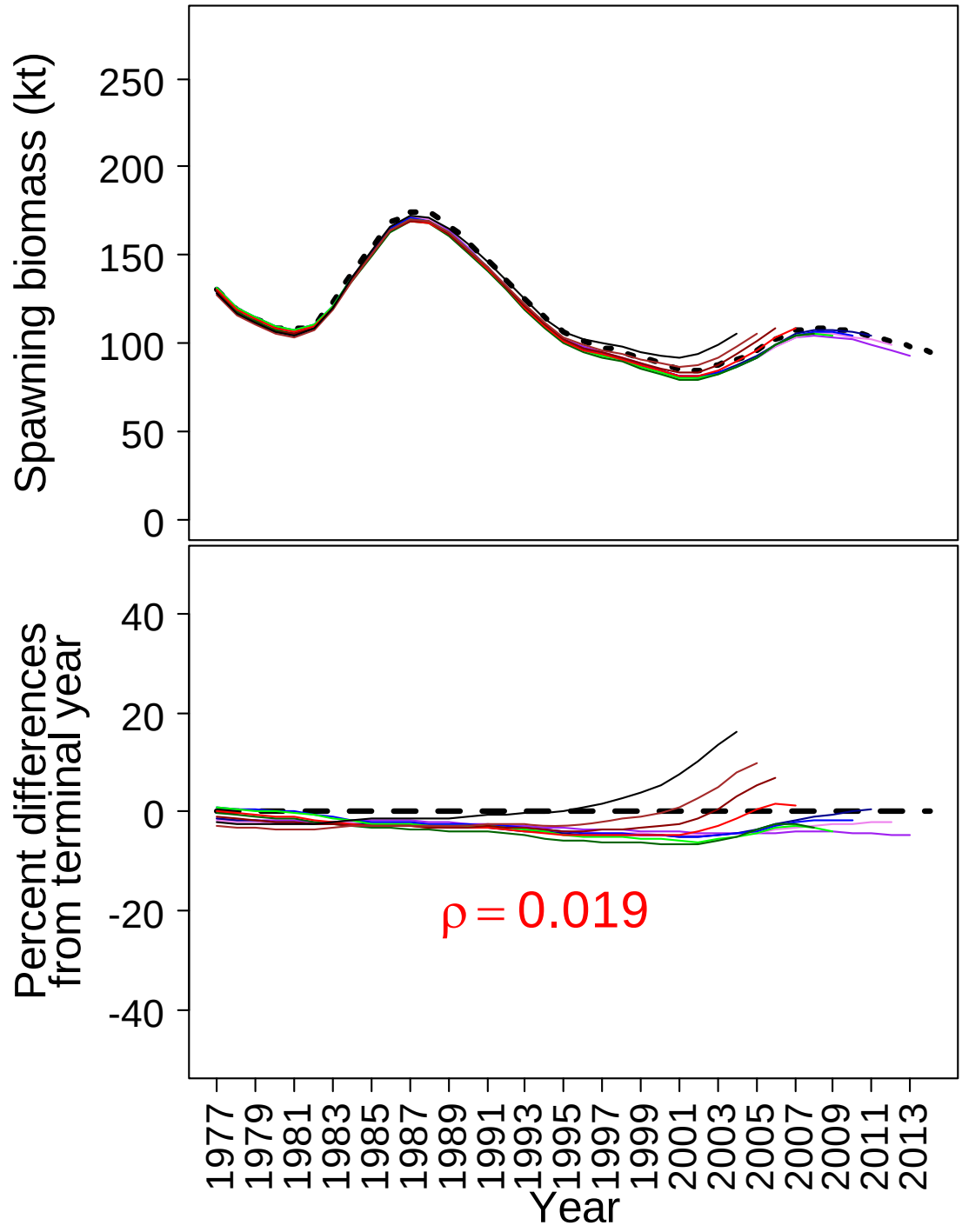

Figure 3.31a. Retrospective trends for spawning biomass (top) and percent difference from terminal year (bottom) from 2004-2014. Mohn's revised ρ = 0.019.

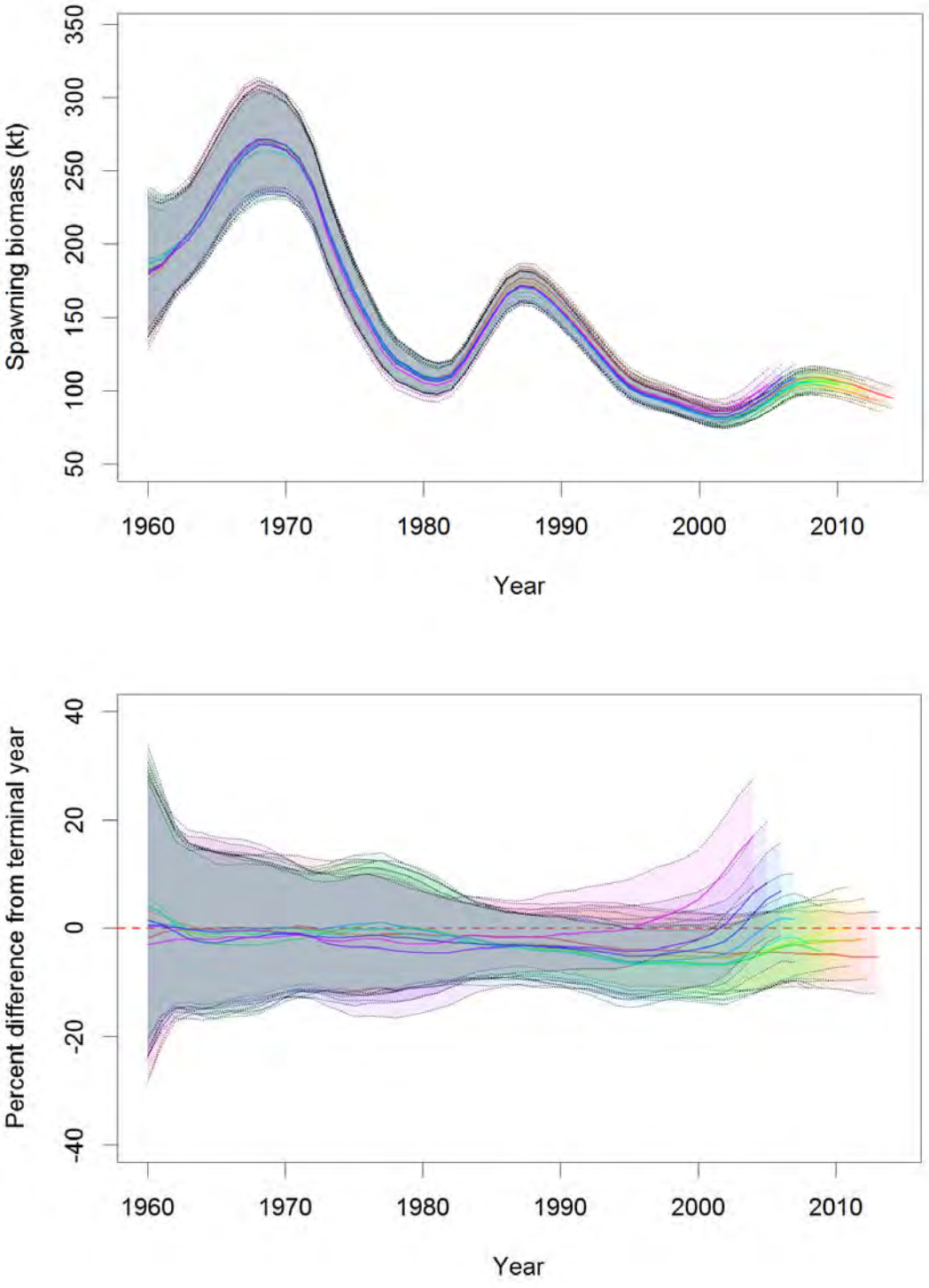

Figure 3.31b. Retrospective trends for spawning biomass (top) and percent difference from terminal year (bottom) from 2004-2014 with MCMC credible intervals per year. Mohn's revised $\rho = 0.019$.

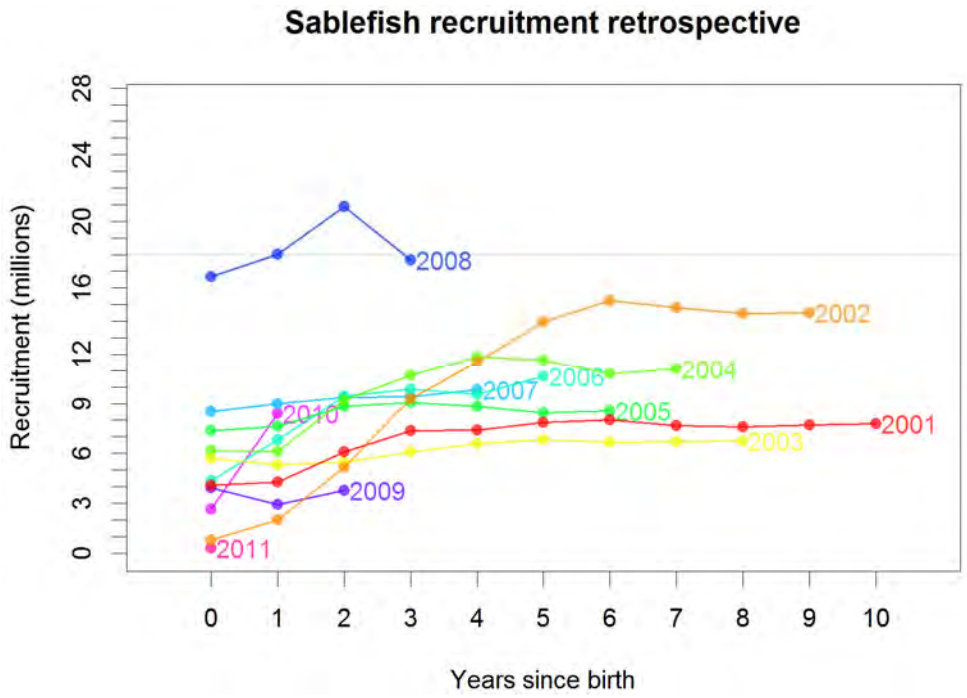

Figure 3.31c. Squid plot of the development of initial estimates of age-2 recruitment since year class 2001 through year class 2011 from retrospective analysis. Number to right of terminal year indicates year class.

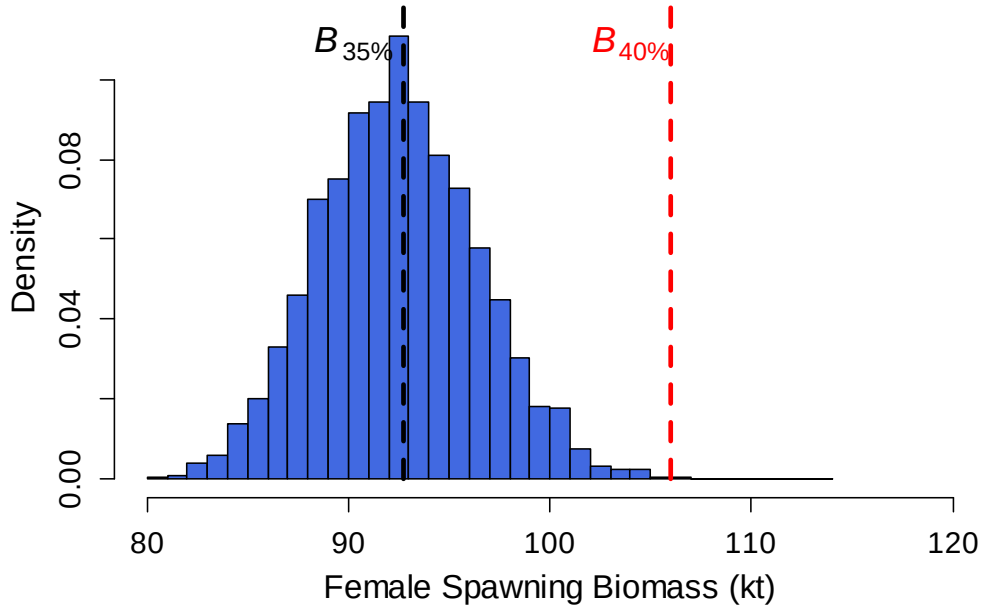

Figure 3.32. Posterior probability distribution for projected spawning biomass (thousands t) in 2014.

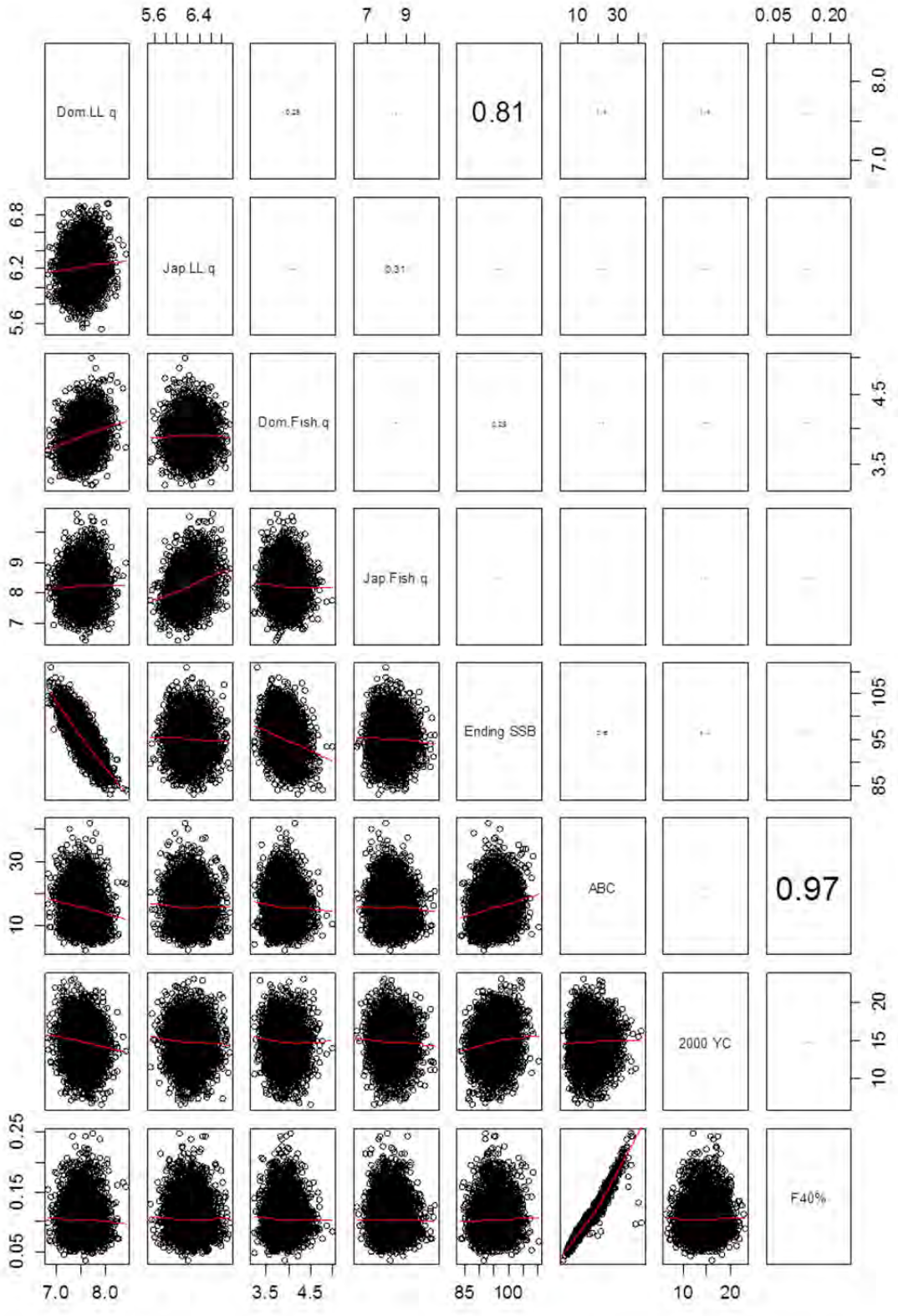

Figure 3.33. Pairwise scatterplots of key parameter MCMC runs. Red curve is loess smooth. Numbers in upper right hand panel are correlation coefficients between parameters.

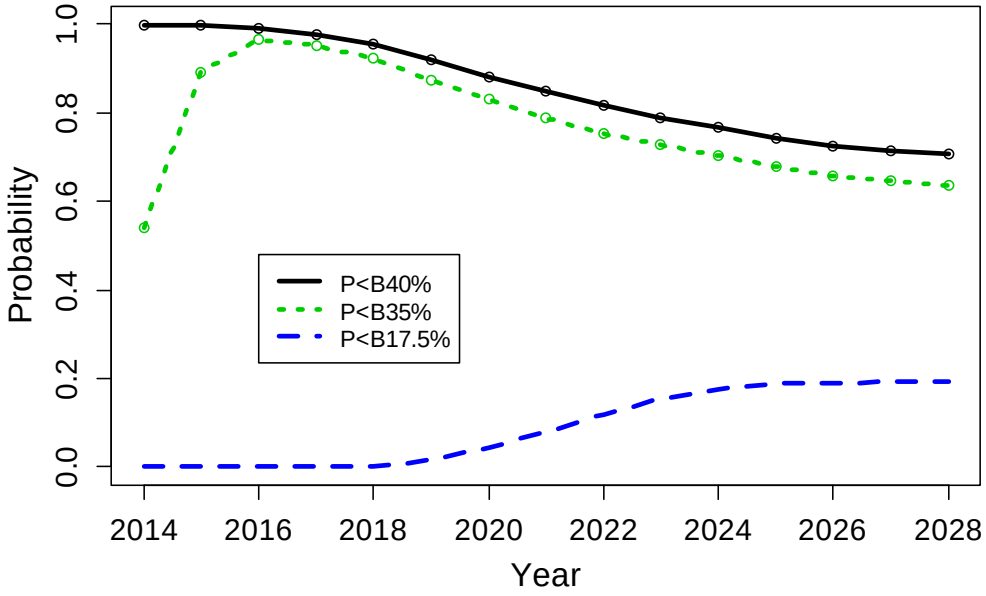

Figure 3.34. Probability that projected spawning biomass (from MCMC) will fall below $B_{40\%}$, $B_{35\%}$ and $B_{17.5\%}$.

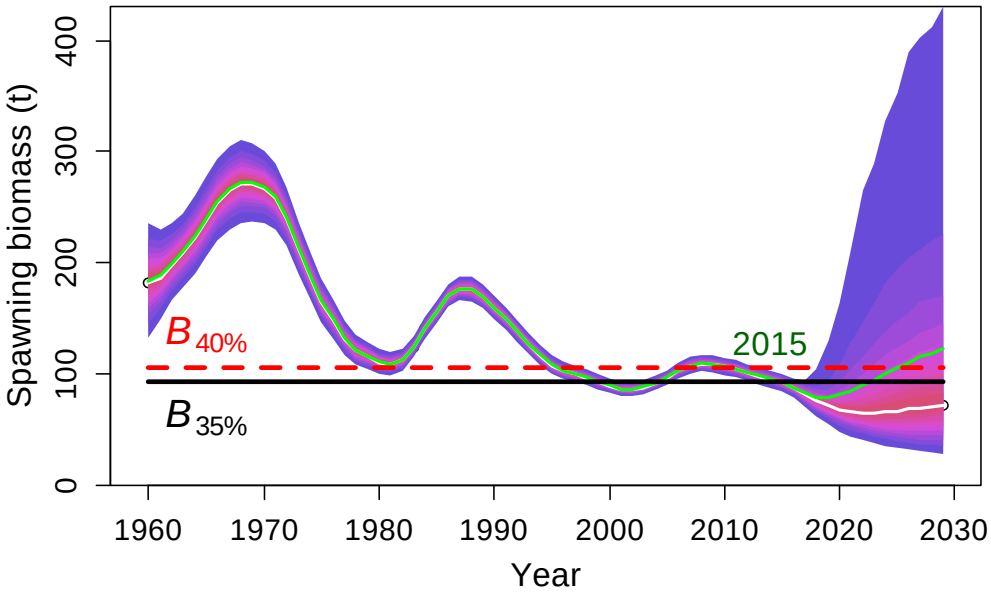

Figure 3.35. Estimates of female spawning biomass (thousands t) and their uncertainty. White line is the median and green line is the mean, shaded fills are 5% increments of the posterior probability distribution of spawning biomass based on 10,000,000 MCMC simulations. Width of shaded area is the 95% credibility interval. Harvest policy is the same as the projections in Scenario 2 (Author's F).

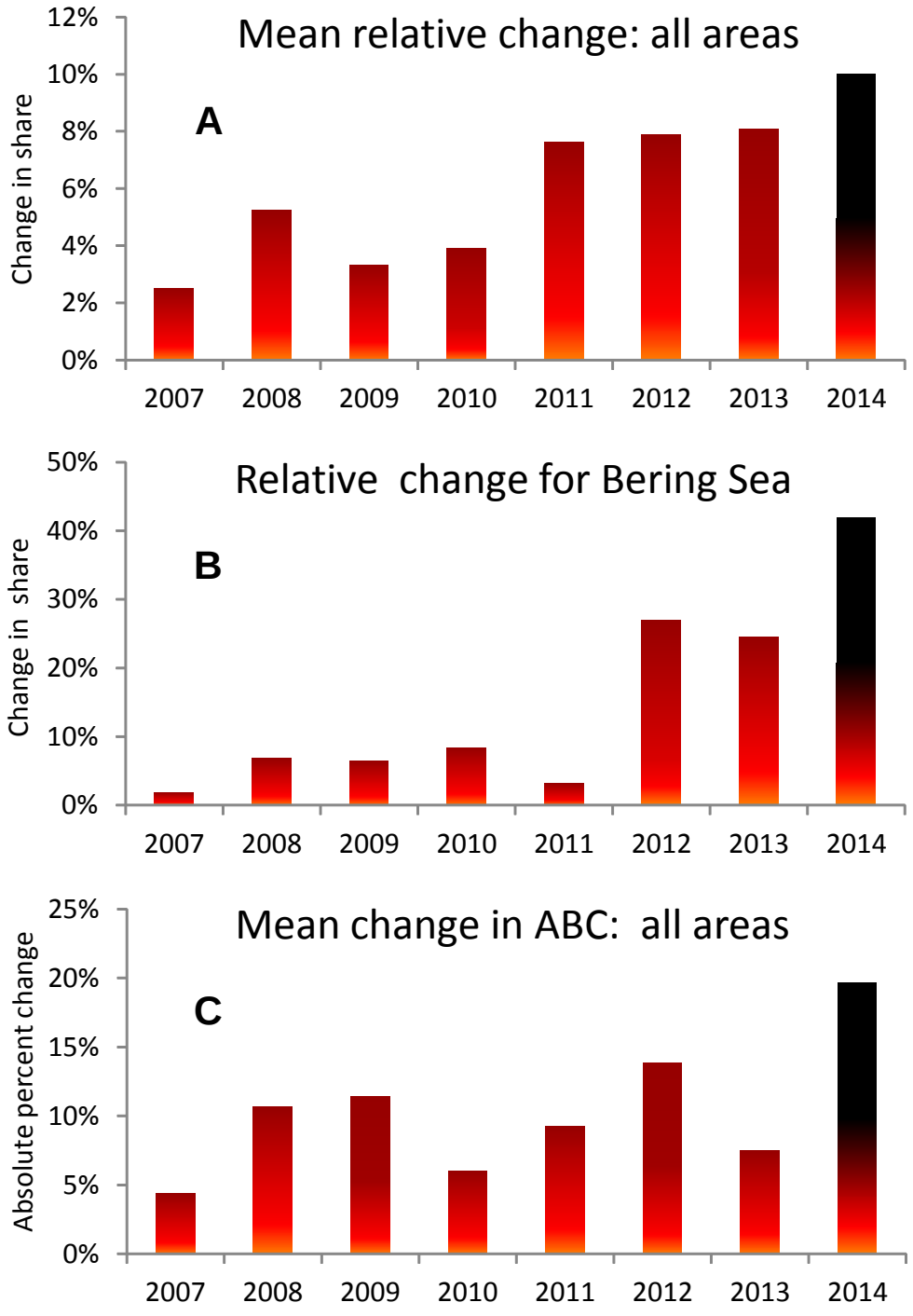

Figure 3.36. (A) The mean relative change in apportionment percentages across areas from 2007-2014. (B) The relative change in the apportionment share for the Bering Sea from 2007-2014. (C) The mean change in ABC for each area from 2007-2014.

Appendix 3A.--Sablefish longline survey - fishery interactions

NMFS has requested the assistance of the fishing fleet to avoid the annual sablefish longline survey since the inception of sablefish IFQ management in 1995. We requested that fishermen stay at least five nautical miles away from each survey station for 7 days before and 3 days after the planned sampling date (3 days allow for survey delays). Beginning in 1998, we also revised the longline survey schedule to avoid the July 1 rockfish trawl fishery opening as well as other short, but less intense fisheries.

History of interactions

Publicity, the revised longline survey schedule, and fishermen cooperation generally have been effective at reducing fishery interactions. Distribution of the survey schedule to all IFQ permit holders, radio announcements from the survey vessel, and the threat of a regulatory rolling closure have had intermittent success at reducing the annual number of longline fishery interactions.
Since 2000, the number of vessels fishing near survey stations has remained relatively low. During the past several surveys, many fishing vessels were contacted by the survey vessel and in most cases fishermen were aware of the survey or willing to help out by fishing other grounds to avoid potential survey interactions.

Longline Survey-Fishery Interactions

	Longline		Trawl		Pot		Total	
Year	Stations	Vessels	Stations	Vessels	Stations	Vessels	Stations	Vessels
1995	8	7	9	15	0	0	17	22
1996	11	18	15	17	0	0	26	35
1997	8	8	8	7	0	0	16	15
1998	10	9	0	0	0	0	10	9
1999	4	4	2	6	0	0	6	10
2000	10	10	0	0	0	0	10	10
2001	1	1	1	1	0	0	2	2
2002	3	3	0	0	0	0	3	3
2003	4	4	2	2	0	0	6	6
2004	5	5	0	0	1	1	6	6
2005	1	1	1	1	0	0	2	2
2006	6	6	1	2	0	0	7	8
2007	8	6	2	2	0	0	10	8
2008	2	2	2	2	0	0	4	4
2009	3	3	0	0	0	0	3	3
2010	2	2	1	1	0	0	3	3
2011	3	3	0	0	0	0	3	3
2012	5	5	0	0	0	0	5	5
2013	5	5	0	0	0	0	5	5
2014	2	2	0	0	0	0	2	2

Recommendation

We have followed several practical measures to alleviate fishery interactions with the survey. Trawl fishery interactions generally have decreased; longline fishery interactions have been low but continue to occur. Discussions with vessels encountered on the survey indicates an increasing level of “hired” skippers who are unaware of the survey schedule. Publicizing the survey schedule to skippers who aren’t quota shareholders should be improved. We will continue to work with association representatives and

individual fishermen from the longline and trawl fleets to reduce fishery interactions and ensure accurate estimates of sablefish abundance.

Appendix 3B.—Supplemental catch data

In order to comply with the Annual Catch Limit (ACL) requirements, two new datasets have been generated to help estimate total catch and removals from NMFS stocks in Alaska.

The first dataset, non-commercial removals, estimates total removals that do not occur during directed groundfish fishing activities. This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System estimates. For sablefish, these estimates can be compared to the research removals reported in previous assessments (Hanselman et al. 2010) (Table 3B.1). The sablefish research removals are substantial relative to the fishery catch and compared to the research removals for many other species. These research removals support a dedicated longline survey. Additional sources of significant removals are bottom trawl surveys and the International Pacific Halibut Commissions longline survey. Recreational removals are relatively minor for sablefish. Total removals from activities other than directed fishery were near 239 tons in 2013. This was 1.7% of the 2014 recommended ABC of 13,722. These removals represent a relatively low risk to the sablefish stock. In 2011, we conducted a model run where these removals were accounted for in the stock assessment model, and it resulted in an increase in ABC of comparable magnitude.

The second dataset, Halibut Fishery Incidental Catch Estimation (HFICE), is an estimate of the incidental catch of groundfish in the halibut IFQ fishery in Alaska, which is currently unobserved. To estimate removals in the halibut fishery, methods were developed by the HFICE working group and approved by the Gulf of Alaska and Bering Sea/Aleutian Islands Plan Teams and the Scientific and Statistical Committee of the North Pacific Fishery Management Council. A detailed description of the methods is available in Tribuzio et al. (2011).

These estimates are for total catch of groundfish species in the halibut IFQ fishery and do not distinguish between “retained” or “discarded” catch. These estimates should be considered a separate time series from the current CAS estimates of total catch. Because of potential overlaps HFICE removals should not be added to the CAS produced catch estimates. The overlap will apply when groundfish are retained or discarded during an IFQ halibut trip. IFQ halibut landings that also include landed groundfish are recorded as retained in eLandings and a discard amount for all groundfish is estimated for such landings in CAS. Discard amounts for groundfish are not currently estimated for IFQ halibut landings that do not also include landed groundfish. For example, catch information for a trip that includes both landed IFQ halibut and sablefish would contain the total amount of sablefish landed (reported in eLandings) and an estimate of discard based on at-sea observer information. Further, because a groundfish species was landed during the trip, catch accounting would also estimate discard for all groundfish species based on available observer information and following methods described in Cahalan et al. (2010). The HFICE method estimates all groundfish caught during a halibut IFQ trip and thus is an estimate of groundfish caught whether landed or discarded. This prevents simply adding the CAS total with the HFICE estimate because it would be analogous to counting both retained and discarded groundfish species twice. Further, there are situations where the HFICE estimate includes groundfish caught in State waters and this would need to be considered with respect to ACLs (e.g. Chatham Strait sablefish fisheries). Therefore, the HFICE estimates should be considered preliminary estimates for what is caught in the IFQ halibut fishery. Improved estimates of groundfish catch in the halibut fishery may become available following restructuring of the Observer Program.

The HFICE estimates of sablefish catch by the halibut fishery are substantial and represent approximately 10% of the annual sablefish ABC (Table 3B.2). Sablefish and halibut are often caught and landed in association with each other by the IFQ fishery. It is unknown what level of sablefish catch reported here is already accounted for as IFQ harvest in the CAS system because the HFICE estimates do not separate retained and discarded catch. If these were strictly additive removals, 10% would represent a significant amount of additional mortality and a potential risk to the stock, but how much is additive is unknown. The HFICE estimates may represent some valuable discard information for sablefish, but that level is unknown until these estimates are separated from the IFQ landings and CAS system.

Literature Cited

Cahalan J., J. Mondragon., and J. Gasper. 2010. Catch Sampling and Estimation in the Federal Groundfish Fisheries off Alaska. NOAA Technical Memorandum NMFS-AFSC-205. 42 p.

Hanselman, D. H., C. Lunsford, and C. Rodgveller. 2010. Alaskan Sablefish. In Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI as projected for 2010. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.pp.

Tribuzio, C.A., S. Gaichas, J. Gasper, H. Gilroy, T. Kong, O. Ormseth, J. Cahalan, J. DiCosimo, M. Furuness, H. Shen, and K. Green. 2011. Methods for the estimation of non-target species catch in the unobserved halibut IFQ fleet. August Plan Team document. Presented to the Joint Plan Teams of the North Pacific Fishery Management Council.

Table 3B.1 Total removals of sablefish (t) from activities not related to directed fishing, since 1977. Trawl survey sources are a combination of the NMFS echo-integration, small-mesh, GOA, AI, and BS Slope bottom trawl surveys, and occasional short-term research projects. Other is recreational, personal use, and subsistence harvest.

Year	Source	Trawl	Japan US longline survey	Domestic longline survey	IPHC longline survey*	Other	Total
1977		3					3
1978		14					14
1979		27	104				131
1980		70	114				184
1981		88	150				238
1982		108	240				348
1983		46	236				282
1984		127	284				412
1985		186	390				576
1986		123	396				519
1987		117	349				466
1988		15	389	303			707
1989		4	393	367			763
1990		26	272	366			664
1991	**Assessment of the sablefish stock in Alaska (Hanselman et al. 2010)**	3	255	386			645
1992		0	281	393			674
1993		39	281	408			728
1994		1	271	395			667
1995		0		386			386
1996		13		430			443
1997		1		396			397
1998		26		325	50		401
1999		43		311	49		403
2000		2		290	53		345
2001		11		326	48		386
2002		3		309	58		370
2003		16		280	98		393
2004		2		288	98		387
2005		18		255	92		365
2006		2		287	64		352
2007		17		266	48		331
2008		3		262	46		310
2009		14		242	47		257
2010		3		291	50	15	359
2011	AKRO	9		273	39	16	312
2012		4		203	27	39	273
2013		4		178	22	35	239

* IPHC survey sablefish removals are released and estimates from mark-recapture studies suggest that these removals are expected to produce low mortality. Some state removals are included.

Table 3B.2. Estimates of Alaska sablefish catch (t) from the Halibut Fishery Incidental Catch Estimation (HFICE) working group. AI = Aleutian Islands, WGOA = Western Gulf of Alaska, CGOA = Central Gulf of Alaska, EGOA = Eastern Gulf of Alaska, PWS = Prince William Sound.

Area	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Western/Central AI	27	19	34	18	14	11	36	44	17	23
Eastern AI	18	16	46	26	20	6	4	13	6	7
WGOA	10	9	12	22	21	16	7	12	3	12
CGOA-Shumagin	184	27	36	65	60	47	21	38	10	37
CGOA-Kodiak/ PWS*	802	107	96	89	82	49	57	33	69	63
EGOA-Yakutat	110	324	291	258	240	149	175	103	207	195
EGOA-Southeast	339	335	389	315	269	242	230	184	242	262
Southeast Inside*	459	1,018	1,181	917	786	739	701	574	731	805
Total	1,948	2,231	2,346	2,469	2,194	2,476	1,937	1,874	1,921	1,594

*These areas include removals from the state of Alaska.

Appendix 3C: Alaska sablefish research update

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Executive Summary

In this appendix we describe some completed and ongoing sablefish research related to stock assessment. New modeling results for estimating the effects of whale depredation are described. In addition, a number of sensitivity model scenarios were conducted that incorporated some of the results of this research. Each section below provides a brief summary of current research and includes model scenarios related to that research. We also provide guidance for future research projects.

Whale depredation and survey modeling

Accounting for whale depredation

Background

Whale depredation has been an ongoing source of uncertainty for the sablefish assessment. Killer whale depredation of the sablefish catch on the longline survey has been a problem in the Bering Sea since the beginning of the survey (Sasaki, 1987). Depredation by killer whales has since been documented commonly in the Aleutian Islands, Bering Sea, and Western Gulf of Alaska. Since 1990, the depredated hachis (skates of 45 hooks), which were identified as depredated by a combination of damaged fish and damaged hooks, were excluded from calculations of abundance indices. At some stations this might result a large number of hachis being removed, or the entire station being removed from abundance calculations. From 1998-2012, the percentage of skates depredated ranged from 12.3 - 55.0% per year in the BS, from 0 - 19% per year in the AI and from 0 - 41% in the WGOA. In management areas like the Bering Sea where there is limited sampling, this can lead to very few stations left to calculate abundance. In addition, if killer whales are non-randomly depredating stations where fish are typically most abundant; this can lead to a downward bias of the index.

Sperm whale depredation has only been documented since 1998. Historically, sperm whale depredation was occurring in the two Eastern Gulf of Alaska (GOA) management areas, but has recently become more common in the Central GOA and occasionally occurs in the Western GOA. Apparent sperm whale depredation on the longline survey is defined as sperm whales being observed and the occurrence of damaged fish. In contrast to killer whale depredation, sperm whale depredation is much more difficult to detect because sperm whales often take only a few fish, and rarely leave behind depredation evidence such as damaged fish or hooks like killer whales. Because actual depredation is difficult to detect, and therefore difficult to document by haul or specific hachis, we use sperm whale presence at a station as a proxy for depredation. Sperm whale presence and evidence of depredation has been variable since 1998 (see figure below).

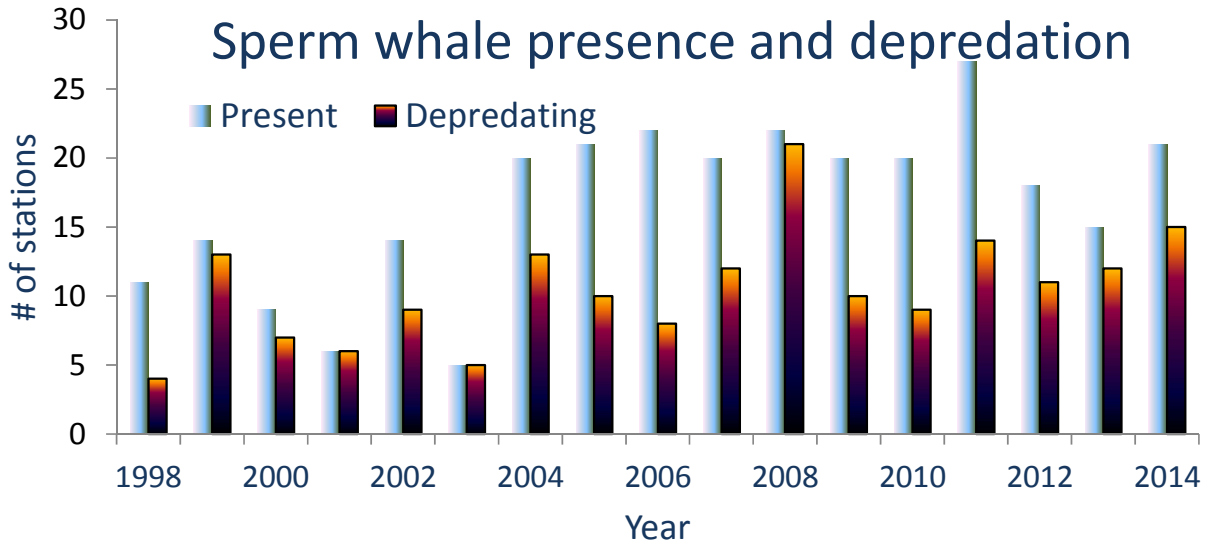

Figure: Sperm whale depredation and presence on the AFSC longline survey since 1998.

A number of studies have examined whale depredation in different ways. An early study using data collected by fisheries observers in Alaskan waters found no significant effect on catch (Hill et al. 1999). In the 2002 SAFE, an analysis was completed using longline survey data from 1998-2001 and found that sablefish catches were significantly less at stations affected by sperm whale depredation. This work was redone in 2006 using additional data from 2002-2004 and general linear models (Sigler et al. 2007). This 2007 study found that neither sperm whale presence ($p = 0.71$) nor depredation rate ($p = 0.78$) increased significantly from 1998 - 2004. Catch rates were about 2% less at locations where depredation occurred, but the effect was not significant ($p = 0.34$). This analysis was updated through 2009 and showed a significant effect of approximately four kilograms per hundred hooks for stations in the CGOA and EGOA, which translates into approximately a 2% decrease in the overall catch rates in those areas (J. Liddle pers. comm.). Another study, using data collected in southeast Alaska, found a small, significant effect comparing longline fishery catches between sets with sperm whales present and sets with sperm whales absent (3% reduction, 95% CI of 0.4 – 5.5%, t-test, $p = 0.02$, Straley et al. 2005).

Hanselman et al. (2010) applied zero-inflated negative binomial models to estimate the effect of sperm whale and killer whale depredation on the longline survey by individual management areas. They estimated that sperm whales decreased the EY/SE area index by 1-10% annually (which we do not correct for), while killer whales affected the Western GOA index by 5-30% annually (which we do correct for). Peterson et al. (2013) used similar methods to estimate depredation effects of killer whales on fishery catch rates of six species including sablefish, Pacific cod, and halibut. They estimated that killer whales when present removed 54-72% of sablefish.

Given perfect data, most of these studies would have provided adequate estimates of the effects of whales. However, the occurrence of whale depredation is sporadic which creates unbalanced data. Analysis of unbalanced designs using fixed-effects models can result in poor estimation and inference compared to mixed-effects models (Zuur et al. 2009). The utility of accounting for depredation effects on survey estimates depends on the precision of model estimates as well as the nature of depredation effects. In particular, if depredation effects are themselves highly variable (e.g., reductions in catch differ appreciably from one event to the next, like for killer whales), then it may not be advisable to "correct" for depredation using a single point estimate derived across numerous depredation events. Other options, such as discarding data from depredated skates, may provide preferable survey estimates.

Since Hanselman et al. (2010), we have conducted simulations and model comparisons to show that a generalized linear mixed effect model (GLMM) performs better than previous modeling methods, in terms of both accuracy and capturing an appropriate amount of uncertainty. Preliminary simulations suggested that a sperm whale correction derived from a GLMM performs well, whereas the benefits of a GLMM model correction for killer whales performed similarly to the current practice of discarding depredated skates. The methods used for estimating sperm and killer whale depredation were similar, but for the purposes of this document we focus on sperm whales. The following section includes a brief description of models compared for sperm whale depredation.

Model structure

The basic structure of the survey data is as follows: year (t), area (i), depth stratum (j), and station (k), where stations are nested within areas. At each station, numerous hachis (skates of 45 hooks) are fished and later assigned to depth strata. Stations are the primary unit of spatial replication, while hachis are essentially pseudo-replicates (subsamples) collected within stations. Modeling data at the hachi level is difficult because of large sample sizes and potential spatial autocorrelation among hachis. Peterson et al. (2013) used a simple and robust alternative, which was to model aggregated data by summing catch and effort (effective hooks fished) across hachis for each year/stratum/station combination. We adopt this approach as well.

A log-linear model of CPUE that accounts for the full structure of the survey data across years (Y_t), areas (A_i), depth strata (D_j), and stations (S_k) is given by:

$$\log(C_{tjk[i]}) = \log(H_{tjk[i]}) + Y_t + A_i + D_j + (YA)_{ti} + (YD)_{tj} + (AD)_{ij} + (YAD)_{tij} + S_{k[i]} + (YS)_{tk[i]} + (DS)_{jk[i]} + (YDS)_{tjk[i]}, \quad (1)$$

where the subscript $k[i]$ indicates that station k is nested in area i, C denotes aggregated catch (summed across hachis), and H denotes total effective hooks (summed across hachis). The term H is a constant that is specified as an "offset" in model fitting (Venables and Ripley 2002, p. 189). Model (1) is "fully saturated" because it includes all main-level effects (Y_t, A_i, etc.) and two-way and three-way interactions, right up to the level of the aggregate data themselves with $(YDS)_{tjk[i]}$. Thus, the theoretical importance of model (1) is that it contains the full factorial structure at which we expect variation in CPUE, that is, up to and including differences among year/stratum/station combinations, i.e., $(YDS)_{tjk[i]}$. With model (1) in mind, we outline the alternative models used to estimate depredation effects of sperm whales.

Model fitting proceeded in two stages, first with area-specific models and then across-area models. Areas with stations flagged for sperm whale depredation included WGOA, CGOA, WY, and EY/SE. For each area, we compared fits of five models. The first three models had a form similar to that used by Peterson et al. (2013):

$$\log(C_{tjk}) = \log(H_{tjk}) + Y_t + D_j + S_k + (YS)_{tk} + \lambda F_{tk}, \quad (2)$$

where the coefficient λ denotes the effect of depredation, and F is an indicator (dummy) variable for depredation ($F = 1$ when a station is flagged for depredation and $F = 0$ otherwise). The first model was a quasi-Poisson (QP) model, which is an *ad hoc* approach to account for over-dispersion in count data (Venables and Ripley 2002, p. 208; fit using the `glm` function in R). The second model was a negative binomial (NB) model, as used by Peterson et al. (2013), which assumes that aggregate catches C_{tjk} follow a negative binomial distribution (Venables and Ripley 2002, p. 206; fit using the `glm.nb` function of the MASS library in R). The QP and NB models are generalized linear models (GLMs) that treat all terms as *fixed effects* (Venables and Ripley 2002, p. 271). Both models have been widely used to address over-dispersion in count data, although model results and suitability can differ appreciable between them (Ver Hoef and Boveng 2007).

The third model (denoted ME.1), also based on the structure in equation (2), was a mixed-effects model assuming a Poisson distribution for C_{tjk} (in this context, a generalized linear mixed model or GLMM; Zuur et al. 2009). Specifically, the terms for year (Y_t), station (S_k), and their crossed interactions $(YS)_{tk}$ were treated as *random effects* instead of fixed effects. Each random-effects term was assumed to follow a normal distribution, e.g., $Y_t \sim N(0, \sigma_Y^2)$. With respect to the survey data, the key potential benefit of a mixed model is to obtain robust estimates despite a highly unbalanced design.

The final two models, which were also Poisson mixed models, had a complete factorial structure for the area-specific survey data:

$$\log(C_{tjk}) = \log(H_{tjk}) + Y_t + D_j + S_k + (YD)_{tj} + (YS)_{tk} + (DS)_{jk} + (YDS)_{tjk} + \lambda F_{tk}. \quad (3)$$

In the fourth model (ME.2), all terms were treated as random effects except for depth strata means (D_j) and the depredation effect (λ). The addition of $(YDS)_{tjk}$ in equation (3) saturates the model, providing an individual random effect for each observation of aggregated catch, C_{tjk}. Such an approach is used to account for overdispersion in Poisson mixed models (e.g., Gelman and Hill 2007, p. 326). In our context, the variance of *YDS* will reflect natural variation in mean CPUE among year/strata/station combinations, as well as additional overdispersion accrued via summing catches across hachi.

The last model (ME.3) examined evidence of variation in depredation effects. Up to this point, it has been assumed that depredation effects are essentially constant across events (i.e., year/station combinations), and thus modelled via a single coefficient λ. However, if there was considerable variation in depredation effects, it would be evident in the data. Such variation would be superimposed upon the natural year/station variation in CPUE, which was modelled as $(YS)_{tk} \sim N(0, \sigma_{YS}^2)$ in ME.2. Suppose the depredation effect followed $\lambda_{tk} \sim N(\lambda, \sigma_\lambda^2)$. Assuming independence, the variance of year/station effects would equal $\sigma_{YS}^2 + \sigma_\lambda^2$ with depredation ($F = 1$), and σ_{YS}^2 otherwise ($F = 0$). Thus, to estimate potential variation in depredation effects in ME.3 models, we added a random-effects term $(YS)_{tk,F=1}$ for depredation events only (i.e., the variance of this term represents the *additional* variance associated with depredation events). All mixed-effects models were fit using the restricted maximum likelihood method of the `glmer` function in R (R Core Team 2012).

In summary, we fit five models (QP, NB, ME.1, ME.2, ME.3) to each area to test for depredation effects of sperm whales. In addition, we examined two different depredation flags (F) that have been recorded for year/station combinations. The first flag indicated a sperm whales sighting, while the second, less prevalent flag indicated evidence of depredation (damaged fish, hooks, etc.).

Area-specific model results

Across years 1998-2012, a total of 1154 year/station combinations were examined in models of sperm whale depredation (Table 3C.1). Of these, 241 (21%) were flagged for depredation based on presence (Flag 1), while only 149 (13%) were flagged based on evidence (Flag 2). Proportions of flagged units were lowest for the WGOA region and highest for WY (Table 3C.1).

Based on Flag 1, estimates of sperm whale depredation (λ) differed appreciably among areas, and in particular, among models (Table 3C.2). For WGOA, which had limited depredation data (Table 3C.1), the QP and NB models gave nonsensical estimates (with huge standard errors) that implied huge proportional increases in CPUE due to depredation (Table 3C.2). In contrast, the three ME models provided similar and reasonably precise estimates; however, these estimates implied slight positive effects of depredation (e.g., a proportional change of 1.12 or a 12% increase in CPUE) and were not significant ($P > 0.2$).

Depredation estimates were more consistent for the remaining three regions (Table 3C.2). For CGOA, estimates were generally weak and none were significant (all $P > 0.37$). Estimates for WY varied widely

across models implying proportional changes of 0.96 (a 4% reduction of CPUE) for model QP, 0.44 (56% reduction) for NB, and roughly 0.8 (20% reduction) for the ME models. All ME estimates were significant ($P \leq 0.001$). Likewise, for EY/SE, the QP and NB estimates were quite different and imprecise (high SEs), while ME estimates were consistent (~17% reductions), precise, and significant ($P < 0.001$).

Depredation estimates for Flag 2 showed similar patterns (Table 3C.3). Note that WGOA was excluded because this region had only one flagged unit (Table 3C.1). Across regions, the QP and NB models provided imprecise estimates that often differed strongly from those of the ME models. In general, the ME estimates indicated reductions in CPUE due to sperm whale depredation of roughly 10% for CGOA (all $P > 0.14$), 12 to 18% for WY ($P < 0.015$), and 19% for EY/SE ($P < 0.001$).

The components of variation in CPUE data differed considerably across regions. Variance estimates are reported for ME.3 models using Flag 1, with depth strata (D) treated as a random effect (Table 3C.4). For example, differences among depth strata (D) accounted for just 10.5% of the variation in CPUE for CGOA, but 50.5% for EY/SE. Our interest lies in the additional year/station variation due to depredation. Without depredation, the standard deviation of year/station random effects (YS) ranged from a low of 0.21 for EY/SE to a high of 0.36 for WGOA. There was mixed evidence of additional variation due to depredation events. The largest value of SD($YS_{F=1}$) was 0.24 for CGOA, implying an additional 10.6% variation in CPUE among depredated units due to variability in the effect of depredation. Slightly higher estimates for SD($YS_{F=1}$) were found for Flag 2 data (0.30 for CGOA, 0.23 for WY, and 0.16 for EY/SE). However, as noted below, such values for SD($YS_{F=1}$) are likely to have little consequence for model estimation of depredation effects.

Given the often divergent estimates of whale depredation provided by the QP, NB, and ME models, we conducted detailed simulations to determine the expected accuracy and precision of competing model estimates. These simulations demonstrated that for unbalanced datasets (i.e., sporadic whale depredation events across stations and years), the ME models provided vastly superior estimates of whale depredation compared to the QP and NB models (both in terms of point estimates and standard errors). Despite their structural differences, all three ME models performed similarly well, even when the simulated data included random effects for depredation (e.g., simulated SD($YS_{F=1}$) = 0.2), which is a component only included in the ME.3 model structure.

Across-area models

Based on the simulation results noted above, analysis of across-area models was limited to mixed models with complex structure. For sperm whales, four mixed models were fit to data across all areas. These models started with the structure defined in equation (1), treating area (A_i), depth stratum (D_j), and their interaction $(AD)_{ij}$ as fixed effects and all remaining terms as random effects. The first model (S.1) estimated the mean effect of depredation by including the term F_{tk}. Model S.1 also accounting for potential variation in depredation effects across events by including a random-effects term $(YS)_{tk,F=1}$. Building on S.1, the second model (S.2) tested for differences in depredation effects among areas by including the interaction $(AF)_{itk}$. The third and fourth models examined evidence of a time trend in depredation effects. The third model (S.3) included a random-effects term for depredation by year ($Y_{t,F=1}$). The fourth model (S.4) included explicit linear trends (fixed effects) modelled as $T_t + (TF)_{tk}$, where T denotes year treated as a continuous variable. This formulation provides estimates of the trend in non-depredated CPUE and the difference in trend associated with depredation. The four across-area models were fitted separately to data for the two sperm whale flags ("presence" and "evidence").

Using Flag1 (presence), the across-area estimate for sperm whale depredation implied a proportional change in CPUE of 0.88 (95% CI: 0.83-0.94), that is, a 12% reduction in CPUE (model S.1, Table 3C.5). However, there was evidence of area differences in the depredation effect. Model S.2, which included area effects, had a lower AIC than S.1 ($\Delta AIC = 8.4$) and a significantly better fit based on the likelihood-ratio test (LRT, $P = 0.002$). Area-specific estimates of proportional change ranged from 0.77 for WY to 1.10 for WGOA (Table 3C.5). Obviously, the estimate for WGOA is not biologically valid (i.e., sperm

whale depredation cannot increase CPUE). However, after removing WGOA, estimates for models S.1 and S.2 changed little, and areas differences remained significant (ΔAIC = 6.4; LRT P = 0.006).

In contrast, there was weak evidence of area differences for Flag 2 (evidence). (These analyses excluded the WGOA region because it had only one depredated unit.) The across-area estimate of depredation implied a proportional change in CPUE of 0.84 (a 16% reduction; model S.1, Table 3C.5), while area-specific estimates ranged from 0.80 for EY/SE to 0.94 for CGOA (model S.2). However, the area-specific model (S.2) had a slightly higher AIC and did not significantly improve fit (LRT, P = 0.25). In addition, there was stronger evidence of variation in depredation effects using Flag 2 (SD[$YS_{F=1}$] ~ 0.2) than for Flag 1 (SD < 0.06) (Table 3C.5).

There was little evidence of time trends in the effects of sperm whale depredation. There was no discernable pattern in year-specific random effects for depredation (model S.3) for either Flag 1 or Flag 2 models, and linear trend estimates for depredation (model S.4) were positive and weak in both cases (P = 0.35 for Flag 1 and P = 0.24 for Flag 2).

Summary and applications

We conclude that mixed-effects modelling is the most promising method for estimating the effect of depredation for sperm whales. Our results did not show a time varying trend in the effect of depredation or presence when they occur (however, incidence of depredation and presence have been increasing). We also found that it was difficult to estimate depredation effects for data sparse regions (WGOA and CGOA). We found similar results using either sperm whale presence or evidence of depredation, but we are more confident in the quality of the presence data. Given these results, we recommend when implemented that an area-wide effect of sperm whale presence and variance be estimated and used as a correction to abundance indices. **The CPUE expansion factor from this analysis is 1.14 for stations where sperm whales are present.** This expansion factor should be re-estimated every few years to ensure it is not changing from the applied estimate. We show applications of the estimated sperm whale depredation from these GLMM models in the ***Applications to the stock assessment*** section using model runs OAW, NAW, NAWK, and NAWA). The effect on the overall abundance index (e.g., Figures 3C.1, 3C.2) is an increase of between 2-5% after accounting for sperm whale depredation.

While we believe we have determined a useful correction for sperm whales, and possibly killer whales, it remains questionable when and whether to utilize these corrected indices in the assessment. First, we do not know the extent of sperm whale depredation prior to 1998 in the survey. Considering its apparent increase, we believe historically it may have been a minor impact, but it is an added uncertainty. Second, it may not be prudent to adjust for whale depredation in the survey and increase the estimates of spawning biomass and ABC, while still not accounting for the additional mortality in the fishery that can be attributed to whale depredation. We regard accounting for this additional mortality in the fishery as the second phase of this project, in which we will use similar modeling methods. The data available to estimate mortality in the fishery are sparse and obtaining precise estimates will be challenging. A post-doctoral researcher from the National Research Council will be starting in December 2014 to aid in this project. Finally, adjusting apportionment in relation to the variable whale depredation across areas is also an important consideration. A more detailed document or journal article addressing modeling sperm whale and killer whale depredation and application to the sablefish stock assessment is forthcoming.

Applications to the stock assessment model

We conducted a number of sensitivity models with different potential mechanisms of accounting for mortality by sperm whale depredation on the survey and in the fishery (Table 3C.6). There are a variety of ways one might consider accounting for this mortality. In Table 3C.6 there are 21 model runs that have some scenario that could be related to whales. The major scenario groups are variations on the following five themes with what we consider to be plausible “low” and “high” states of nature:

1) Whale depredation is a source of fishing mortality, and it occurs on longline gear.
2) Whale depredation is an increase in natural mortality, as in the sablefish vulnerability to predators has been increased
3) Whale depredation began in 1998
4) Whale depredation has occurred throughout the modeled time series
5) Whale depredation has reduced survey catch rates

Most scenarios gave reasonably similar predictions for key parameters (Table 3C.7).The lowest ABC projection was for the ICB scenario which added an increasing amount of catch to the fixed gear fleet since 1998. The highest ABC projections occurred for those scenarios where either natural mortality or survey RPNs was monotonically increasing since 1998 (IMB, ISB, Figure 3C.3). As expected, most scenarios showed higher spawning biomass, ABCs, and recruitment from the reference model (BASE, Table 3C.6, and Figure 3C.3). The range of estimates of female spawning biomass appear to be relatively insensitive to these different accounting of whale depredation (Figure 3C.4, Table 3C.8). However, when we look only at the recent series of female spawning biomass estimates in terms of absolute and relative differences (Figures 5, 6), the effects can be more easily perceived and appear more substantial. We believe that this range of scenarios sets reasonable boundaries on how accounting for whale depredation inside the stock assessment would affect model results. Some of the ABCs resulting from these scenarios are considerably larger than the reference case. However, it would be expected that if ABCs are increased by correcting for survey depredation, it would be necessary to somehow decrement those ABCs for the additional mortality caused by depredation in the fishery.

Variance estimation and missing areas

The longline survey index currently uses a fixed CV of 5% for sablefish in the stock assessment model. Some bootstrap analyses were conducted to arrive at this number (Sigler 2000), but it was an approximation because there is covariance between depth strata within a station and between station depth strata combinations. We have since developed more appropriate analytical variance estimates that include covariances and the additional variance introduced by correcting for whale depredation. For the most part, the coefficients of variation (CVs) for the all-area index were not on average much different than the assumed 5%. However, there is some interannual variability, and the method now provides variance estimates for smaller geographic regions, which will be useful for spatial models and other groundfish assessments that utilize the longline survey index. The estimated coefficients of variation for sablefish from 1990-2013 are shown in Figure 3C.7.

The Aleutian Islands (AI) and Bering Sea (BS) are sampled biennially. The abundance index for the unsampled years are filled in using the previous survey of the area scaled by the average change in the Gulf of Alaska areas, which are sampled annually. In this case, the average GOA index is calculated from the four management areas in the GOA. This approach has an obvious drawback if the six areas are relatively uncorrelated in trend. For example, when the observed mean catch/hachi is plotted by area, it is clear that the Bering Sea index is not positively correlated with any of the other areas, and the Aleutian Islands area is significantly negatively correlated with the Central Gulf of Alaska. Therefore, using this approach across all areas may result in a retrospective bias if estimates in unsampled areas do not match the underlying trend for that area. To fill in the missing years, we demonstrated two alternative methods that have been shown to be useful by the Plan Team working group on survey averaging. In our sensitivity results we show the effect of using an ARIMA (0,2,2, local linear smoothing) model and a random effects model to fill in the BS and AI missing years from 1996-2013. The choice of which of these methods is superior is not yet clear, but they have large effects on the overall RPN index in some years (Figure 3C.8). These are shown in models NAWA and NAWK in Table 1.

New survey area sizes

Previous estimates of the size of each geographic area used to estimate RPNs and RPWs were devised before geographic information systems (GIS) and accurate, high resolution bathymetric maps were readily available. Echave et al. (2013) estimated the area sizes currently used in the AFSC longline survey using GIS methods and updated bathymetry. The largest increase in estimated area sizes occurred in Spencer Gully (in the EY/SE management area) and Bering 3 slope areas (Figure 3C.9). The largest negative changes were in the NW Aleutians slope and East Yakutat slope areas. Overall, more areas were calculated to be smaller than the previously used estimates. Only the shallowest depth stratum used in standard RPN/RPW calculations (200-300 meters) increased, while the areas in deeper depths decreased slightly (Figure 3C.10). In addition, Echave et al. (2013) estimated the size of the areas in the depths sampled between 150-200 m which previously were not used in abundance index calculations. The addition of these depths in the RPN/RPW index increases the potential utility of the longline indices for species such as Pacific cod, halibut and rockfish. We show the effect of the area recalculation on the overall sablefish RPN index for the base model (Figures 11, 12) and in model runs beginning with OA, and NA in Table 3C.6.

Maturity research

The first age at maturity and fecundity study of female sablefish sampled in Alaska near their spawning period was undertaken in 2011. Skipped spawning was documented for the first time in sablefish. These winter samples provided a similar age at 50% maturity estimate (6.8 years) as the mean of visual observations taken during summer surveys from 1996-2012 (mean = 7.0 years) and the estimate currently used in the assessment (mean =6.6 years), when skipped spawners were classified as mature. Interestingly, skipped spawning appeared to be occurring for a substantial portion of the older mature population in shallower shelf waters which could have implications for population dynamics. In addition, four female sablefish were fit with pop-off satellite tags during the winter survey. Despite being a highly migratory species throughout their lives, preliminary results of this tagging data suggest that these sablefish exhibited site fidelity during the spawning season. This may be related to whether a fish is spawning in the current season. The paper describing the study is in the process of being submitted for publication.

Movement

A study on sablefish movement and mortality has been accepted for publication. The analysis included over 300,000 tag releases and over 27,000 tag recoveries from 1979-2009. Movement was modeled in three size groups, small (<57 cm), medium (57 – 66 cm), and large (>66 cm) which corresponded approximately to immature, maturing, and mature fish. Annual movement probabilities were high, with annual probabilities ranging from 10-88%, depending on area of occupancy at each time step, and size group. Overall, movement probabilities were very different between areas of occupancy and moderately different between size groups (Figure 3C.13). Estimated annual movement of small sablefish from the Central GOA had the reverse pattern of a previous study using a small subset of these data, with 29% moving westward and 39% moving eastward. The previous study showed movement of small fish to be primarily westward. Movement probabilities in the current study also varied annually with decreasing movement until the late 1990s, and increasing movement until 2009. Year specific magnitude in movement probability of large fish was highly negatively correlated with the total female spawning biomass estimate from the federal stock assessment. This may indicate that slower somatic growth at high population sizes leads to lower movement probabilities. Total average mortality estimates from time at liberty were similar to the values estimated by the stock assessment model. Results do not show an obvious ecologically directed movement pattern. The analysis in this study was conducted using sablefish lengths, but efforts are underway to read ages from a sample of otoliths taken from tag recoveries. These

data will aid in estimating age-specific movement and be more useful for conducting management strategy evaluations of spatial stock assessment models.

Fishery abundance index

Estimating abundance from fishery dependent data is a well known challenge. Alaska sablefish is the only model in Alaska that incorporates fishery CPUE data as an index of abundance. Presently, longline CPUE is determined through a targeting algorithm, but not statistically standardized. During a one year National Research Council appointment, Mateo and Hanselman (2014) developed several statistical models that appear to hold promise for modeling fishery CPUE for standardization. Covariates that explained the most variation in the models were CPUE of giant grenadier, depth, longitude, and Pacific halibut CPUE. We wish to extend these models to develop an index for use in the sablefish model, and to potentially estimate whale depredation effects on the fishery. This work will continue as a new postdoctoral researcher from the NRC joins us in December, 2014.

Apportionment

In 2013, we recommended that the apportionment proportions to each area be fixed at 2012 values. We justified this because the apportionment strategy was devised to reduce interannual variability in catch recommendations while still reflecting shifts in abundance. We showed that this variability in catch recommendations by area had been increasing since 2007. While some of these changes may actually reflect interannual changes in regional abundance, they most likely reflect the high movement rates of the population and the high variability of our estimates of abundance in the Bering Sea and Aleutian Islands due to whale depredation and estimating abundance index values in years when these areas are not sampled.

Because of the high variability in apportionment seen in recent years, we suggested that the standard method was not meeting the goal of reducing the magnitude of interannual changes in the apportionment. We, therefore, proposed that the apportionment scheme be reevaluated.

A Ph.D. project with the University of Alaska-Fairbanks was initiated in 2012 to conduct management strategy evaluations to re-examine the apportionment strategy with respect to biological and economic yield. The student involved has been working closely with us and has begun testing spatial sablefish stock assessment models to be used in evaluating apportionment. It will also be important to integrate continuing research into whale depredation effects into analyses regarding the implications of different apportionments. The apportionment strategies being tested will focus on objectives that include but are not limited to:

1) Reduce annual variation in TAC changes
2) Maximizing economic yield by region and for the total fishery
3) Maximizing sustainable yield by region and for the total fishery
4) Maintaining a minimum level of harvest in every region

Some apportionment strategies that may attain these goals may include:

1) Status quo (5 year exponential average of fishery and survey abundance)
2) Apportion from terminal year abundance of a spatially explicit model
3) Apportion based on a longer term (e.g., 10 year) average
4) Equal allocation (Divide TAC by the number of regions)
5) Apportion based on size or numbers (to protect spawning biomass)

Meanwhile, for the same reasons we presented in 2013, until the apportionment scheme has been adequately evaluated it seems prudent to keep the apportionment fixed until there are other viable options

to be considered. Therefore, for 2015, we recommend keeping the apportionment fixed from 2014, so that all areas ABCs change equally in accordance with the model results.

Future

There has been much recent research progress on sablefish stock assessment. However, several major challenges remain that include estimating and accounting for whale depredation in the fishery, evaluating the current apportionment strategies, developing a spatial research model of sablefish that includes movement, and determining the ecological basis of year class strength. There is ongoing or planned research for each of these challenges. We are trying to develop a portfolio of complementary model changes before implementing work already accomplished because many changes require other work to balance them. The most obvious example is accounting for whale depredation. We have the potential to correct survey estimates now, but developing estimates for the fishery that account for whale depredation is more difficult. Because it is fishery data, it is noisy, and the observations of depredation are sparse and unbalanced. Thus, we can develop these estimates but they will be less certain than those we can obtain for the survey. In addition, part of our fishery abundance index includes logbook data which do not include whale depredation observations. Until we have both fishery and survey estimates and a good way to use them in concert, it would be unwise to apply one alone. We will be conducting a sablefish CIE review in 2016.This review will provide expert opinion regarding the results of these research projects and provide advice to help integrate the findings into the sablefish stock assessment. We then hope to incorporate this work into the assessment model and bring forward a benchmark assessment.

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Table 3C.1. Number of year/station replicates by area used in models of sperm whale depredation. "Flag 1" corresponds to sperm whale presence; "Flag 2" corresponds to evidence of depredation (damaged fish, hooks, etc.). Data from years 1990 through 2012.

Area	Total	Flag 1	Percent	Flag 2	Percent
WGOA	213	15	7.0	1	0.5
CGOA	366	56	15.3	29	7.9
WY	184	71	38.6	56	30.4
EY/SE	391	99	25.3	63	16.1
Total	**1154**	**241**	**20.9**	**149**	**12.9**

Table 3C.2. Estimates of sperm whale depredation (λ) by model and area using Flag 1 (presence). SE = standard error of the estimate. The estimate of proportional change is given by exp(λ) (e.g., a value of 1.0 implies no change; a value of 0.8 implies a 20% reduction in mean CPUE due to depredation).

Area	Model	Estimate	SE	P value	Proportional Change
WGOA	QP	13.4	708	0.985	6.3E+05
	NB	36.9	7.7E+06	1.000	1.0E+16
	ME.1	0.159	0.127	0.211	1.17
	ME.2	0.114	0.131	0.384	1.12
	ME.3	0.113	0.131	0.389	1.12
CGOA	QP	0.161	0.370	0.663	1.17
	NB	-0.015	0.417	0.971	0.99
	ME.1	-0.047	0.053	0.371	0.95
	ME.2	-0.023	0.055	0.674	0.98
	ME.3	-0.026	0.062	0.677	0.97
WY	QP	-0.044	0.388	0.911	0.96
	NB	-0.829	0.547	0.130	0.44
	ME.1	-0.188	0.055	0.001	0.83
	ME.2	-0.259	0.069	<0.001	0.77
	ME.3	-0.257	0.069	<0.001	0.77
EY/SE	QP	-0.193	0.332	0.560	0.82
	NB	0.264	0.515	0.608	1.30
	ME.1	-0.199	0.038	<0.001	0.82
	ME.2	-0.187	0.043	<0.001	0.83
	ME.3	-0.187	0.044	<0.001	0.83

Table 3C.3. Estimates of sperm whale depredation (λ) by model and area using Flag 2 (evidence). SE = standard error of the estimate. The estimate of proportional change is given by exp(λ) (e.g., a value of 1.0 implies no change; a value of 0.8 implies a 20% reduction in mean CPUE due to depredation).

Area	Model	Estimate	SE	P value	Proportional change
CGOA	QP	0.711	0.444	0.110	2.04
	NB	0.751	0.444	0.091	2.12
	ME.1	-0.102	0.069	0.141	0.90
	ME.2	-0.097	0.071	0.173	0.91
	ME.3	-0.096	0.089	0.280	0.91
WY	QP	-0.044	0.388	0.911	0.96
	NB	-0.829	0.547	0.130	0.44
	ME.1	-0.129	0.053	0.015	0.88
	ME.2	-0.195	0.067	0.004	0.82
	ME.3	-0.192	0.071	0.007	0.83
EY/SE	QP	-0.133	0.339	0.695	0.88
	NB	-0.185	0.460	0.688	0.83
	ME.1	-0.208	0.043	<0.001	0.81
	ME.2	-0.218	0.048	<0.001	0.80
	ME.3	-0.216	0.051	<0.001	0.81

Table 3C.4. Estimates of standard deviation and components of variance (%) for random-effects terms in ME.3 models of CPUE with sperm whale depredation using Flag 1 (presence). The shaded row highlights the additional variance due to random depredation effects.

	Standard deviation				Components of variance (%)			
Term	WGOA	CGOA	WY	EY/SE	WGOA	CGOA	WY	EY/SE
Year (Y)	0.19	0.16	0.28	0.21	3.9	4.8	8.3	4.5
Depth (D)	0.59	0.24	0.55	0.72	37.5	10.5	33.2	50.5
Station (S)	0.30	0.14	0.00	0.42	10.0	3.3	0.0	17.2
Y x D	0.24	0.19	0.23	0.09	6.4	6.8	5.5	0.9
Y x S	0.36	0.24	0.24	0.21	13.9	10.6	6.4	4.3
Y x S (F=1)	0.00	0.24	0.07	0.12	0.0	10.6	0.6	1.5
D x S	0.26	0.37	0.47	0.33	7.3	25.0	24.2	10.5
Y x D x S	0.44	0.40	0.45	0.33	20.9	28.3	21.9	10.6
Total					**100.0**	**100.0**	**100.0**	**100.0**

Table 3C.5. Estimates of sperm whale depredation (λ) for across-area models for Flag 1 (presence) and Flag 2 (evidence). SE = standard error of the estimate. Estimates of proportional change are given by exp(λ) with approximate 95% confidence intervals shown (LCI, UCI).

					Proportional change			Random effects	
Flag	Model	Area	Estimate	SE	exp(Est)	LCI	UCI	SD(YS)	$SD(YS_{F=1})$
1	S.1	All	-0.128	0.032	0.88	0.83	0.94	0.264	0.055
	S.2	WGOA	0.096	0.105	1.10	0.90	1.35	0.264	0.000
		CGOA	-0.016	0.055	0.98	0.88	1.10		
		WY	-0.265	0.066	0.77	0.67	0.87		
		EY/SE	-0.199	0.051	0.82	0.74	0.91		
2	S.1	All	-0.173	0.038	0.84	0.78	0.91	0.226	0.209
	S.2	WGOA						0.226	0.203
		CGOA	-0.066	0.075	0.94	0.81	1.09		
		WY	-0.190	0.064	0.83	0.73	0.94		
		EY/SE	-0.223	0.058	0.80	0.71	0.90		

Table 3C.6. List of scenarios with different ways to correct for sperm whale depredation, including new variance estimates for longline survey abundance, and using new area sizes.

Test	***Description***
BASE	Base model
CB	Increase fixed gear catch by 5% in all years
CS	Increase fixed gear catch by 2% in all years
CSB	Increase fixed gear catch and longline RPN by 5% in all years
CSS	Increase fixed gear catch and longline RPN by 2% in all years
EM	Estimate M deviations from 1998
ICB	Increasing trend on fixed gear catch by 1% per year since 1998
ICS	Increasing trend on fixed gear catch by 0.5% per year since 1998
ICSB	Increasing trend of fixed gear catch and longline RPN by 1% since 1998
ICSS	Increasing trend on fixed gear catch and longline RPN by 0.5% since 1998
IMB	Increasing trend of M by 1% per year since 1998
IMS	Increasing trend of M by 0.5% per year since 1998
ISB	Increasing trend on longline RPN by 1% per year since 1998
ISS	Increasing trend on longline RPN by 0.5% per year since 1998
MB	Increase M by 5% in all years
MS	Increase M by 2% in all years
NA	New longline survey area sizes
NAW	New longline survey area sizes with survey sperm whale correction
NAWA	New longline survey area sizes with survey sperm whale correction, and ARIMA area fill
NAWK	New longline survey area sizes with survey sperm whale correction, and random effects area fill
OA	Base model with survey variance estimates
OAW	Base model with survey sperm whale correction
SB	Increase longline RPN by 5% in all years
SS	Increase longline RPN by 2% in all years

Table 3C.7. Key results from various scenarios for accounting for sperm whale depredation, re-estimating survey variance, and new survey areas (see descriptions of scenarios in Table 1).

Test	-lnL	ABC	Catchability	Projected SSB	2008 YC	B40
BASE	1390.54	13.70	7.75	91.14	20.75	106.36
CB	1389.98	13.52	7.66	91.43	21.28	108.97
CS	1390.12	13.62	7.71	91.26	20.95	107.41
CSB	1389.98	13.53	8.04	91.47	21.29	108.99
CSS	1390.19	13.63	7.86	91.26	20.96	107.41
EMS	1390.54	13.70	7.75	91.14	20.75	106.36
ICB	1385.73	13.09	7.67	89.29	21.69	108.13
ICS	1387.98	13.39	7.71	90.22	21.21	107.22
ICSB	1395.85	17.20	7.63	104.24	25.34	112.51
ICSS	1392.21	15.37	7.69	97.52	22.93	109.36
IMB	1385.89	17.57	7.60	88.72	23.14	85.33
IMS	1387.84	15.84	7.67	90.00	21.87	95.35
ISB	1399.85	17.93	7.70	106.23	24.34	110.79
ISS	1394.55	15.70	7.72	98.47	22.46	108.51
MB	1390.88	14.81	7.61	91.81	21.84	103.78
MS	1390.45	14.14	7.69	91.42	21.18	105.28
NA	1398.37	13.88	7.41	91.61	21.58	106.66
NAW	1403.19	14.79	7.40	95.17	22.01	107.72
NAWA	1399.36	15.75	7.38	98.65	22.89	108.76
NAWK	1426.32	16.92	7.32	101.60	25.65	109.45
OA	1399.74	13.84	7.57	91.57	21.30	106.64
OAW	1404.07	14.74	7.56	95.05	21.75	107.69
SB	1390.54	13.71	8.13	91.18	20.75	106.38
SS	1390.54	13.70	7.90	91.16	20.75	106.37

Table 3C.8. Female spawning biomass trajectories from model scenarios for accounting for sperm whale depredation, re-estimating survey variance, and new survey areas (see descriptions of scenarios in Table 1).

Year	BASE	CB	CS	CSB	CSS	EMS	ICB	ICS	ICSB	ICSS	IMB
1977	129	132	130	132	130	129	129	129	129	129	129
1978	117	120	119	120	119	117	117	117	118	118	118
1979	112	115	113	115	113	112	112	112	113	113	112
1980	107	109	108	109	108	107	107	107	108	108	107
1981	106	108	106	108	106	106	106	106	106	106	106
1982	109	111	110	111	110	109	109	109	110	109	109
1983	121	123	122	123	122	121	121	121	122	121	121
1984	136	139	138	139	138	136	137	137	138	137	137
1985	152	155	153	155	153	152	152	152	154	153	153
1986	165	169	167	169	167	165	166	166	168	166	167
1987	171	175	173	175	173	171	172	172	174	173	173
1988	170	174	172	174	172	170	171	171	173	172	172
1989	164	167	165	167	165	164	164	164	166	165	165
1990	154	157	155	157	155	154	155	154	157	155	156
1991	143	146	144	146	144	143	144	144	146	145	145
1992	132	134	133	134	133	132	133	133	135	134	134
1993	122	123	122	123	122	122	123	122	125	123	124
1994	111	112	111	112	111	111	112	111	114	113	113
1995	103	104	103	104	103	103	104	103	106	104	105
1996	98	99	98	99	98	98	99	98	101	100	100
1997	95	96	95	96	95	95	96	95	99	97	97
1998	92	93	92	93	92	92	93	93	96	94	94
1999	88	89	89	89	89	88	90	89	93	91	91
2000	85	86	85	86	85	85	87	86	90	87	88
2001	82	83	82	83	82	82	83	83	87	85	84
2002	82	82	82	82	82	82	83	82	87	84	84
2003	84	85	84	85	84	84	85	84	90	87	86
2004	87	88	87	88	87	87	89	88	95	91	90
2005	92	92	92	92	92	92	93	92	100	96	95
2006	98	98	98	99	98	98	99	98	108	103	101
2007	103	104	103	104	103	103	104	103	114	108	106
2008	105	106	105	106	105	105	106	105	117	111	107
2009	104	105	104	105	104	104	105	104	116	110	106
2010	102	103	102	103	102	102	102	102	115	108	103
2011	100	100	100	100	100	100	100	100	112	106	100
2012	96	97	97	97	97	96	96	96	109	103	96
2013	93	94	93	94	93	93	92	93	106	100	92

Table 3C.8 (cont.). Female spawning biomass trajectories from model scenarios for accounting for sperm whale depredation, re-estimating survey variance, and new survey areas (see descriptions of scenarios in Table 1).

Year	IMS	ISB	ISS	MB	MS	NA	NAW	NAWA	NAWK	OA	OAW	SB	SS
1977	129	129	129	134	131	129	129	129	128	129	129	129	129
1978	118	118	118	122	119	117	118	118	117	117	118	117	117
1979	112	113	113	117	114	112	113	113	112	112	113	112	112
1980	107	108	108	111	109	107	108	108	107	107	107	107	107
1981	106	106	106	109	107	105	106	106	105	105	106	106	106
1982	109	110	109	113	110	109	109	109	109	109	109	109	109
1983	121	122	121	125	122	120	121	121	121	120	121	121	121
1984	137	138	137	141	138	136	137	137	137	136	137	136	136
1985	152	153	152	157	154	151	152	152	152	151	152	152	152
1986	166	167	166	171	167	165	166	166	166	165	166	165	165
1987	172	173	172	177	174	171	172	172	172	171	172	171	171
1988	171	172	171	176	173	170	171	171	171	170	171	170	170
1989	164	166	165	169	166	163	164	164	164	163	164	164	164
1990	155	156	155	159	156	154	154	155	155	154	154	154	154
1991	144	145	144	147	145	143	144	144	144	143	144	143	143
1992	133	134	133	136	134	132	133	133	133	132	133	132	132
1993	123	124	123	125	123	121	122	122	122	121	122	122	122
1994	112	113	112	114	112	111	112	112	112	111	112	111	111
1995	104	105	104	105	104	103	103	104	104	103	104	103	103
1996	99	100	99	100	99	98	99	100	100	98	99	98	98
1997	96	98	96	97	96	96	96	97	97	96	97	95	95
1998	93	95	93	94	93	93	94	95	95	93	94	92	92
1999	90	92	90	90	89	90	91	91	91	90	91	88	88
2000	86	89	87	87	86	86	88	88	88	86	88	85	85
2001	83	86	84	84	83	83	85	85	85	83	85	82	82
2002	83	86	84	83	82	83	84	85	84	83	84	82	82
2003	85	89	86	85	84	85	86	88	86	85	87	84	84
2004	88	93	90	89	88	88	90	91	89	88	90	87	87
2005	93	99	95	94	92	92	95	96	93	92	95	92	92
2006	99	106	102	100	98	98	101	103	100	98	101	98	98
2007	104	113	107	105	103	103	106	108	105	103	106	103	103
2008	106	116	110	107	105	105	108	111	108	105	108	105	105
2009	105	116	110	106	105	104	107	110	108	104	107	104	104
2010	103	115	108	104	103	102	105	108	107	102	105	102	102
2011	100	113	106	101	100	99	103	106	106	99	103	100	100
2012	96	110	103	97	97	96	100	103	104	96	100	96	96
2013	93	108	100	94	94	93	97	100	102	93	97	93	93

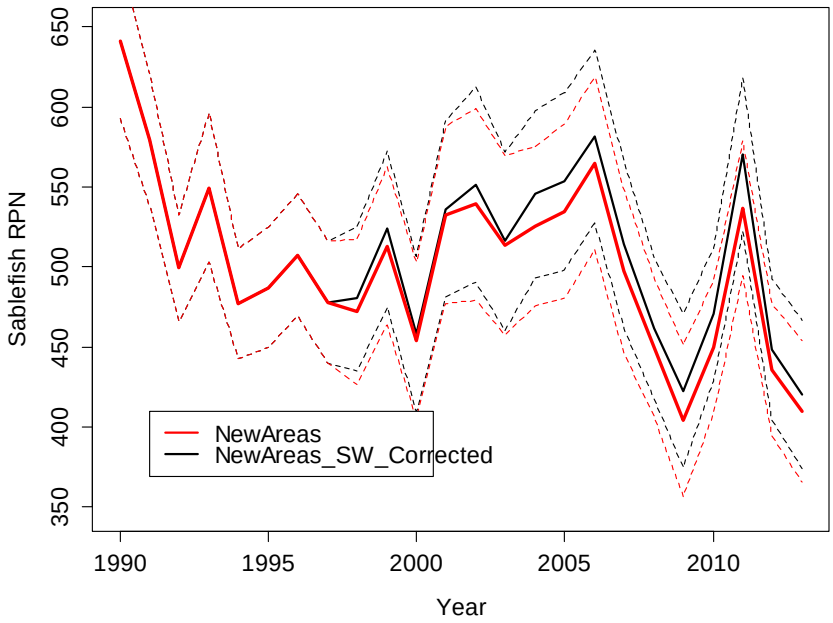


Figure 3C.1. An example of the effect of correcting for sperm whale depredation. Models correspond to NA and NAW in Table 1.

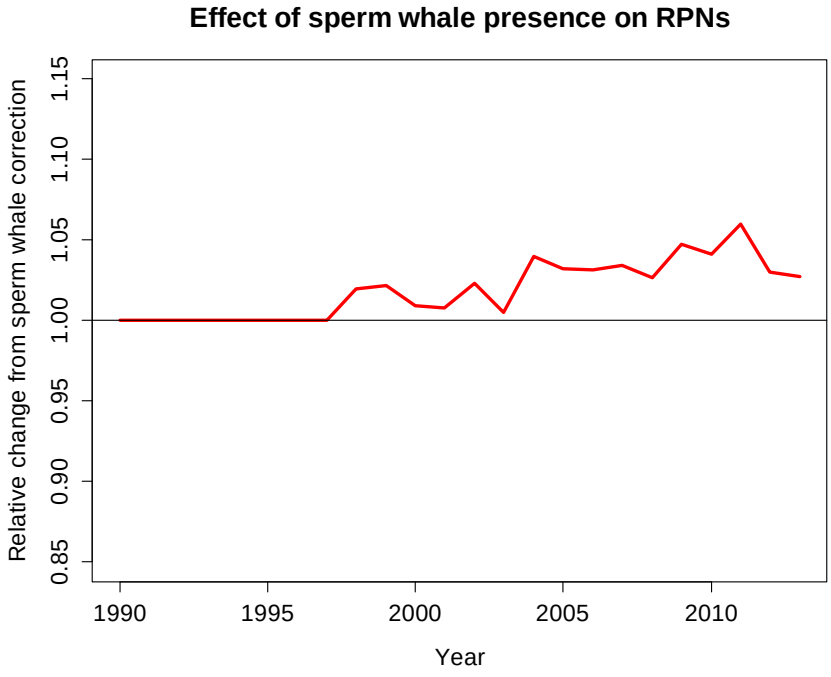


Figure 3C.2. The net increase in the index from the base model after correcting for sperm whale depredation. Black line at 1 corresponds to the NA model, red line is the NAW model in Table 1.

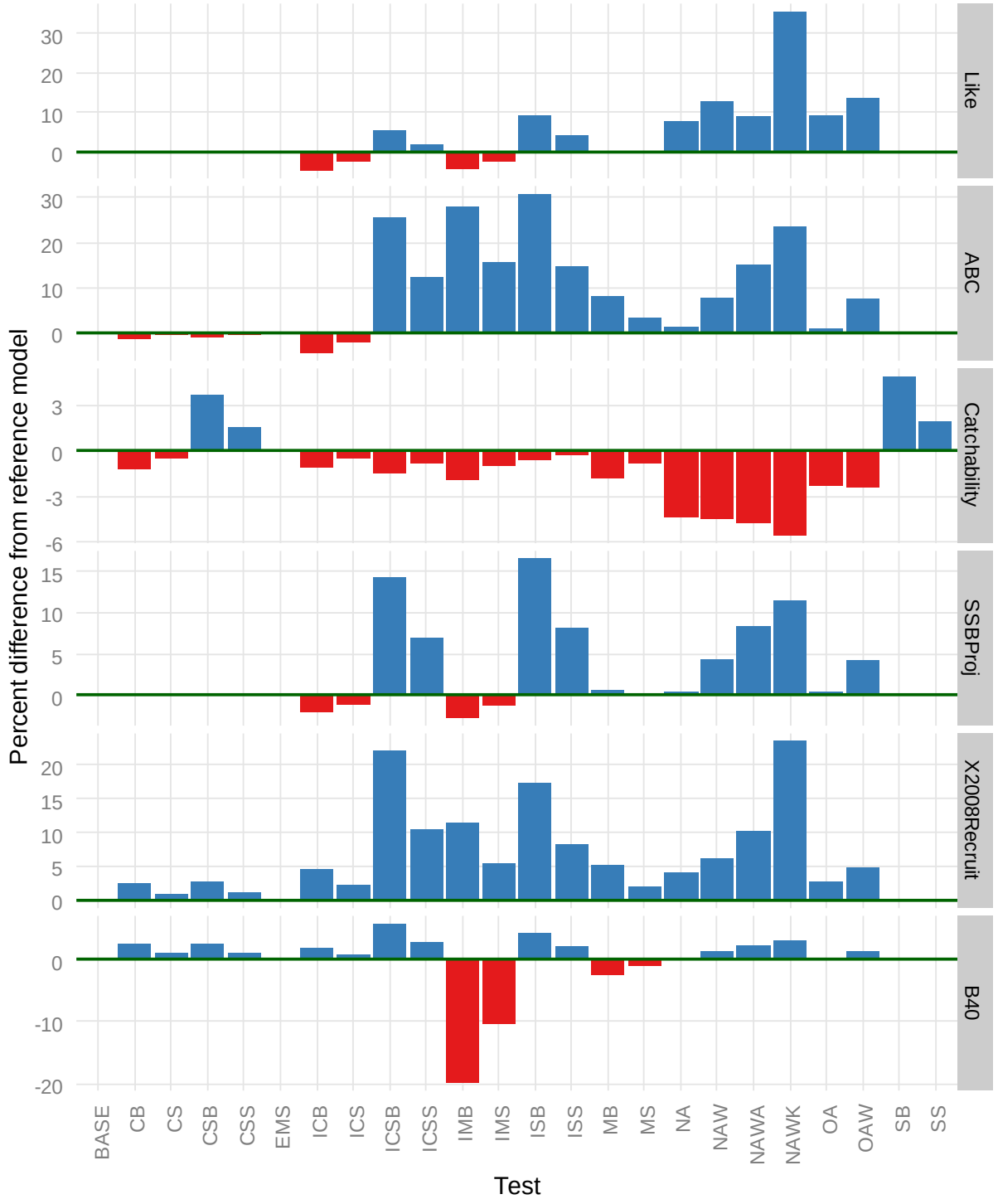


Figure 3C.3. Relative change in key results from sensitivity tests described in Table 1.

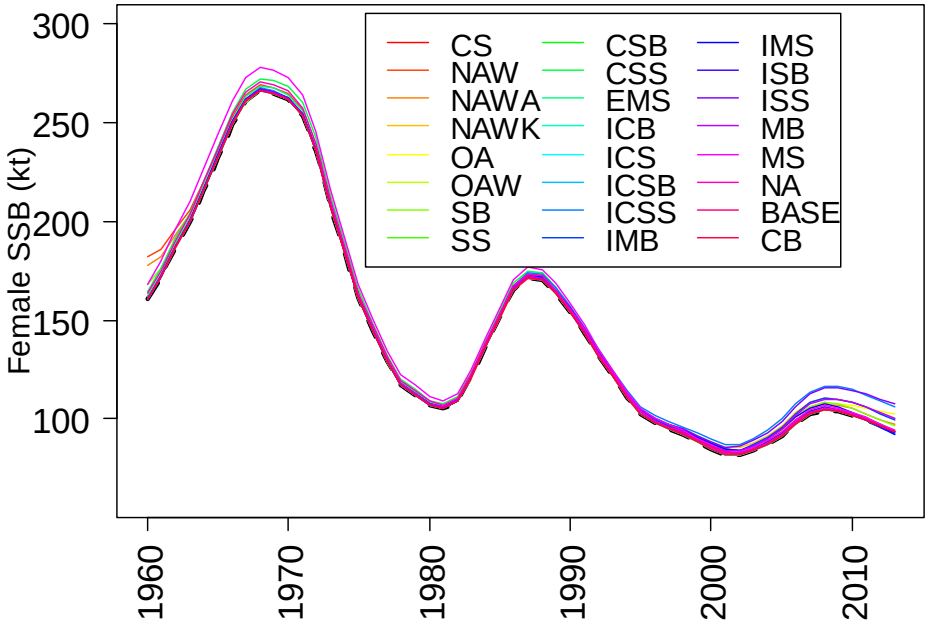


Figure 3C.4. Plots of female spawning biomass for sablefish model sensitivity tests from 1960-2013. Dashed black line is overplotted on the line for BASE model.

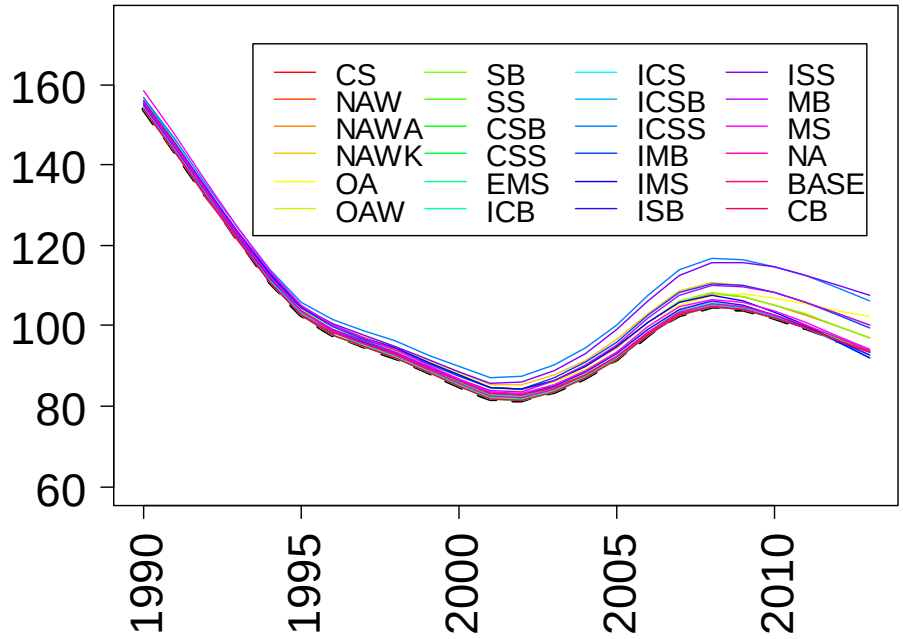


Figure 3C.5. Plots of female spawning biomass for sablefish sensitivity tests from 1990-2013. Dashed black line is overplotted on the line for BASE model.

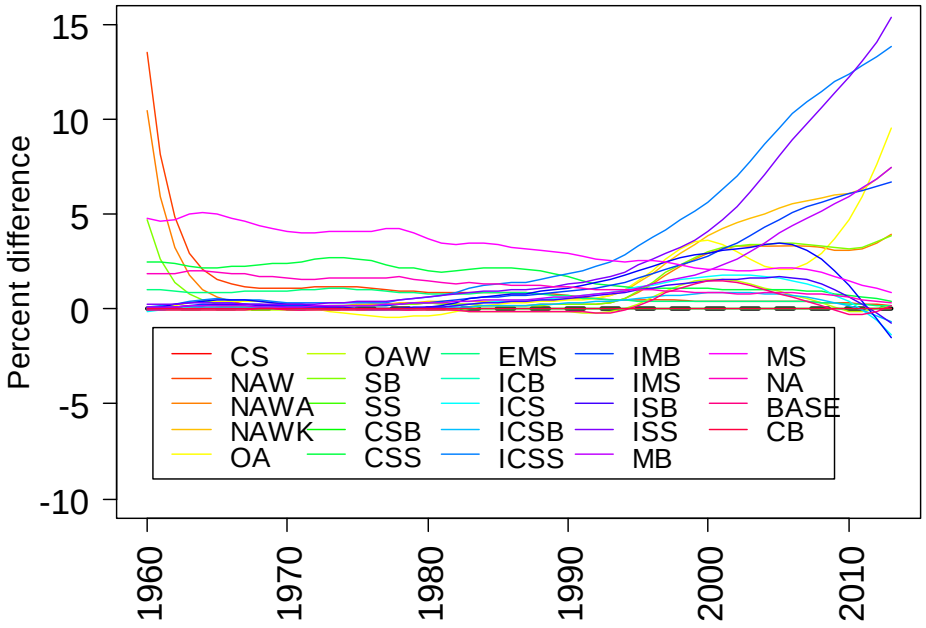


Figure 3C.6. Plots of relative female spawning biomass to reference model for sablefish sensitivity tests from 1990-2013. Dashed black line is overplotted on the line for BASE model.

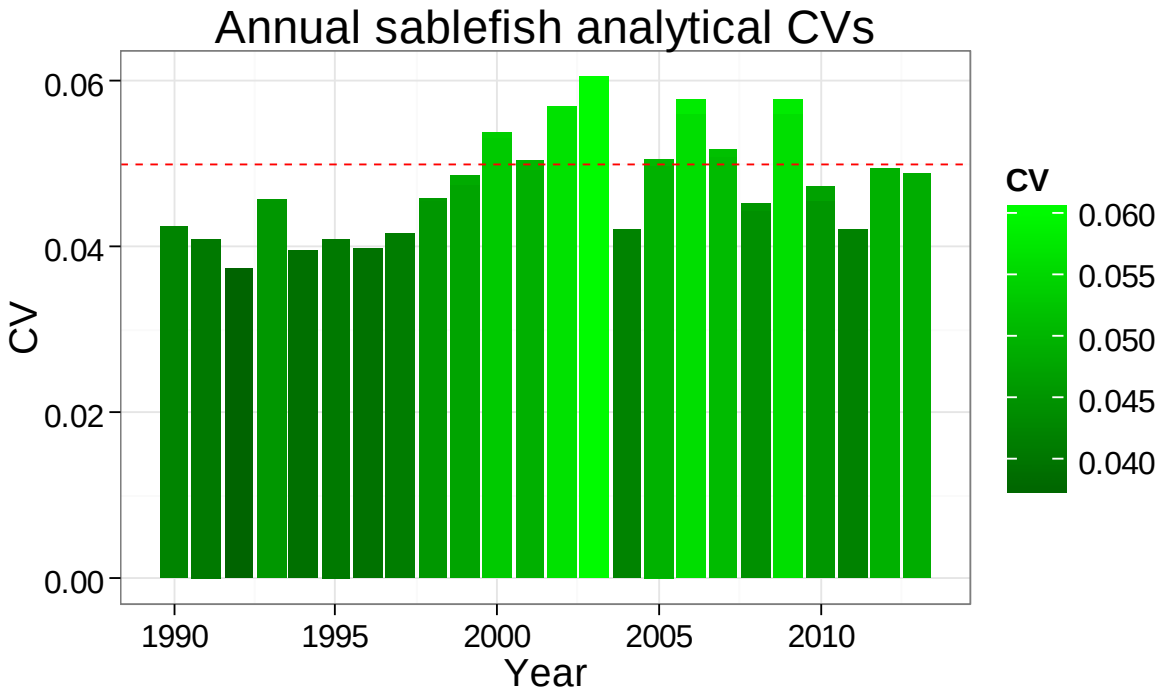


Figure 3C.7. Time series of coefficients of variation (CV) for the all-area sablefish longline RPN index. Five percent CV line is marked as a red dash line.

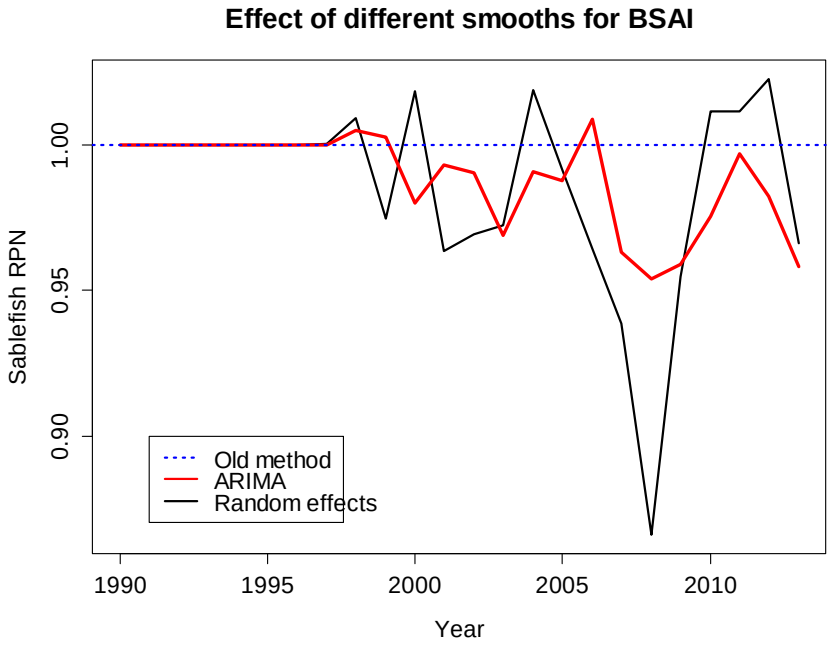


Figure 3C.8. The use of an ARIMA model and a random effects model to fill in missing years for the Bering Sea and Aleutian Islands areas and the effect on the sablefish RPN index.

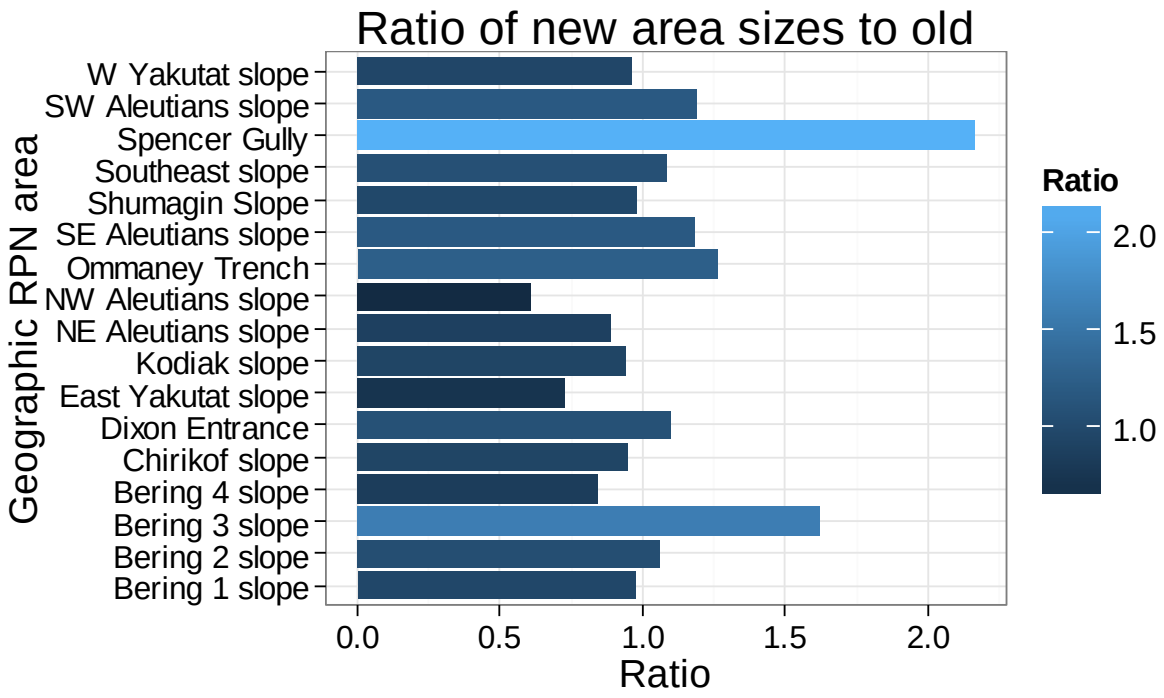


Figure 3C.9. The ratio of new area sizes calculated in Echave et al. (2013) to the area sizes currently used in the sablefish stock assessment by small geographic areas.

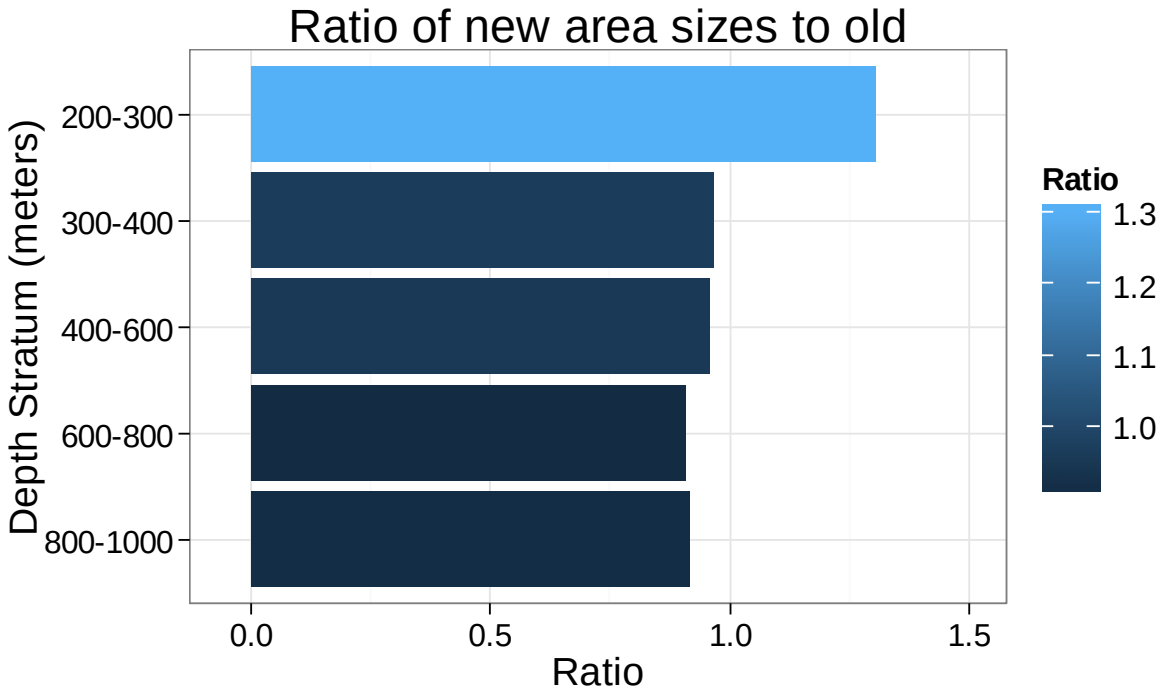


Figure 3C.10. The ratio of new area sizes calculated in Echave et al. (2013) to the area sizes currently used in the sablefish stock assessment by depth strata.

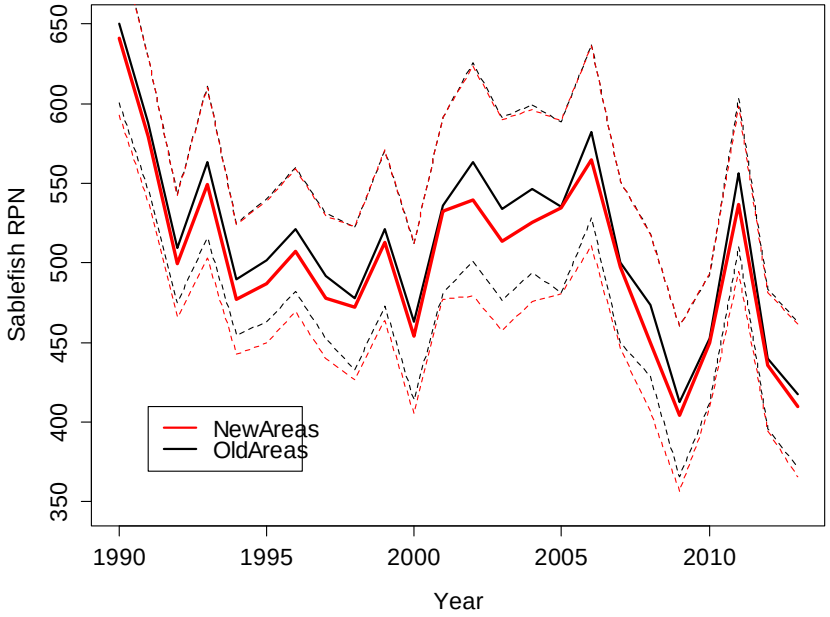


Figure 3C.11. Estimates of sablefish RPNs using new calculated area sizes from Echave et al. (2013) versus using old area sizes used in Hanselman et al. (2013).

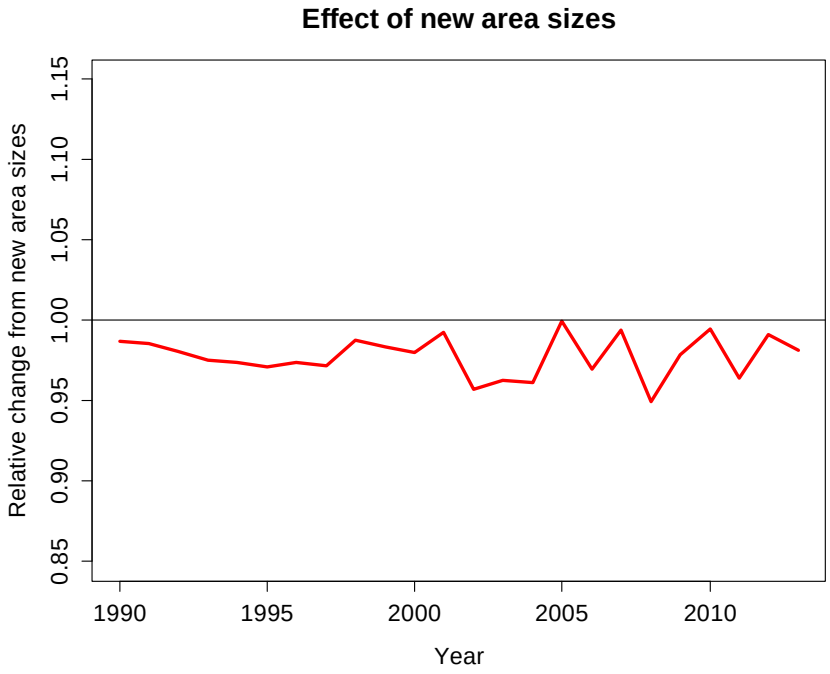


Figure 3C.12. Net effect of new area sizes. Line at 1 is the reference line from the base model in Hanselman et al. (2013).

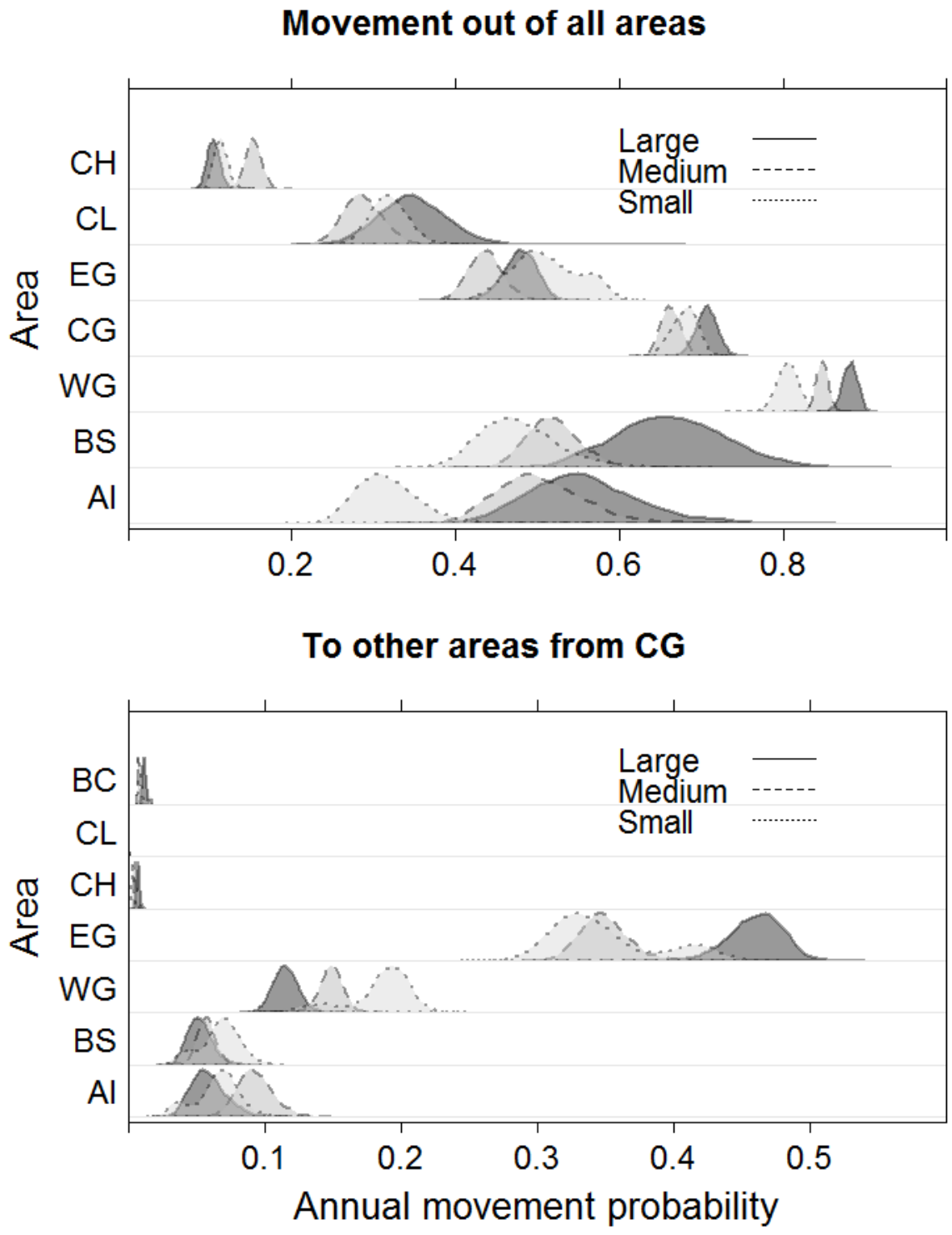


Figure 3C.13. Posterior probability distributions of annual sablefish movement probability by size group and area. Top panel is movement probability out of each area. Bottom panel is movement probability to each area from the central Gulf of Alaska. AI = Aleutian Islands, BS = Bering Sea, WG = western Gulf of Alaska, CG = central Gulf of Alaska, EG = eastern Gulf of Alaska, CH = Chatham Strait, CL = Clarence Strait, Small = <57 cm, Medium = 57-66 cm, Large = >66 cm.

4. Assessment of the yellowfin sole stock in the Bering Sea and Aleutian Islands

Thomas K. Wilderbuer, Daniel G. Nichol and James Ianelli

Executive Summary

Summary of Changes in Assessment Inputs

Changes to the input data

1) 2013 fishery age composition.
2) 2013 survey age composition.
3) 2014 trawl survey biomass point estimate and standard error.
4) Estimate of the discarded and retained portions of the 2013 catch.
5) Estimate of total catch made through the end of 2014.
6) Updated maturity estimates from samples collected in 2012.

Changes to the assessment methodology

No changes were made to the assessment methodology. The assessment updates last year's with results and management quantities that are similar to the 2013 assessment. Yellowfin sole continue to be well-above B_{MSY} and the annual harvest remains below the ABC level. The stock is trending upwards due to a strong 2003 year class.

Summary of Results

Quantity	As estimated or *specified last* year for: 2013	2014	As estimated or *recommended this* year for: 2015	2016
M (natural mortality rate)	0.12	0.12	0.12	0.12
Tier	1a	1a	1a	1a
Projected total (age 6+) biomass (t)	2,113,000	2,188,000	2,127,800	2,100,000
Female spawning biomass (t)				
Projected	581,100	594,800	644,200	648,600
B_0	989,800		989,800	
B_{MSY}	366,000		391,000	
F_{OFL}	0.123	0.123	0.125	0.125
$maxF_{ABC}$	0.113	0.113	0.117	0.117
F_{ABC}	0.113	0.113	0.117	0.117
OFL (t)	259,700	268,900	266,400	262,900
maxABC (t)	239,800	248,300	248,800	245,500
ABC (t)	239,800	248,300	248,800	245,500
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Marine Fisheries Service and should not be construed to represent any agency determination or policy.

Projections are based on estimated catches of 150,000 t used in place of maximum ABC for 2015 and 2016.

Responses to SSC and Plan Team Comments on Assessments in General

No general comments.

Responses to SSC and Plan Team Comments Specific to this Assessment

The SSC notes that maturity data from 1992 and 1993 are used to estimate maturity at age. It may be prudent to reexamine maturity ogives with new data in the near future. Also, the SSC appreciates the retrospective plot of female spawning biomass (Fig. 4.21). In next year's assessment, the SSC requests some analysis of this retrospective plot, which appears to indicate increasingly optimistic biomass estimates with the addition of new data, indicating a negative bias in the model.

New maturity data were introduced into the assessment model for 2015 management from specimens collected in 2012 and subject to histological examination in 2013. Results were very similar to the 1992 and 1993 collections and are shown in Table 4.10. We will try to analyze the retrospective plots and associated bias in 2015.

Plan Team comments: There was some discussion about smoothing the weight-at-age data requested by the SSC and a suggestion to consider a median smoother (among others) in the future. It was also noted that fishing effort was relatively high late into the season this year, but this was not a change in fishing behavior that warranted further discussion. Also noted was a near 50/50 sex ratio and a very large discrepancy between average ages of fish caught in the fishery versus those caught in the survey; just reiterating the ability of the fleet to target older (i.e., larger) fish.

No additional smoothing was tried in this year's assessment.

Introduction

The yellowfin sole (*Limanda aspera*) is one of the most abundant flatfish species in the eastern Bering Sea (EBS) and is the target of the largest flatfish fishery in the world. They inhabit the EBS shelf and are considered one stock. Abundance in the Aleutian Islands region is negligible.

Yellowfin sole are distributed in North American waters from off British Columbia, Canada, (approx. lat. 49^{o} N) to the Chukchi Sea (about lat. 70^{o} N) and south along the Asian coast to about lat. 35^{o} N off the South Korean coast in the Sea of Japan. Adults exhibit a benthic lifestyle and occupy separate winter, spawning and summertime feeding distributions on the eastern Bering Sea shelf. From over-winter grounds near the shelf margins, adults begin a migration onto the inner shelf in April or early May each year for spawning and feeding. The directed fishery has typically occurred from late winter through autumn (Wilderbuer et al. 1992). Yellowfin sole are managed as a single stock in the BSAI management area as there is presently no evidence of stock structure.

Fishery

Yellowfin sole have annually been caught with bottom trawls on the Bering Sea shelf since the fishery began in 1954 and were overexploited by foreign fisheries in 1959-62 when catches averaged 404,000 t annually (Fig. 4.1, top panel). As a result of reduced stock abundance, catches declined to an annual average of 117,800 t from 1963-71 and further declined to an annual average of 50,700 t from 1972-77. The lower yield in this latter period was partially due to the discontinuation of the U.S.S.R. fishery. In the early 1980s, after the stock condition had improved, catches again increased reaching a peak of over 227,000 t in 1985.

During the 1980s, there was also a major transition in the characteristics of the fishery. Yellowfin sole were traditionally taken exclusively by foreign fisheries and these fisheries continued to dominate through 1984. However, U.S. fisheries developed rapidly during the 1980s in the form of joint ventures, and during the last half of the decade began to dominate and then take all of the catch as the foreign fisheries were phased out of the EBS. Since 1990, only domestic harvesting and processing has occurred.

The management of the yellowfin sole fishery changed significantly in 2008 with the implementation of Amendment 80 to the BSAI Fisheries Management Plan. The Amendment directly allocated fishery resources among BSAI trawl harvesters in consideration of their historic harvest patterns and future harvest needs in order to improve retention and utilization of fishery resources by the non-AFA trawl catcher/processor fleet. This was accomplished by extending the groundfish retention standards to all H&G vessels and also by providing the ability to form cooperatives within the newly formed Amendment 80 sector. In addition, Amendment 80 also mandated additional monitoring requirements which included observer coverage on all hauls, motion-compensating scales for weighing samples, flow scales to obtain accurate catch weight estimates for the entire catch, no mixing of hauls and no on-deck sorting. The partitioning of TAC and PSC (prohibited species catch) among cooperatives has significantly changed the way the annual catch has accumulated and the rate of target catch per bycatch ton (Fig 4.1, bottom panel). There is now a more even and slow attainment of the annual catch relative to the pre-Amendment 80 fishing behavior.

Yellowfin sole are usually headed and gutted, frozen at sea, and then shipped to Asian countries for further processing (see "market profile" in the 2011 economic SAFE report for details). In 2010, following a comprehensive assessment process, the yellowfin sole fishery was certified under the Marine Stewardship Council environmental standard for sustainable and well-managed fisheries. The certification also applies to all the major flatfish fisheries in the BSAI and GOA. The total annual catch (t) since implementation of the MFCMA in 1977 is shown in Table 4.1.

Also in 2010, federally permitted vessels using non-pelagic trawl gear whose harvest results in flatfish retained catch that is greater than any other retained fishery category were required to use modified trawl gear. The modifications required the use of elevating devices to raise the section of the trawl warps between the doors and the trawl wing tips by 2.5 inches off the seafloor. The purpose of the management action was to reduce damage of non-target animals, particularly those that form habitat structure or support other fisheries while not substantially reducing flatfish catch rates or causing gear handling problems (Rose et al. 2010).

The 1997 catch of 181,389 t was the largest since the fishery became completely domestic but was at lower levels from 1998 – 2010, averaging 94,004 t. The catch has increased the past four years (2010-2014) averaging 152,000 t. The 2013 catch totaled 165,000 t (73% of the ABC), the highest annual catch in the past 17 years. For 2014, the catch distribution has been spread out fairly evenly over spring and fall months with the majority coming from 4 BSAI management areas (509, 513, 514, 521). As of mid-October 2014, the fishing season is ongoing. In order to estimate the total 2014 catch for the stock assessment model, the average proportion of the 2008-2013 cumulative catch attained by the 38th week of the year (mid-September) was applied to the 2014 catch amount at the same time period and results in a 2014 catch estimate of 146,000 t (61% of the ABC). The size composition of the 2014 catch for both males and females, from observer sampling, are shown in Figure 4.2, the catch proportions by month and area are shown in Figure 4.3, and maps of the locations where yellowfin sole were caught in 2014, by month, are shown in Figure 4.4. The average age of yellowfin sole in the 2013 catch is estimated at 12.6 and 12.0 years for females and males, respectively.

The time-series of catch in Table 6.1 also includes yellowfin sole that were discarded in domestic fisheries during the period 1987 to the present. Annual discard estimates were calculated from at-sea sampling (Table 4.2). The rate of discard has ranged from a low of 2% of the total catch in 2012 to 30% in 1992. The trend has been toward fuller retention of the catch in recent years, and with the advent of the

Amendment 80 harvest practices, discarding is at its lowest level since these estimates have become available. Historically, discarding primarily occurred in the yellowfin sole directed fishery, with lesser amounts in the Pacific cod, Pollock, rock sole, flathead sole, and "other flatfish" fisheries (Table 4.3).

Data

The data used in this assessment include estimates of total catch, bottom trawl survey biomass estimates and their attendant 95% confidence intervals, catch-at-age from the fishery and population age composition estimates from the bottom trawl survey. Weight-at-age and proportion mature-at-age are also available from studies conducted during the bottom trawl surveys.

Data source	**years**
Fishery catch	1954-2014
Fishery age composition	1964-2013
Survey biomass and standard error, bottom temperature	1982-2014
Survey age composition	1979-2013
Annual length-at-age and weight-at-age	1979-2012
Maturity at age	Samples collected in 2012

Fishery Catch and Catch-at-Age

This assessment uses fishery catch data from 1955- 2013 (Table 4.1), including an estimate of the 2014 catch, and fishery catch-at-age (proportions) from 1964-2013 (Table 4.4, 1977-2014). The 2013 fishery age composition is primarily composed of fish older than 9 years with a large amount of 20+ fish.

Survey Biomass Estimates and Population Age Composition Estimates

Indices of relative abundance available from AFSC surveys have also shown a major increase in the abundance of yellowfin sole during the late 1970s increasing from 21 kg/ha in 1975 to 51 kg/ha in 1981 (Fig. 4.2 in Bakkala and Wilderbuer 1990). These increases have also been documented through Japanese commercial pair trawl data and catch-at-age modeling in past assessments (Bakkala and Wilderbuer 1990).

Since 1981, the survey CPUEs have fluctuated widely (Fig. 4.5). Biomass estimates for yellowfin sole from the annual bottom trawl survey on the eastern Bering Sea shelf are shown in Table 4.5. The data show a doubling of survey biomass between 1975 and 1979 with a further increase to over 3.3 million t in 1981. Total survey abundance estimates fluctuated erratically from 1983 to 1990 with biomass ranging from as high as 3.5 million t in 1983 to as low as 1.9 million t in 1986. Biomass estimates since 1990 indicate an even trend at high levels of abundance for yellowfin sole, with the exception of the results from the 1999 and 2000 summer surveys, which were at lower levels. Surveys from 2001-2005 estimated an increase each year but the estimates since 2006 indicate a stable level with some annual variability. However, the 2012 estimate is a 19% decrease from 2011 and the 2013 and 2014 surveys have estimated a 17% increase over 2012. Fluctuations of the magnitude shown between 1980 and 1990 and again between 1998 and 1999, 2008 and 2009 and also 2011 and 2012 are unreasonable considering the combined elements of slow growth and long life span of yellowfin sole and low to moderate exploitation rate, characteristics which should produce more gradual changes in abundance.

Variability of yellowfin sole survey abundance estimates (Fig. 4.6) is in part due to the availability of yellowfin sole to the survey area (Nichol, 1998). Yellowfin sole are known to undergo annual migrations from wintering areas off the shelf-slope break to near shore waters where they spawn throughout the spring and summer months (Nichol, 1995; Wakabayashi, 1989; Wilderbuer et al., 1992). Exploratory

survey sampling in coastal waters of the eastern Bering Sea during early summer indicate that yellowfin sole concentrations can be greater in these shallower areas not covered by the standard AFSC survey than in the survey proper. Commercial bottom trawlers have commonly found high concentrations of yellowfin sole in areas such as near Togiak Bay (Low and Narita, 1990) and in more recent years from Kuskokwim Bay to just south of Nunivak Island. The coastline areas are sufficiently large enough to offer a substantial refuge for yellowfin sole from the current survey.

Over the past 15 years survey biomass estimates for yellowfin sole have shown a positive correlation with shelf bottom temperatures (Nichol, 1998); estimates have generally been lower during cold years. The 1999 survey, which was conducted in exceptionally cold waters, indicated a decline in biomass that was unrealistic. The bottom temperatures during the 2000 survey were much warmer than in 1999, and the biomass increased, but still did not approach estimates from earlier years. Average bottom temperature and biomass both increased again during the period 2001 – 2003, with the 2003 value the highest temperature and biomass observed over the 22 year time series. Given that both 1999 and 2000 surveys were conducted two weeks earlier than previous surveys, it is possible that the time difference may also have also affected the availability of yellowfin sole to the survey. If, for example, the timing of peak yellowfin sole spawning in nearshore waters corresponded to the time of the survey, a greater proportion of the population would be unavailable to the standard survey area. This trend was observed again in 2009 and 2012 when the temperatures and the bottom trawl survey point estimates were lower. Summer shelf bottom temperatures in 2012 were the 2nd coldest recorded by the survey and the time-series and resulted in a 19% decline from 2011.

We propose two possible reasons why survey biomass estimates are lower during years when bottom temperatures are low. First, catchability may be lower because yellowfin sole may be less active when cold. Less active fish may be less susceptible to herding, and escapement under the footrope of survey gear may increase if fish are less active. Secondly, bottom temperatures may influence the timing of the inshore spawning migrations of yellowfin sole and therefore affect their availability to the survey area. Because yellowfin sole spawning grounds include nearshore areas outside the survey area, availability of fish within the survey area can vary with the timing of this migration and the timing of the survey. In the case of 2012, a very cold year in the Bering Sea, it is unclear from examining survey station catches along the survey border near Kuskowkim bay if a significant portion of the biomass lies outside this border (Fig 4.7).

Yellowfin sole population numbers-at-age estimated from the annual bottom trawl surveys are shown in Table 4.6 and their occurrence in trawl survey hauls and associated collections of lengths and age structures since 1982 are shown in Table 4.7. Their total tonnage caught in the resource assessment surveys since 1982 are listed in Table 4.8 and also in an appendix table with IPHC survey catches.

Length and Weight-at-Age

Past assessments of yellowfin sole have used sex-specific, time-invariant growth based on the average length-at-age and weight-at-length relationships from the time-series of survey observations summed over all years since 1982. These weight-at-age estimates were estimated from the following relationships:

Parameters of the von Bertalanffy growth curve have been estimated for yellowfin sole, by sex, from the trawl survey database as follows:

	L_{inf}	K	t_0	n
Males	33.7	0.161	-0.111	656
Females	37.8	0.137	0.112	709

A sex-specific length-weight relationship was also calculated from the survey database using the usual power function, weight (g) = a Length(cm)^b, where a and b are parameters estimated to provide the best fit to the data (Fig. 4.8).

	a	b	n
males	0.00854	3.081	2,701
females	0.0054	3.227	3,662

These estimates of weight at length were applied to the annual trawl survey estimates of population length at age averaged over all years, by sex, to calculate the weight at each age (Fig. 4.8).

Recent applications of dendrochronology (tree-ring techniques) have been used to develop biochronologies from the otolith growth increments of northern rock sole (*Lepidopsetta polyxystra*), yellowfin sole and Alaska plaice (*Pleuronectes quadrituberculatus*) in the eastern Bering Sea. These techniques ensure that all growth increments are assigned the correct calendar year, allowing for estimation of somatic growth by age and year for chronologies that span approximately 25 years (Matta et al. 2010). The analysis indicated that yellowfin sole somatic growth has annual variability and is positively correlated with May bottom water temperature in the Bering Sea (Fig. 4.9).

The relationship between temperature and growth was further explored by reanalyzing yellowfin sole growth by age and year. Length-weight data collected when obtaining otolith (age) samples in RACE surveys (n=7,000 from 1987, 1994 and 1999-2009) also indicate that weight at age exhibits annual variability and is highly correlated with summer bottom water temperature observations with a lag of 2-3 years for the temperature effect to be seen (shown for age 5 fish in figure 4.10) . These observations were then extended back to 1979 using survey population length-at-age estimates (since weight-at-age is a power function of the length-at-age, Clark et al. 1999, Walters and Wilderbuer 2000).

In this assessment the reanalyzed growth data were incorporated and growth was modeled as time-varying and temperature-dependent functions input into an age-structured stock assessment model and then comparing the results with the base model that uses time-invariant growth. Four growth models were developed as follows: Mean age-specific somatic body mass (here referred to as weight-at-age) is modeled as a von Bertalanfy growth function in the initial year of the stock assessment (1954) and projected forward such that the model expected mean weight at age *j* in year *i* for a given sex is constant over the projection (Model 0). In Model 1 the annual observed population mean weight-at-age (time-varying) is used in the stock assessment model. Model 2 is a fit to the data used in Model 1 by the estimation of year and age specific parameters and Model 3 estimates annual weight-at-age as a function of annual May sea surface temperature anomalies. The growth models are as follows:

Model			
0	$\hat{w}_{ij} = \hat{w}_{i-1,j-1} + g_j$	$i > 1954, j > 1$	Constant fixed growth
1	$\hat{w}_{ij} = w_{ij}$, $\hat{w}_{ij} = \overline{w}_{\cdot j}$	$1982 \le i \le 2009$, $i < 1982, i > 2009$	As estimated for each age from survey data
2	$\hat{w}_{ij} = \hat{w}_{i-1,j-1} + g_j e^{\varepsilon_{ij}}$	$i > 1954, j > 1 \quad \varepsilon_i \sim N\left(0, \sigma_g^2\right)$	Year-effect freely estimated on growth increment
3	$\hat{w}_{ij} = \hat{w}_{i-1,j-1} + g_j e^{\varepsilon_{ij}}$, $\varepsilon_{ij} = T_i\alpha + \delta_i$	$i > 1954, j > 1$, $\delta_i \sim N\left(0, \sigma_{res}^2\right)$	Year-effect on growth increment linked to temperature conditions

where w_{ij} represents the observed estimates of mean weights at age and year, g_j is the expected growth increment in the most recent completed year (as estimated from the a sex-specific von-Bertalanfy growth curve) and ε_i is a process error term which is modeled as to have an optional year-effect and separate age effect in model 2. For model 3 temperature anomalies are introduced for the entire period and the parameter α scales them and the residual variance is computed σ_g^2.

For all models except 1, the negative log-likelihood function for the weight-at-age data applied was:

$$-\ln L_w = \sum_{i=1982}^{2009} \sum_{j=5}^{15} \frac{n_{ij}\left(\ln w_{ij} - \ln \hat{w}_{ij}\right)^2}{2\sigma_{ij}^2}$$

Maturity-at-age

Maturity information collected from yellowfin sole females during the 1992 and 1993 eastern Bering Sea trawl surveys have been used in this assessment for the past 20 years (Table 4.10). Nichol (1995) estimated the age of 50% maturity at 10.5 years based on the histological examination of 639 ovaries. Maturity has recently been re-evaluated from a histological analysis of ovaries collected in 2012 (Table 4.10). Results were very similar to the earlier study with only a 2% difference in estimates of yellowfin sole female spawning biomass (TenBrink and Wilderbuer, In review). For yellowfin sole sexual maturity occurs well after the age of enty into the fishery. Yellowfin sole females are 82% selected to the fishery by age 10 whereas they have been found to be only 40% mature at this age.

Analytic Approach

Model Structure

The abundance, mortality, recruitment and selectivity of yellowfin sole were assessed with a stock assessment model using the AD Model Builder language (Ianelli and Fournier 1998). The conceptual model is a separable catch-age analysis that uses survey estimates of biomass and age composition as auxiliary information (Fournier and Archibald 1982). The assessment model simulates the dynamics of the population and compares the expected values of the population characteristics to the characteristics observed from surveys and fishery sampling programs. This is accomplished by the simultaneous estimation of the parameters in the model using the maximum likelihood estimation procedure. The fit of the simulated values to the observable characteristics is optimized by maximizing a log(likelihood) function given some distributional assumptions about the observed data.

Since the sex-specific weight-at-age for yellowfin sole diverges after age of maturity (about age 10 for 40% of the stock) with females growing larger than males, the current assessment model is coded to accommodate the sex-specific aspects of the population dynamics of yellowfin sole. The model allows for the input of sex-specific estimates of fishery and survey age composition and weight-at-age and provides sex-specific estimates of population numbers, fishing mortality, selectivity, fishery and survey age composition and allows for the estimation of sex-specific natural mortality and catchability. The model retains the utility to fit combined sex data inputs.

The suite of parameters estimated by the model are classified by three likelihood components:

Data component	**Distributional assumption**
Trawl fishery catch-at-age	Multinomial
Trawl survey population age composition	Multinomial
Trawl survey biomass estimates and S.E.	Log normal

The total log likelihood is the sum of the likelihoods for each data component (Table 4.11). The likelihood components may be weighted by an emphasis factor, however, equal emphasis was placed on fitting each likelihood component in the yellowfin sole assessment except for the catch. The AD Model Builder software fits the data components using automatic differentiation (Griewank and Corliss 1991) software developed as a set of libraries (AUTODIFF C++ library). Table 4.11 also presents the key equations used to model the yellowfin sole population dynamics in the Bering Sea and Table 4.12 provides a description of the variables used in Table 4.11.

Sharp increases in trawl survey abundance estimates for most species of Bering Sea flatfish between 1981 and 1982 indicate that the 83-112 trawl was more efficient for capturing these species than the 400-mesh eastern trawl used in 1975, and 1979-81. Allowing the model to tune to these early survey estimates would most likely underestimate the true pre-1982 biomass, thus exaggerating the degree to which biomass increased during that period. Although this underestimate would have little effect on the estimate of current yellowfin sole biomass, it would affect the spawner and recruitment estimates for the time-series. Hence, the pre-1982 survey biomass estimates were omitted from the analysis.

The model of yellowfin sole population dynamics was evaluated with respect to the observations of the time-series of survey and fishery age compositions and the survey biomass trend since 1982.

Parameters Estimated Outside the Assessment Model

Natural mortality (M) was initially estimated by a least squares analysis where catch-at-age data were fitted to Japanese pair trawl effort data while varying the catchability coefficient (q) and M simultaneously. The best fit to the data (the point where the residual variance was minimized) occurred at a M value of 0.12 (Bakkala and Wespestad 1984). This was also the value which provided the best fit to the observable population characteristics when M was profiled over a range of values in the stock assessment model using data up to 1992 (Wilderbuer 1992). Since then, natural mortality has been estimated as a free parameter in some of the stock assessment model runs which have been evaluated for the past five years. A natural mortality value of 0.12 is used for both sexes in the base model presented in this assessment.

Yellowfin sole maturity schedules were estimated from in-situ observations as discussed in a previous section (Table 4.10).

Parameters Estimated Inside the Assessment Model

The parameters estimated by the model are presented below:

Fishing mortality	Selectivity	Survey catchability	Year class strength	Spawner-recruit	Total
62	252	2	101	2	419

The increase in the number of parameters estimated in this assessment compared to last year (6) can be accounted for by the input of another year of fishery data and the entry of another year class into the observed population and four more sex-specific fishery selectivity parameters.

Year class strengths
The population simulation specifies the numbers-at-age in the beginning year of the simulation, the number of recruits in each subsequent year, and the survival rate for each cohort as it moves through the population over time using the population dynamics equations given in Table 4.11.

Selectivity
Fishery and survey selectivity was modeled separately for males and females using the two parameter formulation of the logistic function (Table 4.11). The model was run with an asymptotic selectivity curve

for the older fish in the fishery and survey, but still was allowed to estimate the shape of the logistic curve for young fish. The oldest year classes in the surveys and fisheries were truncated at 20 and allowed to accumulate into the age category 20+ years. A single selectivity curve, for both males and females, was fit for all years of survey data.

Given that there have been annual changes in management, vessel participation and most likely gear selectivity, time-varying fishing selectivity curves were estimated. A logistic equation was used to model fishery selectivity and is a function of time-varying parameters specifying the age and slope at 50% selection, φ_t and η_t, respectively. The fishing selectivity (S^f) for age *a* and year *t* is modeled as,

$$S^f_{a,t} = \left[1 + e^{\eta_t (a - \varphi_t)}\right]^{-1}$$

where η_t and φ_t are time-varying and partitioned (for estimation) into parameters representing the mean and a vector of deviations (log-scale) conditioned to sum to zero. The deviations are constrained by a lognormal prior with a variance that was iteratively estimated. The process of iterating was to first set the variance to a high value (diffuse prior) of 0.5^2 and estimate the deviations. The next step was to compare the variability of model estimates. The variability of the model estimates were then rounded up slightly and fixed for subsequent runs. The 2014 values were fixed as the average of the 3 most recent years.

Fishing Mortality
The fishing mortality rates (F) for each age and year are calculated to approximate the catch weight by solving for F while still allowing for observation error in catch measurement. A large emphasis (300) was placed on the catch likelihood component to force the model to match the observed catch.

Survey Catchability
A past assessment (Wilderbuer and Nichol 2001) first examined the relationship between estimates of survey biomass and bottom water temperature. To better understand how water temperature may affect the catchability of yellowfin sole to the survey trawl, catchability was estimated for each year in the stock assessment model as:

$$q = e^{-\alpha + \beta T}$$

where q is catchability, T is the average annual bottom water temperature anomaly at survey stations less than 100 m, and α and β are parameters estimated by the model. The catchability equation has two parts. The $e^{-\alpha}$ term is a constant or time-independent estimate of q. The model estimate of α = -0.132 indicates that q > 1 suggesting that yellowfin sole are herded into the trawl path of the net which is consistent with the experimental results for other flatfish species. The second term, $e^{\beta T}$ is a time-varying (annual) q which responds to metabolic aspects of herding or distribution (availability) which can vary annually with bottom water temperature. The result of incorporating bottom temperature to estimate annual q is shown in Figure 4.11 (for the base model).

Spawner-Recruit Estimation

Annual recruitment estimates were constrained to fit a Ricker (1958) form of the stock recruitment relationship as follows:

$$R = \alpha S e^{-\beta S}$$

where R is age 1 recruitment, S is female spawning biomass (t) the previous year, and α and β are parameters estimated by the model. The spawner-recruit fitting is estimated in a later phase after initial estimates of survival, numbers-at-age and selectivity are obtained.

Results

Model Evaluation

The model evaluation for this stock assessment involved a three-step process. The first step was to evaluate the productivity of the yellowfin sole stock by an examination of which sets of years to include for spawner-recruit fitting. The second step then evaluated the growth models presented in a previous section and the third step evaluated various hypothesized states of nature by fitting natural mortality and catchability estimates in various combinations.

The SSC determined in December 2006 that yellowfin sole would be managed under the Tier 1 harvest guidelines, and therefore future harvest recommendations would be based on MSY and F_{MSY} values calculated from a spawner-recruit relationship. MSY is an equilibrium concept and its value is dependent on both the spawner-recruit estimates which are assumed to represent the equilibrium stock size-recruitment relationship and the model used to fit the estimates. In the yellowfin sole stock assessment model, a Ricker form of the stock-recruit relationship was fit to various combinations of these data and estimates of F_{MSY} and B_{MSY} were calculated, assuming that the fit to the stock-recruitment data represents the long-term productivity of the stock.

For this assessment, 2 different stock-recruitment time-series were investigated: the full time-series 1955-2006 (Model A) and the post-regime shift era, 1978-2006 (Model B) (Fig. 4.12) (see Joint Plan Team recommendations for September 2012). Very different estimates of the long-term sustainability of the stock (F_{MSY} and B_{MSY}) are obtained, depending on which years of stock-recruitment data are included in the fitting procedure (Table 4.13). When the entire time-series from 1955-2006 was fit, the large recruitments that occurred at low spawning stock sizes in the 1960s and early 1970s determined that the yellowfin sole stock was most productive at a smaller stock size with the result that F_{MSY} (0.17) is much higher than $F_{35\%}$ ($F_{35\%}$ = 0.135) and B_{MSY} is 345,000 (Model A). If we limit the analysis to consider only recruitments which occurred after the well-documented regime shift in 1977, a lower value of F_{MSY} is obtained (0.111) and B_{MSY} is 391,000 t. Table 4.13 indicates that the ABC values from the Model A harvest scenario for 2015 would be 69,600 t higher than Model B. Posterior distributions of F_{MSY} for these models indicate that this parameter is estimated with less uncertainty for Model A resulting in the reduced buffer between ABC and OFL relative to Model B (7% for Model B versus < 1% for Model A, Table 4.13 and Fig 4.13).

It is important for the Tier 1 calculations to identify which subset of the stock recruitment data is used. Using the full time series to fit the spawner recruit curve estimates that the stock is most productive at a small stock size. Thus MSY and F_{MSY} are relatively high values and B_{MSY} is a lower value. If the stock was productive in the past at a small stock size because of non-density dependent factors (environment), then reducing the stock size to low levels could be detrimental to the long-term sustainability of the stock if the environment, and thus productivity, had changed from the earlier period. Since observations of yellowfin sole recruitment at low stock sizes are not available from multiple time periods, it is uncertain if future recruitment events at low stock conditions would be as productive as during the late 1960s-early 1970s.

Given the uncertainty of the productivity of yellowfin sole at low spawning stock sizes, and because the AFSC policy for reference point time-series selection is to use the post 1977 regime shift values unless there is a compelling reason to do otherwise, the productivity of yellowfin sole in this assessment is estimated by fitting the 1977-2006 spawner-recruit data in the model (Model B).

The second step in the model evaluation is the evaluation of the growth model for yellowfin sole. Estimates of female spawning biomass from the four growth models (described in a previous section) are shown in Figure 4.15 and indicate that all 4 models estimate the same trend with Model 1estimates trending lower in the last ten years than the others. Estimates of 2015 ABC and F_{ABC} range from 248,800 – 305,000 t with Model 1 values lower than the others.

	model 0	model 1	model 2	model 3
2015 FSB	770,000	644,200	680,000	754,300
2015 F_{ABC}	0.118	0.117	0.125	0.119
2015 ABC	289,900	248,800	305,000	297,000

Growth Model 1 was selected as the model of choice for this assessment since 1) It does not use time invariant growth as in Model 0 (unsupported by the growth data) but instead relies on the annually collected survey population length and age data to calculate annual estimates of length at age and weight-at-age, and 2) in its present formulation, Model 2 does not fit the FSB trend of model 1 in the most recent years and thus warrants more exploration before incorporation into the assessment model. Both Models 2 and 3 could also further benefit from using the estimated population as a covariate to model the annual growth increment due to density dependent effects. The model modifications have not been pursued for this assessment.

The third step in the model evaluation for this assessment entails the use of a single structural model to consider the uncertainty in the key parameters M and catchability. This is the Model which has been the model of choice is the past 7 assessments and operates by fixing M at 0.12 for both sexes and then estimates q using the relationship between survey catchability and the annual average water temperature at the sea floor (from survey stations at less than 100 m). The other models used in the evaluation represented various combinations of estimating M or q as free parameters with different amounts of uncertainty in the parameter estimates (Wilderbuer et al. 2010). The results are detailed in those assessments and are not repeated here except for the following observations.

Modeling survey catchability as a nonlinear function of bottom water temperature returns a mean value of 1.107. This value is consistent with supporting evidence from experiments examining the bridle efficiency of the Bering Sea survey trawl which indicate that yellowfin sole are herded into the trawl path from an area between the wing tips of the net and the point where the bridles contact the seafloor (Somerton and Munro 2001). It is also consistent with our hypothesis of the timing of the survey relative to the temperature dependent timing of the annual spawning migration to nearshore areas which are outside of the survey area. The herding experiments suggest that the survey trawl catchability is greater than 1.0. The likelihood profile of q from the model indicated a small variance with a narrow range of likely values with a low probability of q being equal to the value of 1.0 in a past assessment (Wilderbuer and Nichol 2003).

A model that allows M to be estimated as a free parameter for males with females fixed at 0.12 provided a better fit to the sex ratio estimated from the annual trawl survey age compositions than did the base model (both sexes fixed at M = 0.12). However, since the population sex ratio annually observed at the time of the survey is a function of the timing of the annual spawning in adjacent inshore areas, it is questionable that providing the best fit to these observations is really fitting the population sex ratio better. Thus, the model configuration which utilizes the relationship between annual seafloor temperature and survey catchability with M fixed at 0.12 for both sexes is used to base the assessment of the condition of the Bering Sea yellowfin sole resource for the 2013 fishing season.

Time Series Results

The 2014 trawl survey point estimate increased 10% from 2013. This resulted in higher model estimates of population numbers at age and biomass for the time-series back to the mid-1960s relative to last year's assessment. In addition, a large 2003 year class (11 years old in 2014) is present in the population near their cohort maximum. The model results indicate the stock has been in a slowly declining condition since the mid-1980s but is now in an increasing trend due to the strong 2003 year class. The estimates of female spawning biomass, total biomass and ABC are higher than those used to manage the stock in 2013. Seven of the past 9 years have had negative bottom temperature anomalies in the Bering Sea. 2014

was a warmer year relative to temperatures observed in 2006-2013 with an estimated value just 0.1 deg. C above the long term mean. The temperature-dependent q adjustment for 2014 was 1.108.

Fishing Mortality and Selectivity
The assessment model estimates of the annual fishing mortality in terms of age-specific annual F and on fully selected ages are given in Tables 4.14 and 4.15, respectively. The full-selection F has averaged 0.08 over the period of 1978-2013 with a maximum of 0.12 in 1978 and a minimum in 2001 at 0.043. Selectivities estimated by the model (Table 4.16, Fig. 4.14) indicate that both sexes of yellowfin sole are 50% selected by the fishery at about age 9 and nearly fully selected by age 13, with annual variability.

Abundance Trend
The model estimates q at an average value of 1.07 for the period 1982-2014 which results in the model estimate of the 2014 age 2+ total biomass at 2,313,200 t (Table 4.17). Model results indicate that yellowfin sole total biomass (age 2+) was at low levels during most of the 1960s and early 1970s (700,000-800,000 t) after a period of high exploitation (Table 4.17, Fig. 4.16, bottom left panel). Sustained above average recruitment from 1967-76 combined with light exploitation resulted in a biomass increase to a peak of 2.9 million t by 1984. The population biomass has since been in a slow decline as the strong 1981 and 1983 year-classes have passed through the population with only the 1991 and 1995 year classes at levels observed during the 1970s. However, the total biomass is now increasing again due to the strong 2003 cohort. The present biomass is estimated at 77% of the peak 1984 level.

The female spawning biomass has also declined since the peak in 1994, with a 2014 estimate of 637,000 t (33% decline). The spawning biomass has been in a gradual decline for the past 21 years and is 8% above the $B_{40\%}$ level and 1.6 times the B_{MSY} level (Fig. 4.16). The model estimate of yellowfin sole population numbers at age for all years is shown in Table 4.18 and the resulting fit to the observed fishery and survey age compositions input into the model are shown in the Figure 4.17. The fit to the trawl survey biomass estimates are shown in Figure 4.16. Allowing q to be correlated with annual bottom temperature provides a better fit to the bottom trawl survey estimates (Fig. 4.18). Table 4.19 lists the numbers of female spawners estimated by the model for all ages and years. The estimated average age of yellowfin sole in the population is 6.4 years for males and females.

Both the trawl survey and the stock assessment model indicate that the yellowfin sole resource increased during the 1970s and early 1980s to a peak level during the mid-1980s. The yellowfin sole population biomass slowly decreased over the nineteen years since the mid-1990s as the majority of year-classes during those years were below average strength. Above-average recruitment from the strong 2003 year-class is expected to maintain the abundance of yellowfin sole at a level above B_{MSY} in the near future. The stock assessment projection model indicates an increasing trend in female spawning biomass through 2019 if the fishing mortality rate continues at the same level as the average of the past 5 years.

Recruitment Trends
The primary reason for the sustained increase in abundance of yellowfin sole during the 1970s and early 1980s was the recruitment of a series of stronger than average year classes spawned in 1967-76 (Figure 4.19 and Table 4.20). The 1981 year class was the strongest observed (and estimated) during the 47 year period analyzed and the 1983 year class was also very strong. Survey age composition estimates and the assessment model also estimate that the 1987 and 1988 year classes were average and the 1991 and 1995 year classes were above average. With the exception of these 4 year classes, recruitment from 15 of the last 19 years estimated from 1984-2005 (since the strong 1983 year-class) has been below the 48 year average, which has caused the population to gradually decline. The 2003 year-class has now been observed multiple times in the age compositions and are clearly a strong year class similar to some of the hallmark recruitment mentioned above and are contributing to the reservoir of spawning fish in the current population. In addition, recruitment from 2005-2008 may also be above average but at present, there is uncertainty due to a lack of repeated observations.

Historical Exploitation Rates

Based on results from the stock assessment model, annual average exploitation rates of yellowfin sole ranged from 3 to 8% of the total biomass since 1977, and have averaged 5% (Table 4.14). Posterior distributions of selected parameters from the preferred stock assessment model used in the assessment are shown in Figure 4.20. The values and standard deviations of some selected model parameters are listed in Table 4.21.

A within-model retrospective analysis is also included for the recommended assessment model where retrospective female spawning biomass is calculated by working backwards in time dropping data one year at a time (Fig. 4.21).

Harvest Recommendations

After decreasing since the peak value in 1984, estimates from the stock assessment model indicate the total biomass is now increasing. The estimate of age 6+ total biomass for 2015 is 2,138,000 t.

The SSC has determined that yellowfin sole qualify as a Tier 1 stock and therefore the 2015 ABC is calculated using Tier 1 methodology. In 2006 the SSC selected the 1978-2001 data set for the Tier 1 harvest recommendation. Using this approach again for the 2015 harvest (now the 1978-2006 time-series) recommendation (Model B in Table 4.13 with growth option 1), the $F_{ABC} = F_{\text{harmonic mean}} = 0.117$.

The Tier 1 harvest level is calculated as the product of the harmonic mean of F_{MSY} and the geometric mean of the 2015 biomass estimate, as follows:

$B_{gm} = e^{\ln \hat{B} - \frac{cv^2}{2}}$, where B_{gm} is the geometric mean of the 2015 biomass estimate, $\hat{B}$ is the point estimate of the 2015 biomass from the stock assessment model and cv^2 is the coefficient of variation of the point estimate (a proxy for sigma);

and

$\bar{F}_{har} = e^{\ln \hat{F}_{msy} - \frac{\ln sd^2}{2}}$, where $\bar{F}_{har}$ is the harmonic mean, $\hat{F}_{msy}$ is the peak mode of the F_{MSY} distribution and sd^2 is the square of the standard deviation of the F_{MSY} distribution. This calculation gives a Tier 1 ABC harvest recommendation of **248,800 t** and an OFL of 266,400 t for 2015. This gives a 7% (17,600 t) buffer between ABC and OFL. The ABC value is 4% higher than last year, primarily due to increasing survey estimates in the past two years.

The stock assessment analysis must also consider harvest limits, usually described as overfishing fishing mortality levels with corresponding yield amounts. Amendment 56 to the BSAI FMP sets the Tier 1 harvest limit at the F_{MSY} fishing mortality value. The overfishing fishing mortality values, ABC fishing mortality values and their corresponding yields are given as follows:

Harvest level	F value	2015 Yield
Tier 1 $F_{OFL} = F_{MSY}$	**0.125**	**266,400 t**
Tier 1 $F_{ABC} = F_{\text{harmonic mean}}$	**0.117**	**248,800 t**

Status Determination

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2014 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2015 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2014. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2015, are as follows ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2015 recommended in the assessment to the *max* F_{ABC} for 2015. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 2010-2014 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY level in 2013 and above its MSY level in 2026 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2027 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 4.22 indicate that yellowfin sole are not currently overfished and are not approaching an overfished condition. The projection of yellowfin sole female spawning biomass through 2025 is shown in Figure 4.22 and a phase plane figure of the estimated time-series of yellowfin sole female spawning biomass relative to the harvest control rule is shown in Figure 4.23.

Scenario Projections and Two-Year Ahead Overfishing Level

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. The 2014 numbers at age from the stock assessment model are projected to 2015 given the 2014 catch and then a 2015 catch of 150,000 t is applied to the projected 2015 population biomass to obtain the 2016 OFL.

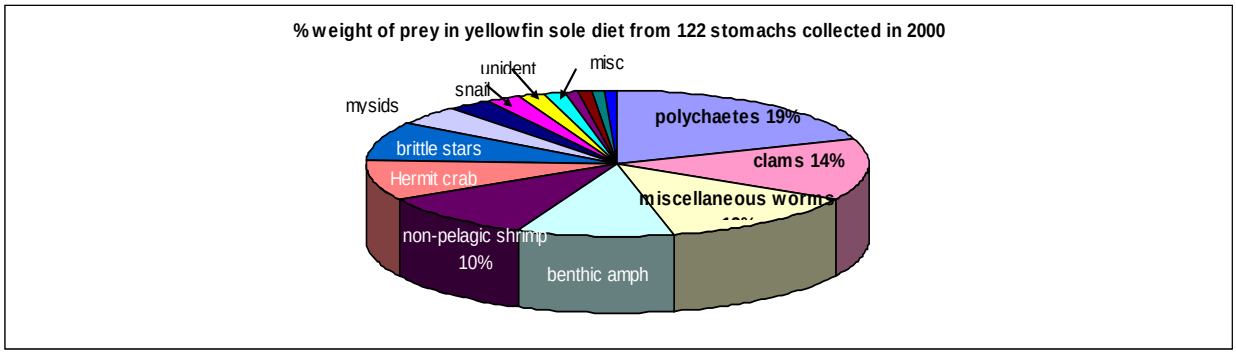
	Tier 1 Projection				
Year	Catch	SSB	Geometric mean 6+ total biomass	ABC	OFL
2015	150,000	644,200	2,127,800	248,800	266,400
2016	150,000	648,600	2,100,000	245,500	262,900

Ecosystem Considerations

Ecosystem Effects on the stock

1) Prey availability/abundance trends

Yellowfin sole diet by life stage varies as follows: Larvae consume plankton and algae, early juveniles consume zooplankton, late juvenile stage and adults prey includes bivalves, polychaetes, amphipods, mollusks, euphausids, shrimps, brittle stars, sculpins and miscellaneous crustaceans. Information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not been re-sampled since. The large populations of flatfish which have occupied the middle shelf of the Bering Sea over the past twenty-five years for summertime feeding do not appear food-limited. These populations have fluctuated due to the variability in recruitment success which suggests that the primary infaunal food source has been at an adequate level to sustain the yellowfin sole resource.



2) Predator population trends

As juveniles, it is well-documented from studies in other parts of the world that flatfish are prey for shrimp species in near shore areas. This has not been reported for Bering Sea yellowfn sole due to a lack of juvenile sampling and collections in near shore areas, but is thought to occur. As late juveniles they have been found in stomachs of Pacific cod and Pacific halibut; mostly on small yellowfin sole ranging from 7 to 25 cm standard length..

Past, present and projected future population trends of these predator species can be found in their respective SAFE chapters in this volume and also from Annual reports compiled by the International

Pacific Halibut Commission. Encounters between yellowfin sole and their predators may be limited since their distributions do not completely overlap in space and time.

3) Changes in habitat quality
Changes in the physical environment which may affect yellowfin sole distribution patterns, recruitment success and migration timing patterns are catalogued in the Ecosystem Considerations Appendix of this SAFE report. Habitat quality may be enhanced during years of favorable cross-shelf advection (juvenile survival) and warmer bottom water temperatures with reduced ice cover (higher metabolism with more active feeding).

Fishery Effects on the ecosystem

1) The yellowfin sole target fishery contribution to the total bycatch of other target species is shown for 1992-2013 in Table 4.23. The catch of non-target species from 2003-2013 is shown in Table 4.24. The yellowfin sole target fishery contribution to the total bycatch of prohibited species is shown for 2011 and 2012 in Table 13 of the Economic SAFE (Appendix C) and is summarized for 2012 as follows:

Prohibited species	Yellowfin sole fishery % of total bycatch
Halibut mortality	25.4
Herring	<1
Red King crab	18.2
C. bairdi	57.2
Other Tanner crab	84.8
Salmon	<1

2) Relative to the predator needs in space and time, the yellowfin sole target fishery has a low selectivity for fish 7-25 cm and therefore has minimal overlap with removals from predation.

3) The target fishery is not perceived to have an effect on the amount of large size target fish in the population due to its history of light to moderate exploitation (6%) over the past 30 years.

4) Yellowfin sole fishery discards are presented in the Catch History section.

5) It is unknown what effect the fishery has had on yellowfin sole maturity-at-age and fecundity.

6) Analysis of the benthic disturbance from the yellowfin sole fishery is available in the Preliminary draft of the Essential Fish Habitat Environmental Impact Statement.

Ecosystem effects on yellowfin sole			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Benthic infauna	Stomach contents	Stable, data limited	Unknown
Predator population trends			
Fish (Pacific cod, halibut, skates)	Stable	Possible increases to yellowfin sole mortality	
Changes in habitat quality			
Temperature regime	Cold years yellowfin sole catchability and herding may decrease, timing of migration may be prolonged	Likely to affect surveyed stock	No concern (dealt with in model)
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability

***Yellowfin sole* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Minor contribution to mortality	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	No concern
HAPC biota	Low bycatch levels of (spp)	Bycatch levels small relative to HAPC biota	No concern
Marine mammals and birds	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Low exploitation rate	Little detrimental effect	No concern
Fishery effects on amount of large size target fish	Low exploitation rate	Natural fluctuation	No concern
Fishery contribution to discards and offal production	Stable trend	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	Unknown	NA	Possible concern

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Tables

Table 4.1--Catch (t) of yellowfin sole 1964-2014. Catch for 2014 is an estimate through the end of 2014.

		Domestic		
Year	Foreign	JVP	DAP	Total
1964	111,777			111,777
1965	53,810			53,810
1966	102,353			102,353
1967	162,228			162,228
1968	84,189			84,189
1969	167,134			167,134
1970	133,079			133,079
1971	160,399			160,399
1972	47,856			47,856
1973	78,240			78,240
1974	42,235			42,235
1975	64,690			64,690
1976	56,221			56,221
1977	58,373			58,373
1978	138,433			138,433
1979	99,019			99,019
1980	77,768	9,623		87,391
1981	81,255	16,046		97,301
1982	78,331	17,381		95,712
1983	85,874	22,511		108,385
1984	126,762	32,764		159,526
1985	100,706	126,401		227,107
1986	57,197	151,400		208,597
1987	1,811	179,613	4	181,428
1988		213,323	9,833	223,156
1989		151,501	1,664	153,165
1990		69,677	14,293	83,970
1991			115,842	115,842
1992			149,569	149,569
1993			106,101	106,101
1994			144,544	144,544
1995			124,740	124,740
1996			129,659	129,659
1997			181,389	181,389
1998			101,201	101,201
1999			67,320	67,320
2000			83,850	83,850
2001			63,395	63,395
2002			73,000	73,000
2003			74,418	74,418
2004			69,046	69,046
2005			94,383	94,383
2006			99,068	99,068
2007			121,029	121,029
2008			148,894	148,894
2009			107,528	107,528
2010			118,624	118,624
2011			151,164	151,164
2012			147,183	147,183
2013			164,944	164,944
2014			145,900	145,900

Table 4.2 Estimates of retained and discarded (t) yellowfin sole caught in Bering Sea fisheries.

Year	Retained	Discarded
1987	3	1
1988	7,559	2,274
1989	1,279	385
1990	10,093	4,200
1991	89,054	26,788
1992	103,989	45,580
1993	76,798	26,838
1994	107,629	36,948
1995	96,718	28,022
1996	101,324	28,334
1997	149,570	31,818
1998	80,365	20,836
1999	55,202	12,118
2000	69,788	14,062
2001	54,759	8,635
2002	62,050	10,950
2003	63,732	10,686
2004	57,378	11,668
2005	85,321	9,062
2006	90,570	8,498
2007	109,084	11,945
2008	141,253	7,659
2009	92,488	5,733
2010	113,244	5,380
2011	146,419	4,745
2012	143,737	3,446
2013	158,781	6,163

Table 4.3. Discarded and retained catch of non-CDQ yellowfin sole, by fishery, in 2013. Source: AKFIN.

Trip Target Name	Discarded	Retained
Atka Mackerel	0	
Pollock - bottom	239	1,289
Pacific Cod	2,069	2,330
Alaska Plaice - BSAI	32	1,201
Other Flatfish - BSAI		
Halibut		
Rockfish	1	3
Flathead Sole	67	1,213
Kamchatka Flounder - BSAI	0	
Pollock - midwater	484	60
Rock Sole - BSAI	217	8,260
Sablefish		
Greenland Turbot - BSAI	0	
Arrowtooth Flounder	0	1
Yellowfin Sole - BSAI	3,055	144,423

Table 4.4. Yellowfin sole fishery catch-at-age (proportions), 1976-2013.

	females										
	7	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17+**
1976	0.03669	0.06686	0.17211	0.1001	0.06663	0.0127	0.00545	0.00339	0.00845	0.00367	0.00317
1977	0.06631	0.1602	0.10641	0.02384	0.00926	0.00691	0.00164	0.00061	0.00057	0.0003	0.00044
1978	0.05423	0.1253	0.11946	0.09349	0.09412	0.03216	0.01465	0.00702	0.0035	0.00175	0.00258
1979	0.02543	0.06863	0.11779	0.1223	0.07777	0.06146	0.02994	0.01147	0.00629	0.00256	0.004
1980	0.06346	0.03843	0.06147	0.10732	0.10217	0.06879	0.07129	0.04335	0.02139	0.01315	0.03064
1981	0.05683	0.06469	0.03499	0.05243	0.09441	0.10631	0.07202	0.0494	0.01566	0.00891	0.00656
1982	0.0269	0.0738	0.05527	0.04852	0.09249	0.09091	0.0521	0.02823	0.01637	0.00607	0.00163
1983	0.06572	0.04693	0.07821	0.04473	0.04783	0.07456	0.06457	0.05208	0.02998	0.01568	0.01264
1984	0.02858	0.03767	0.05111	0.09412	0.04148	0.06174	0.04829	0.05998	0.02637	0.01202	0.0169
1985	0.01611	0.02343	0.05842	0.05275	0.06781	0.06007	0.05477	0.06316	0.04547	0.01464	0.01211
1986	0.03239	0.03143	0.03959	0.09198	0.06725	0.06075	0.04381	0.03113	0.03751	0.02809	0.06184
1987	0.01183	0.02919	0.0186	0.0376	0.04956	0.05472	0.06055	0.04761	0.02667	0.02919	0.08561
1988	0.01828	0.02813	0.06862	0.02138	0.03835	0.05461	0.03677	0.06272	0.05295	0.02302	0.12403
1989	0.00274	0.03872	0.05009	0.04907	0.03212	0.0341	0.05479	0.0249	0.05001	0.04913	0.14596
1990	0.02247	0.00816	0.12501	0.03415	0.05531	0.03334	0.01661	0.01368	0.00797	0.08358	0.08753
1991	0.01257	0.06548	0.01014	0.10981	0.0435	0.03653	0.0098	0.03359	0.04158	0.02357	0.08731
1992	0.00642	0.02368	0.08927	0.0213	0.1431	0.04438	0.03653	0.01385	0.02814	0.01932	0.11872
1993	0.01731	0.01216	0.01825	0.09174	0.00779	0.11665	0.02951	0.03394	0.02063	0.02922	0.17809
1994	0.02131	0.03207	0.02889	0.03379	0.15691	0.00122	0.0995	0.01019	0.04277	0.02136	0.12875
1995	0.03841	0.0576	0.02461	0.01452	0.01781	0.10374	0.00232	0.15515	0.01433	0.02671	0.12129
1996	0.01379	0.03702	0.06043	0.02261	0.0285	0.0312	0.07101	0.00809	0.1068	0.0118	0.10506
1997	0.01839	0.0234	0.06131	0.0306	0.01727	0.02993	0.03143	0.09722	0.00861	0.05862	0.10337
1998	0.02259	0.02874	0.07532	0.0376	0.02122	0.03677	0.03861	0.11945	0.01058	0.07201	0.127
1999	0.01013	0.01793	0.0265	0.0241	0.08416	0.04827	0.02759	0.03811	0.04482	0.06526	0.23285
2000	0.00376	0.01416	0.05356	0.02988	0.02584	0.06716	0.07846	0.04789	0.01579	0.03666	0.21509
2001	0.01431	0.02373	0.04721	0.07791	0.04937	0.04466	0.07302	0.05113	0.0377	0.02042	0.16463
2002	0.00904	0.0214	0.03245	0.03673	0.06261	0.0427	0.03318	0.04305	0.04715	0.02135	0.21119
2003	0.00432	0.04556	0.04498	0.02518	0.04318	0.08206	0.03495	0.02166	0.01904	0.02747	0.18911
2004	0.01473	0.01009	0.10039	0.04505	0.03108	0.02263	0.04806	0.01934	0.01365	0.0455	0.18733
2005	0.01784	0.02658	0.03009	0.07884	0.02926	0.0333	0.03542	0.05525	0.02934	0.0064	0.18753
2006	0.06709	0.05429	0.03498	0.03755	0.13764	0.02269	0.00378	0.01261	0.03267	0.01347	0.09959
2007	0.01235	0.04265	0.03273	0.0215	0.04047	0.08023	0.02993	0.02981	0.02651	0.03268	0.16444
2008	0.0172	0.04493	0.04446	0.05187	0.02756	0.03035	0.06924	0.03737	0.02056	0.02576	0.17444
2009	0.02332	0.03392	0.06191	0.06438	0.035	0.05238	0.03627	0.04745	0.03162	0.02521	0.17014
2010	0.03614	0.02977	0.04362	0.0423	0.03987	0.032	0.03967	0.04079	0.05532	0.02752	0.17223
2011	0.02216	0.04946	0.03794	0.04856	0.03898	0.06036	0.03068	0.02854	0.02927	0.03978	0.15926
2012	0.02459	0.03281	0.04995	0.04348	0.04774	0.01599	0.0494	0.02106	0.00816	0.02339	0.15705
2013	0.00503	0.02062	0.03697	0.06569	0.06157	0.06878	0.05236	0.03717	0.01963	0.03127	0.1379

	males										
	7	8	9	10	11	12	13	14	15	16	17+
1976	0.05499	0.04452	0.1396	0.11466	0.03523	0.0206	0.01685	0.00152	0.00688	0.00071	0.00084
1977	0.03444	0.08169	0.07443	0.11594	0.0904	0.03569	0.02066	0.0025	0.00439	0.00085	0.00045
1978	0.05223	0.08661	0.06646	0.0679	0.07456	0.02795	0.00739	0.00374	0.00212	0.00138	0.00026

1979	0.03019	0.05967	0.11337	0.07054	0.06215	0.03637	0.01766	0.00928	0.00162	0.00083	0.00023
1980	0.03562	0.0202	0.02834	0.04695	0.05314	0.04603	0.01651	0.00294	0.00549	0.0069	0.00738
1981	0.04343	0.03712	0.0324	0.04685	0.07116	0.05913	0.03235	0.01382	0.01051	0.00201	0.00249
1982	0.0387	0.06094	0.04921	0.05025	0.0717	0.07243	0.04486	0.02346	0.00919	0.00166	0.00158
1983	0.06117	0.02988	0.06045	0.04767	0.0388	0.0561	0.04342	0.02244	0.02364	0.01137	0.00821
1984	0.01367	0.06292	0.03556	0.08011	0.03695	0.04903	0.04966	0.03311	0.04204	0.01666	0.01066
1985	0.02171	0.03064	0.0571	0.0637	0.07495	0.06195	0.05413	0.09705	0.03076	0.02018	0.01619
1986	0.03424	0.02402	0.05236	0.05975	0.04474	0.04044	0.06953	0.05566	0.03919	0.04201	0.04866
1987	0.01613	0.05199	0.03546	0.04566	0.04398	0.05057	0.04309	0.02315	0.01641	0.03117	0.13451
1988	0.02555	0.03517	0.08553	0.02395	0.03731	0.04274	0.05777	0.04415	0.03558	0.01335	0.08261
1989	0.0024	0.04493	0.03835	0.05839	0.01808	0.02057	0.02357	0.04975	0.02865	0.0308	0.15556
1990	0.04633	0.00824	0.17686	0.02483	0.05036	0.02135	0.03682	0.02947	0.00299	0.04123	0.07122
1991	0.01265	0.09453	0.00653	0.18859	0.03025	0.06305	0.02661	0.03971	0.02368	0.01749	0.06674
1992	0.0072	0.03172	0.10224	0.03036	0.13837	0.02377	0.00899	0.01362	0.00647	0.00983	0.04466
1993	0.01771	0.01134	0.01429	0.07871	0.01405	0.10398	0.02055	0.01663	0.00818	0.01507	0.09235
1994	0.02278	0.03778	0.02665	0.02191	0.10745	0.00545	0.01809	0.02495	0.02751	0.00714	0.04882
1995	0.02951	0.05589	0.0269	0.01293	0.01577	0.10037	0.08873	0.00992	0.00955	0.01467	0.04893
1996	0.0164	0.0578	0.04064	0.02215	0.00729	0.02849	0.00198	0.09953	0.06721	0.01272	0.06465
1997	0.01507	0.01971	0.04768	0.03817	0.02958	0.03593	0.10031	0.02484	0.01588	0.05018	0.09249
1998	0.01682	0.02383	0.02356	0.05119	0.04046	0.02989	0.01957	0.09914	0.03148	0.01008	0.11706
1999	0.00428	0.01831	0.01093	0.01534	0.04287	0.04882	0.00857	0.01884	0.03153	0.0394	0.11472
2000	0.00147	0.01752	0.04774	0.01322	0.02199	0.05306	0.02586	0.02247	0.0207	0.04564	0.12762
2001	0.00577	0.01671	0.01301	0.03266	0.02949	0.01486	0.02564	0.03016	0.03474	0.01824	0.15922
2002	0.00447	0.02392	0.02545	0.04166	0.08511	0.02639	0.02452	0.02916	0.01449	0.01435	0.13876
2003	0.0067	0.07505	0.04192	0.02618	0.02375	0.04161	0.01716	0.04588	0.02799	0.02361	0.14694
2004	0.00715	0.01919	0.09211	0.01846	0.01628	0.02043	0.01745	0.01846	0.00923	0.01906	0.19452
2005	0.01052	0.04206	0.02437	0.07854	0.02163	0.02087	0.03475	0.01363	0.01576	0.00732	0.14406
2006	0.06266	0.05322	0.03353	0.05053	0.0553	0.02386	0.02701	0.0368	0.02918	0.01006	0.08717
2007	0.01612	0.06636	0.02861	0.02668	0.04993	0.05765	0.01228	0.02142	0.03037	0.01682	0.11591
2008	0.02286	0.02985	0.06149	0.0212	0.03281	0.0167	0.02225	0.01618	0.02262	0.01577	0.11001
2009	0.01299	0.03554	0.02793	0.04783	0.02685	0.0144	0.07439	0.01443	0.0158	0.02117	0.13169
2010	0.06325	0.02935	0.05595	0.02137	0.04709	0.04297	0.02343	0.04266	0.02411	0.0101	0.10297
2011	0.01606	0.06939	0.03478	0.03245	0.033	0.04132	0.02196	0.01283	0.01304	0.03404	0.13678
2012	0.02497	0.0356	0.08152	0.0401	0.03057	0.02958	0.04044	0.03677	0.0098	0.01505	0.16482
2013	0.02006	0.00486	0.03373	0.08464	0.04766	0.0588	0.04386	0.03664	0.02569	0.0135	0.09067

Table 4.5—Yellowfin sole biomass estimates (t) from the annual Bering Sea shelf bottom trawl survey and upper and lower 95% confidence intervals.

Year	Total	Lower CI	Upper CI
1975	972,500	812,300	1,132,700
1979	1,866,500	1,586,000	2,147,100
1980	1,842,400	1,553,200	2,131,700
1981	2,394,700	2,072,900	2,716,500
1982	3,377,800	2,571,000	4,184,600
1983	3,535,300	2,958,100	4,112,400
1984	3,141,200	2,636,800	3,645,600
1985	2,443,700	1,563,400	3,324,000
1986	1,909,900	1,480,700	2,339,000
1987	2,613,100	2,051,800	3,174,400
1988	2,402,400	1,808,400	2,996,300
1989	2,316,300	1,836,700	2,795,800
1990	2,183,800	1,886,200	2,479,400
1991	2,393,300	2,116,000	2,670,700
1992	2,172,900	1,898,900	2,690,600
1993	2,465,400	2,151,500	2,779,300
1994	2,610,500	2,266,800	2,954,100
1995	2,009,700	1,724,800	2,294,600
1996	2,298,600	1,749,900	2,847,300
1997	2,163,400	1,907,900	2,418,900
1998	2,329,600	2,033,130	2,626,070
1999	1,306,470	1,118,800	1,494,150
2000	1,581,900	1,382,000	1,781,800
2001	1,863,700	1,605,000	2,122,300
2002	2,016,700	1,740,700	2,292,700
2003	2,239,600	1,822,700	2,656,600
2004	2,530,600	2,147,900	2,913,300
2005	2,823,500	2,035,800	3,499,800
2006	2,133,070	1,818,253	2,447,932
2007	2,152,738	1,775,191	2,530,285
2008	2,099,521	1,599,100	2,600,000
2009	1,739,238	1,435,188	2,043,288
2010	2,367,830	1,807,430	2,928,230
2011	2,403,021	1,926,371	2,879,671
2012	1,951,400	1,675,982	2,226,819
2013	2,279,004	1,934,134	2,623,874
2014	2,512,250	2,058,018	2,966,482

Table 4.6. Yellowfin sole population numbers-at-age (millions) estimated from the annual bottom trawl surveys, 1982-2014.

Females

year/age	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17+
1979	21	113	150	442	616	386	555	801	626	528	219	274	59	35	29	15
1980	1	92	342	518	800	1055	413	661	880	651	765	285	113	33	23	23
1981	0	20	195	839	692	1321	1155	261	477	744	527	311	168	55	23	45
1982	38	183	349	1211	1485	1424	1619	843	829	832	704	409	246	159	51	84
1983	0	5	59	154	751	1413	843	1065	936	753	1155	866	295	160	60	54
1984	0	53	278	264	427	745	841	1111	1080	941	541	583	480	239	174	133
1985	0	3	105	442	587	406	632	915	441	518	545	384	298	321	205	127
1986	0	8	24	219	349	666	279	574	519	377	284	318	196	250	136	259
1987	0	0	70	120	803	458	843	259	376	599	356	449	243	270	247	688
1988	0	0	7	370	71	1495	560	557	184	239	351	208	360	273	219	886
1989	0	0	14	98	718	234	1337	593	446	74	179	308	234	238	183	565
1990	0	0	70	102	325	1066	192	1257	408	482	101	72	107	78	231	605
1991	0	10	127	248	123	405	896	151	1263	213	525	63	128	87	123	807
1992	0	19	247	485	520	213	286	938	94	825	75	309	129	137	170	715
1993	0	24	100	357	634	434	269	224	1314	78	866	157	165	69	68	674
1994	0	54	95	223	518	905	555	482	284	1170	516	44	274	142	42	588
1995	0	19	153	288	181	889	627	274	135	25	634	21	561	104	80	512
1996	0	16	154	809	288	279	434	517	206	146	151	602	116	637	47	619
1997	0	18	324	502	725	256	239	506	228	114	176	184	500	44	314	533
1998	0	10	83	479	420	900	260	203	370	413	369	170	176	265	67	1167
1999	0	3	65	198	175	185	727	104	107	245	190	186	72	102	175	425
2000	0	11	54	248	208	304	444	537	189	198	237	219	65	117	145	572
2001	0	1	71	239	522	248	403	415	654	374	83	191	154	127	189	617
2002	0	16	123	170	255	778	346	290	229	457	221	91	307	116	152	805
2003	0	15	115	241	251	287	1143	225	279	286	251	103	115	170	168	943
2004	10	33	192	430	560	441	217	966	221	212	218	219	106	20	167	1020
2005	0	53	167	194	602	433	213	487	834	196	144	191	324	170	53	1332

2006	0	67	302	376	276	634	470	176	325	738	133	133	71	156	175	514
2007	0	37	515	348	376	277	504	308	124	227	504	119	137	127	105	724
2008	0	24	115	736	621	546	359	355	198	117	259	350	153	79	85	732
2009	5	38	204	204	1187	609	488	259	210	218	129	138	196	88	43	444
2010	0	33	328	386	438	895	554	517	329	335	155	166	135	173	99	684
2011	0	14	243	539	707	463	769	410	457	204	226	149	142	145	186	619
2012	10	50	229	394	503	293	243	752	256	334	106	156	37	150	128	547
2013	0	4	88	269	420	531	256	221	409	406	358	119	135	133	133	770

Table 4.6.(continued)

Males

year/age	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17+
1979	21	115	143	390	381	303	583	847	604	406	349	247	54	76	29	36
1980	20	78	306	632	853	1221	457	558	616	568	444	370	147	18	8	8
1981	0	50	200	1047	640	1280	858	394	372	546	534	266	66	83	55	12
1982	89	193	428	1780	1781	1059	1673	644	774	463	471	482	302	8	24	8
1983	0	1	65	183	724	1729	808	1049	676	699	722	566	425	550	77	51
1984	0	68	246	323	497	734	830	612	788	718	358	379	201	316	122	106
1985	0	41	172	419	559	263	652	527	401	451	360	224	260	157	112	65
1986	0	13	47	108	373	652	262	327	284	335	211	205	115	210	82	252
1987	0	5	41	106	838	467	673	445	328	277	210	147	106	142	185	600
1988	0	2	10	435	49	1163	553	443	85	187	28	177	336	189	28	599
1989	0	2	23	181	788	177	1306	513	357	135	50	103	54	204	35	478
1990	0	11	47	121	316	888	195	1144	318	263	40	65	67	24	55	389
1991	0	0	103	354	139	275	1046	68	1137	328	244	74	64	60	53	420
1992	0	0	146	445	566	262	226	812	114	907	193	213	12	12	61	607
1993	0	20	52	233	646	393	279	247	1096	69	842	53	53	50	0	341
1994	4	22	71	166	427	953	656	308	191	822	26	622	46	132	11	303
1995	0	0	169	120	270	667	565	94	179	75	478	13	603	49	24	418
1996	0	76	95	837	244	227	425	344	331	141	139	399	61	449	125	495
1997	0	10	214	425	798	181	184	446	245	194	214	108	514	79	264	416

1998	0	48	70	351	569	832	159	226	204	272	346	140	157	191	113	814
1999	0	5	100	142	225	243	575	146	94	309	269	75	53	28	119	425
2000	0	0	36	219	259	143	509	583	78	215	133	77	92	78	66	547
2001	0	0	87	141	652	341	375	357	562	208	87	158	65	73	140	432
2002	0	58	72	158	309	758	318	333	262	442	194	120	220	161	133	507
2003	0	24	95	178	258	251	1074	238	363	53	284	173	10	71	57	682
2004	4	63	114	469	447	199	395	993	263	81	195	223	103	47	249	456
2005	0	49	166	187	474	476	204	288	972	123	142	121	133	69	93	726
2006	0	101	173	348	332	505	393	288	298	384	116	155	89	39	11	590
2007	0	58	481	352	405	284	545	209	166	252	338	101	133	72	59	620
2008	0	10	99	662	462	483	344	453	225	144	185	329	63	66	35	581
2009	0	65	144	289	946	462	555	248	249	217	78	31	195	30	29	363
2010	0	78	199	418	371	1032	462	510	171	189	159	53	117	151	78	678
2011	1	7	150	385	482	358	792	398	224	176	77	81	136	103	157	440
2012	0	69	274	352	344	273	238	425	297	179	98	67	91	34	100	2
2013	0	7	92	366	384	481	211	268	445	200	200	33	89	100	118	612

Table 4.7-Occurance of yellowfin sole in the Bering Sea trawl survey and collections of length and age structures and the number of otoliths aged from each survey.

Year	Total Hauls	Hauls w/Len	Number lengths	Hauls w/otoliths	Hauls w/ages	Number otoliths	Number ages
1982	334	246	37023	35	35	744	744
1983	353	256	33924	37	37	709	709
1984	355	271	33894	56	56	821	796
1985	357	261	33824	44	43	810	802
1986	354	249	30470	34	34	739	739
1987	357	224	31241	16	16	798	798
1988	373	254	27138	14	14	543	543
1989	374	236	29672	24	24	740	740
1990	371	251	30257	28	28	792	792
1991	372	248	27986	26	26	742	742
1992	356	229	23628	16	16	606	606
1993	375	242	26651	20	20	549	549
1994	375	269	24448	14	14	526	522
1995	376	254	22116	20	20	654	647
1996	375	247	27505	16	16	729	721
1997	376	262	26034	11	11	470	466
1998	375	310	34509	15	15	575	570
1999	373	276	28431	31	31	777	770
2000	372	255	24880	20	20	517	511
2001	375	251	26558	25	25	604	593
2002	375	246	26309	32	32	738	723
2003	376	241	27135	37	37	699	695
2004	375	251	26103	26	26	725	712
2005	373	251	24658	34	34	644	635
2006	376	246	28470	39	39	428	426
2007	376	247	24790	66	66	779	772
2008	375	238	25848	65	65	858	830
2009	376	235	22018	70	70	784	752
2010	376	228	20619	77	77	841	827
2011	376	228	21665	65	64	784	753
2012	376	242	23519	72	72	993	973
2013	376	232	23261	70		821	803
2014	376	219	20229	52		799	

Table 4.8—Total tonnage of yellowfin sole caught in resource assessment surveys in the eastern Bering Sea from 1977-4.

Year	Research catch (t)
1977	60
1978	71
1979	147
1980	92
1981	74
1982	158
1983	254
1984	218
1985	105
1986	68
1987	92
1988	138
1989	148
1990	129
1991	118
1992	60
1993	95
1994	91
1995	95
1996	72
1997	76
1998	79
1999	61
2000	72
2001	75
2002	76
2003	78
2004	114
2005	94
2006	74
2007	74
2008	69
2009	60
2010	79
2011	77
2012	64
2013	75
2014	81

Table 4.9—Mean length and weight at age for yellowfin sole.

average mean length at age (cm)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
males	7.4	10.7	11.8	14.3	16.9	19.5	22.0	24.0	25.7	27	28	28.9	29.7	30.3	30.5	31	31.3	31.6	32.2	32.2
females		9.8	12.6	14.6	17.4	19.8	22.4	24.5	26.7	28.5	29.6	30.8	31.7	32.5	33	33.4	34.2	34.3	33.2	33.8

weight at age (g) males

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1954	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1955	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1956	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1957	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1958	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1959	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1960	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1961	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1962	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1963	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1964	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1965	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1966	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1967	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1968	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1969	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1970	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1971	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1972	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1973	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1974	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1975	4	14	18	32	54	85	120	156	193	225	253	280	303	324	330	344	355	366	390	423
1976	4	14	18	32	54	85	120	156	193	225	253	280	303	324	330	344	355	366	390	423
1977	4	14	18	32	54	85	120	156	193	225	253	280	303	324	330	344	355	366	390	423
1978	4	14	18	32	54	85	120	156	193	225	253	280	303	324	330	344	355	366	390	423
1979	4	14	18	32	54	85	120	156	193	225	253	280	303	324	330	344	355	366	390	423
1980	4	14	18	32	54	85	120	156	193	225	253	280	303	324	330	344	355	366	390	423
1981	4	14	18	32	54	85	120	156	193	225	253	280	303	324	330	344	355	366	390	423
1982	4	11	25	50	83	112	133	142	158	182	196	212	218	249	403	386	386	455	532	408
1983	4	5	5	23	57	95	156	156	155	176	212	227	227	254	262	287	271	370	370	408
1984	4	10	20	31	57	121	150	181	202	193	202	213	246	252	257	262	282	415	290	370
1985	4	11	23	32	51	84	148	186	214	227	228	246	277	267	283	305	407	389	532	387
1986	4	9	18	27	34	61	98	176	217	233	239	229	271	263	258	324	265	318	300	370
1987	4	8	14	17	27	53	97	157	211	226	260	267	311	309	276	291	307	296	329	394
1988	4	7	10	18	45	75	76	138	207	242	261	304	301	297	339	304	308	315	326	386
1989	4	7	10	27	47	72	142	130	179	244	270	351	338	352	317	302	391	309	361	348
1990	4	9	16	22	44	64	98	120	175	197	273	323	341	326	337	286	348	353	343	388
1991	4	9	17	29	51	75	100	132	180	212	266	267	325	355	326	359	352	304	532	381

1992	4	9	17	28	53	86	97	125	174	208	239	264	306	508	407	395	344	360	406	360
1993	4	9	18	45	56	93	135	145	206	209	238	265	387	303	349	363	376	349	342	384
1994	4	23	32	53	76	92	116	182	198	207	259	336	311	345	345	407	356	479	349	424
1995	4	10	19	32	59	88	110	154	177	207	249	258	336	294	319	377	367	383	401	448
1996	4	10	19	32	54	107	134	163	184	215	221	264	281	295	314	326	333	418	326	435
1997	4	8	14	37	64	75	149	174	185	239	231	248	261	303	349	336	384	370	346	444
1998	4	10	20	27	49	79	113	156	208	207	259	262	289	301	291	332	330	354	350	392
1999	4	6	7	18	37	63	95	123	170	171	245	281	269	269	347	330	395	350	350	450
2000	4	10	20	36	32	64	88	133	161	284	233	271	302	255	291	331	351	349	373	385
2001	4	9	16	27	38	51	91	152	161	198	268	240	280	299	292	320	343	357	430	434
2002	4	9	18	21	57	59	81	134	188	204	241	248	269	306	303	343	336	304	368	414
2003	4	11	22	39	53	83	109	161	179	251	248	304	263	468	330	339	305	339	352	405
2004	4	7	20	40	64	94	157	157	213	266	334	310	297	356	360	338	387	414	443	446
2005	4	11	24	44	77	110	136	170	201	262	278	332	366	308	328	350	375	347	349	434
2006	4	10	19	36	71	124	139	180	207	237	233	315	330	380	385	446	369	335	382	390
2007	4	10	19	36	63	107	140	181	208	248	291	286	311	340	375	342	353	369	422	430
2008	4	8	13	29	50	91	113	181	194	252	262	289	306	364	366	369	372	374	417	481
2009	4	7	11	20	39	74	112	133	194	273	270	302	348	321	379	320	405	370	391	460
2010	4	14	18	32	54	85	120	156	193	225	253	280	303	324	330	344	355	366	390	423
2011	4	14	17	25	47	81	134	164	174	305	283	330	291	346	332	344	389	364	375	400
2012	4	14	12	27	48	83	126	181	214	249	274	296	295	341	342	382	380	388	396	400
2013	4	14	12	27	48	83	126	181	214	249	274	296	295	341	342	382	380	388	396	400
2014	4	14	12	27	48	83	126	181	214	249	274	296	295	341	342	382	380	388	396	400
Females	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1954	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1955	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1956	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1957	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1958	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1959	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1960	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1961	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1962	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1963	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1964	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1965	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1966	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1967	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1968	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1969	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1970	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1971	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1972	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1973	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1974	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1975	6	8	20	31	55	84	124	165	217	266	301	341	374	407	428	443	480	483	499	590

1976	6	8	20	31	55	84	124	165	217	266	301	341	374	407	428	443	480	483	499	590
1977	6	8	20	31	55	84	124	165	217	266	301	341	374	407	428	443	480	483	499	590
1978	6	8	20	31	55	84	124	165	217	266	301	341	374	407	428	443	480	483	499	590
1979	6	8	20	31	55	84	124	165	217	266	301	341	374	407	428	443	480	483	499	590
1980	6	8	20	31	55	84	124	165	217	266	301	341	374	407	428	443	480	483	499	590
1981	6	8	20	31	55	84	124	165	217	266	301	341	374	407	428	443	480	483	499	590
1982	6	8	20	42	75	98	139	176	214	233	235	289	300	339	336	406	490	417	386	568
1983	6	10	14	26	60	103	162	185	201	243	255	280	329	395	477	539	583	578	630	685
1984	6	14	26	33	57	110	156	177	222	246	294	338	332	325	422	436	458	497	665	654
1985	6	11	16	28	46	77	177	202	251	286	302	323	371	370	421	425	499	624	600	620
1986	6	14	27	23	41	71	103	173	239	284	338	342	350	402	351	391	422	440	455	611
1987	6	10	14	20	47	55	127	179	256	317	324	373	373	385	384	422	412	458	436	523
1988	6	9	12	16	34	66	85	159	237	286	307	378	396	404	388	415	437	429	485	578
1989	6	12	21	33	67	71	112	133	197	279	339	402	430	449	456	456	456	578	476	516
1990	6	11	17	24	38	65	99	126	197	243	321	449	450	416	446	464	455	471	523	569
1991	6	11	16	23	58	56	100	142	156	238	310	370	457	446	473	474	490	492	484	598
1992	6	12	21	29	55	85	121	177	176	283	305	284	352	435	516	459	484	519	459	547
1993	6	15	28	35	64	93	155	165	232	244	301	333	368	442	452	497	499	471	538	586
1994	6	20	46	53	86	87	125	155	235	276	284	337	396	351	461	464	480	476	514	553
1995	6	12	20	28	60	84	123	160	217	284	332	340	443	384	414	454	439	619	482	589
1996	6	11	16	36	51	108	137	167	202	222	311	318	334	405	399	432	534	462	523	558
1997	6	16	34	33	72	85	157	200	236	260	292	353	373	401	469	440	490	431	515	600
1998	6	10	14	36	51	90	104	177	237	278	279	318	370	416	405	403	448	407	532	581
1999	6	9	12	18	37	67	103	131	239	284	296	328	348	384	396	416	461	502	477	639
2000	6	11	16	33	33	91	81	158	175	237	306	310	373	401	440	422	494	506	483	636
2001	6	6	6	32	41	57	83	148	179	255	305	357	372	447	415	420	422	476	522	598
2002	6	11	18	27	48	65	87	120	224	243	261	337	346	374	408	434	452	505	489	585
2003	6	9	12	31	53	86	124	156	213	289	303	344	407	425	399	434	365	438	457	536
2004	6	9	18	43	63	101	168	172	245	299	346	380	407	483	543	450	461	464	500	604
2005	6	14	26	44	78	114	152	213	238	277	337	347	397	439	461	531	522	438	539	629
2006	6	9	13	40	82	125	153	204	245	319	314	375	370	533	460	476	865	480	537	691
2007	6	11	16	36	66	115	173	198	244	316	311	362	358	417	461	462	497	491	611	640
2008	6	13	24	28	54	98	129	199	226	286	320	355	384	442	434	471	530	530	552	630
2009	6	6	9	18	45	69	127	163	239	306	322	375	416	381	413	473	736	539	491	679
2010	6	8	20	31	55	84	124	165	217	266	301	341	374	407	428	443	480	483	499	590
2011	6	8	18	25	56	80	126	188	205	327	332	372	403	415	440	426	369	491	542	590
2012	6	8	12	26	49	81	144	169	256	313	341	349	445	459	471	476	444	527	525	590
2013	6	8	12	26	49	81	144	169	256	313	341	349	445	459	471	476	444	527	525	590
2014	6	8	12	26	49	81	144	169	256	313	341	349	445	459	471	476	444	527	525	590

Table 4.10. Female yellowfin sole proportion mature at age from Nichol (1994) and TenBrink and Wilderbuer (In review).

Age	1992, 1993 samples	2012 samples
1	0.00	0
2	0.00	0
3	.001	0
4	.004	0
5	.008	0
6	.020	.01
7	.046	.03
8	.104	.09
9	.217	.21
10	.397	.43
11	.612	.68
12	.790	.86
13	.899	.94
14	.955	.98
15	.981	.99
16	.992	1
17	.997	1
18	1.0	1
19	1.0	1
20	1.0	1

Table 4.11. Key equations used in the population dynamics model.

$N_{t,1} = R_t = R_0 e^{\tau_t}, \quad \tau_t \sim N(0, \delta^2{}_R)$	Recruitment 1956-75
$N_{t,1} = R_t = R_\gamma e^{\tau_t}, \ \tau_t \sim N(0, \delta^2{}_R)$	Recruitment 1976-96
$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}\left(1 - e^{-z_{t,a}}\right)N_{t,a}$	Catch in year *t* for age *a* fish
$N_{t+1,a+1} = N_{t,a} e^{-z_{t,a}}$	Numbers of fish in year *t+1* at age *a*
$N_{t+1,A} = N_{t,A-1} e^{-z_{t,A-1}} + N_{t,A} e^{-z_{t,A}}$	Numbers of fish in the "plus group"
$S_t = \sum N_{t,a} W_{t,a} \phi_a$	Spawning biomass
$Z_{t,a} = F_{t,a} + M$	Total mortality in year *t* at age *a*
$F_{t,a} = s_a \mu^F \exp^{\varepsilon^F{}_t}, \ \varepsilon^F{}_t \sim N(o, \sigma^{2}{}_F)$	Fishing mortality
$s_a = \frac{1}{1 + \left(e^{-\alpha + \beta a}\right)}$	Age-specific fishing selectivity
$C_t = \sum C_{t,a}$	Total catch in numbers
$P_{t,a} = {}^{C_{t,a}}\!/_{C_t}$	Proportion at age in catch
$SurB_t = q \sum N_{t,a} W_{t,a} v_a$	Survey biomass

Table 4.11—continued.

$$qprior = \lambda \frac{0.5(\ln q_{est,t} - \ln q_{prior})^2}{\sigma_q^2}$$ survey catchability prior (when estimated)

$$mprior = \lambda \frac{0.5(\ln m_{est} - \ln m_{prior})^2}{\sigma_m^2}$$ natural mortality prior (when estimated)

$$reclike = \lambda(\sum_{i=1965}^{endyear} \bar{R} - R_i)^2 + \sum_{a=1}^{20} (\bar{R}_{init} - R_{init,a})^2 + \frac{1}{2((\sum_{i=1965}^{endyear} \bar{R} - R_i)\frac{1}{n+1})}$$ recruitment likelihood

$$catchlike = \lambda \sum_{i=startyear}^{endyear} (\ln C_{obs,i} - \ln C_{est,i})^2$$ catch likelihood

$$surveylike = \lambda \frac{(\ln B - \ln \hat{B})^2}{2\sigma^2}$$ survey likelihood

$$SurvAgelike = \sum_{i,t} m_t P_{t,a} \ln \frac{\hat{P}_{t,a}}{P_{t,a}}$$ survey age composition likelihood

$$FishAgelike = \sum_{i,t} m_t P_{t,a} \ln \frac{\hat{P}_{t,a}}{P_{t,a}}$$ fishery age composition likelihood

Table 4.12. Variables used in the population dynamics model.

Variables	
R_t	Age 1 recruitment in year *t*
R_0	Geometric mean value of age 1 recruitment, 1956-75
R_γ	Geometric mean value of age 1 recruitment, 1976-96
τ_t	Recruitment deviation in year *t*
$N_{t,a}$	Number of fish in year *t* at age *a*
$C_{t,a}$	Catch numbers of fish in year *t* at age *a*
$P_{t,a}$	Proportion of the numbers of fish age *a* in year *t*
C_t	Total catch numbers in year *t*
$W_{t,a}$	Mean body weight (kg) of fish age *a* in year *t*
ϕ_a	Proportion of mature females at age *a*
$F_{t,a}$	Instantaneous annual fishing mortality of age *a* fish in year *t*
M	Instantaneous natural mortality, assumed constant over all ages and years
$Z_{t,a}$	Instantaneous total mortality for age *a* fish in year *t*
s_a	Age-specific fishing gear selectivity
μ^F	Median year-effect of fishing mortality
ε_t^F	The residual year-effect of fishing mortality
ν_a	Age-specific survey selectivity
α	Slope parameter in the logistic selectivity equation
β	Age at 50% selectivity parameter in the logistic selectivity equation
σ_t	Standard error of the survey biomass in year t

Table 4.13. Models evaluated for stock productivity in the 2014 stock assessment of yellowfin sole

	Model A	Model B
Years included	1955-2006	1978-2006
Fmsy	0.133	0.111
Bmsy (t)	345,000	391,000
ABC (t)	348,000	223,900
OFL (t)	342,000	237,600
Buffer between ABC and OFL	<1%	6%

Table 4-14. Model estimates of annual average fishing mortality for male and female yellowfin sole.

Females

year/age	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1964	0.03	0.13	0.24	0.29	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
1965	0.01	0.03	0.08	0.16	0.22	0.24	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
1966	0.01	0.03	0.09	0.22	0.35	0.42	0.45	0.45	0.46	0.46	0.46	0.46	0.46	0.46
1967	0.13	0.30	0.44	0.49	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
1968	0.00	0.00	0.01	0.04	0.12	0.26	0.37	0.43	0.45	0.45	0.45	0.45	0.45	0.45
1969	0.03	0.15	0.44	0.61	0.65	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
1970	0.29	0.60	0.68	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
1971	0.64	1.14	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
1972	0.13	0.35	0.42	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
1973	0.00	0.00	0.00	0.02	0.07	0.21	0.37	0.44	0.46	0.47	0.47	0.47	0.47	0.47
1974	0.00	0.00	0.00	0.01	0.03	0.08	0.13	0.15	0.16	0.16	0.17	0.17	0.17	0.17
1975	0.02	0.06	0.10	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
1976	0.01	0.03	0.06	0.09	0.11	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13
1977	0.03	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1978	0.03	0.07	0.10	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
1979	0.02	0.04	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
1980	0.02	0.03	0.04	0.06	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
1981	0.01	0.03	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1982	0.02	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1983	0.02	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1984	0.02	0.04	0.06	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
1985	0.02	0.04	0.07	0.09	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1986	0.03	0.06	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1987	0.01	0.02	0.04	0.07	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
1988	0.01	0.03	0.07	0.11	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
1989	0.00	0.01	0.04	0.07	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
1990	0.00	0.01	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1991	0.01	0.01	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1992	0.01	0.03	0.05	0.06	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
1993	0.01	0.01	0.02	0.03	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1994	0.01	0.03	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
1995	0.02	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1996	0.02	0.03	0.05	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
1997	0.02	0.04	0.06	0.08	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
1998	0.02	0.03	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1999	0.00	0.01	0.02	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2000	0.00	0.01	0.02	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2001	0.01	0.01	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2002	0.00	0.01	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2003	0.01	0.01	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2004	0.01	0.01	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2005	0.01	0.02	0.03	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

2006	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2007	0.02	0.03	0.05	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2008	0.02	0.04	0.07	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
2009	0.01	0.03	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2010	0.01	0.03	0.05	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
2011	0.01	0.03	0.05	0.08	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
2012	0.01	0.02	0.04	0.07	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
2013	0.00	0.01	0.04	0.08	0.11	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
2014	0.01	0.03	0.06	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

Table 4.14 continued.

Males

year/age	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1964	0.01	0.05	0.14	0.22	0.26	0.26	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
1965	0.02	0.08	0.19	0.24	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
1966	0.03	0.10	0.24	0.37	0.42	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
1967	0.01	0.03	0.09	0.23	0.40	0.49	0.52	0.53	0.53	0.53	0.53	0.53	0.53	0.53
1968	0.05	0.14	0.25	0.31	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
1969	0.02	0.16	0.49	0.64	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
1970	0.32	0.61	0.67	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
1971	0.91	1.42	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46
1972	0.00	0.00	0.02	0.09	0.19	0.24	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
1973	0.11	0.34	0.40	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
1974	0.08	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
1975	0.05	0.10	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
1976	0.01	0.03	0.06	0.10	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
1977	0.01	0.03	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1978	0.03	0.06	0.09	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
1979	0.02	0.04	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
1980	0.01	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.07	0.08	0.08	0.08	0.08	0.08
1981	0.01	0.02	0.03	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1982	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1983	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1984	0.02	0.05	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
1985	0.04	0.08	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
1986	0.04	0.08	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1987	0.02	0.05	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1988	0.02	0.06	0.11	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
1989	0.00	0.02	0.05	0.08	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
1990	0.01	0.02	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1991	0.01	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1992	0.02	0.04	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
1993	0.01	0.02	0.03	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1994	0.02	0.04	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
1995	0.02	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

1996	0.03	0.05	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
1997	0.03	0.06	0.08	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1998	0.01	0.02	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1999	0.00	0.00	0.01	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2000	0.00	0.01	0.02	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2001	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2002	0.00	0.01	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2003	0.01	0.02	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2004	0.01	0.01	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2005	0.01	0.03	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2006	0.03	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2007	0.02	0.05	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
2008	0.02	0.05	0.08	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
2009	0.01	0.02	0.05	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
2010	0.02	0.04	0.07	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
2011	0.01	0.03	0.06	0.09	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
2012	0.01	0.03	0.06	0.09	0.11	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13
2013	0.02	0.05	0.08	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11

Table 4.15. Model estimates of yellowfin sole full selection fishing mortality and exploitation rate (catch/total biomass).

Year	Full selection F	Exploitation Rate
1964	**0.30**	**0.14**
1965	**0.26**	**0.07**
1966	**0.46**	**0.12**
1967	**0.51**	**0.20**
1968	**0.46**	**0.11**
1969	**0.66**	**0.22**
1970	**0.69**	**0.18**
1971	**1.20**	**0.22**
1972	**0.43**	**0.06**
1973	**0.47**	**0.08**
1974	**0.17**	**0.04**
1975	**0.13**	**0.05**
1976	**0.13**	**0.03**
1977	**0.06**	**0.03**
1978	**0.12**	**0.06**
1979	**0.07**	**0.04**
1980	**0.08**	**0.03**
1981	**0.06**	**0.04**
1982	**0.05**	**0.03**
1983	**0.05**	**0.04**
1984	**0.08**	**0.05**
1985	**0.11**	**0.08**
1986	**0.11**	**0.07**
1987	**0.10**	**0.06**
1988	**0.13**	**0.08**
1989	**0.10**	**0.06**
1990	**0.04**	**0.03**
1991	**0.05**	**0.03**
1992	**0.08**	**0.06**
1993	**0.06**	**0.04**
1994	**0.07**	**0.05**
1995	**0.06**	**0.05**
1996	**0.07**	**0.05**
1997	**0.10**	**0.07**
1998	**0.06**	**0.04**
1999	**0.05**	**0.03**
2000	**0.06**	**0.04**
2001	**0.04**	**0.03**
2002	**0.05**	**0.03**
2003	**0.05**	**0.03**
2004	**0.04**	**0.03**
2005	**0.06**	**0.04**
2006	**0.05**	**0.04**

2007	**0.07**	**0.05**
2008	**0.10**	**0.07**
2009	**0.07**	**0.05**
2010	**0.08**	**0.05**
2011	**0.11**	**0.07**
2012	**0.12**	**0.06**
2013	**0.14**	**0.07**
2014		**0.06**

Table 4.16-Model estimates of yellowfin sole age-specific selectivities for the survey and fishery (ages 1 to 20 from left to right).

								survey females												
1982-2014	0.0	0.0	0.0	0.2	0.5	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
								survey males												
	0.0	0.0	0.0	0.1	0.4	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
								fishery females												
1964	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1965	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1966	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1967	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.6	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1968	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0
1969	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1970	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1971	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1972	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1973	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0
1974	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0
1975	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1976	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1977	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.6	0.8	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1978	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1979	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1980	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.5	0.7	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1981	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.6	0.8	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1982	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1983	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1984	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1985	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1986	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1987	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.7	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1988	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1990	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1991	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1992	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1993	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.6	0.7	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1994	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1995	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1996	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.5	0.7	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1997	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.6	0.8	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1998	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.5	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1999	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.7	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

2000	0.0		0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.7	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2001	0.0		0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2002	0.0		0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2003	0.0		0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2004	0.0		0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2005	0.0		0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2006	0.0		0.0	0.0	0.0	0.1	0.3	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2007	0.0		0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.7	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2008	0.0		0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2009	0.0		0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2010	0.0		0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2011	0.0		0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2012	0.0		0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2013	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2014	0.0		0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

fishery males

1964	0.0	0.0	0.0	0.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1965	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1966	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1967	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1968	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1969	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1970	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1971	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.7	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1972	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1973	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1974	0.0	0.0	0.0	0.0	0.1	0.2	0.6	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1975	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1976	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1977	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1978	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1979	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1980	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.7	0.8	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0
1981	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.5	0.6	0.8	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1982	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.7	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1983	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1984	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1985	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1986	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1987	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1988	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1990	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1991	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

1992	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1993	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.4	0.6	0.7	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1994	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1995	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1996	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1997	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.5	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1998	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1999	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.7	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2002	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2003	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2004	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2005	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2006	0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2007	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2008	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2009	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2010	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2011	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.5	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2012	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.5	0.7	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2013	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2014	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Table 4.17. Model estimates of yellowfin sole age 2+ total biomass (t) and begin-year female spawning biomass (t) from the 2013 and 2014 stock assessments.

	2013 Assessment		2014 Assessment	
Year	Female spawning biomass	Total biomass	Female spawning biomass	Total biomass
1964	128,916	779,784	136,981	773,167
1965	144,813	777,174	161,064	775,532
1966	162,027	831,076	192,902	833,801
1967	154,268	823,012	197,900	826,945
1968	133,895	746,221	180,950	749,034
1969	125,631	771,265	166,559	776,307
1970	101,100	724,316	111,492	724,495
1971	90,814	751,985	59,827	742,106
1972	91,809	784,413	30,675	767,644
1973	97,381	962,921	31,171	952,496
1974	104,688	1,147,400	46,673	1,146,960
1975	135,561	1,412,760	81,731	1,420,230
1976	181,097	1,669,720	137,000	1,682,960
1977	250,703	1,938,100	220,535	1,957,180
1978	340,085	2,192,830	324,755	2,217,080
1979	430,780	2,339,210	430,793	2,368,640
1980	534,042	2,505,400	547,397	2,539,620
1981	632,460	2,657,740	654,459	2,695,440
1982	721,023	2,787,560	747,659	2,829,440
1983	801,450	2,882,110	830,586	2,927,500
1984	860,593	2,946,590	893,770	2,994,950
1985	879,214	2,934,760	916,229	2,985,880
1986	867,261	2,853,940	905,007	2,907,620
1987	845,446	2,787,250	882,851	2,843,140
1988	812,032	2,765,630	844,700	2,823,900
1989	773,138	2,685,510	805,072	2,745,670
1990	781,876	2,676,890	815,042	2,738,970
1991	827,905	2,710,160	870,301	2,773,640
1992	863,332	2,712,710	911,873	2,777,450
1993	888,272	2,642,890	941,511	2,708,850
1994	902,563	2,601,120	954,845	2,668,010
1995	891,342	2,512,890	940,372	2,580,730
1996	869,571	2,449,370	912,244	2,518,790
1997	829,189	2,377,610	871,184	2,448,830
1998	787,211	2,249,500	828,599	2,322,670
1999	766,924	2,203,530	808,392	2,279,360
2000	758,269	2,215,810	798,348	2,295,540
2001	753,683	2,211,140	795,351	2,295,470
2002	746,861	2,210,630	790,373	2,300,000
2003	748,528	2,208,500	793,544	2,303,750

2004	745,337	2,209,820	790,488	2,310,300
2005	743,817	2,212,150	793,112	2,317,970
2006	735,119	2,188,710	788,107	2,298,580
2007	720,061	2,179,260	774,773	2,292,840
2008	688,110	2,173,370	741,499	2,286,200
2009	648,594	2,155,470	703,486	2,260,480
2010	623,607	2,198,590	679,764	2,289,400
2011	601,560	2,245,240	661,570	2,316,890
2012	581,630	2,273,960	645,180	2,319,210
2013	576,652	2,314,360	639,008	2,326,290
2014			636,935	2,313,170

	2013 Assessment		2014 Assessment	
Year	Female spawning biomass	Total biomass	Female spawning biomass	Total biomass
1964	128,916	779,784	136,981	773,167
1965	144,813	777,174	161,064	775,532
1966	162,027	831,076	192,902	833,801
1967	154,268	823,012	197,900	826,945
1968	133,895	746,221	180,950	749,034
1969	125,631	771,265	166,559	776,307
1970	101,100	724,316	111,492	724,495
1971	90,814	751,985	59,827	742,106
1972	91,809	784,413	30,675	767,644
1973	97,381	962,921	31,171	952,496
1974	104,688	1,147,400	46,673	1,146,960
1975	135,561	1,412,760	81,731	1,420,230
1976	181,097	1,669,720	137,000	1,682,960
1977	250,703	1,938,100	220,535	1,957,180
1978	340,085	2,192,830	324,755	2,217,080
1979	430,780	2,339,210	430,793	2,368,640
1980	534,042	2,505,400	547,397	2,539,620
1981	632,460	2,657,740	654,459	2,695,440
1982	721,023	2,787,560	747,659	2,829,440
1983	801,450	2,882,110	830,586	2,927,500
1984	860,593	2,946,590	893,770	2,994,950
1985	879,214	2,934,760	916,229	2,985,880
1986	867,261	2,853,940	905,007	2,907,620
1987	845,446	2,787,250	882,851	2,843,140
1988	812,032	2,765,630	844,700	2,823,900
1989	773,138	2,685,510	805,072	2,745,670
1990	781,876	2,676,890	815,042	2,738,970
1991	827,905	2,710,160	870,301	2,773,640

1992	863,332	2,712,710	911,873	2,777,450
1993	888,272	2,642,890	941,511	2,708,850
1994	902,563	2,601,120	954,845	2,668,010
1995	891,342	2,512,890	940,372	2,580,730
1996	869,571	2,449,370	912,244	2,518,790
1997	829,189	2,377,610	871,184	2,448,830
1998	787,211	2,249,500	828,599	2,322,670
1999	766,924	2,203,530	808,392	2,279,360
2000	758,269	2,215,810	798,348	2,295,540
2001	753,683	2,211,140	795,351	2,295,470
2002	746,861	2,210,630	790,373	2,300,000
2003	748,528	2,208,500	793,544	2,303,750
2004	745,337	2,209,820	790,488	2,310,300
2005	743,817	2,212,150	793,112	2,317,970
2006	735,119	2,188,710	788,107	2,298,580
2007	720,061	2,179,260	774,773	2,292,840
2008	688,110	2,173,370	741,499	2,286,200
2009	648,594	2,155,470	703,486	2,260,480
2010	623,607	2,198,590	679,764	2,289,400
2011	601,560	2,245,240	661,570	2,316,890
2012	581,630	2,273,960	645,180	2,319,210
2013	576,652	2,314,360	639,008	2,326,290
2014			636,935	2,313,170

Table 4.18—Model estimates of yellowfin sole population numbers at age (billions) for 1954-2014.

Females

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1954	1.02	0.70	0.32	0.25	0.25	0.23	0.23	0.23	0.23	0.23	0.23	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
1955	0.82	0.90	0.62	0.28	0.22	0.22	0.21	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.39
1956	0.69	0.73	0.80	0.55	0.25	0.20	0.19	0.18	0.18	0.18	0.18	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.52
1957	2.35	0.61	0.65	0.71	0.49	0.22	0.18	0.17	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.61
1958	1.50	2.08	0.54	0.57	0.63	0.44	0.20	0.16	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.66
1959	1.00	1.33	1.85	0.48	0.51	0.56	0.39	0.18	0.14	0.13	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.68
1960	0.89	0.89	1.18	1.64	0.43	0.45	0.49	0.34	0.15	0.11	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.62
1961	0.50	0.79	0.79	1.04	1.45	0.38	0.40	0.43	0.29	0.12	0.08	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.39
1962	0.90	0.44	0.70	0.70	0.93	1.29	0.33	0.35	0.38	0.24	0.09	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.11
1963	0.49	0.80	0.39	0.62	0.62	0.82	1.14	0.30	0.31	0.33	0.21	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1964	0.46	0.43	0.71	0.35	0.55	0.55	0.71	0.93	0.22	0.21	0.21	0.13	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1965	0.59	0.40	0.38	0.63	0.31	0.49	0.48	0.61	0.72	0.15	0.14	0.14	0.09	0.03	0.01	0.00	0.00	0.00	0.00	0.00
1966	0.59	0.52	0.36	0.34	0.56	0.27	0.43	0.42	0.52	0.59	0.11	0.10	0.10	0.06	0.02	0.01	0.00	0.00	0.00	0.00
1967	1.23	0.53	0.46	0.32	0.30	0.49	0.24	0.38	0.36	0.42	0.42	0.07	0.06	0.06	0.03	0.01	0.00	0.00	0.00	0.00
1968	1.85	1.09	0.47	0.41	0.28	0.26	0.42	0.19	0.25	0.21	0.23	0.23	0.04	0.03	0.03	0.02	0.01	0.00	0.00	0.00
1969	1.87	1.64	0.97	0.41	0.37	0.25	0.23	0.37	0.17	0.22	0.18	0.18	0.15	0.02	0.02	0.02	0.01	0.00	0.00	0.00
1970	2.45	1.66	1.46	0.86	0.37	0.32	0.22	0.20	0.28	0.09	0.10	0.08	0.08	0.07	0.01	0.01	0.01	0.00	0.00	0.00
1971	2.71	2.17	1.47	1.29	0.76	0.32	0.27	0.15	0.10	0.13	0.04	0.05	0.04	0.04	0.03	0.00	0.00	0.00	0.00	0.00
1972	2.12	2.40	1.93	1.31	1.15	0.67	0.26	0.13	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
1973	1.47	1.88	2.13	1.71	1.16	1.02	0.58	0.20	0.08	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
1974	1.98	1.30	1.67	1.89	1.52	1.03	0.90	0.52	0.18	0.07	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	2.33	1.76	1.16	1.48	1.67	1.35	0.91	0.80	0.46	0.16	0.06	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1976	1.53	2.07	1.56	1.03	1.31	1.48	1.19	0.79	0.67	0.37	0.13	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
1977	1.93	1.36	1.83	1.38	0.91	1.16	1.31	1.04	0.68	0.56	0.30	0.10	0.04	0.01	0.01	0.01	0.00	0.00	0.00	0.00
1978	1.26	1.71	1.21	1.62	1.22	0.80	1.01	1.13	0.89	0.58	0.47	0.25	0.08	0.03	0.01	0.01	0.01	0.00	0.00	0.00
1979	0.80	1.12	1.52	1.07	1.44	1.08	0.70	0.87	0.94	0.71	0.46	0.37	0.20	0.07	0.02	0.01	0.00	0.00	0.00	0.00
1980	1.55	0.71	0.99	1.34	0.95	1.27	0.95	0.61	0.74	0.79	0.59	0.38	0.30	0.16	0.05	0.02	0.01	0.00	0.00	0.00
1981	1.15	1.38	0.63	0.88	1.19	0.84	1.12	0.83	0.52	0.63	0.66	0.49	0.31	0.25	0.13	0.04	0.02	0.00	0.00	0.01
1982	3.32	1.02	1.22	0.56	0.78	1.05	0.74	0.98	0.72	0.45	0.53	0.55	0.41	0.26	0.21	0.11	0.04	0.01	0.00	0.01
1983	0.61	2.94	0.91	1.08	0.50	0.69	0.93	0.64	0.84	0.61	0.38	0.45	0.47	0.35	0.22	0.18	0.09	0.03	0.01	0.01
1984	2.72	0.54	2.61	0.80	0.96	0.44	0.60	0.80	0.55	0.71	0.52	0.32	0.38	0.40	0.29	0.19	0.15	0.08	0.03	0.02
1985	0.94	2.41	0.48	2.31	0.71	0.85	0.39	0.53	0.69	0.46	0.59	0.43	0.26	0.31	0.32	0.24	0.15	0.12	0.06	0.04

Table 4.18—Model estimates of yellowfin sole population numbers at age (billions) for 1954-2014 (continued).

	Females																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1986	0.72	0.83	2.14	0.43	2.05	0.63	0.75	0.34	0.45	0.57	0.37	0.47	0.34	0.21	0.25	0.26	0.19	0.12	0.10	0.08
1987	0.97	0.64	0.74	1.90	0.38	1.81	0.55	0.64	0.28	0.36	0.45	0.30	0.38	0.27	0.17	0.20	0.21	0.15	0.10	0.14
1988	1.32	0.86	0.56	0.65	1.68	0.34	1.60	0.49	0.56	0.24	0.30	0.37	0.24	0.30	0.22	0.13	0.16	0.16	0.12	0.19
1989	1.31	1.17	0.76	0.50	0.58	1.49	0.30	1.41	0.42	0.46	0.19	0.23	0.29	0.19	0.23	0.17	0.10	0.12	0.13	0.24
1990	0.65	1.16	1.04	0.68	0.44	0.51	1.32	0.26	1.23	0.36	0.38	0.15	0.19	0.23	0.15	0.19	0.13	0.08	0.10	0.30
1991	0.72	0.57	1.03	0.92	0.60	0.39	0.45	1.17	0.23	1.06	0.30	0.32	0.13	0.16	0.19	0.13	0.16	0.11	0.07	0.33
1992	1.58	0.64	0.51	0.91	0.82	0.53	0.35	0.40	1.02	0.20	0.91	0.26	0.27	0.11	0.13	0.16	0.11	0.13	0.10	0.34
1993	0.93	1.40	0.57	0.45	0.81	0.72	0.47	0.30	0.35	0.86	0.16	0.75	0.21	0.22	0.09	0.11	0.13	0.09	0.11	0.36
1994	0.79	0.83	1.25	0.50	0.40	0.72	0.64	0.41	0.27	0.30	0.74	0.14	0.63	0.18	0.19	0.07	0.09	0.11	0.07	0.39
1995	0.79	0.70	0.73	1.10	0.44	0.35	0.63	0.56	0.35	0.22	0.25	0.61	0.12	0.52	0.15	0.15	0.06	0.08	0.09	0.38
1996	1.94	0.70	0.62	0.65	0.98	0.39	0.31	0.55	0.48	0.30	0.19	0.21	0.51	0.10	0.43	0.12	0.13	0.05	0.06	0.39
1997	0.84	1.72	0.62	0.55	0.58	0.86	0.35	0.27	0.47	0.40	0.25	0.16	0.17	0.42	0.08	0.36	0.10	0.11	0.04	0.38
1998	0.70	0.74	1.53	0.55	0.48	0.51	0.76	0.30	0.23	0.39	0.33	0.20	0.13	0.14	0.34	0.06	0.29	0.08	0.09	0.34
1999	0.86	0.62	0.66	1.35	0.48	0.43	0.45	0.66	0.26	0.20	0.33	0.28	0.17	0.10	0.12	0.28	0.05	0.24	0.07	0.35
2000	1.19	0.77	0.55	0.58	1.20	0.43	0.38	0.40	0.58	0.22	0.17	0.28	0.24	0.14	0.09	0.10	0.24	0.05	0.20	0.36
2001	0.79	1.06	0.68	0.49	0.52	1.06	0.38	0.34	0.35	0.50	0.19	0.14	0.24	0.20	0.12	0.07	0.08	0.20	0.04	0.47
2002	1.15	0.70	0.94	0.60	0.44	0.46	0.94	0.34	0.29	0.30	0.43	0.16	0.12	0.20	0.17	0.10	0.06	0.07	0.17	0.43
2003	1.15	1.02	0.62	0.83	0.53	0.39	0.41	0.83	0.29	0.25	0.26	0.37	0.14	0.10	0.17	0.14	0.09	0.05	0.06	0.51
2004	2.15	1.02	0.91	0.55	0.74	0.47	0.34	0.36	0.73	0.25	0.22	0.22	0.31	0.12	0.09	0.14	0.12	0.07	0.05	0.48
2005	1.04	1.91	0.90	0.80	0.49	0.65	0.42	0.30	0.31	0.63	0.22	0.19	0.19	0.26	0.10	0.07	0.12	0.10	0.06	0.45
2006	1.20	0.92	1.69	0.80	0.71	0.43	0.58	0.37	0.26	0.27	0.53	0.18	0.16	0.16	0.22	0.08	0.06	0.10	0.09	0.43
2007	1.58	1.07	0.81	1.50	0.71	0.63	0.38	0.49	0.31	0.22	0.23	0.45	0.15	0.13	0.13	0.19	0.07	0.05	0.09	0.43
2008	1.52	1.40	0.95	0.72	1.33	0.63	0.55	0.33	0.42	0.26	0.18	0.19	0.37	0.13	0.11	0.11	0.15	0.06	0.04	0.43
2009	1.79	1.35	1.24	0.84	0.64	1.18	0.55	0.48	0.28	0.35	0.21	0.15	0.15	0.30	0.10	0.09	0.09	0.12	0.05	0.38
2010	1.36	1.59	1.20	1.10	0.74	0.57	1.04	0.48	0.41	0.23	0.29	0.18	0.12	0.12	0.25	0.08	0.07	0.07	0.10	0.35
2011	0.91	1.21	1.41	1.06	0.98	0.66	0.50	0.91	0.42	0.35	0.19	0.24	0.14	0.10	0.10	0.20	0.07	0.06	0.06	0.37
2012	1.09	0.80	1.07	1.25	0.94	0.86	0.58	0.44	0.79	0.35	0.29	0.16	0.19	0.11	0.08	0.08	0.16	0.05	0.05	0.34
2013	1.16	0.96	0.71	0.95	1.11	0.83	0.76	0.51	0.38	0.67	0.29	0.23	0.12	0.15	0.09	0.06	0.06	0.13	0.04	0.30
2014	1.16	1.02	0.86	0.63	0.84	0.98	0.74	0.67	0.45	0.33	0.55	0.23	0.18	0.10	0.12	0.07	0.05	0.05	0.10	0.27

Table 4.18—Model estimates of yellowfin sole population numbers at age (billions) for 1954-2014 (continued).

Males

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1954	1.02	0.40	0.27	0.24	0.24	0.23	0.23	0.23	0.23	0.23	0.23	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
1955	0.82	0.90	0.36	0.24	0.21	0.21	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.39
1956	0.69	0.73	0.80	0.32	0.21	0.19	0.19	0.18	0.18	0.18	0.18	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.52
1957	2.35	0.61	0.65	0.71	0.28	0.19	0.17	0.17	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.61
1958	1.50	2.08	0.54	0.57	0.63	0.25	0.17	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.66
1959	1.00	1.33	1.85	0.48	0.51	0.56	0.22	0.15	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.68
1960	0.89	0.89	1.18	1.64	0.43	0.45	0.49	0.19	0.12	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.62
1961	0.50	0.79	0.79	1.04	1.45	0.37	0.39	0.40	0.14	0.08	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.39
1962	0.90	0.44	0.70	0.70	0.92	1.26	0.31	0.27	0.20	0.05	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.11
1963	0.49	0.78	0.38	0.56	0.48	0.46	0.32	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1964	0.46	0.43	0.70	0.33	0.50	0.43	0.39	0.26	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1965	0.59	0.40	0.38	0.61	0.24	0.33	0.28	0.26	0.17	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1966	0.59	0.52	0.36	0.34	0.54	0.21	0.29	0.24	0.21	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1967	1.23	0.53	0.46	0.32	0.30	0.48	0.19	0.25	0.19	0.14	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1968	1.85	1.09	0.47	0.41	0.28	0.27	0.43	0.17	0.22	0.16	0.11	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1969	1.87	1.64	0.97	0.41	0.37	0.25	0.23	0.36	0.12	0.14	0.10	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1970	2.45	1.66	1.46	0.86	0.37	0.32	0.22	0.20	0.29	0.08	0.08	0.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1971	2.71	2.17	1.47	1.29	0.76	0.33	0.29	0.19	0.18	0.25	0.07	0.05	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
1972	2.12	2.40	1.93	1.31	1.15	0.68	0.29	0.25	0.16	0.14	0.16	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1973	1.47	1.88	2.13	1.71	1.16	1.02	0.60	0.25	0.22	0.14	0.11	0.10	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1974	1.98	1.30	1.67	1.89	1.52	1.03	0.89	0.46	0.15	0.12	0.08	0.06	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.00
1975	2.33	1.76	1.16	1.48	1.67	1.33	0.88	0.72	0.36	0.12	0.09	0.06	0.05	0.04	0.01	0.00	0.00	0.00	0.00	0.00
1976	1.53	2.07	1.56	1.03	1.31	1.48	1.17	0.74	0.57	0.28	0.09	0.07	0.05	0.04	0.03	0.01	0.00	0.00	0.00	0.00
1977	1.93	1.36	1.83	1.38	0.91	1.16	1.31	1.02	0.64	0.48	0.22	0.07	0.06	0.04	0.03	0.02	0.01	0.00	0.00	0.00
1978	1.26	1.71	1.21	1.62	1.23	0.81	1.03	1.15	0.88	0.54	0.40	0.19	0.06	0.05	0.03	0.02	0.02	0.00	0.00	0.00
1979	0.80	1.12	1.52	1.07	1.44	1.08	0.71	0.89	0.96	0.72	0.43	0.31	0.15	0.05	0.04	0.02	0.02	0.02	0.00	0.00
1980	1.55	0.71	0.99	1.34	0.95	1.27	0.95	0.61	0.76	0.81	0.60	0.36	0.26	0.12	0.04	0.03	0.02	0.02	0.01	0.01
1981	1.15	1.38	0.63	0.88	1.19	0.84	1.12	0.84	0.54	0.66	0.70	0.51	0.30	0.22	0.10	0.03	0.03	0.02	0.01	0.02
1982	3.32	1.02	1.22	0.56	0.78	1.05	0.74	0.98	0.73	0.46	0.56	0.59	0.43	0.25	0.18	0.08	0.03	0.02	0.01	0.02
1983	0.61	2.94	0.91	1.08	0.50	0.68	0.92	0.64	0.84	0.62	0.39	0.47	0.50	0.36	0.21	0.15	0.07	0.02	0.02	0.03
1984	2.72	0.54	2.61	0.80	0.96	0.44	0.60	0.80	0.55	0.72	0.52	0.33	0.40	0.42	0.31	0.18	0.13	0.06	0.02	0.04
1985	0.94	2.41	0.48	2.31	0.71	0.85	0.38	0.52	0.67	0.45	0.59	0.43	0.27	0.33	0.35	0.25	0.15	0.11	0.05	0.05

Table 4.18. Model estimates of yellowfin sole population numbers at age (billions) for 1954-2014 (continued).

Males	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1986	0.72	0.83	2.14	0.43	2.05	0.63	0.74	0.33	0.43	0.54	0.36	0.47	0.34	0.22	0.26	0.27	0.20	0.12	0.08	0.08
1987	0.97	0.64	0.74	1.90	0.38	1.82	0.55	0.64	0.27	0.34	0.43	0.29	0.37	0.27	0.17	0.21	0.22	0.16	0.09	0.13
1988	1.32	0.86	0.56	0.65	1.68	0.34	1.60	0.48	0.54	0.22	0.27	0.34	0.23	0.30	0.22	0.14	0.17	0.17	0.13	0.18
1989	1.31	1.17	0.76	0.50	0.58	1.49	0.30	1.40	0.40	0.43	0.17	0.21	0.27	0.18	0.23	0.17	0.11	0.13	0.13	0.24
1990	0.65	1.16	1.04	0.68	0.44	0.51	1.32	0.26	1.22	0.34	0.35	0.14	0.17	0.21	0.14	0.18	0.14	0.09	0.10	0.30
1991	0.72	0.57	1.03	0.92	0.60	0.39	0.45	1.16	0.23	1.04	0.29	0.30	0.12	0.15	0.18	0.12	0.16	0.11	0.07	0.34
1992	1.58	0.64	0.51	0.91	0.82	0.53	0.35	0.40	1.01	0.19	0.88	0.25	0.25	0.10	0.12	0.15	0.10	0.13	0.10	0.35
1993	0.93	1.40	0.57	0.45	0.81	0.72	0.47	0.30	0.34	0.84	0.16	0.72	0.20	0.20	0.08	0.10	0.13	0.08	0.11	0.36
1994	0.79	0.83	1.25	0.50	0.40	0.72	0.64	0.41	0.26	0.29	0.72	0.13	0.61	0.17	0.17	0.07	0.08	0.10	0.07	0.39
1995	0.79	0.70	0.73	1.10	0.44	0.35	0.63	0.55	0.35	0.22	0.24	0.59	0.11	0.50	0.14	0.14	0.06	0.07	0.09	0.38
1996	1.94	0.70	0.62	0.65	0.98	0.39	0.31	0.55	0.47	0.29	0.18	0.20	0.49	0.09	0.42	0.12	0.12	0.05	0.06	0.39
1997	0.84	1.72	0.62	0.55	0.58	0.86	0.34	0.27	0.46	0.40	0.25	0.15	0.17	0.41	0.08	0.35	0.10	0.10	0.04	0.37
1998	0.70	0.74	1.53	0.55	0.48	0.51	0.75	0.30	0.23	0.38	0.32	0.20	0.12	0.13	0.33	0.06	0.28	0.08	0.08	0.33
1999	0.86	0.62	0.66	1.35	0.49	0.43	0.45	0.66	0.26	0.19	0.32	0.27	0.16	0.10	0.11	0.27	0.05	0.23	0.06	0.34
2000	1.19	0.77	0.55	0.59	1.20	0.43	0.38	0.40	0.59	0.22	0.17	0.28	0.23	0.14	0.09	0.10	0.23	0.04	0.20	0.34
2001	0.79	1.06	0.68	0.49	0.52	1.06	0.38	0.34	0.35	0.51	0.19	0.14	0.23	0.19	0.12	0.07	0.08	0.19	0.04	0.45
2002	1.15	0.70	0.94	0.60	0.44	0.46	0.94	0.34	0.30	0.31	0.44	0.17	0.12	0.20	0.16	0.10	0.06	0.07	0.16	0.41
2003	1.15	1.02	0.62	0.83	0.53	0.39	0.41	0.83	0.30	0.26	0.26	0.38	0.14	0.10	0.17	0.14	0.08	0.05	0.06	0.49
2004	2.15	1.02	0.91	0.55	0.74	0.47	0.34	0.36	0.73	0.25	0.22	0.22	0.32	0.12	0.09	0.14	0.12	0.07	0.04	0.46
2005	1.04	1.91	0.90	0.80	0.49	0.65	0.42	0.30	0.31	0.63	0.22	0.19	0.19	0.27	0.10	0.07	0.12	0.10	0.06	0.43
2006	1.20	0.92	1.69	0.80	0.71	0.43	0.58	0.37	0.26	0.27	0.53	0.18	0.16	0.16	0.23	0.08	0.06	0.10	0.08	0.41
2007	1.58	1.07	0.81	1.50	0.71	0.63	0.38	0.50	0.31	0.22	0.23	0.45	0.15	0.13	0.13	0.19	0.07	0.05	0.08	0.42
2008	1.52	1.40	0.95	0.72	1.33	0.63	0.56	0.33	0.42	0.26	0.18	0.19	0.37	0.13	0.11	0.11	0.16	0.06	0.04	0.41
2009	1.79	1.35	1.24	0.84	0.64	1.18	0.55	0.48	0.28	0.35	0.21	0.15	0.15	0.30	0.10	0.09	0.09	0.13	0.05	0.37
2010	1.36	1.59	1.20	1.10	0.74	0.57	1.04	0.49	0.42	0.24	0.29	0.17	0.12	0.12	0.24	0.08	0.07	0.07	0.10	0.34
2011	0.91	1.21	1.41	1.06	0.98	0.66	0.50	0.91	0.41	0.35	0.19	0.24	0.14	0.10	0.10	0.20	0.07	0.06	0.06	0.36
2012	1.09	0.80	1.07	1.25	0.94	0.86	0.58	0.44	0.78	0.35	0.29	0.16	0.19	0.11	0.08	0.08	0.16	0.05	0.05	0.33
2013	1.16	0.96	0.71	0.95	1.11	0.83	0.76	0.51	0.38	0.65	0.28	0.23	0.12	0.15	0.09	0.06	0.06	0.12	0.04	0.30
2014	1.16	1.02	0.86	0.63	0.84	0.98	0.74	0.67	0.44	0.32	0.54	0.23	0.18	0.10	0.11	0.07	0.05	0.05	0.10	0.27

Table 4.19—Model estimates of the number of female spawners (millions) 1964-2014.

year/age	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1964	5.5	21.2	83.8	45.8	89.9	144.8	113.2	41.2	14.6	2.7	0.3	0.1	0.1	0.1	0.7
1965	4.9	14.4	54.5	152.2	65.2	94.7	120.7	81.4	28.2	9.7	1.8	0.2	0.1	0.0	0.5
1966	2.7	12.9	38.1	109.8	255.3	77.9	85.2	91.6	58.5	19.6	6.7	1.2	0.2	0.0	0.4
1967	4.9	7.2	34.0	76.4	181.3	286.8	61.3	54.1	54.2	33.3	11.1	3.8	0.7	0.1	0.2
1968	2.6	12.6	16.9	51.9	89.1	155.4	194.0	35.8	30.0	29.2	17.9	5.9	2.0	0.4	0.2
1969	2.5	7.0	33.6	34.9	93.1	119.9	154.4	145.5	22.7	17.5	16.7	10.1	3.3	1.1	0.3
1970	3.2	6.6	18.2	59.6	40.8	70.8	70.2	77.7	69.8	10.6	8.1	7.7	4.6	1.5	0.7
1971	3.2	8.2	13.2	20.5	54.8	28.7	39.8	34.1	36.0	31.3	4.7	3.6	3.4	2.1	1.0
1972	6.7	7.9	11.5	8.8	11.2	23.1	9.7	11.6	9.5	9.7	8.4	1.3	1.0	0.9	0.8
1973	10.2	17.5	18.4	16.8	10.4	10.2	16.8	6.1	6.9	5.5	5.6	4.8	0.7	0.6	1.0
1974	10.3	27.0	46.7	38.1	30.4	14.4	10.7	13.2	3.9	4.0	3.1	3.1	2.7	0.4	0.9
1975	13.5	27.4	71.8	96.5	69.1	42.2	15.6	9.6	10.8	3.0	3.0	2.3	2.4	2.0	0.9
1976	14.8	35.6	71.4	140.1	157.9	85.5	41.6	13.3	7.8	8.5	2.3	2.4	1.8	1.8	2.3
1977	11.6	39.3	93.6	143.2	239.2	201.7	85.6	35.7	10.8	6.2	6.7	1.8	1.8	1.4	3.2
1978	8.0	30.4	101.7	186.4	247.9	317.9	213.7	78.3	31.1	9.2	5.2	5.6	1.5	1.5	3.9
1979	10.8	21.0	78.1	196.9	307.4	310.9	317.0	183.8	64.2	24.7	7.3	4.1	4.4	1.2	4.3
1980	12.7	28.5	54.7	155.4	338.1	403.9	325.5	286.5	158.4	53.6	20.6	6.0	3.4	3.6	4.5
1981	8.4	33.5	74.6	110.2	270.8	448.7	424.3	293.7	245.8	131.4	44.4	16.9	4.9	2.8	6.7
1982	10.5	22.1	87.8	150.4	192.5	361.4	475.5	387.2	255.2	206.8	110.5	37.0	14.1	4.1	7.9
1983	6.9	27.8	57.8	176.8	262.9	258.5	387.1	439.8	341.5	218.0	176.6	93.4	31.3	11.9	10.1
1984	4.4	18.1	72.1	115.3	307.0	351.7	276.2	357.4	387.2	291.3	186.0	149.2	78.9	26.4	18.6
1985	8.5	11.6	47.3	144.0	198.1	402.3	366.6	248.3	306.3	321.5	241.8	152.8	122.6	64.9	37.0
1986	6.3	22.4	30.2	93.7	243.4	253.0	405.9	318.0	205.1	244.9	257.0	191.4	121.0	97.0	80.6
1987	18.1	16.6	58.0	58.7	155.3	308.4	255.6	354.2	264.6	165.4	197.5	205.1	152.8	96.5	141.7
1988	3.4	48.1	43.8	117.4	101.9	202.9	316.3	224.5	295.6	213.7	133.4	157.7	163.8	122.0	190.3

Table 4.19 (continued).

year/age	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1989	14.9	8.9	126.6	87.6	198.2	128.2	200.7	268.8	181.6	231.7	167.4	103.5	122.3	127.1	242.2
1990	5.1	39.6	23.6	258.2	153.2	259.4	131.5	176.3	224.8	147.0	187.5	134.1	82.9	98.0	295.9
1991	3.9	13.6	105.0	48.2	456.9	207.0	279.0	122.0	156.1	192.7	126.0	159.1	113.8	70.4	334.3
1992	5.3	10.4	36.1	214.3	85.2	617.1	222.1	257.9	107.4	133.1	164.3	106.4	134.3	96.1	341.5
1993	7.2	14.1	27.4	72.7	371.5	112.1	643.0	199.1	220.2	88.8	110.0	134.4	87.0	109.9	358.1
1994	7.2	19.1	37.2	56.0	129.0	503.4	120.3	591.9	174.0	185.9	74.9	91.8	112.1	72.6	390.2
1995	3.5	18.9	50.2	74.5	96.3	169.4	526.4	108.5	509.2	145.0	155.0	61.8	75.7	92.5	381.8
1996	3.9	9.4	49.5	100.2	128.4	127.3	178.6	479.2	94.2	428.3	122.0	129.0	51.4	63.0	394.9
1997	8.6	10.4	24.5	99.3	173.9	170.2	134.1	162.0	414.1	78.8	358.2	101.0	106.8	42.6	379.1
1998	5.1	22.7	27.0	48.7	169.7	225.4	174.4	117.9	135.4	334.9	63.7	286.4	80.7	85.4	337.2
1999	4.3	13.4	59.4	54.0	84.5	225.6	238.7	159.4	102.7	114.3	282.6	53.2	239.3	67.4	353.0
2000	4.3	11.4	35.6	122.0	96.4	114.9	243.2	221.4	140.8	87.9	97.8	239.3	45.1	202.6	356.0
2001	10.6	11.4	30.2	73.0	216.7	130.2	122.8	223.4	193.6	119.2	74.4	81.9	200.5	37.8	468.0
2002	4.6	28.2	30.2	61.5	129.1	293.4	140.4	114.2	198.0	166.3	102.3	63.2	69.6	170.4	429.9
2003	3.9	12.2	74.9	61.9	109.4	174.9	315.3	129.9	100.7	169.2	142.1	86.6	53.5	58.9	507.8
2004	4.7	10.3	32.3	152.9	109.5	147.9	188.0	292.3	114.8	86.2	144.8	120.4	73.3	45.3	480.1
2005	6.5	12.6	27.1	65.9	270.5	148.3	159.4	174.8	259.1	98.6	74.0	123.1	102.3	62.3	446.5
2006	4.3	17.3	33.1	54.9	115.7	362.7	158.0	146.3	152.8	219.3	83.4	62.0	103.1	85.7	426.2
2007	6.3	11.3	44.3	65.1	94.5	153.7	385.4	145.1	128.1	129.7	186.1	70.1	52.1	86.6	430.0
2008	6.3	16.6	29.5	88.8	112.4	124.4	160.7	347.2	124.5	106.6	107.8	153.2	57.7	42.9	425.2
2009	11.8	16.5	43.4	58.5	150.2	144.5	127.1	141.6	291.7	101.4	86.7	86.9	123.4	46.5	377.1
2010	5.7	31.2	43.6	87.0	100.4	196.6	150.7	114.4	121.6	242.7	84.3	71.4	71.5	101.6	348.8
2011	6.6	15.0	82.0	87.8	150.7	131.8	204.3	134.8	97.5	100.3	200.1	68.8	58.3	58.4	367.7
2012	8.6	17.4	39.5	165.1	150.9	194.5	133.8	177.8	111.5	78.1	80.3	158.6	54.5	46.2	337.6
2013	8.3	22.9	45.9	79.9	286.9	197.6	199.4	117.0	147.3	89.3	62.4	63.5	125.4	43.1	303.5
2014	9.8	22.1	60.5	93.6	139.8	373.0	198.3	169.7	94.3	114.7	69.5	48.1	48.9	96.6	267.0

Table 4.20. Model estimates of yellowfin sole age 5 recruitment (millions) from the 2013 and 2014 stock assessments.

Year class	2013 Assessment	2014 Assessment
1964	706	730
1965	724	734
1966	1,500	1,527
1967	2,263	2,293
1968	2,280	2,318
1969	2,986	3,034
1970	3,294	3,345
1971	2,582	2,621
1972	1,792	1,819
1973	2,412	2,449
1974	2,830	2,874
1975	1,865	1,894
1976	2,342	2,379
1977	1,529	1,553
1978	976	992
1979	1,888	1,918
1980	1,399	1,422
1981	4,033	4,101
1982	744	757
1983	3,309	3,368
1984	1,137	1,158
1985	870	887
1986	1,178	1,202
1987	1,598	1,632
1988	1,580	1,617
1989	781	801
1990	865	889
1991	1,900	1,958
1992	1,116	1,153
1993	936	969
1994	923	970
1995	2,307	2,401
1996	985	1,038
1997	807	872
1998	1,009	1,069
1999	1,400	1,474
2000	889	974
2001	1,291	1,425
2002	1,329	1,416
2003	2,684	2,657
2004	1,241	1,281
2005	1,626	1,486
2006	1,942	1,950

2007	1,880
2008	2,210
2009	1,682

Table 4.21—Selected parameter estimates and their standard deviation from the preferred stock assessment model.

	parameter	value	std dev
	alpha (q-temp model)	-0.07	0.04
	beta (q-temp model)	0.09	0.02
	mean_log_rec	0.84	0.10
	mean sel_slope_fsh (females)	1.20	0.08
	mean sel50_fsh (females)	8.72	0.25
	mean sel_slope_fsh_males	1.32	0.09
	mean sel50_fsh_males	8.29	0.25
	sel_slope_srv (females)	1.60	0.09
	sel50_srv (females)	5.08	0.07
	sel_slope_srv_males	-0.06	0.08
	sel50_srv_males	0.02	0.02
	Ricker SR logalpha	-4.15	0.50
	Ricker SR logbeta	-6.14	0.29
	Fmsy	0.11	0.03
	log (Fmsy)	-2.23	0.24
	ABC_biomass 2013	2143.30	147.60
	ABC_biomass 2014	2124.50	165.85
	msy	365.76	117.56
	Bmsy	390.99	67.79
1954	total biomass	2174900	201460
1955	total biomass	2142600	189960
1956	total biomass	2097100	177260
1957	total biomass	2057900	159420
1958	total biomass	2034200	138620
1959	total biomass	2004500	116370
1960	total biomass	1850200	91350
1961	total biomass	1458400	59372
1962	total biomass	1022300	25469
1963	total biomass	734670	14461
1964	total biomass	773170	14997
1965	total biomass	775530	15897
1966	total biomass	833800	17818
1967	total biomass	826940	18233
1968	total biomass	749030	17651
1969	total biomass	776310	18409
1970	total biomass	724490	18520
1971	total biomass	742110	20409
1972	total biomass	767640	22701
1973	total biomass	952500	27363
1974	total biomass	1147000	32747

	parameter	value	std dev
1975	total biomass	1420200	38760
1976	total biomass	1683000	44935
1977	total biomass	1957200	50947
1978	total biomass	2217100	56573
1979	total biomass	2368600	61442
1980	total biomass	2539600	65871
1981	total biomass	2695400	69622
1982	total biomass	2829400	72962
1983	total biomass	2927500	75644
1984	total biomass	2994900	77898
1985	total biomass	2985900	79590
1986	total biomass	2907600	81113
1987	total biomass	2843100	82546
1988	total biomass	2823900	84321
1989	total biomass	2745700	85552
1990	total biomass	2739000	86990
1991	total biomass	2773600	87777
1992	total biomass	2777400	88149
1993	total biomass	2708900	88338
1994	total biomass	2668000	88060
1995	total biomass	2580700	87504
1996	total biomass	2518800	87290
1997	total biomass	2448800	87068
1998	total biomass	2322700	86512
1999	total biomass	2279400	86501
2000	total biomass	2295500	87513
2001	total biomass	2295500	88695
2002	total biomass	2300000	89358
2003	total biomass	2303800	90568
2004	total biomass	2310300	91845
2005	total biomass	2318000	93096
2006	total biomass	2298600	94360
2007	total biomass	2292800	96466
2008	total biomass	2286200	99517
2009	total biomass	2260500	103110
2010	total biomass	2289400	107880
2011	total biomass	2316900	114090
2012	total biomass	2319200	122000
2013	total biomass	2326300	132220
2014	total biomass	2313200	145630

Table 4.22. Projections of yellowfin sole female spawning biomass (1,000s t), catch (1,000s t) and full selection fishing mortality rate for seven future harvest scenarios.

Scenarios 1 and 2

Maximum Tier 3 ABC harvest permissible

Year	Female spawning biomass	catch	F
2014	689.211	145.849	0.10
2015	698.309	172.767	0.11
2016	711.664	175.808	0.11
2017	716.798	177.587	0.11
2018	720.141	175.407	0.11
2019	720.208	170.668	0.11
2020	702.972	164.48	0.11
2021	690.734	160.842	0.11
2022	670.457	157.771	0.11
2023	652.234	155.31	0.11
2024	640.487	153.667	0.11
2025	632.881	152.262	0.11
2026	630.577	151.026	0.11
2027	630.005	149.977	0.11

Scenario 4

1/2 Maximum Tier 3 ABC harvest permissible

Year	Female spawning biomass	catch	F
2014	689.211	145.849	0.10
2015	711.177	86.3815	0.06
2016	763.272	92.2222	0.06
2017	805.993	97.1322	0.06
2018	845.005	99.6964	0.06
2019	879.051	100.58	0.06
2020	889.642	100.043	0.06
2021	903.056	100.44	0.06
2022	900.245	100.585	0.06
2023	895.627	100.674	0.06
2024	894.767	100.911	0.06
2025	896.016	101.195	0.06
2026	902.639	101.73	0.06
2027	908.846	102.228	0.06

Scenario 3

Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2014	689.211	145.849	0.10
2015	702.418	145.48	0.09
2016	725.397	166.538	0.11
2017	734.722	168.997	0.11
2018	741.654	167.614	0.11
2019	744.893	163.728	0.11
2020	729.867	158.311	0.11
2021	719.603	155.208	0.11
2022	700.291	152.518	0.11
2023	682.674	150.335	0.11
2024	671.307	148.876	0.11
2025	663.9	147.861	0.11
2026	661.706	147.46	0.11
2027	660.776	147.225	0.11

Scenario 5

No fishing

Year	Female spawning biomass	catch	F
2014	689.211	145.849	0.10
2015	723.650	0	0
2016	816.052	0	0
2017	902.035	0	0
2018	986.104	0	0
2019	1066.940	0	0
2020	1120.330	0	0
2021	1176.860	0	0
2022	1208.740	0	0
2023	1235.300	0	0
2024	1262.420	0	0
2025	1289.000	0	0
2026	1321.540	0	0
2027	1350.610	0	0

Table 4.22—continued.

Scenario 6

Determination of whether yellowfin sole are currently overfished **B35=514.800**

Year	Female spawning biomass	catch	F
2014	689.211	145.849	0.10
2015	693.416	204.899	0.14
2016	692.761	204.8	0.14
2017	685.278	203.625	0.14
2018	677.492	198.267	0.14
2019	667.677	190.369	0.14
2020	643.119	181.429	0.14
2021	624.664	175.86	0.14
2022	600.919	171.397	0.14
2023	580.937	165.21	0.13
2024	569.472	159.729	0.13
2025	563.714	156.672	0.13
2026	563.294	156.017	0.13
2027	564.4	155.806	0.13

Scenario 7

Determination of whether the stock is approaching an overfished condition **B35=514.800**

Year	Female spawning biomass	catch	F
2014	689.211	145.849	0.10
2015	698.309	172.771	0.11
2016	711.663	175.808	0.11
2017	711.778	210.598	0.14
2018	700.941	204.186	0.14
2019	687.939	195.297	0.14
2020	659.935	185.43	0.14
2021	638.562	179.105	0.14
2022	612.054	173.989	0.14
2023	589.607	168.915	0.13
2024	575.685	162.386	0.13
2025	568.085	158.472	0.13
2026	566.333	157.197	0.13
2027	566.471	156.561	0.13

Table 4-23. Catch and bycatch (t) of other BSAI target species in the yellowfin sole directed fishery from 1992-2012 estimated from a combination of regional office reported catch and observer sampling of the catch.

Species	1992	1993	1994	1995	1996	1997	1998	1999	2000
Pollock	13,100	15,253	33,200	27,041	22,254	24,100	15,335	8,701	13,425
Arrowtooth Flounder	366	1,017	1,595	346	820	386	2,382	1,627	1,998
Pacific Cod	8,700	8,723	16,415	13,181	8,684	12,825	10,224	4,380	5,192
Groundfish, General	7,990	3,847	3,983	2,904	2,565	4,755	3,580	2,524	3,541
Rock Sole	14,646	7,301	8,097	7,486	12,903	16,693	9,825	10,773	7,345
Flathead Sole		1,198	2,491	3,929	3,166	3,896	5,328	2,303	2,644
Sablefish	0	0		0	0	0	0	4	0
Atka Mackerel	1	0			0	0	1	33	0
Pacific ocean Perch	0	5		0		0	1	12	1
Rex Sole			1	1		0	20	36	1
Flounder, General	16,826	6,615	7,080	11,092	10,372	10,743	6,362	8,812	7,913
Squid	0		5	0	11	0	2	1	0
Dover Sole			35						
Thornyhead					0		1		
Shortraker/Rougheye	0				1	0	1	15	
Butter Sole			0			3	3		2
Eulachon smelt								0	
Starry Flounder		227	106	16	37	124	35	48	71
Northern Rockfish						1	0	0	
Dusky Rockfish								0	
Yellowfin Sole	136,804	91,931	126,163	108,493	112,818	169,661	90,062	62,941	71,479
English Sole		1							
Unsp.demersal rockfish						12	0		
Greenland Turbot	1	5	5	67	8	4	103	70	24
Alaska Plaice		1,579	2,709	1,130	553	6,351	2,758	2,530	2,299
Sculpin, General								215	97
Skate, General								26	4
Sharpchin Rockfish								1	
Bocaccio	0								
Rockfish, General	0		0	3	23	0	1	3	4
Octopus								0	
Smelt, general								0	0
Chilipepper		1							
Eels								1	1
Lingcod									
Jellyfish (unspecified)									127
Snails								12	4
Sea cucumber								0	56
Korean horsehair crab								0	0
Greenling, General									0

Table 4-23. (continued).

Species	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Pollock	16,502	14,489	11,396	10,382	10,312	6,084	4,041	9,867	7,024	3,749	8,685	11,226	20,246
Arrowtooth Flounder	1,845	998	1,125	279	645	352	216	1,969	1,858	868	2,338	995	2,012
Pacific Cod	6,531	6,259	4,621	3,606	3,767	2,588	2,529	5,769	10,849	8,649	16,300	19,230	24,382
Groundfish, General	3,936	2,678	3,133	1,612	2,134	2,333	4003			3,048			
Rock Sole	5,810	10,665	8,419	10,068	10,086	8,113	8,218	10,487	9,109	9,030	9,762	8,959	7,737
Flathead Sole	3,231	2,190	2,899	1,102	1,246	2,039	1,744	5,581	3,525	1,895	3,236	2,109	4,191
Sablefish	0				1			<1	<1		<1		
Atka Mackerel	0	0	17		110	17		<1	<1		<1	<1	<1
Pacific ocean Perch	1	1	11		15			<1	<1		<1		17
Rex Sole	2	0						2					
Other flatfish												1,201	388
Squid	0	0	1					<1			<1		
Dover Sole													
Thornyhead													
Shortraker/Rougheye	1												
Butter Sole		7											
Starry Flounder	82	133											
Northern Rockfish		1			3							<1	
Dusky Rockfish		0											
Yellowfin Sole	54,722	66,178	68,954	65,604	82,420	84,178	108,254	131,000	98,194	90,008	136,905	133,719	147,477
English Sole		1											
Unsp.demersal rockfish													
Greenland Turbot	32	2		1	7	8	1	<1	4		6	6	335
Alaska Plaice	1,905	10,396	365	5,891	8,707	14,043	16,389	13,519	10,748	10,749	18,340	13,613	16,006
Sculpin, General	12	1,226						2,891	1,438		1,808	1,924	1,922
Skate, General	21	1,042						1,301	1,481		1,969	2,270	2,686
Sharpchin Rockfish													
Bocaccio													
Rockfish, General	1		1	3	1	1		<1					<1
Octopus												1.3	
Smelt, general	0												
Chilipepper													
Eels	0	0											
Lingcod	2												
Jellyfish (unspecified)	173	161											
Snails	0	4											
Sea cucumber		0											
Korean horsehair crab	0												
Kamchatka flounder												110	147

Species	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Pollock	16,502	14,489	11,396	10,382	10,312	6,084	4,041	9,867	7,024	3,749	8,685	11,226	20,246
Arrowtooth Flounder	1,845	998	1,125	279	645	352	216	1,969	1,858	868	2,338	995	2,012
Pacific Cod	6,531	6,259	4,621	3,606	3,767	2,588	2,529	5,769	10,849	8,649	16,300	19,230	24,382
Groundfish, General	3,936	2,678	3,133	1,612	2,134	2,333	4003			3,048			
Rock Sole	5,810	10,665	8,419	10,068	10,086	8,113	8,218	10,487	9,109	9,030	9,762	8,959	7,737
Flathead Sole	3,231	2,190	2,899	1,102	1,246	2,039	1,744	5,581	3,525	1,895	3,236	2,109	4,191
Sablefish	0				1			<1	<1		<1		
Atka Mackerel	0	0	17		110	17		<1	<1		<1	<1	<1
Pacific ocean Perch	1	1	11		15			<1	<1		<1		17
Rex Sole	2	0						2					
Other flatfish												1,201	388
Squid	0	0	1					<1			<1		
Dover Sole													
Thornyhead													
Shortraker/Rougheye	1												
Butter Sole		7											
Starry Flounder	82	133											
Northern Rockfish		1			3							<1	
Dusky Rockfish		0											
Yellowfin Sole	54,722	66,178	68,954	65,604	82,420	84,178	108,254	131,000	98,194	90,008	136,905	133,719	147,477
English Sole		1											
Unsp.demersal rockfish													
Greenland Turbot	32	2		1	7	8	1	<1	4		6	6	335
Alaska Plaice	1,905	10,396	365	5,891	8,707	14,043	16,389	13,519	10,748	10,749	18,340	13,613	16,006
Sculpin, General	12	1,226						2,891	1,438		1,808	1,924	1,922
Skate, General	21	1,042						1,301	1,481		1,969	2,270	2,686
Sharpchin Rockfish													
Bocaccio													
Rockfish, General	1		1	3	1	1		<1					<1
Octopus												1.3	
Smelt, general	0												
Chilipepper													
Eels	0	0											
Lingcod	2												
Jellyfish (unspecified)	173	161											
Snails	0	4											
Sea cucumber		0											
Korean horsehair crab	0												
Kamchatka flounder												110	147

Table 4-24. Estimated non-target species catch (t) in the yellowfin sole fishery, 2003-2013 (PSC not included).

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Benthic urochordata	1670846	1695563	674762.4	520091.4	114427.4	347756.2	205806	155571.5	132867.4	143575.8	59971.79
Birds			0				0	0	0		
Bivalves	1542.82	1113.09	1327.44	343.22	447.7	1483.57	1300.1	1822.05	1670.78	692.05	345.3
Brittle star unidentified	34302.87	32271.17	28705.62	19961.38	7526.49	19047.93	5208.82	4081.56	14023.73	13126.42	1440.18
Capelin	2.67	4518.5	45.09	108	321.47	160.96	251.49	717.98	3768.89	2324.6	180.56
Corals Bryozoans	239.86	45.5	1231.63	9378.05	161.67	8309.49	312.1	504.22	950.09	676.5	960.83
Eelpouts	19044.18	12256.3	7729.27	4514.26	2344.44	5597.91	5188.39	5144.11	29320.08	14293.47	43287.9
Eulachon	12.03	277.55	33.15	115.04	5074.69	21.84	89.45	133.33	453.29	133.21	19.89
Giant Grenadier									235.58		
Greenlings	646.04	753.19	282.8	703.14	474.41	182.73	24.2	53.48	48.68	97.62	
Grenadier					339.3		357.8				
Gunnels					1.19						0.65
Hermit crab unidentified	87939.91	51999.48	82996.41	26898.09	35819.7	36606.14	15623.28	16760.07	15897.91	10096.95	2945.35
Invertebrate unidentified	556494.8	625561.3	418512.4	177181.3	40008.9	70400.76	30664.99	25883.21	65462.15	120895.9	21252.66
Misc crabs	14432.08	21523.78	11774.18	10570.58	27966.67	14094.76	11051.61	11681.31	20215.58	18002.27	12094.84
Misc crustaceans	13.8	185.99	225.41	2325.42	1401.8	719.29	1334.96	935.43	539.01	501.3	571.28
Misc fish	95744.69	91469.01	66164.3	42470.32	70970.52	66421.67	48912.64	29255.96	40107.75	86011.68	31511.52
Misc inverts (worms etc)	20.22	123.25	24.52	49.77	46.33	152.28	170.17	105.17	181.36	97.14	227.31
Other osmerids	4257.76	4291.77	496.86	633.64	35770.11	9832.96	848.75	2829.56	2053.14	4692.28	956.36
Pacific Sand lance	9.07	167	97.05	32.73	17.12	36.98	14.91	34.6	394.84	169.68	21.15
Pandalid shrimp	215.69	919.62	114.92	772.47	101.27	305.2	493.67	743.55	2272.93	605.64	1980.37
Polychaete unidentified	16.04	68.43	42.04	360.08	69.18	175.12	74.78	102.37	212.39	53.38	177.51
Scypho jellies	111900.4	299034	115550.4	46784.63	42345.58	146153	222943.9	152367.2	309001	176727.9	206559.8
Sea anemone unidentified	6086.94	6202.28	2580.69	4895.6	8790.75	24839.66	25572.46	20526.38	14667.5	5964.91	22625.99
Sea pens whips	9.28	28.05	164.2	3.01	12.05	323.91	184.8	634.57	19.59	66.6	38.71
Sea star	1939624	1865768	1606948	1308482	1456620	1831017	684867.4	791632.2	1662779	1728950	500173.1
Snails	118257	191064.2	69769.44	141516.9	95875.79	139765.1	58354.07	57060.24	74718.49	33707.79	23106.13
Sponge unidentified	11433.58	6807.34	12205.34	3118.2	405.2	6720.98	69506.33	16622.61	11311.53	12383.7	13330.54
Stichaeidae	72.11	31.78		9.92	784.32	238.7	9.55	171.16	383.74	135.62	147.32
Surf smelt						1.02					
urchins dollars cucumbers	2253.73	314.93	2548.64	845.45	3477.35	4897.16	7548.42	1278.18	987.46	753.88	667.21

Table 4.25--Yellowfin sole TAC and ABC levels, 1980- 2014

Year	TAC	ABC
1980	117,000	169,000
1981	117,000	214,500
1982	117,000	214,500
1983	117,000	214,500
1984	230,000	310,000
1985	229,900	310,000
1986	209,500	230,000
1987	187,000	187,000
1988	254,000	254,000
1989	182,675	241,000
1990	207,650	278,900
1991	135,000	250,600
1992	235,000	372,000
1993	220,000	238,000
1994	150,325	230,000
1995	190,000	277,000
1996	200,000	278,000
1997	230,000	233,000
1998	220,000	220,000
1999	207,980	212,000
2000	123,262	191,000
2001	113,000	176,000
2002	86,000	115,000
2003	83,750	114,000
2004	86,075	114,000
2005	90,686	124,000
2006	95,701	121,000
2007	136,000	225,000
2008	225,000	248,000
2009	210,000	210,000
2010	219,000	219,000
2011	196,000	239,000
2012	202,000	203,000
2013	198,000	206,000
2014	184,000	239,800

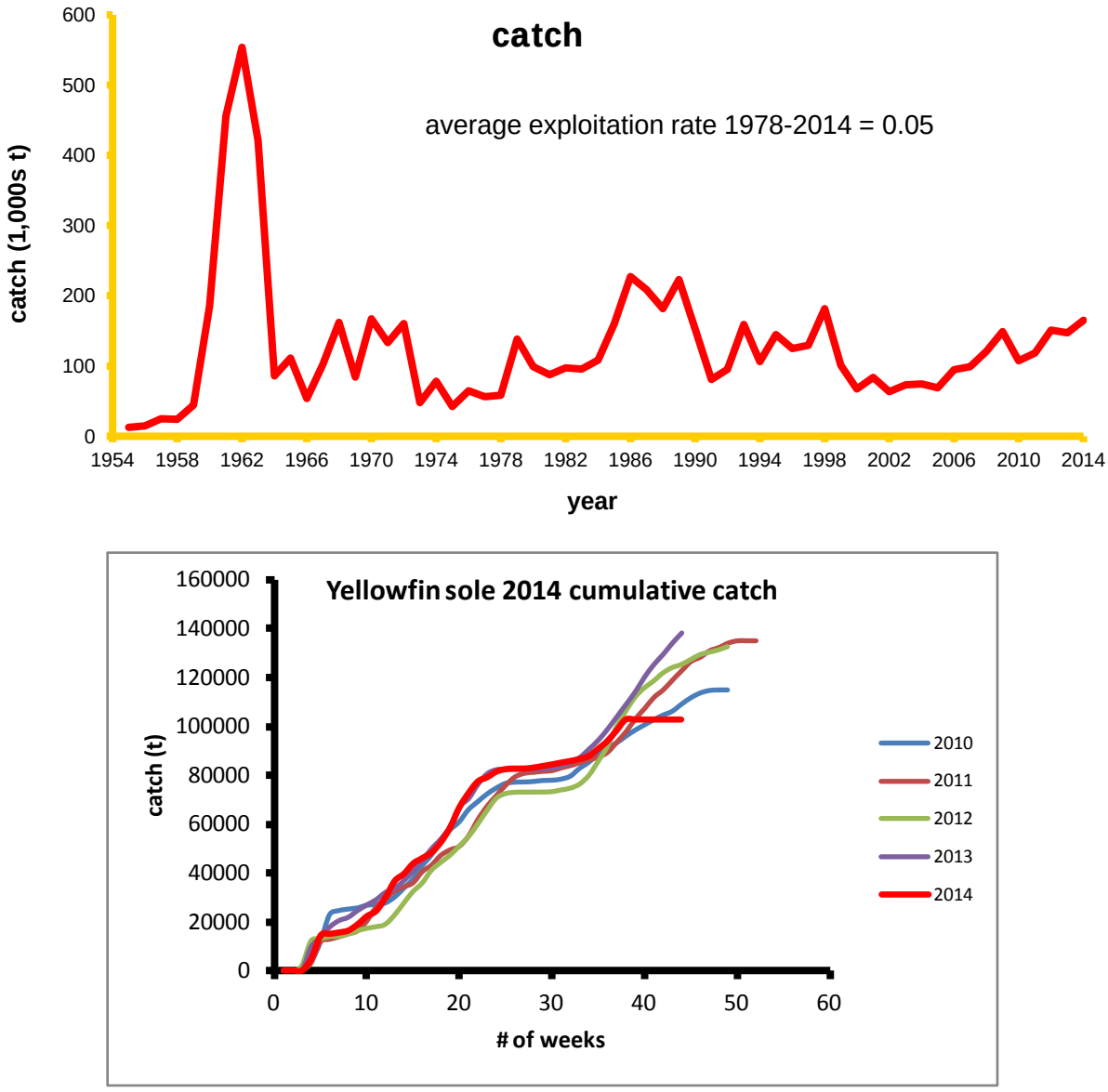


Figure 4.1—Yellowfin sole annual catch (1,000s t) in the Eastern Bering Sea from 1954-2013 (top panel) and catch by week from 2010 – September 2014 (bottom panel).

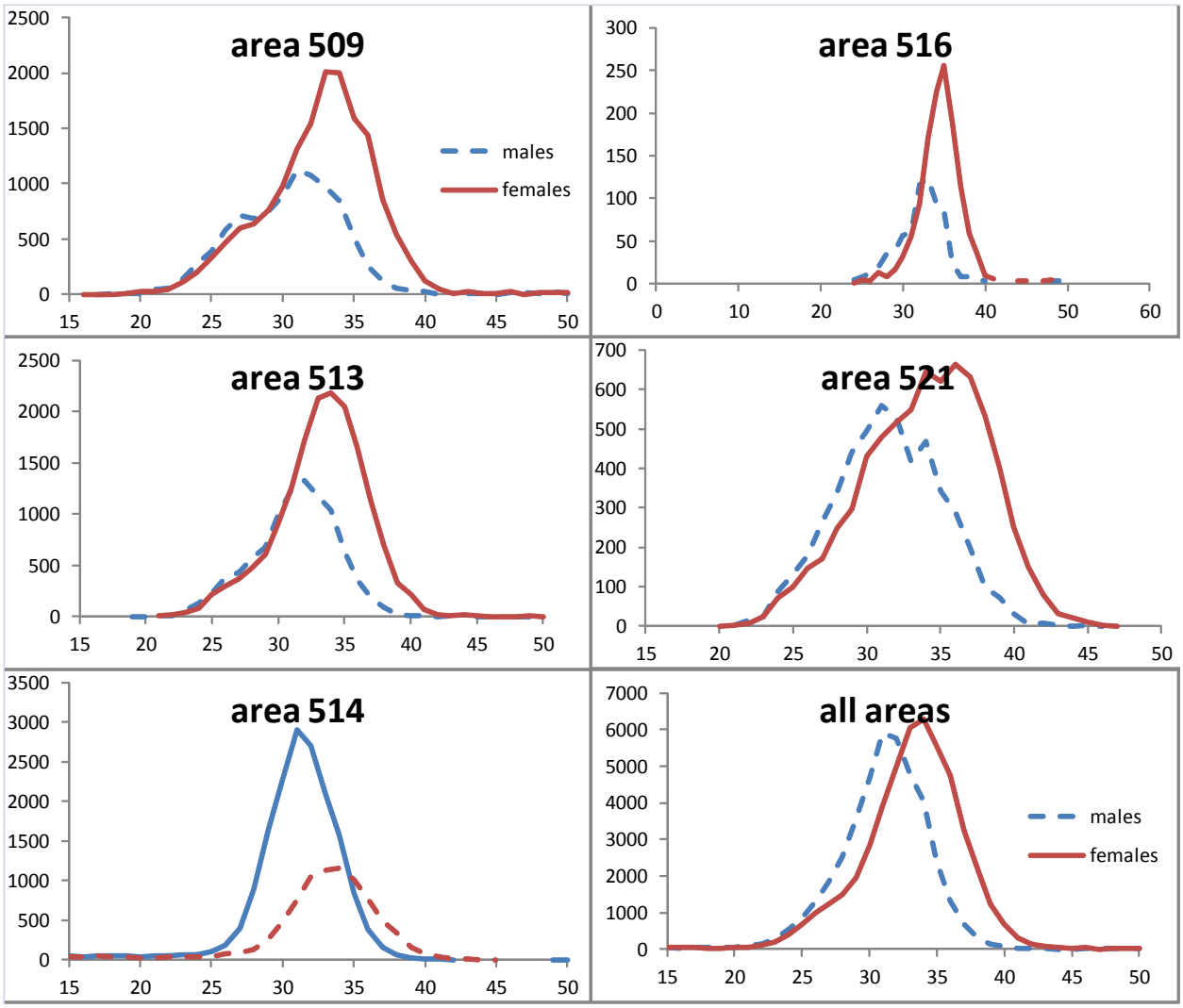


Figure 4.2--Size composition of the yellowfin sole catch in 2013 (through September), by subarea and total.

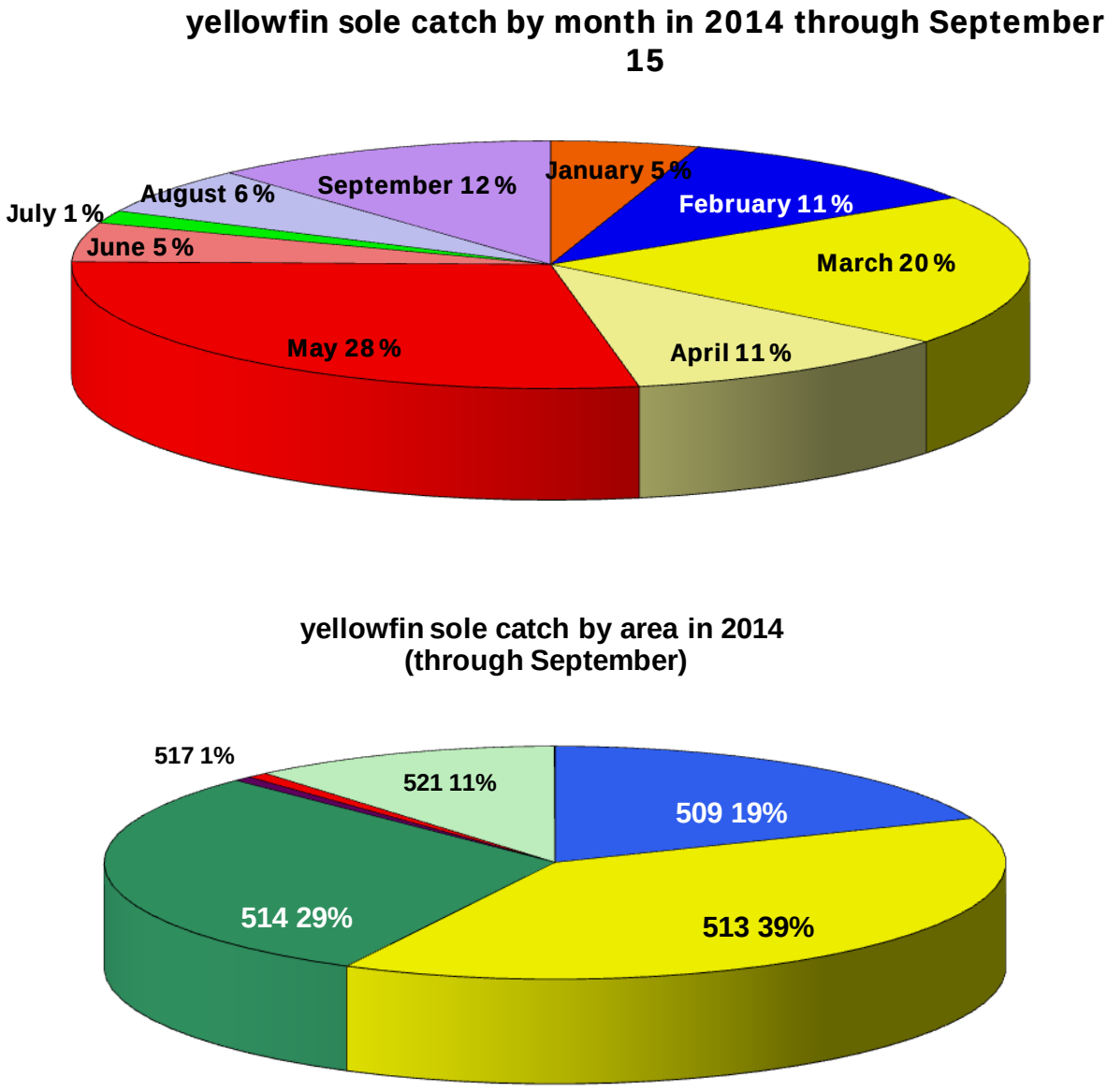
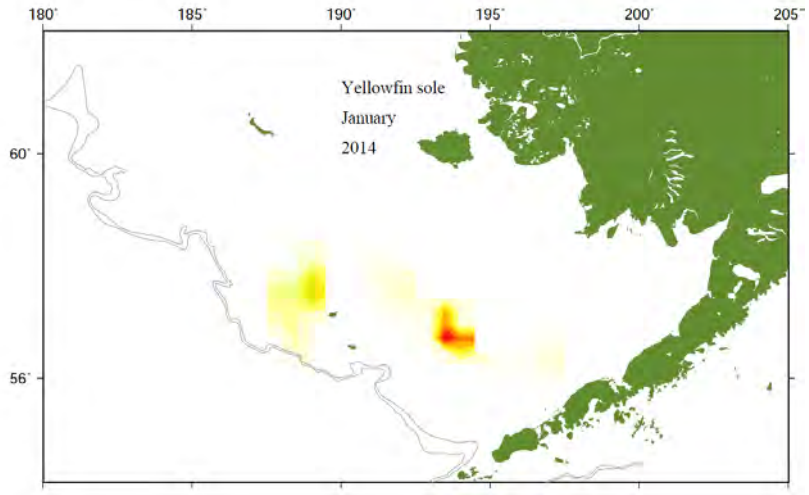
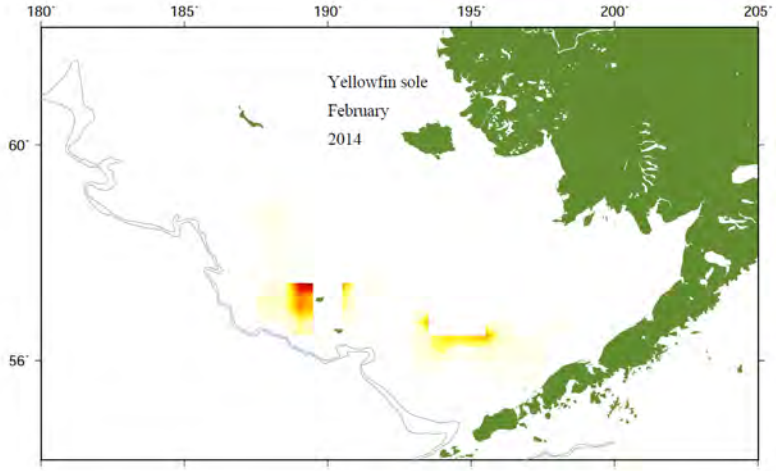
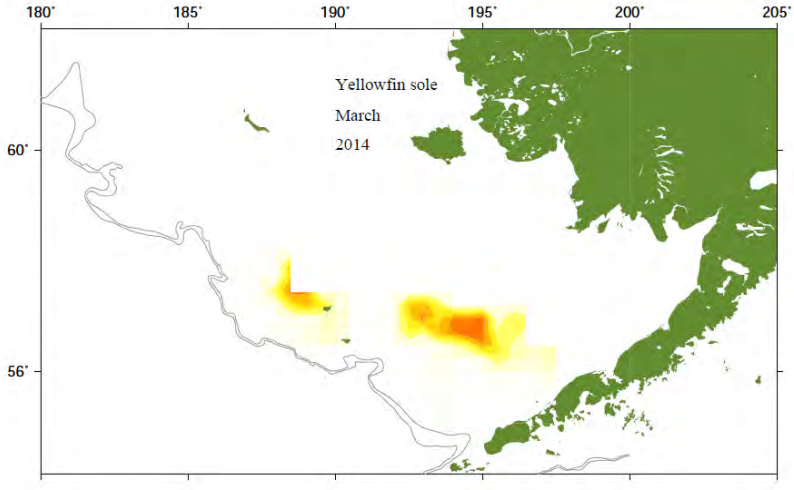
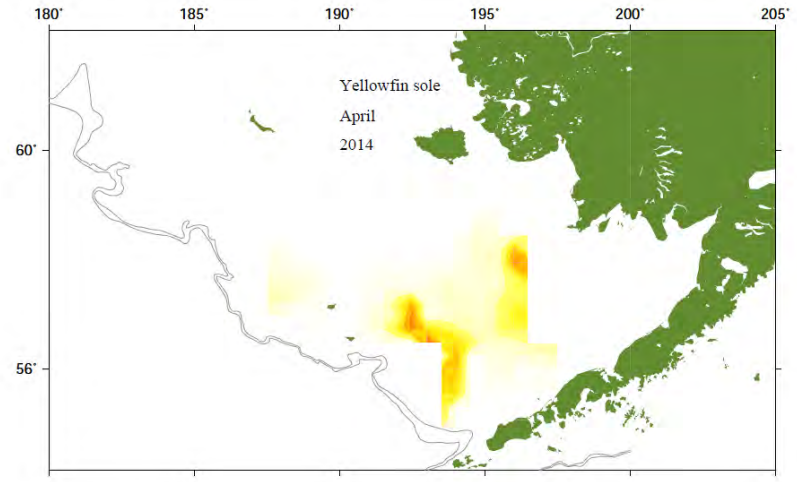


Figure 4.3 Yellowfin sole catch by month and area in the Eastern Bering Sea in 2013.


180°
185°
190°
195°
200°
205°
60°
56°
Yellowfin sole
January
2014


180°
185°
190°
195°
200°
205°
60°
56°
Yellowfin sole
February
2014


180°
185°
190°
195°
200°
205°
60°
56°
Yellowfin sole
March
2014


180°
185°
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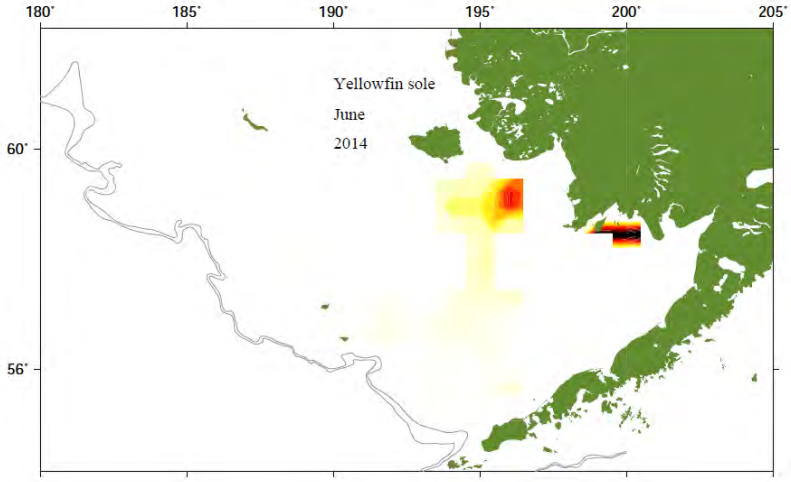
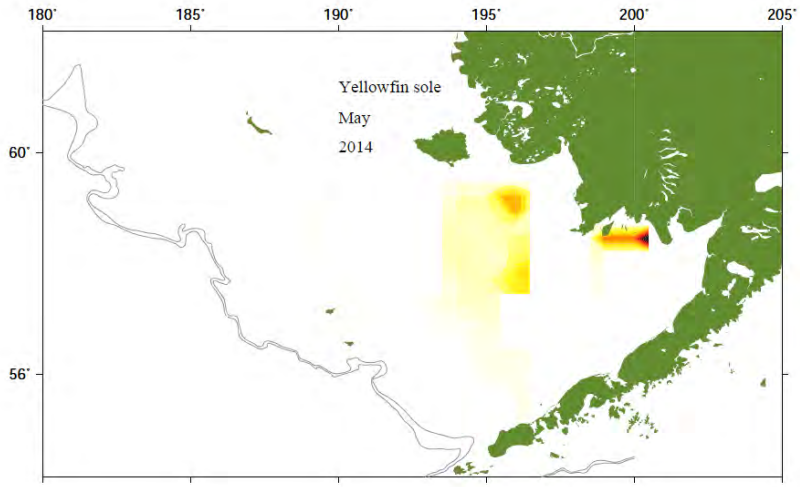
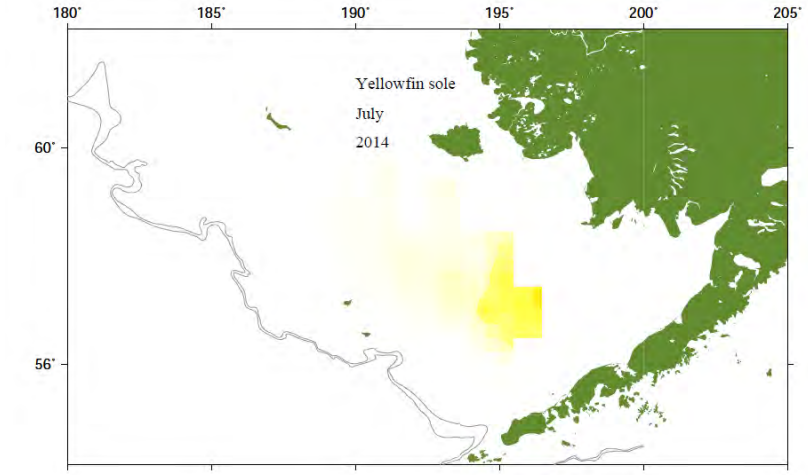
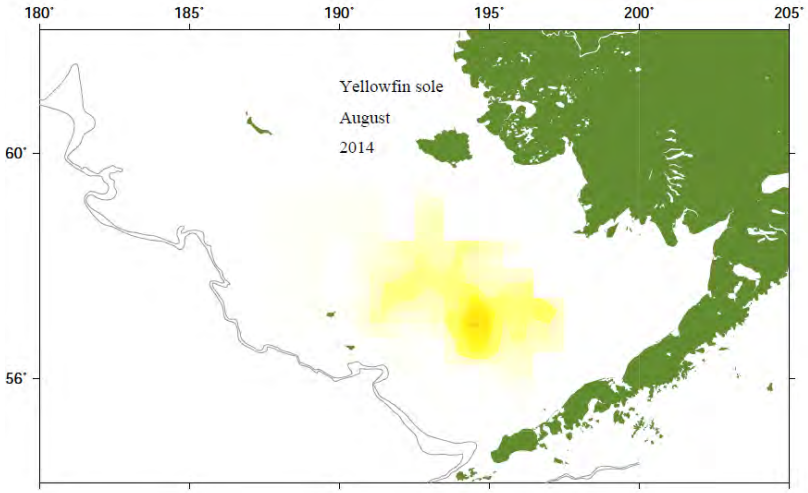
195°
200°
205°
60°
56°
Yellowfin sole
April
2014


180°
185°
190°
195°
200°
205°
60°
56°
Yellowfin sole
June
2014


180°
185°
190°
195°
200°
205°
60°
56°
Yellowfin sole
May
2014





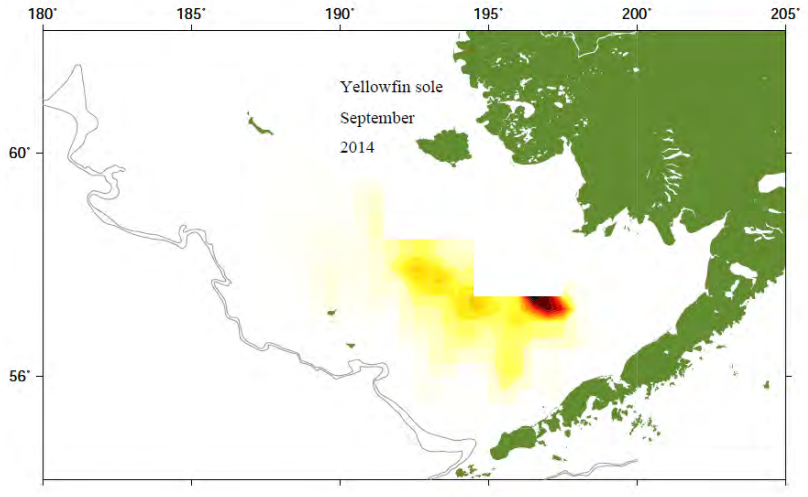


Figure 4.4— (Fishery locations by month).

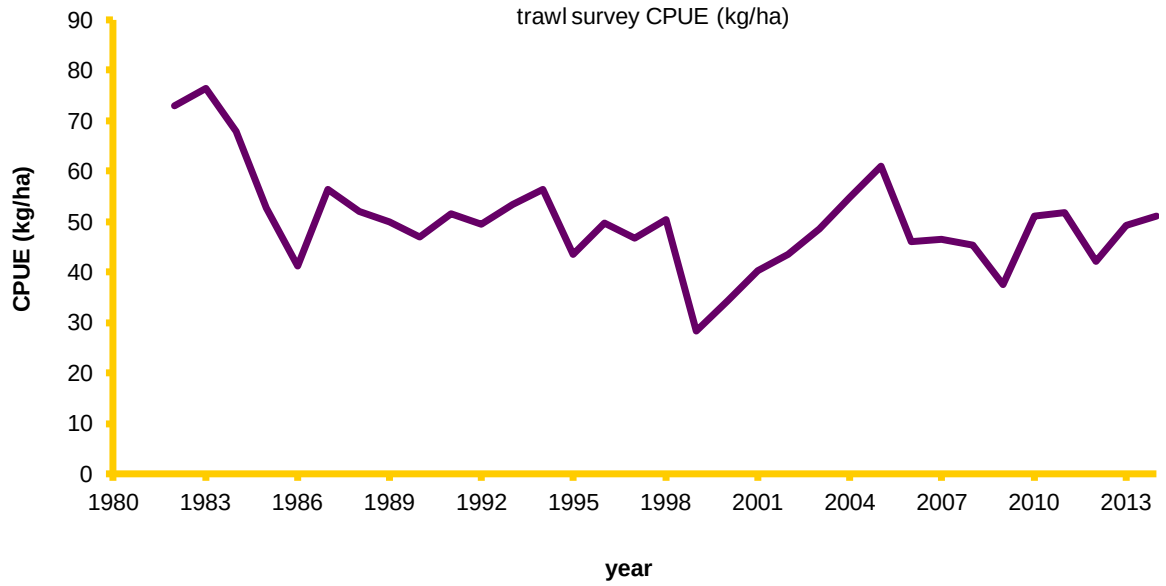


Figure 4.5.--Yellowfn sole CPUE (catch per unit effort in kg/ha) from the annual Bering Sea shelf trawl surveys, 1982-2014.

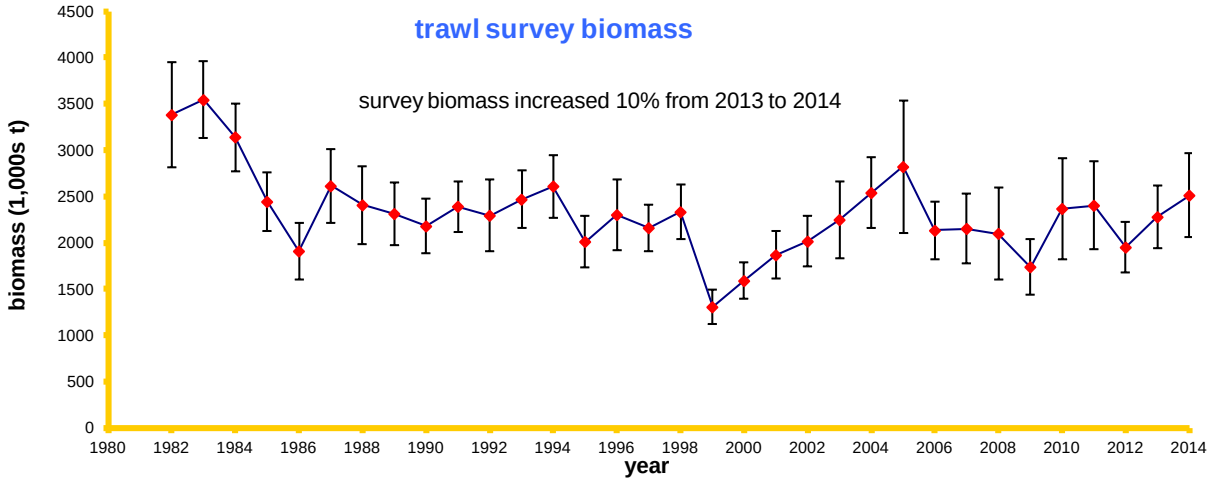


Figure 4.6.--Annual bottom trawl survey biomass point-estimates and 95% confidence intervals for yellowfin sole, 1982-2014.

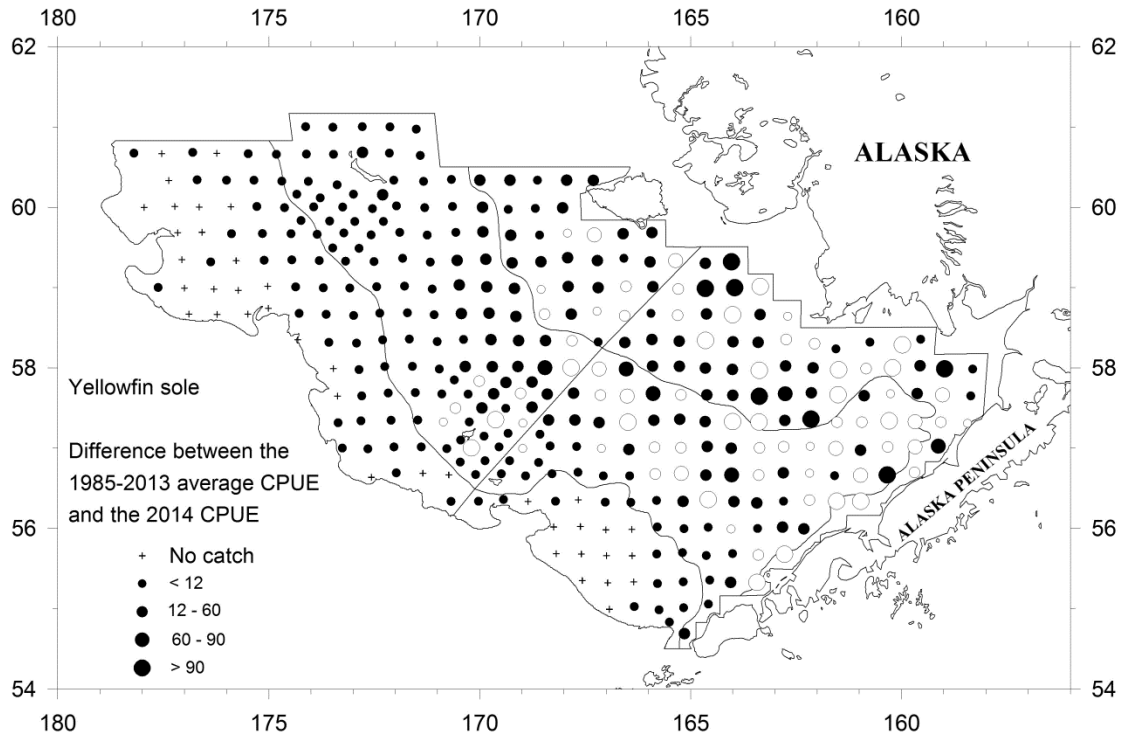


Figure 4.7.--Difference between the 1985-2013 average trawl survey CPUE for yellowfin sole and the 2014 survey CPUE. Open circles indicate that the magnitude of the catch was greater in 2014 than the long-term average, closed circles indicate the catch was greater in the long-term average than in 2014.

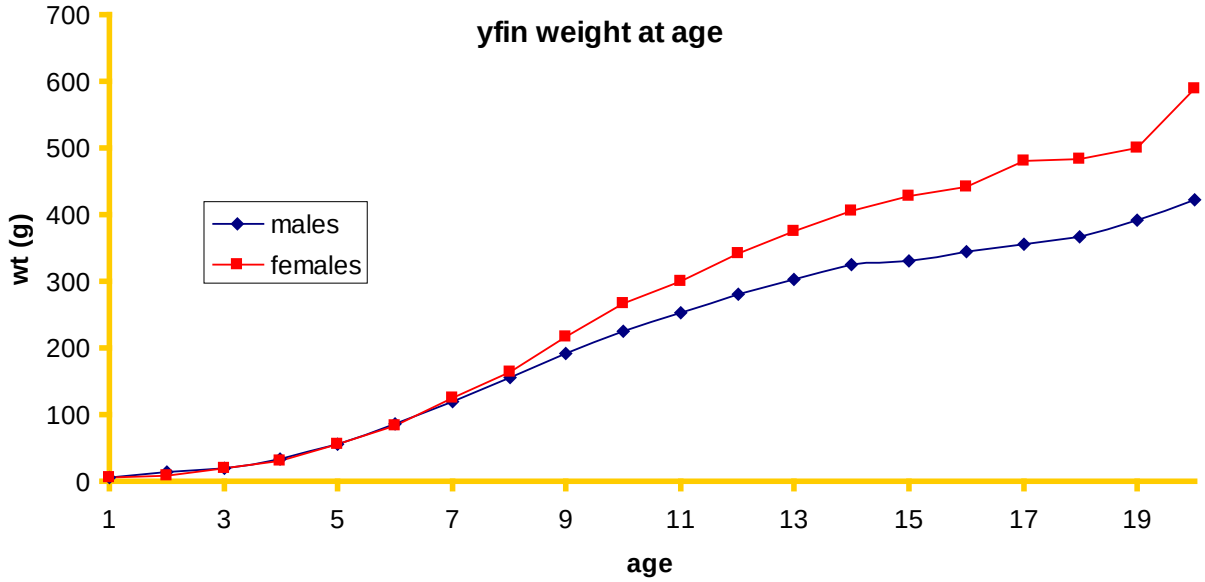


Figure 4.8--Estimates of average yellowfin sole weight-at-age (g) from trawl survey observations.

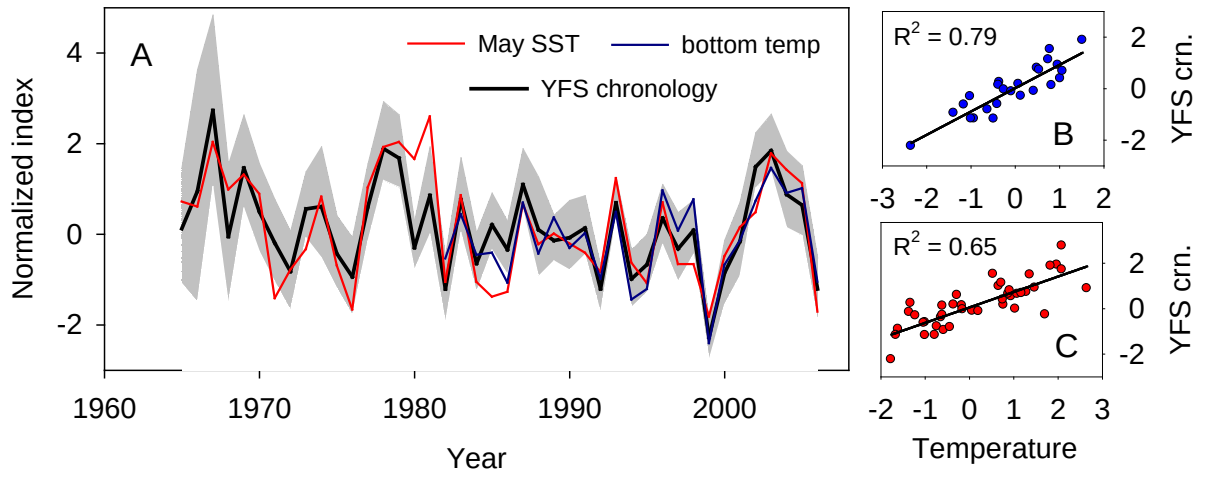


Figure 4.9--Master chronology for yellowfin sole and time series of mean summer bottom temperature and May sea surface temperature for the southeastern Bering Sea (Panel A). All data re normalized to a mean of 0 and standard deviation of 1. Correlations of chronologies with bottom temperature and sea surface temperature are shown in panels B and C, respectively. From Matta et al. 2010.

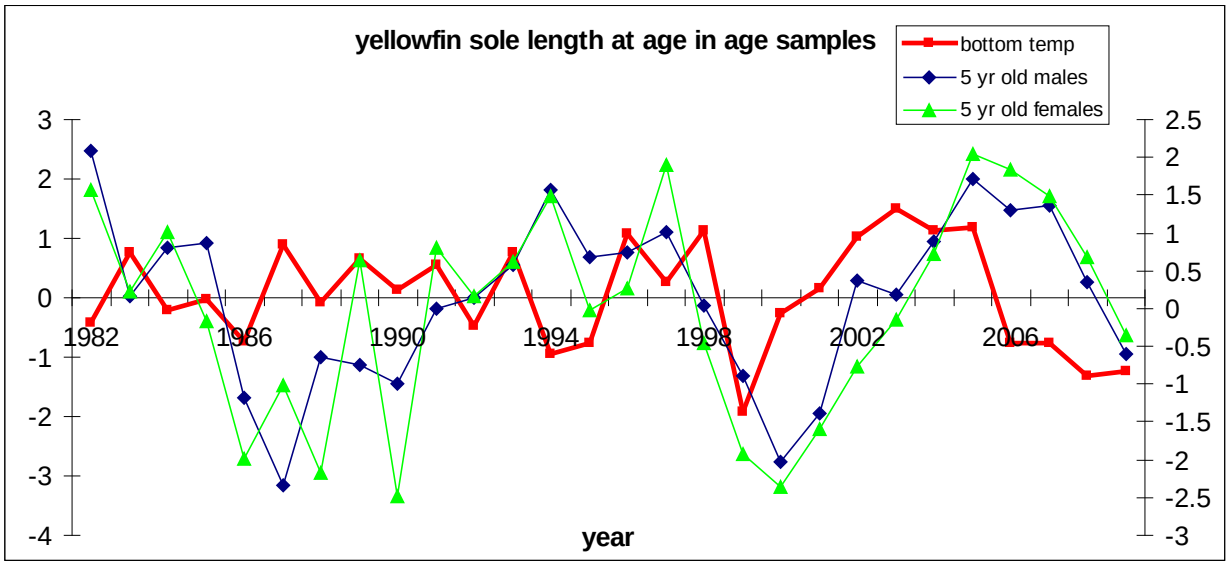


Figure 4.10—Yellowfin sole length-at-age anomalies, for males and females, and bottom temperature anomalies. Correspondence in these residuals is apparent with a 2-3 year lag effect from the mid-1990s to 2009. Late 1980s and early 1990s pattern may be a density-dependent response in growth from the large 1981 and 1983 year-classes.

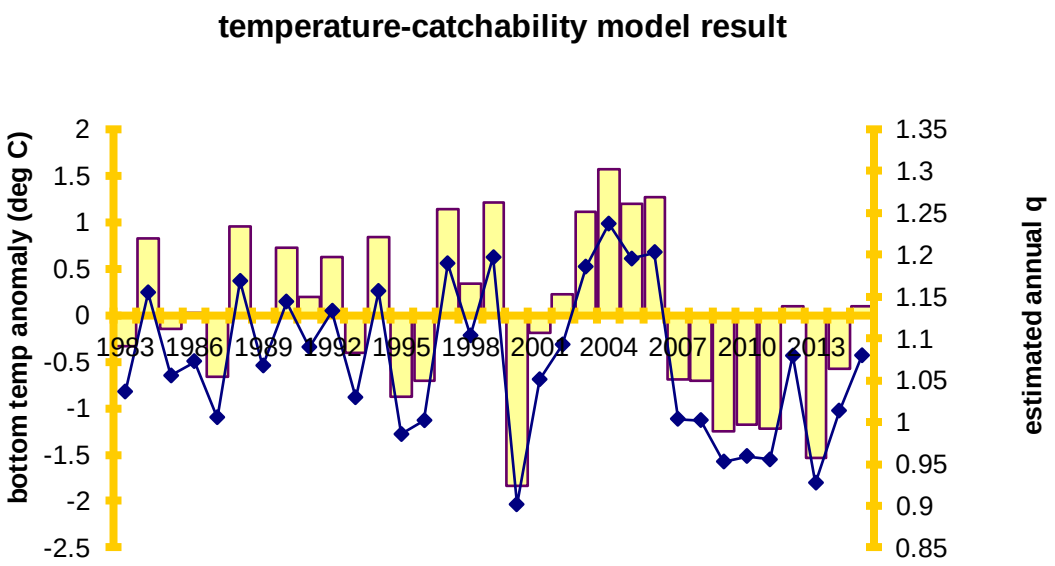


Figure 4.11.--Average bottom water temperature from stations less than or equal to 100 m in the Bering Sea trawl survey (bars) and the stock assessment model estimate of q for each year 1982-2014.

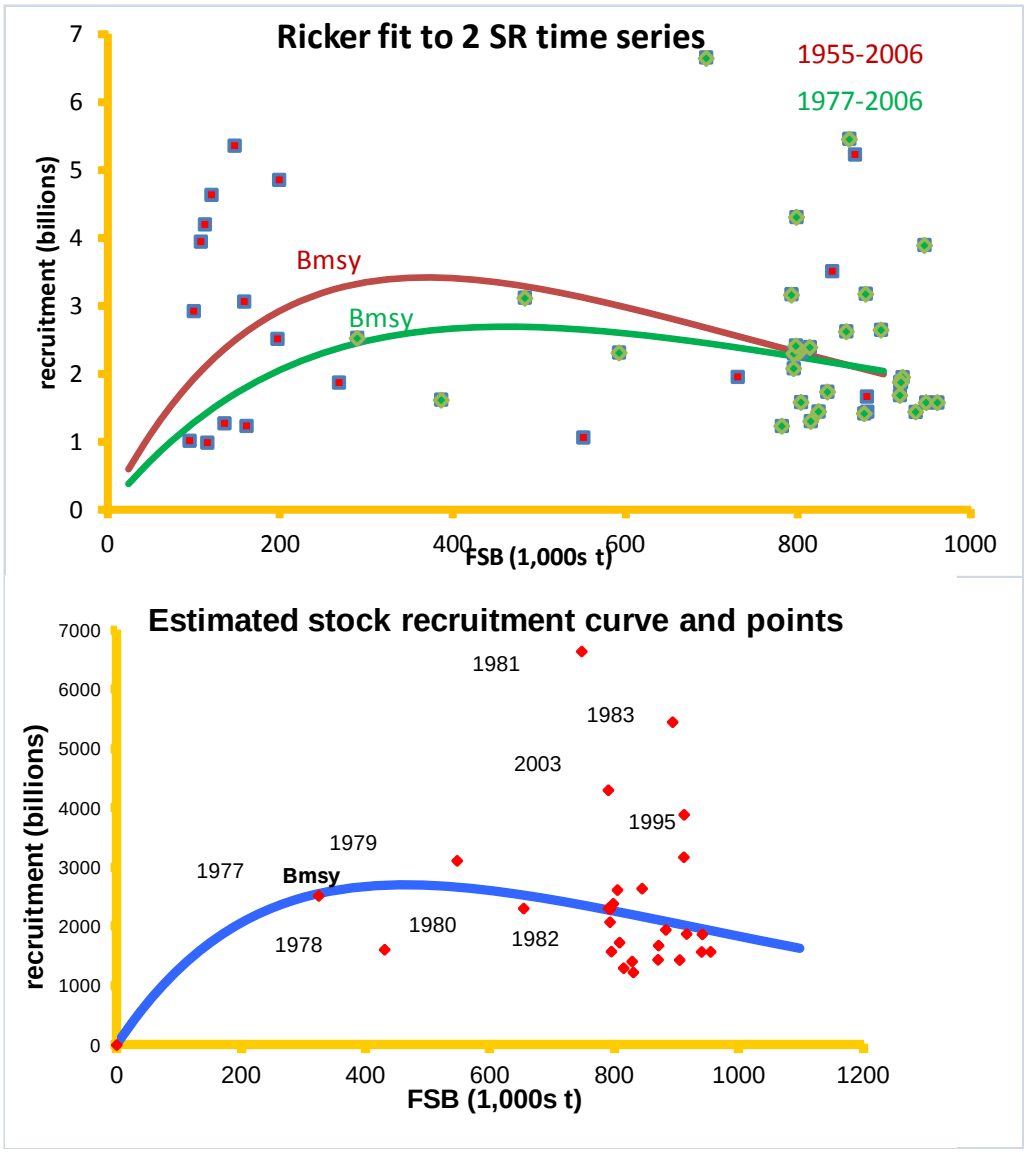


Figure 4.12--Fit of the Ricker (1958) stock recruitment model to two distinct stock recruitment time-series data sets (top panel), and the fit to the assessment preferred model (model B, lower panel).

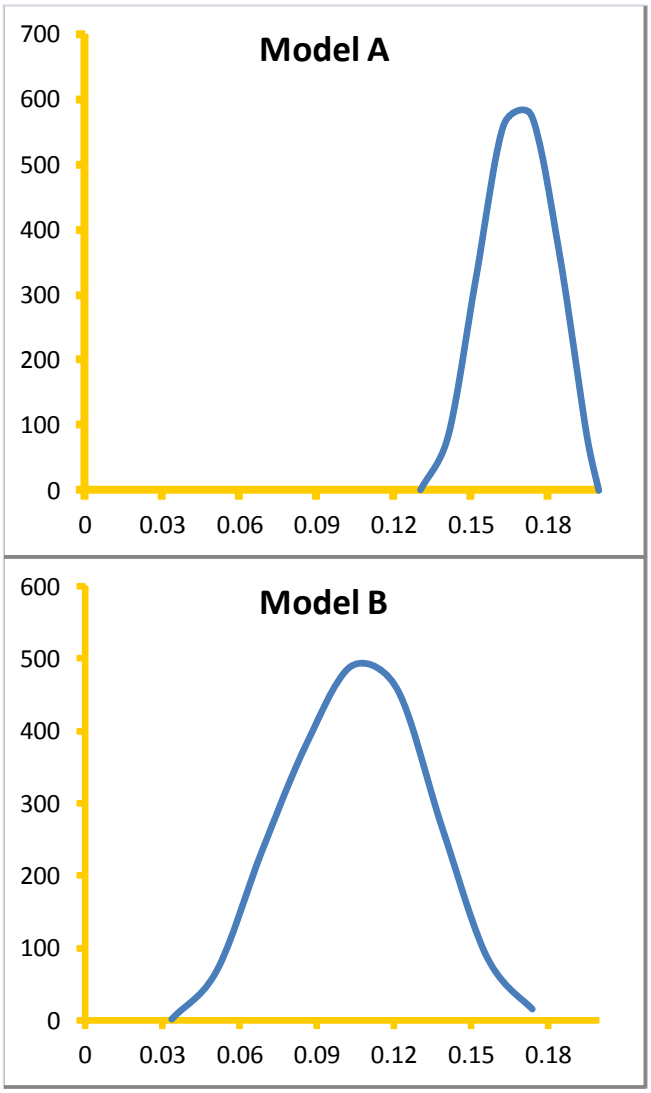


Figure 4.13--Posterior distributions of F_{msy} for the two models considered in the stock productivity analysis.

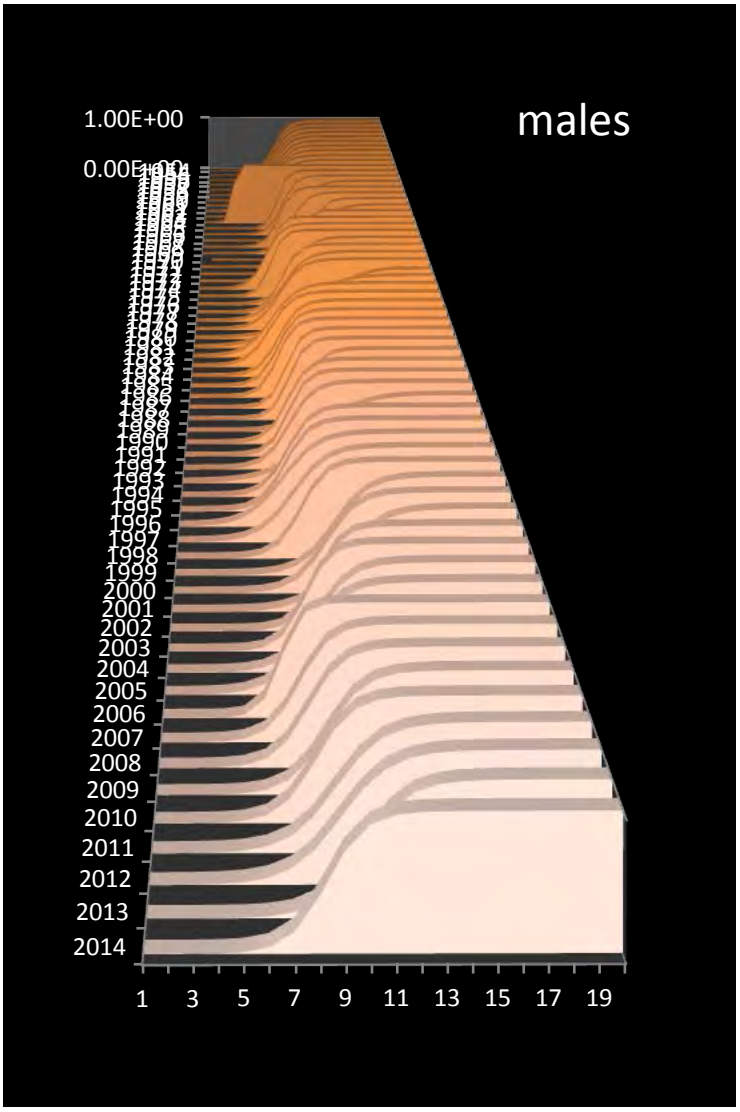


Figure 4.14a--Estimated male fishery selectivity by age and year.

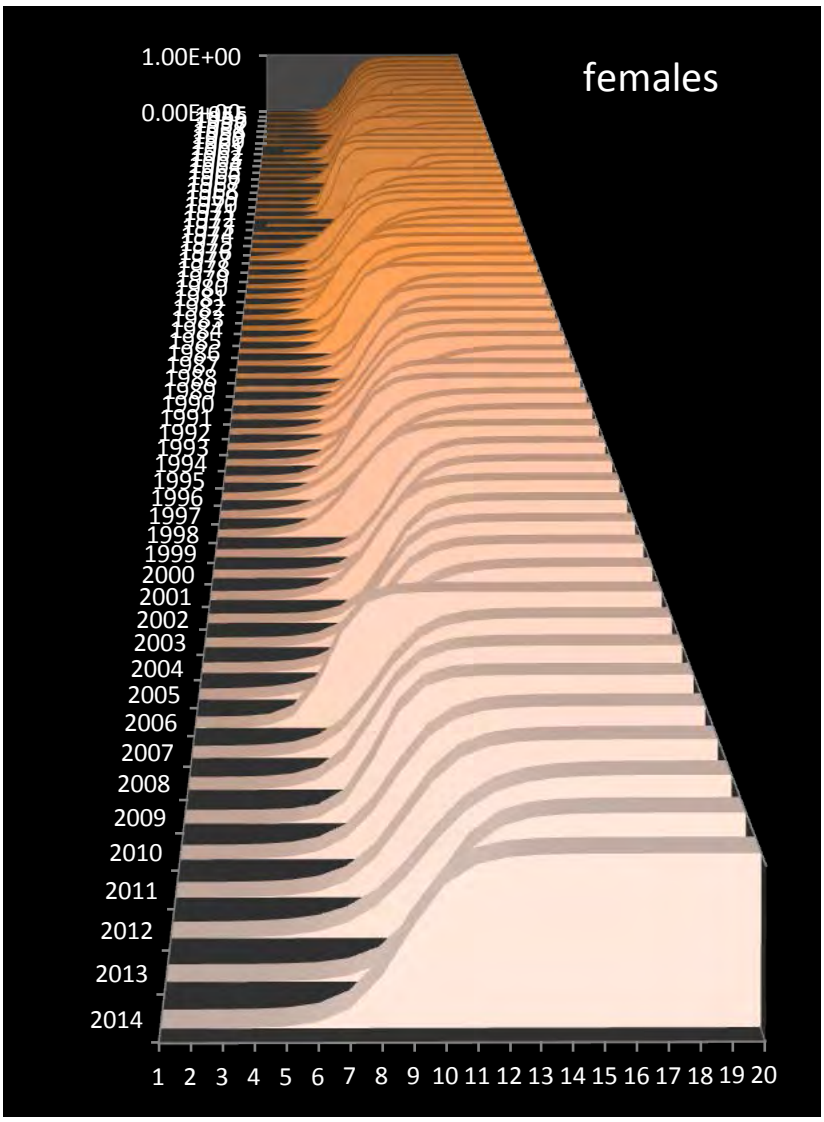


Figure 4.14b.--Estimated female fishery selectivity by age and year.

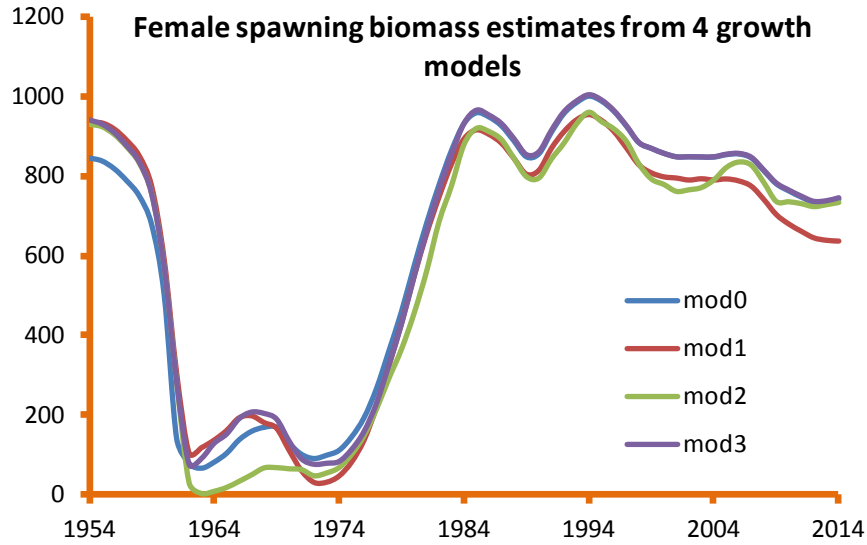


Figure 4.15—Estimates of female spawning biomass (1978-2014) from the 3 growth models considered in the assessment (Model 3, did not converge and is not shown).

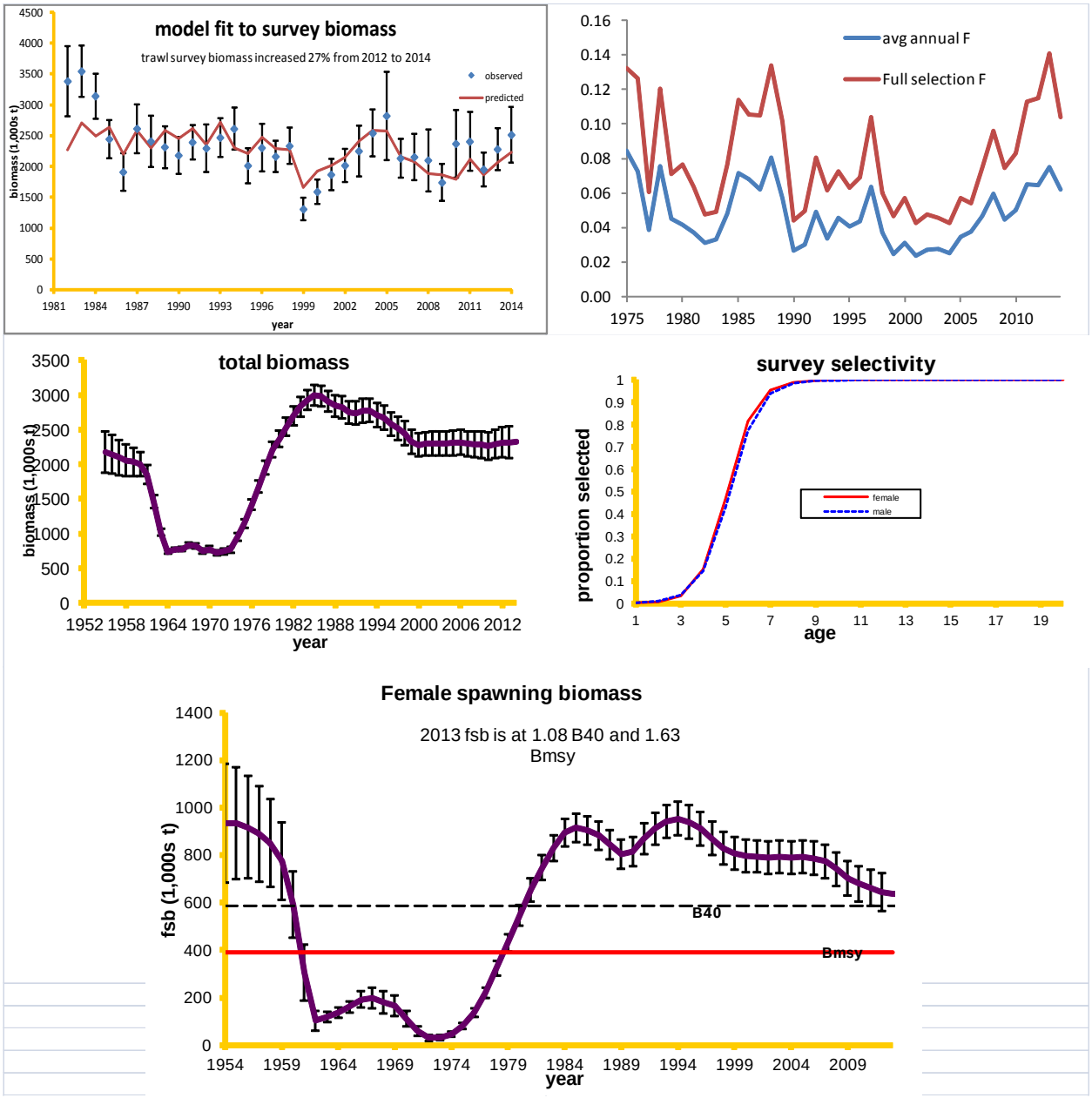


Figure 4.16. Model fit to the survey biomass estimates (top left panel), model estimate of the full selection fishing mortality rate throughout the time-series (top right panel), model estimate of total biomass (middle left panel), the model estimate of survey selectivity (middle right panel) and the estimate of female spawning biomass (bottom left panel).

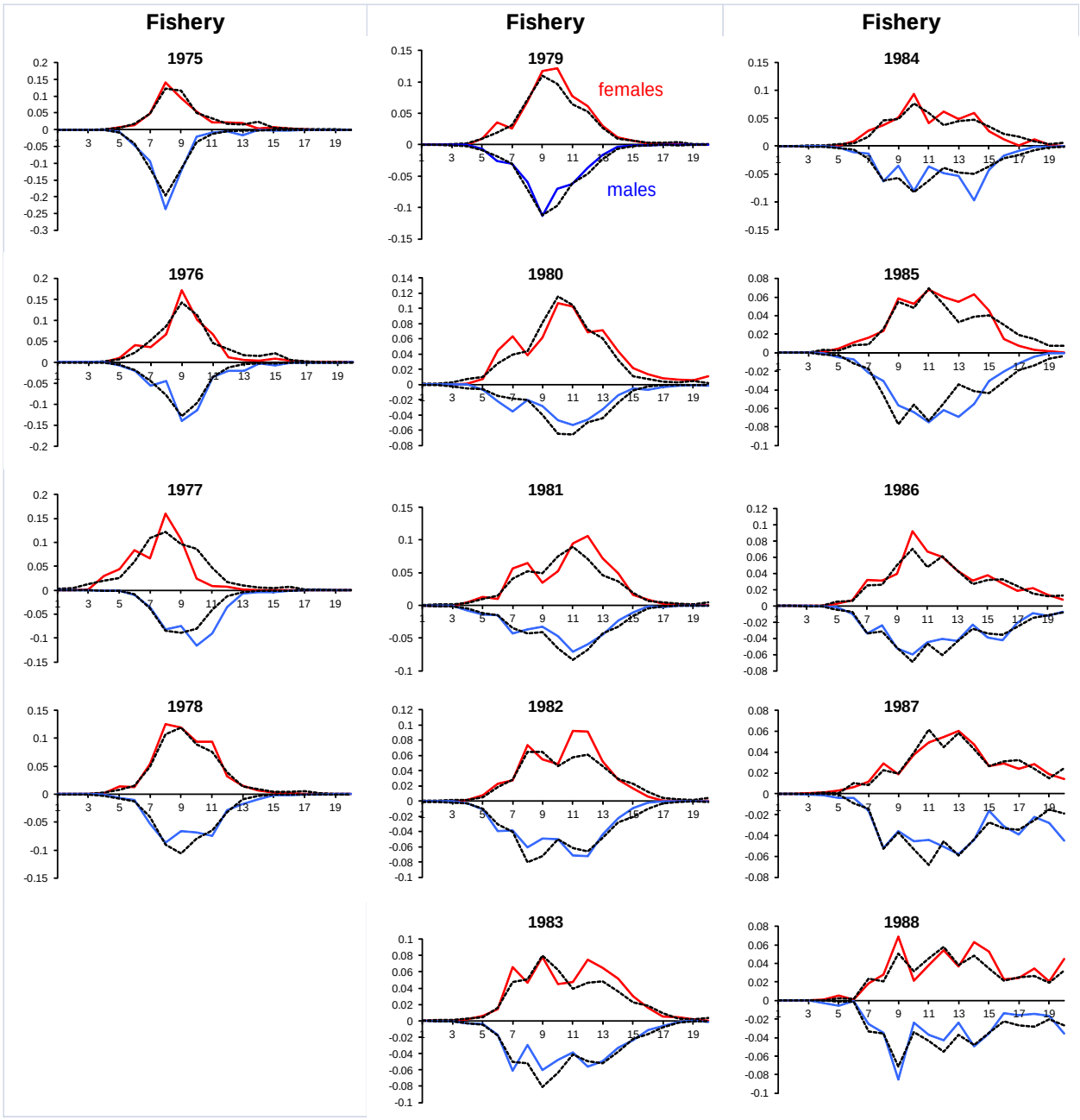


Figure 4.17. Stock assessment model fit to the time-series of fishery and survey age composition, by sex.

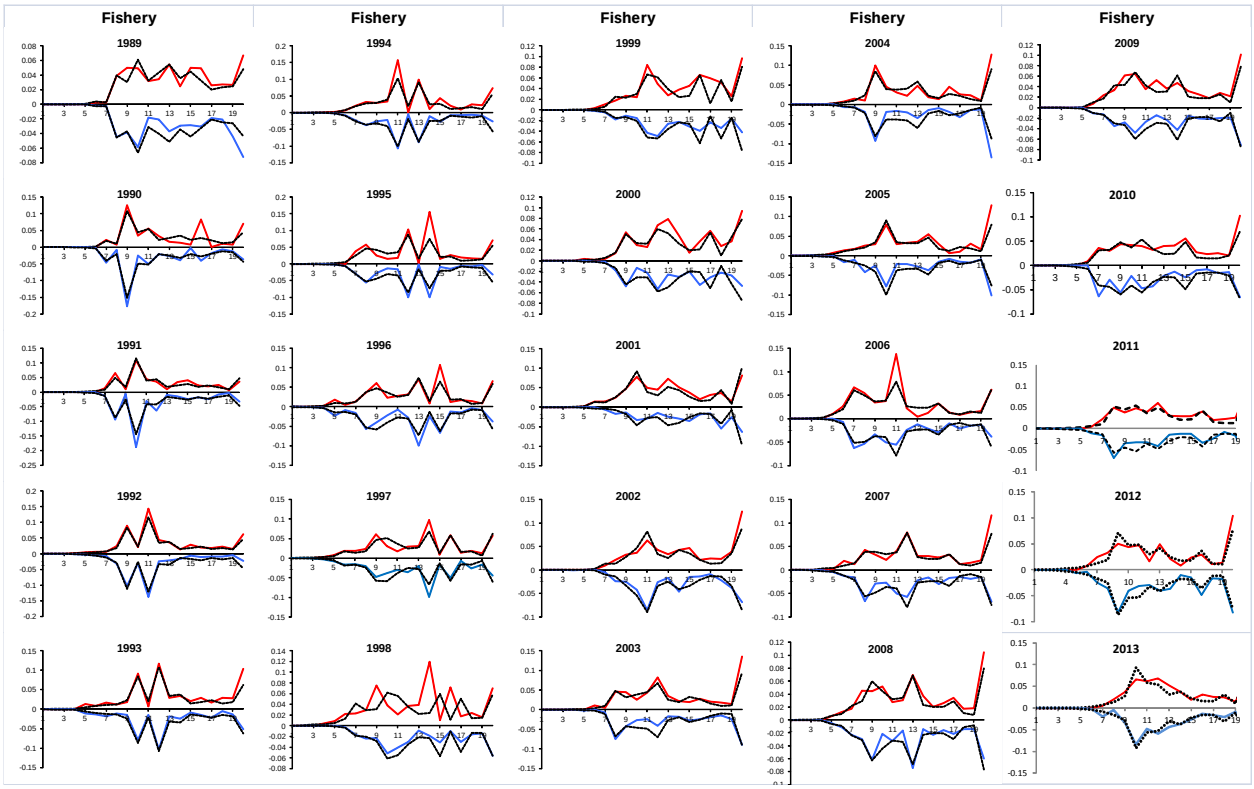


Figure 4.17 (continued).

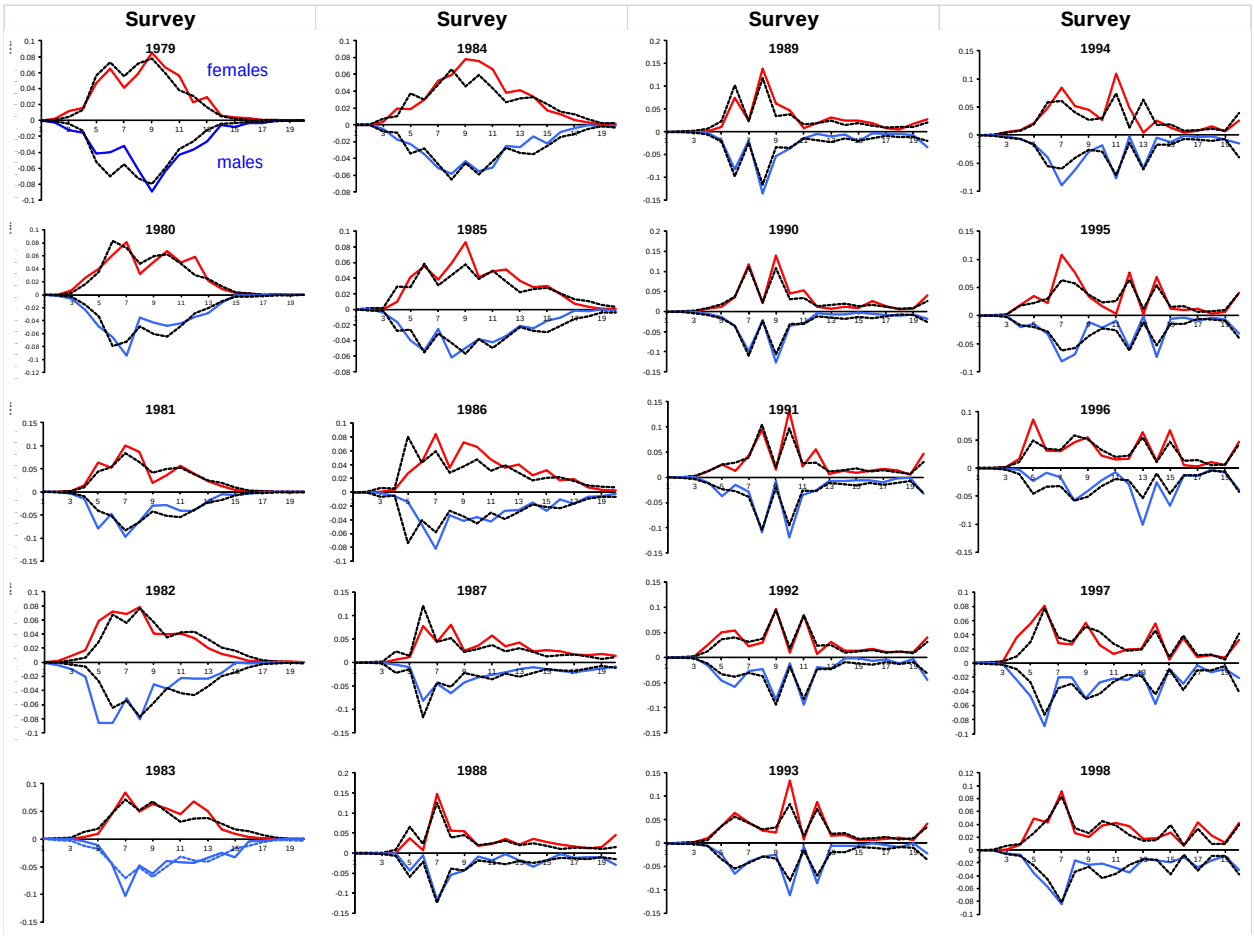


Figure 4.17 (continued).

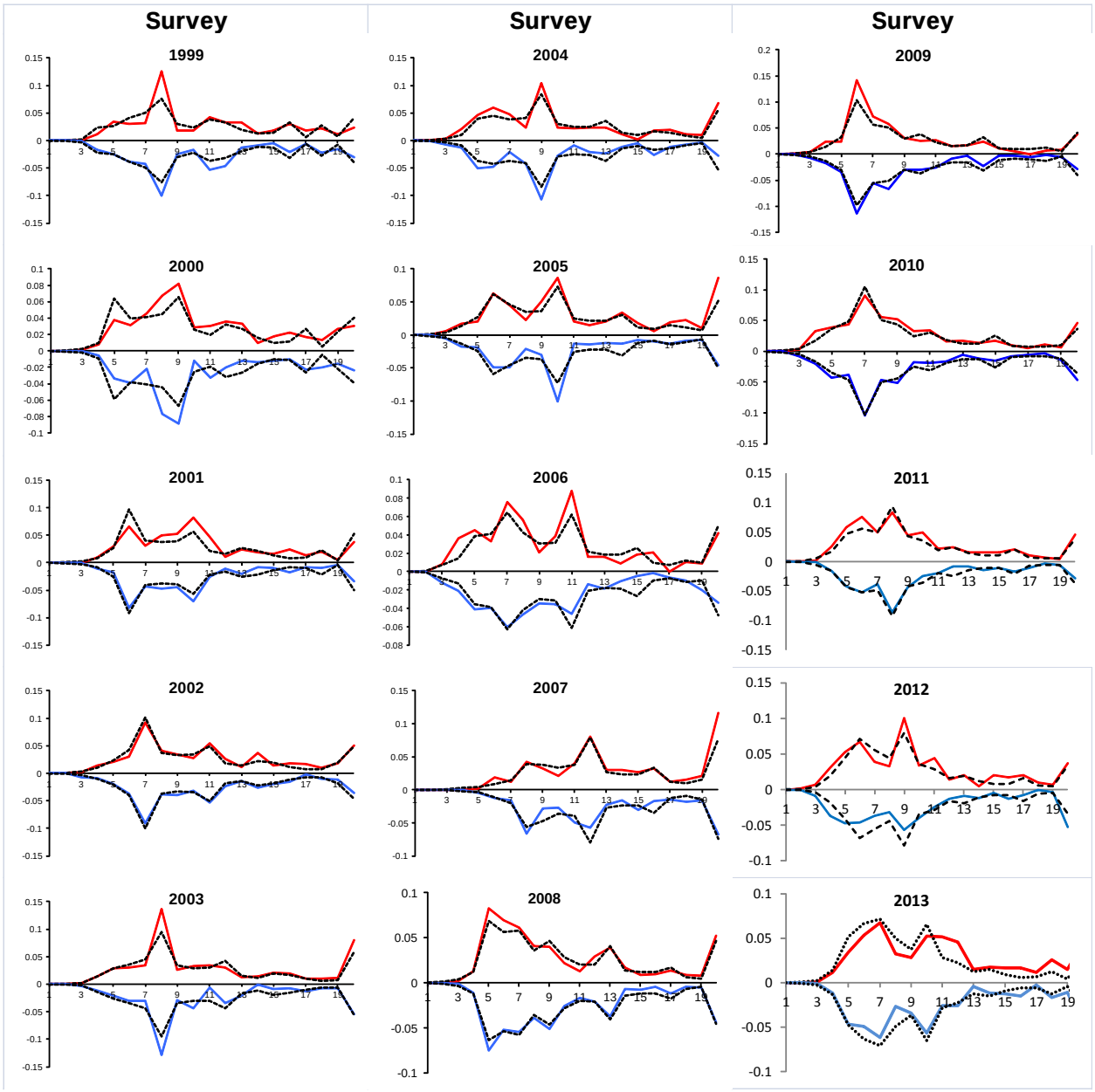


Figure 4.17 (continued).

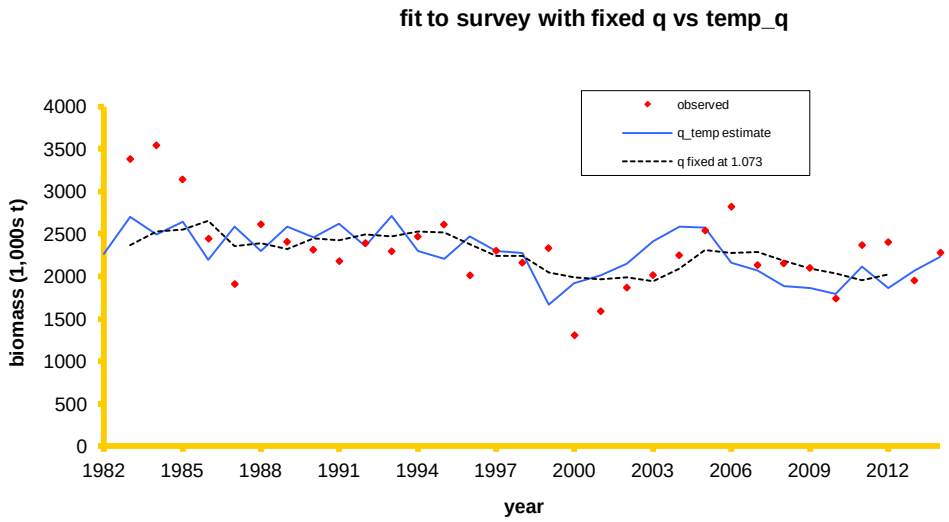


Figure 4.18.--Comparison of the fit to the survey biomass using a fixed q and the q-bottom temperature relationship.

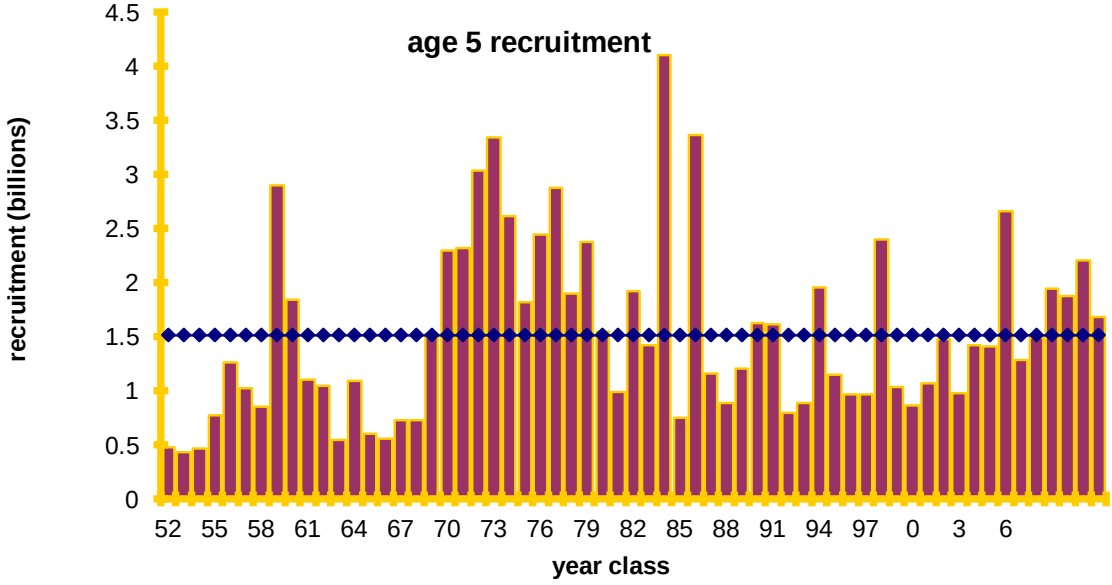


Figure 4.19--Year class strength of age 5 yellowfin sole estimated by the stock assessment model. The dotted line is the average of the estimates from 56 years of recruitment.

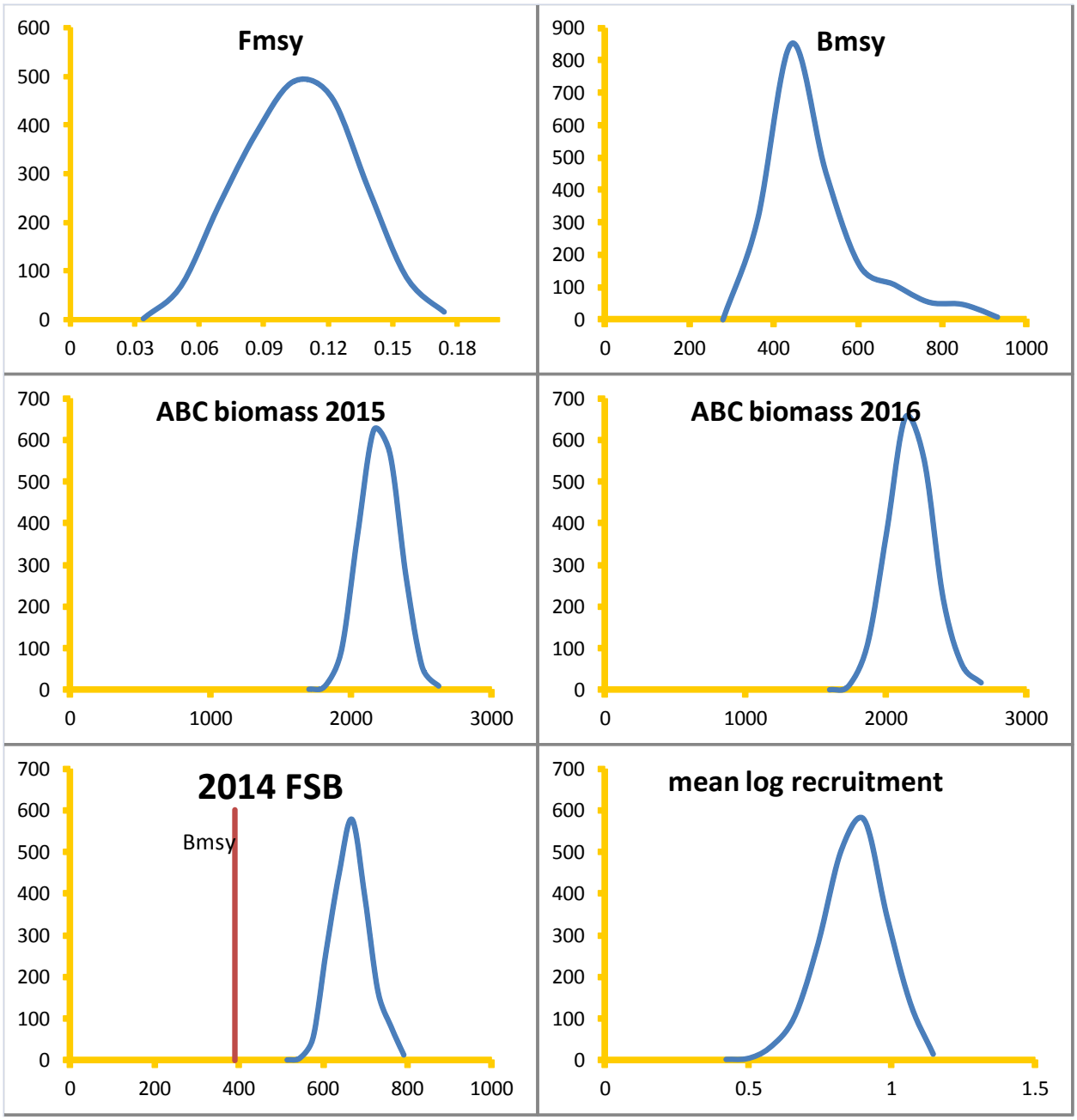


Figure 4.20.--Posterior distributions of some important parameters estimated by the preferred stock assessment model (from mcmc integration).

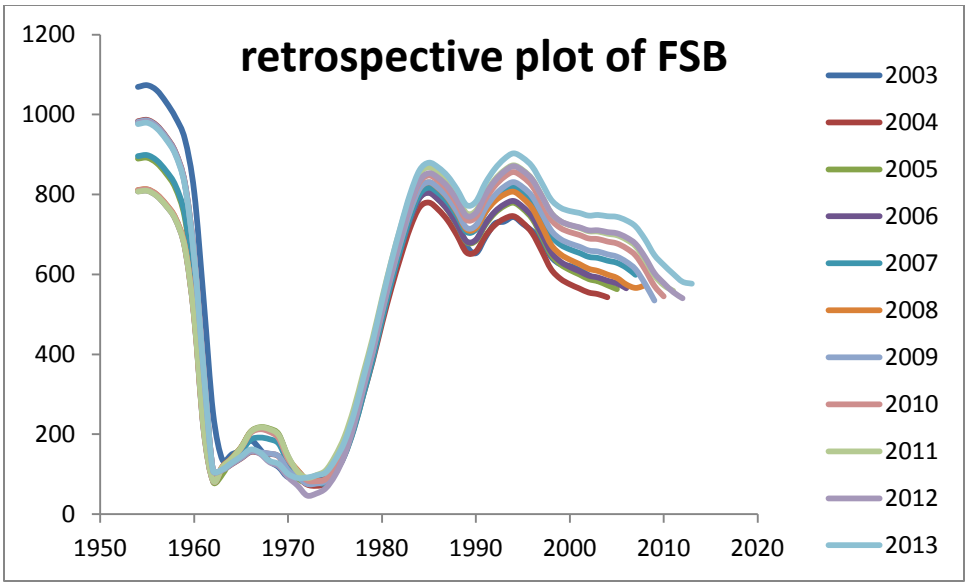


Figure 4.21—Retrospective plot of yellowfin sole female spawning biomass (1,000s t), 2003-2013, from the recommended assessment model.

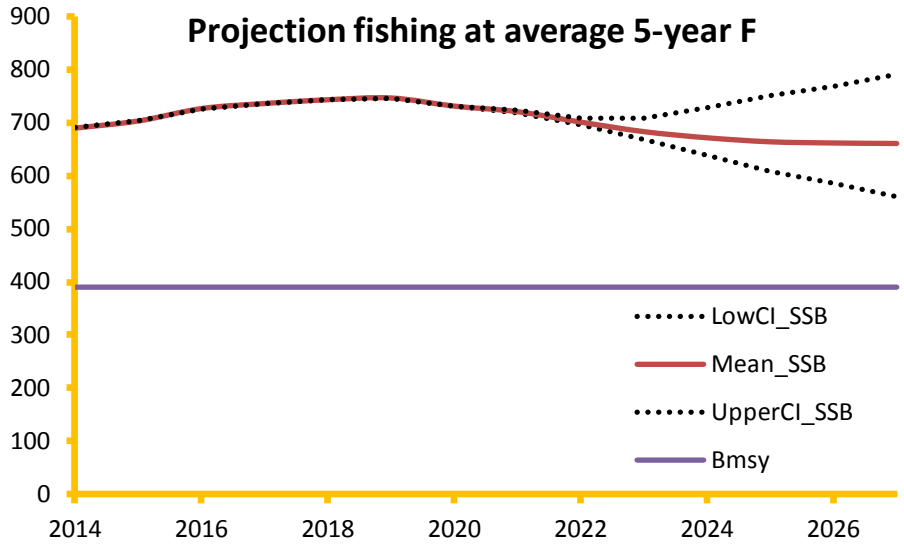


Figure 4.22.--Projection of yellowfin sole female spawning biomass (1,000s t) at the average full-selection F from the past 5 years (0.104) through 2027 with $B_{40\%}$ and B_{msy} levels indicated.

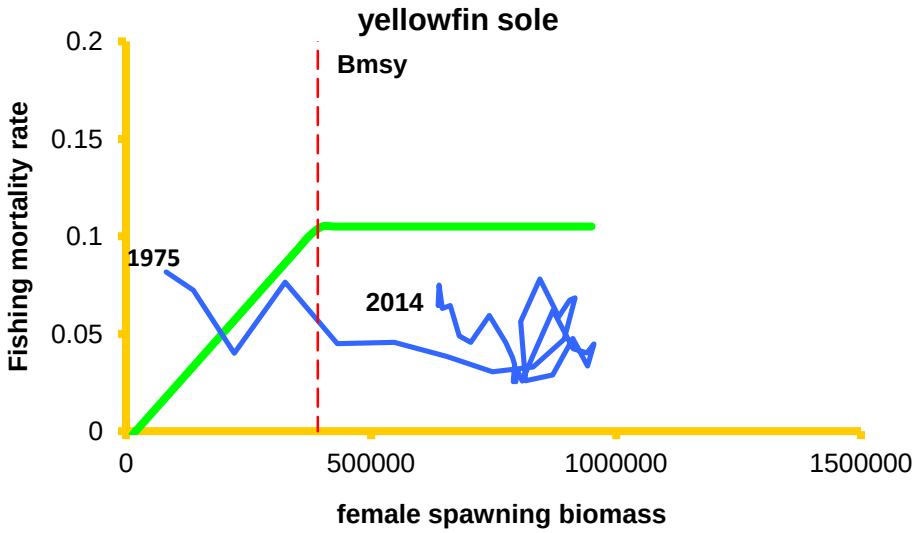
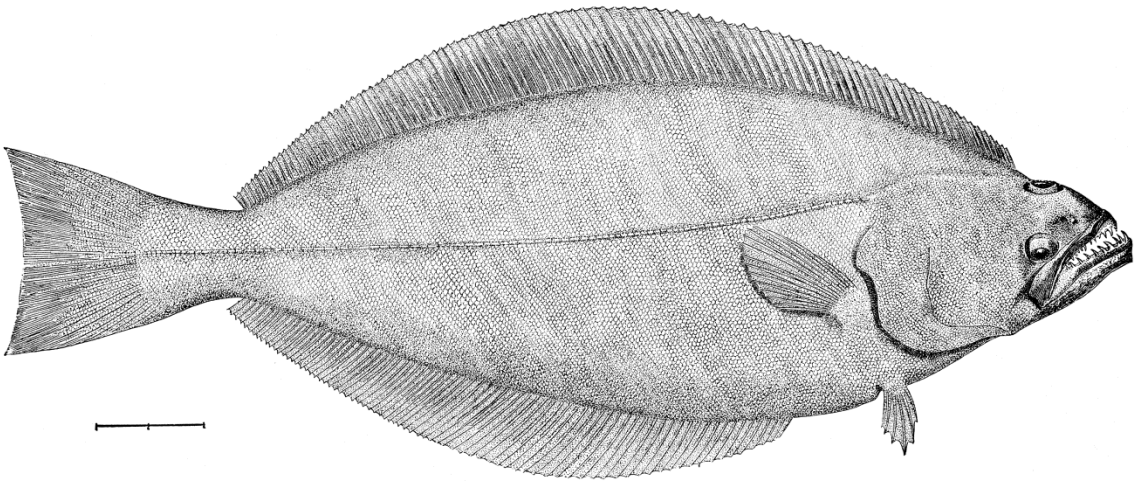


Figure 4.23.--Phase plane figure of the time-series of yellowfin sole female spawning biomass relative to the harvest control rule with 1975 and 2014 indicated.

Appendix

	IPHC research catch of yellowfin sole	
	number	weight (kg)
2007	707	502
2008	0	0
2009	0	0
2010	898	741

5. Assessment of the Greenland Turbot (*Reinhardtius hippoglossoides*) in the Bering Sea and Aleutian Islands



THE GREENLAND TURBOT.

Steven J. Barbeaux, James Ianelli, Dan Nichols and Jerry Hoff

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National Marine Fisheries Service
Alaska Fisheries Science Center
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Executive Summary

Two models are presented this year. Model 1 is the same as last year's (2013) Model 1 with updated and corrected data. Model 2 is based on Model 2 from last year (2013) with some minor improvements on selectivity and catchability as well as updated and corrected data. For the previous two years the authors have put forward Model 2 as an alternative model configuration which includes an autocorrelation parameter for recruitment deviations. The primary reason this model was not chosen is because the authors and the Plan Team concluded that the approach had not yet been thoroughly vetted. Thorson et al . (2014) show not only that this approach can be useful, but also provides a prior distribution for the autocorrelation parameter for Pleuronectidae species. We recommend the autocorrelated model (Model 2) be used for managing this species as it provides an improvement in overall fit to the data and better addresses recruitment in the 1960s when catches were high, but there were no composition or fishery independent data.

This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Marine Fisheries Service and should not be construed to represent any agency determination or policy.

Summary of Changes in Assessment Inputs

Changes in the model

The length of females at 50% mature was discovered to be incorrect in the models and has been changed from 55 cm to 60 cm as per D'yakov's (1982). A comparison between Model 1 resulting spawning stock biomass and reference points at different length of females at 50% mature has been provided.

Other than updating the female length at 50% mature, Model 1 has the same configuration as Model 1 from 2013.

Model 2 has been adjusted from Model 2 for 2013. A prior of 0.437 (sd = 0.265) was used for the recruitment autocorrelation parameter instead of fixed at 0.6 as parameterized last year. Catchability (q) for both the shelf and slope surveys were fixed at 0.62 and 0.57 instead of like last year's Model 2 being fit with informative priors. An additional selectivity bin (2010-2014) was added to the longline fishery length composition data for Model 2.

Addition of new fishery and survey data

There was a new shelf bottom trawl survey and Auke Bay Laboratory (ABL) longline survey in 2014. The index values for the shelf bottom trawl survey used in 2013 included estimates from the expanded northern strata, but the length composition was only from the standard survey region. This has been corrected for this assessment. The shelf composition data were changed to include all length and age data for the expanded survey into the northern strata for 1987 onward. The abundance estimate (or RPN for the ABL longline survey) and length data from both the 2014 shelf bottom trawl and ABL longline surveys were added to this assessment

Fishery catch data for this year's model were updated to the 2014 numbers. There was a 433 t decline in the 2003 catch estimtate from last year. For all other years the change was minor (less than 12t). For Model 2 the 2006 and 2007 trawl fishery length composition data were removed as the sample sizes were deemed too small.

Summary of Results

This assessment applies the newly available survey and fishery data to Model 1 and alters Model 2 to provide the best fit to the new data. The 2007-2009 year classes still prove to be very large and are contributing to the steep increase in abundance in the BSAI. This after a 37-year decline in the stock where recruitment had not kept up with natural and fishing mortality. Both Models presented this year show an increase in both total biomass and spawning biomass as the strong 2007-2009 year classes mature. This year's estimate of $B_{100\%}$ for Model 1 (90,578 t) and Model 2 (130,123 t) bracket last year's estimate of 99,764 t. The estimated 2014 spawning stock biomass for Model 1 is 20,825t and Model 2 is 26,341t, which are equivalient to $B_{23\%}$ or $B_{20\%,}$ which for Model 1 is the same as last year's projected status for 2014 at $B_{23\%}$. The projected 2015 estimated total biomass for Model 1 is 79,020 t and for Model 2 is 122,298 t, again bracketing last year's projectied total biomass estimate for 2015 of 96,298 t. The stock remains in Tier 3B

and therefore the ABC and OFL recommendations are reduced by the descending portion in the harvest control rule. The long-term Fabc and Fofl for Model 1 are 0.203 and 0.252 and for Model 2 are 0.176 and 0.218. The 2015 recommended ABC from Model 1 is 2,923 t and 3,173 t for Model 2. Model 1 is at 92 % and Model 2 is at 100% of last year's projected 2015 ABC. Estimated catch indicates that overfishing did not occur in 2014. Neither model presented this year show the stock as currently overfished, and the stock is not approaching an overfished condition.

	As estimated or *specified last* year for:		As estimated or *recommended this* year* for:	
Quantity	2014	2015	2015	2016
M (natural mortality rate)	0.112	0.112	0.112	0.112
Tier	3b	3b	3b	3b
Projected total (age 1+) biomass	84,546	96,298	122,298	132,666
Female spawning biomass (t)	22,010	27,624	30,853	38,848
Projected				
$B_{100\%}$	99,764	99,764	130,123	130,123
$B_{40\%}$	39,906	39,906	52,049	52,049
$B_{35\%}$	34,917	34,917	45,543	45,543
F_{OFL}	0.14	0.18	0.12	0.18
$maxF_{ABC}$	0.12	0.15	0.10	0.15
F_{ABC}	0.12	0.15	0.10	0.15
OFL (t)	2,647	3,864	3,903	6,453
maxABC (t)	2,124	3,173	3,172	5,284
ABC (t)	2,124	3,173	3,172	5,284
EBS	1,659	2,478	2,448	4,050
Aleutian Islands	465	695	724	1,198
	As determined *last* year		As determined *this* year	
Status	2012	2013	2013	2014
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

*Based on Model 2

Responses to SSC and Plan Team Comments on Assessments in General

None

Responses to SSC and Plan Team Comments Specific to this Assessment

From December 2013: The SSC looks forward to the authors' responses to SSC comments from last year's (2012) assessment, as well as a more thorough evaluation of Model 2 (model with autocorrelation) in next year's assessment. Research into potential mechanisms behind such an autocorrelation is a high priority for this depressed stock.

Authors' Response: We continued to evaluate autocorrelation in recruitment for this stock and have determined that Model 2, with autocorrelation specifically modeled is the better choice for management as it provides the better model fit and diffuses the large pre-1970 recruitment seen in previous uncorrelated models. Thorson et al. (2014) analysis of autocorrelation in stock recruitment have provided substantial documentation on including autocorrelation in recruitement and a prior for use in Pleuronectidae species assessments such as Greenland *turbot.*

Introduction

Two models are presented for consideration. Model 1 is the model configuration that has been accepted by the SSC for the previous 2 years updated with the most recent data. An error was discovered in the female length at 50% mature used last year and has been corrected in both models presented this year. Model 2 is similar to the models presented for the past 2 years with a parameter for autocorrelation in recruitment. Model 2 differs from last year's autocorrelated model in that an additional time block (2010-2014) for the longline fishery selectivity was added to improve the residual pattern, and catchability was fixed for shelf and survey indices. The stock continues to be modeled using the same software as previous assessments (Stock Synthesis 3).

Life History

Greenland turbot (*Reinhardtius hippoglossoides*) is a Pleuronectidae (right eyed) flatfish that has a circumpolar distribution inhabiting the North Atlantic, Arctic and North Pacific Oceans. The American Fisheries Society uses "Greenland halibut" as the common name for *Reinhardtius hippoglossoides* instead of Greenland turbot. To avoid confusion with the Pacific halibut, *Hippoglossus stenolepis*, common name of Greenland turbot which is also the "official" market name in the US and Canada (AFS 1991) is retained.

In the Pacific Ocean, Greenland turbot have been found from the Sea of Japan to the waters off Baja California. Specimens have been found across the Arctic in both the Beaufort (Chiperzak et al. 1995) and Chuchki seas. This species primarily inhabits the deeper slope and shelf waters (between 100 m to 2000 m; Fig. 5.1) in bottom temperatures ranging from -2°C to 5°C. The area of highest density of Greenland turbot in the Pacific Ocean is in the northern Bering Sea, straddling the border between US and Russian exclusive economic zones. Juveniles are believed to spend the first 3 or 4 years of their lives on the continental shelf and then move to the continental slope (Alton et al. 1988; Sohn 2009; Fig. 5.2). Adult Greenland turbot distribution in the Bering Sea appears to be dependent on size and maturity as larger more mature fish migrate to deeper warmer waters. In the annual summer shelf trawl surveys conducted by the Alaska Fisheries Science Center (AFSC) the distribution by size shows a clear preference by the smaller fish for shallower (< 100m) and colder shelf waters (< 0°C). The larger specimens were in higher concentrations in deeper (> 100 m), warmer waters (> 0°C) (Fig. 5.3 and Fig. 5.4).

Juveniles are absent in the Aleutian Islands (AI) regions, suggesting that the population in the Aleutians originates from the EBS or elsewhere. In this assessment, Greenland turbot found in the two regions are assumed to represent a single management stock. NMFS initiated a tagging

study in 1997 to supplement earlier international programs. Results from conventional and archival tag return data suggest that individuals can range distances of several thousands of kilometers and spend summer periods in deep water in some years and in other years spend time on the shallower EBS shelf region.

Greenland turbot are sexually dimorphic with females achieving a larger maximum size and having a faster growth rate. For this assessment, data from the AFSC slope and shelf surveys from 2003 - 2011 were pooled to obtain growth curves for both male and female Greenland Turbot (Fig. 5.5). This sexual dimorphic growth is consistent with trends observed in the North Atlantic. Collections in the North Atlantic suggest that males may have higher mortality than females. Evidence from the Bering Sea shelf and slope surveys suggest males reach a much smaller maximum size than females, but that mortality may not be higher than in females.

Prior to 1985 Greenland turbot and arrowtooth flounder were managed together. Since then, the Council has recognized the need for separate management quotas given large differences in the market value between these species. Furthermore, the abundance trends for these two species are clearly distinct (e.g., Wilderbuer and Sample 1992).

Fishery

Catches of Greenland turbot and arrowtooth flounder were not reported separately during the 1960s. During that period, combined catches of the two species ranged from 10,000 to 58,000 t annually and averaged 33,700 t. Beginning in the 1970s the fishery for Greenland turbot intensified with catches of this species reaching a peak from 1972 to 1976 of between 63,000 t and 78,000 t annually (Fig. 5.6). Catches declined after implementation of the MFCMA in 1977, but were still relatively high in 1980-83 with an annual range of 48,000 to 57,000 t (Table 5.1). Since 1983, however, trawl harvests declined steadily to a low of 7,100 t in 1988 before increasing slightly to 8,822 t in 1989 and 9,619 t in 1990. This overall decline is due mainly to catch restrictions placed on the fishery because of apparent low levels of recruitment. From 1990- 1995 Council set the ABC's (and TACs) to 7,000 t as an added conservation measure citing concerns about recruitment. Between 1996 and 2012 the ABC levels varied but averaged 6,540 t (with catch for that period averaging 4,468 t). For 2013 the ABC was lowered to 2,060 to correct for changes in the stock assessment model and total catch for 2013 was 1752 t. The 2014 ABC remained low at 2,124 t and as of October 27 catch in 2014 was at 1,645 t. However the fishery is expected to take the remaining quota by the end of the year.

The majority of the catch over time has been concentrated in deeper waters (> 150 m) along the shelf edge ringing the eastern Bering Sea (Fig. 5. 7 and Fig. 5. 8), but Greenland turbot has been consistently caught in the shallow water on the shelf as bycatch in the trawl fisheries (Table 5.2 and Table 5.3). Catch of Greenland turbot is generally dispersed along the shelf and shelf edge in the northern most portion of the management area. Since 2008, however, at a 400km^2 resolution, the cells with highest amounts of catch have been observed in the Eastern Aleutian Islands (Fig. 5.9), suggesting high densities of Greenland turbot in these areas. These areas of high Greenland

turbot catch in the Aleutians are coincident with the appearance of the Kamchatka and arrowtooth flounder fishery. This fishery has the higest catch of Greenland turbot outside of the directed fishery. For 2008, 2012, 2013 and in the preliminary catch data for 2014, Greenland tubot catch in the Arrowtooth/Kamchatka fishery has exceeded the directed catch.

Within the domestic fishery from 1995-2006, the majority (~2/3) of Greenland turbot catch was from the longline fishery. In 2007-2009, and 2012-2014, trawl-caught Greenland turbot exceeded the level of catch by longline vessels (Table 5.3). The shift in the proportion of catch by sector was due in part to changes arising from Amendment 80 passed in 2007. Amendment 80 to the BSAI Fishery Management Plan (FMP) was designed to improve retention and utilization of fishery resources. The amendment extended the American Fisheries Act (AFA) Groundfish Retention Standards to all vessels and established a limited access privilege program for the non-AFA trawl catcher/processors. This authorized the allocation of groundfish species quotas to fishing cooperatives and effectively provided better means to reduce bycatch and increase the value of targeted species.

The longline fleet generally targets pre-spawning aggregations of Greenland turbot; the fishery opens May 1 but usually occurs June-August in the EBS to avoid killer whale predation. Catch information prior to 1990 included only the tonnage of Greenland turbot retained by Bering Sea fishing vessels or processed onshore (as reported by PacFIN). Discard levels of Greenland turbot have typically been highest in the sablefish fisheries (approximately 55% of all sources of Greenland turbot discards during 1992-2003) while Pacific cod fisheries and the “flatfish” fisheries also have contributed substantially to the discard levels (Table 5.2). About 10.3% of all Greenland turbot caught in groundfish fisheries were discarded (on average) during 2004-2014. The overall discard rate of Greenland turbot has dropped substantially in recent years from a high of 84% discarded in 1992 down to only 2% in 2011 and 2012. Because of the drop in the ABC for 2013 and 2014 the overall discard rate has increased to 20% in 2013 and 15% so far in 2014. In the preliminary 2014 catch data 60% of the Greenland turbot discard (208 t) has come from the Arrowtooth and Kamchatka fisheries.

Greenland turbot catch in the Aleutian Islands through 2007 was split nearly even between trawl and longline fisheries In 2008 the trawl fishery started catching the majority of Greenland turbot (Table 5.4). In the domestic EBS fishery, catch of Greenland turbot was predominantly from the longline fishery except for 1991,1994,2008, 2013, and 2014 (Table 5.3). In the preliminary 2014 data the EBS trawl fishery has caught a larger share of EBS quota than longliners(813 t and 656 t, respectively). By target fishery, the gain in trawl-fishery has occurred primarily in the Greenland turbot target fishery in 2009 and arrowtooth flounder/Kamchatka fisheries in 2008 - 2014 (Table 5.3).

Data

Fisheries data used within this assessement were split into the longline (including all fixed gear) and trawl fisheries. Both the trawl and longline fishery data include observations and catch from

targeted catch and bycatch. There are also data from three surveys: the shelf and slope bottom trawl surveys conduced by the RACE Division of the AFSC and the ABL longline survey.. The type of data and relevant years from each can be found in Table 5.5 and Figure 5.10.

Fishery data

Catch

The catch data were used as presented above for both the longline and trawl fisheries (Table 5.1). The early catches included Greenland turbot and arrowtooth flounder combined. In order to separate the catch of Greenland turbot from the combined catch, the ratio of the two species for the years 1960-64 were assumed to be the same as the mean ratio caught by USSR vessels from 1965-69.

Size and age composition

Extensive length frequency compositions have been collected by the NMFS observer program from the period 1980 to 2013. The length composition data from the trawl and longline fisheries are presented in the Appendix 5.1 (along with the expected values from the assessment model) and absolute sample sizes for the period of the domestic fishery by sex and fishery from 1989-2014 are given in Table 5.6

Catch totals from research and other sources

Annual research catches (t, 1977 - 2014) from NMFS longline and trawl surveys are estimated as follows:

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
NMFS BT surveys	62.5	48.3	103.0	123.6	15.0	0.6	175.1	26.1	0.5	18.5	0.6	0.7	11.4	0.9	1.4	8.5	1.4
Longline surveys	3	3	6	11	9	7	8	7	11	6	16	10	10	22	23	23	
Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
NMFS BT surveys	1.5	4.6	1.4	1.0	6.6	1.1	6.6	1.1	12.8	0.7	3.0	0.6	4.8	0.4	6.6	1.0	4.9
Longline surveys	1.3	37.43	8.4	18.8	4.1	15.4	3.8	13.1	3.0	8.8	1.8	6.3	1.3	3.1	0.6	3.3	*
Year	2013	2014															
NMFS BT surveys	1.0	1.3															
Longline surveys	*	*															

* Not yet available from AKFIN

2010 sport and research catches for Greenland turbot:

Source	t
2010 Aleutian Island Bottom Trawl Survey	0.530
2010 Bering Sea Acoustic Survey	0.000
2010 Bering Sea Bottom Trawl Survey	0.816
2010 Bering Sea Slope Survey	5.210
2010 Northern Bering Sea Bottom Trawl Survey	0.004
Blue King Crab Pot	0.056
IPHC (halibut commission)	2.989
NMFS LL survey	0.364

Analyses examining the bycatch of Greenland turbot in directed halibut fisheries indicate an average of just over 109 t from 2001-2010 with about 49 t average since 2006 (NMFS Regional Office).

EBS slope and shelf bottom trawl survey

The older juveniles and adults on the slope have been surveyed triennially from 1979-1991 (also in 1981) as part of a U.S.-Japan cooperative agreement. From 1979-1985, the slope trawl surveys were conducted by Japanese shore-based (Hokuten) trawlers chartered by the Japan Fisheries Agency. In 1988, the NOAA ship R/V Miller Freeman was used to survey the resources on the EBS slope region. In this same year, chartered Japanese vessels performed side-by-side experiments with the R/V Miller Freeman for calibration purposes,however, the R/V Miller Freeman sampled a smaller area and fewer stations in 1988 than the previous years. The R/V Miller Freeman sampled 133 stations over a depth interval of 200-800 m as opposed to earlier slope surveys where Japanese vessels usually sampled 200-300 stations over a depth interval of 200-1000 m. In 2002, the AFSC re-established the bottom trawl survey of the EBS upper continental slope and a second survey was conducted in 2004. Planned biennial slope surveys lapsed (the 2006 survey was canceled) but resumed in the summer of 2008, 2010, and 2012 (Table 5.7). Although the size composition data for trawl surveys prior to 2002 were used in this assessment, the abundance estimates were not (Table 5.8). This was decided after discussions with Dr. Jerry Hoff, the current Slope survey Chief Scientist. Dr. Hoff stated that the older slope survey data were not comparable to the most recent surveys, and may not have been conducted consistently enough in the early years to be considered a time series. The surveys differed in vessel power, in gear used, and in the ability of the surveyors to determine whether the gear was in contact with the bottom.

The slope trawl surveys are likely to under estimate the BSAI-wide biomass of Greenland turbot since fish are found consistently in other regions. A similar issue likely affects the distribution of Greenland turbot on the shelf region(Ianelli et al. 2011). The shelf and recent slope survey biomass estimates are therefore treated as a relative abundance index and a separate catchability parameter were set for each.

The estimated biomass of Greenland turbot in this region has fluctuated over the years. When US-Japanese slope surveys were conducted in 1979, 1981, 1982 and 1985, the combined survey biomass estimates from the shelf and slope indicate a decline in EBS abundance. After 1985, the combined shelf plus slope biomass estimates (comparable since similar depths were sampled) averaged 55,000 t, with a 2004 level of 57,500 t. The average shelf-survey biomass estimate during the last 20 years (1994-2014) was 27,077 t. The number of hauls and the levels of Greenland turbot sampling in the shelf surveys are presented in Table 5.8. In 2010 and 2011 there was an increase in the proportion of tows with Greenland turbot present and the abundance estimates from the shelf surveys indicated a significant increase of Greenland turbot recruitment (Fig. 5.11). These observations suggest that the extent of the spatial distribution has remained

relatively constant prior to 2010 (with a slight increase) and that the most recent surveys have both higher densities and broader spatial distribution.

Although the 2012 EBS slope biomass estimate of 17,984 t was down from 2010 estimate of 19,873 t (Table 5.9), the population numbers in 2012 of 11,839,700 fish was more than double the 2010 estimate of 5,839,126 fish (Table 5.10). The 2012 Slope survey abundance estimate was the highest population estimate since the Slope survey was reinstated in 2002. Most of the change in population estimates is due to the changes in Greenland turbot abundance found in the two shallowest strata between 200 and 600 m (Tables 5.9 and 5.10). In the 200-400 m strata the population was more than 8 times that of the 2010 survey estimate and the 400-600 m strata was more than double the 2010 estimate. These high numbers, but low abundance is a reflection of the large number of smaller fish moving into the slope region from the shelf due to the large 2007, 2008, and2009 year classes as evidenced by the large number of fish between 30 cm and 50 cm observed in this survey (Fig. 5.12).

Survey size composition

A time series of estimated size composition of the population is available for both shelf and slope trawl surveys. The slope surveys typically sample more turbot than the shelf trawl surveys; consequently, the number of fish measured in the slope survey is greater. The shelf survey is useful for detecting recruitment patterns that are consistent with the trends in biomass. Increase in recruitment has been visible over the last 7 years (Greenland turbot less than about 40 cm) following an absence of small fish during 2004-2006.

Survey size-at-age data used for estimating growth and growth variability were previously available from 1979-1982. Gregg et al. (2006) revised age-determination methods for Greenland turbot and survey age composition data from 2003-2012 were included.

Aleutian Islands survey

The 2014 AI bottom trawl survey estimate was 2,529 t, well below the 1991-2012 average level of 12,598 t (Table 5.11) and comparable to the 2012 estimate of 2,600 t. The distribution of Greenland turbot in 2014 indicate much lower abundance in the survey compared to pre-2012 surveys (Fig. 5.11). The breakdown of area specific survey biomass for the Aleutian Islands region shows that the Eastern Aleutian Islands Area (Area 541) abundance estimate had a sharp drop from 3,695 t in 2010 (59% of AI biomass) to 181 t (7% of AI biomass) in 2012 and remained low in 2014 at 489 t (19% of AI biomass). The estimated proportion of Greenland turbot in the eastern area of the AI for 2014 of 19% is far below the 1980- 2010 average of 67% of the survey abundance. Only in 2004 and 2012 was the area estimate lower than the other regions. We are not certain why there was such a dramatic decline in the Greenland tubot abundance estimate in the AI trawl survey in 2012 and 2014. For 2012 we speculated that lower bottom temperatures in the shallow areas in the eastern area may have been a contributing factor (Lowe et. al. 2012), but that did not hold true for 2014 where we saw an increase in bottom

temperatures. The trawl-survey area-swept data for the AI component of the Greenland turbot stock is not presently included in the stock assessment model.

Longline survey

The ABL longline survey for groundfish alternates years between the AI and the EBS slope region. The combined time series is used as a relative abundance index (Table 5. 12). It is computed by taking the average RPN from 1996-2014 for both areas and computing the average proportion. The combined *RPN* in each year (RPN_t^c) was thus computed as:

$$RPN_t^c = I_t^{AI} \frac{RPN_t^{AI}}{p^{AI}} + I_t^{EBS} \frac{RPN_t^{EBS}}{p^{EBS}}$$

where I_t^{AI} and I_t^{EBS} are indicator functions (0 or 1) depending on whether a survey occurred in either the Aleutian Islands or EBS, respectively. The average proportions (1996-2014) are given here by each area as: p^{AI} and p^{EBS} . Note that each year data are added to this time series, the estimate of the combined index changes (slightly) in all years and that this approach assumes that the population proportion in these regions is constant. The time series of size composition data from the ABL longline survey extends back to the U.S.-Japanese cooperative longline survey in 1979 and is shown in Fig. 5.12.

Analytic Approach

Model Structure

A version of the stock synthesis program (Methot 1990) has been used to model the EBS component of Greenland turbot since 1994. The software and assessment model configuration has changed over time, particularly in the past seven years as newer versions have become available.

Total catch estimates used in the model are from 1960 to 2014. Model parameters are estimated by maximizing the log posterior distribution of the predicted observations given the data. The model includes data from two fisheries (fixed gear (longline and pots) and trawl), together with three surveys covering various years (Table 5.5). No new modeling approaches were examined in this year's assessment. The models presented are based on 2013 Model1 and Model 2. These continue to use the Beverton-Holt curve, and early recruitment series is carried back to 1945. The results from these two models were similar.

Parameters Estimated Outside the Assessment Model

All independently estimated parameters were the same for both models presented. These parameters are listed in the following table.

Parameter	Estimate	Source
Natural Mortality	0.112	Cooper et al. (2007)
Length at Age		
L_{min} CV	8%	Gregg et al. (2006)
L_{max} CV	7%	Gregg et al. (2006)
Maturity and Fecundity		
Length 50% mature	60	D'yakov (1982), Cooper et al. (2007)
Maturity curve slope	-0.25	D'yakov (1982), Cooper et al. (2007)
Eggs/kg intercept	1	D'yakov (1982), Cooper et al. (2007)
Eggs/kg slope	0	D'yakov (1982), Cooper et al. (2007)
Length-weight		
Male		
Alpha	3.4×10^{-6}	1977-2011 NMFS Survey data
Beta	3.2189	1977-2011 NMFS Survey data
Female		
Alpha	2.43×10^{-6}	1977-2011 NMFS Survey data
Beta	3.325	1977-2011 NMFS Survey data
Recruitment		
Steepness	0.79	Myers et al. (1999)
Sigma R	0.6	Ianelli et al. (2011)

Natural mortality and length at age

The natural mortality of Greenland turbot is assumed to be 0.112 based on Cooper et al. (2007). This is also more consistent with re-analyses of age structures that suggest Greenland turbot live beyond 30 years (Gregg et al. 2006).

Maturation and fecundity

Maturity and fecundity followed the same assumptions as last year's models except the female length at 50% mature was corrected from 55cm to 60cm as per D'yakov (1982). Recent studies on the fecundity of Greenland turbot indicate that maturity estimates at length may be somewhat higher than most estimates from other studies and areas (Cooper et al., 2007). In particular, the values were higher than that found from D'yakov's (1982) study. The data for proportion mature at length from the new study suggest a larger length at 50% maturity but data were too limited to provide revised estimates and may be biased large due to the lack of smaller fish in the study. For this analysis, a logistic maturity-at-size relationship was used with 50% of the female population mature at 60 cm; 2% and 98% of the females are assumed to be mature at about 50 and 70 cm respectively. This is based on an approximation from D'yakov's (1982) study.

Weight at length relationship

The weight at length relationship was devised using the combined data from the ABL longline and both bottom trawl surveys conducted by the AFSC in the BSAI. From 2003 to 2011 the Greenland turbot stock assessment models used the same weight at length relationship for males and females ($w = 2.44 \times 10^{-6} L^{-3.34694}$, where L = length in cm, and w = weight in kilograms). Given the great deal of sexual dimorphism observed in this species, separate weight at length relationships were calucated for each sex in 2012 that continue to be used ($w = 2.43 \times 10^{-6} L^{3.325}$ is used for females and $w = 3.40 \times 10^{-6} L^{3.2189}$ for males). This relationship is similar to the weight at length relationship observed by Ianelli et al. (1993) and used in the Greenland turbot stock assessment prior to 2002. The weight at length analysis was presented at the September 2012 Plan team and SSC meetings (Barbeaux et al. 2012, Appendix 5.1).

Size composition multinomial sample size

Determining the appropriate multinomial sample size for the size composition data is always problematic. This year's assessment model was fit following the methods employed by many of the Northwest Fisheries Science Center groundfish. Initial values were selected and then the models were tuned to match the output effective sample size by having the effective N/ adjusted input values close to 1. Initial sample sizes for the two fisheries for each year were set to 50 (Table 5.13). The initial annual size composition sample sizes for the surveys were set at the same values as those used in previous assessments. The shelf trawl survey sample sizes were set to 200, the 2002 through 2012 slope survey sample sizes were set to 50, while those prior to 2000 were set to 25. The ABL longline sample sizes were set to 60.

Parameters Estimated Inside the Assessment Model

The following are the key parameters estimated and the corresponding number of parameters within the two candidate models.:

Parameter	# of Parameters Model 1	# of Parameters Model 2
Recruitment		
Early Rec. Devs	(1945-1970) 25	(1945-1970) 25
Main Rec. Devs	(1970-2012) 43	(1970-2012) 43
Late Rec. Devs	(2013-2014) 3	(2013-2014) 3
Future Rec. Devs	(2015-2016) 2	(2015-2016) 2
R_0	1	1
Rho	0	1
Growth		
L_{min} (M and F)	2	2
L_{max} (M and F)	2	2
Von Bert K (M and F)	2	2
Catchability		
q_{Shelf}	1	0
q_{Slope}	1	0
Selectivity		
Trawl Fishery	21	21
Longline Fishery	7	13
Shelf Survey	17	17
Slope Survey	2	2
ABL Longline Survey	2	2
Total Parameters	130	135

Recruitment and generating initial conditions

Because there was a large fishery on this stock prior to there being size or age composition data available (1960 – 1977), constraints on recruitment estimation were needed for these earlier years. Initial analysis without constraints resulted in a single, unrealistically large recruitment event being estimated. It seems more probable that the year classes that contributed to the large catches were more diverse (i.e., that a period of good year classes contributed to the biomass that was removed). Consequently, in 2011 the assessment was configured to have an estimated R_0 during 1960 through 1969 that differed from the latter period. This resulted in a different mean recruitment being assumed for years 1960 through 1969 and 1970 through 2010 and an assumption of higher productivity in these early years. In all periods a Beverton-Holt stock recruitment curve with steepness set to 0.9 with σ_R (log-scale recruitment variability) set to 0.6.

In the 2012 and 2013 assessment models and both of the models considered this year, a single R_0 was assumed for all years and fit using an uninformative log normal prior. The models were fit to Beverton-Holt stock recruitment curve with steepness (h) set to 0.79 and σ_R set to 0.6, consistent with values found for Greenland turbot stocks in the North Atlantic and Arctic Ocean (Myers et al. 1999). For Model 2 an autocorrelation parameter was investigated where the prior component due to stock-recruitment residuals (ε_i) is

$\pi_R = \frac{\varepsilon_1^2}{2\sigma_R^2} + \sum_{i=2}^{n} \frac{\left(\varepsilon_i - \rho\varepsilon_{i-1}\right)^2}{2\sigma_R^2\left(1-\rho^2\right)}$, where ρ is the autocorrelation coefficient and σ_R^2 is the assumed stock recruitment variance term. Although different ρ -values were explored last year, ρ was fixed at 0.6 for the 2013 Model 2. For this year's Model 2 we used the prior of 0.473 (SD=0.265) estimated by Thorson et al. (2014) for Pleuronectidae species. For both Model 1 and 2 the starting year was pushed back to 1945 which allowed more flexibility for estimating a variety of age classes in the model given the assumed natural mortality of 0.112. Recruitment deviations for 1945-1970 (Early Rec. Dev.s) were estimated separately from the post-1970 recruitment deviations (Main Rec. Dev.s). Both sets of Rec.Dev.s are deviations from R_0 and sum to 0.0 seperately. Seperating the Rec. Dev.s can be used to reduce the influence of recruitment estimation in the early period when there is little data on the later period in some model configurations. It should be noted that in the models explored for 2014 this differentiation between the two periods had no effect on model results. This configuration is simply implemented to allow flexibility in exploring other model alternatives in the future.

Catchability in the Slope Survey

In Model 1 the shelf survey was fit with a lognormal prior (log(q) = -0.6938, q = 0.5) log SD = 0.4) and an informative lognormal prior on the slope survey (log(q) = -0.28768, q = 0.75) log SD = 0.1). With the change in data the fit for q with these priors started to become unreasonably high. To counteract this for the Model 2 presented this year we selected catchabilities for the shelf and slope from a model fit without the 2007 through 2014 data. This was meant to eliminate the effects of the 2007 through 2009 year classes ($\log(q_{shelf})$ = -0.4850235 and $\log(q_{slope})$= -0.5555418).

Selectivity

Sex-specific size-based selectivity functions were estimated for the two trawl surveys and the two fisheries. The different time blocks for the fisheries and surveys are shown in the table below. For Model 1these blocks were the same as those used in the 2013 models. For Model 2 we added a time block for 2010-2014 for the longline fishery. Data from the longline survey are combined hence a sex aggregated size-based selectivity function was used.

	Sex specific?	Number of blocks	Block years
Trawl Fishery	Yes	3	1945-1988, 1989-2005, 2005-2012
Longline Fishery			
Model 1	Yes	Model1(2)	1945-1990, 1991-2014
Model2	Yes	Model2(3)	1945-1990,1991-2009, 2010-2014
Shelf Survey	Yes	4	1945-1991, 1992-1995, 1996-2000, 2001-2013
Slope Survey	Yes	1	1945-2012
ABL Longline Survey	No	1	1945-2013

If the size selectivity pattern is specified as logistic, then SS3 requires 3 parameters to differentiate the curve from the opposite sex:

p1 is added to the first selectivity parameter (inflection)

p2 is added to the second selectivity parameter (width of curve)

p3 is the asymptotic selectivity

If the size selectivity pattern is specified as a double normal, then five parameters are needed to differentiate from the opposite sex:

p1 is added to the first selectivity parameter (peak)

p2 is added to the third selectivity parameter (width of ascending side)

p3 is added to the fourth selectivity parameter (width of descending side)

p4 is added to the sixth selectivity parameter (selectivity at final size bin)

p5 is the apical selectivity

This method was used for all fisheries and surveys with separate sex data. As in the 2013 models, the longline fishery and slope survey selectivity assume a single logistic curve. The longline survey size composition data poses a challenge to modeling since sexes are aggregated and the data are often bimodal which presumably represents males and females. Although a simple logistic model can be fit to the data, the residual pattern is often undesirable.

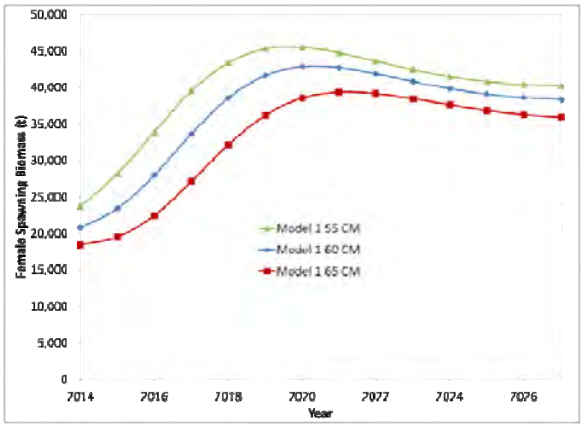
Length-at-age

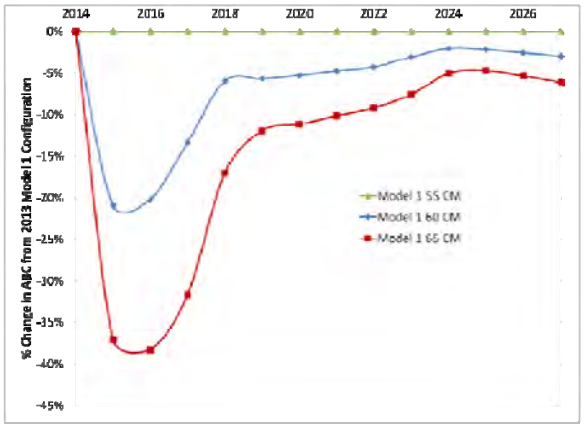
Parameters describing length-at-age are estimated within the model. Length at age 1 is assumed to be the same for both sexes and the variability in length at age 1 is assumed to have an 8% CV while at age 21 a CV of 7% is assumed. This appears to encompass the observed variability in length-at-age. As with last year, size-at-age information from the methods described by Gregg et al. (2006) were used and this information is summarized in Table 5.14.

Results

Female length at 50% mature

As describe previously the female length at 50% mature was incorrectly parameterized in previous models, back to 2002. The value used previously was 55 cm but was changed to 60 cm for models considered in this year's assessment. We ran last year's configuration, Model 1, with values at 55 cm, 60 cm, and 65 cm to show the effects of changing this value. A length of 65 cm is near the value suggested by Cooper et al. (2007). This change does not effect the status of the stock or the model fit. It did however change the reference points and current estimates of spawning biomass (Fig. 5.13 and below) and therefore the ABC and OFL values.





Model Evaluation

Two models are presented in this year's assessment. Model 1 is the same as the 2013 Model 1 with updated data through 2014. Model 2 was configured as Model 1, except that recruitment was modeled with an informative prior on an autocorrelation parameter with a mean of 0.473 and standard deviation of 0.265, catchability was fixed, and an additional selectivity time block was instituted for the more recent (2010-2014) longline fishery length compositon data. Both candidate models were configured to have Beverton-Holt stock recruitment curve with fixed parameters noted above.

Table 5.15 includes the likelihood values for last year's reference model and both of this year's models, key parameter fits, reference points, and key model results. The tuning of the size and age composition sample size for last year's model were different from this year's and therefore direct comparisons of size and age composition likelihood estimates were not possible. Table 5.16 provides measures of model fit to the individual component of all three models including survey index RMSE, mean effective N for the age and size composition data and the recruitement variability for the candidate models. The fits to the data are very similar between the the two models presented.

Selection of the 2014 Author's selected model was based on the following considerations. Models 1 and 2 have different error and data structures and therefore can not be compared using

model likelihoods. Model 2 has a marginally worse fit to the survey indices due to fixed catchability, but has a marginally better fit to the length and age components for the fishery data and shelf survey, and slightly worse fit for the slope and ABL longline survey length composition data.

The inclusion of an autocorrelation parameter made a difference in the pre-1970 recruitment deviations. To have enough Greenland turbot to support the early fishery, Model 1 created a single large positive deviation in 1964, while Model 2 created a series of lesser positive deviations between 1961 and 1968 (Fig.5.13). Because these models rely primarily on size composition data, especially in the early part of the catch time series, the estimates of population age structure prior to 1970 is uncertain. Importantly, the autocorrelation parameter reflects characteristics of many groundfish stocks which undergo periods of low recruitment and periods of above average recruitment. Such a pattern might be more plausible, particularly absent any information suggesting a single strong year class occurred in 1962 (other than the fact that the population as modeled required more fish to account for the large catches).

In addition the retrospective pattern for the two models are substantially different and Model 2 shows a substantial improvement over Model 1 (Model 1 Rho = 0.62 vs. Model 2 Rho = 0.32). The majority of this improvement was simply due to fixing the shelf and slope survey catchability and therefore may not actually show an improvement in the model.

In the end there is little quantifiable difference between the two models that can be used to decide between the two models. In the Authors' opinion Model 2 is the preferred model due to how it handles the pre-1970 recruitment deviations, providing a more diverse age structure in the "pre-historic" model. In addition the large late-1970's and late 2000's high recruitment are evidenced in the data and shown to cover a number of years suggesting there is autocorrelation in recruitment for this species.

Model 2 diagnostics and suggestions for future improvement

Model predicted numbers at size, number at age, and size selectivities for each fishery and survey are presented in an Excel spreadsheet in supplemental Appendix 5.1.

Survey indices

The fit to all the surveys is approximately the same as the fit in last year's models. The shelf survey fails to fit the high 1994 shelf survey biomass estimate (Fig. 5.14). In addition the model does not fit the 2003 and 2004 increase in abundance but provides a simple slope from the high in 1995 through the low in 2009. The model estimated shelf survey biomass follows the general trend and shows an increase due to the high numbers of small fish observed in the 2008 through 2013 shelf surveys. Larger Greenland turbot are thought to migrate off the shelf and this probably varies depending on environmental conditions. This type of variability (due to irregular ontongenetic movement) may indicate the need for time-varying selectivity curves (Fig. 5.15).

The slope survey index used in this year's assessment comprises only 5 points yet fits reasonably well (Fig. 5.16). Besides issues related to variable ontogenetic movement discussed above, the stock also straddles the US/Russian border. The rate that fish migrate between these regions is unknown. Such migration could affect the population available to the US surveys. Additional tagging studies should be conducted to address the issue of adult Greenland turbot movement. Ideally, tagging studies should be conducted cooperatively between the US and Russian management agencies.Although not implemented this year, the authors are exploring a split area model that would allow ontogenetic movement between the slope and shelf.

The fit to the ABL longline survey index of abundance mimics the 1996 - 2010 index decline (Fig. 5.17). Instead of showing a sharp decline from earlier years and slight incline in the latest survey data, given the high uncertainty in these data, the model prefers to fit a shallow decline throughout the data series with a slight leveling off in recent years. A trend is present in the residuals in which the earlier high values tend to be underestimated and the later low values overestimated. The RPN index values are highly variable between years in the later period. It should be noted that the uncertainty used for all of the survey index values in this model was CV = 0.198. Because the 2006 through 2010 values were low compared to the earlier surveys, the uncertaintly around these points was also lower. The point estimates for this period are likely less precise then what was assumed. A geostastical based estimate of variability should be explored for this index which could provide a better starting point for the uncertainty used in our assessment.

Age composition

The shelf survey age composition predictions matched the data well for both males and females (Fig. 5.18). The model consistently underestimated the peak proportion at age for the younger fish and overestimated the proportion at age for older fish. The difference was more inflated in the females then the males. However, with the exception of the 1998 age composition data, this disagreement was generally small. The large proportion of age 2 and 3 fish were not fit well in the 1998 shelf survey data. The high numbers of young fish observed in the shelf survey for 2007 through 2009 were consistent with the size composition data and were fit well by the model.

Length at age

The model fit the length at age data for both males and females well (Fig. 5.19). There was some annual variability, but this could be due to the lower sample sizes for those age classes and years (the fits lie within the data confidence intervals for the majority of points).

Size composition

Overall Model 2 did a reasonable job of capturing the large trends observed in the size composition data (Fig. 5.20). The trawl fishery size composition data (Fig. 5.21 and Fig. 5.22) is not fit well and and fitting these data remain problematic. There was a large shift in the trawl fishery selectivity between the foreign and domestic fisheries (Fig. 5.23 and Table 5.17) and another less severe change in 2008 when the Arrowtooth/Kamchatka fishery started. Even with

the additional flexibility in fitting the two sexes with time varying selectivity, there remains patterns in the residuals for females that are problematic in the early years of the size data (1979-1989; Fig. 5.23). The trawl fishery size composition data are pooled from the directed fishery and from bycatch in other fisheries. The directed fishery targeted the larger fish (predominantly females) on the slope, while the bycatch fishery mostly caught smaller fish (predominantly males) on the shelf, resulting in very different expected selectivity patterns for the two sexes. Currently SS3 can't handle such a large difference in selectivity patterns between sexes for the same fishery. The author attempted to seperate out the bycatch trawl data from the targeted trawl fishery data to see if the patterns in the size composition data for these early years could be rectified in future assessments. Since target was not included in the data prior to 2003, this task did not prove possible given the constraints of the data.

With this year's improvements the Model 2 fit to the longline fishery data (Fig. 5.24. Fig. 5.25, and Table 5.16) appeared reasonable. There was only a small shift in selectivity to smaller fish between the two early time blocks and a larger shift in the later 2010-2014 time block (Fig. 5.26). The ability of the model to fit a lower selectivity for large males while keeping high selectivity for large females ,which are targeted by the fishery, allowed tighter fits to the data . Having higher selectivity for smaller males than females mimicks the migration of males to deeper waters at a smaller size than females.

Model 2 fit to the shelf survey data is similar to the fit to the 2013 Model 1 configuration. The model performs poorly in 1999 through 2005 when there are a higher proportion of large fish on the shelf than in earlier and later years (Fig. 5.27 and Fig. 5.28). In this case the model appears to consistently underestimate the proportion of larger fish, particularly for larger females.

The slope survey size composition selectivity was modeled as a logistic model (Fig. 5.29) with no time blocks, but separate selectivity for males and females. The model fits (Fig. 5.30) were about the same as last year's Model 1. The fits were rather poor and generally underestimated the peak of the highest abundance size bins, particularly for males (Fig. 5.30). This may therefore underestimate the large males in the population. No other survey or fishery encounters these large males. Although the model predicts there to have been a larger proportion of males to females (males:female ratio up to 1.6:1) in the population between 50 cm and 70 cm (Fig. 5.31), the raw survey data show no trend in male to female ratio for all sizes in aggregate (Fig. 5.32).

The ABL longline survey size composition data were from combined sexes and as such they are very difficult to model using standard selectivity curves. Better model fits were achieved in models presented at last year's September plan team that used splines. These were rejected by the Plan Team and the authors agree that using splines has the problem of overfitting the data and making selectivity curves that are not easily interpretable. There is no real improvement to the model fit from last year. We fit the model using a single logistic curve(Fig. 5.33), but these data were bimodal and the model tends to fit a single mode to these data resulting (Fig. 5.34) in overfitting between the male and female peaks and underfitting the two peaks for all years.

Splitting the selectivity for males and females and increasing the weight to the slope survey may improve the fit slightly, but short of this or using splined selectivity, there are no further options available for improving the fit to these data.

Time Series Results

In this section we will present the results from Model 2 and predicted time series. In all instances in this section "total biomass" refers to age 1+ biomass, spawning biomass is the female spawning biomass, and recruitment is age 0 numbers from the model unless otherwise specified.

Recruitment

Model 2 fits an autocorrelation parameter for the recruitment deviations with a prior of 0.473 and standard deviation of the prior of 0.265. The posterior autocorrelation parameter has a value of 0.601 with a standard deviation of 0.04. The most striking feature of the Model 2 recruitment (Fig. 5.35, Table 5.18, and Table 5.19)are the extremely large 1962- 1967 year classes with between 75 and 292 million age-0 recruits. This is an artifact of the model as there were no size or age composition data prior to 1977 to steer recruitment in these early years. A larger than average abundance was needed for the large 1960's fishery and to leave enough large fish in the 1970s and 1980s to account for the large fish observed in the size composition data. Unlike Model 1 used in 2013, Model 2 fits autocorrelation in the recruitment forcing the model to create several large year classes throughout the 60s. Due to how the recruitment deviations likelihood is specified using SS3, if autocorrelation is not allowed the model will always fit a single large recruitment instead of multiple events when it does not have composition or index data to inform the model. Model 2 was intended as a means to spread these recruitment events out without assuming changes in early productivity. The Model 2 configuration was rejected by the Plan Team in 2012 because the inclusion of autocorrelation in SS3 had not been throuroughly vetted. A recent study by Thorson et al (2014) has shown improved model performance with the assumption of autcorrelated recruitment deviations and in this case we see an improvement in recruitment and how these early years are handled by the model.

After 1970, Model 2 fits another large recruitment event during 1974-1978 with an average recruitment of 95 million fish during these five years reaching a maximum of 149 million age-0 fish in 1975. As there were no size composition data prior to 1977, the basis for these large year classes was the existence of many large fish in the early longline fishery. Because Greenland turbot appear to reach a terminal size, the exact ages were not known and therefore the exact years for these recruitment events were not known and may change in future models under different configurations. The 1978 year class was well documented and can be traced from the trawl fishery through the longline fishery and surveys. It should be noted that for the projection model, used for determining the reference points and setting catch levels, we only use age 1 recruitment from1977 onward.

Recruitment from 1980 through 2006 was low with a mean of 5.4 million age-0 fish (rec.var=0.92). The mean age-0 recruitment from 1977 through 2014 was estimated at 13.8

million fish (rec. var. = 1.24). Recruitment of age-0 fish was estimated in 2007 at 16.1 million, 2008 at 43.4 million, 2009 at 84.6 million and 2010 at 17.1 million age-0 fish. 2009 saw the largest recruitment since 1976. These recent recruitment events were captured over multiple years in the shelf survey size and age composition data, in the size composition from the last two slope surveys, and in the size composition data from the last two years in the trawl fishery. Although the 2014 longline fishery data are not complete for 2014 as a significant portion of the fishery occurs in October and November, we do see these large year classes beginning to enter the size composition data. The influx of new recruits from 2007 through 2010 result in a sharp drop in the predicted population mean size and mean age (Fig. 5.36 and Fig. 5.37).

Biomass and fisheries exploitation

The BSAI Greenland turbot spawning biomass in Model 2 was projected for 2015 at 30,853 t to be increasing from its lowest level of 24,931 t ($B_{19\%}$) in 2013, a drop from a peak of 230,809 t in 1977 ($B_{177\%}$; Table 5.20, Table 5.21, Fig.5.38 and Fig. 5.39). The large early 1980s fishery combined with a lack of good recruitment in the mid- to late-1980s through the 1990s drove the steepest part of the decline in spawning biomass. The mean age-0 recruitment from 1986 to 2006 was 4.6 million fish (33% of the overall 1977-2014 mean recruitment). In 1990 the NPFMC cut ABCs to 7,000 t until 1996 to account for low recruitment; however the ABCs were exceeded in 5 of the 7 years (Table 5.1). The stock continued to decline in the 1990s as poor recruitment continued. In 1997 the NPFMC started managing the stock as a Tier 3 stock and the ABCs were allowed to increase (Table 5.1). The mean ABC between 1997 and 2002 was 9,783 t, the mean catch however was lower and averaged about 6,355 t per year over this period. From 2003 to 2008 the ABC levels remained relatively low with a high of 4,000 t in 2003 and a low of 2,440 t in 2007. The catch dropped even lower to an average of just 2,417 t per year in this period. In 2008 with Amendment 80 an arrowtooth/ Kamchatcka fishery emerged that more than doubled the catch of Greenland turbot in 2008 and continued to double the catch of Greenland turbot through 2012. The average catch from 2008 through 2012 was 3,988 t. The ABCs during this period, due to a clerical error in the projection model, increased from 2,500 t in 2008 to 7,380 in 2009. From 2009 to 2012 the ABC averaged 7,325 t with a high of 9,660 t in 2012. Although the decline in spawning biomass began to slow in 2005 through 2007, the decline in spawning biomass again steepened post-2008. This decline may be correlated with increased fishing pressure during this period. Between 1986 and 2007 the mean total exploitation was estimated at 0.13 with a maximum total exploitation rate of 0.25 (Table 5.17 and Fig. 5.40). The increased fishing explotation rate in 2009 and 2010, that may have steepened the most recent decline, was only 0.21 and 0.17, respectively. The catch levels in 2008 through 2012 however exceeded the OFL control rule levels projected from Model 2 (Fig. 5.41). The effects of the incoming 2007-2010 year classes are creating a steep increase in both the total biomass and female spawning biomass estimates. Projections for 2015 and onward predict an increase in spawning biomass as these year classes grow and mature.

The 2014 Model 2 total age 1+ biomass estimates were similar to the female spawning biomass with a steep decline from an estimated peak in 1972 of 503,964 t to its lowest point in 2010 of 58,390 t (Fig. 5.39). The difference is that the total biomass shows the impact of the 2007- 2010 recruitments starting in 2011. Since its low point in 2010 total age +1 biomass is projected to have increased to 97,442 in 2014 and projected to be at 122,298 t in 2015. The increase in total age 1+ and female spawning biomass over last year's model is partly due to a change the size at age relationship from last year (Table 5.22) with the addition of data from the northern portion of the shelf survey.

Retrospective analysis

The restrospective analysis was conducted in SS3 by removing data systematically by year from both Model 1 and Model 2 for 10 years (Figs. 5.42, 5.43, 5.44, and 5.45). The largest changes in the retrospectives for both models were between -7 and -6 years (from 2007 to 2008). In Model 1 as we removed data, catchability for both the shelf and the slope surveys trended lower until between -7 and -6, at which point it stabilized somewhat (Fig. 5.44). This is likely the effect of the large 2007-2010 year classes entering the shelf survey, but not yet fully recruited as adults to the slope in the 2012 slope survey. The Model 1 provides a better fit with an increasing q with the newer shelf survey index because it doesn't show a large increase in biomass. The maturing fish are likely migrating out of the shelf survey area. In essence the model is "skeptical" of the new large year classes as they are not observed in the ABL longline survey composition data and none of the more recent indices show a large increase in biomass that would be expected if the fish had remained in the area. This highlights the problem resulting from the lack of 2014 slope survey. Greenland turbot are a migratory stock and should be evident in this region. Using the alternating ABL longline survey as an index without the balancing slope survey is also problematic as the 2014 longline survey occurred in the Aleutian Islands and the recent large recruitments observed on the shelf have not yet been observed in the Aleutian Islands.

In general, Model 2 with the fixed catchability provides a better retrospective pattern (Model 1 Rho = 0.62 vs. Model 2 Rho = 0.32). This is not unexpected because Model 2 is constrained by the fixed catchabilities. In both models R_0 is affected by the large year classes. Even with a fixed catchability for Model 2, an increasing trend is evident as data are removed. However, the change in R_0 is a bit steeper between -7 and -6 in Model 1, where q is allowed to change. Other parameter changes with recruitment of the large incoming year classes including shelf and slope survey selectivity parameters, main recruitment deviations, and growth parameters (Fig. 5.45). The shift in both slope survey selectivity parameters is dramatic with the exclusion of the 2012 composition data between year -2 and -3 in both models. The main recruitment deviations post-1984 show an increasing trend as data are removed. Von Bertalanffy K parameter for females shows a slower growth estimated when we include the most recent data. Again the change appears to occur with the recruitment of the large 2007-2010 year classes to the shelf survey beween years -7 and -6.

MCMC

This year we are presenting Bayesian posterior distributions of our parameter estimates simply as an informative exercise (Fig. 5.46). We used a Markov chain approach to investigate the behaviors of our parameter estimates. This approach was not used to determine any of our final model estimates where the asymptotic likelihoos estimates were used. In short, a random walk through the parameter space was simulated using a Markov chain. The Markov chain converges to a stationary distribution approximating a posterior distribution. For this exercise we removed the first 10,000 iterations out of 2,000,000 for burn-in and "thinned" the sample to every 2,000th iteration, leaving 995 iterations. Most parameters in Model 2 behaved as expected, The maximum likelihood estimates (MLE) for recruitment and spawning stock biomass fit within the posterior distribution and median well (Fig. 5.47 and Fig. 5.48). The recruitment deviations were well behaved in this model (Fig. 5.49). There is general agreement between the MLE and the MCMC posterior median for most parameters. There was a difference between the MLE and the posterior median for the recruitment autocorrelation parameter (0.60 vs. 0.53), but the difference was not enough to greatly influence recruitment estimates (Fig. 5.47). In addition selectivity parameters for the trawl fishery and shelf survey appear to have differences, but again appear to have little effect on the ending model estimates. In some cases it appears there is little information in the size composition data to inform the individual parameter selection, here the posterior distributions appear flat and both the posterior median and asymptotic fit remain at the initial value. This is translated into increased uncertaintly in the estimates. For several of the selectivity parameters for the trawl fishery and shelf survey it appears that the maximum likelihood estimates are likely limited by parameter boundaries. This raises a question of whether the selectivities presented are appropriate and further likelihood profiles and sensitivity analyses will be conducted to determine the effects of these parameter selections on model performance and final estimates.

Harvest Recommendations

Amendment 56 Reference Points

The $B_{40\%}$ value using the mean recruitment estimated for the period 1977-2014 gives a long-term average female spawning biomass of 52,049 t. The estimated 2014 female spawning biomass is at 26,341 t or $B_{20\%}$,well below the estimate of $B_{35\%}$ (45,543 t). Because the projected spawning biomass in year 2014 is below $B_{40\%}$ Greenland turbot ABC and OFL levels will be determined at Tier 3b of Amendment 56.

Specification of OFL and Maximum Permissible ABC and ABC Recommendation

In the past several years, the ABC has been set below the maximum permissible estimates.; e.g.,in 2008 the ABC recommendation was 21% of the maximum permissible level. The rationale for these lower values were generally due to concerns over stock structure uncertainty, lack of apparent recruitment, and modeling issues. In 2013 a slope survey was conducted and while some areas show lower abundances (i.e., the Aleutian Islands) the signs of recruitment are

the best seen for this stock. Therefore we recommend that the ABC be set to the maximum permissible.

The projected Greenland turbot maximum permissible ABC and OFL levels for 2015 and 2016 are shown below (catch for 2014 was set to 1,805 t):

Year	Catch (for projection)	Maximum permissible ABC	Recommended ABC	OFL	Female spawning biomass
2015	3,172 t	3,172 t	3,172 t	3,903 t	30,853 t
2016		5,248 t	5,248 t	6,453 t	38,848 t

The estimated overfishing level based on the adjusted $F_{35\%}$ rate is 3,903 t corresponding to a full-selection F of 0.12. The value of the Council's overfishing definition depends on the age-specific selectivity of the fishing gear, the somatic growth rate, natural mortality, and the size (or age) - specific maturation rate. As this rate depends on assumed selectivity, future yields are sensitive to relative gear-specific harvest levels. Because harvest of this resource is unallocated by gear type, the unpredictable nature of future harvests between gears is an added source of uncertainty. However, this uncertainty is considerably less than uncertainty related to treatment of survey biomass levels, i.e., factors which contribute to estimating absolute biomass (Ianelli et al. 1999).

Subarea Allocation

In this assessment, the hypothesis proposed by Alton et al. (1989) regarding the stock structure of Greenland turbot in the EBS and AI regions was adopted. Briefly, spawning is thought to occur throughout the adult range with post-larval settlement occurring on the shelf in shallow areas. The young fish on the shelf begin to migrate to the slope region at about age 4 or 5. In our treatment, the spawning stock includes adults in the AI and the EBS. In support of this hypothesis, the length compositions from the AI surveys appear to have few small Greenland turbot, which suggests that these fish migrate from other areas (Ianelli et al. 1993). Historically, the catches between the AI and EBS has varied (Table 5.23).

Recent research on recruitment processes holds promise for clearer understanding (e.g., Sohn 2009). Stock structure between regions remains uncertain and therefore the policy has been to harvest the "stock" evenly by specifying region-specific ABCs. Based on EBS slope survey estimates and AI surveys, the proportions of the adult biomass in the AI region over the past four surveys (when both areas were covered) were 50.0%, 22.4%, 10.7%, and 8.3%. These average 22.8% which when applied to the BSAI ABC gives the following region-specific allocation:

	2015 ABC	2016 ABC
Aleutian Islands ABC	724	1,198
Eastern Bering Sea ABC	2,448	4,050
Total	3,172	5,248

Standard harvest scenarios and projections

A standard set of projections for population status under alternatives were conducted to comply with Amendment 56 of the FMP. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2014 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2015 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2014 (here assumed to be 1,805 t). In each subsequent year, the fishing mortality rate is prescribed based on the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2015, are as follows ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to the author's recommend level. Due to current conditions of strong recruitment and a projected increasing biomass, the recommendation is set equal to the maximum permissible ABC.

Scenario 3: In all future years, F is set equal to the 2008-2013 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 4: In all future years, F is set equal to the $F_{75\%}$. (Rationale: This scenario was developed by the NMFS Regional Office based on public feedback on alternatives.

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA′s requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above half of its MSY level in 2014 and above its MSY level in 2024 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2026 under this scenario, then the stock is not approaching an overfished condition.)

Scenarios 1 through 7 were projected 13 years from 2014 (Table 5.24). Fishing at the maximum permissible rate indicate that the spawning stock (Fig. 5.50) began increasing in 2014 with the incoming large 2007-2009 year classes.

Our projection model run under these conditions indicates that for Scenario 6, the Greenland turbot stock is not overfished based on the first criterion (year 2013 spawning biomass estimated at 19,865 t relative to $0.5B_{35\%}$ = 17,459 t) and will be above its MSY value (34,918 t) in 2023 at 50,259 t.

Projections with fishing at the maximum permissible level result in an expected value of spawning biomass of 57,526 t by 2027. These projections illustrate the impact of the recent recruitment observed in the surveys and fishery data. For example, under all scenarios, the spawning biomass is expected to continue increasing through 2020 and then levels off as the influence of the 2007-2010 year classes wain and the projection relies on mean recruitment.

Under Scenarios 6 and 7 of the 2014 Model 2 the projected spawning biomass for Greenland turbot is not currently overfished, nor is it approaching an overfished status.

Ecosystem Considerations

Greenland turbot have undergone dramatic declines in the abundance of immature fish on the EBS shelf region compared to observations during the late 1970's. It may be that the high level of abundance during this period was unusual and the current level is typical for Greenland turbot life history pattern. Without further information on where different life-stages are currently residing, the plausibility of this scenario is speculation. Several major predators on the shelf were at relatively low stock sizes during the late 1970's (e.g., Pacific cod, Pacific halibut) and these increased to peak levels during the mid 1980's. Perhaps this shift in abundance has reduced the

survival of juvenile Greenland turbot on the EBS shelf. Alternatively, the shift in recruitment patterns for Greenland turbot may be due to the documented environmental regime that occurred during the late 1970's. That is, perhaps the critical life history stages are subject to different oceanographic conditions that affect the abundance of juvenile Greenland turbot on the EBS shelf.

Data Gaps and Research Priorities

Besides the assessment model improvements suggested above, a number of research issues continue to require further consideration. These include:

- An evaluation of possible differential natural mortality between males and females,
- Spatial distribution and migration needs to be better explored through tagging experiments,
- Evaluating the extent that Greenland turbot are affected by temperature and environmental conditions relative to survey gear.
- Although we understand that a portion of this stock extends into Russian waters, Russian catch is not considered in this assessment. How to take into account this unknown mortality should be explored further.

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Tables

Table 5.1 Catch estimates of Greenland turbot by gear type (t; including discards) and ABC and TAC values since implementation of the MFCMA.

Year	Trawl	Longline & Pot	Total	ABC	TAC
1977	29,722	439	30,161	40,000	
1978	39,560	2,629	42,189	40,000	
1979	38,401	3,008	41,409	90,000	
1980	48,689	3,863	52,552	76,000	
1981	53,298	4,023	57,321	59,800	
1982	52,090	32	52,122	60,000	
1983	47,529	29	47,558	65,000	
1984	23,107	13	23,120	47,500	
1985	14,690	41	14,731	44,200	
1986	9,864	0.4	9,864	35,000	33,000
1987	9,551	34	9,585	20,000	20,000
1988	6,827	281	7,108	14,100	11,200
1989	8,293	529	8,822	20,300	6,800
1990	12,119	577	12,696	7,000	7,000
1991	6,246	1,617	7,863	7,000	7,000
1992	749	3,003	3,752	7,000	7,000
1993	1,145	7,325	8,470	7,000	7,000
1994	6,427	3,846	10,272	7,000	7,000
1995	3,979	4,216	8,194	7,000	7,000
1996	1,653	4,903	6,556	7,000	7,000
1997	1,210	5,990	7,200	9,000	9,000
1998	1,576	7,181	8,757	15,000	15,000
1999	1,795	4,058	5,853	9,000	9,000
2000	1,947	5,027	6,974	9,300	9,300
2001	2,149	3,164	5,313	8,400	8,400
2002	1,033	2,602	3,635	8,000	8,000
2003	931	2,615	3,546	4,000	4,000
2004	675	1,583	2,258	3,500	3,500
2005	729	1,879	2,608	3,500	3,500
2006	361	1,625	1,986	2,740	2,740
2007	458	1,544	2,002	2,440	2,440
2008	1,935	988	2,923	2,540	2,540
2009	3,080	1,431	4,511	7,380	7,380
2010	1,977	2,160	4,138	6,120	6,120
2011	1,618	2,028	3,646	6,140	5,060
2012	2,612	2,107	4,720	9,660	8,660
2013	1,046	700	1,745	2,060	2,060
2014*	946	700	1,646	2,124	2,124

*Catch estimated as of October 23, 2014

Table 5.2. Estimates of discarded and retained (t) Greenland turbot based on NMFS estimates by "target" fishery, 1992-2014. 2014 numbers are estimates through October and are not final.

Fishery:	Greenland turbot		Sablefish		Pacific cod		Rockfish		Flatfish		Arrowtooth/Kamchatka		Halibut		Others		Combined	
Year	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard
1992	62	13	202	2,687	135	656	180	103	7	1	6	2			23	12	700	3,724
1993	5,687	332	235	1,916	161	108	572	87	18	183	1	2			2	116	6,683	2,823
1994	6,316	368	195	2,305	149	211	317	37	27	235					36	15	7,040	3,233
1995	5,093	327	157	1,546	145	284	362	25	5	97		5			27	27	5,789	2,405
1996	3,451	173	200	1,026	170	307	598	113	171	63					129	94	4,733	1,823
1997	4,709	521	129	619	270	283	202	19	212	92					12	7	5,540	1,660
1998	6,689	290	123	84	281	155	35	1	541	162	40	86			49	48	7,813	945
1999	4,009	227	179	120	180	50	25	2	465	193	131	76			117	48	5,124	729
2000	4,798	177	192	254	130	109	39	1	576	83	262	93			165	43	6,184	791
2001	2,727	89	171	325	203	92	431	30	563	188	201	149			52	22	4,391	921
2002	1,979	73	144	207	210	137	175	18	76	59	225	158			95	10	2,934	701
2003	1,724	44	114	107	178	95	198	5	68	18	129	52			87	48	2,578	534
2004	1,222	19	78	30	220	83	80	3	134	110	37	18	46	158	82	41	1,882	376
2005	1,534	21	63	21	152	30	136	5	165	26	146	8	20	62	131	37	2,359	249
2006	1,199	14	62	69	65	32	71	8	51	13	141	19	13	90	85	32	1,778	211
2007	1,207	28	60	78	128	91	36	13	54	24	19	0	53	10	127	13	1,705	299
2008	944	3	42	87	16	69	142	1	95	16	762	414	5	15	142	82	2,207	704
2009	2,490	51	76	74	65	21	67	8	49	10	1,158	285	1	10	116	2	4,053	461
2010	1,932	19	71	28	97	19	57	2	13	5	1,659	80	0	0	61	1	3,910	235
2011	1,769	8	49	8	165	9	27	1	4	5	1,466	17	1	74	61	3	3,564	89
2012	1,899	15	36	16	116	9	17	3	47	6	2,269	12	0	30	203	7	4,624	96
2013	579	13	27	38	12	5	49	10	38	42	635	208	0	13	38	2	1,394	351
2014*	624	16	11	44	12	5	40	1	28	49	598	129	1	27	44	0	1,391	255

Table 5.3. Estimates of Greenland turbot catch (t) by gear and "target" fishery, 2005-2014. Source: NMFS AK Regional Office catch accounting system.

	"Target" fishery	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014*
Longline and pot	Greenland turbot	1,531	1,212	1,232	743	1,191	1,833	1,773	1,914	589	626
	Sablefish	76	132	137	124	149	100	57	52	63	55
	Pacific cod	166	77	129	76	84	111	174	123	15	15
	Kam/Arrow flounder	0	140	16	0	9	49	0	4	0	0
	Halibut	104	63	19	12	0	74	30	13	28	3
	Others	2	5	11	22	1	0	0	1	4	0
Trawl	Greenland turbot	24	0	2	205	1,349	118	4	0	3	14
	Pacific cod	15	21	90	9	2	5	0	1	2	2
	Kam/Arrow flounder	154	21	3	1,176	1,434	1,690	1,483	2,277	843	727
	Atka mackerel	167	117	130	201	118	62	64	209	40	45
	Flathead sole	150	28	58	99	49	13	2	46	39	19
	Pollock	31	65	107	86	44	26	29	53	21	41
	Rockfish	139	74	47	142	73	59	28	18	54	41
	Other Flatfish	34	1	12	11	4	1	0	1	4	0
	Rock sole	1	27	8	0	2	3	1	0	3	5
	yellowfin sole	7	8	1	1	4	1	6	6	35	52
	Sablefish	7	0	0	5	1	0	0	0	1	0
	Others	0	0	0	0	0	0	0	0	0	0

* Through October 2014

Table 5.4. Estimates of Greenland turbot catch by gear and area based on NMFS Regional Office estimates, 2003-2014.

Area	Gear	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014*
Aleutian Islands	Fixed	360	238	167	358	345	110	99	220	90	58	66	44
	Trawl	340	196	301	179	178	712	2,164	1,653	442	1,600	231	133
AI Total		700	434	468	537	523	822	2,263	1,872	532	1,658	296	177
EBS	Fixed	1,821	1,346	1,713	1,270	1,201	867	1,336	1,948	1,944	2,050	634	656
	Trawl	591	479	427	183	280	1,222	916	325	1,176	1,012	815	813
EBS Total		2,412	1,825	2,140	1,453	1,481	2,089	2,252	2,273	3,120	3,062	1,449	1,469
Grand Total		3,111	2,259	2,608	1,989	2,004	2,911	4,515	4,145	3,652	4,720	1,745	1,646

* Estimated through Oct. 2014.

Table 5.5. Data sets used in the stock synthesis (SS3) model for Greenland turbot in the EBS. All size and age data except for the ABL longline survey are specified by sex .

Data source	Data type	Years of data
Trawl fisheries		
	Catch	1960-2014
	Size composition	1977-1987, 1989-1991,1994-2006, 2008-2014
Longline fisheries		
	Catch	1960-2014
	Size composition	1979-1985,1993-2014
Shelf Survey		
	Abundance Index	1987-2014
	Size composition	1982-2014
	Age composition	1998,2003-2012
Slope Survey		
	Abundance Index	2002,2004,2008,2010,2012
	Size composition	1979,1981,1982,1985,1988,1991,2002,2004,2008, 2010,2012
ABL Longline survey		
	RPN abundance index	1996-2014
	Size composition	1979-2014

Table 5.6. Greenland turbot BSAI fishery length sample sizes by gear type and sex, 1989-2014. Source: NMFS observer program data. The % female do not include unidentified fish.

	Trawl fishery				Longline fishery			
Year	Female	Male	Unident.	% Female	Female	Male	Unident.	% Female
1989	1,405	5,568	947	20%				
1990	3,864	5,762	6,100	40%				
1991	1,851	1,752	9,295	51%				
1992							71	
1993			425		3,921	915	12,464	81%
1994	1,122	1,027	5,956	52%	503	150	1,200	77%
1995	245	363	4,086	40%	1,870	715	5,630	72%
1996	112	390		22%	941	442	7,482	68%
1997					2,393	1,014	14,833	70%
1998	307	696	822	31%	3,510	2,127	22,794	62%
1999	1,044	1,556		40%	8,033	2,899	266	73%
2000	724	1,328	25	35%	6,550	2,962	73	69%
2001	467	892	43	34%	4,054	1,550	271	72%
2002	186	433		30%	4,725	1,811	40	72%
2003	197	325	1	38%	4,624	2,113	2	69%
2004	179	433	10	29%	4,340	2,612	1	62%
2005	118	211		36%	4,650	1,902	43	71%
2006	15	76		16%	3,339	1,474	32	69%
2007	34	23		60%	3,833	2,130	134	64%
2008	421	1,572	1	21%	1,577	1,481		52%
2009	1,017	2,993	26	25%	3,492	2,709	39	56%
2010	298	3,562	174	8%	3,290	2,860	108	53%
2011	853	2,025	37	30%	2,494	1,694	7	60%
2012	1,742	3,153	14	36%	3,141	2,292	69	58%
2013	1,268	1,367	2	48%	1,087	675		62%
2014	1,009	1,304		44%	382	463		45%

Table 5.7. Survey estimates of Greenland turbot biomass (t) for the Eastern Bering Sea shelf and slope areas and for the Aleutian Islands region, 1975-2014. Note that the shelf survey estimates from 1985, and 1987-2014 include the northwestern strata (8 and 9) and these were the values used in the model. The Aleutian Islands surveys prior to 1990 used different operational protocols and may not compare well with subsequent surveys. The 1988 and 1991 slope estimates are from 200-800 m whereas the other slope estimates are from 200 - 1,000m.

	Eastern Bering Sea		Aleutian Islands
Year	Shelf	Slope	Survey
1975	126,700		
1979	225,600	123,000	
1980	172,200		3,598*
1981	86,800	99,600	
1982	48,600	90,600	
1983	35,100		9,684*
1984	17,900		
1985	7,700	79,200	
1986	5,600		31,759*
1987	11,787		
1988	13,353	42,700	
1989	13,209		
1990	16,199		
1991	12,484	40,500	11,925
1992	28,638		
1993	35,692		
1994	57,181		28,235
1995	37,636		
1996	40,611		
1997	35,303		28,342
1998	34,885		
1999	21,536		
2000	23,184		9,362
2001	27,280		
2002	24,000	27,589	9,891
2003	31,010		
2004	28,287	36,557	11,334
2005	21,302		
2006	20,933		20,934
2007	16,723		
2008	13,511	17,901	
2009	10,953		
2010	23,414	19,873	6,758
2011	26,156		
2012	21,792	17,984	2,600
2013	24,907		
2014	28,028		2,529

Table 5.8. Levels of Greenland turbot biological sampling from the EBS shelf surveys. Note that in 1982-1984, and 1986 the northwestern stations were not sampled.

Year	Total Hauls	Hauls w/ turbot	Length samples	Otolith sample hauls	Hauls w/age	Otolith Samples	Ages
1982	367	150	1,567	11	11	292	292
1983	442	120	951				
1984	460	65	536	20		263	
1985	417	94	685				
1986	388	59	195				
1987	393	53	377				
1988	441	63	414				
1989	444	75	432				
1990	404	78	544				
1991	406	74	658				
1992	361	73	616	5		7	
1993	396	73	632	7		179	
1994	436	57	536	17		196	
1995	537	51	353				
1996	382	75	450	8		100	
1997	382	66	298	11		79	
1998	616	73	445	25	21	200	127
1999	426	51	207	8		11	
2000	423	61	248	34		188	
2001	426	61	274	45		217	
2002	404	70	455	21		71	
2003	408	71	622	62	62	435	407
2004	413	64	606	45	45	290	280
2005	417	64	442	57	56	294	278
2006	457	56	427	49	48	262	239
2007	443	84	499	68	68	334	311
2008	432	79	406	59	59	245	235
2009	422	104	856	72	71	351	344
2010	415	145	3,199	70	69	362	358
2011	422	156	4,381	61	59	427	381
2012	451	110	2,133	62	62	418	408
2013	455	96	1,160	63		382	
2014	428	96	1,567	59		359	

Table 5.9. Eastern Bering Sea slope survey estimates of Greenland turbot biomass (t), 2002, 2004, 2008, 2010, and 2012 by depth category.

Depth (m)	2002	2004	2008	2010	2012
200-400	4,081	2,889	4,553	1,166	2,420
400-600	**14,174**	**25,360**	**6,707**	**10,352**	**10,268**
600-800	4,709	5,303	4,373	5,235	3,822
800-1000	2,189	1,800	1,487	2,041	1,018
1000-1200	1,959	1,206	781	1,079	456
Total	27,113	36,557	17,901	19,873	17,984

Table 5.10. Eastern Bering Sea slope survey estimates of Greenland turbot numbers, 2002, 2004, 2008, 2010, and 2012 by depth category.

Depth (m)	2002	2004	2008	2010	2012
200-400	993,994	745,401	1,740,599	421,257	3,374,545
400-600	3,668,882	4,885,557	1,913,410	3,428,133	7,055,925
600-800	1,070,165	998,631	1,196,717	1,330,889	1,089,539
800-1000	504,257	360,764	273,120	432,937	228,151
1000-1200	374,192	224,570	126,498	225,910	91,540
Total	6,611,490	7,214,922	5,250,344	5,839,126	11,839,700

Table 5.11. Time series of Aleutian Islands survey sub-regions estimates of Greenland turbot biomass (t), 1980-2014.

Year	Western Aleutian	Central Aleutian	Eastern Aleutian	Southern Bering Sea	Total
1980	0	799	2,720	79	3,598
1983	525	2,328	5,737	1,094	9,684
1986	1,747	2,495	19,580	7,937	31,759
1991	2,195	3,320	4,607	1,803	11,925
1994	2,401	4,007	15,862	5,966	28,235
1997	2,146	3,130	22,708	359	28,343
2000	842	2,351	5,703	467	9,362
2002	793	1,658	6,996	444	9,891
2004	2,588	2,948	2,564	3,234	11,334
2006	1,973	1,937	15,742	1,282	20,934
2010	1,071	1,507	3,695	486	6,758
2012	1,091	1,231	181	98	2,600
2014	553	989	490	497	2,529
Avg. since 1991	1,565	1,464	2,308	7,855	13,191

Table 5.12. Auke Bay Laboratory longline survey RPNs for Greenland turbot biomass by year and region.

Relative Population No. (RPN)																			
	Year																		
Area	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Bering 4		11,729		13,072		16,082		11,965		3,717		1,561		3,406		1,494		1,641	
Bering 3		6,172		6,156		5,005		3,784		1,826		1,754		640		705		3,082	
Bering 2		27,936		33,848		24,766		24,660		15,268		13,523		21,192		12,164		13,473	
Bering 1		13,491		10,068		5,123		6,206		2,297		1,235		2,612		1,821		2,970	
NE Aleutians	23,133		23,121		12,987		10,942		8,551		3,031		3,155		2,033		4,714		4,240
NW Aleutians	7,212		7,208		4,049		3,411		2,666		945		984		634		1,470		1,322
SE Aleutians	2,142		1,791		1,201		1,397		936		566		297		163		350		181
SW Aleutians	6,775		5,665		3,800		4,420		2,962		1,789		939		517		1,106		573
Bering Sea (total)		59,328		63,144		50,975		46,616		23,107		18,074		27,850		16,184		21,166	
Aleutians (total)	39,262		37,784		22,037		20,170		15,115		6,331		5,374		3,347		7,639		6,315
Combined (/1000)	142.53	81.88	137.17	87.15	80.00	70.36	73.22	64.34	54.87	31.89	22.98	24.95	19.51	38.44	12.15	22.34	27.73	29.21	22.93

Table 5.13. Summary of the length-at-age information used for this BSAI Greenland turbot assessment (see Gregg et al. 2006 for methods).

	1998				2003				2004			
	Females		Males		Females		Males		Females		Males	
Age	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N
1	17.67	3			15.67	3	13.00	3	15.0	1	16.3	4
2	24.94	18	25.58	19	22.37	30	22.15	34	21.8	5	23.9	9
3	33.14	7	34.00	11	29.68	37	28.97	38	29.9	29	30.3	40
4	32.00	1	33.80	5	33.44	16	36.06	18	34.6	10	34.8	18
5	35.00	2	36.50	2	38.96	24	38.96	27	40.9	21	42.6	20
6			50.00	1	47.00	3	40.67	9	43.1	7	43.1	15
7					43.67	3	46.20	10	53.0	3	51.2	10
8			49.00	1	50.00	6	49.20	5	57.0	1	58.0	1
9			58.00	1	57.50	2	48.50	2			61.8	4
10	65.80	5	58.33	3	51.00	1	66.40	5	70.3	4	63.8	4
11	65.00	5			60.00	2	60.00	2	83.0	2		
12	78.67	3	59.75	4	78.33	3	72.00	1	78.3	4	73.2	5
13			66.75	4	83.67	3	76.00	1	85.6	5	68.7	3
14	75.00	1	75.00	1	83.20	5			83.8	5		
15			67.50	2	80.00	1			87.2	6	74.0	2
16	76.00	2			84.20	5	70.00	2	82.0	4	78.0	2
17	81.00	1	71.00	3	86.43	7	72.00	1	85.2	6	78.0	1
18					85.67	6	72.00	1	91.7	3	77.0	3
19			74.00	2	90.67	6	78.00	1	92.5	2	81.0	1
20	80.33	3			89.56	9	81.50	2	89.5	2	73.5	2
21	82.00	1			90.00	5	76.50	2	90.7	3		
22					88.00	4	81.00	2				
23	79.00	1			90.17	6	74.00	1	96.5	2		
24	79.00	2	69.50	2	90.00	5	76.33	3	97.0	1		
25	79.00	2			91.33	3	73.00	2	91.0	3		
26	95.00	1			92.33	3	77.00	3	94.5	2		
27					93.67	3	74.00	1	85.7	3		
28					92.00	4			91.0	1		
29					91.75	4	78.00	1				
30			81	2	91.00	5						

Table 5.13(Cont.) Summary of the length-at-age information used for this BSAI Greenland turbot assessment (see Gregg et al. 2006 for methods).

	2005				2006				2007			
	Females		Males		Females		Males		Females		Males	
Age	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N
1			13.50	2			11.50	2	12.17	18	12.50	26
2	25.00	1	24.00	2	24.33	3	21.00	1	22.50	4	21.00	8
3	32.20	10	33.19	16	30.33	3			30.00	1	28.67	6
4	35.95	38	36.97	35	39.00	2	39.50	2	39.50	2	35.00	4
5	42.58	31	41.33	27	38.00	11	38.38	16	46.18	17	44.40	15
6	48.85	13	47.10	10	42.69	16	43.75	20	47.00	17	47.18	22
7	53.33	9	48.00	5	46.60	25	44.33	15	50.72	18	51.70	23
8	62.50	6	51.83	6	54.53	19	47.25	16	54.67	15	52.67	15
9	62.00	1	52.00	1	57.90	10	53.18	11	59.75	12	56.00	4
10	67.50	2	72.00	1	65.67	3	64.25	4	62.33	6	55.00	3
11	86.00	1	64.67	3	62.00	1	62.25	4	63.00	1	62.75	4
12	77.00	3			71.00	6	74.00	1	62.00	3		
13	88.00	1	72.50	2	56.50	2			65.00	7		
14	81.33	3	76.00	1	77.00	1						
15	85.50	2	79.00	1	78.00	2	73.00	1	61.67	3		
16			75.50	4	84.67	3	77.00	2	80.00	1	69.00	1
17	85.00	2	76.00	1	86.25	4	74.00	1	90.00	4	75.50	4
18	92.00	3	76.00	1	88.67	3	76.00	1	85.00	1	77.50	2
19	84.60	5	74.33	3	87.60	5	79.00	1	91.67	3		
20	90.20	5	79.00	1	90.33	6	79.00	1	89.00	3		
21	89.00	2			91.00	2			90.67	3	76.50	2
22	87.00	1			90.00	2	74.00	1			77.00	1
23	82.00	1			88.00	1	88.00	1	87.00	1		
24	88.00	2	74.00	1			77.00	1			84.00	1
25	86.75	4	75.50	2	88.50	2	83.00	2			72.00	1
26	96.50	2							92.00	3		
27			73.00	1								
28			78.00	1								
29									92.00	1	82.00	1
30	88.00	1			107.00	1			90.00	1	79.00	1

Table 5.13(Cont.) Summary of the length-at-age information used for this BSAI Greenland turbot assessment (see Gregg et al. 2006 for methods).

	2008				2009				2010			
	Females		Males		Females		Males		Females		Males	
Age	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N
1	12.81	16	13.10	21	15.00	6	14.25	12	14.08	38	14.06	48
2	18.94	17	19.64	36	22.05	41	21.93	73	23.22	54	23.91	57
3	23.13	8	23.36	11	29.72	29	28.60	47	30.23	22	33.30	27
4	28.50	2	30.00	4	33.30	10	33.27	11	34.57	7	36.43	14
5	34.50	2	35.50	4	35.50	2	45.00	1	38.00	2	39.75	4
6	49.60	5	47.50	6			42.50	2	42.00	1	42.00	1
7	52.14	14	51.83	12	56.00	3	52.00	1	67.00	1		
8	56.68	25	52.15	20	56.00	1	53.75	4			50.50	2
9	61.73	22	56.79	19	59.56	9	58.33	3			59.00	1
10	64.50	20	58.95	20	63.75	4	54.50	2	62.25	4		
11	64.36	14	60.76	17	64.00	4			73.00	4		
12	68.90	10	62.64	14					67.25	8	60.00	1
13	71.56	9	63.67	6	74.50	2			69.50	2	67.00	2
14	79.83	6	67.17	6	78.00	2			73.50	4		
15	79.80	5	66.22	9								
16	85.67	6	72.75	8					80.00	1		
17	77.00	5	69.71	7								
18	83.13	8	72.82	11					97.00	1		
19	90.50	4	69.00	5	88.00	1	78.50	2				
20	86.75	8	72.00	14	90.50	2	79.00	1				
21	91.56	9	68.00	5	87.67	3	70.00	1			73.00	1
22	91.30	10	74.13	8	94.00	1	77.00	2	94.50	2	73.00	1
23	93.88	8	70.71	7	92.50	4			80.50	2	88.00	1
24	90.56	9	73.00	7	100.00	1					82.00	1
25	89.92	13	69.50	6	89.00	2	71.00	1				
26	90.67	3	72.50	6	93.00	1	78.00	1	88.00	1		
27	90.50	4	71.86	7	83.00	2						
28	94.67	9	71.70	10	93.33	3					79.00	1
29	91.07	15	76.14	7					93.00	1	78.00	1
30	91.74	35	70.52	31	89.75	4	76.75	4	92.00	3		

Table 5.13(Cont.) Summary of the length-at-age information used for this BSAI Greenland turbot assessment (see Gregg et al. 2006 for methods).

	2011				2012			
	Females		Males		Females		Males	
Age	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N
1	16.44	9	16.10	21	14.18	17	13.45	22
2	23.74	76	23.10	90	23.28	40	22.48	44
3	32.18	33	32.09	44	32.08	49	31.30	60
4	37.06	16	36.87	15	36.77	31	36.72	25
5	41.65	17	41.78	9	42.35	23	40.87	23
6	46.17	6	45.33	3	46.00	13	47.43	7
7	46.50	2	0.00	0	54.80	5	53.00	3
8	57.00	1	55.50	2	47.50	2		
9	72.00	2	47.00	1				
10	65.00	2			69.50	2	66.00	1
11	68.67	3	69.00	1	74.00	3		
12			65.50	2	75.00	1		
13	71.50	4			77.00	1	68.00	1
14					80.00	1	56.00	1
15	77.00	1						
16								
17			66.00	1	75.00	2		
18	66.00	1			84.00	2		
19			73.00	1				
20	87.00	1	70.00	1	81.00	1	75.00	1
21	93.50	2						
22								
23					85.00	1		
24					100.00	1		
25	99.00	1						
26								
27	81.67	3			97.50	2		
28			76.00	1				
29	86.00	1						
30	96.00	1					76.00	2

Table 5.14. Starting multinomial sample sizes for size composition data by fishery and survey: Trawl = trawl fishery, Longline = longline fishery, Shelf = AFSC bottom trawl slope survey, Slope = AFSC bottom trawl slope survey, ABL Longline = ABL longline survey.

Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Trawl	50	50	50	50	50	50	50	50	50	50	50		50
Longline			50	50	50	50	50	50	50				
Shelf						200	200	200	200	200	200	200	200
Slope			25		25	25			25			25	
ABL Longline			60	60	60	60	60	60	60	60	60	60	60
Shelf-Age													

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Trawl	50	50			50	50	50		50	50	50	50	50
Longline				50	50	50	50	50	50	50	50	50	50
Shelf	200	200	200	200	200	200	200	200	200	200	200	200	200
Slope													100
ABL Longline	60	60	60	60	60		60	60	60	60	60	60	60
Shelf-Age									100				

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Trawl	50	50	50			50	50	50	50	50	50	50
Longline	50	50	50	50	50	50	50	50	50	50	50	50
Shelf	200	200	200	200	200	200	200	200	200	200	200	200
Slope		100				100		100		100		
ABL Longline	60	60	60	60	60	60	60	60	60	60	60	60
Shelf-Age	100	100	100	100	100	100	100	100	100	100		

Table 5.15. Candidate model likelihoods components, main parameters, and results. Please note that the likelihood components are not comparable across all models due to sample size tuning and differences in recruitment estimation.

		2013	Model 1	Model 2
Likelihoods				
	Total	2428.7	2156.78	2015.07
	Survey	-30.1	-44.52	-36.87
	Length Composition	1181.8	993.60	887.18
	Age Composition	140.8	72.85	71.08
	Size at Age	1015.2	1016.82	1023.58
	Recruitment	118.7	115.40	66.00
	Parameter priors	2.2	2.45	3.96
Parameters				
	$LN(R_0)$	9.23	9.19	9.67
	Steepness	0.79	0.79	0.79
	Natural Mortality	0.112	0.11	0.11
	q_{Shelf}	0.61	0.95	0.62
	q_{Slope}	0.61	0.65	0.57
	Mean q_{ABLL}	0.88	0.97	0.82
	L_{max} Female	87.53	88.07	88.14
	L_{max} Male	73.32	73.49	73.29
	Von Bert K Female	0.12	0.12	0.12
	Von Bert K Male	0.16	0.17	0.17
Results				
Model				
	SSB_{1978} (t)	299,238	244,962	247,240
	SSB_{2011} (t)	23,797	23,599	25,258
Projection				
	$SSB_{100\%}$ (t)	99,464	90,578	130,123
	SSB_{2014} (t)		20,825	26,341
	$SSB_{2014\%}$		23%	20%
	SSB_{2015} (t)		23,437	30,853
	$SSB_{2015\%}$		26%	24%
2015				
	ABC (t)		2,924	3,172
	F_{ABC}		0.13	0.10
	OFL (t)		3,611	3,903
	F_{OFL}		0.16	0.12
2016				
	ABC (t)		4,179	5,248
	F_{ABC}		0.15	0.13
	OFL (t)		5,158	6,453
	F_{OFL}		0.19	0.16

Table 5.16. Model index RMSE, tuning diagnostics, and recruitment variability for candidate models.

		2013	Model 1	Model 2
Retrospective				
	Rho	NA	0.62	0.32
Index RMSE				
	Shelf	0.24	0.22	0.25
	Slope	0.20	0.20	0.23
	ABL Longline	0.40	0.37	0.39
Size Comp				
Mean EffN	Trawl	56.9	60.1	64.3
	Longline	66.4	66.9	68.7
	Shelf	82.1	97.2	98.4
	Slope	39.2	44.0	41.4
	ABL Longline	35.9	43.3	41.9
Mean input N	Trawl	55.0	30.0	30.0
	Longline	65.4	43.5	43.5
	Shelf	90	46.0	46.0
	Slope	40	26.6	26.6
	ABL Longline	36	30.0	30.0
Age Comp				
	Mean EffN	52.0	74.8	84.8
	Mean input N	50.0	30.0	30.0
Rec. Var. (1975-2014)				
	Std.dev(ln(No. Age 1))	1.48	1.48	1.41

Table 5.17. Age-equivalent sex-specific selectivity estimates (as estimated for 2014) from each gear type for Greenland turbot in the BSAI. Note that selectivity processes are modeled as a function of size and that some selectivities-at-length are allowed to vary over time.

	Trawl Fishery		Longline fishery	
Age	Female	Male	Female	Male
1	0.0067	0.0067	0.0000	0.0000
2	0.0067	0.0067	0.0000	0.0000
3	0.0068	0.0069	0.0000	0.0000
4	0.0091	0.0103	0.0000	0.0000
5	0.0262	0.0302	0.0005	0.0015
6	0.0782	0.0845	0.0089	0.0189
7	0.1653	0.1748	0.0528	0.0722
8	0.2622	0.2842	0.1538	0.1543
9	0.3422	0.3916	0.2961	0.2426
10	0.3928	0.4831	0.4463	0.3215
11	0.4145	0.5535	0.5803	0.3857
12	0.4139	0.6039	0.6886	0.4358
13	0.3986	0.6380	0.7714	0.4742
14	0.3750	0.6601	0.8328	0.5036
15	0.3477	0.6738	0.8777	0.5262
16	0.3196	0.6819	0.9104	0.5439
17	0.2924	0.6867	0.9341	0.5578
18	0.2669	0.6894	0.9514	0.5689
19	0.2436	0.6912	0.9641	0.5780
20	0.2226	0.6927	0.9734	0.5854
21	0.2037	0.6942	0.9803	0.5917
22	0.1868	0.6961	0.9854	0.5969
23	0.1718	0.6985	0.9892	0.6014
24	0.1583	0.7015	0.9920	0.6052
25	0.1473	0.7004	0.9937	0.6075
26	0.1388	0.6952	0.9944	0.6083
27	0.1315	0.6908	0.9951	0.6091
28	0.1252	0.6869	0.9956	0.6097
29	0.1198	0.6836	0.9959	0.6101
30	0.1099	0.6784	0.9966	0.6109

Table 5.18. Time series of age-0 recruits (number in 1,000s) with lower (LCI) and upper (UCI) 95% confidence intervals for 1960-2013.

Year	Age-0 Recruits	LCI	UCI	Year	Age-0 Recruits	LCI	UCI
1960	32,702	0	73,133	1994	1,387	575	2,200
1961	46,216	0	105,037	1995	4,421	2,787	6,054
1962	75,901	0	174,744	1996	3,145	1,791	4,499
1963	144,350	0	326,279	1997	2,493	1,275	3,710
1964	270,369	0	549,846	1998	3,528	1,860	5,197
1965	292,952	0	593,575	1999	9,220	6,310	12,130
1966	157,988	0	348,680	2000	9,834	6,858	12,809
1967	74,489	0	162,219	2001	10,224	7,524	12,924
1968	40,951	0	86,176	2002	1,871	933	2,810
1969	27,641	0	56,433	2003	765	308	1,221
1970	22,663	286	45,040	2004	744	292	1,196
1971	22,221	1,578	42,864	2005	1,439	660	2,218
1972	26,072	3,824	48,320	2006	9,624	6,577	12,672
1973	37,953	9,374	66,532	2007	16,093	10,854	21,332
1974	71,149	25,779	116,519	2008	43,422	30,894	55,950
1975	148,799	83,338	214,262	2009	84,588	61,615	107,561
1976	95,454	43,118	147,790	2010	17,084	8,757	25,411
1977	84,864	37,314	132,414	2011	9,993	4,060	15,926
1978	75,799	35,970	115,628	2012	7,094	1,861	12,327
1979	19,166	5,492	32,840	2013	8,937	1,276	16,598
1980	9,265	1,938	16,591	2014	12,629	0	27,802
1981	5,900	1,184	10,617				
1982	4,568	1,054	8,081	**1977-2013 Average 13,853**			
1983	4,510	1,334	7,686				
1984	6,804	2,675	10,933				
1985	17,979	12,277	23,681				
1986	4,972	2,562	7,382				
1987	5,214	2,944	7,483				
1988	5,334	2,969	7,698				
1989	14,471	10,494	18,448				
1990	4,458	2,263	6,653				
1991	1,454	556	2,352				
1992	1,035	373	1,697				
1993	874	307	1,441				

Table 5.19. Estimated beginning of year numbers (1×10^7) of Greenland turbot by age and sex.

Females

Yr	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1977	4.24	4.27	5.89	2.43	1.07	0.59	0.38	0.29	0.26	0.28	0.37	0.57	0.76	0.51	0.20	0.07	0.03	0.01	0.01	0.00	0.01
1978	3.79	3.79	3.79	5.16	2.08	0.90	0.48	0.31	0.23	0.20	0.21	0.28	0.43	0.57	0.38	0.15	0.05	0.02	0.01	0.01	0.01
1979	0.96	3.39	3.37	3.30	4.36	1.70	0.71	0.37	0.23	0.17	0.14	0.15	0.20	0.29	0.39	0.26	0.10	0.04	0.02	0.01	0.01
1980	0.46	0.86	3.01	2.93	2.79	3.56	1.34	0.54	0.27	0.17	0.12	0.10	0.10	0.13	0.20	0.26	0.17	0.07	0.02	0.01	0.01
1981	0.30	0.41	0.76	2.59	2.43	2.21	2.70	0.98	0.38	0.19	0.11	0.08	0.06	0.07	0.08	0.12	0.16	0.11	0.04	0.01	0.01
1982	0.23	0.26	0.37	0.65	2.13	1.89	1.64	1.91	0.66	0.25	0.12	0.07	0.05	0.04	0.04	0.05	0.07	0.09	0.06	0.02	0.02
1983	0.23	0.20	0.23	0.31	0.53	1.65	1.39	1.15	1.28	0.43	0.16	0.07	0.04	0.03	0.02	0.02	0.03	0.04	0.05	0.04	0.02
1984	0.34	0.20	0.18	0.20	0.26	0.41	1.22	0.98	0.77	0.84	0.27	0.10	0.04	0.03	0.02	0.01	0.01	0.02	0.02	0.03	0.03
1985	0.90	0.30	0.18	0.16	0.17	0.21	0.33	0.96	0.76	0.59	0.63	0.20	0.07	0.03	0.02	0.01	0.01	0.01	0.01	0.02	0.05
1986	0.25	0.80	0.27	0.16	0.14	0.15	0.18	0.28	0.78	0.61	0.47	0.50	0.16	0.06	0.03	0.01	0.01	0.01	0.01	0.01	0.05
1987	0.26	0.22	0.72	0.24	0.14	0.12	0.12	0.15	0.23	0.65	0.50	0.39	0.41	0.13	0.05	0.02	0.01	0.01	0.01	0.01	0.05
1988	0.27	0.23	0.20	0.63	0.21	0.12	0.10	0.11	0.13	0.19	0.54	0.42	0.32	0.33	0.11	0.04	0.02	0.01	0.01	0.00	0.04
1989	0.72	0.24	0.21	0.18	0.56	0.18	0.10	0.09	0.09	0.11	0.16	0.45	0.35	0.27	0.28	0.09	0.03	0.01	0.01	0.01	0.04
1990	0.22	0.65	0.21	0.19	0.16	0.50	0.16	0.09	0.08	0.08	0.09	0.14	0.38	0.29	0.22	0.23	0.07	0.03	0.01	0.01	0.04
1991	0.07	0.20	0.58	0.19	0.17	0.14	0.45	0.15	0.08	0.07	0.06	0.07	0.11	0.30	0.23	0.17	0.18	0.06	0.02	0.01	0.04
1992	0.05	0.06	0.18	0.52	0.17	0.15	0.13	0.40	0.13	0.07	0.06	0.05	0.06	0.09	0.25	0.19	0.14	0.15	0.05	0.02	0.04
1993	0.04	0.05	0.06	0.16	0.46	0.15	0.13	0.11	0.35	0.11	0.06	0.05	0.05	0.06	0.08	0.22	0.17	0.13	0.13	0.04	0.05
1994	0.07	0.04	0.04	0.05	0.14	0.41	0.14	0.12	0.10	0.31	0.10	0.05	0.04	0.04	0.05	0.07	0.19	0.14	0.11	0.11	0.08
1995	0.22	0.06	0.03	0.04	0.05	0.13	0.37	0.12	0.10	0.09	0.26	0.08	0.04	0.03	0.03	0.04	0.06	0.15	0.11	0.09	0.15
1996	0.16	0.20	0.06	0.03	0.03	0.04	0.11	0.33	0.11	0.09	0.07	0.22	0.07	0.04	0.03	0.03	0.03	0.05	0.12	0.09	0.20
1997	0.12	0.14	0.18	0.05	0.03	0.03	0.04	0.10	0.29	0.09	0.08	0.06	0.19	0.06	0.03	0.02	0.02	0.03	0.04	0.10	0.25
1998	0.18	0.11	0.13	0.16	0.04	0.02	0.03	0.03	0.09	0.26	0.08	0.07	0.05	0.16	0.05	0.03	0.02	0.02	0.02	0.03	0.30
1999	0.46	0.16	0.10	0.11	0.14	0.04	0.02	0.02	0.03	0.08	0.22	0.07	0.06	0.05	0.14	0.04	0.02	0.02	0.02	0.02	0.27
2000	0.49	0.41	0.14	0.09	0.10	0.13	0.04	0.02	0.02	0.03	0.07	0.19	0.06	0.05	0.04	0.11	0.04	0.02	0.01	0.01	0.24
2001	0.51	0.44	0.37	0.13	0.08	0.09	0.11	0.03	0.02	0.02	0.02	0.06	0.16	0.05	0.04	0.03	0.09	0.03	0.02	0.01	0.21
2002	0.09	0.46	0.39	0.33	0.11	0.07	0.08	0.10	0.03	0.02	0.02	0.02	0.05	0.13	0.04	0.03	0.03	0.08	0.02	0.01	0.18
2003	0.04	0.08	0.41	0.35	0.29	0.10	0.06	0.07	0.09	0.02	0.01	0.01	0.02	0.04	0.11	0.03	0.03	0.02	0.07	0.02	0.16
2004	0.04	0.03	0.07	0.37	0.31	0.26	0.09	0.06	0.06	0.08	0.02	0.01	0.01	0.01	0.03	0.09	0.03	0.02	0.02	0.06	0.16
2005	0.07	0.03	0.03	0.07	0.33	0.28	0.23	0.08	0.05	0.06	0.07	0.02	0.01	0.01	0.01	0.03	0.08	0.03	0.02	0.02	0.18
2006	0.48	0.06	0.03	0.03	0.06	0.29	0.25	0.21	0.07	0.04	0.05	0.06	0.02	0.01	0.01	0.01	0.03	0.07	0.02	0.02	0.17
2007	0.80	0.43	0.06	0.03	0.02	0.05	0.26	0.22	0.19	0.06	0.04	0.04	0.05	0.01	0.01	0.01	0.01	0.02	0.06	0.02	0.16
2008	2.17	0.72	0.38	0.05	0.02	0.02	0.05	0.23	0.20	0.16	0.06	0.03	0.04	0.04	0.01	0.01	0.01	0.01	0.02	0.05	0.15
2009	4.23	1.94	0.64	0.34	0.05	0.02	0.02	0.04	0.20	0.17	0.14	0.05	0.03	0.03	0.04	0.01	0.01	0.01	0.01	0.02	0.17
2010	0.85	3.78	1.73	0.57	0.31	0.04	0.02	0.02	0.04	0.17	0.14	0.12	0.04	0.02	0.02	0.03	0.01	0.00	0.00	0.00	0.14
2011	0.50	0.76	3.38	1.55	0.51	0.27	0.04	0.02	0.01	0.03	0.15	0.12	0.09	0.03	0.02	0.02	0.02	0.01	0.00	0.00	0.12
2012	0.35	0.45	0.68	3.02	1.38	0.46	0.24	0.03	0.01	0.01	0.03	0.12	0.10	0.08	0.03	0.02	0.02	0.02	0.01	0.00	0.10
2013	0.45	0.32	0.40	0.61	2.70	1.24	0.41	0.22	0.03	0.01	0.01	0.02	0.10	0.08	0.06	0.02	0.01	0.01	0.01	0.00	0.08
2014	0.63	0.40	0.28	0.36	0.54	2.41	1.10	0.36	0.19	0.02	0.01	0.01	0.02	0.08	0.07	0.05	0.02	0.01	0.01	0.01	0.07

Table 5.19 (cont.) Estimated beginning of year numbers (1×10^7) of Greenland turbot by age and sex.

Males

Yr	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1977	4.24	4.27	5.85	2.38	1.05	0.59	0.41	0.33	0.34	0.41	0.63	1.12	1.73	1.34	0.60	0.26	0.12	0.07	0.04	0.03	0.21
1978	3.79	3.79	3.78	5.09	2.04	0.89	0.49	0.34	0.28	0.28	0.35	0.53	0.94	1.45	1.12	0.50	0.21	0.10	0.06	0.04	0.20
1979	0.96	3.39	3.35	3.26	4.29	1.69	0.73	0.40	0.28	0.23	0.23	0.28	0.43	0.76	1.17	0.91	0.40	0.17	0.08	0.05	0.19
1980	0.46	0.86	2.99	2.89	2.74	3.55	1.39	0.60	0.33	0.23	0.19	0.19	0.23	0.35	0.61	0.95	0.73	0.33	0.14	0.07	0.20
1981	0.30	0.41	0.75	2.55	2.39	2.22	2.84	1.10	0.47	0.26	0.18	0.15	0.15	0.18	0.27	0.48	0.74	0.57	0.25	0.11	0.21
1982	0.23	0.26	0.36	0.64	2.08	1.90	1.74	2.21	0.86	0.37	0.20	0.14	0.11	0.11	0.14	0.21	0.37	0.57	0.44	0.20	0.25
1983	0.23	0.20	0.23	0.31	0.52	1.65	1.48	1.35	1.71	0.66	0.28	0.16	0.11	0.09	0.09	0.11	0.16	0.28	0.44	0.34	0.35
1984	0.34	0.20	0.18	0.20	0.25	0.41	1.29	1.15	1.05	1.33	0.51	0.22	0.12	0.08	0.07	0.07	0.08	0.13	0.22	0.35	0.55
1985	0.90	0.30	0.18	0.16	0.17	0.21	0.34	1.08	0.96	0.87	1.10	0.43	0.18	0.10	0.07	0.06	0.06	0.07	0.10	0.19	0.75
1986	0.25	0.80	0.27	0.16	0.13	0.14	0.18	0.29	0.92	0.82	0.74	0.94	0.36	0.16	0.09	0.06	0.05	0.05	0.06	0.09	0.80
1987	0.26	0.22	0.72	0.24	0.14	0.12	0.12	0.16	0.25	0.79	0.71	0.64	0.81	0.31	0.13	0.07	0.05	0.04	0.04	0.05	0.77
1988	0.27	0.23	0.20	0.63	0.21	0.12	0.10	0.11	0.14	0.22	0.69	0.61	0.56	0.70	0.27	0.12	0.06	0.04	0.04	0.04	0.72
1989	0.72	0.24	0.21	0.18	0.56	0.18	0.10	0.09	0.09	0.12	0.19	0.60	0.53	0.49	0.61	0.24	0.10	0.06	0.04	0.03	0.66
1990	0.22	0.65	0.21	0.19	0.16	0.50	0.16	0.09	0.08	0.08	0.10	0.17	0.52	0.46	0.42	0.53	0.20	0.09	0.05	0.03	0.60
1991	0.07	0.20	0.58	0.19	0.17	0.14	0.44	0.15	0.08	0.07	0.07	0.09	0.14	0.43	0.38	0.35	0.44	0.17	0.07	0.04	0.54
1992	0.05	0.06	0.18	0.52	0.17	0.15	0.12	0.40	0.13	0.07	0.06	0.06	0.07	0.12	0.37	0.33	0.30	0.38	0.15	0.06	0.50
1993	0.04	0.05	0.06	0.16	0.46	0.15	0.13	0.11	0.35	0.11	0.06	0.05	0.05	0.07	0.10	0.32	0.29	0.26	0.33	0.13	0.49
1994	0.07	0.04	0.04	0.05	0.14	0.41	0.14	0.12	0.10	0.31	0.10	0.06	0.05	0.05	0.06	0.09	0.27	0.24	0.22	0.28	0.52
1995	0.22	0.06	0.03	0.04	0.05	0.13	0.37	0.12	0.10	0.09	0.27	0.09	0.05	0.04	0.04	0.05	0.07	0.23	0.20	0.18	0.67
1996	0.16	0.20	0.06	0.03	0.03	0.04	0.11	0.33	0.11	0.09	0.07	0.23	0.07	0.04	0.03	0.03	0.04	0.06	0.19	0.17	0.72
1997	0.12	0.14	0.18	0.05	0.03	0.03	0.04	0.10	0.29	0.09	0.08	0.07	0.20	0.06	0.03	0.03	0.03	0.03	0.05	0.16	0.75
1998	0.18	0.11	0.13	0.16	0.04	0.02	0.03	0.03	0.09	0.26	0.08	0.07	0.06	0.17	0.05	0.03	0.02	0.02	0.03	0.04	0.76
1999	0.46	0.16	0.10	0.11	0.14	0.04	0.02	0.02	0.03	0.08	0.22	0.07	0.06	0.05	0.14	0.04	0.02	0.02	0.02	0.02	0.65
2000	0.49	0.41	0.14	0.09	0.10	0.13	0.04	0.02	0.02	0.03	0.07	0.19	0.06	0.05	0.04	0.12	0.04	0.02	0.02	0.02	0.56
2001	0.51	0.44	0.37	0.13	0.08	0.09	0.11	0.03	0.02	0.02	0.02	0.06	0.16	0.05	0.04	0.03	0.10	0.03	0.02	0.01	0.47
2002	0.09	0.46	0.39	0.33	0.11	0.07	0.08	0.10	0.03	0.02	0.02	0.02	0.05	0.14	0.04	0.03	0.03	0.08	0.03	0.01	0.40
2003	0.04	0.08	0.41	0.35	0.29	0.10	0.06	0.07	0.09	0.02	0.01	0.01	0.02	0.04	0.12	0.04	0.03	0.02	0.07	0.02	0.35
2004	0.04	0.03	0.07	0.37	0.31	0.26	0.09	0.06	0.06	0.08	0.02	0.01	0.01	0.01	0.04	0.10	0.03	0.03	0.02	0.06	0.32
2005	0.07	0.03	0.03	0.07	0.33	0.28	0.23	0.08	0.05	0.06	0.07	0.02	0.01	0.01	0.01	0.03	0.09	0.03	0.02	0.02	0.32
2006	0.48	0.06	0.03	0.03	0.06	0.29	0.25	0.21	0.07	0.04	0.05	0.06	0.02	0.01	0.01	0.01	0.03	0.07	0.02	0.02	0.29
2007	0.80	0.43	0.06	0.03	0.02	0.05	0.26	0.22	0.19	0.06	0.04	0.04	0.05	0.01	0.01	0.01	0.01	0.02	0.06	0.02	0.26
2008	2.17	0.72	0.38	0.05	0.02	0.02	0.05	0.23	0.20	0.16	0.06	0.03	0.04	0.05	0.01	0.01	0.01	0.01	0.02	0.05	0.24
2009	4.23	1.94	0.64	0.34	0.05	0.02	0.02	0.04	0.20	0.17	0.14	0.05	0.03	0.03	0.04	0.01	0.01	0.01	0.01	0.02	0.25
2010	0.85	3.78	1.73	0.57	0.31	0.04	0.02	0.02	0.04	0.17	0.14	0.12	0.04	0.02	0.03	0.03	0.01	0.00	0.00	0.01	0.22
2011	0.50	0.76	3.38	1.55	0.51	0.27	0.04	0.02	0.02	0.03	0.15	0.12	0.10	0.03	0.02	0.02	0.03	0.01	0.00	0.00	0.19
2012	0.35	0.45	0.68	3.02	1.38	0.46	0.24	0.03	0.01	0.01	0.03	0.12	0.10	0.08	0.03	0.02	0.02	0.02	0.01	0.00	0.16
2013	0.45	0.32	0.40	0.61	2.70	1.24	0.41	0.22	0.03	0.01	0.01	0.02	0.10	0.08	0.06	0.02	0.01	0.01	0.02	0.00	0.13
2014	0.63	0.40	0.28	0.36	0.54	2.41	1.10	0.36	0.19	0.02	0.01	0.01	0.02	0.08	0.07	0.05	0.02	0.01	0.01	0.01	0.12

Table 5.20. Total harvest rate (catch / mid-year biomass), spawning and total biomass (compared with the 2013 assessment) for BSAI Greenland turbot, 1960-2015. 2015 through 2016 biomass estimates are from the projection Model 2.

				Female Spawning Biomass		Total Age 1+ Biomass	
Year	Apical Fishing Mortality	Total Exploitation	1-SPR.	2013 Assessment	Current Assessment	2013 Assessment	Current Assessment
1960	0.24	0.11	0.65	94,542	134,275	171,303	257,656
1961	0.46	0.18	0.84	84,439	126,605	145,232	233,366
1962	0.62	0.22	0.90	66,012	112,539	104,428	195,418
1963	0.42	0.15	0.82	43,627	95,852	80,997	159,072
1964	0.53	0.18	0.87	30,276	86,168	87,245	146,472
1965	0.16	0.05	0.51	21,712	75,566	155,246	139,513
1966	0.17	0.06	0.54	22,831	73,863	271,766	163,601
1967	0.25	0.09	0.66	36,679	73,211	401,567	205,919
1968	0.27	0.10	0.69	84,536	73,594	520,367	263,098
1969	0.21	0.08	0.60	166,810	78,183	614,757	327,237
1970	0.12	0.05	0.42	258,212	92,317	685,939	394,907
1971	0.21	0.09	0.60	338,662	120,946	740,738	465,396
1972	0.36	0.15	0.77	389,705	157,786	751,827	503,964
1973	0.30	0.13	0.72	404,040	190,005	708,598	492,326
1974	0.39	0.16	0.80	403,455	218,715	662,466	476,651
1975	0.38	0.16	0.79	381,524	230,249	591,356	433,886
1976	0.41	0.16	0.81	353,243	230,809	527,117	393,101
1977	0.22	0.09	0.62	319,958	220,707	465,802	354,323
1978	0.32	0.12	0.74	299,238	216,994	446,800	351,340
1979	0.33	0.12	0.74	270,484	202,766	423,287	342,498
1980	0.43	0.16	0.82	244,497	187,714	403,625	338,430
1981	0.50	0.18	0.85	220,159	170,056	376,333	324,898
1982	0.48	0.17	0.85	200,503	154,920	343,016	303,115
1983	0.47	0.17	0.85	186,598	146,680	310,985	279,206
1984	0.24	0.09	0.65	173,834	140,905	278,406	252,111
1985	0.16	0.06	0.51	171,526	144,250	265,156	242,469
1986	0.11	0.04	0.39	171,281	149,145	256,367	236,353
1987	0.11	0.04	0.39	170,794	153,092	249,175	231,233
1988	0.08	0.03	0.32	167,626	153,590	240,154	223,876
1989	0.15	0.04	0.32	163,217	151,975	231,629	216,911
1990	0.25	0.06	0.45	155,369	146,043	219,865	206,711
1991	0.15	0.04	0.35	144,028	135,926	202,935	191,342
1992	0.04	0.02	0.20	135,669	127,908	191,211	180,666
1993	0.09	0.05	0.37	128,585	122,021	182,668	174,067
1994	0.22	0.06	0.46	117,791	112,379	169,462	162,668
1995	0.17	0.06	0.42	106,737	102,350	153,775	148,580
1996	0.11	0.05	0.37	97,356	93,809	140,300	136,386
1997	0.11	0.06	0.41	89,119	86,418	128,653	125,728
1998	0.15	0.08	0.48	80,376	78,581	116,596	114,551
1999	0.13	0.06	0.41	70,611	69,676	103,361	102,184
2000	0.17	0.08	0.48	63,302	62,993	93,242	92,879
2001	0.17	0.06	0.45	55,378	55,516	82,613	83,051
2002	0.11	0.05	0.37	49,071	49,540	74,315	75,638
2003	0.11	0.04	0.36	44,131	44,875	68,560	70,934
2004	0.09	0.03	0.31	39,615	40,923	63,713	67,760
2005	0.10	0.04	0.35	36,640	38,006	60,709	66,010
2006	0.07	0.03	0.31	33,872	35,446	57,441	64,081
2007	0.07	0.03	0.32	32,136	34,051	54,983	62,749
2008	0.13	0.05	0.42	30,806	33,315	52,666	61,342
2009	0.21	0.08	0.55	29,176	32,612	49,983	59,651
2010	0.17	0.07	0.54	26,531	30,921	47,577	58,390
2011	0.16	0.06	0.52	23,797	28,835	48,189	60,747
2012	0.23	0.07	0.62	21,647	26,865	54,380	69,331
2013	0.09	0.02	0.35	20,006	24,931	72,376	80,929
2014	0.08	0.02	0.33	22,010	26,342	84,546	97,442
2015				27,624	**30,853**	96,298	**122,298**
2016					**38,848**		**132,666**

Table 5.21. Spawning biomass with lower (LCI) and upper (UCI) 95% confidence intervals for 1977-2015 for BSAI Greenland turbot. Confidence bounds are based on 1.96×standard error. 2015 values are from the production model.

Year	Spawning Biomass	LCI	UCI
1977	220,710	177,974	263,446
1978	216,990	177,884	256,096
1979	202,770	166,822	238,718
1980	187,710	154,537	220,883
1981	170,060	139,541	200,579
1982	154,920	126,745	183,095
1983	146,680	120,371	172,989
1984	140,910	116,136	165,684
1985	144,250	120,559	167,941
1986	149,150	126,547	171,753
1987	153,090	131,624	174,556
1988	153,590	133,326	173,854
1989	151,970	132,904	171,036
1990	146,040	128,280	163,800
1991	135,930	119,510	152,350
1992	127,910	112,723	143,097
1993	122,020	107,986	136,054
1994	112,380	99,479	125,281
1995	102,350	90,550	114,150
1996	93,809	82,983	104,635
1997	86,418	76,454	96,382
1998	78,581	69,398	87,764
1999	69,676	61,209	78,143
2000	62,993	55,165	70,821
2001	55,516	48,274	62,758
2002	49,540	42,822	56,258
2003	44,875	38,630	51,120
2004	40,923	35,104	46,742
2005	38,006	32,556	43,456
2006	35,446	30,307	40,585
2007	34,051	29,153	38,949
2008	33,315	28,598	38,032
2009	32,612	28,035	37,189
2010	30,921	26,456	35,386
2011	28,835	24,489	33,181
2012	26,865	22,634	31,096
2013	24,931	20,756	29,106
2014	26,342	22,097	30,587
2015	30,853	26,111	35,595

Table 5.22. Age and sex-specific mean length and weights-at-age estimates for BSAI Greenland turbot from the 2013 stock assessment (Barbeaux et al. 2013) and for the 2014 Model 2.

	Mid-year length (cm)				Mid-year weight (kg)			
	2013 Reference		2014 Model 2		2013 Reference		2014 Model 2	
Age	Females	Males	Females	Males	Females	Males	Females	Males
1	14.29	14.16	14.19	13.84	0.02	0.02	0.02	0.02
2	22.06	22.21	22.13	22.27	0.08	0.08	0.08	0.08
3	29.87	30.02	30.11	30.44	0.21	0.21	0.22	0.22
4	36.82	36.67	37.20	37.33	0.42	0.40	0.44	0.42
5	42.99	42.33	43.48	43.15	0.71	0.63	0.73	0.67
6	48.48	47.15	49.06	48.06	1.05	0.89	1.09	0.94
7	53.36	51.25	54.00	52.21	1.44	1.16	1.50	1.23
8	57.71	54.74	58.39	55.71	1.87	1.43	1.94	1.51
9	61.57	57.72	62.28	58.66	2.31	1.69	2.40	1.77
10	65.00	60.25	65.74	61.16	2.76	1.93	2.86	2.02
11	68.05	62.40	68.80	63.26	3.21	2.16	3.32	2.25
12	70.77	64.23	71.51	65.04	3.66	2.37	3.77	2.46
13	73.18	65.79	73.92	66.53	4.08	2.55	4.19	2.64
14	75.33	67.12	76.06	67.80	4.49	2.72	4.60	2.80
15	77.23	68.25	77.96	68.87	4.88	2.86	4.98	2.94
16	78.93	69.22	79.64	69.77	5.24	2.99	5.33	3.06
17	80.44	70.04	81.13	70.53	5.57	3.10	5.65	3.16
18	81.78	70.73	82.45	71.17	5.87	3.20	5.94	3.24
19	82.97	71.33	83.63	71.71	6.16	3.28	6.21	3.32
20	84.03	71.83	84.67	72.17	6.41	3.35	6.45	3.38
21	84.98	72.26	85.59	72.56	6.64	3.41	6.66	3.43
22	85.82	72.63	86.41	72.88	6.85	3.46	6.86	3.48
23	86.56	72.94	87.14	73.16	7.04	3.50	7.03	3.51
24	87.22	73.21	87.78	73.39	7.21	3.53	7.19	3.54
25	87.81	73.43	88.35	73.59	7.37	3.57	7.33	3.57
26	88.34	73.63	88.86	73.75	7.51	3.60	7.46	3.60
27	88.80	73.79	89.31	73.89	7.64	3.62	7.57	3.62
28	89.22	73.93	89.71	74.01	7.75	3.65	7.67	3.64
29	89.59	74.05	90.06	74.11	7.85	3.66	7.76	3.65
30	90.31	74.23	90.74	74.26	8.05	3.69	7.92	3.68

Table 5.23. Estimated total Greenland turbot harvest by area, 1977-2014. *Values for 2014 are through Oct. 23th, 2014 and are preliminary.

Year	EBS	Aleutians	Year	EBS	Aleutians
1977	27,708	2,453	1996	4,844	1,712
1978	37,423	4,766	1997	6,435	764
1979	34,998	6,411	1998	8,075	682
1980	48,856	3,697	1999	5,386	467
1981	52,921	4,400	2000	5,888	1,086
1982	45,805	6,317	2001	4,253	1,060
1983	43,443	4,115	2002	3,151	485
1984	21,317	1,803	2003	2,412	700
1985	14,698	33	2004	1,825	434
1986	7,710	2,154	2005	2,140	468
1987	6,519	3,066	2006	1,453	537
1988	6,064	1,044	2007	1,481	523
1989	4,061	4,761	2008	2,089	822
1990	7,702	2,494	2009	2,252	2,263
1991	4,398	3,465	2010	2,273	1,872
1992	2,462	1,290	2011	3,120	532
1993	6,332	2,137	2012	3,062	1,658
1994	7,143	3,131	2013	1,449	296
1995	5,856	2,338	2014*	1,469	177

Table 5.24. Mean spawning biomass (t), F, and yield projections (t) for Greenland turbot, 2014-2027. The full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed to be **50:50**.

SSB	Max F_{abc}	F_{abc}	5-year avg.	$F_{75\%}$	No Fishing	Scenario 6	Scenario 7
2014	26,341	26,341	26,341	26,341	26,341	26,341	26,341
2015	30,853	30,853	30,853	30,853	30,853	30,853	30,853
2016	38,848	38,848	39,894	39,798	40,450	38,484	38,848
2017	48,759	48,759	51,460	51,255	52,667	47,934	48,759
2018	57,448	57,448	63,012	62,665	65,079	55,956	56,628
2019	63,131	63,131	72,723	72,187	75,947	60,660	61,247
2020	65,600	65,600	80,020	79,246	84,701	62,026	62,528
2021	65,630	65,630	85,248	84,205	91,615	60,976	61,397
2022	64,327	64,327	89,019	87,693	97,190	58,751	59,098
2023	62,568	62,568	91,848	90,244	101,844	56,298	56,580
2024	60,845	60,845	94,062	92,195	105,828	54,189	54,402
2025	59,361	59,361	95,823	93,715	109,264	52,740	52,895
2026	58,266	58,266	97,233	94,908	112,231	51,817	51,930
2027	57,526	57,526	98,385	95,866	114,818	51,269	51,350
F							
2014	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2015	0.10	0.10	0.03	0.04	0.00	0.12	0.10
2016	0.13	0.13	0.03	0.04	0.00	0.16	0.13
2017	0.16	0.16	0.03	0.04	0.00	0.20	0.20
2018	0.18	0.18	0.03	0.04	0.00	0.22	0.22
2019	0.18	0.18	0.03	0.04	0.00	0.22	0.22
2020	0.18	0.18	0.03	0.04	0.00	0.22	0.22
2021	0.18	0.18	0.03	0.04	0.00	0.22	0.22
2022	0.18	0.18	0.03	0.04	0.00	0.22	0.22
2023	0.18	0.18	0.03	0.04	0.00	0.22	0.22
2024	0.18	0.18	0.03	0.04	0.00	0.20	0.21
2025	0.17	0.17	0.03	0.04	0.00	0.20	0.20
2026	0.16	0.16	0.03	0.04	0.00	0.19	0.19
2027	0.16	0.16	0.03	0.04	0.00	0.18	0.18
Catch							
2014	1,805	1,805	1,805	1,805	1,805	1,805	1,805
2015	3,172	3,172	1,096	1,284	0	3,903	3,172
2016	5,248	5,248	1,453	1,699	0	6,335	5,248
2017	8,639	8,639	1,938	2,263	0	10,267	10,610
2018	11,192	11,192	2,439	2,844	0	13,403	13,549
2019	12,495	12,495	2,860	3,329	0	14,756	14,886
2020	13,053	13,053	3,164	3,673	0	15,168	15,281
2021	13,045	13,045	3,362	3,894	0	14,901	14,997
2022	12,741	12,741	3,489	4,030	0	14,318	14,397
2023	12,352	12,352	3,574	4,118	0	13,548	13,637
2024	11,947	11,947	3,637	4,182	0	12,535	12,609
2025	11,402	11,402	3,687	4,230	0	11,823	11,876
2026	10,961	10,961	3,727	4,269	0	11,382	11,419
2027	10,655	10,655	3,760	4,301	0	11,128	11,154

Figures

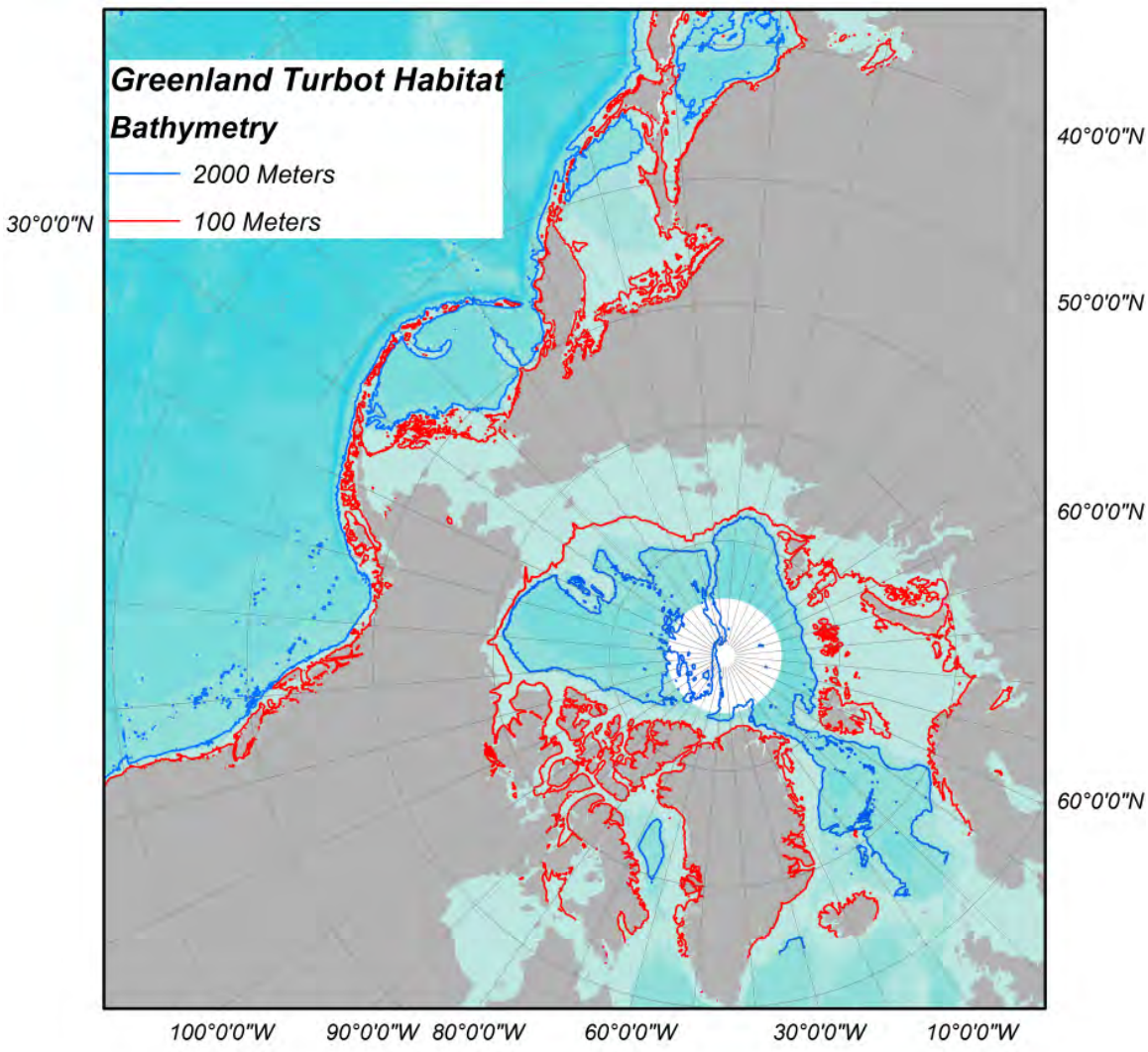
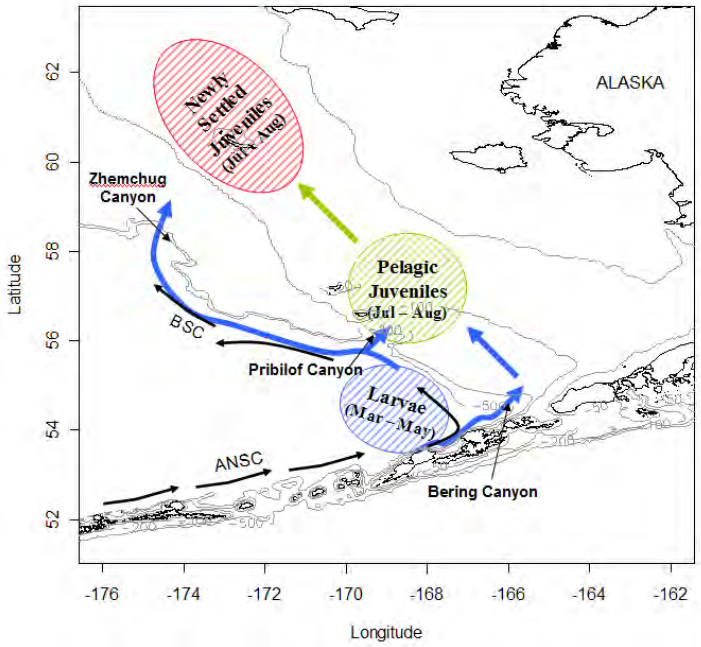


Figure 5.1. Map of the northern oceans with bathymetry at 100 meters (red) and 2000 meters (blue), between which is possible Greenland turbot habitat.

(a)



(b)

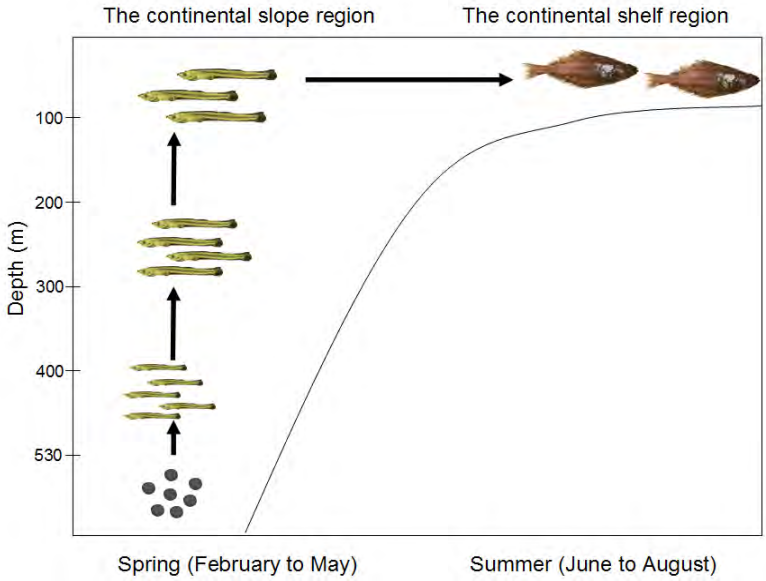


Figure 5.2. Schematic representation of Greenland turbot distribution and connectivity from larvae to settled juveniles. (a) Horizontally changed distribution through different life history stages (Blue circle: slope spawning ground, Green circle: shelf nursery ground of pelagic juveniles, Red circle: settlement ground). Blue arrows: possible larval transport routes from slope to shelf. (b) Vertically changed distribution as they develop. ***Source: Sohn (2009).***

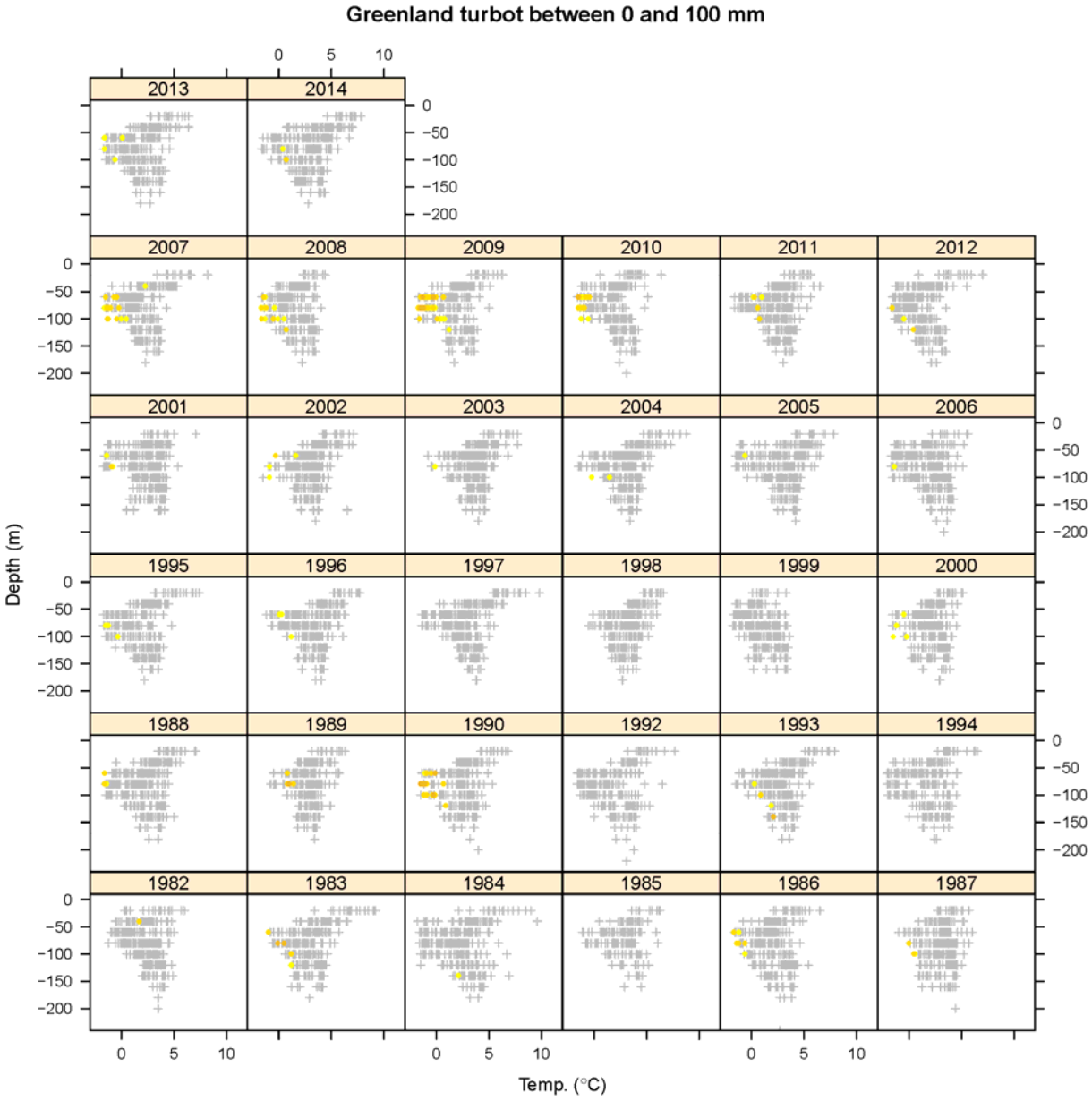


Figure 5.3. Greenland turbot (0-100 mm) density distribution by temperature and depth (left) for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

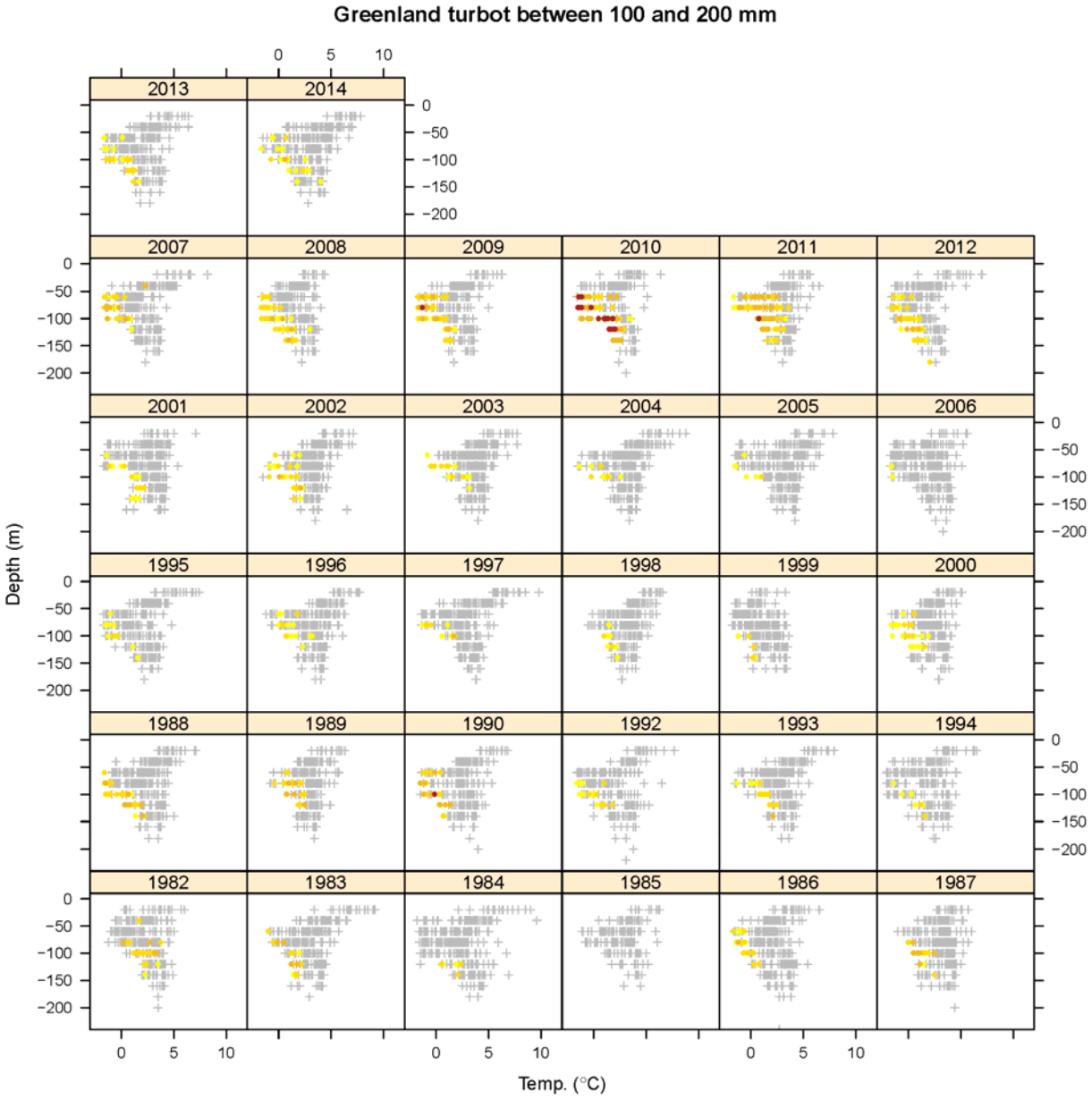


Figure 5.3.(Cont.) Greenland turbot (100-200 mm) density distribution by temperature and depth for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

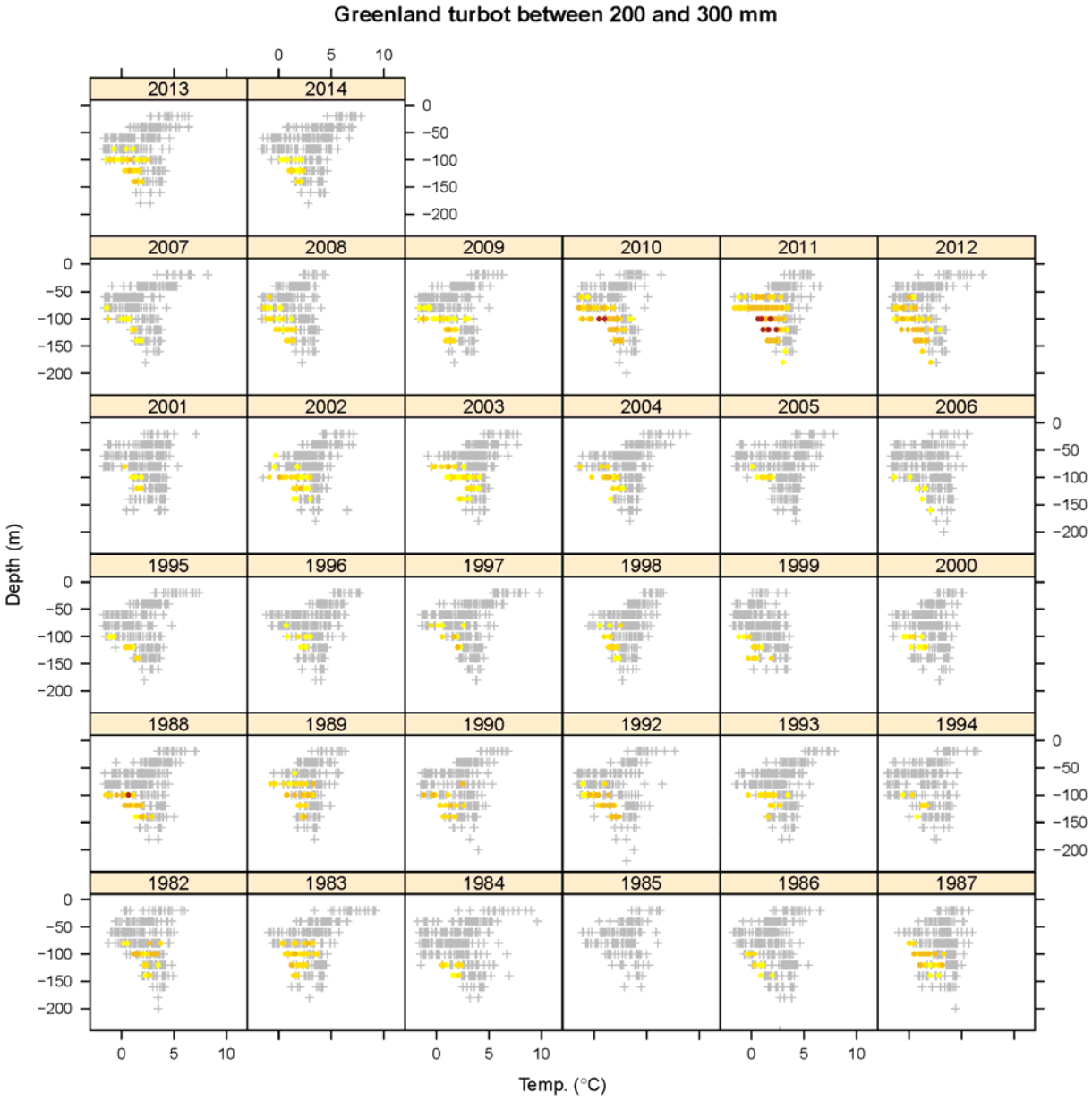


Figure 5.3.(Cont.) Greenland turbot (200-300 mm) density distribution by temperature and depth for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

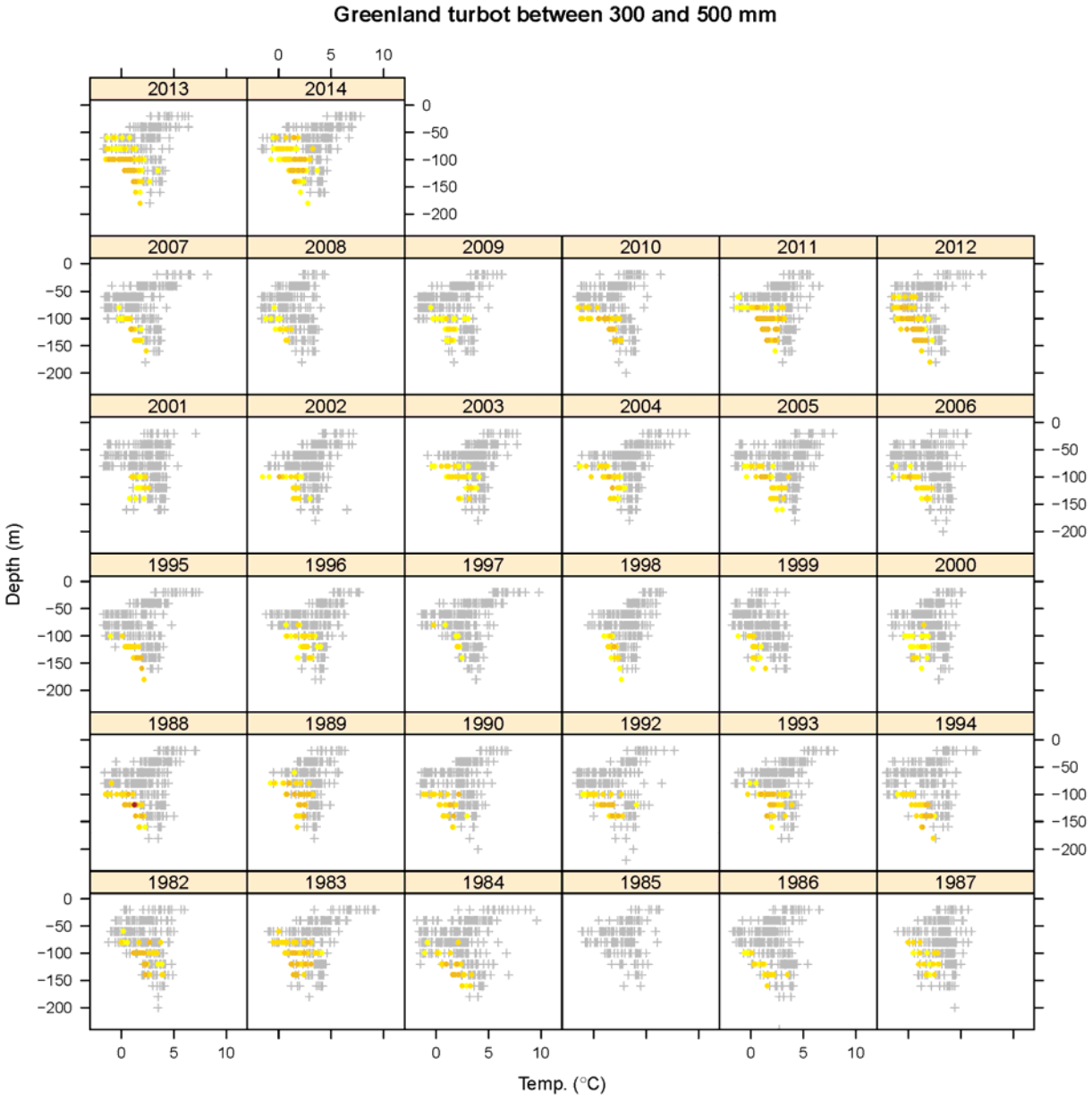


Figure 5.3.(Cont.) Greenland turbot (300-500 mm) density distribution by temperature and depth for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

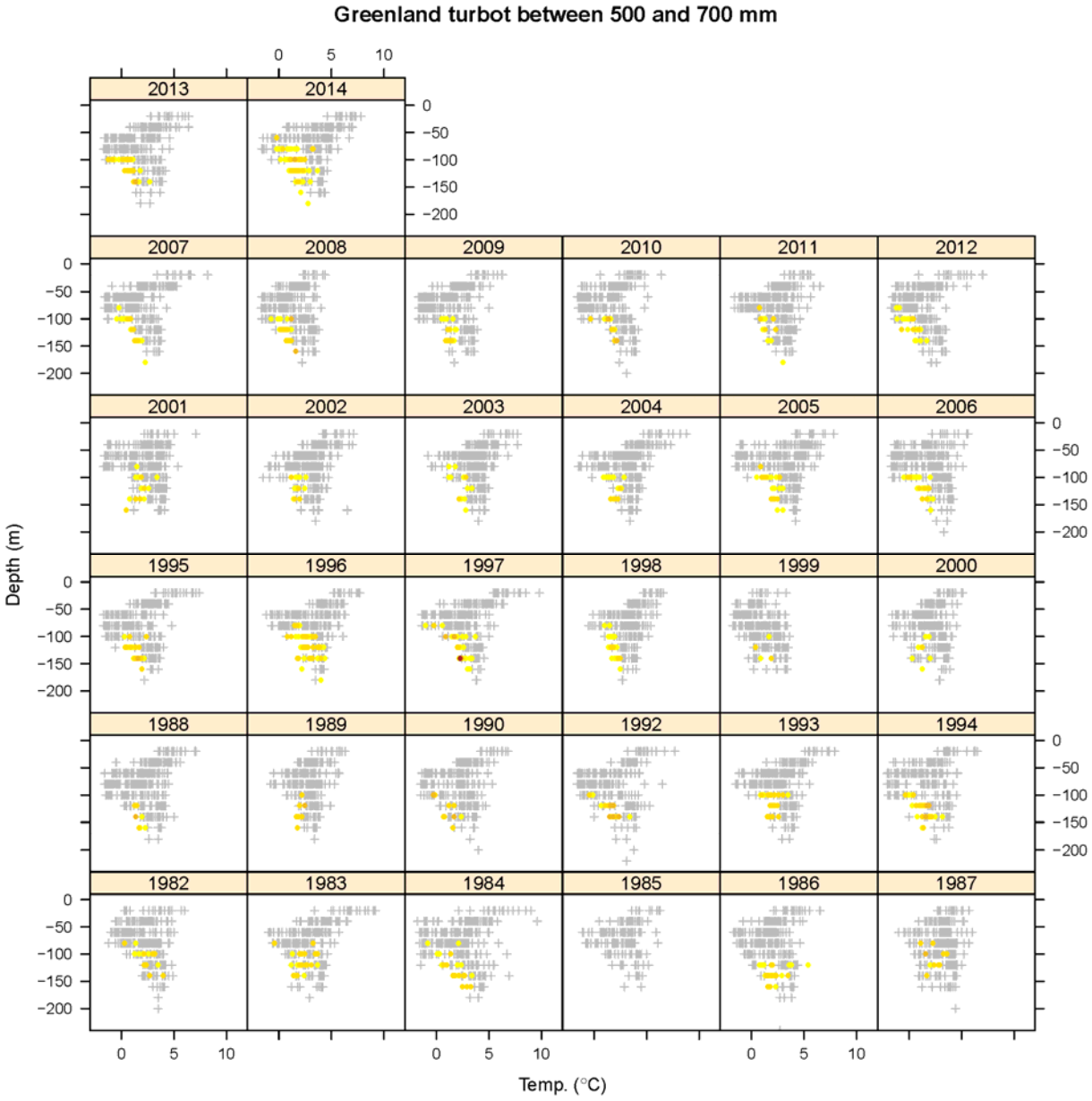


Figure 5.3.(Cont.) Greenland turbot (500-700 mm) density distribution by temperature and depth for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

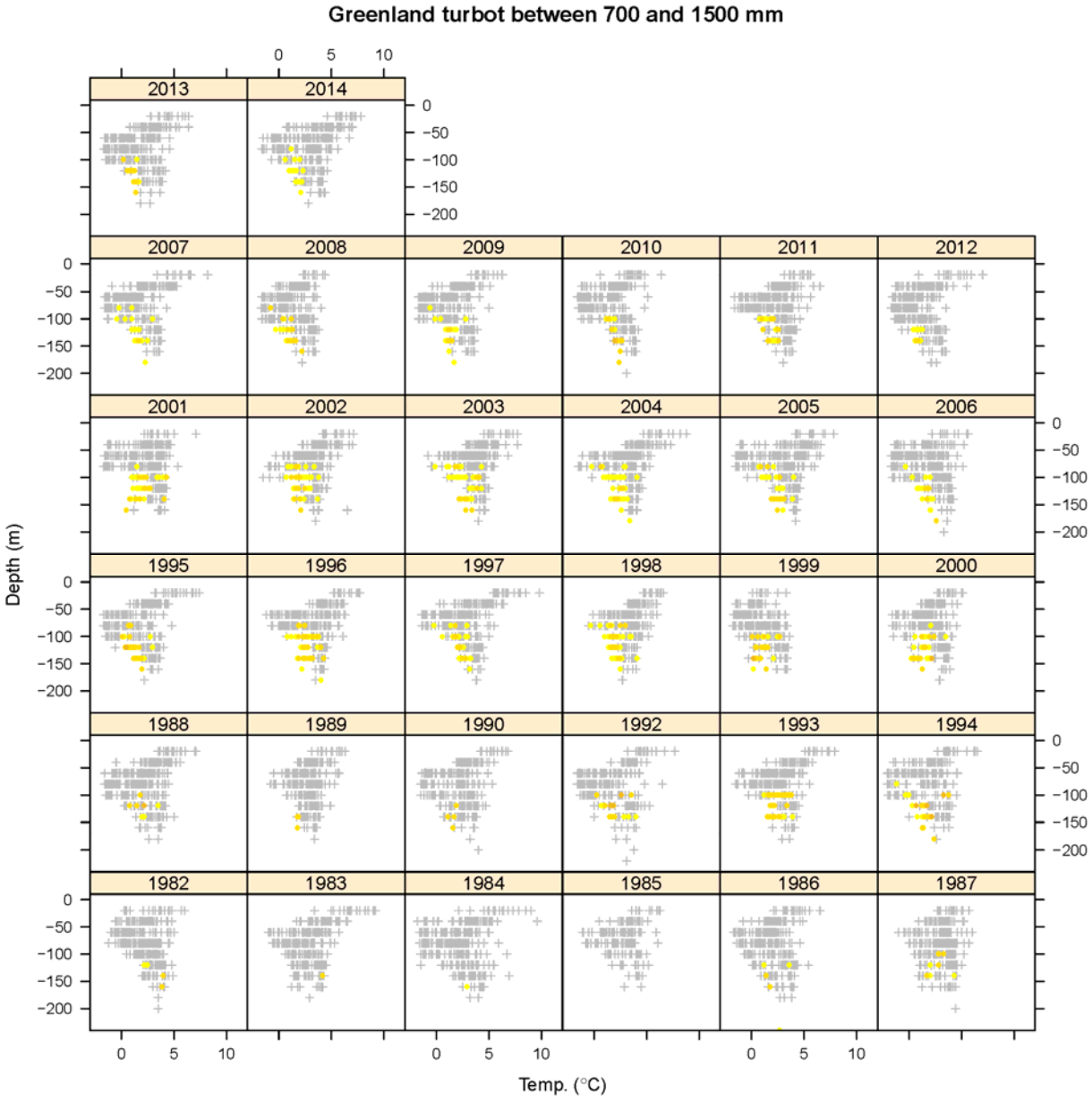


Figure 5.3.(Cont.) Greenland turbot (700-1500 mm) density distribution by temperature and depth for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

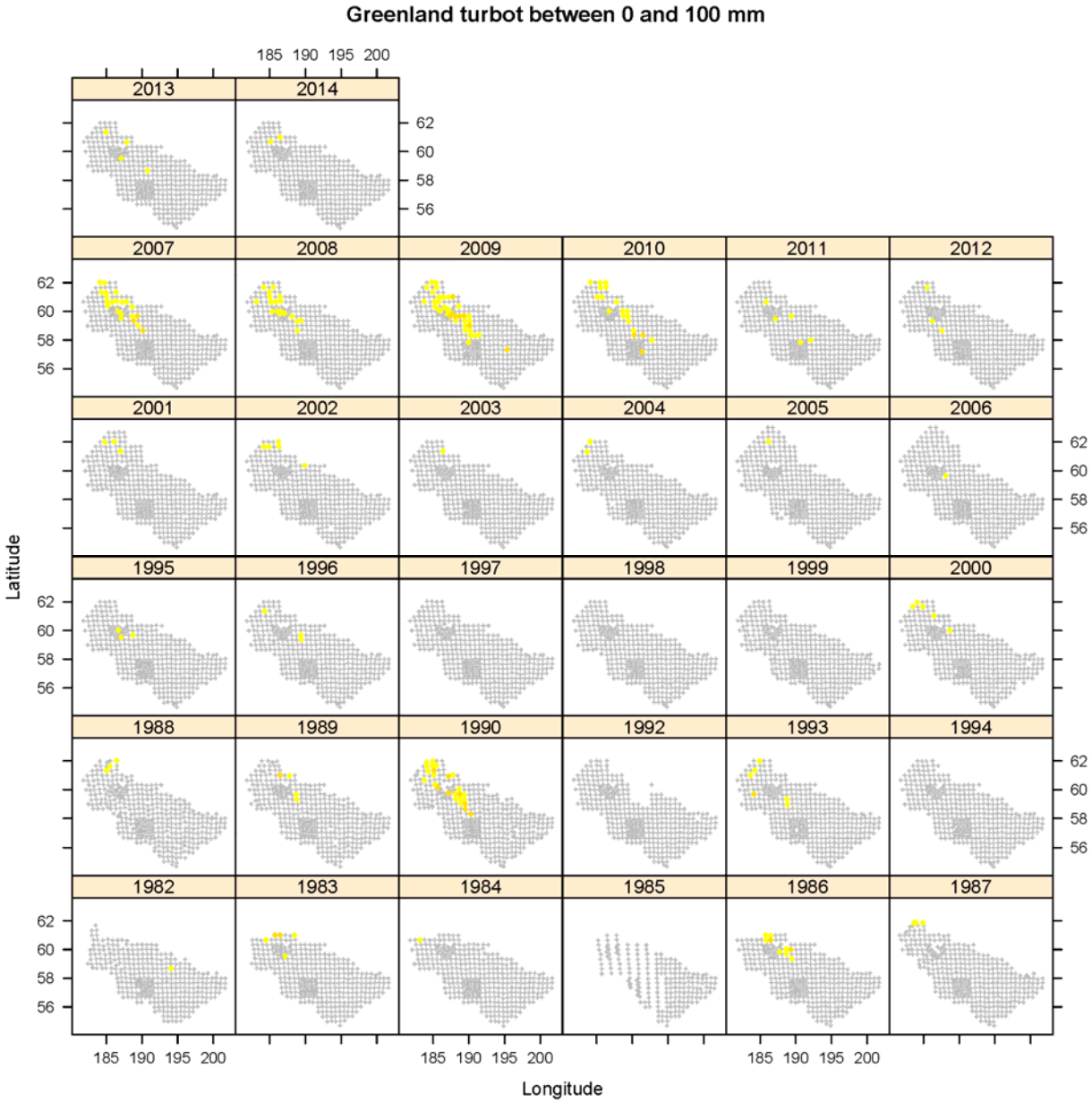


Figure 5.4. Greenland turbot (0-100 mm) density distribution by latitude and longitude for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

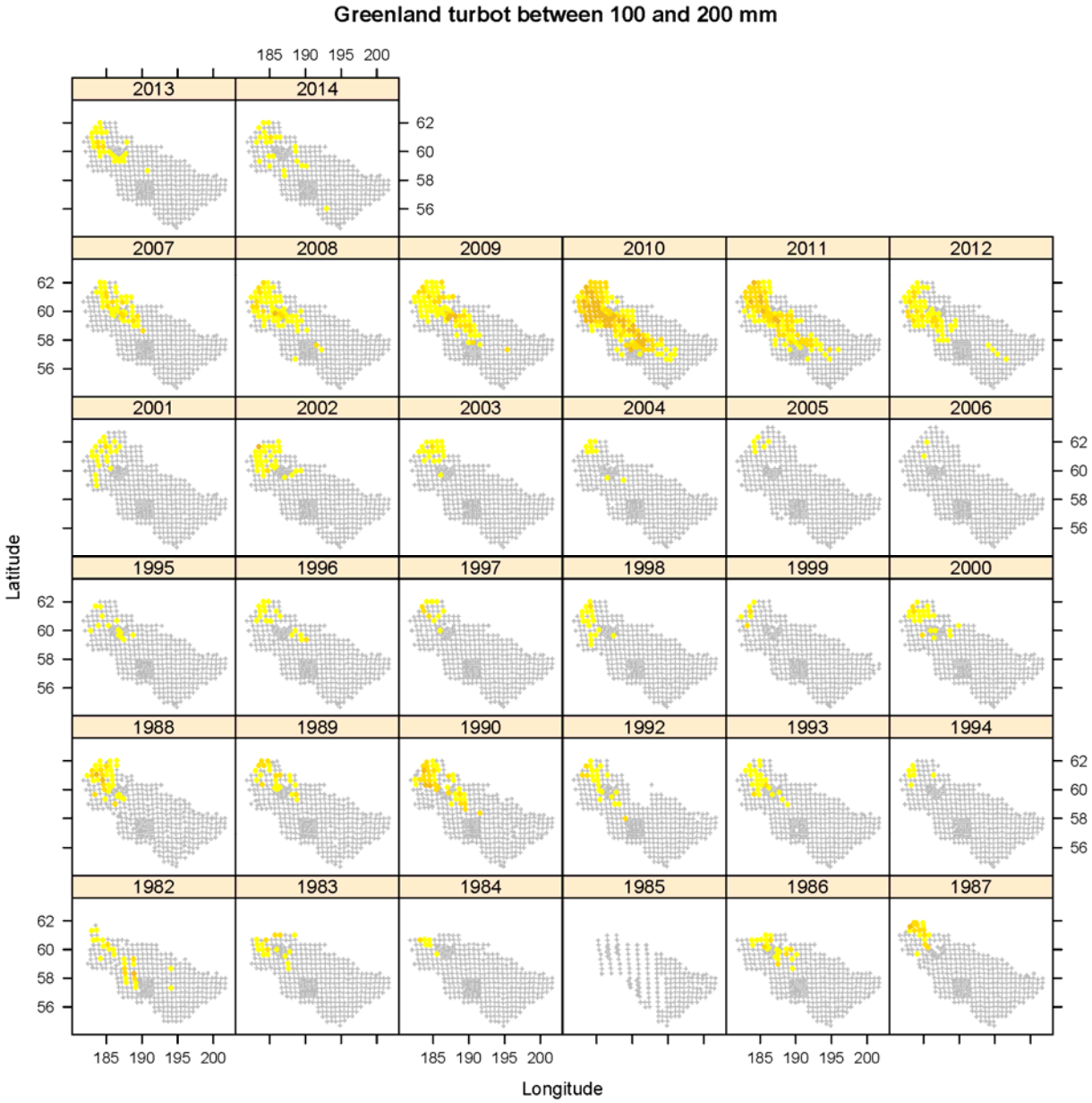


Figure 5.4.(Cont.) Greenland turbot (100-200 cm) density distribution by latitude and longitude for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

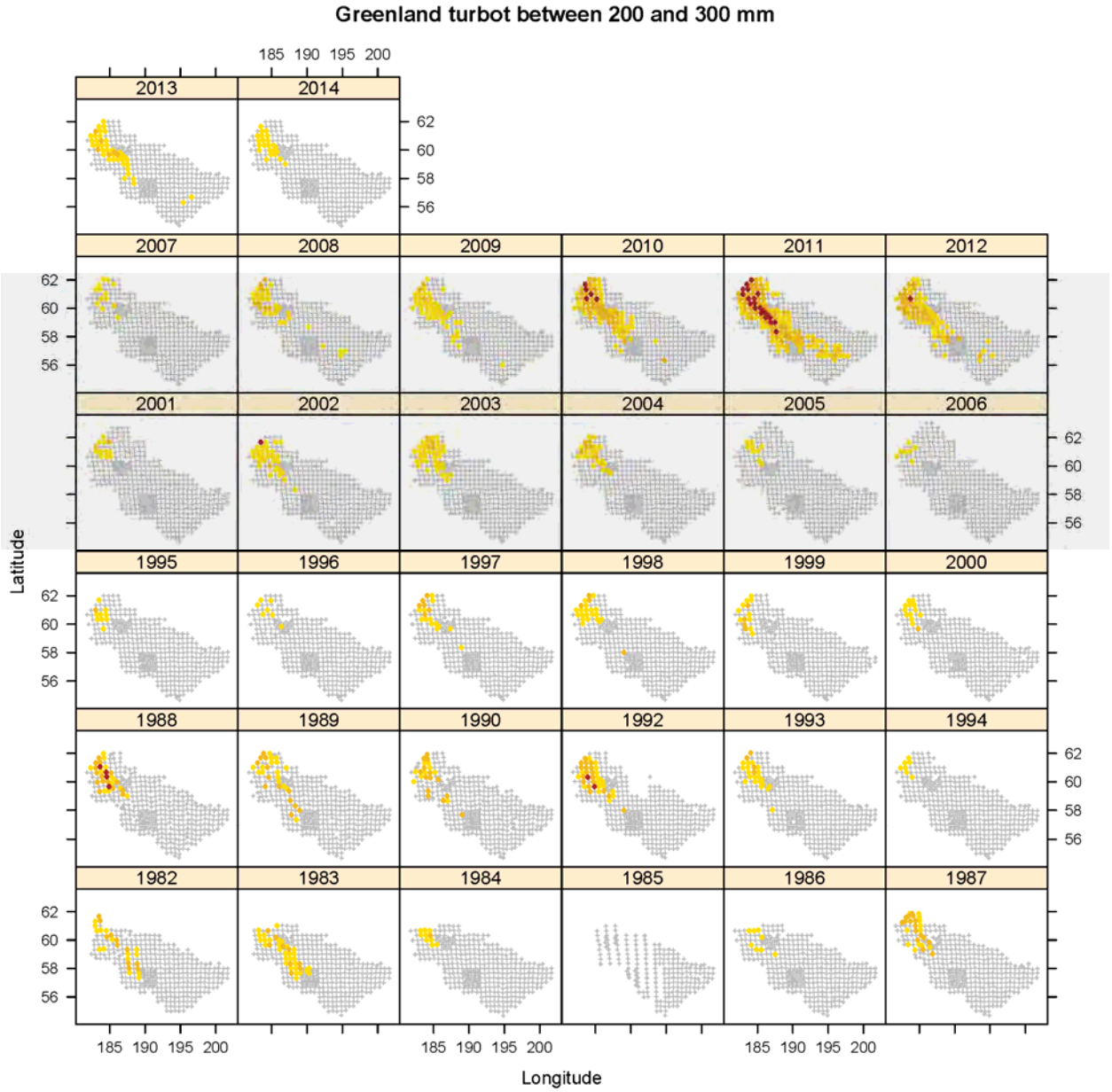


Figure 5.4.(Cont.) Greenland turbot (200-300 cm) density distribution by latitude and longitude for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

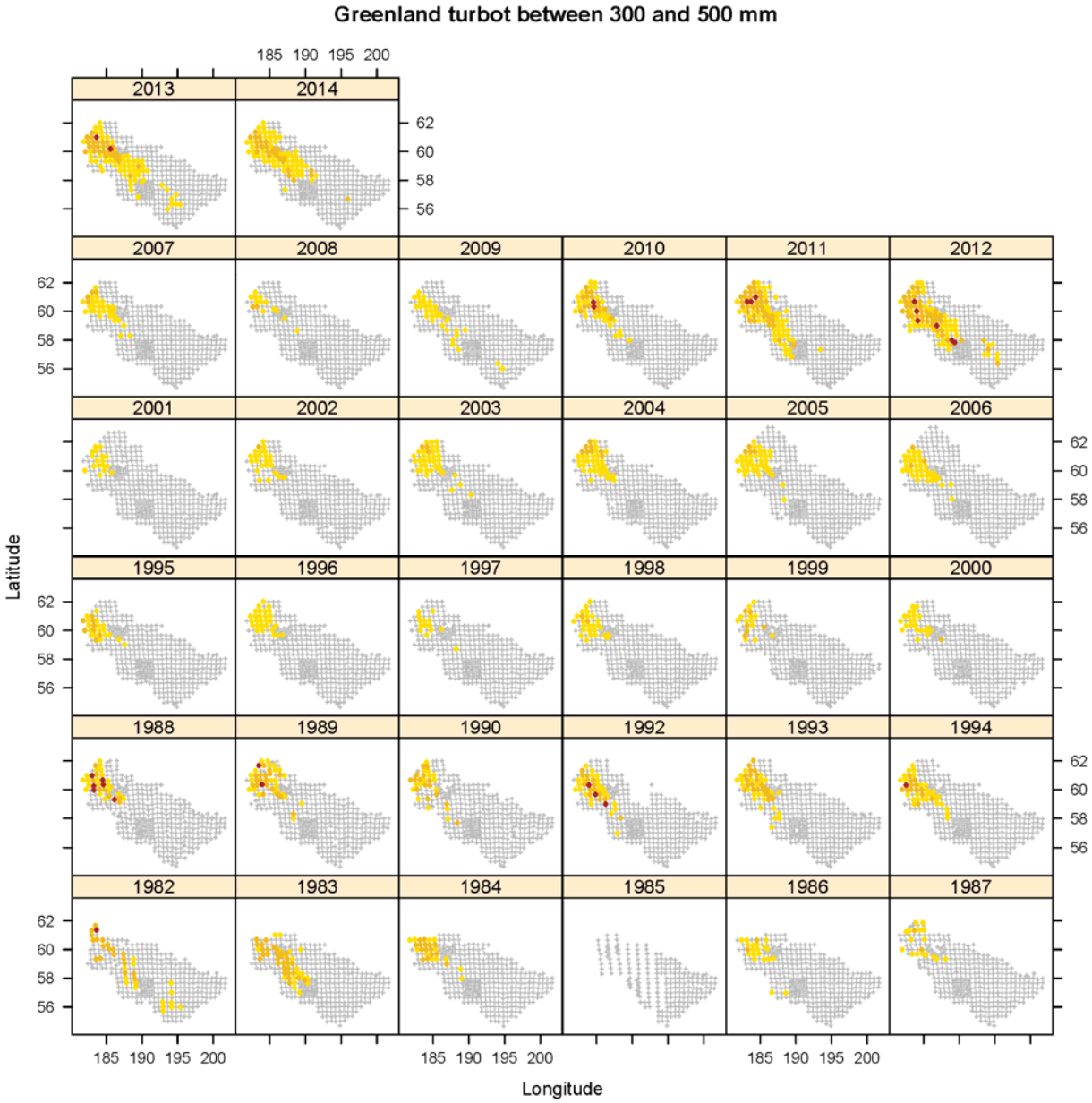


Figure 5.4.(Cont.) Greenland turbot (300- 500 mm) density distribution by latitude and longitude for 1988 – 2012 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

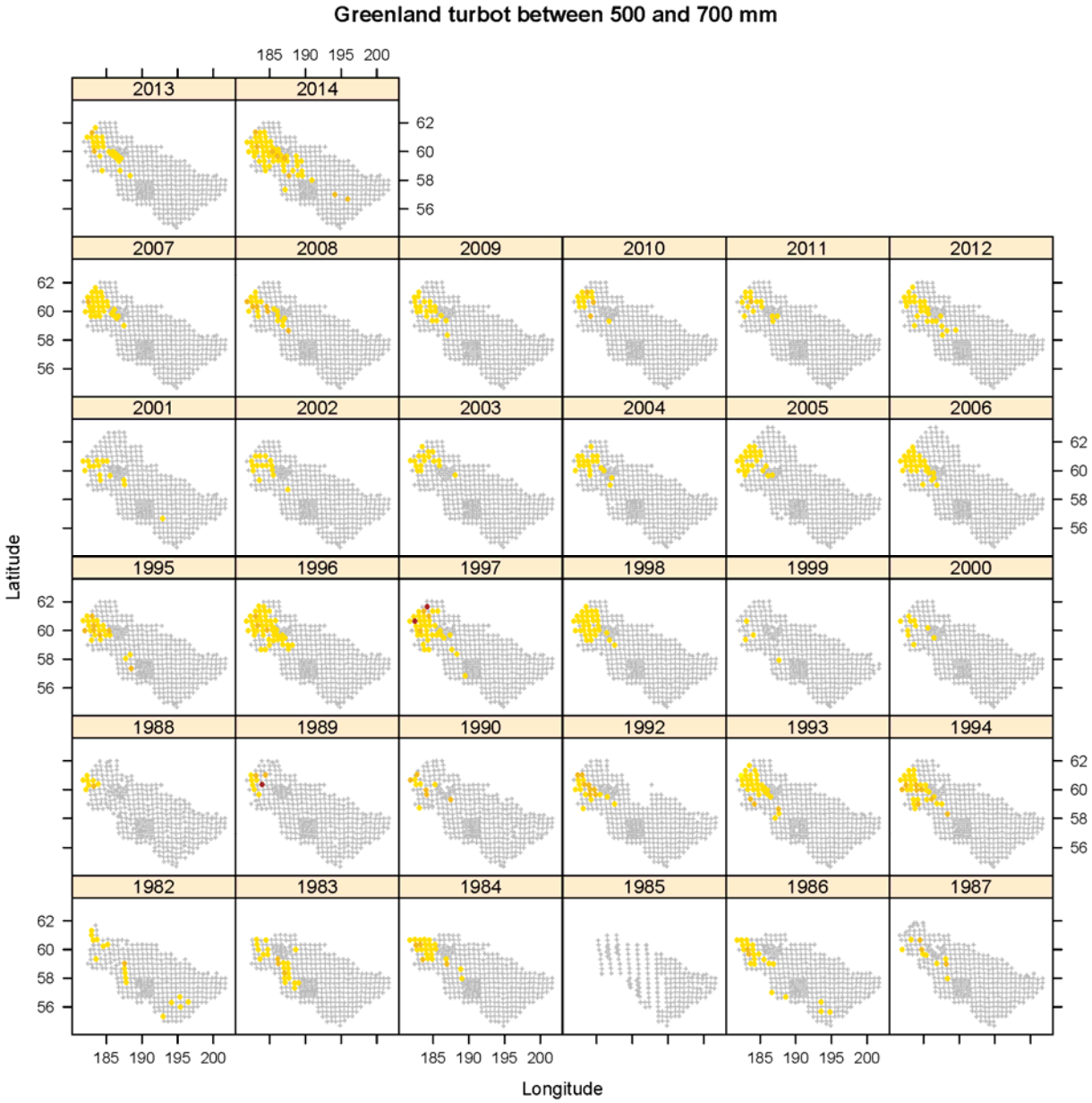


Figure 5.4.(Cont.) Greenland turbot (500- 700 mm) density distribution by latitude and longitude for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

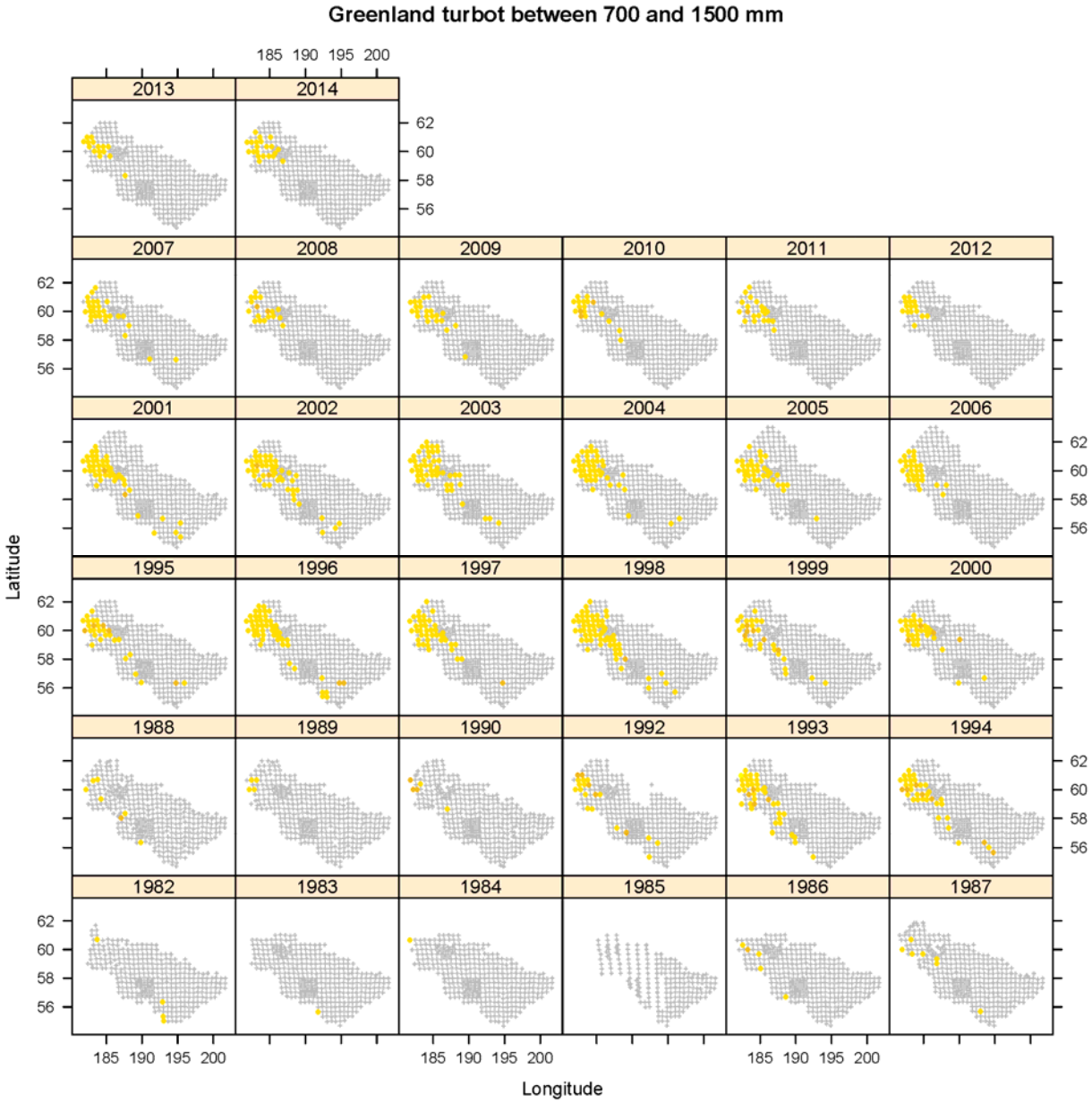


Figure 5.4.(Cont.) Greenland turbot (700- 1500 mm) density distribution by latitude and longitude for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

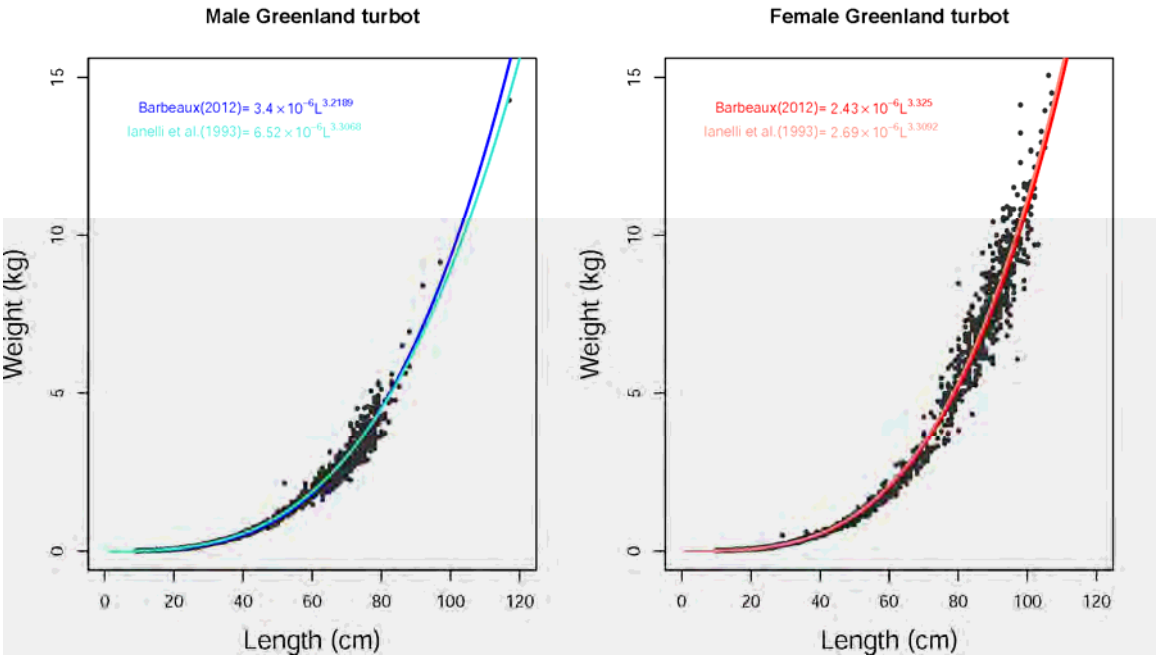


Figure 5. 5. Weight at length relationship for male (left panel) and female (right panel) Greenland turbot fit to all AFSC survey data from the Bering Sea and Aleutian Islands area, years 2003-2011. The weight at length relationships from Ianelli et al. (1993) are shown for comparison.

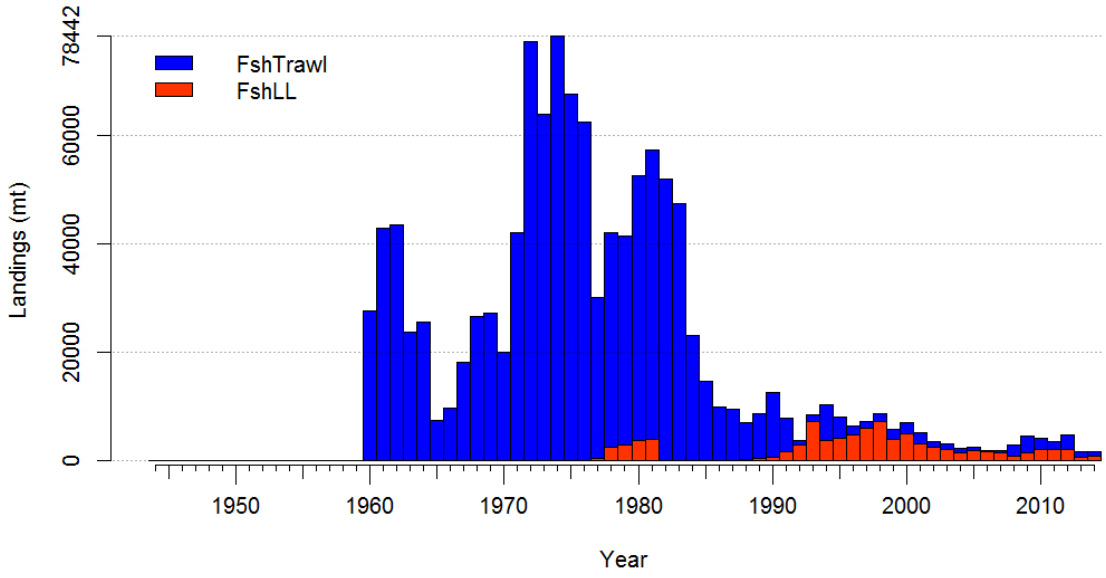


Figure 5. 6. Greenland turbot longline (FshLL, red bars) and trawl (FshTrawl, blue bars) catch in the Bering Sea and Aleutian Islands area from 1960 through 2014. This data includes targeted catch and bycatch.

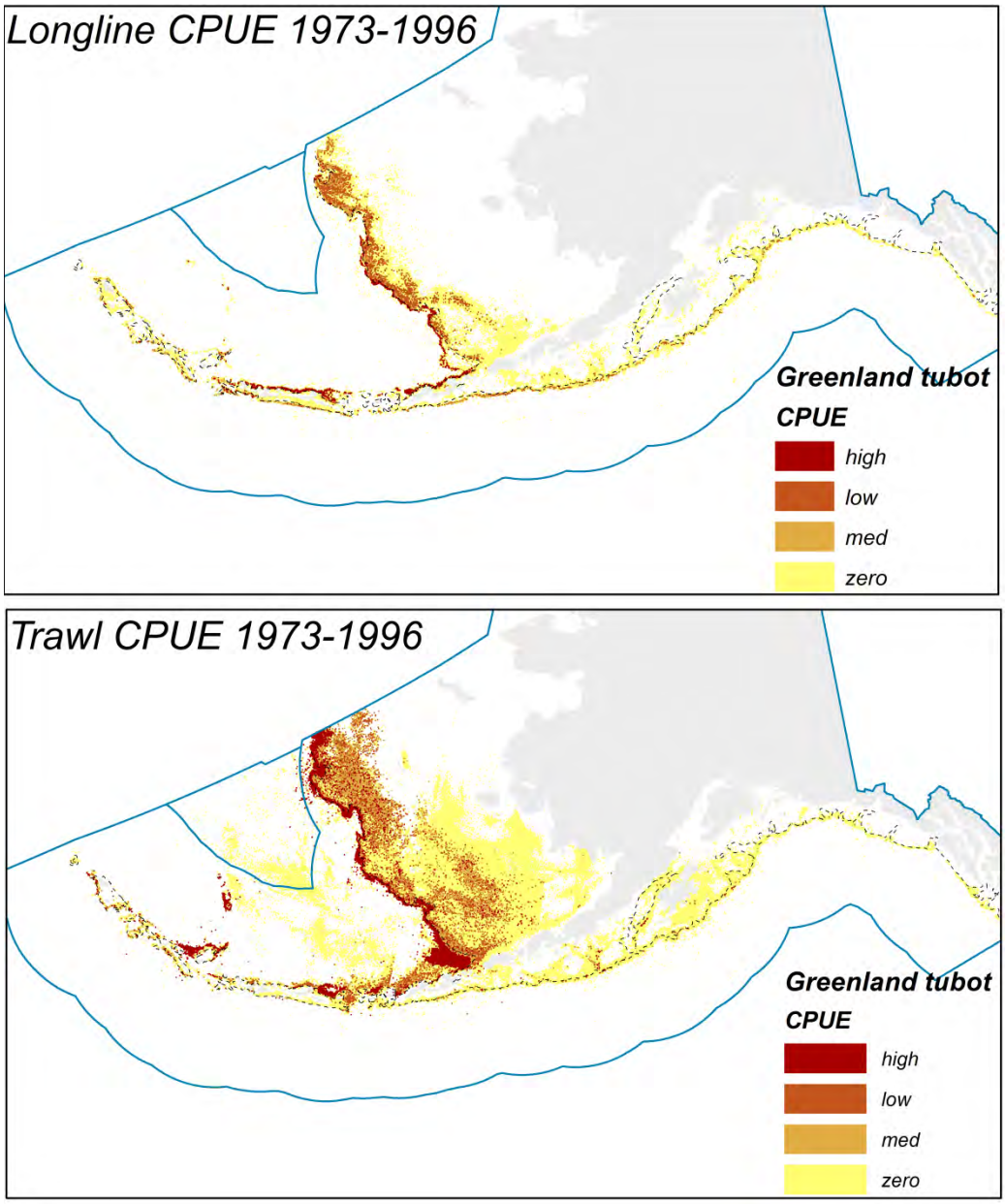


Figure 5.7. Distribution of Greenland turbot fishing CPUE 1973- 1996 from observer data within the longline (top panel) and trawl (bottom panel) fisheries (Fritz et al 1998).

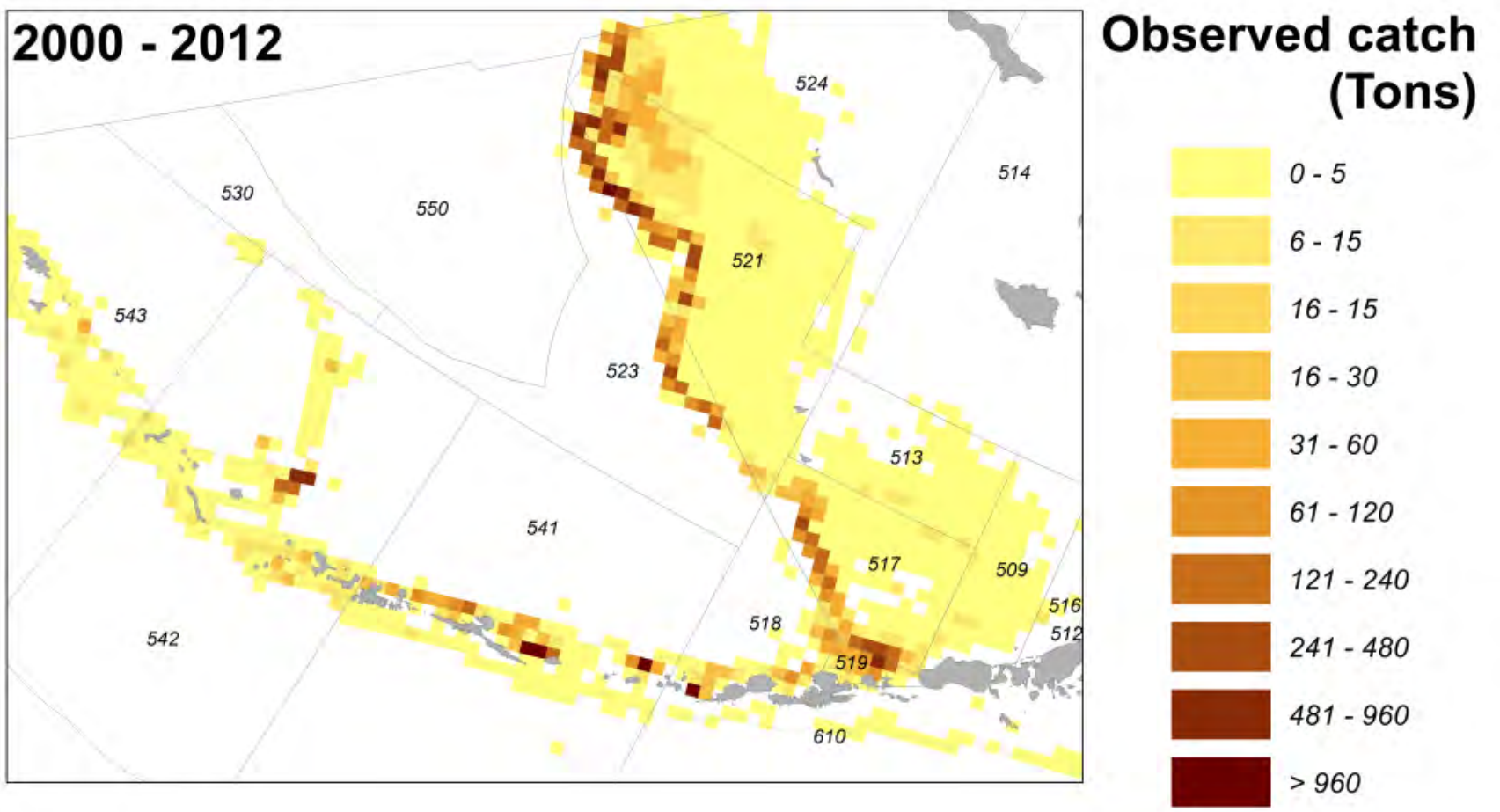


Figure 5.8 All observed Greenland turbot catch in the BSAI for 2000 through 2012, data are aggregated spatially at a 400 km^2 grid.

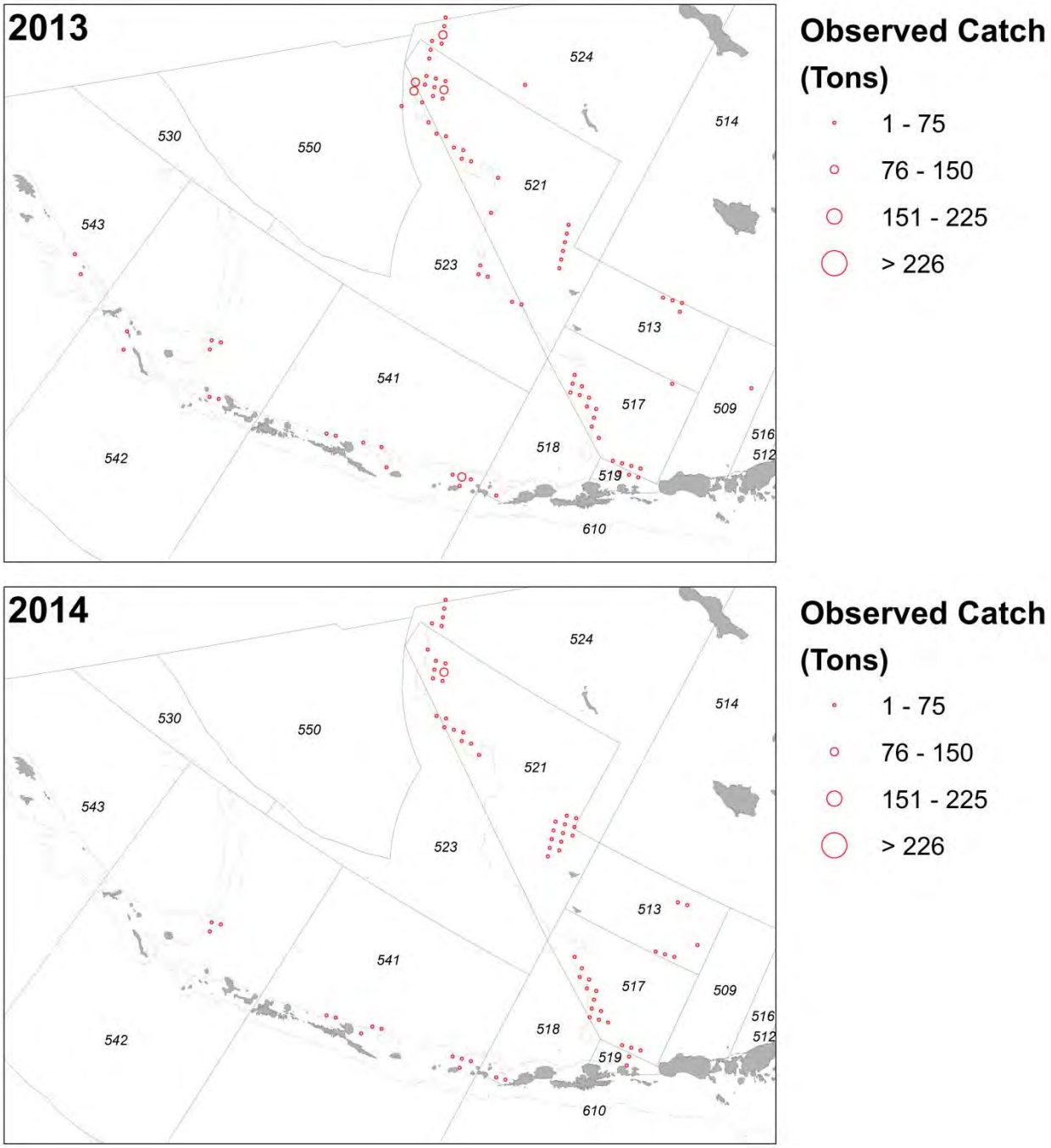


Figure 5.9.All observed Greenland turbot catch for 2013 and 2014. Data are aggregated for each year at 400 km^2. Note that areas with less than 1t are not shown.

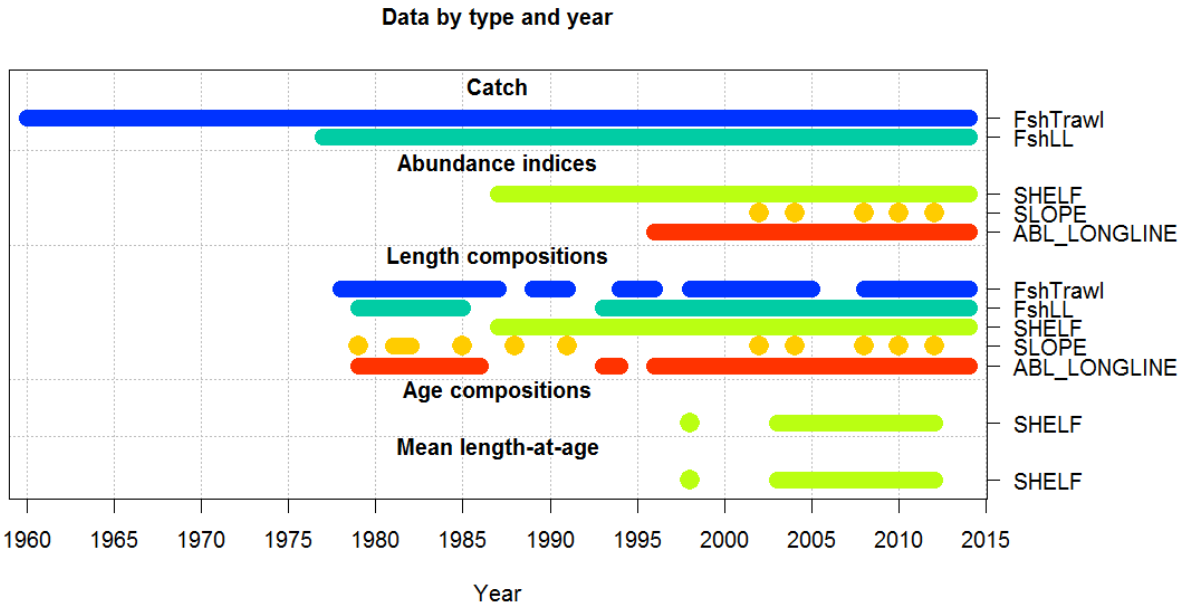


Figure 5.10. Timeline of all data included in the 2014 stock assessment models. FshTrawl = trawl fishery, FshLL = longline fishery, SHELF = Bering Sea trawl shelf survey, SLOPE = Bering Sea trawl slope survey, ABL_LONGLINE = Auke Bay Laboratory longline survey.

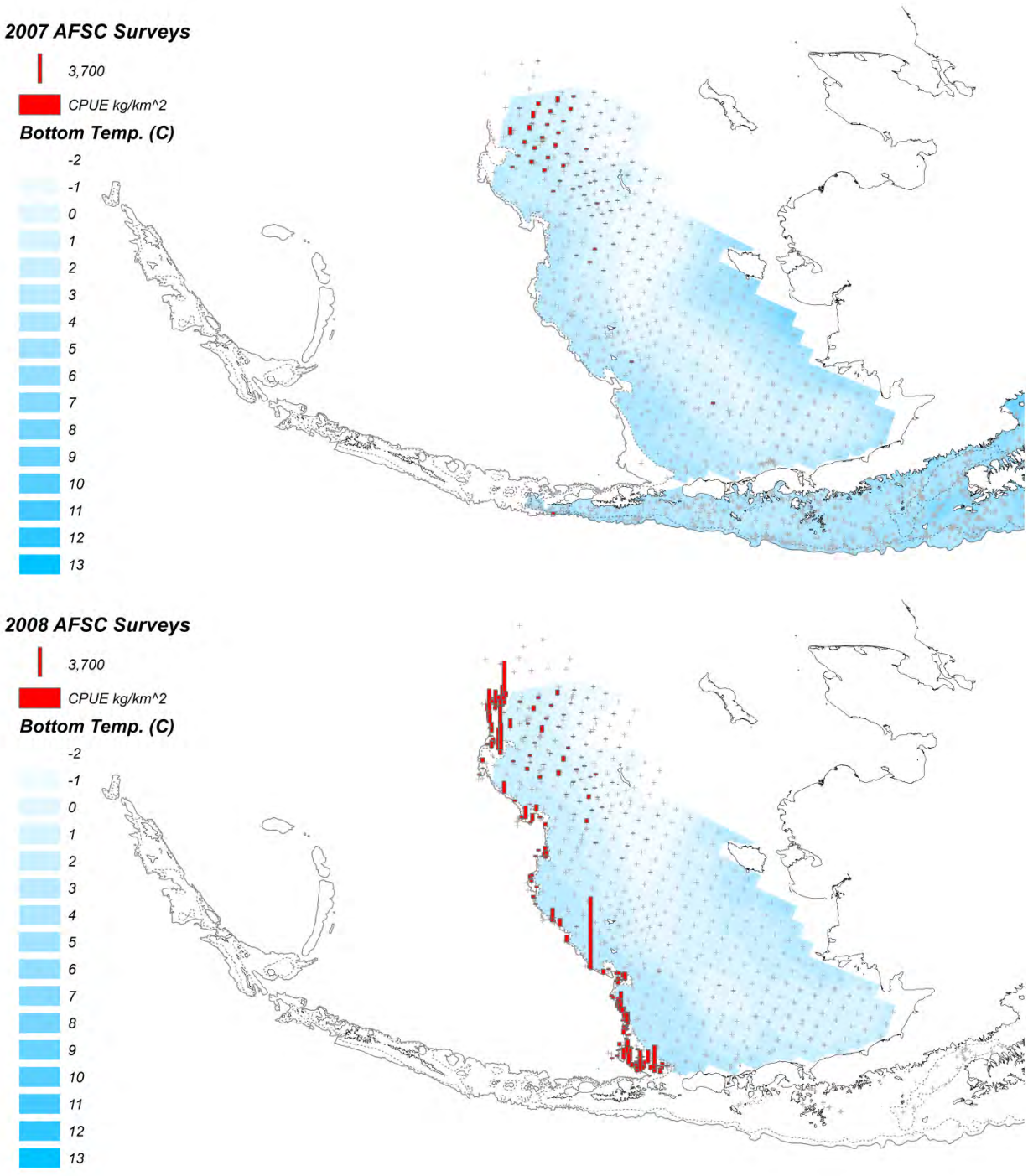


Figure 5.11. Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in celcius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot catch are marked with red bars. All CPUE bars are on the same scale for all surveys.

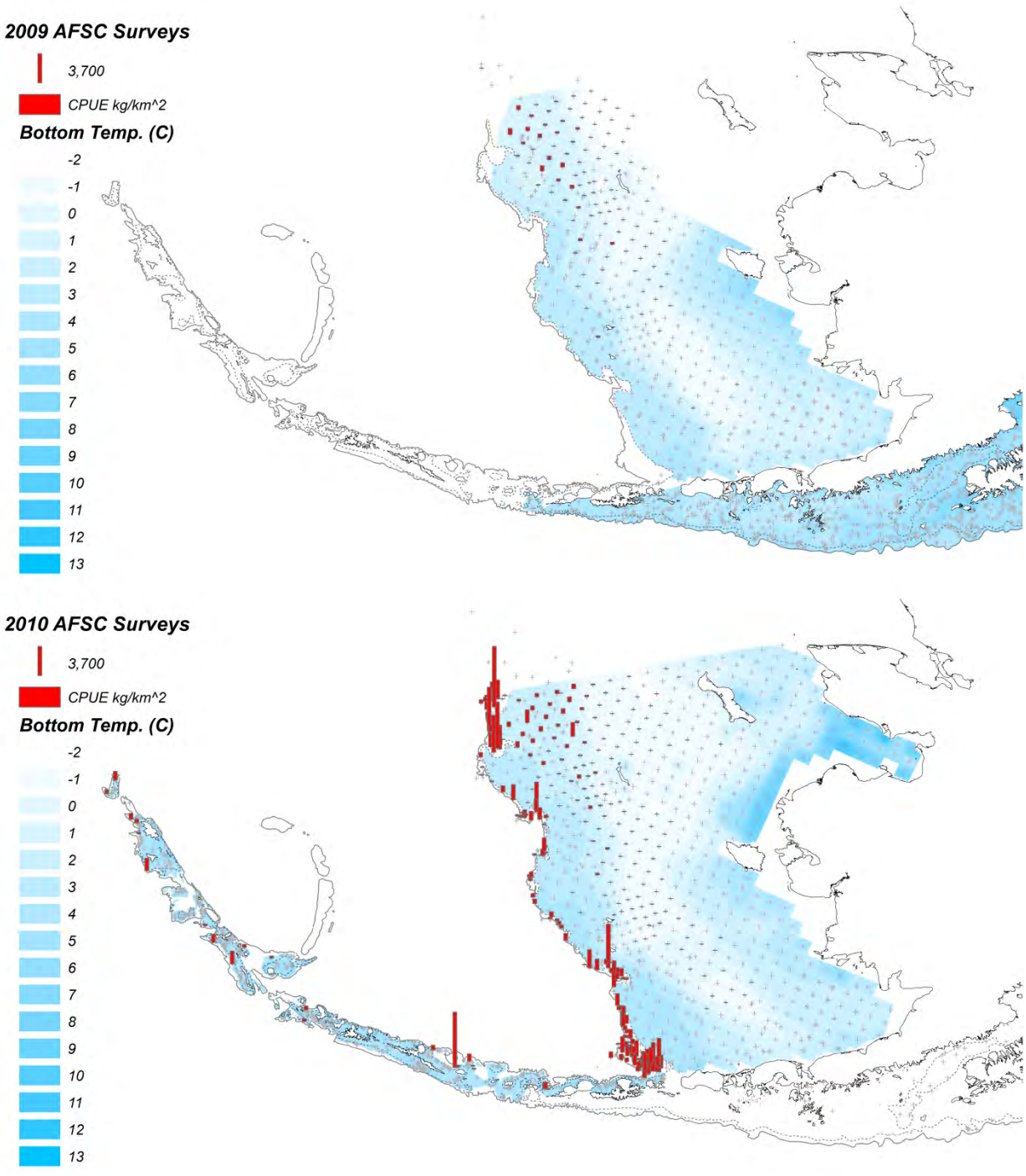


Figure 5.11.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in celcius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot catch are marked with red bars. All CPUE bars are on the same scale for all surveys.

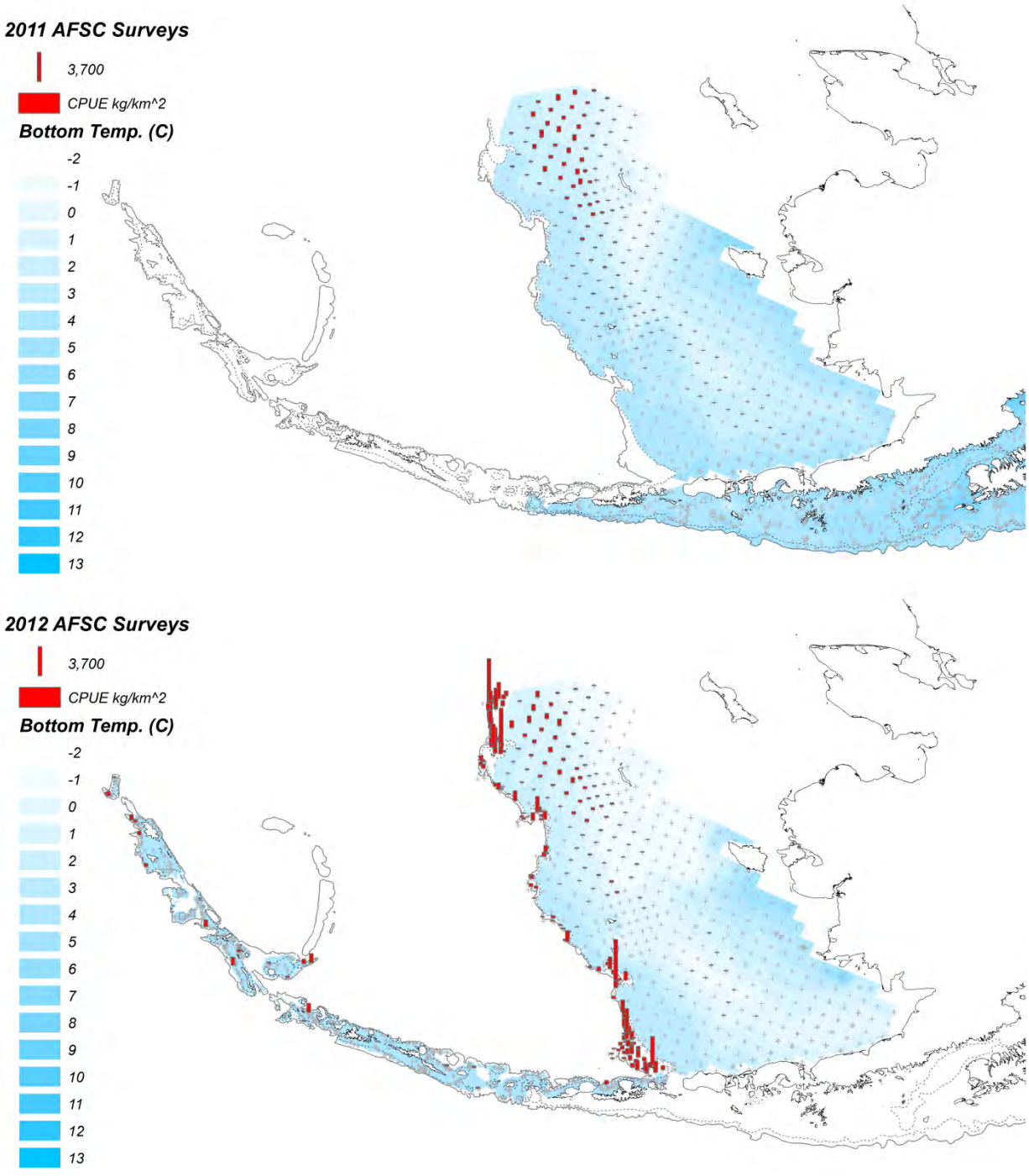


Figure 5.11.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in celcius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot catch are marked with red bars. All CPUE bars are on the same scale for all surveys.

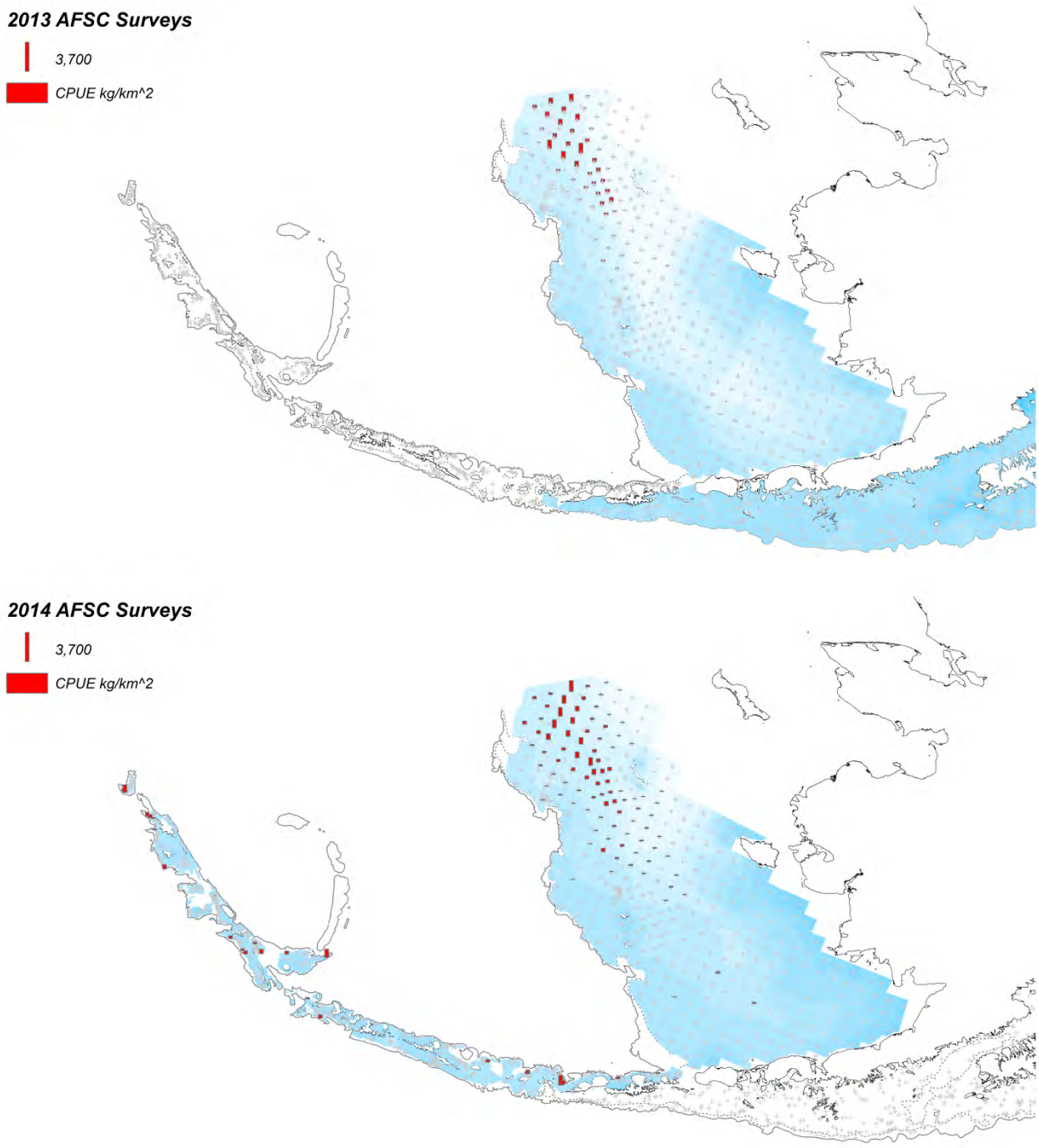


Figure 5.11.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in celcius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot catch are marked with red bars. All CPUE bars are on the same scale for all surveys.

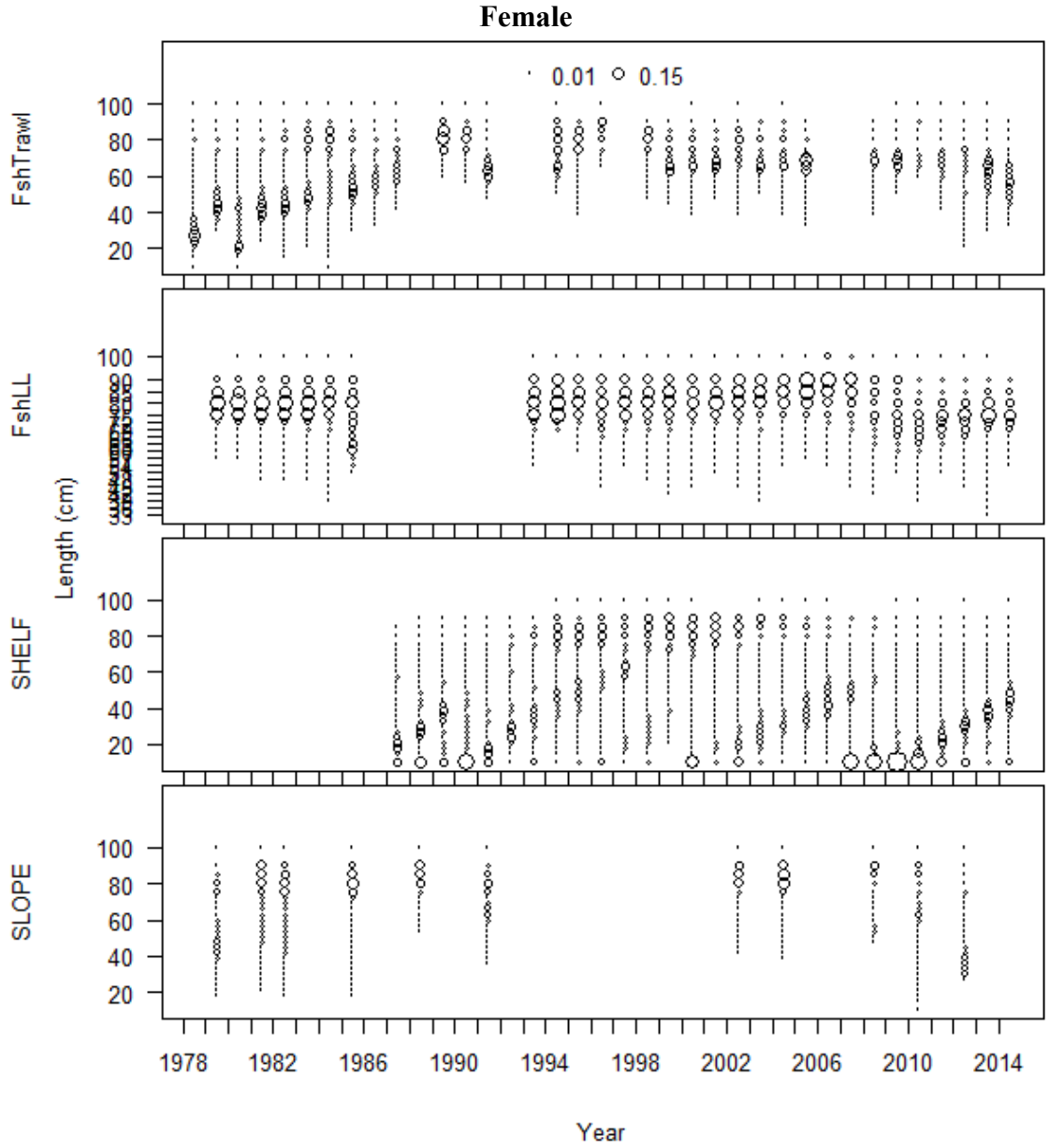


Figure 5.12. Greenland turbot size composition data for females from the trawl fishery (FshTrawl), longline fishery (FshLL), shelf survey (SHELF)and slope survey (SLOPE).

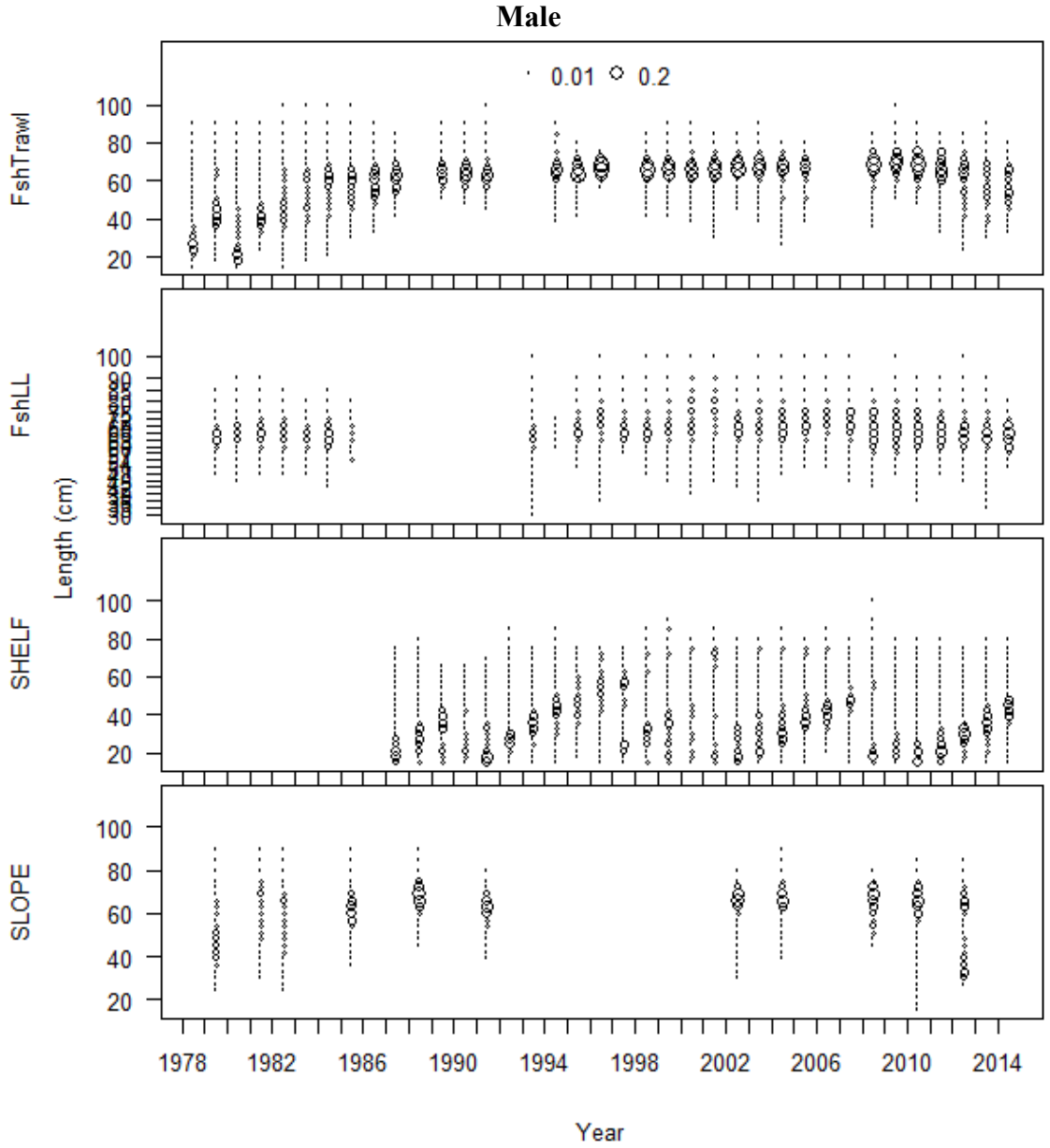


Figure 5.12. (Cont.) Greenland turbot size composition data for males from the trawl fishery (FshTrawl), longline fishery (FshLL), shelf survey (SHELF) and slope survey (SLOPE).

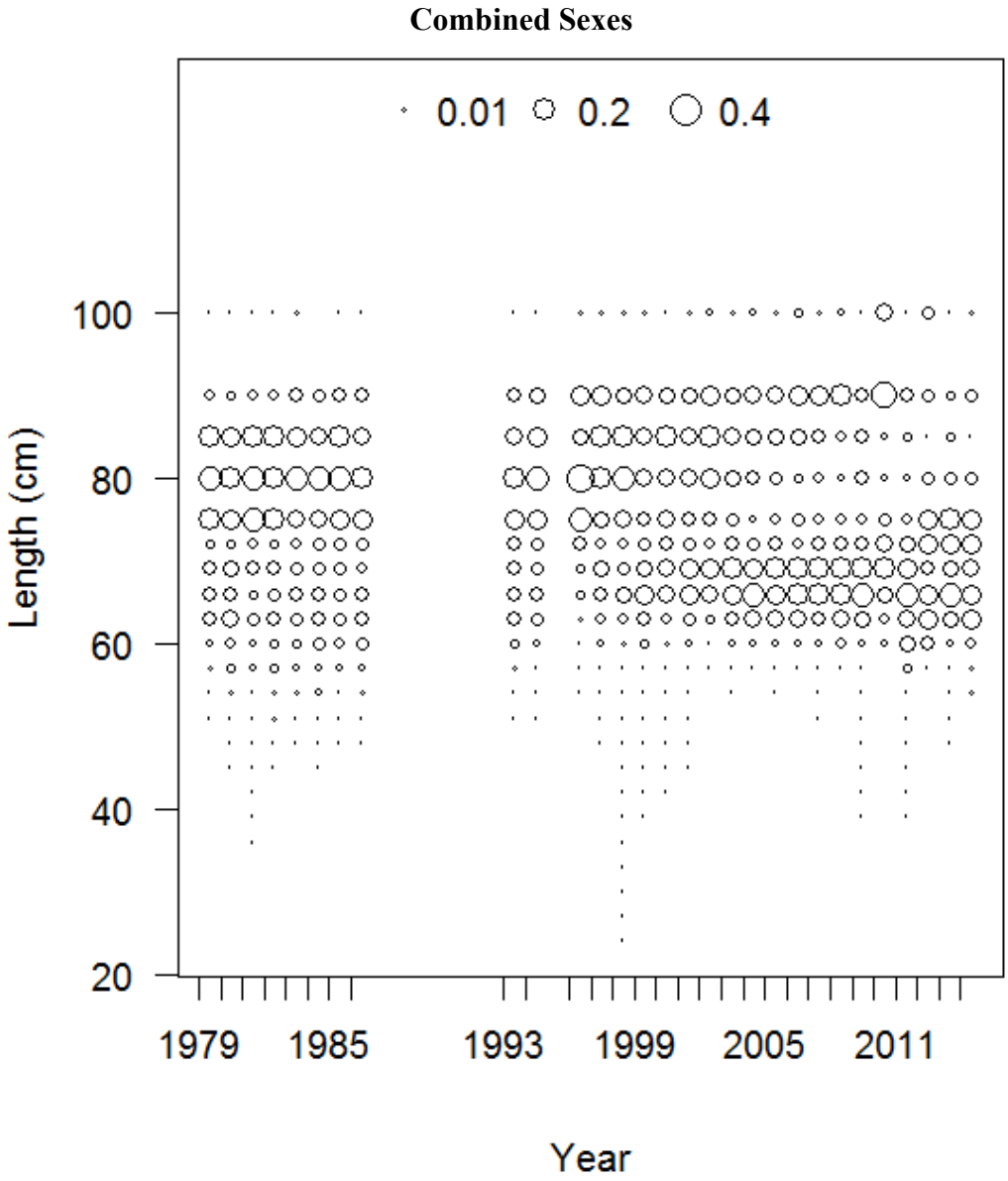


Figure 5.12. (Cont.) Greenland turbot size composition data for combined sexes from the Auke Bay Laboratory longline survey.

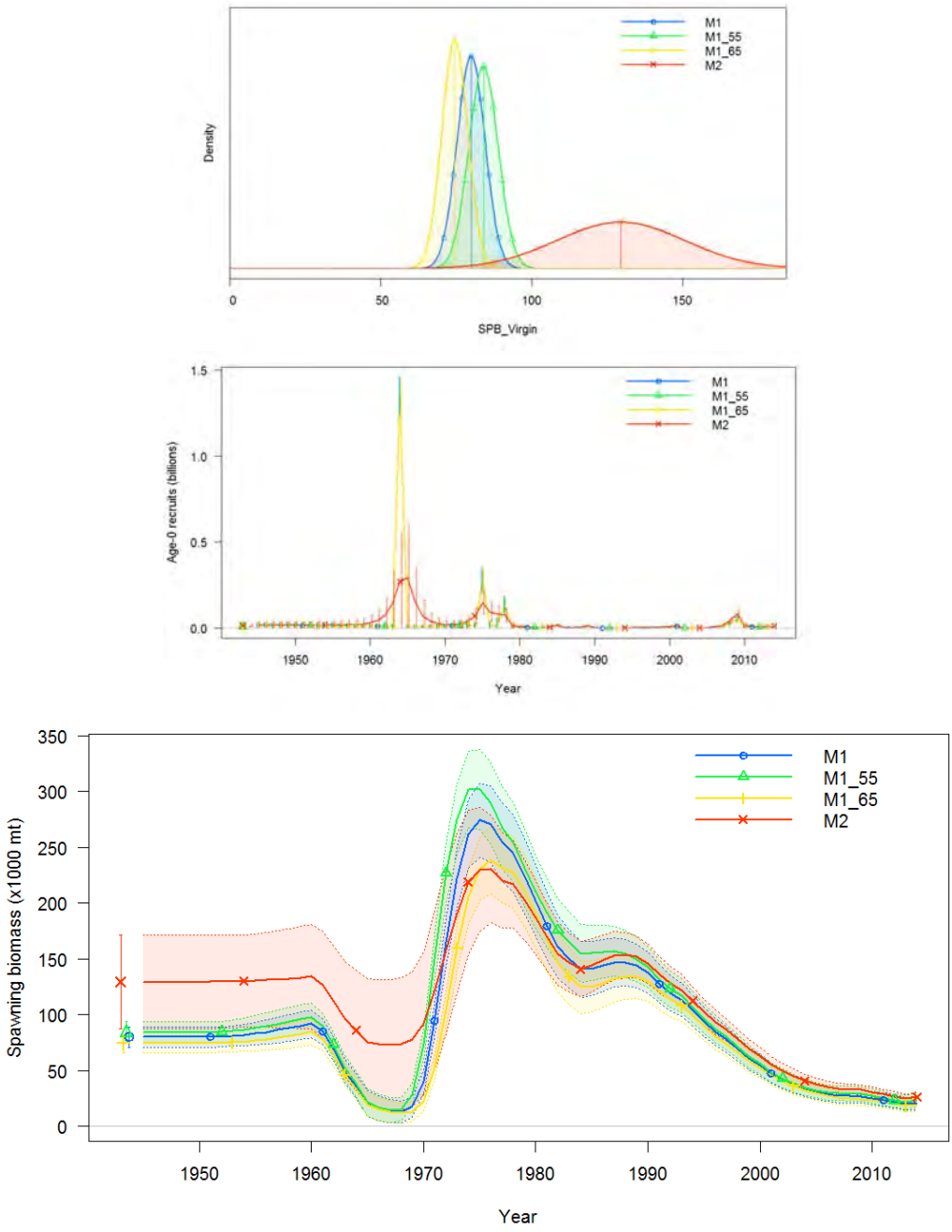


Figure 5.13. Virgin spawning biomass (top panel), age-0 recruitment (middle panel), and female spawning biomass (bottom panel) for Model 1 (M1) and Model 2 (M2). M1_55 and M1_65 are Model 1 with female length at 50% mature at 55cm and 65cm respectively.

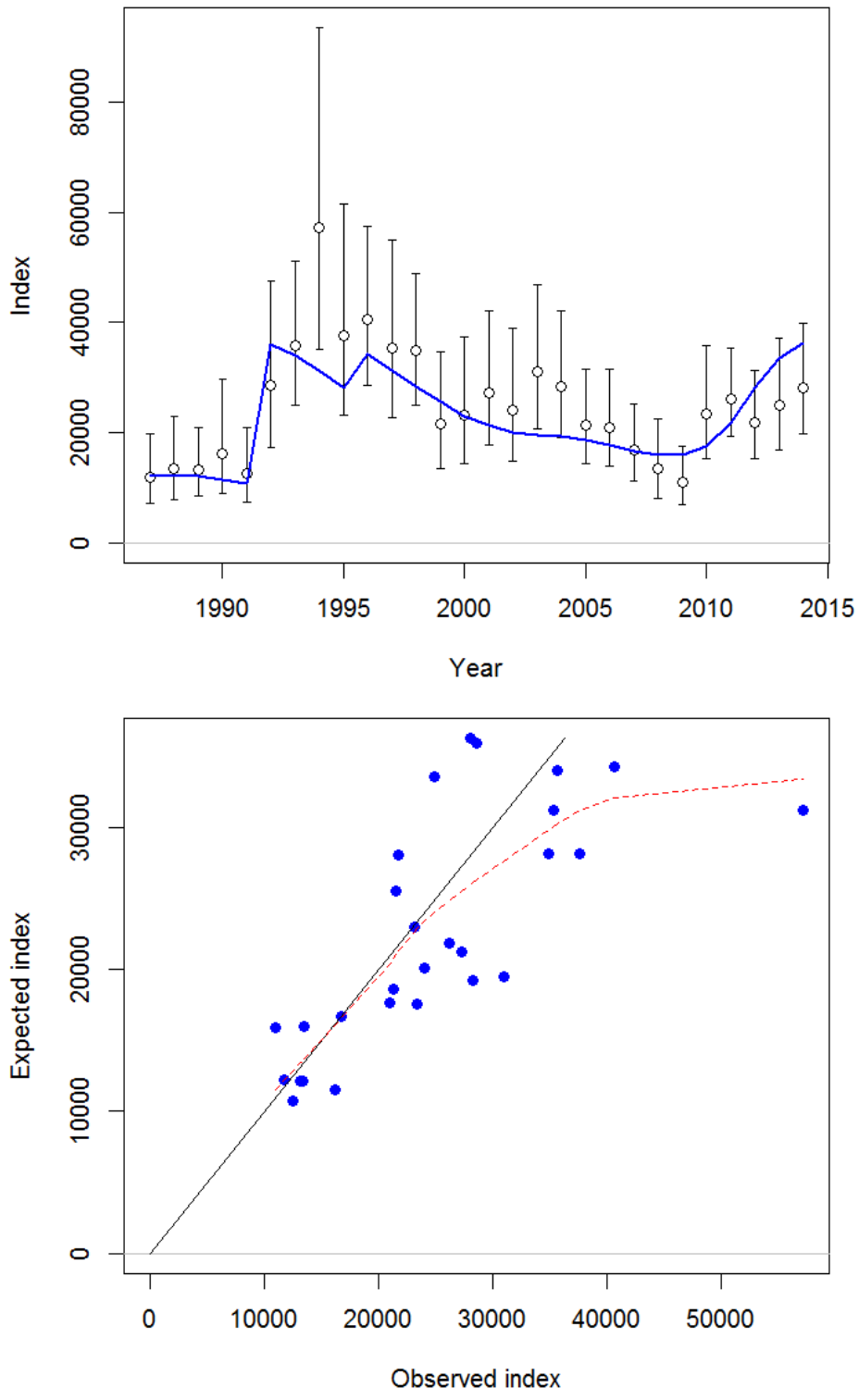


Figure 5.14. (Top Panel) Shelf survey index (index values are total survey biomass in tons), error bars as 95% confidence intervals, Model 2 fit (blue line). (Bottom panel) Model 2 expected index values plotted by observed index values with 1:1 line (black line) and loess smooth (red line).

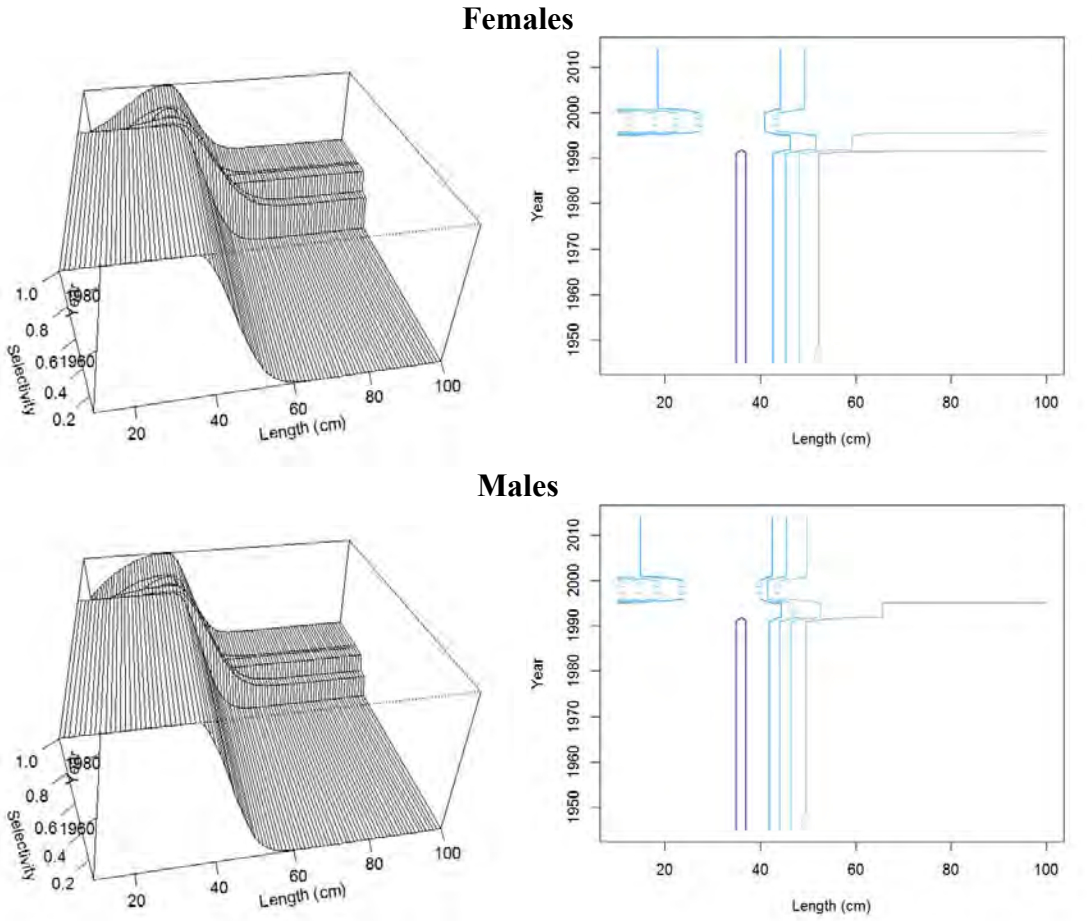


Figure 5.15. Time-varying selectivity at size for the shelf survey for Model 2 for females (top) and males (bottom).

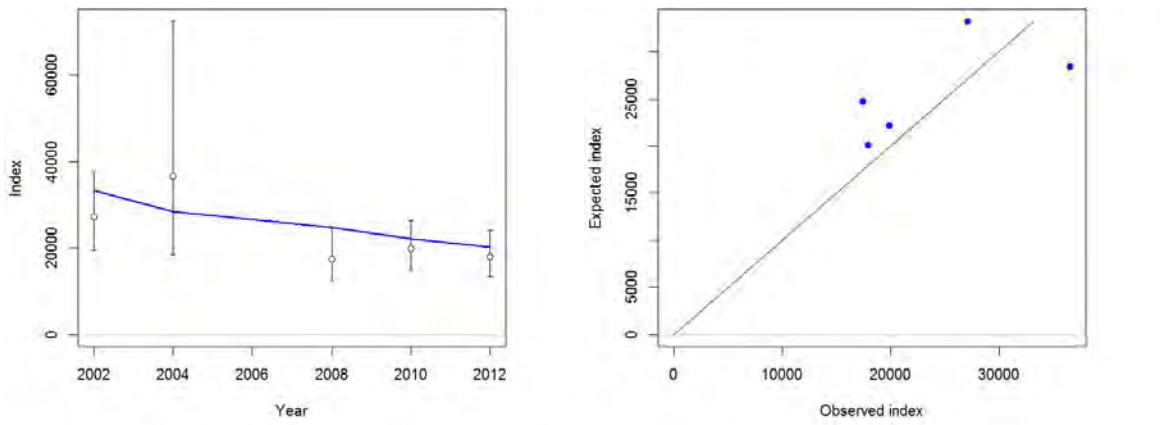


Figure 5.16. (Left Panel) Slope survey index (index values are total survey biomass in tons), error bars as 95% confidence intervals, and Model 2 fit (blue line). (Right panel) Model 2 expected index values plotted by observed index values with 1:1 line (black line) and loess smooth (red line).

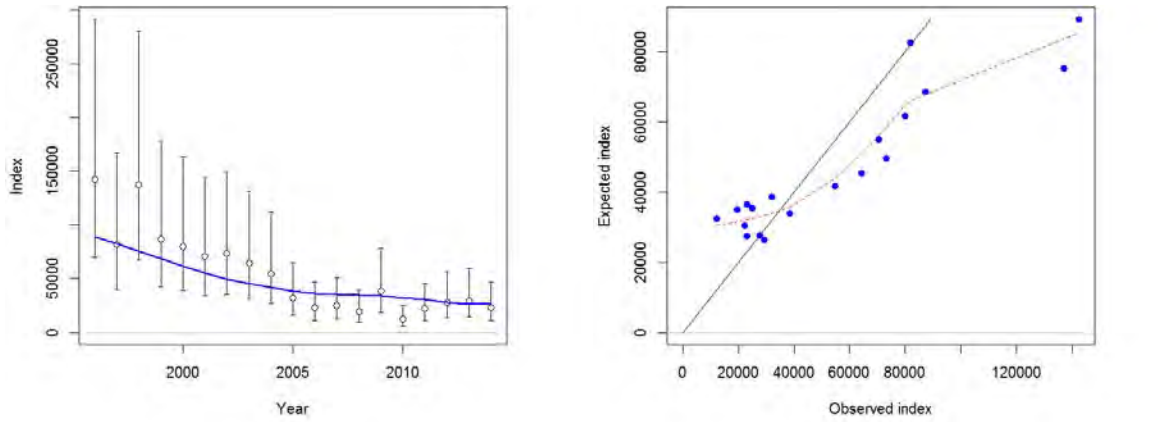


Figure 5.17. (Left Panel)The longline survey index (index values are in relative population numbers (RPN)), error bars as 95% confidence intervals, and Model 2 fit (blue line). (Bottom panel) Model 2 expected index values plotted by observed index values with 1:1 line (black line) and loess smooth (red line).

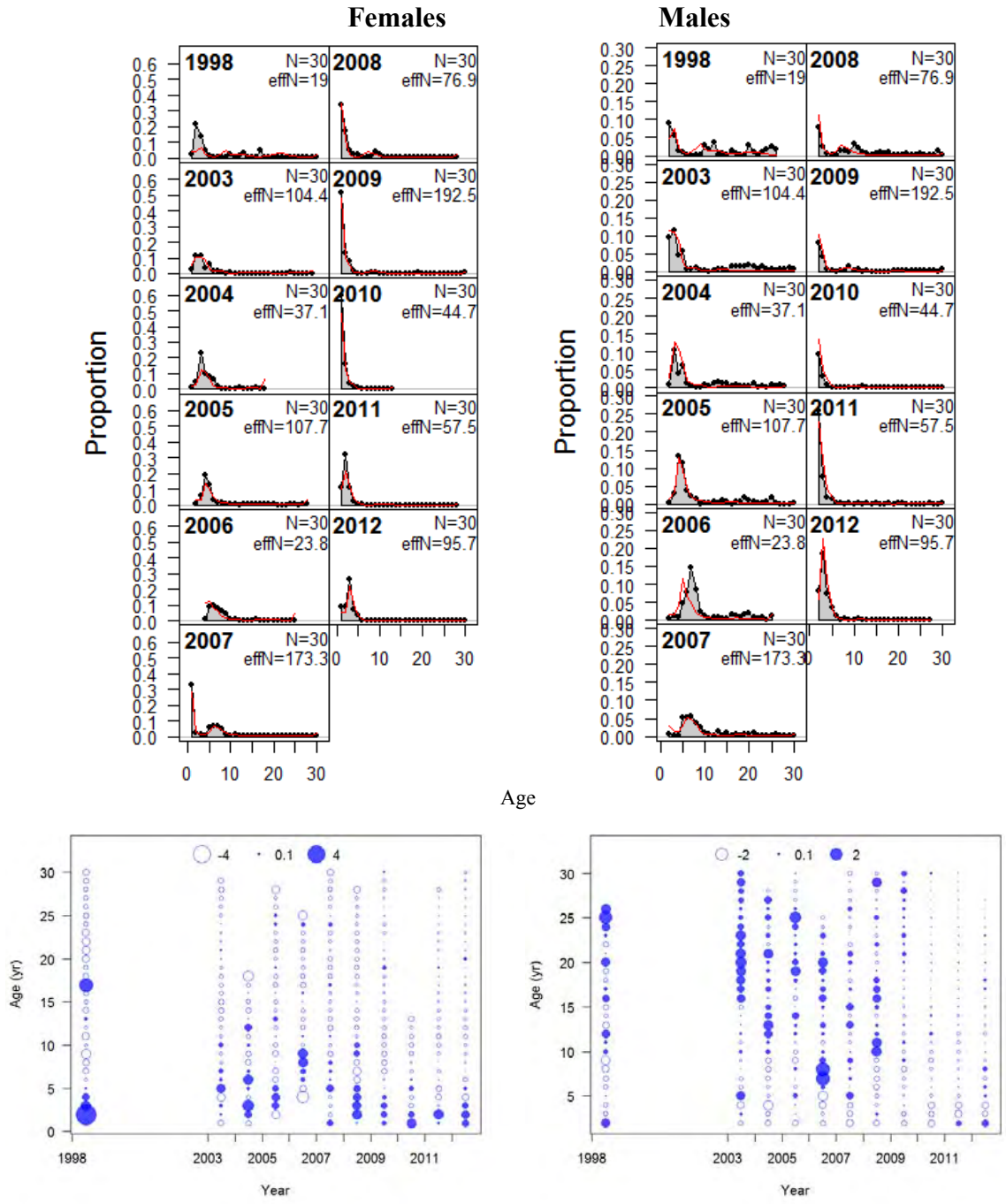


Figure 5.18. Shelf survey age composition data and Model 2 fits (red line) by year for females (top left panel) and males (top right panel). Shelf survey age composition Pearson residuals for females (bottom left panel) and males (bottom right panel).

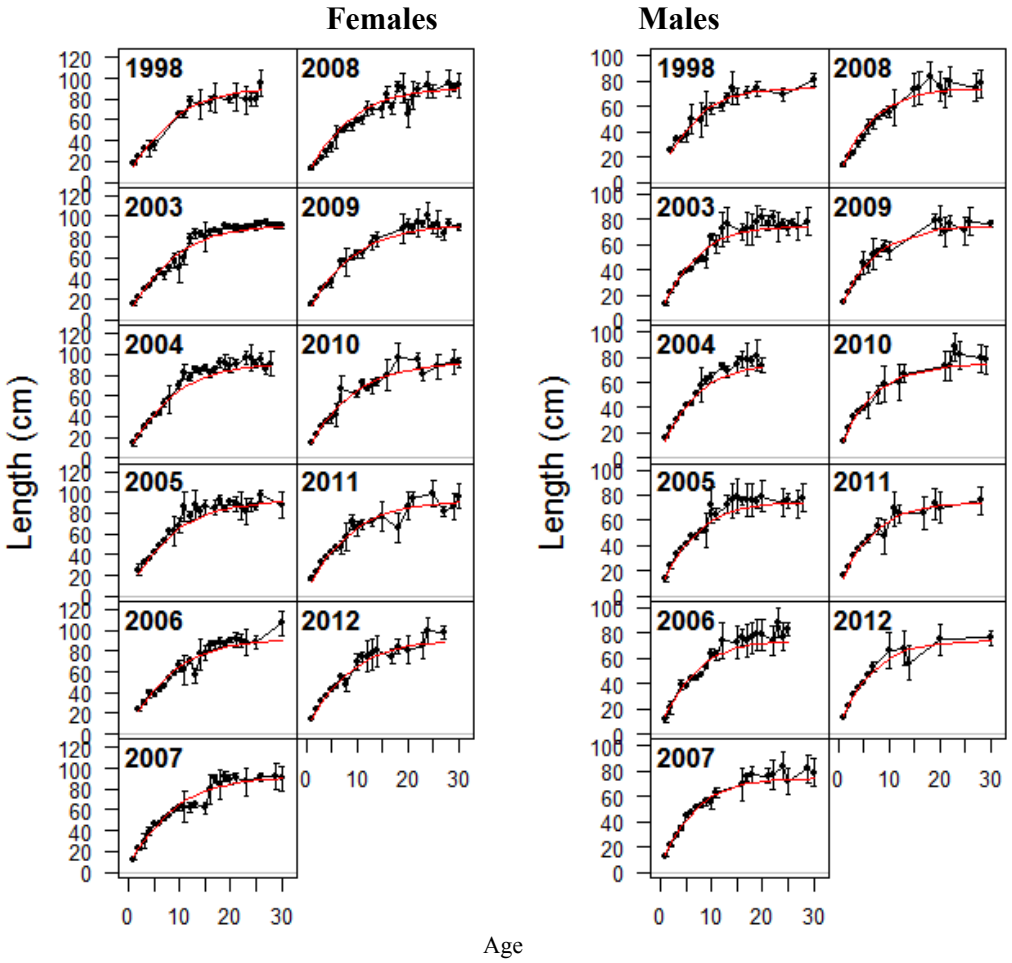


Figure 5.19. Length at age data and Model 2 fits (red line) by year for females (left panel) and males (right panel).

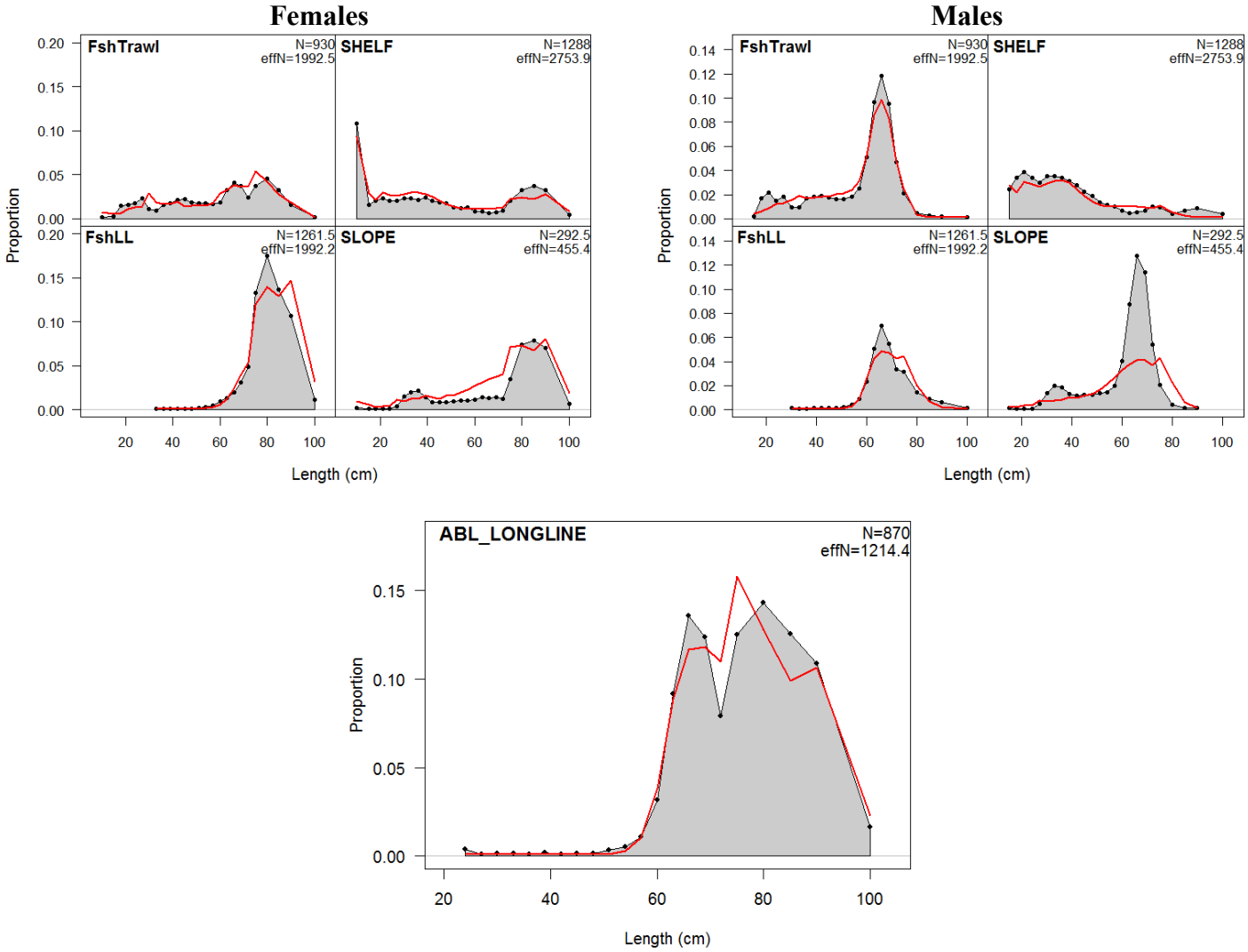


Figure 5.20. Greenland turbot size composition data combined across years and separated by sex (females in top left panel, males in top right panel) with Model 2 fits (red line) from the Trawl fishery (FshTrawl), longline fishery (FshLL), shelf survey (SHELF) and slope survey (SLOPE). ABL longline (bottom panel) size composition data are combined across years and sex.

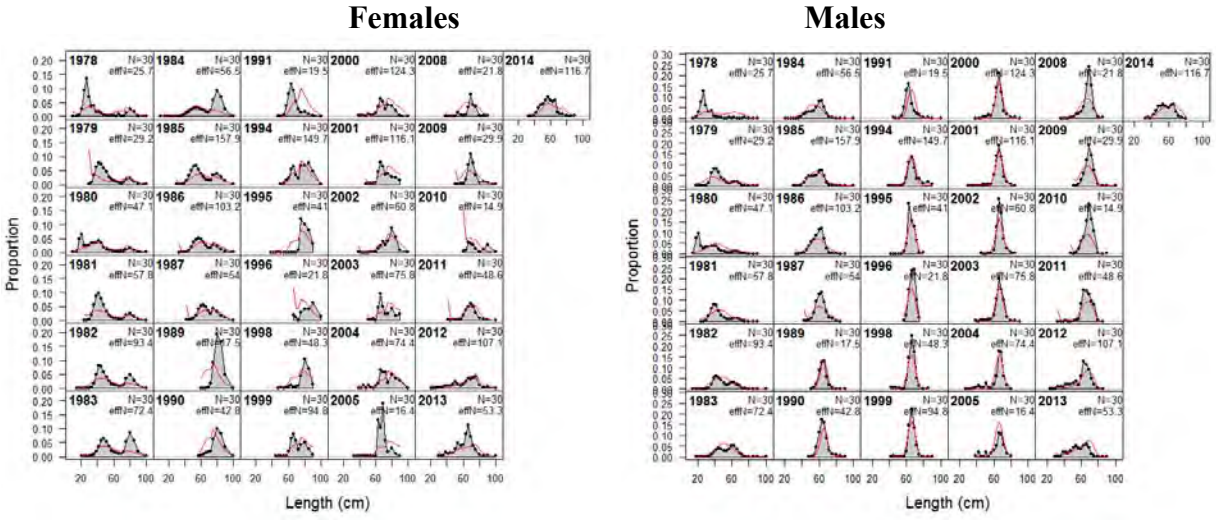


Figure 5.21. Trawl fishery size composition data and Model 2 fits (red line) by year for females (left panel) and males (right panel).

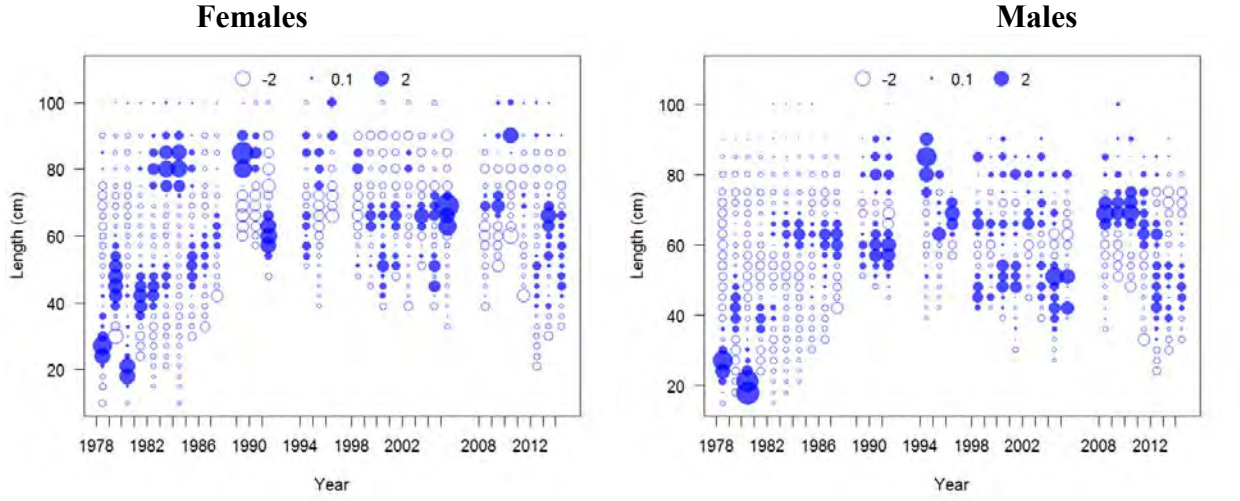


Figure 5.22. Trawl fishery size composition Pearson residuals for females (left panel) and males (right panel) .

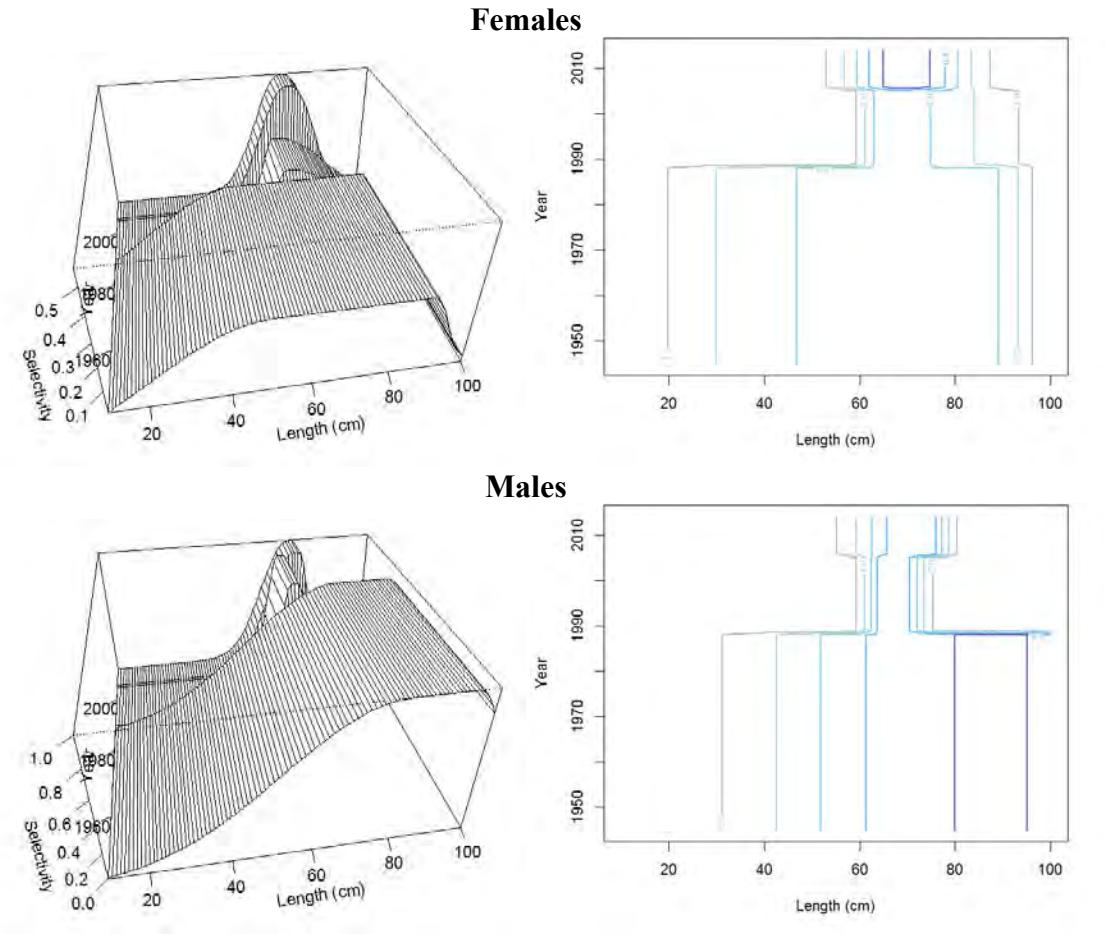


Figure 5.23. Time-varying selectivity at size for the trawl fishery for Model 2 for females (top) and males (bottom).

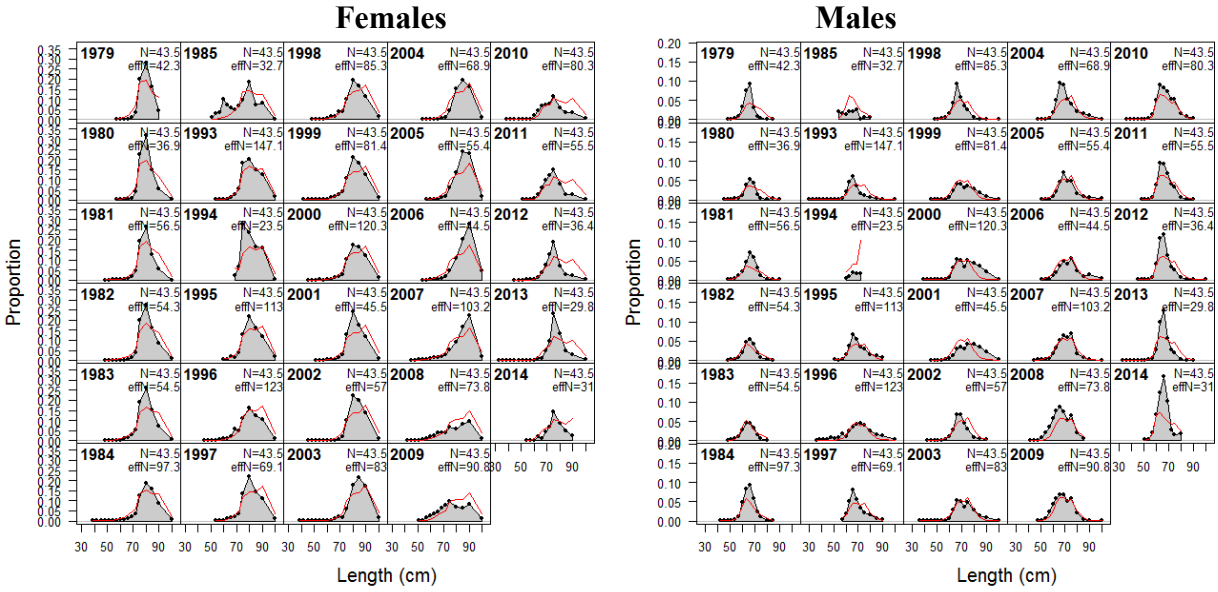


Figure 5.24. Longline fishery size composition data and Model 2 fits (red line) by year for females (left panel) and males (right panel).

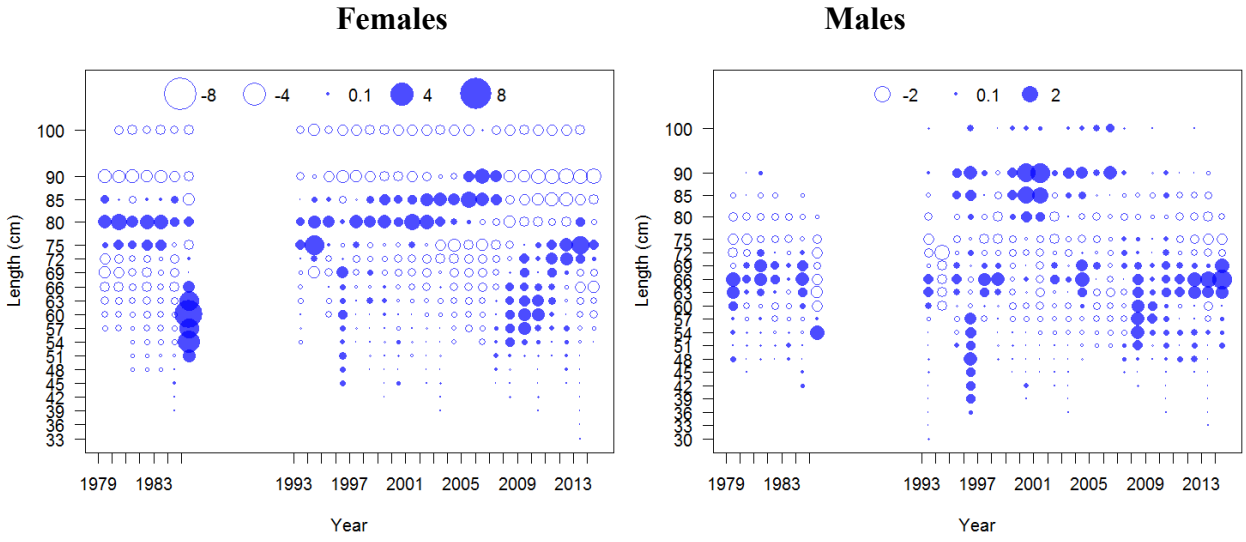


Figure 5.25. Longline fishery size composition Pearson residuals for females (left panel) and males (right panel).

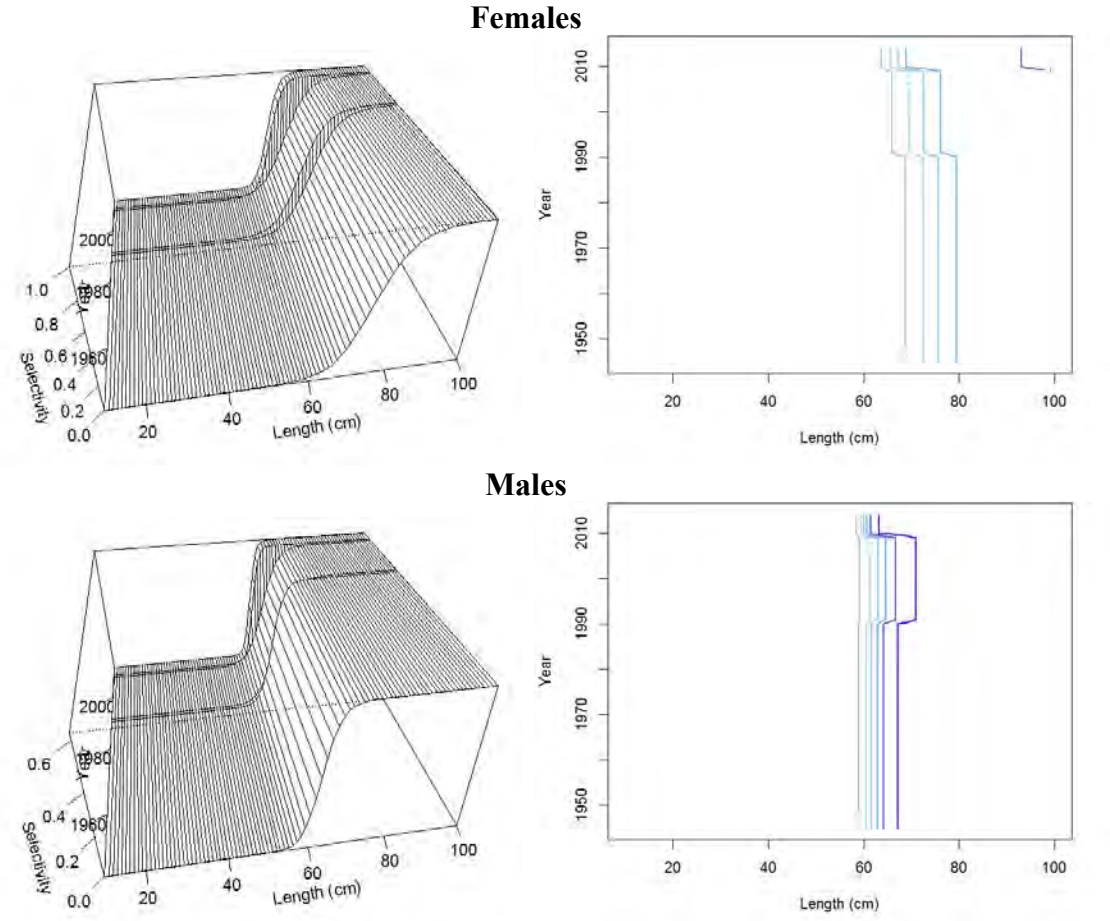


Figure 5.26. Time-varying selectivity at size for the longline fishery for Model 2 for females (top) and males (bottom). Notice the y-axes and scales are different.

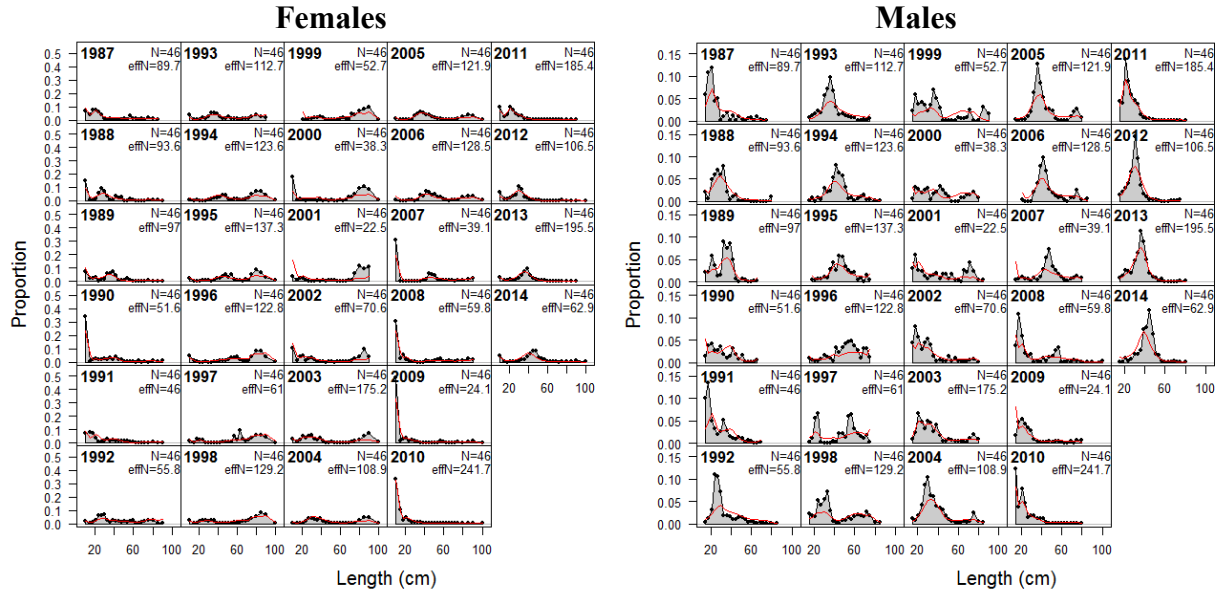


Figure 5.27. Shelf survey size composition data and Model 2 fits (red line) by yearfor females (left panel) and males (right panel).

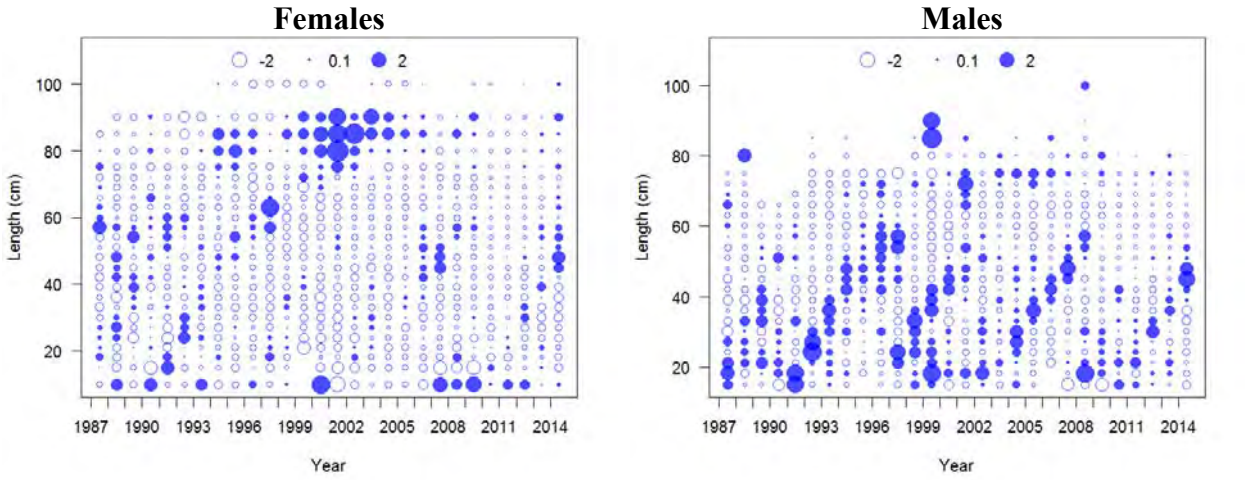


Figure 5.28. Shelf survey size composition Pearson residuals for females (left panel) and males (right panel) . Closed bubbles are positive residuals and open bubbles are negative residuals.

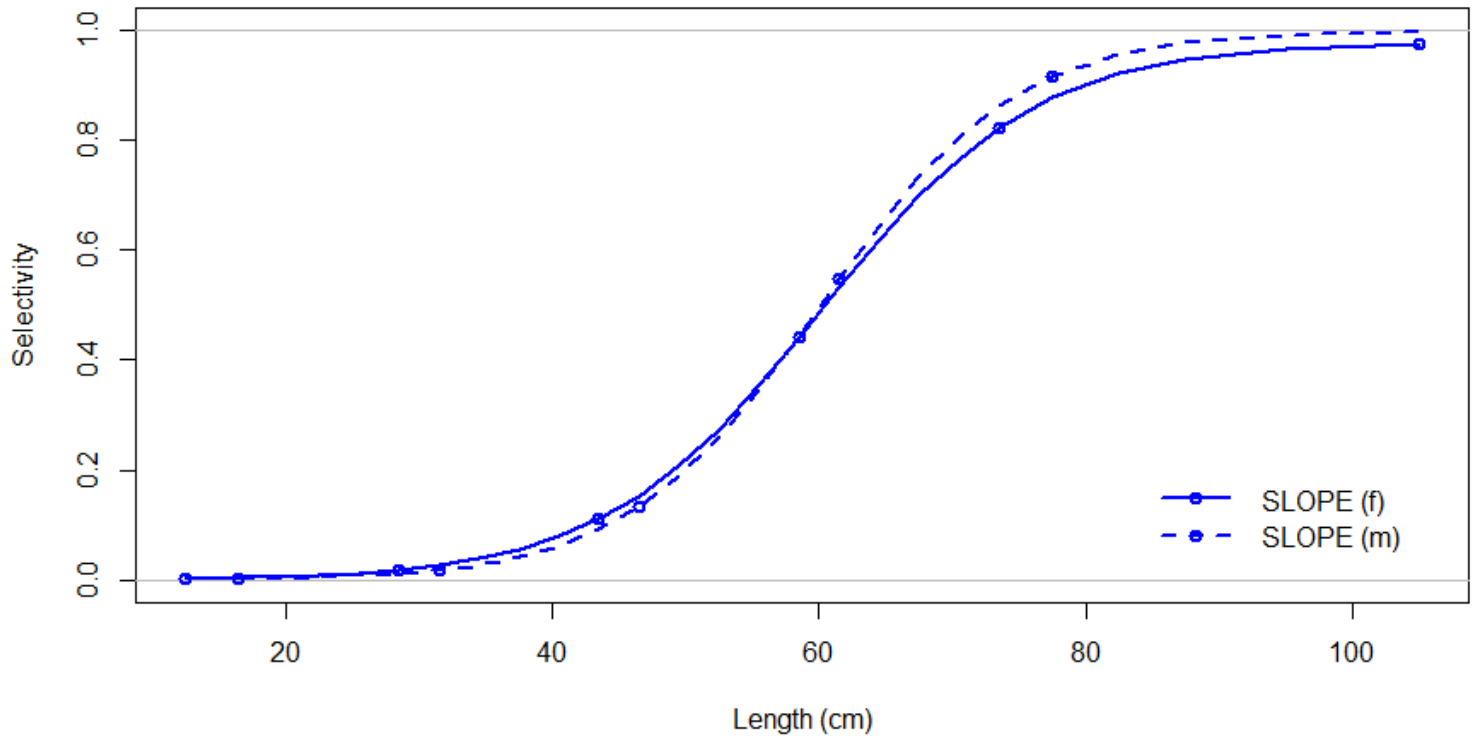


Figure 5.29. The slope survey size selectivity by sex (solid line = females, dashed line = males) for all years combined for Model 2.

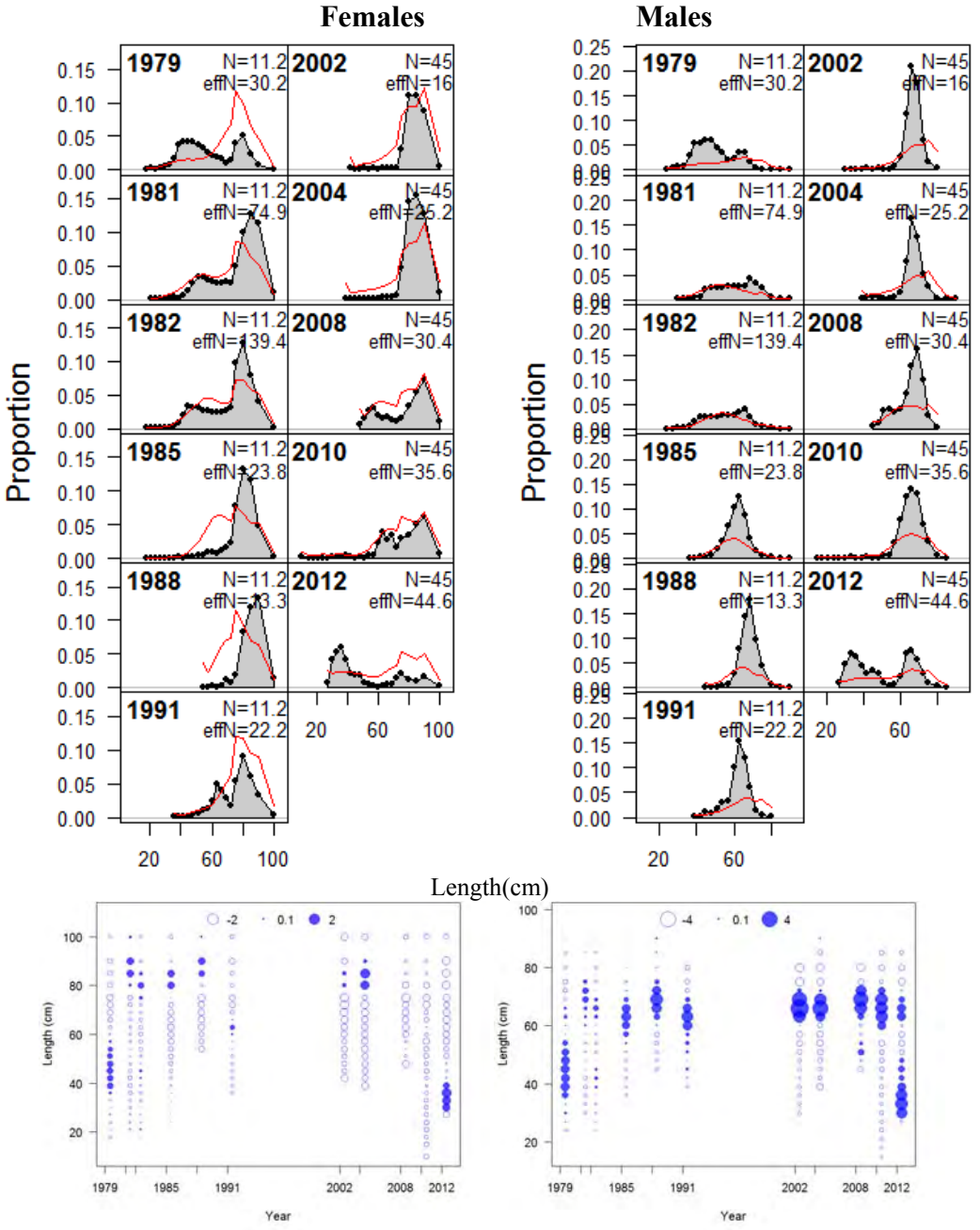


Figure 5.30. Slope survey size composition data and Model 2 fits (red line) by year for females (top left panel) and males (top right panel). Slope survey size composition Pearson residuals for females (bottom left panel) and males (bottom right panel).

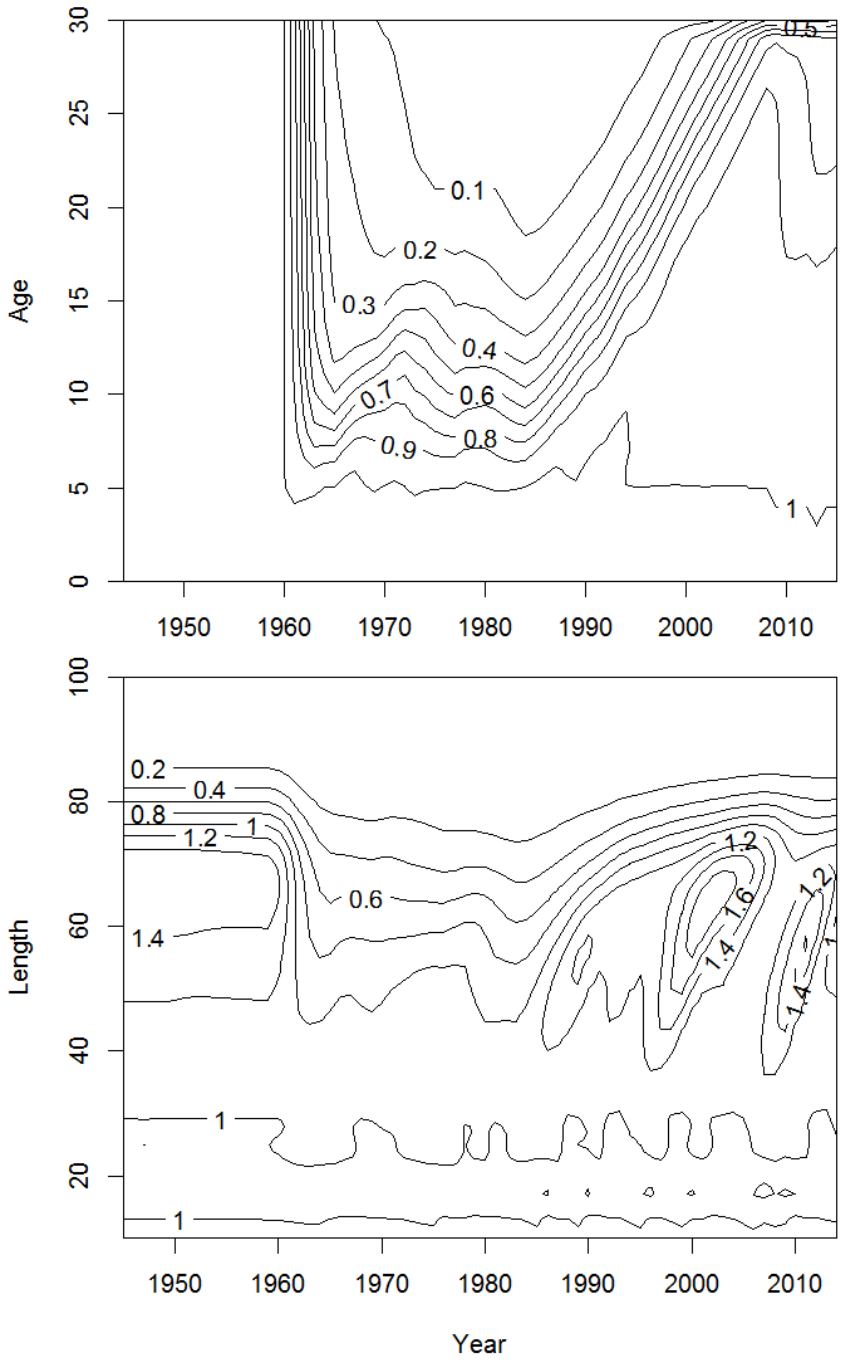


Figure 5.31. BSAI Greenland turbot sex ratio (males:females) by age (top panel) and size (bottom panel).

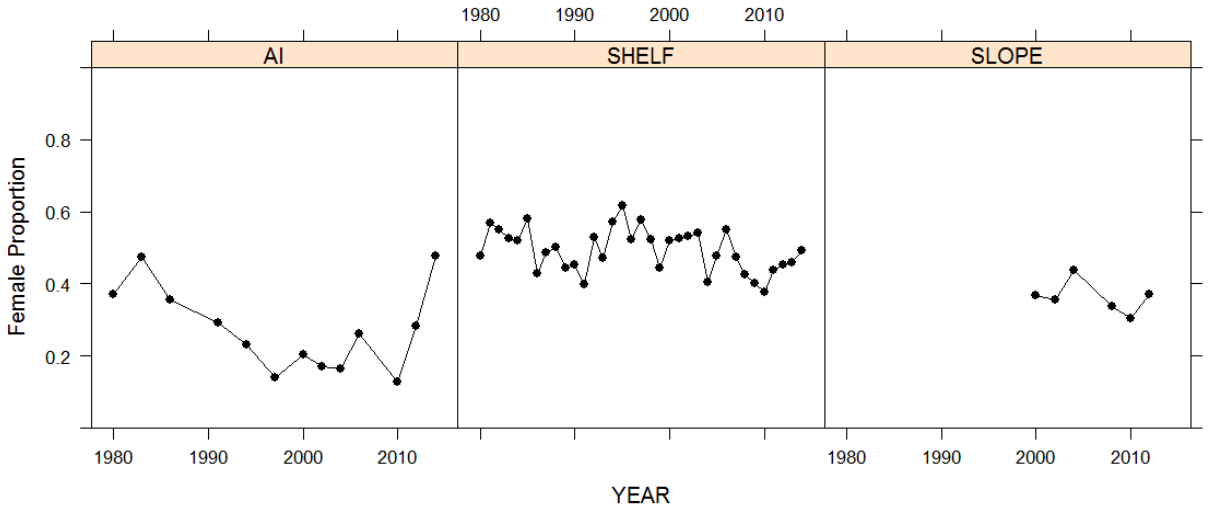


Figure 5.32. Proportion of females in the size composition data by survey and year. AI = Aleutian Islands trawl survey, Shelf = EBS shelf trawl survey, and Slope = EBS slope trawl survey.

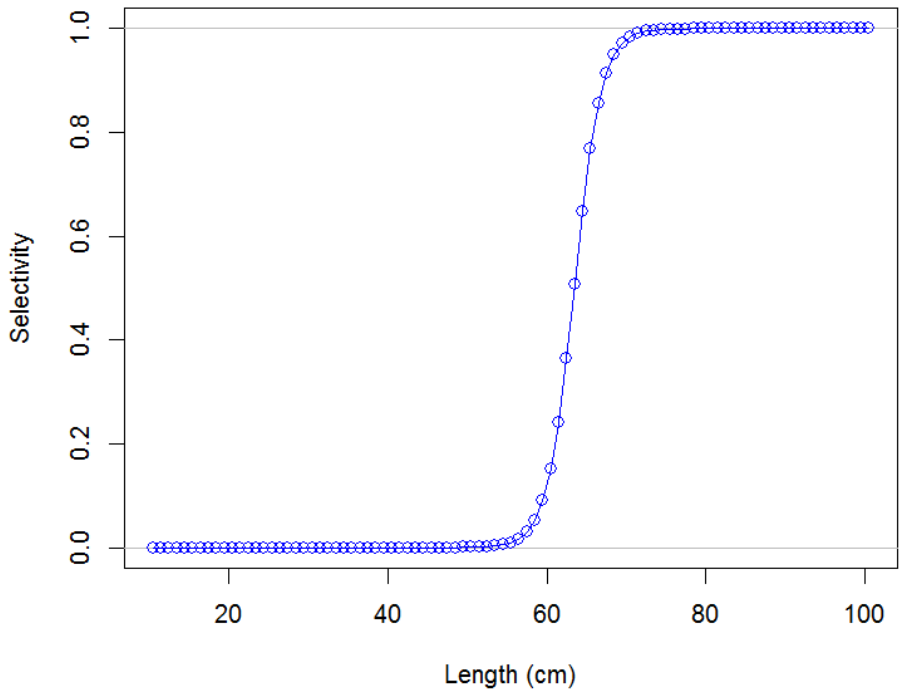


Figure 5.33. TheABL longline survey size selectivity for both sexes and all years combined for Model 2.

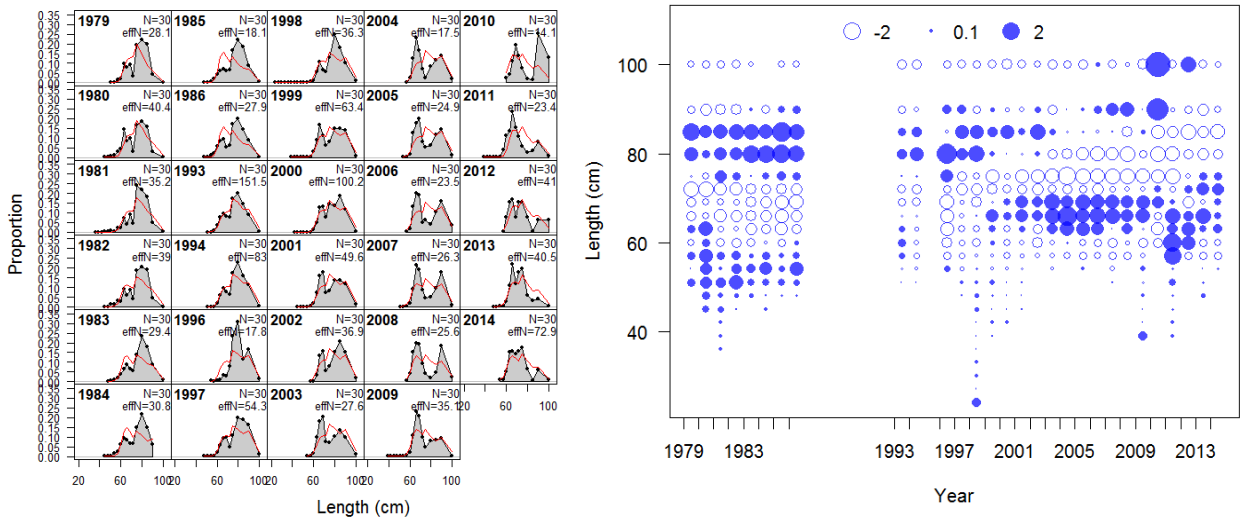


Figure 5.34. Auke Bay Laboratory longline survey size composition data and Model 2 fits (red line) by year for combined sexes (left panel). Auke Bay Laboratory longline survey size composition Pearson residuals (right panel).

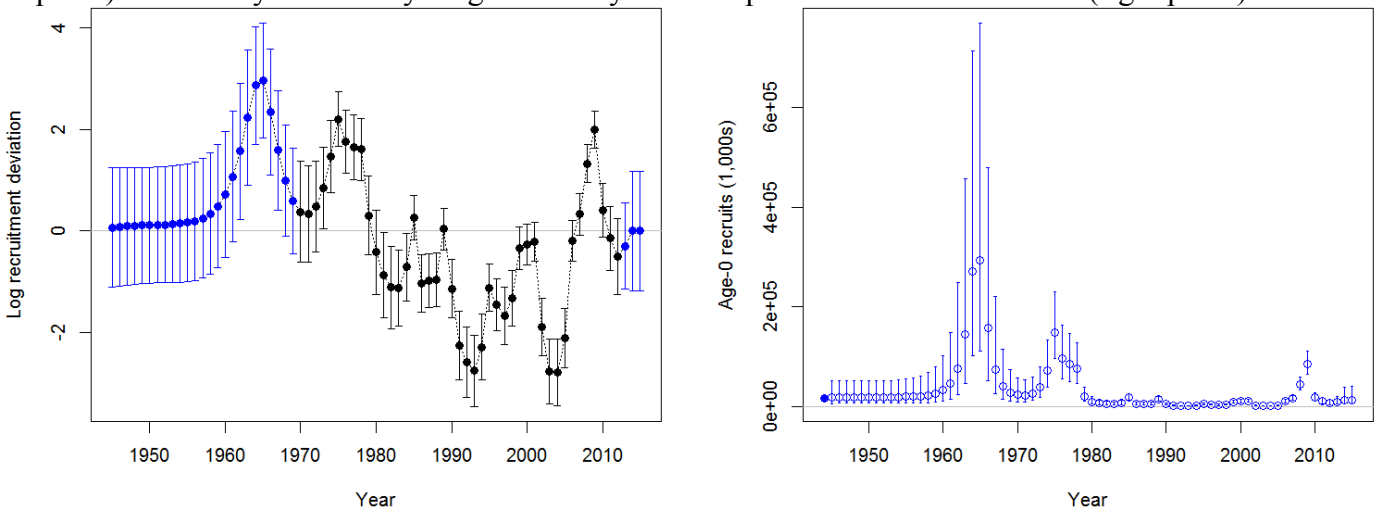


Figure 5.35. Log recruitment deviations (left panel) and age-0 recruits (right panel) in thousands for Model 2.

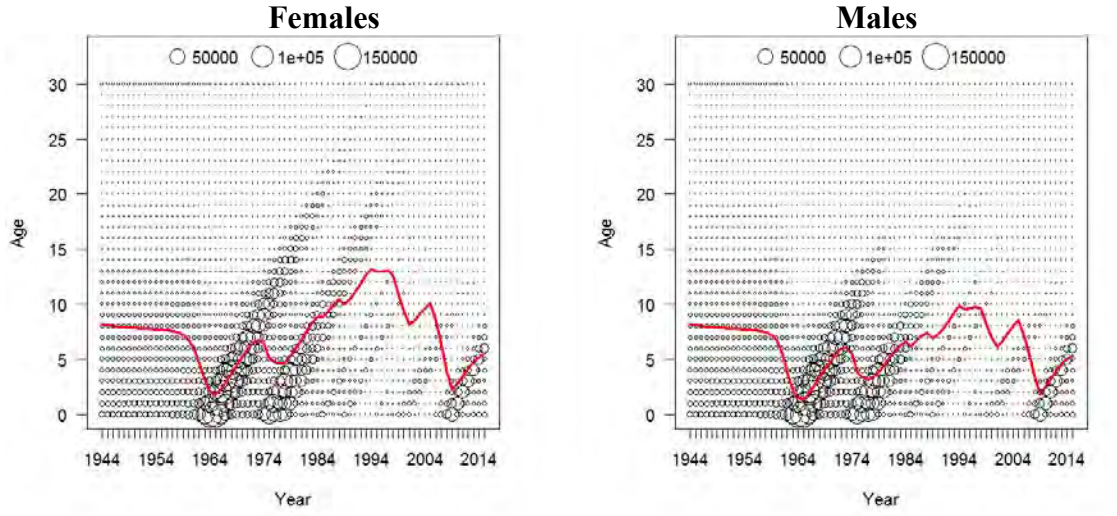


Figure 5.36. Model 2 BSAI Greenland turbot numbers at age and mean age by year (red line) for females (left panel) and males (right panel).

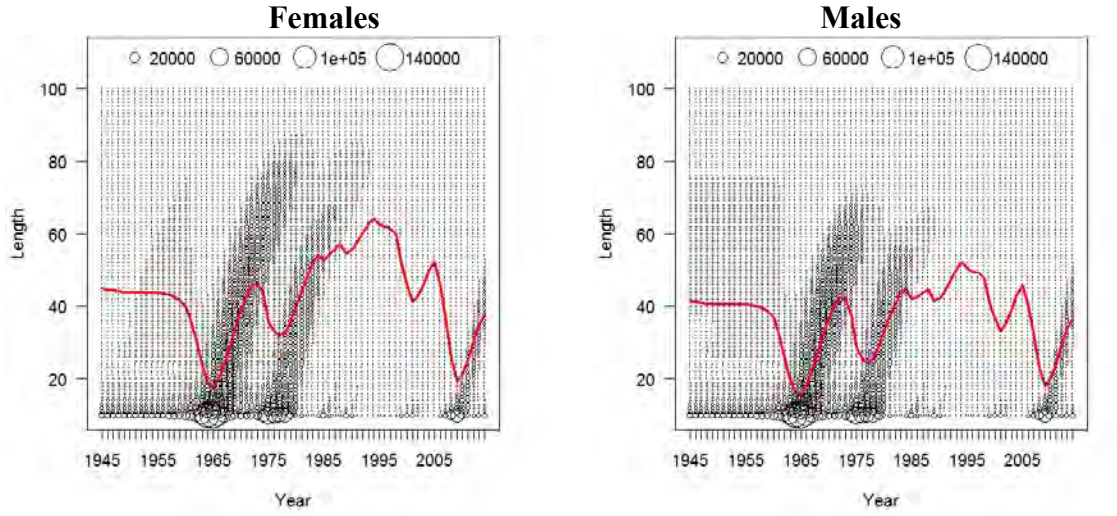


Figure 5.37. Model 2 BSAI Greenland turbot numbers at size and mean size by year (red line) for females (left panel) and males (right panel).

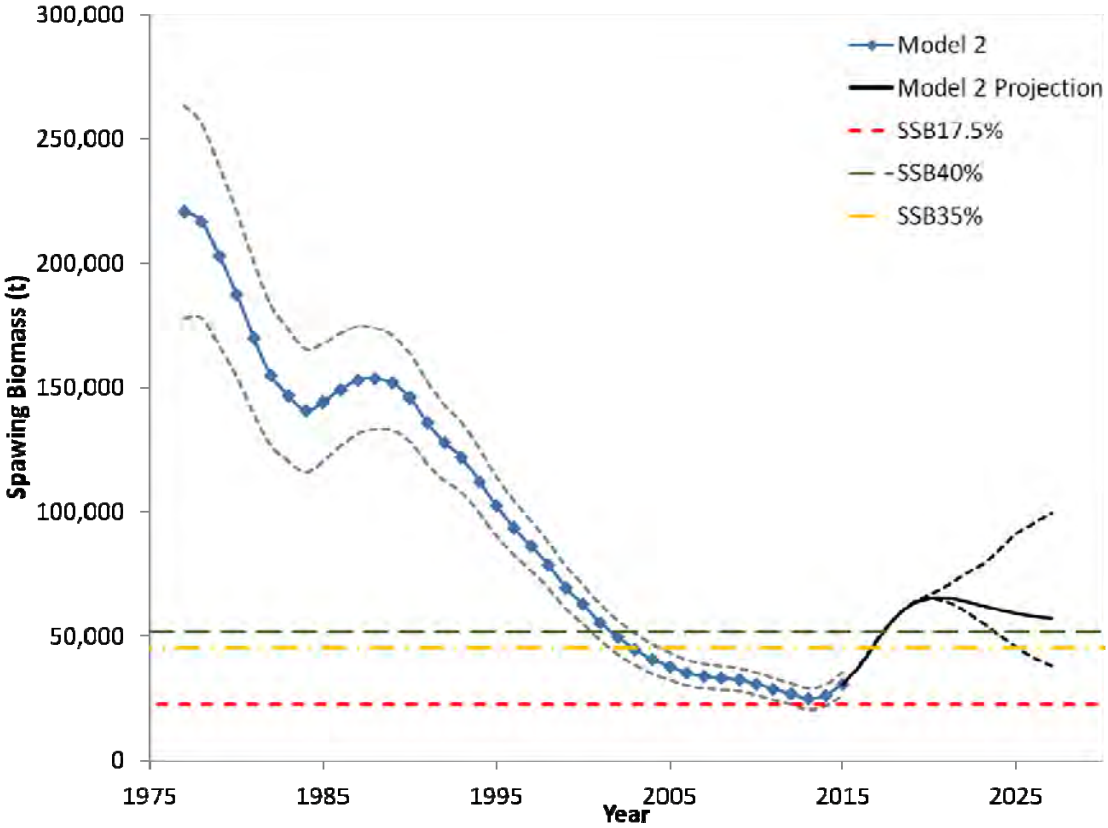


Figure 5.38. Female spawning biomass in tons for BSAI Greenland turbot for Model 2 with reference levels and projection to 2027 from Alternative 1 $F_{40\%}$ fishing levels. Model error bars (gray dashed lines) are 95% confidence intervals based on the inverted Hessian, projection error bars are 95% credible intervals based on 1,000 simulations (black dashed lines).

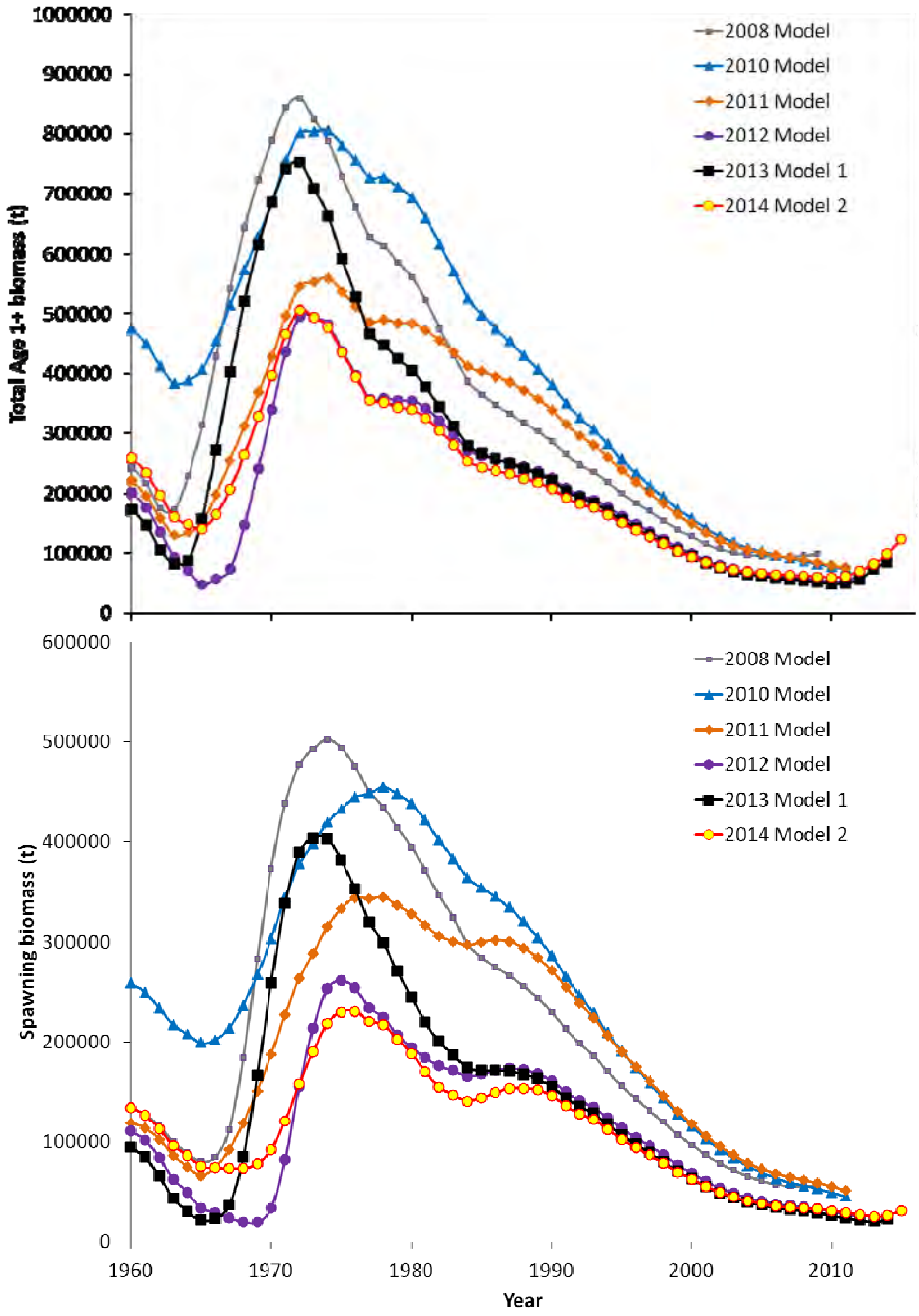


Figure 5.39. Total age +1 biomass (t; top panel) and female spawning biomass in tons (bottom panel) for BSAI Greenland turbot for this year's Model 2 and previous years' stock assessment models.

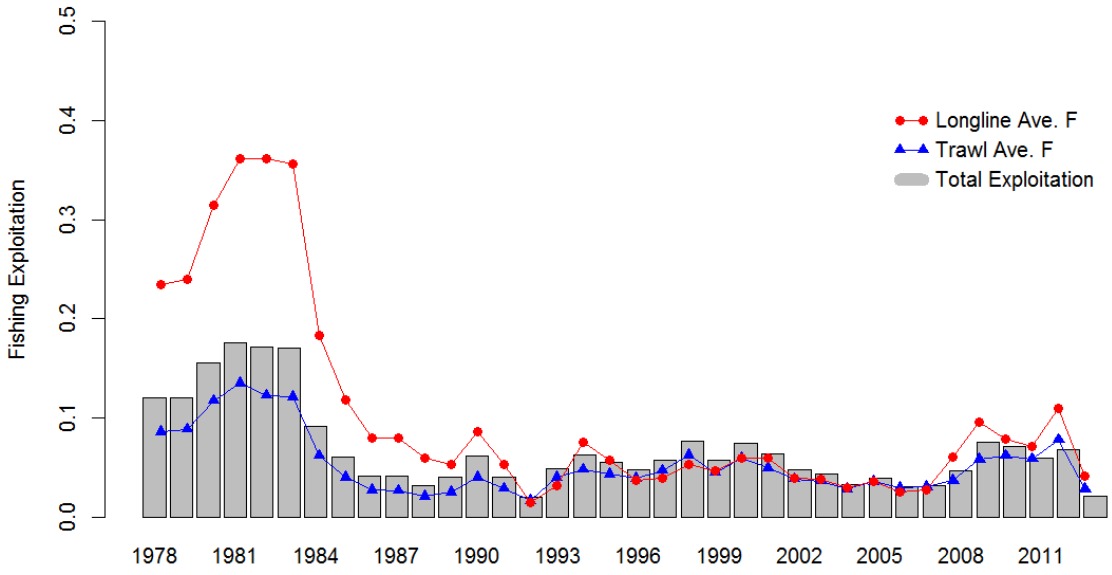


Figure 5.40. BSAI Greenland turbot total exploitation rate (bars) and average Fs for the trawl (blue line with triangles) and longline (red line with circles) fisheries.

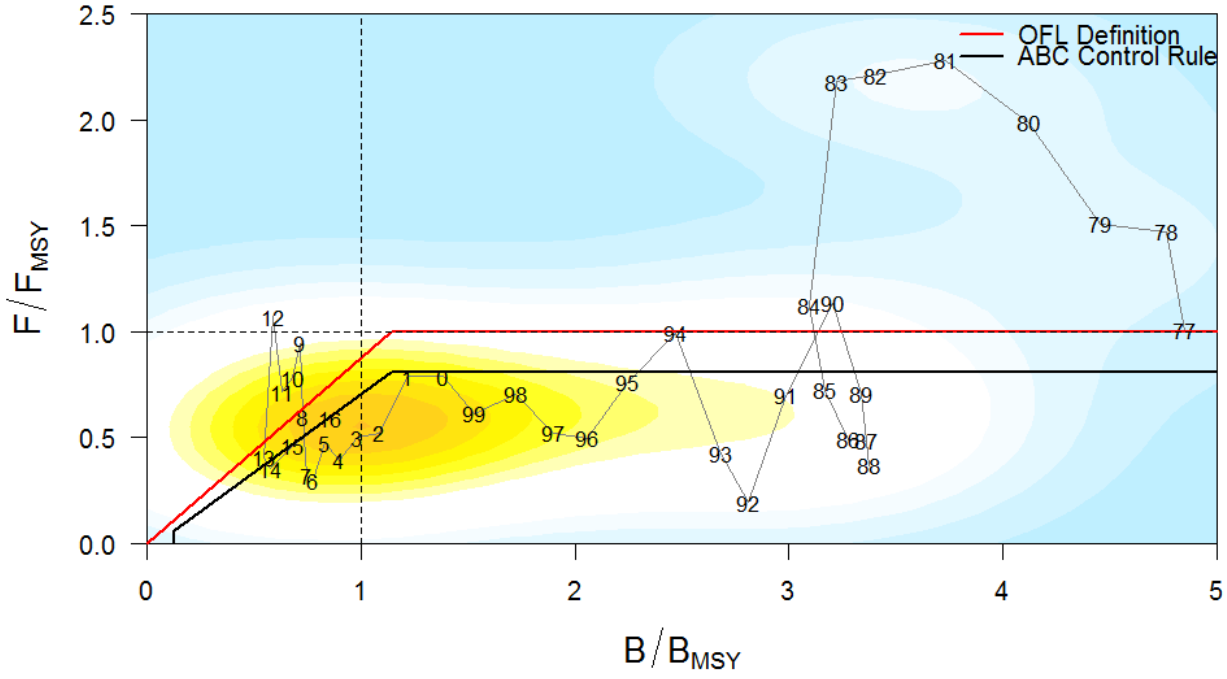


Figure 5.41. Ratio of historical F/F_{msy} versus female spawning biomass relative to B_{msy} for BSAI Greenland turbot, 1977-2016. Note that the proxies for F_{msy} and B_{msy} are $F_{35\%}$ and $B_{35\%}$, respectively. The Fs presented are the sum of the full Fs across fleets.

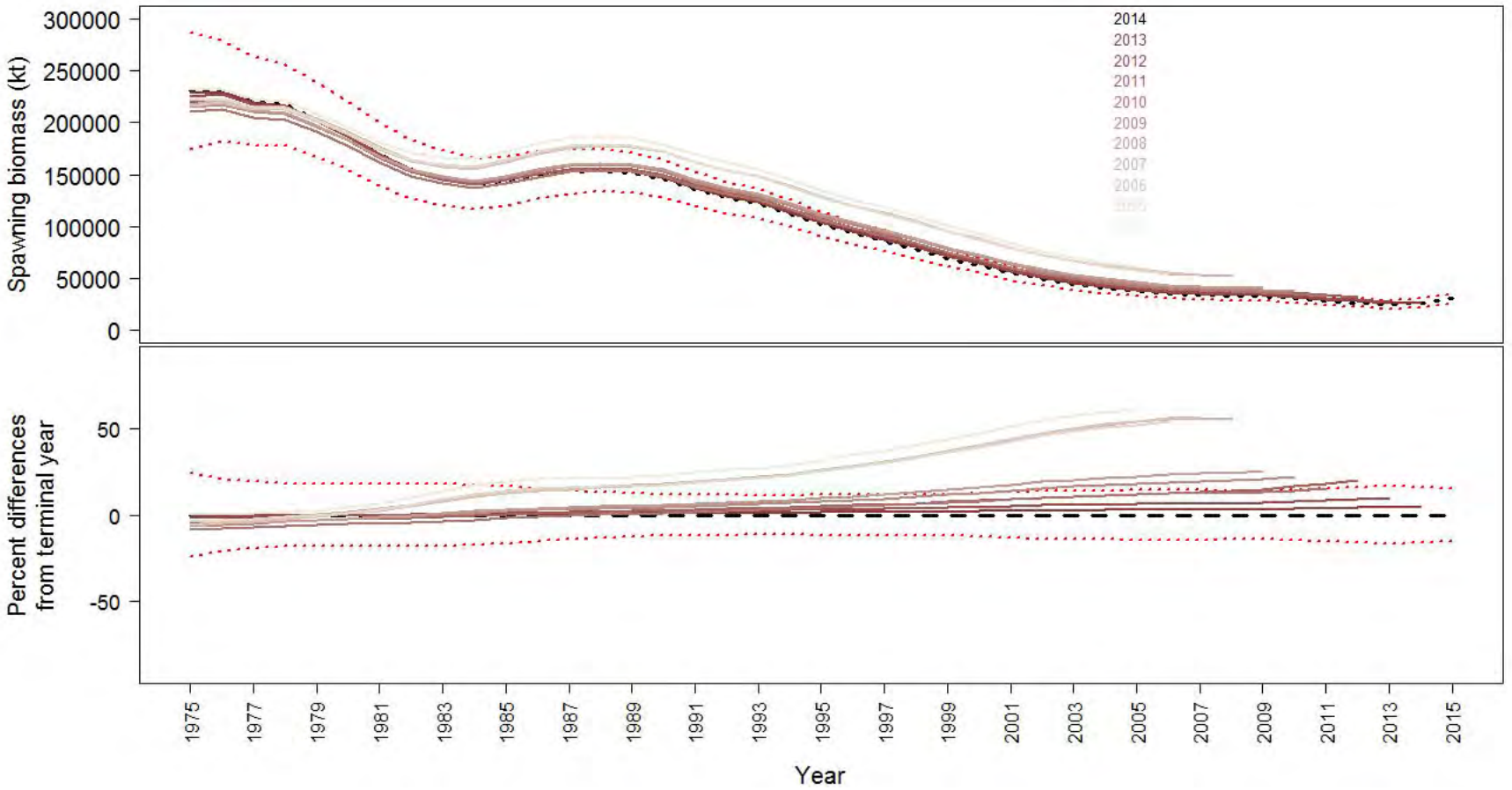


Figure 5.42. Model 2 retrospective analysis plot of spawning biomass (top panel) and change in spawning biomass per year for the retrospective runs (bottom panel).

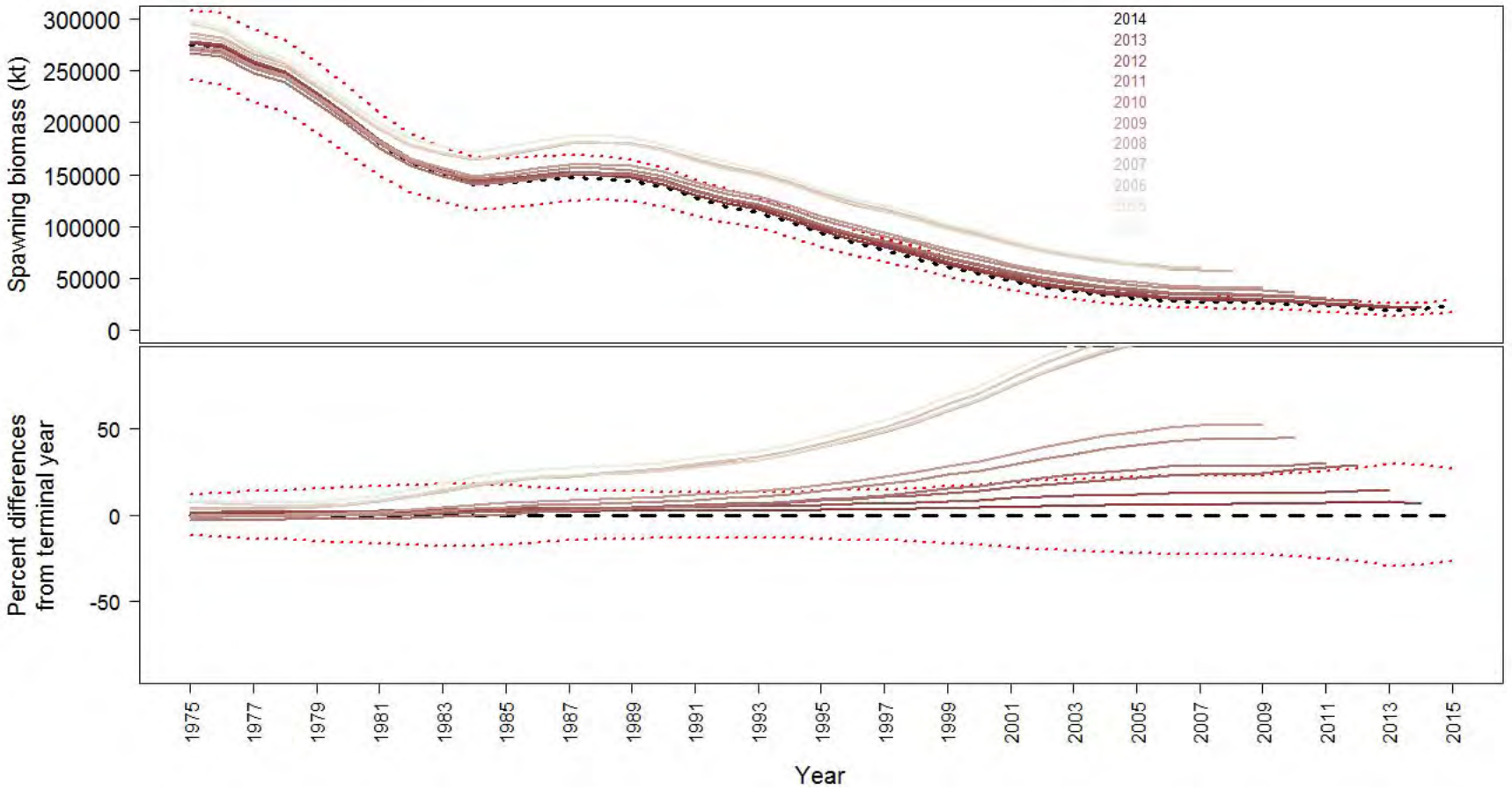


Figure 5.43. Model 1 retrospective analysis plot of spawning biomass (top panel) and change in spawning biomass per year for the retrospective runs (bottom panel).

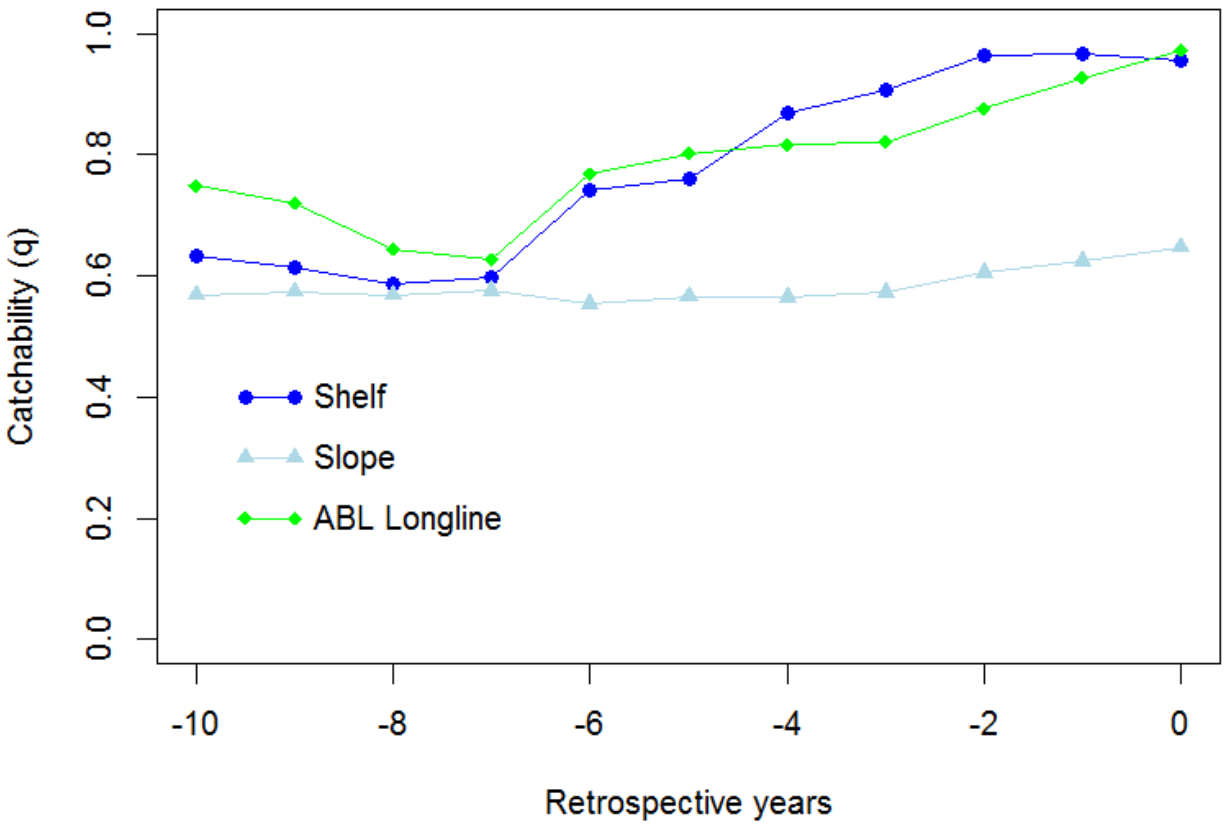


Figure 5.44. Model 1 retrospective analysis plot of catchability (q) for shelf, slope, and ABL longline surveys.

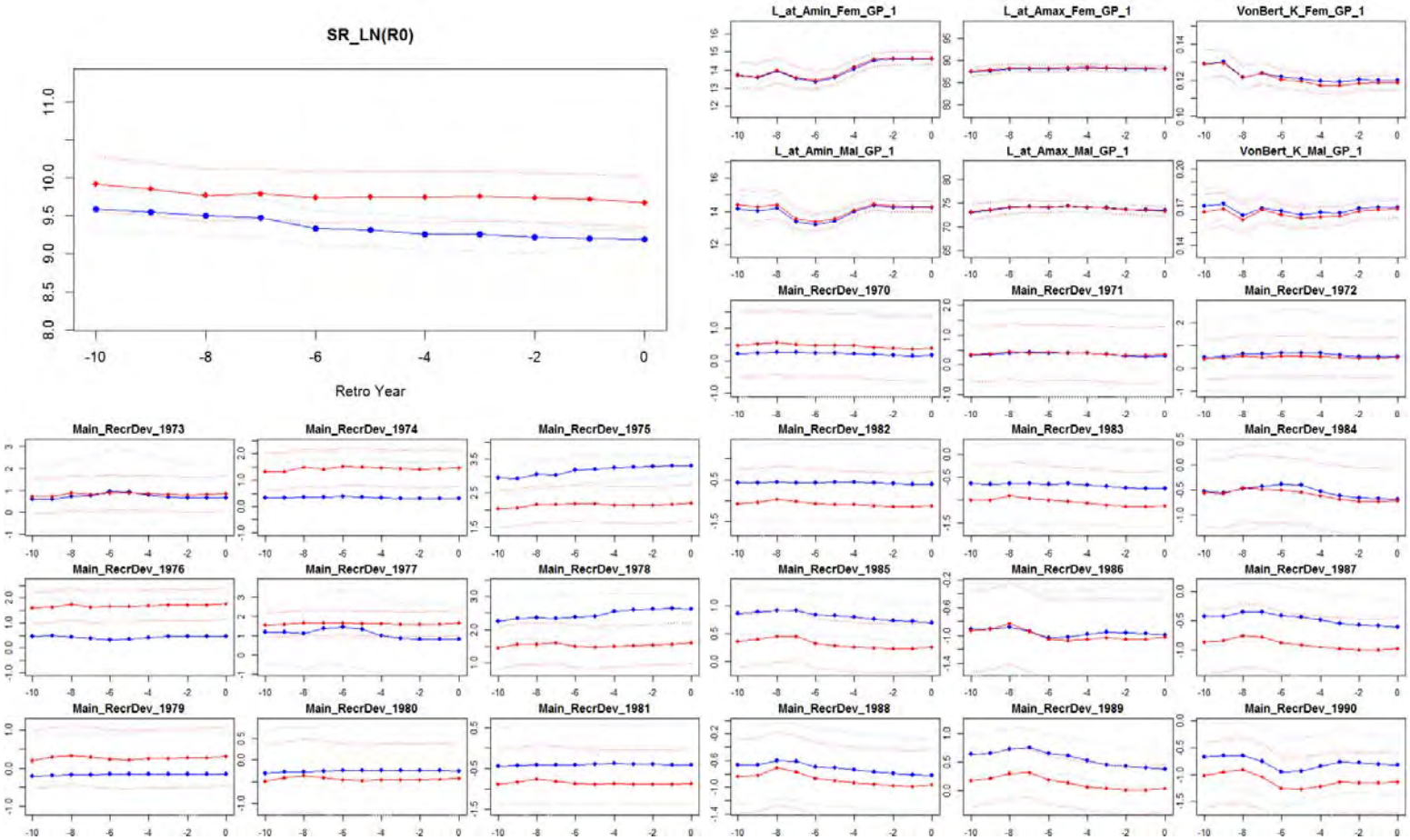


Figure 5.45. Model parameters with 10-year retrospective for Model 1 (blue) and Model 2 (red).

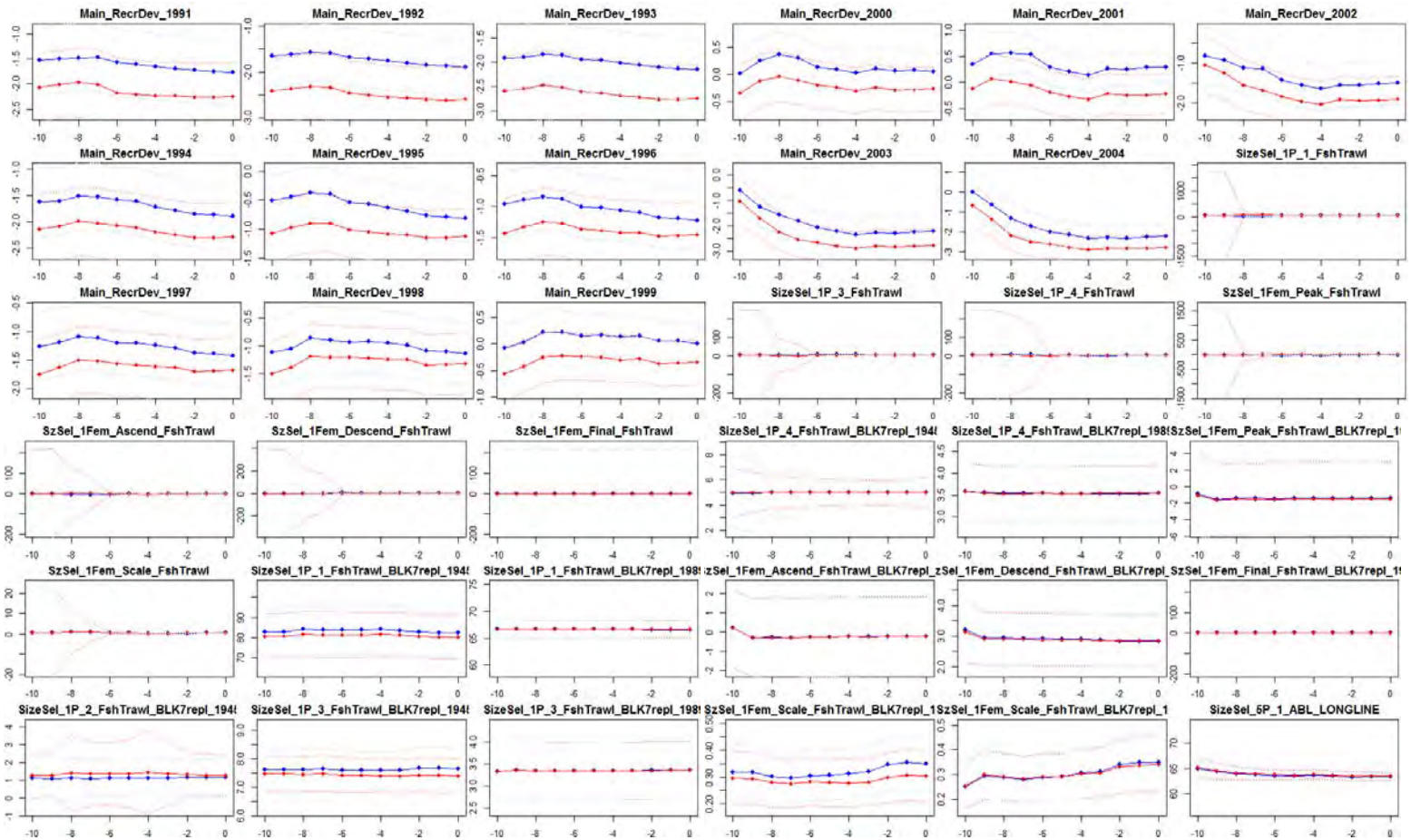


Figure 5.45 cont. Model parameters with retrospective for Model 1 (blue) and Model 2 (red).

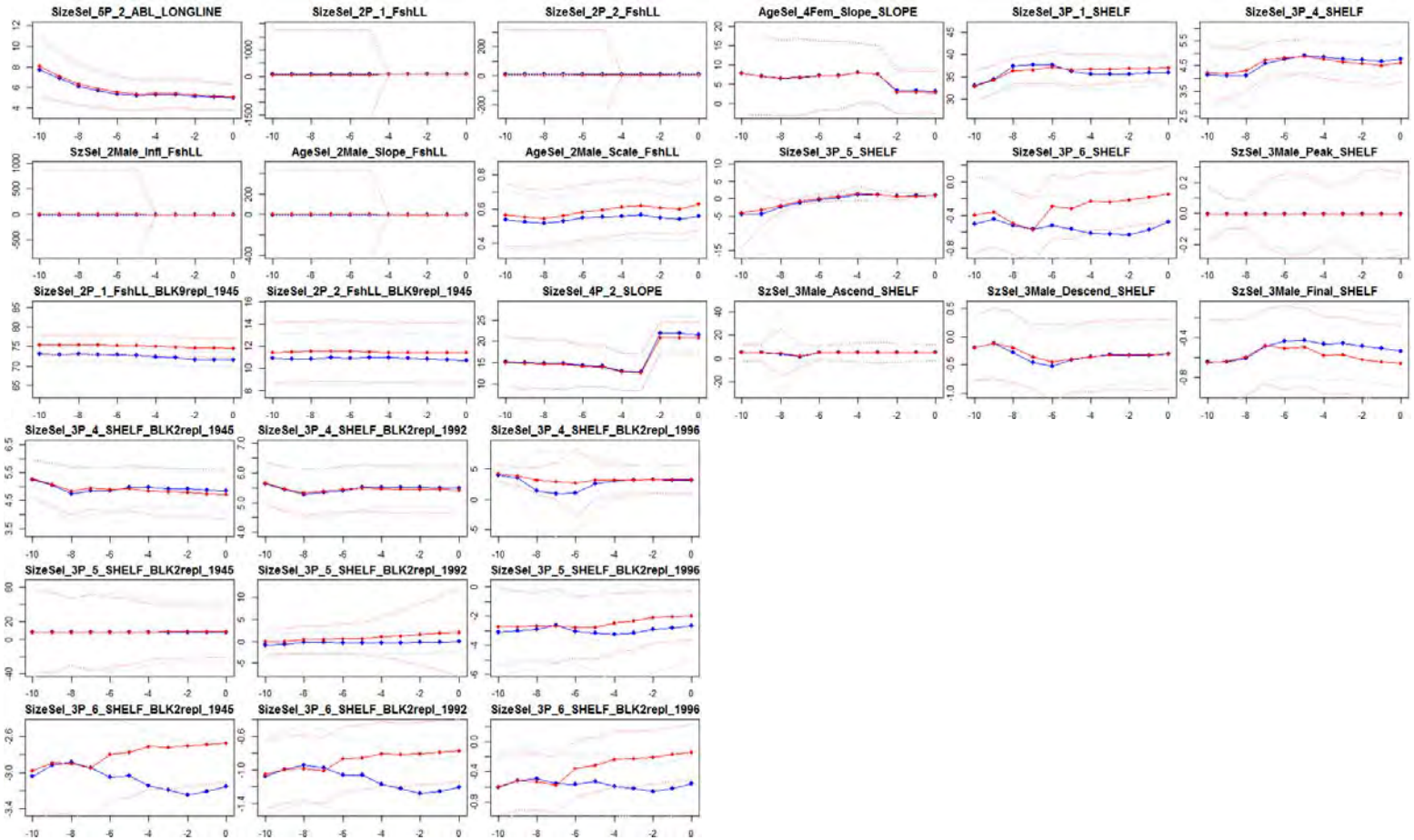


Figure 5.45 cont. Model parameters with retrospective for Model 1 (blue) and Model 2 (red).

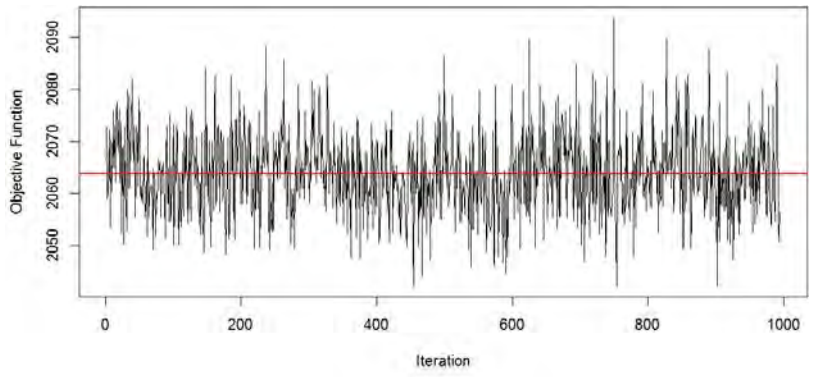


Figure 5.46. MCMC trace of Model 2 objective function for 2,000,000 runs with a 10,000 burn in and thinned to every 2000th iteration. Red line is the median objective function.

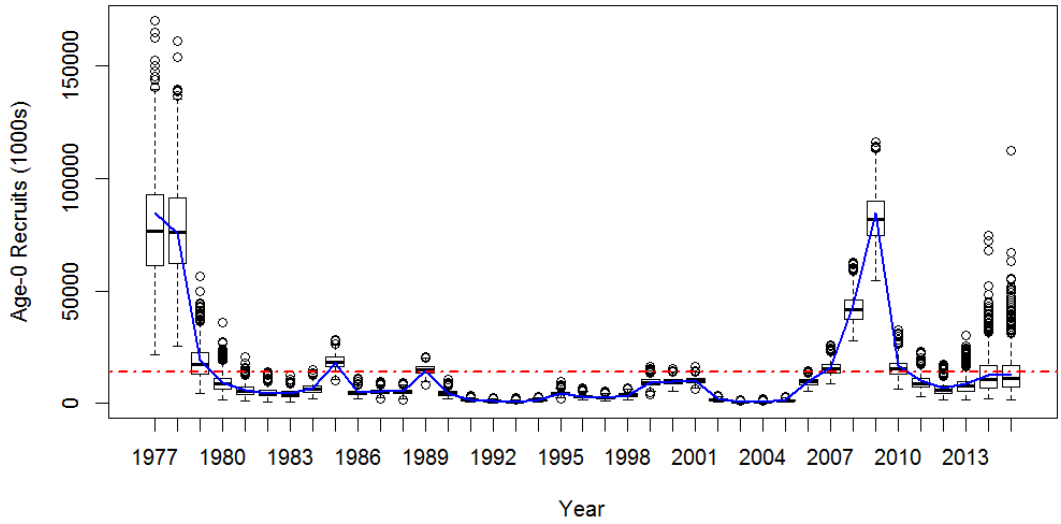


Figure 5.47. Boxplot of posterior distribution of age-0 recruits (1,000s), MLEs (blue line) and MLE mean recruitment for 1977-2013 (red dot-dash line).

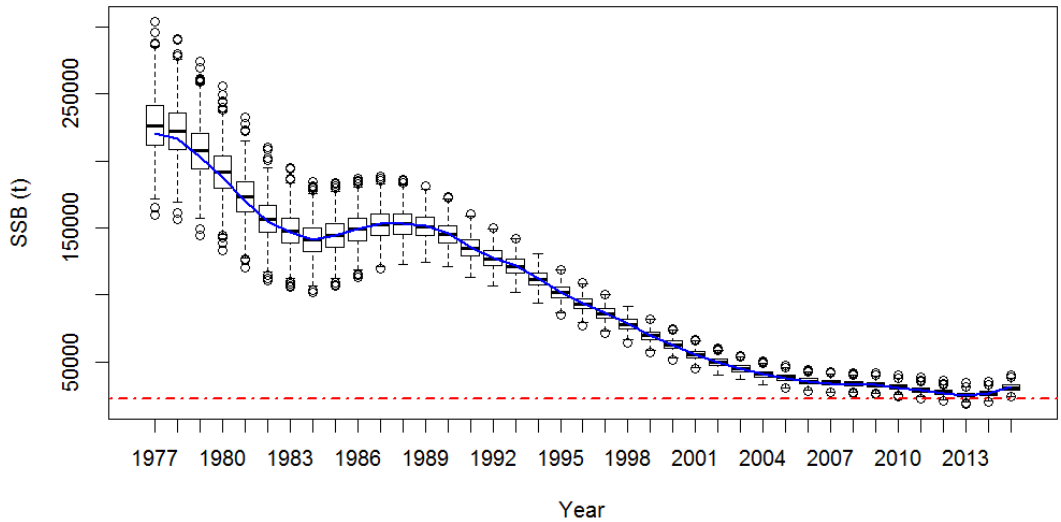


Figure 5.48. Boxplot of posterior distribution of female spawning biomass, MLEs (blue line), and MLE projected $SSB_{17.5\%}$ (red dot-dash line).

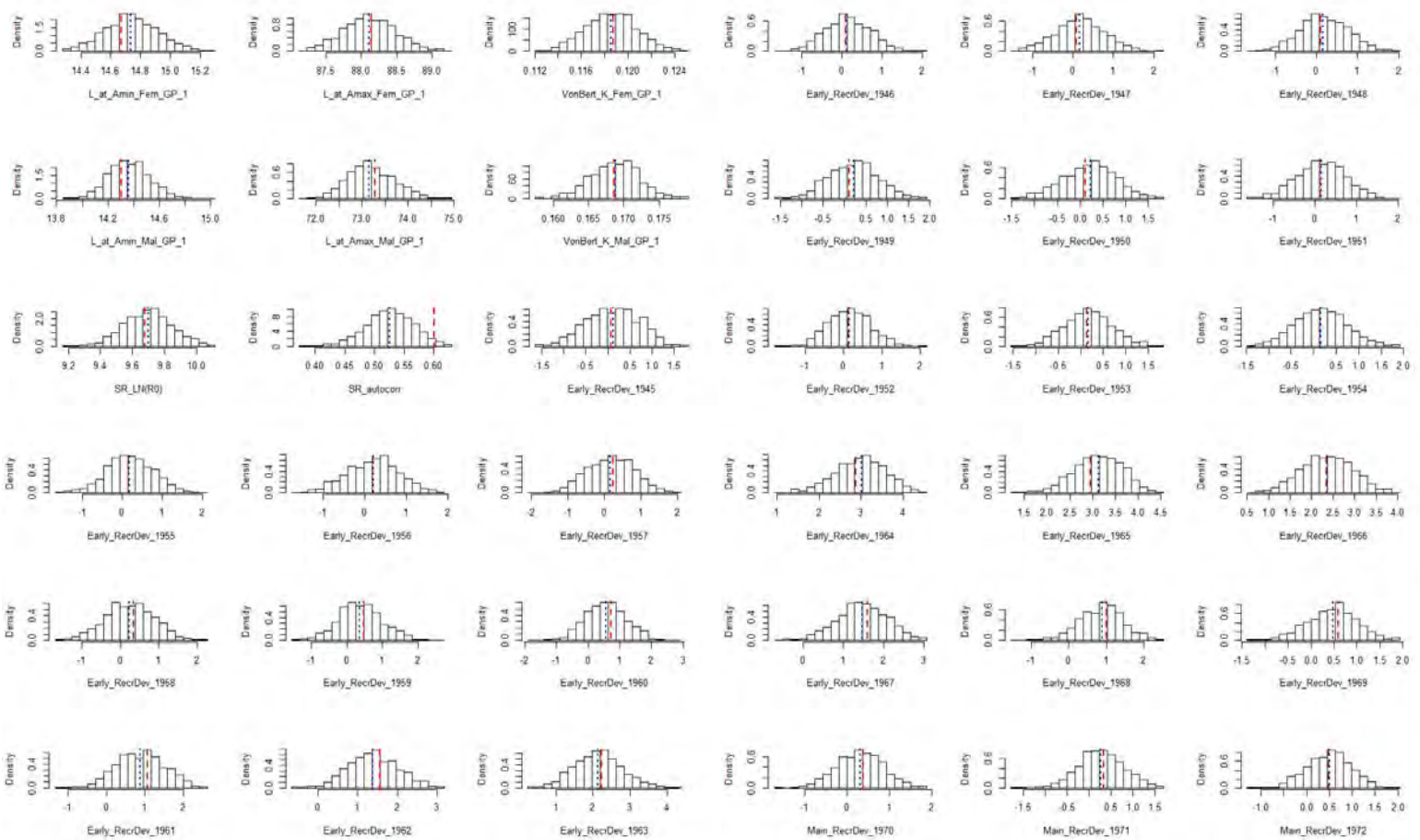


Figure 5.49. Posterior densities for Model 2 parameters, red dashed line is the maximum likelihood estimate, blue dotted line is the posterior median.

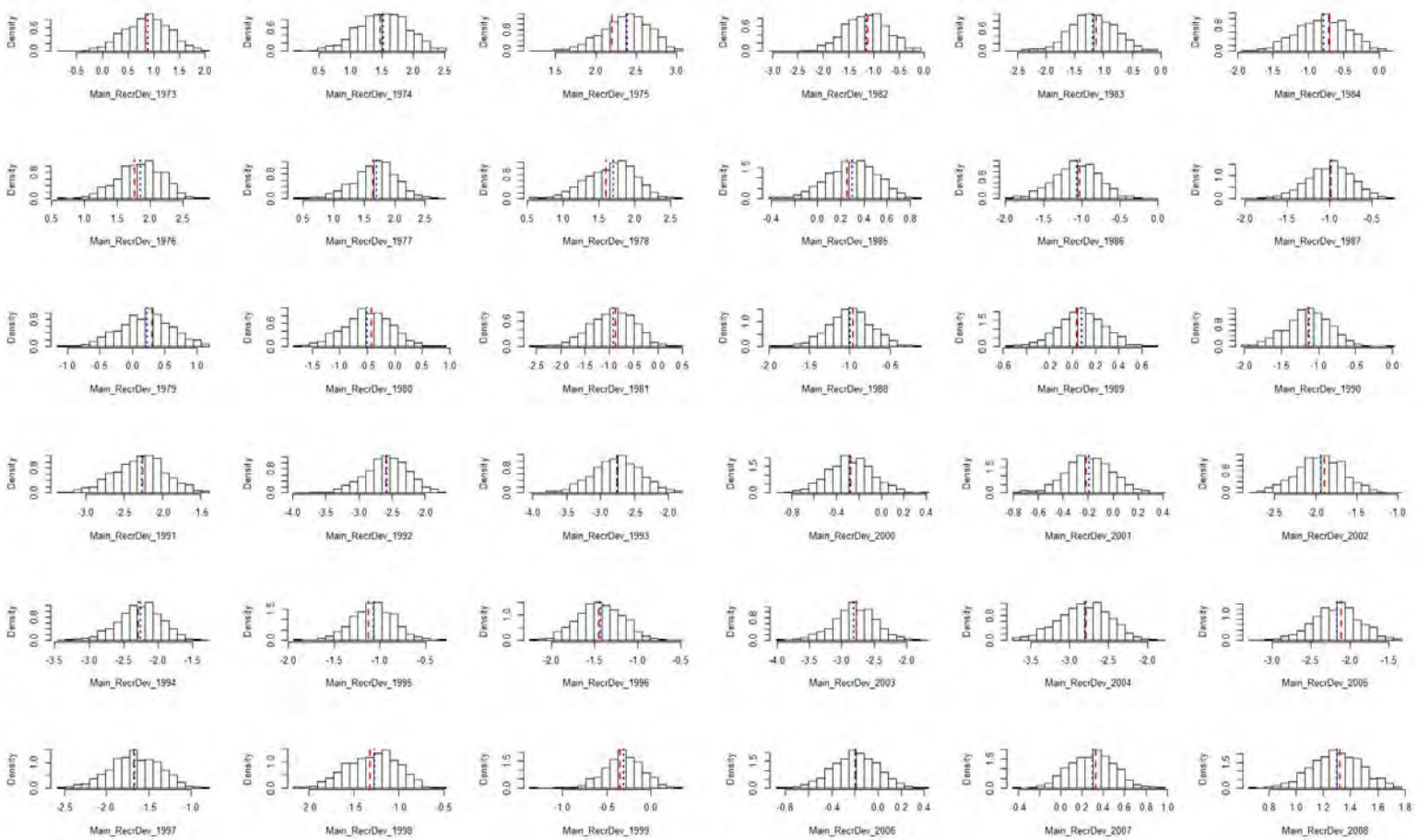


Figure 5.49 cont. Posterior densities for Model 2 parameters, red dashed line is the maximum likelihood estimate, blue dotted line is the posterior median.

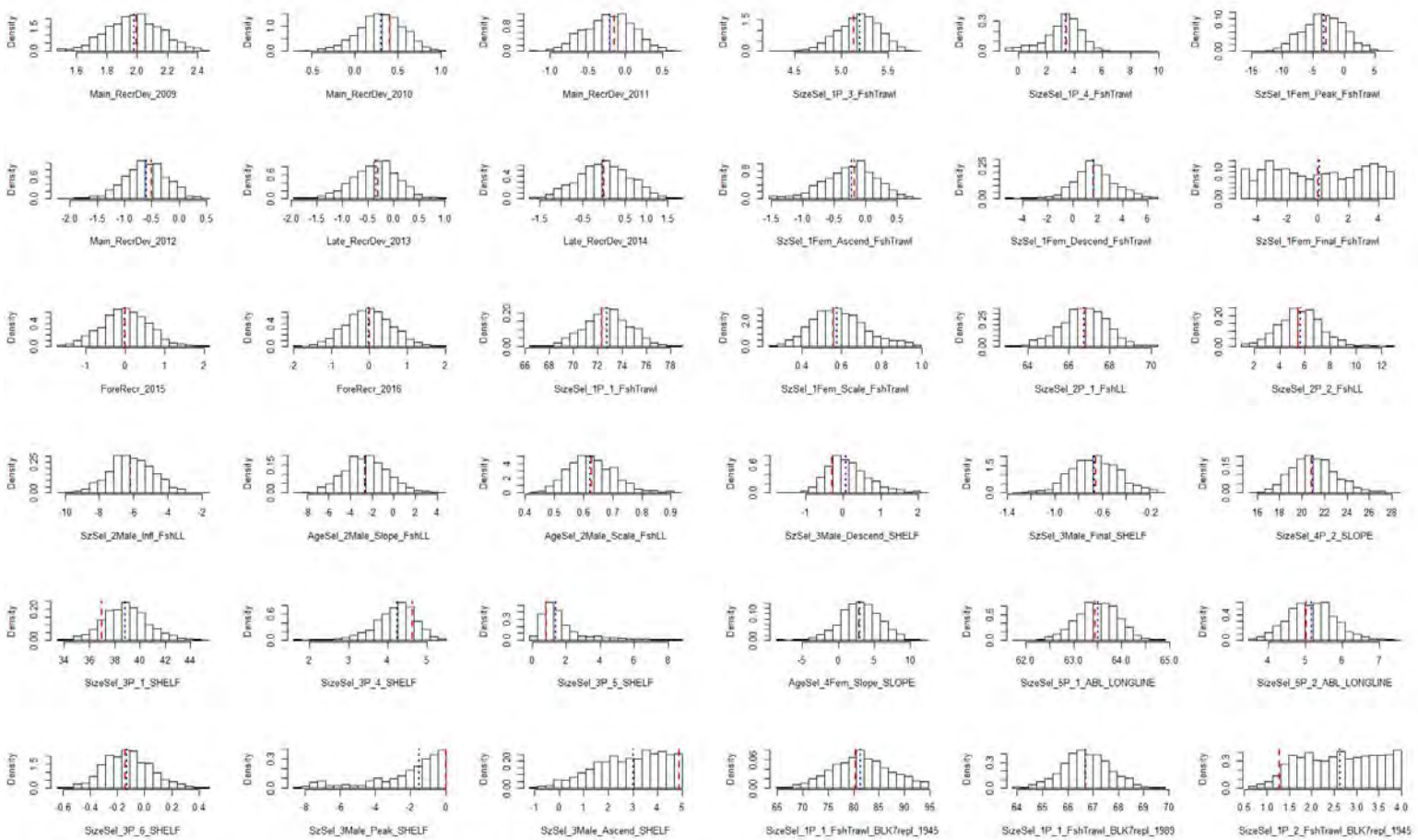


Figure 5.49 cont. Posterior densities for Model 2 parameters, red dashed line is the maximum likelihood estimate, blue dotted line is the posterior median.

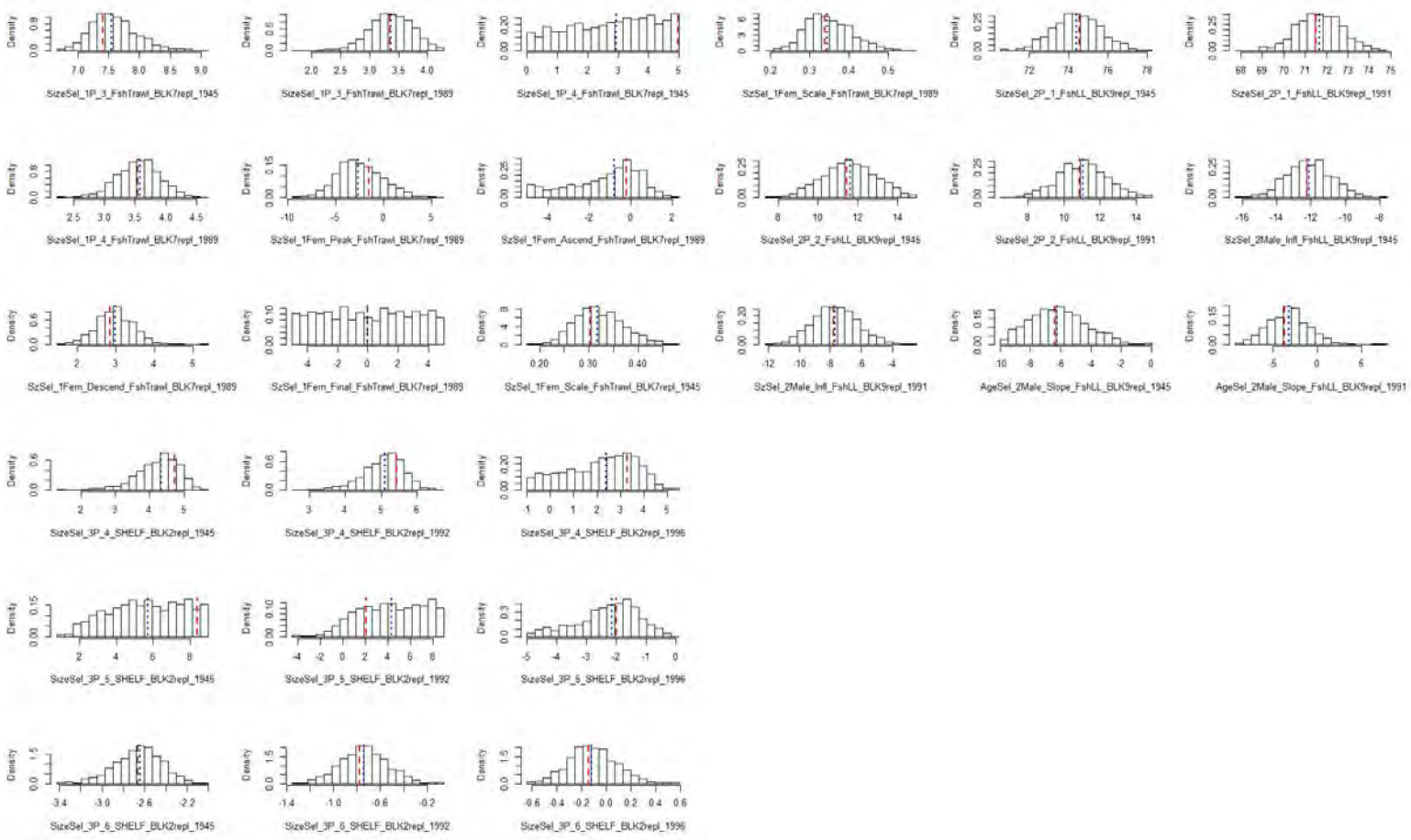


Figure 5.49 cont. Posterior densities for Model 2 parameters, red dashed line is the maximum likelihood estimate, blue dotted line is the posterior median.

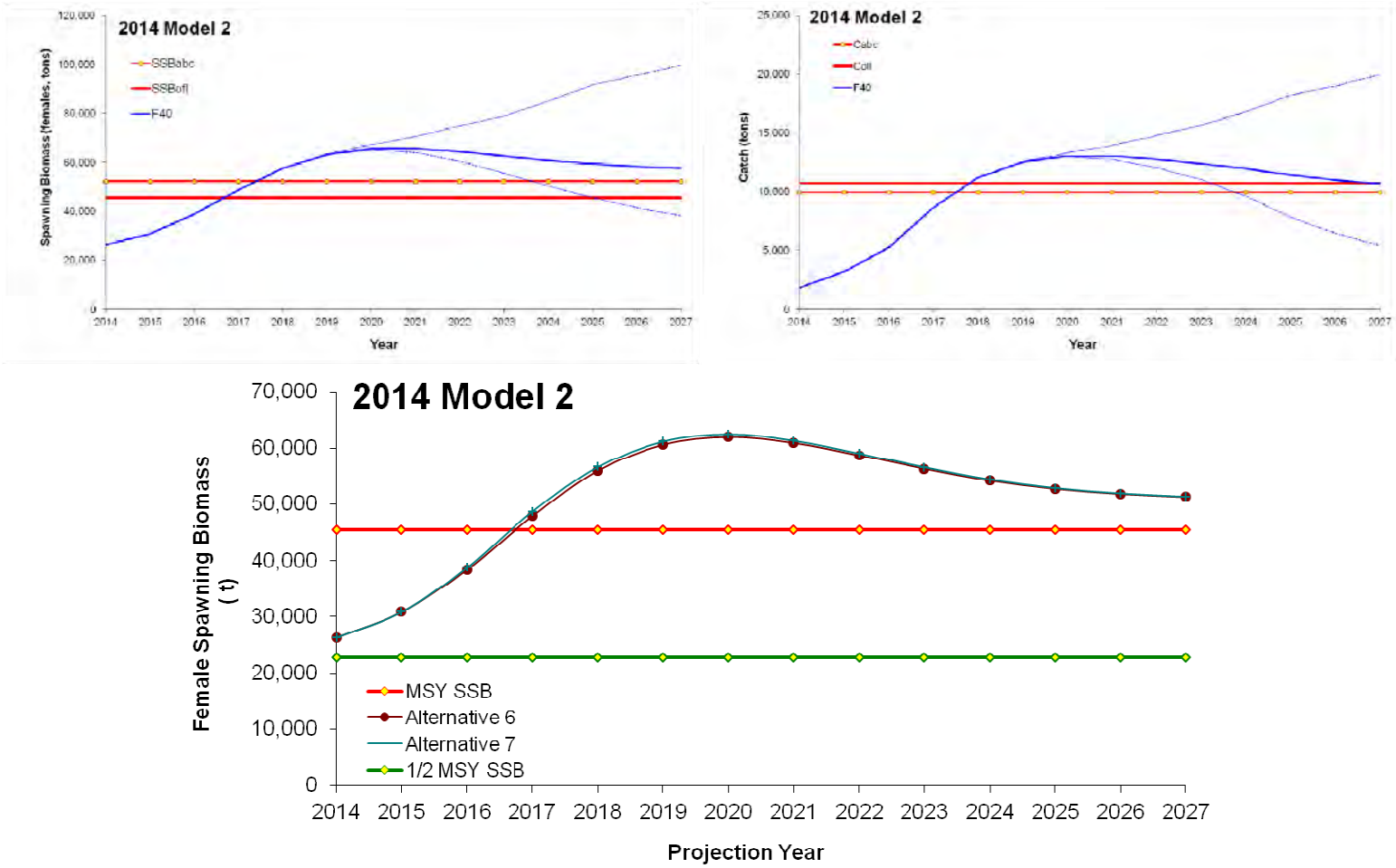


Figure 5.50. Alternative 1 projected female spawning stock biomass (upper left panel) and catch (upper right panel) at $F_{40\%}$ fishing with long-term expected OFL and ABC reference levels, and projected female spawning stock biomass under Alternatives 6 and 7 with SSB_{MSY} and ½ SSB_{MSY} reference levels (bottom panel). $SSB_{35\%}$ is our proxy for SSB_{MSY}.

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6. Assessment of the arrowtooth flounder stock in the Eastern Bering Sea and Aleutian Islands

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National Marine Fisheries Service

Executive Summary

The following changes have been made to this assessment relative to the November 2013 SAFE.

Summary of changes in assessment model input data

The following new data was included in the model:

1) Survey size compositions from the 2013 and 2014 Eastern Bering Sea shelf survey, and 2014 Aleutian Islands survey.
2) Biomass point-estimates and standard errors from the 2013 and 2014 Eastern Bering Sea shelf survey, and 2014 Aleutian Islands survey.
3) Fishery size compositions for 2012, 2013, and 2014. Fishery size composition data was also added for 1992-1999 that had not previously been included.
4) Estimates of catch through October 10, 2014.
5) Age data from the 2010 Bering Sea shelf and 2010 Aleutian Islands surveys, as well as the 2004 shelf survey, which was not previously included.

Summary of changes to the assessment model methodology

The age-structured assessment model is similar to the model used for the 2012 and 2013 assessments, and was developed using AD Model Builder (a C++ software language extension and automatic differentiation library). The 2014 model implemented the following changes based on Plan Team and SSC comments:

1) Fishery selectivity is estimated non-parametrically rather than using a 2-parameter logistic function.
2) An additional likelihood component was added to incorporate new Aleutian Islands age data that had not been included in the past.

Summary of results

1) The projected age 1+ total biomass for 2015 is 908,379 t.

2) The projected female spawning biomass for 2015 is 533,731 t.

3) The recommended 2015 ABC is 80,547 t based on an $F_{0.40}$=0.153 harvest level.

4) The 2015 overfishing level is 93,856 t based on a F_{OFL}=0.180 harvest level.

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Quantity/Status	Last year 2014	Last year 2015	This year 2015	This year 2016
M (natural mortality – Male, Female)	0.35, 0.2	0.35, 0.2	0.35, 0.2	0.35, 0.2
Specified/recommended Tier	3a	3a	3a	3a
Projected biomass (ages 1+)	1,023,440	995,494	908,379	911,652
Female spawning biomass (t)				
Projected	626,319	632,319	533,731	528,020
$B_{100\%}$	577,538	577,538	555,049	555,049
$B_{40\%}$	231,015	231,015	222,019	222,019
$B_{35\%}$	202,138	202,138	194,267	194,267
F_{OFL}	0.186	0.186	0.180	0.180
$maxF_{ABC}$ (maximum allowable = $F_{40\%}$)	0.156	0.156	0.153	0.153
Specified/recommended F_{ABC}	0.156	0.156	0.153	0.153
Specified/recommended OFL (t)	125,642	125,025	93,856	91,663
Specified/recommended ABC (t)	106,599	106,089	80,547	78,661
Is the stock being subjected to overfishing?	no	no	no	no
Is the stock currently overfished?	no	no	no	no
Is the stock approaching a condition of being overfished?	no	no	no	no

Responses to SSC and Plan Team Comments on Assessments in General

In December 2013 the SSC noted that different stock assessment scientists often use different methods for catch estimation to estimate catches between late October and December 31 of the current assessment year, as well as catches to be taken during the following two years for use in the catch specification process. The SSC understands that Dana Hanselman will compile the various methods in use. The SSC looks forward to Plan Team advice on the merits of the various alternatives.

Authors' response: The best method for catch projections appears to be species-specific. The 2014 catch of arrowtooth flounder through October 13, 2014 was 18,119 t. The total catch in 2014 and 2015 was estimated to be the same as the 2013 catch of 20,501 t. This choice is discussed further under Projected Biomass.

Responses to SSC and Plan Team Comments on Assessments Specific to this Assessment

In December 2013 the SSC accepted the author's and Plan Team's recommended ABCs and OFLs for 2014 and 2015 under Tier 3a using the current model updated with female maturity information based on research by Stark (2011). The SSC looks forward to a full analysis of the model results with the old and new data in next year's stock assessment. The assessment should compare the alternative maturity curves, along with their uncertainty.

Authors' response: Assessment results using Stark (2011) and Zimmerman (1997) maturity values are presented in the Appendix.

In September 2014, the BSAI Plan Team recommended that the arrowtooth flounder assessment bring forward a model that explores selectivity shapes for both the survey and the fishery, including a model with non-parametric selectivity-by-age as an alternative to the logistic model. For the selectivity-by-age model, the weightings used in the smoothing penalties should also be explored.

Authors' response: The 2014 BSAI arrowtooth assessment is based on the author's preferred model, which incorporates non-parametric fisheries selectivity as an alternative to the logistic model, as well as the Stark (2011) female maturity values. The logistic model is compared with the non-parametric fishery selectivity model and results of the logistic model are included in the Appendix. Weightings used in the smoothing penalties are also explored in Appendix.

Introduction

Arrowtooth flounder (*Atheresthes stomias*) is a relatively large flatfish that is found throughout the BSAI management area. Their abundance is approximately six times higher in the eastern Bering Sea than in the Aleutian Islands region. Spawning occurs in deep water in the Gulf of Alaska and along the shelf break in the eastern Bering Sea. Spawning females have been found at 400m and males at ≥450m in the Gulf of Alaska, and larvae have been found at depths greater than 200 m (Blood et al. 2007; De Forest et al. 2014). The distribution of ages appears to vary by region and sex; male arrowtooth as old as 36 years have been observed in the Aleutian Islands are not commonly observed older than age 10 on the Bering Sea shelf, while the female length and weight relationships do not vary significantly between the two regions (Figure 6.1)

Arrowtooth flounder begin to recruit to the continental slope at about age 4. Based on age data from the 1982 U.S.-Japan cooperative survey, recruitment to the slope gradually increases at older ages and reaches a maximum at age 9. However, greater than 50% of age groups 9 and older continue to occupy continental shelf waters. The low proportion of the overall biomass on the slope during the 1988 and 1991 surveys, relative to that of earlier surveys, indicates that the proportion of the population occupying slope waters may vary considerably from year to year depending on the age structure of the population.

The arrowtooth flounder resource in the EBS and the Aleutians is managed as a single stock although little is known about stock structure. There has been no research on this topic in this species.

Fishery

Arrowtooth flounder were managed with Greenland turbot as a species complex until 1985 because of similarities in their life history characteristics, distribution and exploitation. Greenland turbot were the target species and arrowtooth flounder were caught as bycatch. Management of Greenland turbot and the *Atheresthes* complex was performed separately starting in 1986 due to considerable differences in their stock condition. Two species of *Atheresthes* occur in the Bering Sea, arrowtooth flounder (*Atheresthes stomias*) and Kamchatka flounder (*A. evermanni*). These two species are very similar in appearance and were not routinely distinguished in the commercial catches until 2007 (Figure 6.2). Until about 1992, these species were not consistently separated in trawl survey catches and were combined in the arrowtooth flounder stock assessment. The species complex was split in 2010 due to the emergence of a directed fishery for Kamchatka flounder in the BSAI management area. Before 2010, the ABC for the species complex was determined by the large amount (~93%) of arrowtooth flounder relative to Kamchatka flounder in the species complex; overharvest of Kamchatka flounder could occur as the ABC for the species complex exceeded the Kamchatka flounder biomass. Separate management of arrowtooth flounder and Kamchatka flounder began in the 2011 fishing season and separate assessments began in 2010.

Arrowtooth flounder has remained lightly exploited with catches (extrapolated for arrowtooth only) averaging 14,447 t from 1976-2014. Catch records of arrowtooth flounder and Greenland turbot were combined during the 1960s. The fisheries for Greenland turbot intensified during the 1970s and the bycatch of arrowtooth flounder is assumed to have also increased. In 1974-76, total catches of arrowtooth flounder reached peak levels ranging from 19,000 to 25,000 t (Table 6.1). Catches decreased after implementation of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1976. The decline after 1976 resulted from catch restrictions placed on the fishery for Greenland turbot and phasing out of the foreign fishery in the U.S. EEZ. Catches in Table 6.2 are for arrowtooth flounder and Kamchatka flounder combined until 2008, the year in which the NMFS Alaska Regional Office (AKRO) started providing separate catch statistics for arrowtooth and Kamchatka flounder. The estimated proportion of Kamchatka flounder in the combined catch of arrowtooth and Kamchatka are shown in Table 6.2 through 2007, while Table 6.1 provides catch estimates for arrowtooth only. Total catch reported through October 13, 2014 is 18,119 t (below the 2014 TAC of 25,000 t). The NMFS AKRO BLEND/Catch Accounting System reports indicate that bottom trawling accounted for 95% of the 2014 catch (3% by pelagic trawl and 2% by hook and line).

Although much research has been conducted on their commercial utilization (e.g. Greene and Babbit 1990, Wasson et al. 1992, Porter et al. 1993, Reppond et al. 1993, Cullenberg 1995) and some targeting occurs in the Gulf of Alaska and the Bering Sea, arrowtooth flounder continue to be captured primarily in pursuit of higher value species and historically have been mostly discarded in the Bering Sea and the Aleutian Islands. The catch information in Table 6.1 reports the past annual total catch tonnage for the foreign and JV fisheries and the current domestic fisheries. The proportions of retained and discarded arrowtooth flounder in Bering Sea fisheries are estimated from observer at-sea sampling for 1985-2014 are shown in Table 6.2, and include Kamchatka flounder as well as arrowtooth flounder through 2007. With the implementation Amendment 80 in 2008, the percentage of arrowtooth flounder retained in catches has increased to 89% in 2014. The largest discard amounts occur in the Pacific cod fishery and the various flatfish fisheries. The increasing trend of retention is expected to continue in the near future due to the recent changes in fishing practices.

Data

The data used in this assessment include estimates of total catch, trawl survey biomass estimates and standard error from the Bering Sea shelf, Bering Sea slope and Aleutian Islands surveys, sex-specific trawl survey length frequencies and fishery length-frequencies from observer sampling. Length

composition data is available from each NFMS survey. It is used in the model for each year unless age composition data is available.

Source	Data	Years
NMFS Bering Sea shelf survey	Survey biomass	1982-2014
	Age Composition	1996, 1998, 2004, 2010
	Length composition	1982-2014
NMFS Bering Sea slope survey	Survey biomass	1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010, 2012
	Length composition	1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010, 2012
NMFS Aleutian Islands survey	Survey biomass	1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014
	Age composition	2010
	Length composition	1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014
Fishery	Catch length composition	1978 – 1988, 1990 -2014

Fishery:
Fishery catch data from 1976 - October 13, 2014 (Table 6.1) and fishery length-frequency data from 1978-2014 are used in the assessment. Actual arrowtooth flounder catch is available from observer at-sea sampling applied to the Alaska regional office blend estimates for 2007-2014. For 1976-2006 the annual arrowtooth flounder catch is calculated as 93% of the combined arrowtooth flounder-Kamchatka flounder catch on record, based on their average annual proportions in trawl surveys since 1992 (the first year of reliable identification by species). These corrections have been applied to the catch totals in Table 6.1, under "ATF est". New fishery length-at-age data is incorporated in this assessment, and is shown in Figure 6.3. The number of fisheries length observations in each year is shown below.

Year	Number of length observations	Year	Number of length observations
1978	11,426	1997	3,914
1979	6,565	1998	3,819
1980	9,945	1999	3,974
1981	7,790	2000	1,415
1982	36,784	2001	2,984
1983	31,955	2002	2,404
1984	23,189	2003	3,565
1985	25,817	2004	4,367
1986	14,399	2005	2,689
1987	24,066	2006	2,143
1988	833	2007	601
1989	224	2008	1,422
1990	3,831	2009	557
1991	10,179	2010	922
1992	816	2011	887
1993	1,570	2012	529
1994	410	2013	643
1995	3,098	2014	156
1996	1,185		

Catch from sources other than those that are included in the Alaska Region's official estimate of catch (e.g., removals due to scientific surveys, subsistence fishing, recreational fishing, fisheries managed under other FMPs is shown in Table 6.3.

Survey:
The relative abundance of arrowtooth flounder increased substantially on the continental shelf from 1982 to 1990 as the CPUE from AFSC shelf surveys increased steadily from 1.6 to 9.9 kg/ha (Figure 6.1). The overall shelf catch rate decreased slightly to 7.1 kg/ha in 1991. The CPUE continued to increase through 1997 to 15.0 kg/ha. These increases in CPUE were also observed on the slope from 1981 to 1986 as CPUE from the Japanese land-based fishery increased from 1.5 to 21.0 t/hr (Bakkala and Wilderbuer 1990). From 1999 to 2005 the shelf survey CPUE increased at a high rate each year. Survey estimates are fairly consistent from 2003-2014 (between 8-11 kg/ha), although the 2005 CPUE of 15.39 kg/ha was the highest ever estimated from the shelf survey. The 2014 survey estimates for the shelf and Aleutian Islands survey are slightly up from 2012 estimates (Figure 6.4).

Biomass estimates (t) for arrowtooth flounder from the standard survey area in the eastern Bering Sea and Aleutian Islands region are shown in Table 6.4. Table 6.3 lists the total research catch of these species. Although the standard sampling trawl for the shelf changed in 1982 to the more efficient trawl 83/112 trawl which may have caused an overestimate of the biomass increase in the pre-1982 part of the time-series, biomass estimates from AFSC surveys on the continental shelf have shown a consistent increasing trend since 1975. Since 1982, biomass point estimates indicate that arrowtooth abundance has increased eight-fold to a high of 570,600 t in 1994. The population biomass remained at a high level from 1992-97. Results from the 1997-2000 bottom trawl surveys indicate the Bering Sea shelf population biomass had declined to 340,000 t, 60% of the peak 1994 biomass point estimate. Beginning in 2002 the shelf survey estimate increased again and peaked in 2005 at a biomass of 722,209 t. In 2006 - 2007 the estimates declined slightly but remained at high levels, between 400,000 t – 550,000 t through 2014. Survey biomass estimates were all lower in 2012 than in previous years. The 2012 shelf survey estimate of 445,736 t (s.e. 43,514) was the lowest since 2002. Similarly, the 2012 Aleutian Islands survey estimate of 60,371 t (s.e. 10,118) was the lowest since 1994, and the slope survey estimate of 73,676 t (s.e. 8199) was the lowest since 2004. The 2014 estimates of biomass on the EBS shelf and Aleutian Islands were slightly higher, 465,616 t (s.e. 32,255) for the shelf and 75,958 t (s.e. = 11,055) for the Aleutians (Figure 6.4).

Trawl surveys were intermittently conducted over the continental slope (1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010 and 2012). Only the surveys conducted since 2002 are considered part of a standard time series of biomass. These surveys sampled depths ranging from 200 - 1,200 meters and the Poly Nor' Eastern bottom trawl net with mud sweep ground gear was the standard sampling net. The slope surveys conducted in 1988 and 1991 sampled depths from 200-800 m and used a polyethylene Nor' Eastern trawl with bobbin roller gear. Slope surveys conducted between 1979 and 1985 sampled depths ranging from 200-1000 m and used different gear altogether. These surveys show that arrowtooth flounder biomass increased significantly from 1979 to 1985. The biomass estimate in 1988 and 1991 were lower. Based on slope surveys conducted between 1979 and 1985, 67% to 100% of the arrowtooth flounder biomass on the slope was found at depths less than 800 m. These data suggest that less than 20% of the total EBS population occupied slope waters in 1988 and 1991, a period of high arrowtooth flounder abundance. Surveys conducted during periods of low and increasing arrowtooth abundance (1979-85) indicate that 27% to 51% of the population weight occupied slope waters. Although the 2002-2004 surveys were deeper than earlier slope surveys, over 90% of the estimated arrowtooth biomass was located in waters less than 800 meters.

Error estimates in the survey biomass estimates are due to sampling variability. Arrowtooth flounder absolute abundance estimates are based on "area-swept" bottom trawl survey methods. These methods require several assumptions which can add to the uncertainty of the estimates. For example, it is assumed

that the sampling plan covers the distribution of the species and that all fish in the path of the trawl are captured (no losses due to escape or gains due to herding).

Analytic Approach

Model Structure

This stock assessment utilizes AD Model Builder software (a C++ software language extension and automatic differentiation library) to model the population dynamics of Bering Sea and Aleutian Islands arrowtooth flounder. The model is a length-based approach where survey and fishery length composition observations are used to calculate estimates of population numbers-at-age by the use of a length-age (growth) matrix. The model simulates the dynamics of the population and compares the expected values of the population characteristics to those observed from surveys and fishery sampling programs. This is accomplished by the simultaneous estimation of the parameters in the model using the maximum likelihood estimation procedure. The fit of the simulation values to the observed characteristics is optimized by maximizing the likelihood function given some distributional assumptions about the observed data (see Table 6.5).

The age-structured assessment model is similar to the model used for the 2012 and 2013 assessments. The 2014 model implemented two changes based on Plan Team and SSC comments. First, fishery selectivity is estimated non-parametrically rather than using a 2-parameter logistic function as was done in past models. Separate fishery selectivities were estimated non-parametrically for each age, and the shape of the selectivity curve was constrained to be a monotonic, smooth function. The non-parametric method for estimating fishery selectivity results in a lower Akaike information criterion (AIC) when applied to the BSAI model, and is therefore the preferred model. The Appendix to this stock assessment provides details on the model when logistic fishery selectivity is applied, and provides a comparison between the two methods. The second change was the addition of a likelihood component for Aleutian Islands age data that had not been included in the past.

Parameters Estimated Outside the Assessment Model

Parameters of the von Bertalanffy growth curve for arrowtooth flounder from age data collected during the 1982 U.S.-Japan cooperative survey and the 1991 slope survey (Zimmermann and Goddard 1996) are as follows:

Sex	Sample size	Age range	L_{inf}	k	t_o
1982 age sample					
Male	528	2-14	45.9	0.23	-0.70
Female	706	2-14	73.8	0.14	-0.20
Sexes Combined	1,234	2-14	59.0	0.17	-0.50
1991 age sample					
Male	53	3-9	57.9	0.17	-2.17
Female	134	4-12	85.0	0.16	-0.81

Based on 282 observations during an AFSC survey in 1976, the length (mm)-weight (gm) relationship for arrowtooth flounder (sexes combined) is described by the equation:

$$W = 5.682 \times 10^{-6} * L^{3.1028}.$$

Maturity information from a histological examination of arrowtooth flounder in the Gulf of Alaska (Zimmerman 1997) indicates that 50% of male and female fish become mature at 46.9 and 42.2 cm, respectively. A similar study based on female samples only found that 50% of female fish become

mature at approximately 46 cm and 7 years (Stark 2011). The maturity-at-age is governed by the relationship:

$$Q_a = \frac{1}{1+e^{-(A+aB)}},$$

where *A* and *B* are parameters in the relationship (i.e. Tables 1 and 2; Stark 2011) and *a* represents age. The parameters A and B are based on a February 2008 collection of n=175 female fish (Stark 2011). The weight-at-age and maturity-at age schedules used in the model are shown in Table 6.6.

Attempts to estimate catchability by profiling over fixed q values in a previous assessment (Wilderbuer and Sample 1995) were unsuccessful as estimated values always reached the upper bounds placed on the parameter. The results indicated q values as high as 2.0 which suggests that more fish are caught in the survey trawl than are present in the "effective" fishing width of the trawl (i.e. some herding occurs or the "effective" fishing width of the trawl may be the distance between where the sweep lines contact the seafloor instead of between the wingtips of the survey trawl). Results from two herding experiments conducted in 1994 to discern the herding characteristics of the standard shelf survey trawl indicated a trawl catch of flatfish was composed of fish which were directly in the trawl path as well as those which moved into the trawl path because of the mud cloud disturbance caused by the bridle contact with the seafloor (Somerton and Munro 2001). Thus the "area-swept" technique of estimation would overestimate the abundance when herding occurred. Further research on the whole gear efficiency, the proportion of fish passing between the otter doors of a bottom trawl net that are subsequently captured, included arrowtooth flounder. Results indicated that arrowtooth have high efficiency, varying by fish length, similar to other flatfish, approximately 40-50% (Somerton et al. 2007).

Examination of Bering Sea shelf survey biomass estimates indicate that some of the annual variability seemed to positively co-vary with bottom water temperature. Variations in CPUE (Figure 6.1) were particularly evident during the coldest year (1999) and the warmest year (2003). The relationship between average annual bottom water temperature collected during the survey and annual survey biomass estimates can be better understood by modeling survey catchability as:

$$q = e^{-\alpha+\beta T}$$

where q is catchability, α and β are a parameters estimated by the model, and T_t is the average annual bottom water temperature. The catchability equation has two parts. The e^{α} term is a constant or time-independent estimate of q. The model estimate of $\alpha = -0.52$ indicates that $q > 1$ suggesting that arrowtooth flounder are herded into the trawl path of the net which is consistent with the experimental results for other flatfish species. The second term, $e^{\beta T}$ is a time-varying (annual) q which relates to the metabolic aspect of herding or distribution (availability) which can vary annually with bottom water temperature. In 2014, the temperature anomaly was positive, following two years of low temperatures; resulting in an increase in the catchability estimate (Figure 6.5).

Parameters Estimated Inside the Assessment Model

The suite of parameters estimated by the base model are classified by the following likelihood components:

Data Component	Distribution assumption
Trawl fishery size composition	Multinomial
Shelf survey population size composition	Multinomial
Slope survey population size composition	Multinomial
Shelf survey age composition	Multinomial

Aleutian survey age composition	Multinomial
Trawl survey biomass estimates and S.E.	Log normal

The total log likelihood is the sum of the log likelihoods for each data component. The model allows for the individual likelihood components to be weighted by an emphasis factor. The number of parameters estimated by the base model are presented below:

Fishing mortality	Selectivity	Temp-q	Year class strength	Total
40	58	5	59	162

The recruitment parameters are comprised of 21 initial ages in 1976 and 39 subsequent age sex-specific recruitment estimates from 1976-2014. Recruitment in 2014 was set at the average from 1976-2009. The difference in the number of parameters estimated in this assessment compared to last year can be accounted for by additional years of survey data, estimates of more years of recruitment and fishing mortality. Five more parameters, alpha, beta, and a proportion attributed to each survey, are estimated in a later stage to estimate the annual relationship between bottom water temperature (to 200 m) and shelf survey catchability and the overall value of catchability which relates to the capture process and availability of the stock (discussed in the next section). In addition, two parameters per sex are estimated for increasing logistic selectivity for the three surveys, and 19 parameters per sex for the fishery selectivity.

It was assumed that the shelf and slope surveys measure non-overlapping segments of the arrowtooth flounder stock. Biomass was apportioned between the three areas by a linear fit to the 3 survey time-series and the averages of the annual proportions were estimated from the linear regressions (Fig 6.3). The resulting proportions are 76% shelf, 10% slope and 14% in the Aleutian Islands. Equal emphasis was placed on fitting all data components for this assessment. The relationship between annual bottom water temperature and shelf survey catchability was modeled to improve the fit to the shelf survey biomass estimates. Results are closely linked to fitting the general trend of increasing shelf survey biomass estimates during the 1980s to the present high level, and to fitting the male and female size compositions (Fig 6.10) and sex ratios from the shelf, slope and Aleutian Islands surveys.

Parameters Estimated Conditionally

The population simulation specifies the number-at-age in the beginning year of the simulation, the number of recruits in subsequent years, and the survival rate for each cohort as it moves through the population calculated from the population dynamics equations (see Table 6.5 and Table 6.7).

The fishing mortality rates (F) for each age and year are calculated to approximate the catch weight by solving for F while still allowing for observation error in catch measurement (Table 6.8). A large emphasis (300) was placed on the catch likelihood component.

Selectivity and sex ratio

Survey results indicate that fish less than about 4 years old (< 30 cm) are found only on the Bering Sea shelf. Males from 30-50 cm and females 30-70 cm are found in shelf and slope waters, and males > 50 cm and females > 70 cm are mainly found on the slope. Sex specific "domed-shaped" selectivity was freely estimated for males and females in the shelf survey. We assumed an asymptotic selectivity pattern for both sexes in the slope surveys and the Aleutian Islands surveys.

Past estimates of the natural mortality of arrowtooth flounder were assumed to be 0.20. This estimate was used because it is similar to that of other species of flatfish with approximately the same age range as

arrowtooth flounder and is the same estimate used by Okada et al. (1980). However, examination of shelf and slope survey population estimates indicated that females are consistently estimated to be in higher abundance than males (Figure 6.6). This difference was also evident in the Gulf of Alaska from triennial surveys conducted from 1984-2007 (Turnock et al. 2007). Possible reasons for the higher estimates of females in the survey observations may be: 1) there is a spatial separation of males and females where males are less available to the survey trawl, 2) there is a higher natural mortality for males than females, or 3) there are some sampling problems.

Since there is a current lack of evidence that male arrowtooth flounder are less available to the Bering Sea shelf survey sampling trawl than females, differential sex-specific natural mortality has been investigated as an alternative model in past assessments as an explanation of the observed differences in survey catch sex ratio (Figure 6.7; Wilderbuer and Sample 2002).

For this assessment, model runs were again made with female natural mortality fixed at 0.2 for a range of values for males. Model runs were evaluated with respect to the estimate of male and female selectivity for the shelf survey, the estimated sex ratio and the overall model fit. Also, a constraint was placed on fitting the sex ratio estimated from the trawl surveys, as follows:

$$SRlike = 0.5\left[\frac{\sum\left(\ \overline{SR}_{obs} - SR_{pred}\ \right)^2}{\sigma_{obs}}\right]$$

where SRlike is the sex ratio likelihood component, SR_{obs} is the observed sex ratio in shelf survey trawl surveys from 1982-2014, SR_{pred} is the model predicted sex ratio in the estimated population, and σ_{obs} is the standard error of the observed population sex ratio.

Results

Model Evaluation

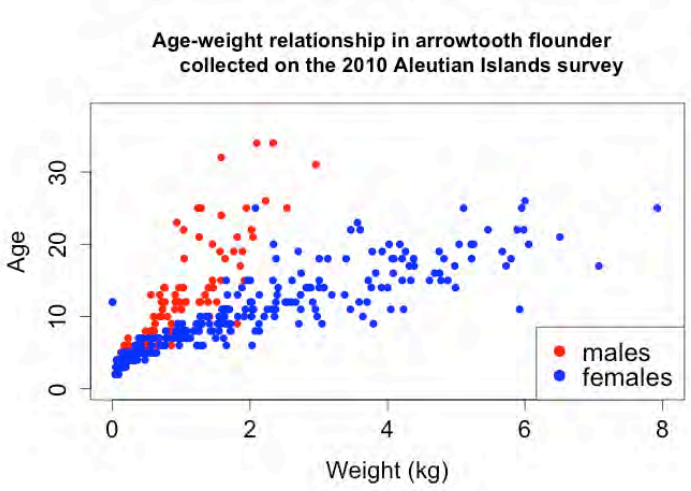
In September 2014, the BSAI Plan Team recommended that the arrowtooth flounder assessment bring forward a model that explores selectivity shapes for both the survey and the fishery, including a model with non-parametric selectivity-by-age as an alternative to the logistic model. For the selectivity-by-age model, the weightings used in the smoothing penalties should also be explored. Both types of fishery selectivity were explored, and the criterion to determine the best model was the Akaike Information Criterion (AIC; Akaike 1974). The method used to calculate AIC is described in the Appendix.

The non-parametric method for estimating fishery selectivity adds 38 new parameters to the model, but results in a lower AIC, 9,818 for the non-parametric model vs. 9,990 for the logistic method (Table A2). However, the effective number of parameters may be smaller than 38 due to the non-parametric method applied. If this were the case, the AIC would still be lower with the non-parametric method; therefore, the authors prefer the non-parametric model. Logistic fisheries selectivity results are presented in the Appendix. Parameter estimates of selectivity using the non-parametric method are shown in Table 6.9 and Figure 6.8. Age-specific selectivity estimated by the model (Table 6.9, Figure 6.8) indicate that arrowtooth flounder are 50% selected by the fishery at about 6 years for females and 6.5 years for females. Selectivity increases to its highest level of 100% for males at age 9 and age 8 for females, before declining to 69% for females and 67% for females at age 21.

In this year's assessment, model runs were made using the shelf and slope surveys and Aleutian Islands survey data with female natural mortality fixed at 0.2 and male natural mortality fixed at 0.35. The BSAI data analyzed with the current model configuration indicates that male M most likely ranges between 0.27 and 0.36. Lower values in this range do not provide estimates of maximum selectivity and sex ratio which would be expected with the differential sex-specific natural mortality hypothesis. The run with male M = 0.35 is the preferred run since it provides a reasonable fit to all the data components and is consistent with the hypothesis that differences in sex ratios observed from trawl surveys are the result of differential sex-specific natural mortality and not availability. These male and female natural mortality values are also used in the Gulf of Alaska stock assessment, an assessment with age data from eight surveys, which may provide more precise estimates.

As in past years, it is important to evaluate the value of the maximum male selectivity on the shelf because estimates of this value at a level well less than 1.0 indicate that the sex ratio observed in the surveys are a result of a difference in male and female capture behavior or availability to the survey trawls and not the result of differential sex-specific natural mortality. The current year estimate of maximum male shelf selectivity was approximately 0.8, compared to 1.0 for females (Figure 6.8). This is lower than in past years, and may suggest low male selectivity rather than high natural morality.

In the past, age data from the Gulf of Alaska and the Bering Sea shelf indicated that the maximum age of males was lower than females. This result is what would be expected in age compositions from a population with a higher M for males than females (Turnock et al. 2007; Wilderbuer and Turnock 2009). This stock assessment incorporates the first aged sample of Aleutian Island arrowtooth flounder. The sample was collected on the 2010 Aleutian Islands survey, and consisted of 294 females and 183 males. The maximum age of males observed was 34 and females were only observed as old as 26. A similar pattern is seen in Pacific halibut (*hippoglossus stenolepis*); older males are observed in the Western Aleutian Islands but not in the Gulf of Alaska or the Bering Sea shelf (Figure 20 in Stewart et al. 2012). This may suggest either that the males in the Aleutian Islands consist of a distinct stock as arrowtooth from other regions, or that sex-specific mortality is not as discrepant as previously suspected. The issue of sex-specific natural mortality and the discrepancy in age frequencies will be addressed in the next full BSAI arrowtooth flounder assessment.



Time Series Results

This year's model shows a recent trend of increasing female spawning biomass, but a decrease in total biomass (Figure 6.9). The 2014 model estimates similar levels of total biomass as the 2012 assessment through 2004, but indicate slightly lower total biomass subsequent to 2004. This is the first year that the assessment model suggested that total biomass in BSAI arrowtooth flounder may not be increasing.

Estimates indicate that arrowtooth flounder total biomass increased almost four fold from 1976 to the 2009 value of 907,756 t (Figure 6.9, Table 6.10). After a rapid increase from 1985-94, the population increase slowed to a lower rate from 1992-1999 before increasing at a higher rate to the highest level estimated in 2009 (Figure 6.9), largely from the influence of the largest shelf survey biomass estimates ever recorded of 772,998 t in 2005 (Table 6.4) and consecutive years of good recruitment. Biomass estimates from surveys have declined for the Bering Sea shelf since 2005 and the slope since 2008. The most recent year of Aleutian Islands data is also lower than the highest estimate in 2006 (Table 6.4). Female spawning biomass in 2014 is estimated at 527,622 t, which is similar to estimates for the past 5 years (Table 6.10). The model estimates of population numbers by age, year, and sex are given in Table 6.11.

The model fit to the shelf survey tracks the trend of increasing abundance from 1982 to the high levels from 1993-97 and 2005-2006 (Figure 6.9). It does not fit the extremely high values in 2005 or the lower values in recent years. Consideration of the relationship between annual bottom water temperature and catchability improves the fit to the shelf survey biomass. The model indicates an increasing biomass trend on the slope and provides good fits to the 2002, 2004, 2008, 2010, and 2012 trend in survey estimates, but is slightly lower than survey estimates (Figure 6.9). The slope biomass represents a smaller fraction of the total stock and does not fit the 1985 slope survey. The Aleutian Islands survey estimates in 1986 and 2006 were highly variable and were not fit very well by the model but the general trend in this index was fit well.

The model provides reasonable fits to the survey size composition time-series for males and females, which are shown in Figure 6.10. The shelf survey has the best fit, due to the fact that there are more years of data for that survey. The model provides better fits to the survey age compositions, Bering Sea shelf in 1996, 1998, 2004, 2010, as well as the 2010 Aleutian Islands survey (Figure 6.10).

Increases in abundance from 1983-95 were the result of strong year-classes spawned in 1981, 1984, 1987, 1988, and 1989 (Figure 6.11, Table 6.12). From 1989-1993 recruitment was below average and stock abundance leveled-off. Recent leveling off in arrowtooth flounder biomass can be attributed to below-average year classes in 2006 and 2010, as well as lower estimates of survey biomass in recent years.

The posterior distribution of the female spawning biomass estimate for 2014 (Figure 6.12), calculated from mcmc integration of the preferred model run indicates the spawning stock is at a high level and that the estimate is highly certain. A Beverton-Holt fit curve to the estimated spawning biomass-age 1 recruitment estimates was done outside the stock assessment model and is shown in Figure 6.13.

Harvest Recommendations

Arrowtooth flounder have a wide-spread bathymetric distribution in the Bering Sea/Aleutian Islands region and are believed to be at a high level, primarily due to increasing recruitment since 1976-1992 and minimal commercial harvest. **The estimate of projected 2015 total biomass from the stock assessment projection model is 908,379 t (95% CI: 835,653, 981,105) and the female spawning biomass is estimated at 533,731 t (95% CI: 490,186 – 577,276 t)**.

The reference fishing mortality rate for arrowtooth flounder is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Equilibrium female spawning biomass is calculated by applying the female spawning biomass per recruit resulting from a constant $F_{0.40}$ harvest to an estimate of average equilibrium recruitment. Year classes spawned in 2000-2009 are used to calculate the average equilibrium recruitment. Using the time-series of age 1 recruitment from 1974-2009 from the stock assessment model results in an estimate of $B_{0.40}$ = 231,015 t for 2014. The stock assessment model estimates the 2014 level of female spawning biomass at 632,319 t. Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and $B>B_{0.40}$ (632,319 > 231,015), arrowtooth flounder reference fishing mortality is defined in tier 3a. For the 2014 harvest: $F_{ABC} \square F_{0.40}$ = 0.153 and $F_{OFL}= F_{0.35}$ = 0.180 (full selection F values).

Acceptable biological catch is estimated for 2014 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2014 estimate of age-specific total biomass as follows:

$$ABC = \sum_{a=a_r}^{a_{nages}} \overline{w}_a n_a \left(1 - e^{-M - Fs_a}\right) \frac{Fs_a}{M + Fs_a}$$

where S_a is the selectivity at age, M is natural mortality, W_a is the mean weight at age, and n_a is the beginning of the year numbers at age. **This results in a 2015 ABC of 80,547 t.**

The overfishing level is estimated for 2015 by applying the $F_{35\%}$ fishing mortality rate and age-specific fishery selectivities to the projected 2013 estimate of age-specific total biomass. **This results in a 2015 OFL of 93,856 t.**

The potential yield of arrowtooth flounder in 2015 is summarized as follows:

F level	Exploitation rate	Potential yield
F_{OFL}	0.180	163,508 t
$F_{0.40}$	0.153	138,982 t

Projected Biomass

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of current year numbers at age estimated in the assessment. This vector is then projected forward to the beginning of the following year (current year +1) using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for the current year. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of

maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for next year (current year +1), are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for next year's (current year +1) recommended in the assessment to the *max* F_{ABC} for next year. Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.

Scenario 4: In all future years, F is set equal to the most recent 5-year (current year -6 – current year -1) average F. Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.

Scenario 5: In all future years, F is set equal to zero. Rationale: In extreme cases, TAC may be set at a level close to zero.

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above ½ of its MSY level in the current year and above its MSY level in 10 (current year +10) years under this scenario, then the stock is not overfished.

Scenario 7: In the next year and the following year (current year +1, current year +2), F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 13 years (current year +13) under this scenario, then the stock is not approaching an overfished condition.

Simulation results (Table 6.13) indicate that arrowtooth flounder are not currently overfished and the stock is not considered to be approaching an overfished condition. The stock projection at the average exploitation rate for the past 5 years is shown in Figure 6.14 and a phase-plane diagram showing the time-series of FSB estimates relative to the harvest control rule is shown in Figure 6.15. The ABC and TAC values that have been used to manage the combined stock since 1980 are listed in Table 6.14.

Scenario Projections and Two-Year Ahead Overfishing Level

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While

Scenario 6 gives the best estimate of OFL for 2015, it does not provide the best estimate of OFL for 2016, because the mean 2016 catch under Scenario 6 is predicated on the 2015 catch being equal to the 2015 OFL, whereas the actual 2015 catch will likely be less than the 2015 ABC. Therefore, the projection model was re-run with the 2015 and 2016 catch fixed equal to the 2014 catch estimate to calculate the 2016 ABC and OFL.

The 2014 catch through October 13, 2014 was 18,119 t. The total catch in 2014, 2015, and 2016 was estimated to be the same as the 2013 catch of 20,501. Arrowtooth flounder catches have ranged from 20,195-22,379 for the past six full years, between 2008 and 2013, with exception of the high catches of 29,900 t in 2009 and 38,881 t in 2010. These high catches were the result of bycatch in targeted Kamchatka flounder fishing, and such high catches are unlikely to occur again. Therefore, the most recent full years catch of 20,501 t in 2013 is a good estimate of future catch.

Year	Catch	ABC	OFL
2015	20,501	80,547	93,856
2016	20,501	78,661	91,663

Ecosystem Considerations

Predators of arrowtooth flounder

Arrowtooth flounder are a high trophic level predator in the Bering Sea, feeding on both benthic and pelagic components of the food web (Figure 6.16). Unlike the Gulf of Alaska however, they are not at the top of the food chain on the eastern Bering Sea shelf. Arrowtooth flounder in the Bering Sea are an occasional prey in the diets of groundfish in the Bering Sea and are eaten by Pacific cod, walleye pollock, Alaska skates, and sleeper sharks. However, given the large biomass of these species as juveniles in the Bering Sea overall, these occasionally recorded events translate into considerable total mortality for the arrowtooth flounder population in the Bering Sea ecosystem. Using the year 1991 as a baseline, the top three predators on arrowtooth flounder >30 cm, by relative importance, are walleye pollock (29% of the total mortality), Alaska skate (21%) and sleeper shark (11%) (Figure 6.17). After these predators the next highest sources of mortality (1991) on arrowtooth flounder are four fisheries, the flatfish trawl (7%) pollock trawl (6%), cod trawl (4) and the cod longline fishery (2%). In the Aleutian Islands, sleeper sharks are the primary predators on arrowtooth flounder adults, while Pacific cod are the primary predator on arrowtooth flounder juveniles.

Most of the occurrences of arrowtooth flounder measured in groundfish stomachs was of fish between 20-40cm fork length, and were found in larger individuals of the predator species. For juvenile arrowtooth flounder (<20cm fork length), 97% of the total mortality is unknown with the remaining 3% primarily attributed to arrowtooth flounder and a few other species (Figure 6.18).

The three major predators listed above do not depend on arrowtooth flounder in terms of their total consumption. Arrowtooth flounder only comprise approximately 2% of the diet of Bering Sea Pollock, 3% of Alaska skate and 12% of the sleeper shark diet. Therefore it is not expected that a change in arrowtooth flounder would have a great effect on these species' prey availability, while decreases in the large adults of these species might reduce overall predation mortality experienced by arrowtooth flounder.

Arrowtooth flounder predation

Arrowtooth flounder are an important ecosystem component as predators. This is particularly relevant as this stock assessment indicates that they are now increasing rapidly in abundance in the eastern Bering Sea. Nearly half of the adult diet is comprised of juvenile pollock (47%) followed by adult pollock (19%) and euphausiids (9%). This is in marked contrast to their diet in the Gulf of Alaska, where pollock are a relatively small percentage of their forage base, which instead consists primarily of shrimp.

The balance of the arrowtooth flounder diet in the eastern Bering Sea includes eelpouts, shrimp, herring, eulachon and flathead sole juveniles (Figure 6.19). Diets of juvenile arrowtooth flounder are more similar to other Bering Sea shelf flatfish species than to arrowtooth flounder adults. Nonpandalid shrimp compose 42% of the total consumption, euphausiids 25%, juvenile Pollock 22% and then polychaetes, sculpins and mysids accounting for another 10% (Figure 6.20). With the exception of juvenile pollock, juvenile arrowtooth flounder exhibit a stronger benthic pathway in their diet than adults. In the Aleutian Islands, arrowtooth flounder feed on the range of available forage fishes, including myctophids, Atka mackerel, and pollock. They are an important predator on Atka mackerel juveniles, making up 23% of the assumed natural mortality of this species.

In terms of the size of pollock consumed, arrowtooth flounder consume a greater number of pollock between the range of 15-25cm fork length than do Pacific cod or Pacific halibut, which consume primarily adult fish and fish smaller than 15cm (Figure 6.21).

Analysis of role in the ecosystem

Food web models for the Bering Sea have been constructed to discern what the effect of changes in key predators has as a source of mortality on species which are linked to them through consumption pathways. These models are 30 year realizations run 1,000 times and thus give a measure of the uncertainty in the food model parameters. A simulation analysis where arrowtooth flounder survival was decreased by 10% and the rest of the ecosystem was allowed to adjust to this decrease for 30 years (Figure 6.22) indicates that positive changes in biomass for affected species were only minimal with flathead sole showing the largest increase (~3%), probably due to competition for a variety of shared prey resources such as shrimp. As expected the largest negative changes in biomass were for arrowtooth flounder (both adults and juveniles) themselves and a smaller negative change for sleeper sharks (<4%). All other effects were on the order of 1-2%. When juvenile arrowtooth flounder are decreased, again it is flathead sole biomass which is increased, but only by a small percentage change, even if the change in arrowtooth juveniles is as much as 60% (Figure 6.23). As in the first simulation, the changes are minor for all other species and fisheries. However, it's important to note that this reflects a sensitivity analysis around conditions in the early 1990s; the increase of arrowtooth flounder in recent years suggests that this analysis should be re-performed with current conditions.

To evaluate the dependence of arrowtooth flounder adults and juveniles on a suite of species and fisheries which are dynamically related to them, a simulation analysis was conducted where survival of each species group/fishery on the X axis in Figure 6.24 was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. These model runs indicate that the biomass of arrowtooth juveniles is very sensitive to changes on the order of only 10% in key species, whereby their biomass may be reduced by 40-60%. The changes are primarily bottom-up, with few top-down or competitive effects. This supports the research of Wilderbuer et al. (2002) which suggests that the control of arrowtooth flounder production is primarily based on physical drivers, e.g. advection to nursery habitat. However, it's important to note that the effect of decreasing pollock (adults or juveniles) is to increase arrowtooth flounder in the model rather than decrease it; this suggests that the role of pollock as a predator on arrowtooth flounder (potentially limiting their population growth) is greater than the importance of pollock as prey, at least for small perturbations of pollock. For adults, the pattern is similar although the percent change in biomass is less (30%).

Ecosystem Effects on the stock

1) Prey availability/abundance trends

Arrowtooth flounder diet varies by life stage as indicated in the previous section. Regarding juvenile prey and its associated habitat, information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not be re-sampled since. Information on pollock abundance is available in Chapter 1 of this SAFE report. It has been hypothesized that predators on pollock, such as adult arrowtooth flounder, may be important species which control (with other factors) the variation in year-class strength of juvenile pollock (Hunt et al. 2011). The populations of arrowtooth flounder which have occupied the outer shelf and slope areas of the Bering Sea over the past twenty years for summertime feeding do not appear food-limited. These populations have fluctuated due to the variability in recruitment success which suggests that the primary infaunal food source has been at an adequate level to sustain the arrowtooth flounder population.

2) Predator population trends

As juveniles, it is well-documented from studies in other parts of the world that flatfish are prey for shrimp species in nearshore areas. This has not been reported for Bering Sea arrowtooth flounder due to a lack of juvenile sampling and collections in nearshore areas, but is thought to occur. As late juveniles they are found in stomachs of pollock and Pacific cod, mostly small arrowtooth flounder ranging from 5 to 15 cm standard length.

Past, present and projected future population trends of these predator species can be found in their respective SAFE chapters in this volume. Encounters between arrowtooth flounder and their predators may be limited as their distributions do not completely overlap in space and time.

3) Changes in habitat quality

Changes in the physical environment which may affect arrowtooth flounder distribution patterns, recruitment success, migration timing and patterns are catalogued in the Ecosystem Considerations section of this SAFE report. Habitat quality may be enhanced during years of favorable cross-shelf advection (juvenile survival) and warmer bottom water temperatures with reduced ice cover (higher metabolism with more active feeding).

Fishery Effects on the ecosystem

1) Arrowtoooth flounder are not pursued as a target fishery at this time and thus have no "fishery effect" on the ecosystem. In instances when arrowtooth flounder were caught in sufficient quantities in the catch that they could be classified as a target, their contribution to the total bycatch of prohibited species is summarized for 2006 and 2007 in Table 13 of the Economic SAFE (Appendix C) and is summarized for 2007 as follows:

Prohibited species	Arrowtooth flounder "fishery" % of total bycatch
Halibut mortality	<1
Herring	0
Red King crab	0
C. bairdi	<1
Other Tanner crab	<1
Salmon	<1

2) Relative to the predator needs in space and time, harvesting of arrowtooth flounder selects few fish between 5-15 cm and therefore has minimal overlap with removals from predation.

3) The catch is not perceived to have an effect on the amount of large size target fish in the population due to it's history of very light exploitation (2%) over the past 30 years.

4) Arrowtooth flounder discards are presented in the Catch History section.

5) It is unknown what effect the catch has had on arrowtooth flounder maturity-at-age and fecundity.

6) Analysis of the benthic disturbance from harvesting arrowtooth flounder is available in the Preliminary draft of the Essential Fish Habitat Environmental Impact Statement.

Ecosystem effects on arrowtooth flounder			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Benthic infauna	Stomach contents	Stable, data limited	Unknown
Predator population trends			
Fish (Pollock, Pacific cod)	Stable	Possible increases to arrowtooth mortality	
Changes in habitat quality			
Temperature regime	Cold years arrowtooth catchability and herding may decrease	Likely to affect surveyed stock	No concern (dealt with in model)
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability

***Arrowtooth flounder* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Minor contribution to mortality	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	No concern
HAPC biota	Low bycatch levels of (spp)	Bycatch levels small relative to HAPC biota	No concern
Marine mammals and birds	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Very low exploitation rate	Little detrimental effect	No concern
Fishery effects on amount of large size target fish	Very low exploitation rate	Natural fluctuation	No concern
Fishery contribution to discards and offal production	Stable trend	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	Unknown	NA	Possible concern

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Tables

Table 6.1. All nation total combined catch (t) of arrowtooth and Kamchatka flounder in the eastern Bering Sea and Aleutian Islands regiona, 1970-2014. Totals for arrowtooth (ATF) and Kamchatka are under "Combined" total, extrapolated ATF only is under "ATF est".

	Eastern Bering Sea				Aleutian Islands Region				Combined	ATF est.
Year	Non-U.S.[b]	U.S. J.V.[c]	U.S. DAH[d]	Total	Non-U.S.	U.S. J.V.	U.S. DAH	Total	Total	Total
1970	12,598			12,598	274			274	12,872	11,971
1971	18,792			18,792	581			581	19,373	18,017
1972	13,123			13,123	1,323			1,323	14,446	13,435
1973	9,217			9,217	3,705			3,705	12,922	12,017
1974	21,473			21,473	3,195			3,195	24,668	22,941
1975	20,832			20,832	784			784	21,616	20,103
1976	17,806			17,806	1,370			1,370	19,176	17,834
1977	9,454			9,454	2,035			2,035	11,489	10,685
1978	8,358			8,358	1,782			1,782	10,140	9,430
1979	7,921			7,921	6,436			6,436	14,357	13,352
1980	13,674	87		13,761	4,603			4,603	18,364	17,079
1981	13,468	5		13,473	3,624	16		3,640	17,113	15,915
1982	9,065	38		9,103	2,356	59		2,415	11,518	10,712
1983	10,180	36		10,216	3,700	53		3,753	13,969	12,991
1984	7,780	200		7,980	1,404	68		1,472	9,452	8,790
1985	6,840	448		7,288	11	59	89	159	7,447	6,926
1986	3,462	3,298	5	6,766		78	337	415	7,181	6,678
1987	2,789	1,561	158	4,508		114	237	351	4,859	4,519
1988		2,552	15,395	17,947		22	2,021	2,043	19,990	18,591
1989		2,264	4,000	6,264			1,042	1,042	7,306	6,795
1990		660	7,315	7,975			5,083	5,083	13,058	12,144
1991									22,052	20,508
1992									10,382	9,655
1993									9,338	8,684
1994									14,366	13,360
1995									9,280	8,631
1996									14,652	13,626
1997									10,054	9,350
1998									15,241	14,174
1999									10,573	9,833
2000									12,929	12,024
2001									13,908	12,934
2002									11,540	10,732
2003									12,834	11,936
2014									17,809	16,562
2005									13,685	12,727
2006									13,309	12,377
2007									11,913	10,722
2008*										21,368
2009										29,900
2010										38,881
2011										20,195
2012										22,379
2013										20,501
2014**										18,119

[a]Catches from data prior to 1990 are on file Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115. [b]Non-U.S. fisheries: Japan, U.S.S.R., Republic of Korea, Taiwan, Poland, and Federal Republic of Germany. [c]Joint ventures between U.S. fishing vessels and foreign processing vessels. [d]Domestic annual harvesting. *Species-specific estimates of catch available starting in 2008.**Catch information through 13 October, 2014 (NMFS regional office).

Table 6.2. Estimates of retained and discarded arrowtooth flounder catch, and the proportion of arrowtooth flounder in the total catch of 1985-2014. Beginning in 2007, when the two species were differentiated in commercial catches, catch is calculated based on values from the Observer Interface Database; prior to 2007, proportion was calculated as 0.07. Arrowtooth flounder were identified to species starting in 2008; therefore only arrowtooth flounder data is presented from this year onward.

Year	Retained	Discarded	Total (t)	% Retained	Proportion ATF in catch
1985	17	72	89	19	0.07
1986	65	277	342	19	0.07
1987	75	320	395	19	0.07
1988	3,309	14,107	17,416	19	0.07
1989	958	4,084	5,042	19	0.07
1990*	2,356	10,042	12,398	19	0.07
1991	3,211	18,841	22,052	15	0.07
1992	675	9,707	10,382	7	0.07
1993	403	6,775	7,178	6	0.07
1994	626	13,641	14,267	4	0.07
1995	509	8,772	9,281	5	0.07
1996	1,372	13,280	14,652	9	0.07
1997	1,029	9,024	10,054	10	0.07
1998	2,896	12,345	15,241	19	0.07
1999	2,538	8,035	10,573	24	0.07
2000	5,124	7,805	12,929	60	0.07
2001	4,271	6,959	11,230	62	0.07
2002	4,039	7,501	11,540	35	0.07
2003	4,024	8,810	12,834	31	0.07
2004	4,987	12,822	17,809	28	0.07
2005	8,211	5,474	13,685	60	0.07
2006	6,921	6,388	13,309	52	0.07
2007	6,910	5,003	11,913	58	0.10
2008	14,316	7,051	21,368	67	-
2009	21,827	8,073	29,900	73	-
2010	27,994	10,887	38,881	72	-
2011	16,560	3,635	20,195	82	-
2012	19,470	2,909	22,379	87	-
2013	17,015	3,485	20,501	83	-
2014	16,126	1,993	18,119	89	-

*1990 retained rate was applied to the 1985-89 reported catch. The 2014 catch is through 10/13/2014.
Source: NMFS AKRO BLEND/Catch Accounting System.

Table 6.3. Total tonnage of the research catch for arrowtooth flounder and Kamchatka flounder through 2007, and for arrowtooth only from 2008 onwards. Data for 1991-2012 is from AKFIN, Noncommercial Fishery Catch (accessed October 15, 2014). Data for 2013, 2014 are incomplete.

Year	Research catch (t)
1977	1
1978	3.7
1979	22.5
1980	63.6
1981	48.4
1982	46.6
1983	21.8
1984	6.1
1985	194.1
1986	57.7
1987	9.4
1988	33.7
1989	22.8
1990	21.9
1991	21.5
1992	23.6
1993	32.1
1994	22.5
1995	38.9
1996	27.5
1997	47.6
1998	43
1999	68.8
2000	48.3
2001	49.3
2002	24.8
2003	38.7
2004	22.6
2005	38
2006	27.6
2007	38.5
2008	22.3
2009	31.3
2010	196.1
2011	242.7
2012	50.4
2013	14.8
2014	0

Table 6.4. Estimated arrowtooth flounder biomass from trawl surveys conducted on the Eastern Bering Sea shelf, slope and the Aleutian Islands. The 1988 and 1991 slope estimates were from the depth ranges of 200-800 m while earlier slope estimates were from 200-1,000 m. The 2002 and 2004 slope estimates were from sampling conducted from 200-1,200 m.

Year	shelf survey	slope survey	Aleutian Islands
1979		36,700	
1980			16,500
1981		34,900	
1982	69,990	24,700	
1983	110,643		24,465
1984	160,396		
1985	163,637	74,400	
1986	229,865		110,476
1987	294,670		
1988	297,210	30,600	
1989	355,844		
1990	402,326		
1991	298,670	28,400	21,897
1992	370,517		
1993	497,085		
1994	514,336		58,191
1995	446,826		
1996	527,249		
1997	463,081		73,893
1998	345,130		
1999	239,708		
2000	314,694		65,028
2001	378,107		
2002	331,345	61,153	88,750
2003	543,569		
2004	549,338	68,568	94,998
2005	772,988		
2006	670,132		183,836
2007	547,496		
2008	588,342	96,248	
2009	456,371		
2010	586,954	74,065	80,060
2011	568,200		
2012	445,736	73,676	60,371
2013	405,509		
2014	465,616		75,958

Table 6.5. Key equations used in the population dynamics model.

$N_{t,1} = R_t = R_0 e^{\tau_t}, \quad \tau_t \sim N(0, \delta^2{}_R)$	Recruitment 1956-75
$N_{t,1} = R_t = R_\gamma e^{\tau_t}, \ \tau_t \sim N(0, \delta^2{}_R)$	Recruitment 1976-2005
$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}\left(1 - e^{-z_{t,a}}\right)N_{t,a}$	Catch in year *t* for age *a* fish
$N_{t+1,a+1} = N_{t,a} e^{-z_{t,a}}$	Numbers of fish in year *t+1* at age *a*
$N_{t+1,A} = N_{t,A-1} e^{-z_{t,A-1}} + N_{t,A} e^{-z_{t,A}}$	Numbers of fish in the "plus group"
$S_t = \sum N_{t,a} W_{t,a} \phi_a$	Spawning biomass
$Z_{t,a} = F_{t,a} + M$	Total mortality in year *t* at age *a*
$F_{t,a} = s_a \mu^F \exp^{\varepsilon^F{}_t}, \ \varepsilon^F{}_t \sim N(o, \sigma^{2}{}_F)$	Fishing mortality
$s_a = \frac{1}{1 + \left(e^{-\alpha + \beta a}\right)}$	Age-specific fishing selectivity
$C_t = \sum C_{t,a}$	Total catch in numbers
$P_{t,a} = {}^{C_{t,a}}\!/_{C_t}$	Proportion at age in catch
$SurB_t = q \sum N_{t,a} W_{t,a} v_a$	Survey biomass
$reclike = \lambda(\sum_{i=1965}^{endyear} \bar{R} - R_i)^2 + \sum_{a=1}^{20} (\bar{R}_{init} - R_{init,a})^2$	recruitment likelihood
$catchlike = \lambda \sum_{i=startyear}^{endyear} (\ln C_{obs,i} - \ln C_{est,i})^2$	catch likelihood

$$surveylike = \lambda \frac{(\ln B - \ln \hat{B})^2}{2\sigma^2}$$ survey biomass likelihood

$$SurvAgelike = \sum_{t,a} n_t P_{t,a} (\ln \hat{P}_{t,a} + 0.001) - \sum_{t,a} n_t P_{t,a} (\ln P_{t,a} + 0.001)$$ survey age comp likelihood

$$SurvLengthlike = \sum_{t,a} n_t P_{t,a} (\ln \hat{P}_{t,a} + 0.001) - \sum_{t,a} n_t P_{t,a} (\ln P_{t,a} + 0.001)$$ survey length comp likelihood

$$Sexratiolike = \frac{\sum_{i=1982}^{lastsurvey} (S\bar{R}_{obs} - SR_i)^2}{\sigma_{SR}}$$ sex ratio likelihood

Table 6.6. Arrowtooth flounder male and female weight-at-age (kg) and proportion of females mature at age.

age	female weight at age	male wt at age	female maturity at age (Zimmerman 2007)	female maturity at age (Stark 2011)
1	0.02	0.01	0	0.00
2	0.04	0.04	0	0.00
3	0.11	0.09	0	0.01
4	0.22	0.17	0.02	0.02
5	0.36	0.27	0.39	0.06
6	0.55	0.39	0.84	0.16
7	0.76	0.52	0.97	0.34
8	0.99	0.66	1.00	0.59
9	1.25	0.80	1.00	0.80
10	1.52	0.94	1	0.97
11	1.80	1.08	1	0.99
12	2.08	1.21	1	1
13	2.35	1.34	1	1
14	2.61	1.45	1	1
15	2.83	1.56	1	1
16	3.01	1.66	1	1
17	3.16	1.75	1	1
18	3.27	1.83	1	1
19	3.37	1.91	1	1
20	3.44	1.98	1	1
21	3.53	2.04	1	1

Table 6.7. Variables used in the population dynamics model.

Variables	
R_t	Age 1 recruitment in year *t*
R_0	Geometric mean value of age 1 recruitment, 1956-75
R_γ	Geometric mean value of age 1 recruitment, 1976-96
τ_t	Recruitment deviation in year *t*
$N_{t,a}$	Number of fish in year *t* at age *a*
$C_{t,a}$	Catch numbers of fish in year *t* at age *a*
$P_{t,a}$	Proportion of the numbers of fish age *a* in year *t*
C_t	Total catch numbers in year *t*
$W_{t,a}$	Mean body weight (kg) of fish age *a* in year *t*
ϕ_a	Proportion of mature females at age *a*
$F_{t,a}$	Instantaneous annual fishing mortality of age *a* fish in year *t*
M	Instantaneous natural mortality, assumed constant over all ages and years
$Z_{t,a}$	Instantaneous total mortality for age *a* fish in year *t*
s_a	Age-specific fishing gear selectivity
μ^F	Median year-effect of fishing mortality
ε_t^F	The residual year-effect of fishing mortality
ν_a	Age-specific survey selectivity
α	Slope parameter in the logistic selectivity equation
β	Age at 50% selectivity parameter in the logistic selectivity equation
σ_t	Standard error of the survey biomass in year *t*

Table 6.8. Model estimates of arrowtooth flounder fishing mortality and exploitation rate (catch/total biomass).

year	Full selection F	Exploitation rate
1976	0.092	0.066
1977	0.053	0.040
1978	0.043	0.035
1979	0.057	0.047
1980	0.074	0.060
1981	0.070	0.055
1982	0.046	0.037
1983	0.053	0.043
1984	0.035	0.028
1985	0.026	0.021
1986	0.024	0.019
1987	0.015	0.012
1988	0.057	0.045
1989	0.021	0.016
1990	0.034	0.025
1991	0.053	0.040
1992	0.023	0.018
1993	0.019	0.016
1994	0.026	0.023
1995	0.016	0.014
1996	0.025	0.022
1997	0.017	0.015
1998	0.026	0.022
1999	0.018	0.015
2000	0.021	0.018
2001	0.022	0.018
2002	0.018	0.015
2003	0.019	0.016
2004	0.026	0.021
2005	0.019	0.016
2006	0.019	0.016
2007	0.016	0.014
2008	0.028	0.024
2009	0.038	0.033
2010	0.050	0.043
2011	0.027	0.023
2012	0.029	0.025
2013	0.026	0.023
2014	0.026	0.023

Table 6.9. Model estimates of arrowtooth flounder age-specific fishery and survey selectivities, by sex.

	Fishery		shelf survey		slope survey		Aleutians survey	
Age	females	males	females	males	females	males	females	males
1	0.01	0.01	0.05	0.11	0.00	0.03	0.04	0.08
2	0.02	0.02	0.15	0.17	0.00	0.05	0.08	0.13
3	0.06	0.05	0.41	0.27	0.00	0.08	0.15	0.20
4	0.13	0.11	0.79	0.39	0.00	0.12	0.27	0.29
5	0.26	0.21	1.00	0.55	0.06	0.18	0.43	0.40
6	0.51	0.40	0.96	0.71	0.91	0.27	0.61	0.52
7	0.85	0.67	0.81	0.82	1.00	0.38	0.77	0.64
8	0.95	0.90	0.66	0.84	1.00	0.50	0.87	0.75
9	0.93	1.00	0.52	0.77	1.00	0.63	0.93	0.83
10	0.89	0.99	0.41	0.62	1.00	0.73	0.97	0.89
11	0.84	0.94	0.32	0.46	1.00	0.82	0.98	0.93
12	0.81	0.89	0.24	0.32	1.00	0.88	0.99	0.96
13	0.77	0.84	0.18	0.21	1.00	0.93	1.00	0.97
14	0.75	0.80	0.14	0.14	1.00	0.95	1.00	0.98
15	0.73	0.76	0.10	0.09	1.00	0.97	1.00	0.99
16	0.72	0.73	0.08	0.05	1.00	0.98	1.00	0.99
17	0.71	0.70	0.06	0.03	1.00	0.99	1.00	1.00
18	0.70	0.68	0.04	0.02	1.00	0.99	1.00	1.00
19	0.69	0.67	0.03	0.01	1.00	1.00	1.00	1.00
20	0.69	0.67	0.02	0.01	1.00	1.00	1.00	1.00
21	0.69	0.67	0.02	0.00	1.00	1.00	1.00	1.00

Table 6.10. Model estimates of arrowtooth flounder 1+ total biomass (t) and female spawning biomass (t) from the 2012 and 2014 assessments.

	2012 Assessment		2014 Assessment	
	Total biomass	Female Spawning biomass	Total biomass	Female Spawning biomass
1976	261,843	145,079	269,581	137,913
1977	259,394	135,957	267,323	127,605
1978	265,437	140,201	273,114	128,654
1979	274,039	149,543	281,156	136,179
1980	278,544	155,185	284,669	142,697
1981	282,838	154,787	287,394	144,561
1982	289,105	154,463	291,738	144,598
1983	304,256	160,634	304,652	148,601
1984	319,243	165,944	317,146	152,209
1985	338,135	176,108	333,697	159,777
1986	360,542	190,169	353,901	170,170
1987	389,916	207,577	381,113	182,853
1988	423,607	226,675	412,852	199,211
1989	450,671	231,305	437,638	204,155
1990	491,982	248,134	477,253	216,960
1991	526,128	264,652	510,536	228,980
1992	546,661	279,076	531,547	239,547
1993	571,926	310,864	559,302	263,221
1994	592,011	346,248	583,417	293,761
1995	601,598	371,401	598,051	320,825
1996	614,404	391,549	616,089	345,783
1997	621,046	398,706	627,504	359,496
1998	635,335	404,618	645,562	371,083
1999	649,181	402,715	661,463	375,655
2000	670,513	404,531	683,861	381,405
2001	695,086	407,830	707,317	385,656
2002	721,321	415,548	731,488	391,757
2003	755,958	430,045	761,140	403,703
2004	792,770	448,107	791,072	418,167
2005	827,972	467,148	816,099	431,908
2006	869,734	491,079	845,881	450,913
2007	909,359	516,763	870,942	470,156
2008	948,231	548,056	895,262	491,018
2009	980,823	580,548	907,756	505,908
2010	1,002,620	608,551	905,159	513,829
2011	1,017,650	630,021	889,634	510,566
2012	1,023,890	652,156	888,498	517,672
2013			881,413	522,331
2014			877,781	527,622

Table 6.11. Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

females	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	99,854	36,124	88,697	69,612	75,583	29,045	16,248	11,126	8,530	6,963
1977	134,535	81,656	29,478	72,014	56,006	59,784	22,216	11,868	8,018	6,166
1978	97,794	110,071	66,725	24,017	58,363	44,942	47,045	17,019	9,020	6,105
1979	104,931	80,022	89,979	54,416	19,503	47,016	35,638	36,506	13,123	6,965
1980	102,024	85,846	65,381	73,284	44,067	15,627	36,889	27,166	27,593	9,938
1981	233,579	83,451	70,099	53,173	59,168	35,100	12,118	27,571	20,086	20,454
1982	90,140	191,065	68,152	57,029	42,960	47,191	27,291	9,098	20,488	14,961
1983	73,116	73,756	156,172	55,565	46,285	34,572	37,344	21,104	6,988	15,761
1984	215,759	59,820	60,270	127,243	45,033	37,143	27,208	28,612	16,042	5,322
1985	155,957	176,569	48,916	49,190	103,492	36,393	29,639	21,336	22,323	12,531
1986	125,630	127,644	144,428	39,954	40,075	83,913	29,230	23,498	16,851	17,646
1987	390,774	102,826	104,418	117,998	32,568	32,526	67,533	23,252	18,629	13,370
1988	215,315	319,879	84,143	85,379	96,346	26,522	26,350	54,316	18,662	14,958
1989	222,861	176,154	261,356	68,534	69,148	77,209	20,815	20,096	41,078	14,142
1990	159,389	182,415	144,118	213,588	55,896	56,186	62,276	16,620	15,998	32,724
1991	167,744	130,440	149,168	117,634	173,757	45,190	44,872	48,904	12,987	12,515
1992	197,292	137,243	106,591	121,540	95,343	139,455	35,573	34,394	37,192	9,895
1993	158,123	161,480	112,272	87,087	99,075	77,390	112,252	28,306	27,275	29,518
1994	161,020	129,429	132,122	91,768	71,054	80,562	62,511	89,842	22,594	21,785
1995	200,538	131,788	105,869	107,918	74,764	57,612	64,706	49,560	70,958	17,861
1996	261,783	164,153	107,837	86,552	88,088	60,846	46,615	51,938	39,687	56,853
1997	210,862	214,261	134,277	88,091	70,531	71,455	48,914	37,011	41,088	31,423
1998	243,482	172,602	175,316	109,769	71,893	57,384	57,780	39,221	29,604	32,884
1999	321,293	199,281	141,186	143,207	89,441	58,306	46,112	45,845	31,004	23,422
2000	236,170	262,993	163,055	115,410	116,860	72,750	47,125	36,944	36,637	24,792
2001	251,240	193,307	215,157	133,242	94,112	94,924	58,642	37,586	29,375	29,152
2002	298,720	205,639	158,140	175,801	108,632	76,416	76,455	46,711	29,842	23,340
2003	362,206	244,515	168,256	129,266	143,451	88,353	61,751	61,238	37,316	23,855
2004	270,734	296,476	200,056	137,520	105,455	116,619	71,334	49,386	48,840	29,781
2005	186,261	221,586	242,514	163,418	112,055	85,529	93,720	56,608	39,046	38,648
2006	333,811	152,461	181,298	198,220	133,325	91,108	69,073	74,988	45,171	31,177
2007	274,448	273,234	124,740	148,180	161,709	108,389	73,560	55,244	59,809	36,050
2008	234,999	224,652	223,576	101,979	120,949	131,599	87,691	59,034	44,231	47,912
2009	316,645	192,331	183,745	182,585	83,052	97,996	105,546	69,354	46,499	34,872
2010	160,354	259,118	157,251	149,916	148,406	67,030	77,995	82,410	53,848	36,150
2011	173,447	131,201	211,764	128,160	121,574	119,238	52,878	59,997	62,926	41,188
2012	198,602	141,958	107,317	172,966	104,408	98,565	95,752	41,909	47,369	49,726
2013	306,064	162,541	116,105	87,635	140,844	84,568	79,006	75,656	32,974	37,307
2014	409,222	250,499	132,953	94,834	71,395	114,191	67,916	62,625	59,740	26,061

Table 6.11 (cont'd). Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

	females				numbers at age (1,000s)						
	11	12	13	14	15	16	17	18	19	20	21
1976	5,879	5,078	4,432	3,893	3,438	3,042	2,685	2,374	2,076	1,810	4,180
1977	5,060	4,297	3,730	3,269	2,881	2,550	2,261	1,998	1,769	1,548	4,467
1978	4,710	3,878	3,302	2,874	2,524	2,227	1,974	1,751	1,549	1,371	4,664
1979	4,726	3,655	3,017	2,574	2,244	1,973	1,742	1,545	1,372	1,214	4,730
1980	5,293	3,604	2,796	2,314	1,979	1,727	1,520	1,344	1,192	1,059	4,590
1981	7,398	3,958	2,706	2,107	1,748	1,497	1,309	1,153	1,020	906	4,293
1982	15,297	5,557	2,984	2,047	1,597	1,328	1,139	997	879	778	3,965
1983	11,541	11,832	4,309	2,319	1,593	1,245	1,036	889	778	687	3,706
1984	12,040	8,845	9,095	3,320	1,790	1,232	963	802	689	604	3,407
1985	4,165	9,444	6,951	7,159	2,617	1,412	972	761	634	545	3,170
1986	9,921	3,303	7,499	5,526	5,697	2,084	1,125	775	607	505	2,962
1987	14,019	7,893	2,631	5,980	4,410	4,549	1,665	899	619	485	2,773
1988	10,744	11,277	6,354	2,119	4,820	3,556	3,669	1,343	725	500	2,629
1989	11,373	8,197	8,631	4,875	1,630	3,711	2,741	2,831	1,037	560	2,417
1990	11,279	9,082	6,553	6,906	3,904	1,306	2,975	2,198	2,270	832	2,388
1991	25,650	8,859	7,146	5,165	5,449	3,083	1,032	2,352	1,738	1,796	2,548
1992	9,565	19,667	6,812	5,509	3,989	4,214	2,387	799	1,824	1,349	3,370
1993	7,863	7,612	15,671	5,434	4,398	3,186	3,368	1,908	639	1,459	3,774
1994	23,601	6,294	6,099	12,567	4,360	3,531	2,559	2,706	1,533	514	4,205
1995	17,247	18,714	4,998	4,849	10,000	3,472	2,813	2,039	2,157	1,223	3,763
1996	14,324	13,845	15,036	4,019	3,901	8,049	2,795	2,265	1,643	1,738	4,017
1997	45,079	11,374	11,009	11,970	3,202	3,110	6,420	2,231	1,808	1,312	4,595
1998	25,173	36,150	9,130	8,844	9,621	2,575	2,502	5,166	1,795	1,455	4,754
1999	26,055	19,976	28,728	7,264	7,042	7,666	2,053	1,995	4,121	1,433	4,955
2000	18,748	20,877	16,022	23,059	5,834	5,659	6,163	1,651	1,605	3,315	5,138
2001	19,751	14,955	16,673	12,808	18,447	4,670	4,531	4,936	1,322	1,286	6,774
2002	23,193	15,734	11,928	13,312	10,234	14,749	3,735	3,626	3,951	1,059	6,452
2003	18,677	18,578	12,616	9,572	10,690	8,222	11,853	3,003	2,915	3,177	6,040
2004	19,058	14,938	14,876	10,111	7,676	8,576	6,599	9,516	2,411	2,341	7,403
2005	23,600	15,126	11,873	11,836	8,052	6,117	6,838	5,264	7,593	1,924	7,777
2006	30,892	18,886	12,117	9,519	9,496	6,463	4,912	5,492	4,228	6,101	7,795
2007	24,910	24,710	15,122	9,711	7,634	7,619	5,187	3,944	4,411	3,396	11,161
2008	28,906	19,993	19,850	12,157	7,811	6,143	6,133	4,177	3,176	3,553	11,725
2009	37,836	22,866	15,839	15,746	9,653	6,207	4,884	4,878	3,323	2,528	12,160
2010	27,171	29,548	17,895	12,418	12,362	7,586	4,881	3,843	3,840	2,617	11,567
2011	27,732	20,907	22,800	13,840	9,621	9,590	5,891	3,794	2,989	2,988	11,036
2012	32,597	21,983	16,597	18,121	11,010	7,659	7,638	4,694	3,024	2,383	11,181
2013	39,228	25,760	17,400	13,154	14,377	8,742	6,084	6,071	3,732	2,405	10,786
2014	29,529	31,100	20,452	13,831	10,465	11,446	6,963	4,849	4,839	2,976	10,518

Table 6.11 (cont'd). Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

males	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	99,854	31,092	65,708	44,386	41,481	13,720	6,606	3,894	2,569	1,805
1977	134,535	70,267	21,841	45,984	30,829	28,399	9,158	4,255	2,431	1,582
1978	97,794	94,728	49,425	15,329	32,132	21,363	19,390	6,125	2,794	1,584
1979	104,931	68,869	66,654	34,716	10,729	22,338	14,676	13,100	4,077	1,848
1980	102,024	73,878	48,435	46,767	24,244	7,425	15,216	9,776	8,557	2,641
1981	233,579	71,814	51,930	33,943	32,578	16,695	5,011	9,981	6,254	5,416
1982	90,140	164,425	50,485	36,402	23,658	22,459	11,290	3,298	6,415	3,979
1983	73,116	63,476	115,685	35,453	25,467	16,432	15,404	7,607	2,188	4,227
1984	215,759	51,482	44,648	81,194	24,774	17,648	11,221	10,302	4,996	1,426
1985	155,957	151,962	36,235	31,381	56,904	17,269	12,184	7,643	6,935	3,346
1986	125,630	109,857	106,990	25,485	22,024	39,775	11,985	8,371	5,205	4,705
1987	390,774	88,498	77,353	75,263	17,893	15,407	27,648	8,256	5,722	3,546
1988	215,315	275,313	62,333	54,451	52,918	12,553	10,766	19,212	5,709	3,948
1989	222,861	151,597	193,628	43,736	38,028	36,627	8,553	7,175	12,557	3,700
1990	159,389	156,999	106,755	136,240	30,723	26,628	25,505	5,909	4,923	8,591
1991	167,744	112,262	110,507	75,038	95,500	21,423	18,397	17,393	3,984	3,303
1992	197,292	118,112	78,965	77,562	52,439	66,185	14,631	12,308	11,428	2,597
1993	158,123	138,980	83,166	55,549	54,460	36,687	46,012	10,082	8,415	7,787
1994	161,020	111,396	97,876	58,525	39,033	38,157	25,576	31,850	6,935	5,773
1995	200,538	113,424	78,430	68,838	41,074	27,283	26,482	17,573	21,692	4,705
1996	261,783	141,283	79,885	55,202	48,387	28,800	19,046	18,373	12,126	14,933
1997	210,862	184,406	99,475	56,189	38,749	33,834	20,001	13,101	12,532	8,241
1998	243,482	148,554	129,873	70,010	39,491	27,162	23,608	13,865	9,030	8,617
1999	321,293	171,512	104,593	91,346	49,140	27,609	18,858	16,230	9,451	6,132
2000	236,170	226,351	120,790	73,608	64,194	34,439	19,257	13,065	11,178	6,492
2001	251,240	166,373	159,391	84,984	51,700	44,938	23,969	13,294	8,954	7,637
2002	298,720	176,986	117,151	112,134	59,679	36,180	31,257	16,530	9,099	6,109
2003	362,206	210,448	124,644	82,445	78,800	41,822	25,231	21,650	11,380	6,248
2004	270,734	255,169	148,203	87,710	57,926	55,201	29,146	17,455	14,881	7,801
2005	186,261	190,710	179,658	104,239	61,564	40,498	38,327	20,040	11,900	10,108
2006	333,811	131,219	134,305	126,427	73,243	43,132	28,229	26,525	13,782	8,161
2007	274,448	235,165	92,408	94,509	88,828	51,309	30,059	19,530	18,233	9,448
2008	234,999	193,352	165,626	65,040	66,431	62,280	35,815	20,852	13,474	12,550
2009	316,645	165,531	136,122	116,470	45,633	46,405	43,173	24,561	14,164	9,115
2010	160,354	223,005	116,494	95,648	81,583	31,773	31,973	29,309	16,458	9,438
2011	173,447	112,913	156,877	81,782	66,872	56,591	21,737	21,452	19,331	10,776
2012	198,602	122,177	79,496	110,332	57,394	46,738	39,269	14,931	14,605	13,111
2013	306,064	139,891	86,012	55,899	77,400	40,082	32,384	26,908	10,132	9,869
2014	409,222	215,594	98,491	60,492	39,230	54,098	27,815	22,247	18,322	6,873

Table 6.11 (cont'd). Estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

males	numbers at age (1,000s)										
	11	12	13	14	15	16	17	18	19	20	21
1976	1,312	975	733	554	421	321	244	185	140	105	128
1977	1,114	814	609	461	351	268	205	156	119	90	150
1978	1,032	729	535	402	305	233	178	137	104	80	160
1979	1,048	685	485	357	269	205	157	120	92	71	162
1980	1,199	682	448	319	235	178	136	104	80	61	155
1981	1,674	763	437	288	206	153	116	89	68	52	142
1982	3,450	1,071	491	282	187	134	100	76	58	45	128
1983	2,624	2,281	711	327	189	125	90	67	51	39	116
1984	2,757	1,717	1,499	469	216	125	83	60	45	34	104
1985	955	1,852	1,156	1,012	317	147	85	57	41	31	94
1986	2,271	650	1,261	789	692	217	101	58	39	28	86
1987	3,206	1,550	444	864	541	475	149	69	40	27	79
1988	2,447	2,215	1,072	307	599	375	330	104	48	28	73
1989	2,562	1,594	1,449	704	203	396	249	219	69	32	67
1990	2,532	1,755	1,094	996	484	140	273	172	151	48	69
1991	5,767	1,704	1,184	739	675	329	95	186	117	103	79
1992	2,155	3,776	1,120	781	490	448	219	63	124	78	122
1993	1,770	1,471	2,582	767	536	336	308	151	44	86	138
1994	5,344	1,217	1,012	1,779	529	370	232	213	104	30	155
1995	3,919	3,634	829	691	1,216	362	254	160	146	72	127
1996	3,240	2,701	2,508	573	478	842	251	176	111	102	138
1997	10,153	2,207	1,843	1,714	392	328	578	172	121	76	165
1998	5,668	6,991	1,521	1,272	1,184	271	227	400	120	84	167
1999	5,854	3,857	4,766	1,039	870	811	186	156	275	82	172
2000	4,214	4,027	2,657	3,287	717	602	561	129	108	191	176
2001	4,438	2,884	2,761	1,824	2,260	494	414	387	89	74	253
2002	5,213	3,033	1,974	1,893	1,253	1,554	340	286	267	61	226
2003	4,196	3,584	2,088	1,361	1,307	865	1,075	235	198	185	199
2004	4,284	2,881	2,464	1,438	938	902	598	743	163	137	266
2005	5,301	2,916	1,964	1,683	984	643	619	411	510	112	277
2006	6,935	3,641	2,006	1,353	1,161	679	444	428	284	353	269
2007	5,597	4,761	2,503	1,381	933	801	469	307	296	196	430
2008	6,504	3,857	3,285	1,729	955	646	555	325	213	205	435
2009	8,494	4,410	2,621	2,237	1,180	652	442	380	223	146	439
2010	6,078	5,678	2,956	1,762	1,507	797	441	299	258	151	397
2011	6,185	3,996	3,747	1,958	1,171	1,004	532	295	201	173	368
2012	7,311	4,204	2,721	2,556	1,338	801	688	365	203	138	372
2013	8,864	4,952	2,853	1,851	1,742	913	548	471	250	139	349
2014	6,697	6,025	3,373	1,947	1,265	1,192	626	376	323	172	335

Table 6.12. Estimated age 2 recruitment of arrowtooth flounder (thousands of fish) from the 2012 and 2014 stock assessments. Average over all years from 2014 assessment = 312,040.

Year class	2012 Assessment	2014 Assessment
1974	230,069	67,217
1975	297,213	151,923
1976	245,370	204,799
1977	260,994	148,890
1978	466,116	159,724
1979	278,861	155,265
1980	279,797	355,490
1981	295,261	137,232
1982	261,457	111,302
1983	512,622	328,531
1984	300,425	237,501
1985	424,330	191,324
1986	454,913	595,192
1987	228,364	327,751
1988	469,933	339,414
1989	570,669	242,702
1990	346,025	255,355
1991	608,477	300,460
1992	709,081	240,825
1993	533,246	245,212
1994	590,261	305,436
1995	484,687	398,667
1996	422,013	321,156
1997	461,524	370,793
1998	440,673	489,344
1999	501,638	359,680
2000	439,534	382,625
2001	375,534	454,963
2002	369,206	551,645
2003	381,796	412,296
2004	327,427	283,680
2005	322,479	508,399
2006	346,488	418,004
2007	389,187	357,862
2008		482,123
2009		244,114

Table 6.13. Projections of arrowtooth flounder female spawning biomass (t), future catch (t) and full selection fishing mortality rates for seven future harvest scenarios.

Scenarios 1 and 2
Maximum ABC harvest permissible

	Female		
Year	spawning biomass	catch	F
2014	530,889	20,501	0.04
2015	529,660	80,547	0.15
2016	481,674	72,088	0.15
2017	434,751	65,261	0.15
2018	393,679	61,202	0.15
2019	363,823	59,752	0.15
2020	345,632	58,859	0.15
2021	333,040	56,342	0.15
2022	319,430	53,281	0.15
2023	303,991	50,558	0.15
2024	288,928	48,317	0.15
2025	275,621	46,516	0.15
2026	264,416	45,092	0.15
2027	255,232	43,929	0.15

Scenario 3
1/2 Maximum ABC harvest permissible

	Female		
Year	spawning biomass	catch	F
2014	530,889	20,501	0.04
2015	532,426	40,274	0.07
2016	516,863	16,421	0.03
2017	512,701	16,157	0.03
2018	506,844	16,215	0.03
2019	505,637	16,682	0.03
2020	512,311	17,212	0.03
2021	522,832	17,288	0.03
2022	529,326	17,076	0.03
2023	529,092	16,783	0.03
2024	524,371	16,476	0.03
2025	517,530	16,181	0.03
2026	509,885	15,918	0.03
2027	501,982	15,689	0.03

Scenario 4
Harvest at average F over the past 5 years

	Female		
Year	spawning biomass	catch	F
2014	530,889	20,501	0.04
2015	533,135	29,601	0.05
2016	523,538	41,138	0.08
2017	500,033	39,036	0.08
2018	476,545	37,953	0.08
2019	459,612	38,022	0.08
2020	451,787	38,306	0.08
2021	448,433	37,586	0.08
2022	442,331	36,347	0.08
2023	431,756	35,092	0.08
2024	419,113	33,957	0.08
2025	406,455	32,969	0.08
2026	394,710	32,152	0.08
2027	384,140	31,485	0.08

Scenario 5
No fishing

	Female		
Year	spawning biomass	catch	F
2014	530,889	20,501	0.04
2015	535,049	0	0
2016	549,429	0	0
2017	558,020	0	0
2018	563,313	0	0
2019	571,716	0	0
2020	587,151	0	0
2021	606,195	0	0
2022	620,630	0	0
2023	627,061	0	0
2024	627,533	0	0
2025	624,574	0	0
2026	619,717	0	0
2027	613,636	0	0

Table 6.13 (continued).

Scenario 6

Determination of whether arrowtooth flounder are currently overfished

B35=194,267

Year	Female spawning biomass	catch	F
2014	530,889	20,501	0.04
2015	528,711	93,856	0.18
2016	470,597	82,316	0.18
2017	416,041	73,232	0.18
2018	369,729	67,770	0.18
2019	336,388	65,546	0.18
2020	315,620	64,041	0.18
2021	300,848	60,765	0.18
2022	285,649	57,029	0.18
2023	269,447	53,818	0.18
2024	254,310	51,231	0.18
2025	241,395	48,907	0.18
2026	231,059	46,835	0.18
2027	223,233	45,190	0.17

Scenario 7

Determination of whether arrowtooth flounder are approaching an overfished condition

B35=194,267

Year	Female spawning biomass	catch	F
2014	530,889	20,501	0.04
2015	529,660	80,547	0.15
2016	481,673	72,088	0.15
2017	433,982	76,071	0.18
2018	384,850	70,023	0.18
2019	348,817	67,309	0.18
2020	325,635	65,401	0.18
2021	308,778	61,798	0.18
2022	291,825	57,804	0.18
2023	274,186	54,395	0.18
2024	257,898	51,667	0.18
2025	244,075	49,305	0.18
2026	232,990	47,176	0.18
2027	224,564	45,448	0.17

Table 6.14. TAC and ABC used to manage the BSAI arrowtooth flounder complex since 1980.

	arowtooth flounder	
year	**TAC**	**ABC**
1980		20,000
1981		16,500
1982		16,500
1983		20,000
1984		20,000
1985		20,000
1986	20,000	20,000
1987	9,795	30,900
1988	5,531	99,500
1989	6,000	163,700
1990	10,000	106,500
1991	20,000	116,400
1992	10,000	82,300
1993	10,000	72,000
1994	10,000	93,400
1995	10,227	113,000
1996	9,000	129,000
1997	20,760	108,000
1998	16,000	147,000
1999	134,354	140,000
2000	131,000	131,000
2001	22,015	117,000
2002	16,000	113,000
2003	12,000	112,000
2004	12,000	115,000
2005	12,000	108,000
2006	13,000	136,000
2007	20,000	158,000
2008	75,000	244,000
2009	75,000	156,000
2010	75,000	156,000
2011	25,900	153,000
2012	25,900	157,000
2013	25,000	152,000

Figures

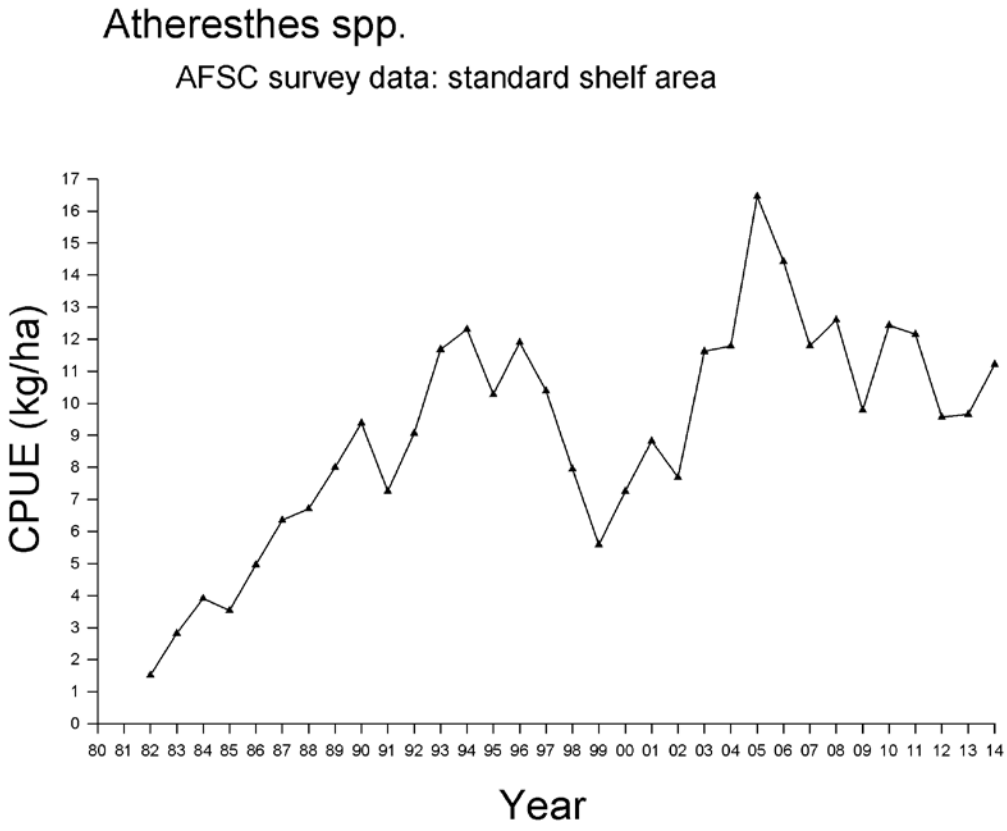

Figure 6.1. Arrowtooth flounder CPUE (kg/ha) from the standard shelf survey area (1982-1992) and standard shelf survey area including Northwestern stratum 82 and 90 (1993-2012).

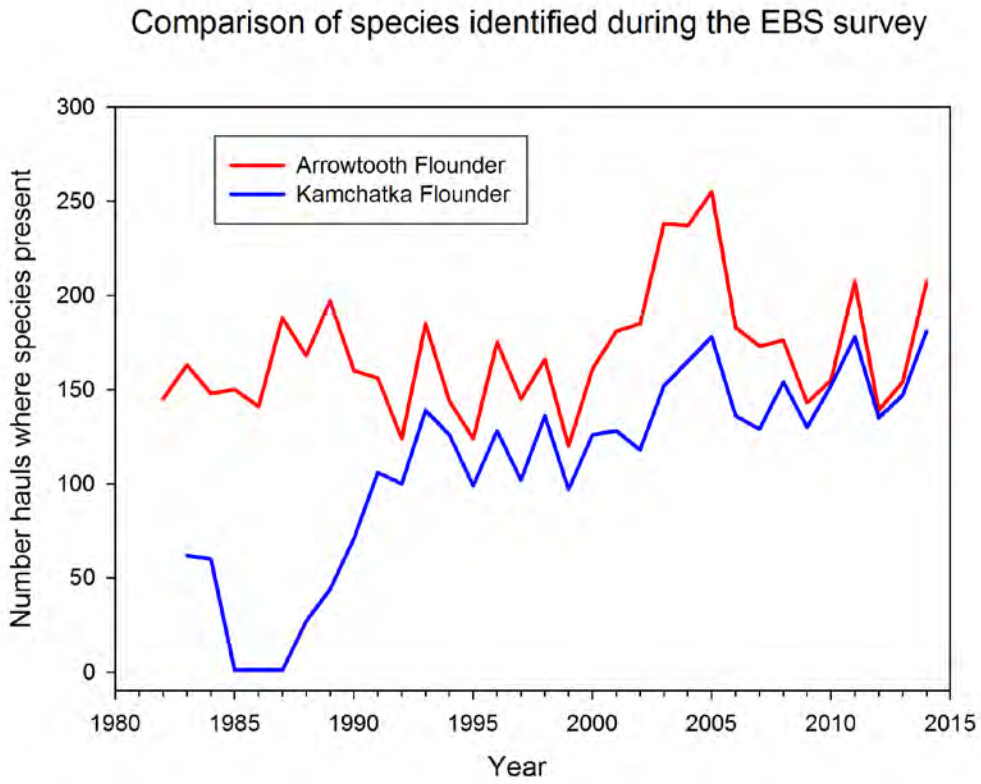

Figure 6.2. Number of hauls where arrowtooth flounder and Kamchatka flounder were identified during the annual Bering Sea shelf surveys, 1982-2014, within the standard survey area.

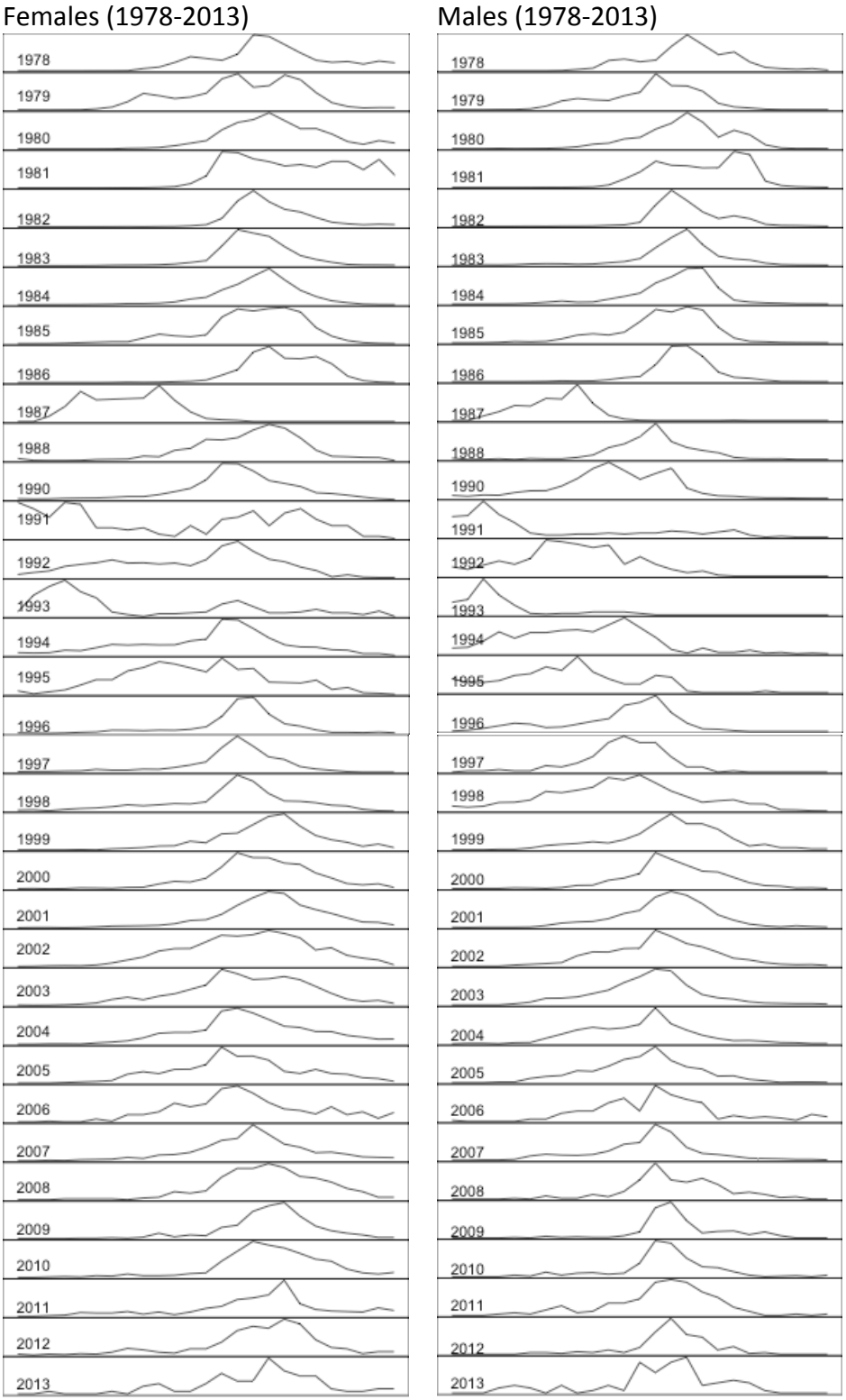

Figure 6.3. Size composition of arrowtooth flounder from the fishery data 1976-2013.

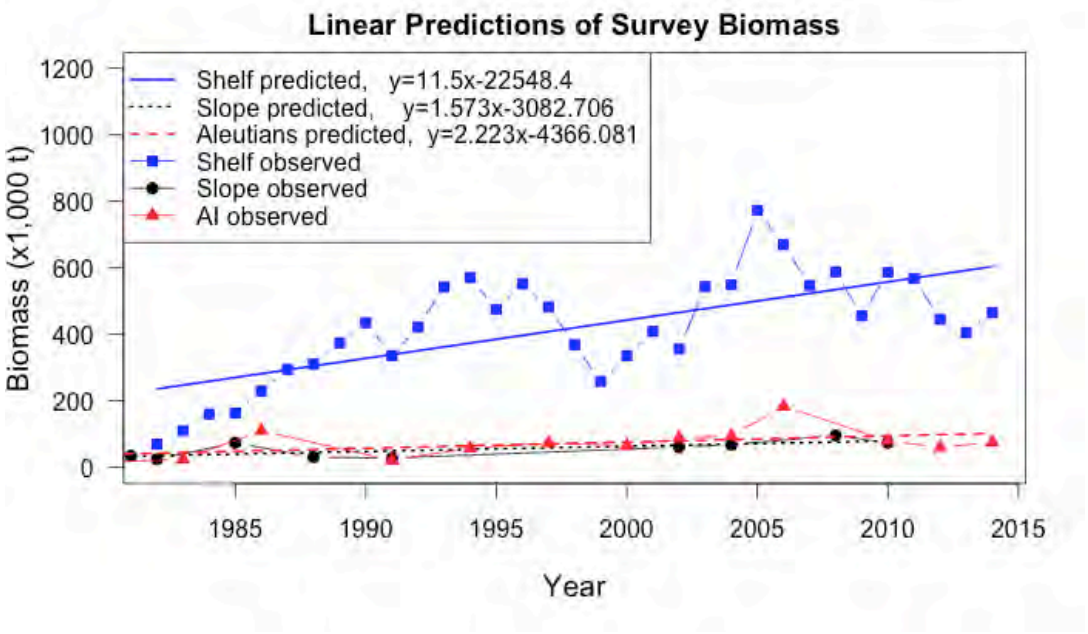

Figure 6.4. Linear regressions of trawl survey estimates for the Bering Sea shelf, slope and the Aleutian Islands used to estimate the proportion of biomass in each area.

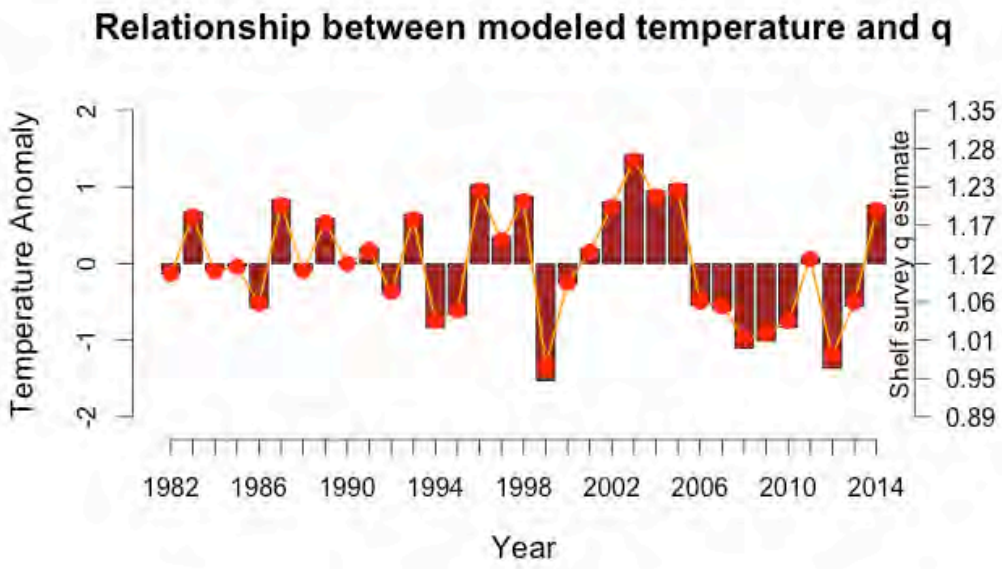

Figure 6.5. Shelf survey annual avg. bottom temperature anomalies (bars), model estimate of annual shelf survey q due to effect of water temperature (circles with lines).

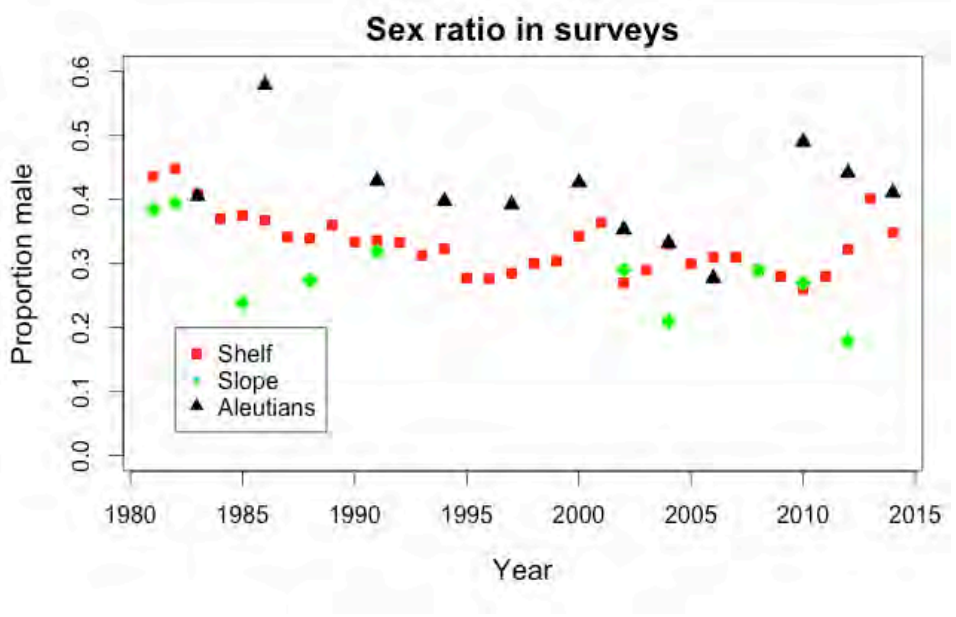

Figure 6.6. Proportion of the estimated male population from Bering Sea and Aleutian Islands trawl surveys on the continental shelf and slope.

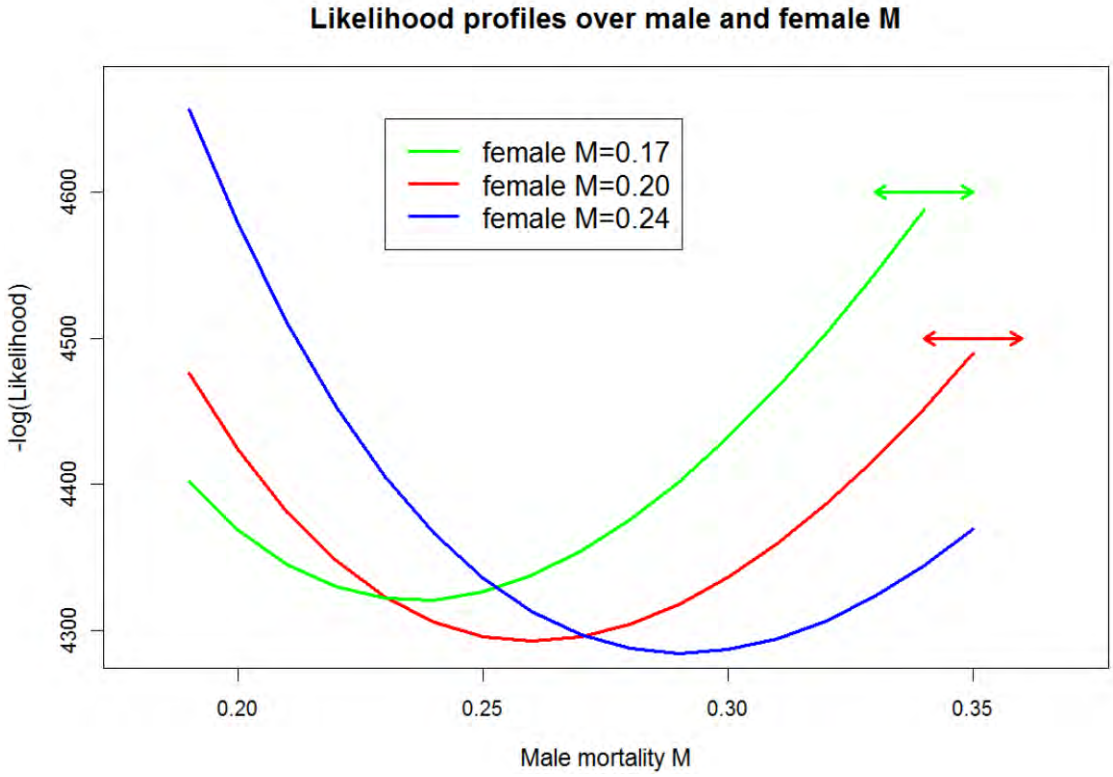

Figure 6.7. Fit to the stock assessment model in terms of –log(likelihood) when profiling over male natural mortality (x axis) for three different levels of female natural mortality. Arrows indicate the values of male natural mortality where the model estimates that maximum male selectivity is close to 1.0 for a given combination of male and female natural mortality.

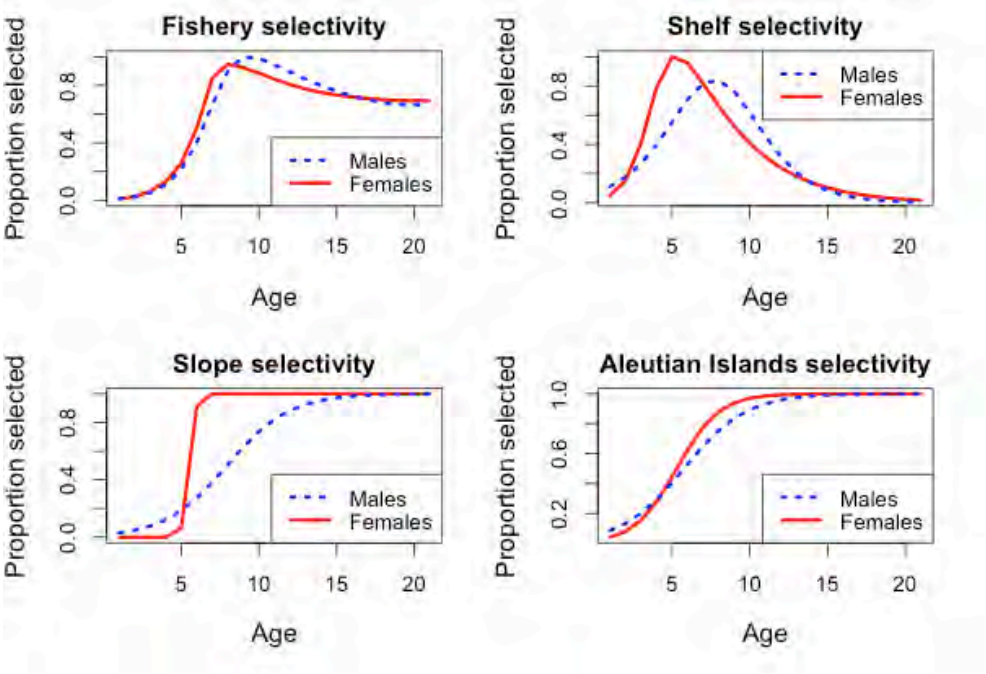

Figure 6.8. Age-specific fishery selectivity (top left panel), shelf survey selectivity (top right panel) slope survey selectivity (bottom left panel) and Aleutian Islands survey selectivity (bottom right panel), by sex, estimated from the stock assessment model.

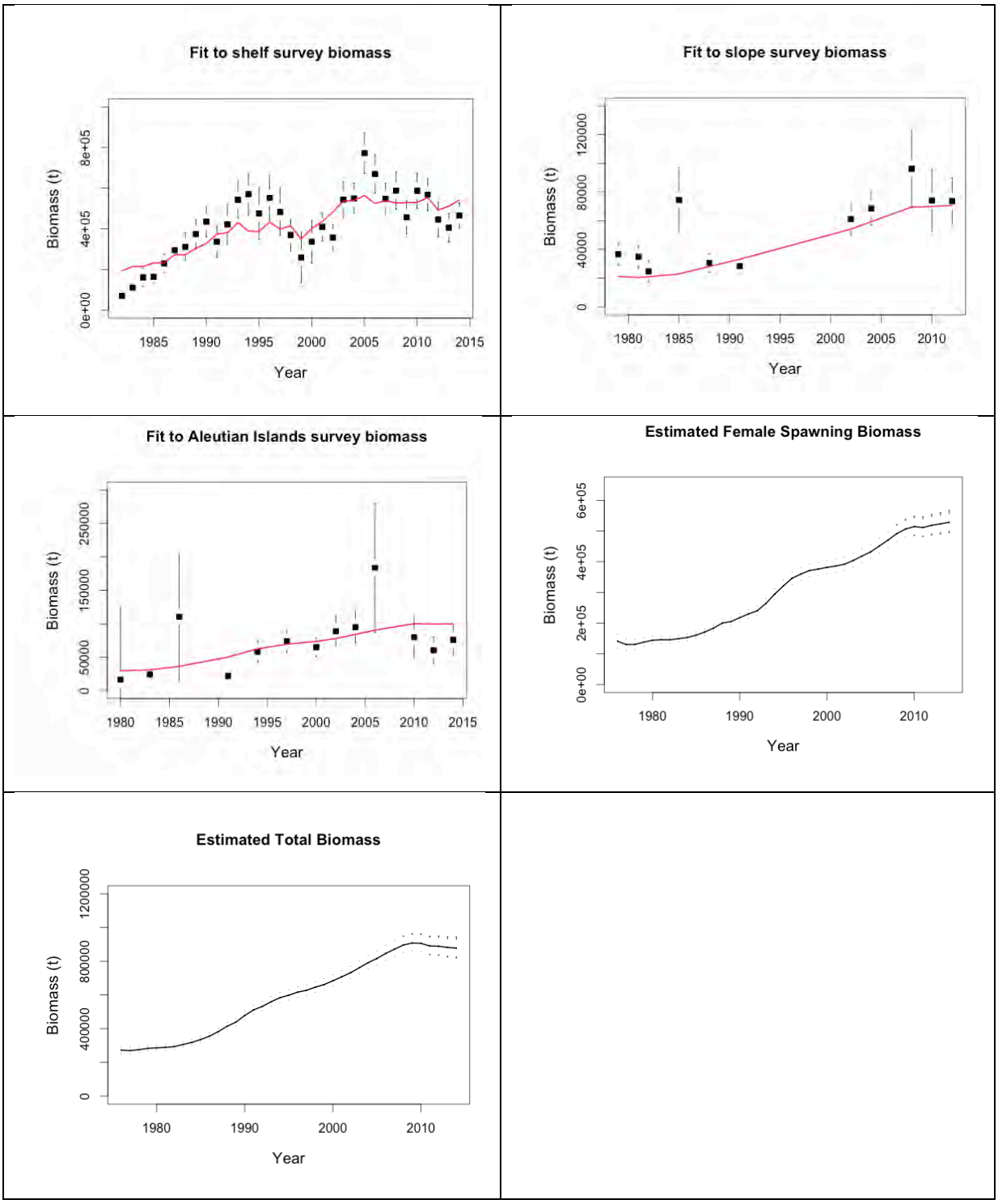

Figure 6.9. Stock assessment model results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), estimate of female spawning biomass with $B_{35\%}$ and $B_{40\%}$ indicated (middle right panel), the fit to the Aleutian Islands survey (middle left panel) and the estimate of total biomass (bottom panel). Credible intervals on model estimates of female spawning biomass and total biomass are from 5% and 95% quantiles of MCMC posterior values.

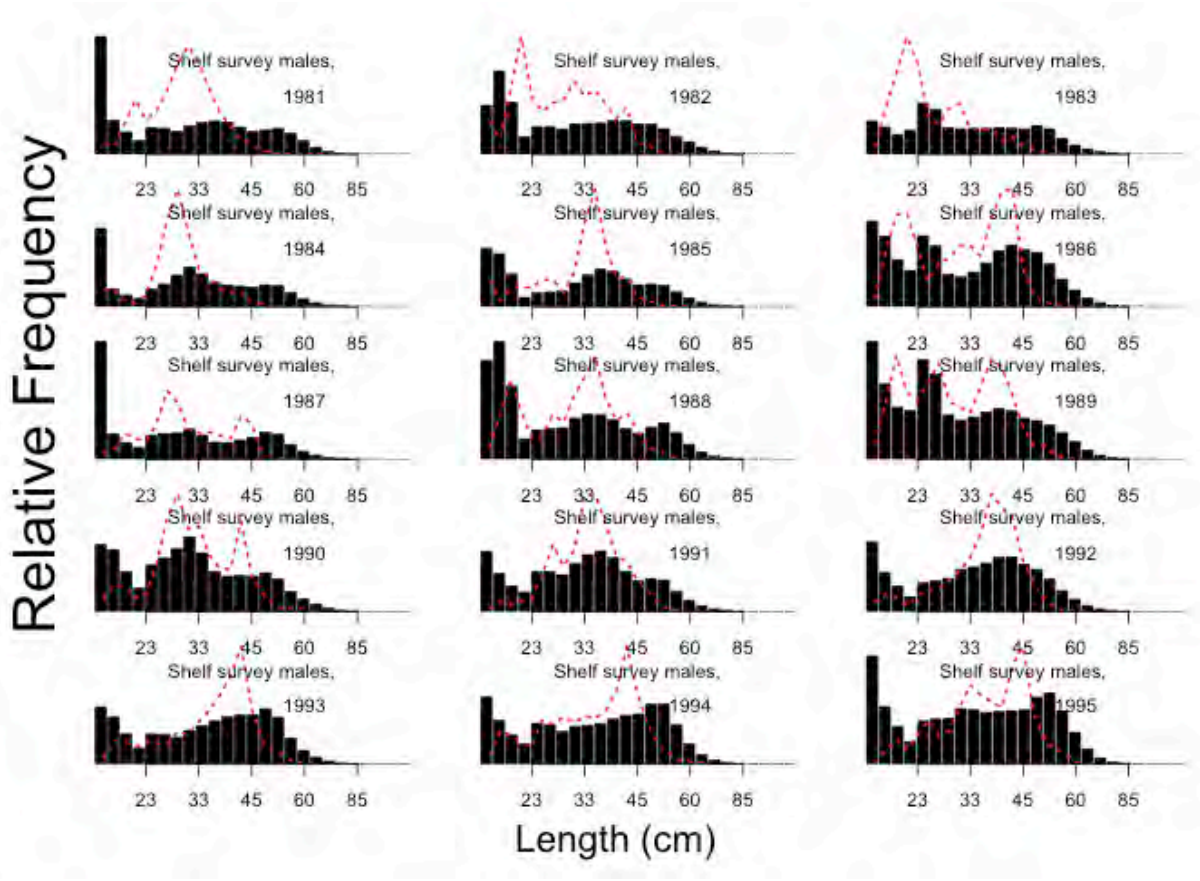

Figure 6.10. Model fit (dotted lines) to Bering Sea shelf survey observed length composition (bar plots).

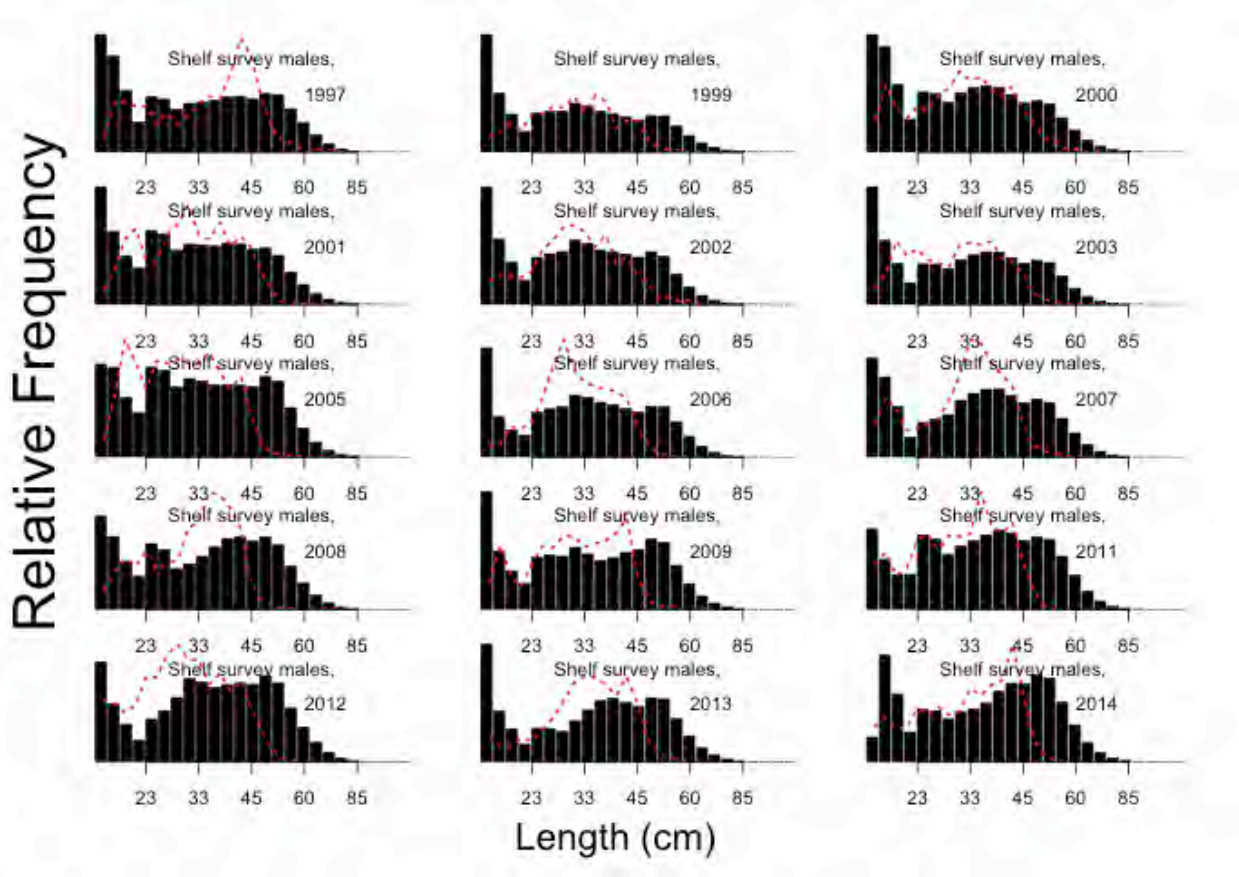

Figure 6.10 (cont'd). Model fit (dotted lines) to Bering Sea shelf survey observed length composition (bar plots).

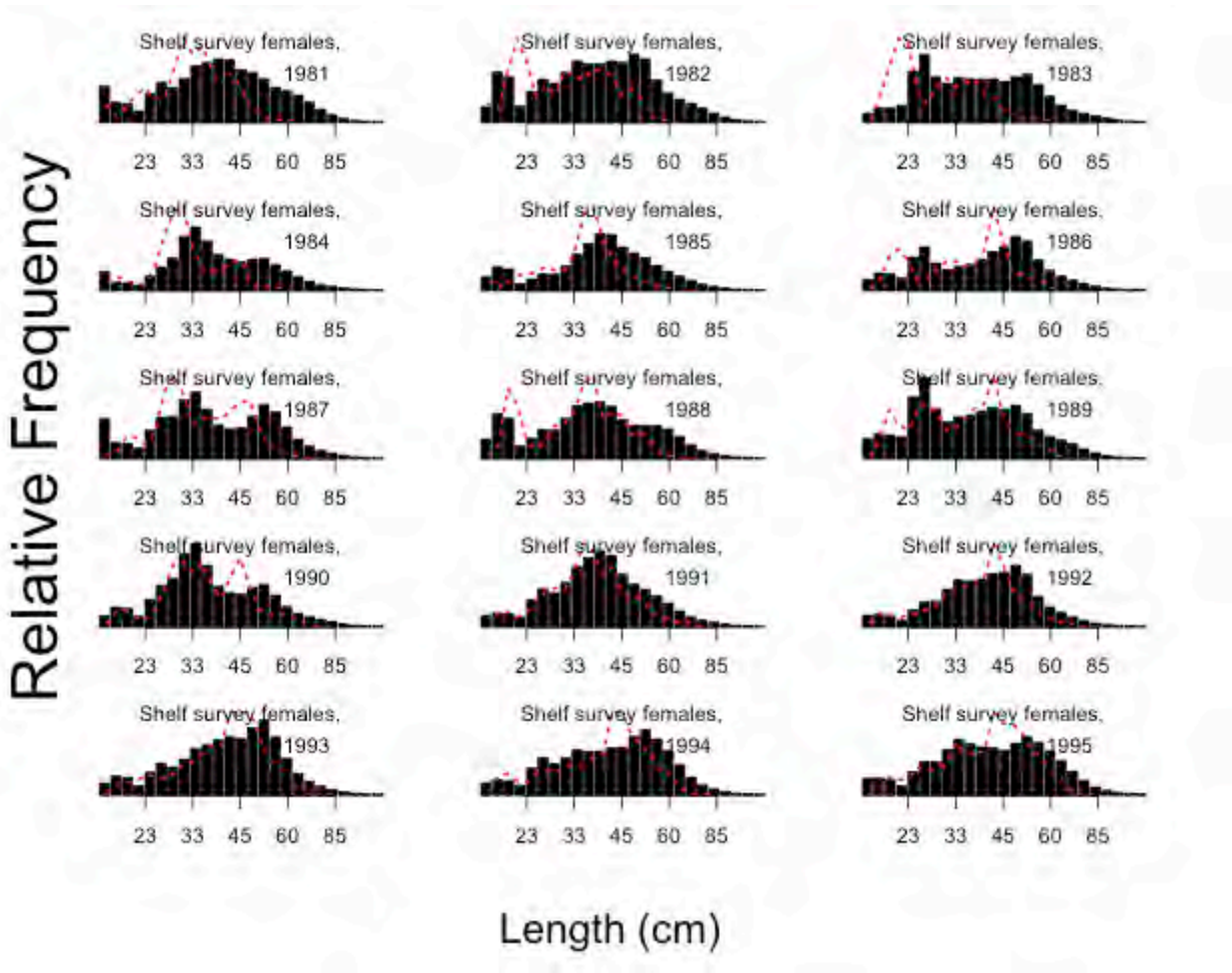

Figure 6.10 (cont'd). Model fit (dotted lines) to Bering Sea shelf survey observed length composition (bar plots).

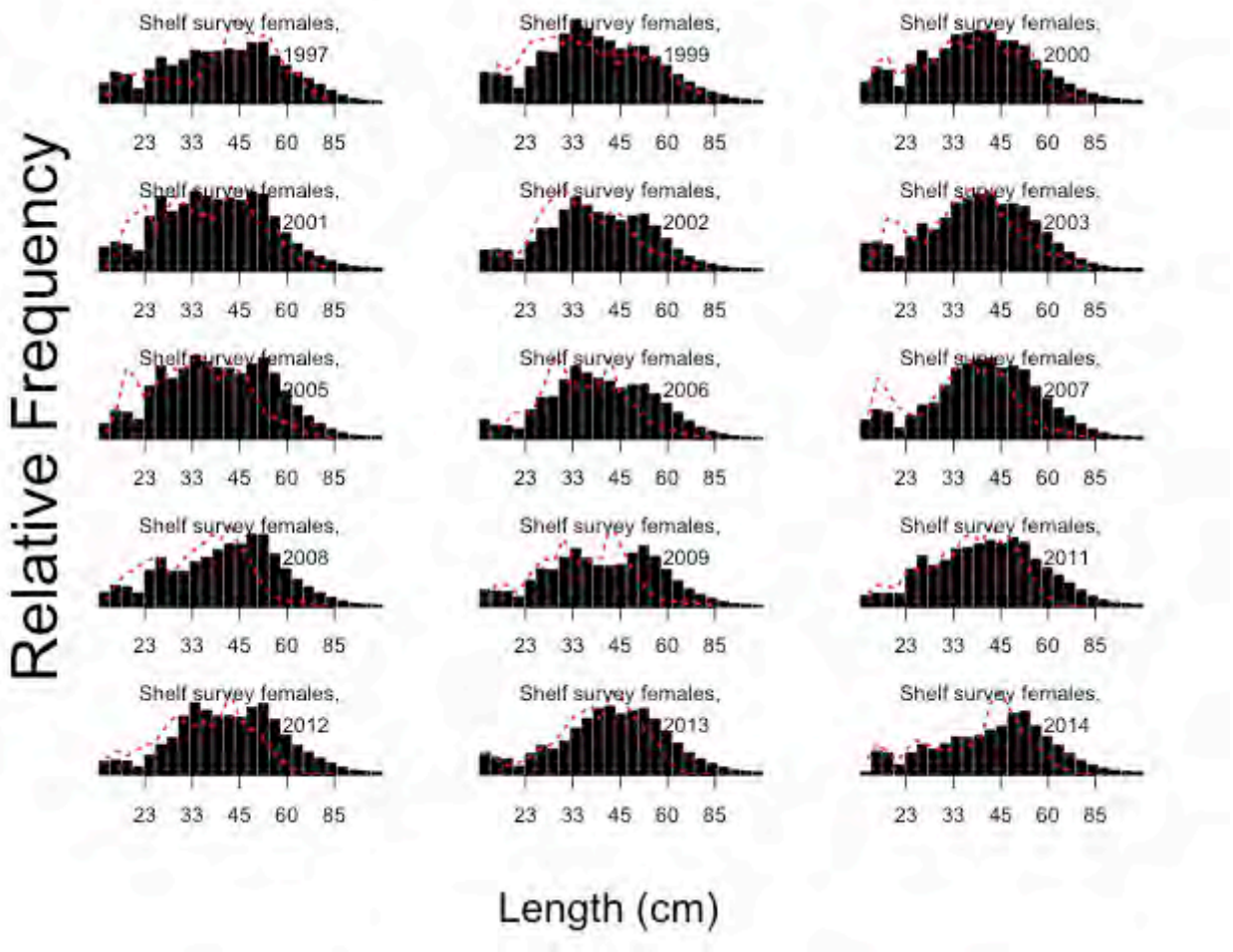

Figure 6.10 (cont'd). Model fit (dotted lines) to Bering Sea shelf survey observed length composition (bar plots).

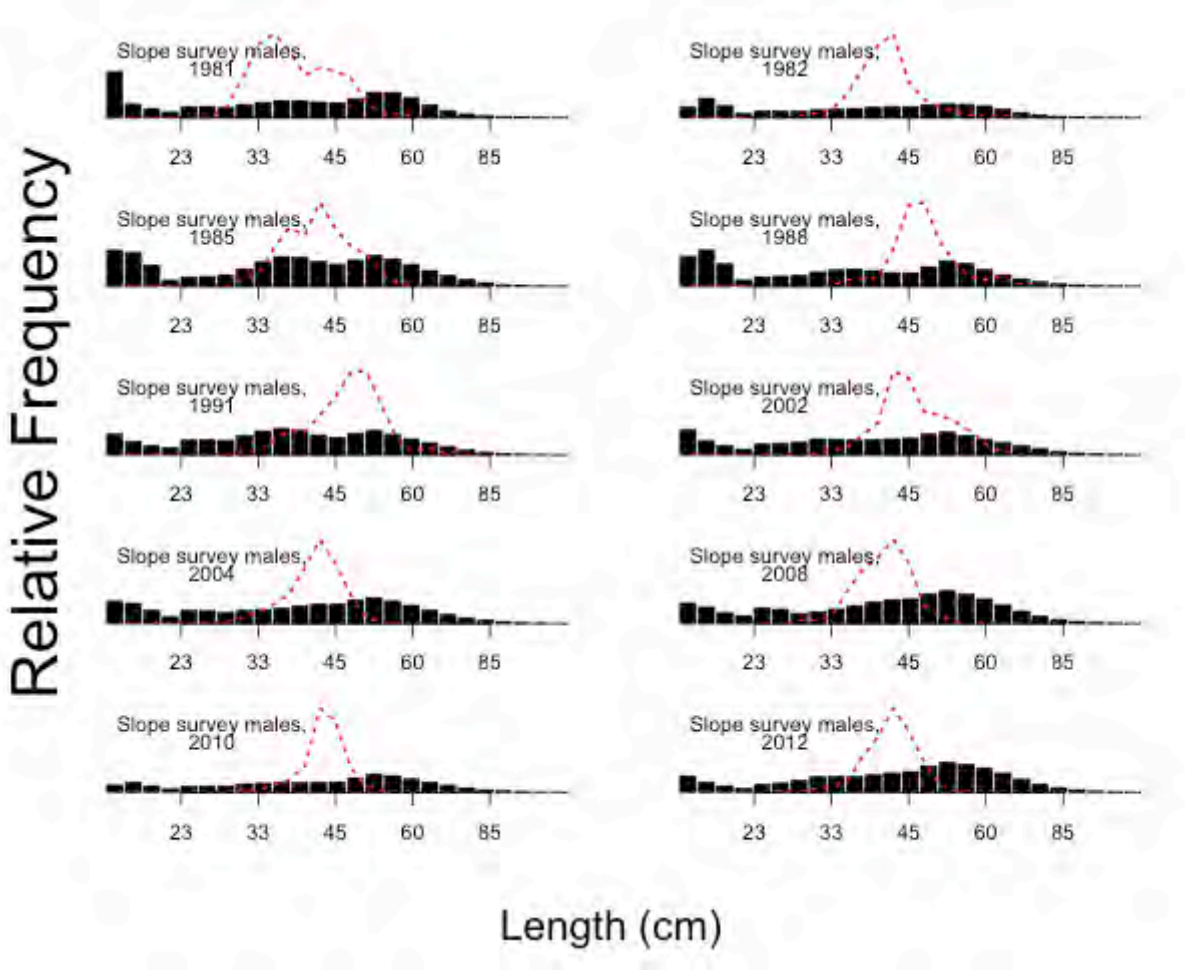

Figure 6.10 (cont'd). Model fit (dotted lines) to Bering Sea slope survey observed length composition (bar plots).

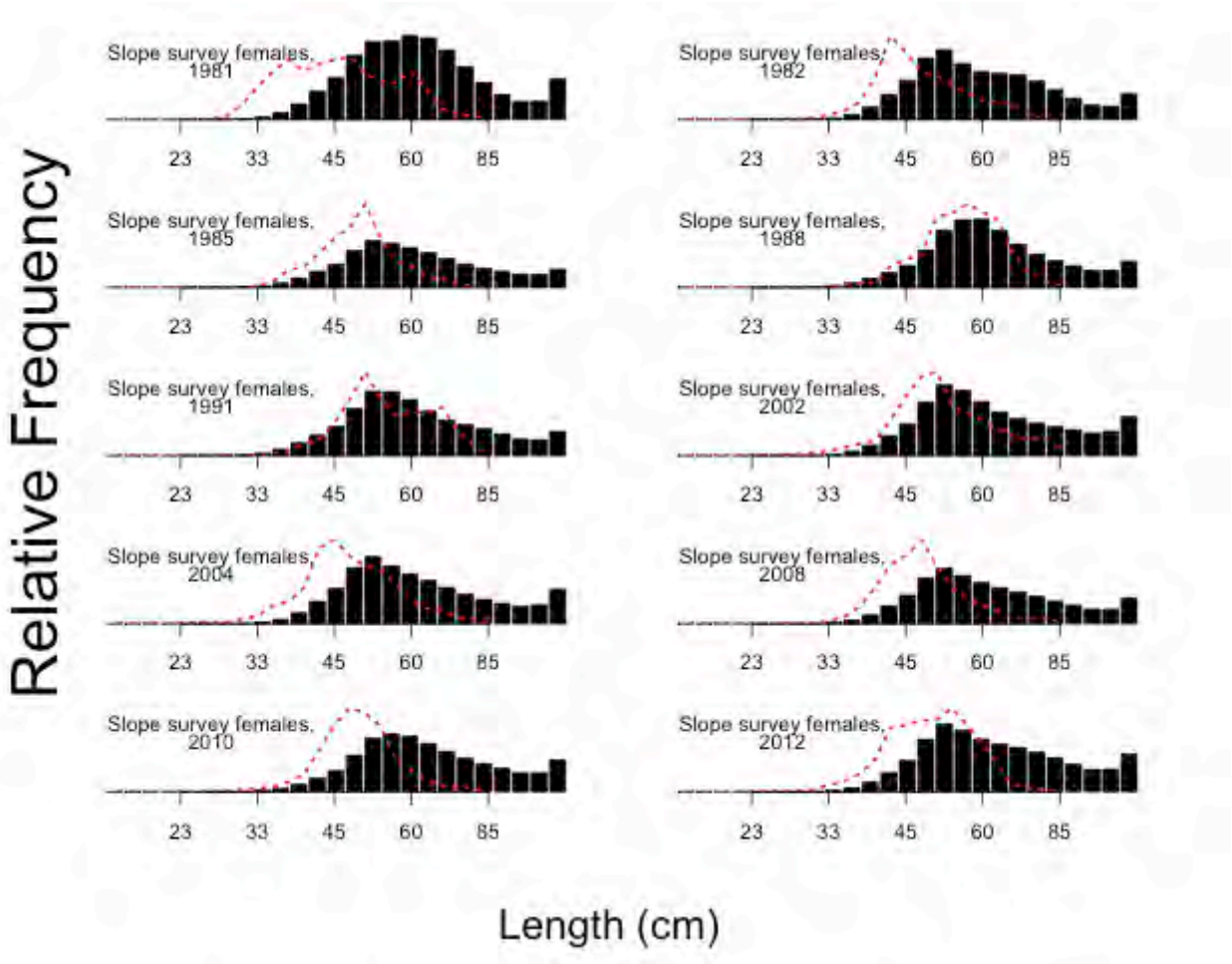

Figure 6.10 (cont'd). Model fit (dotted lines) to Bering Sea slope survey observed length composition (bar plots).

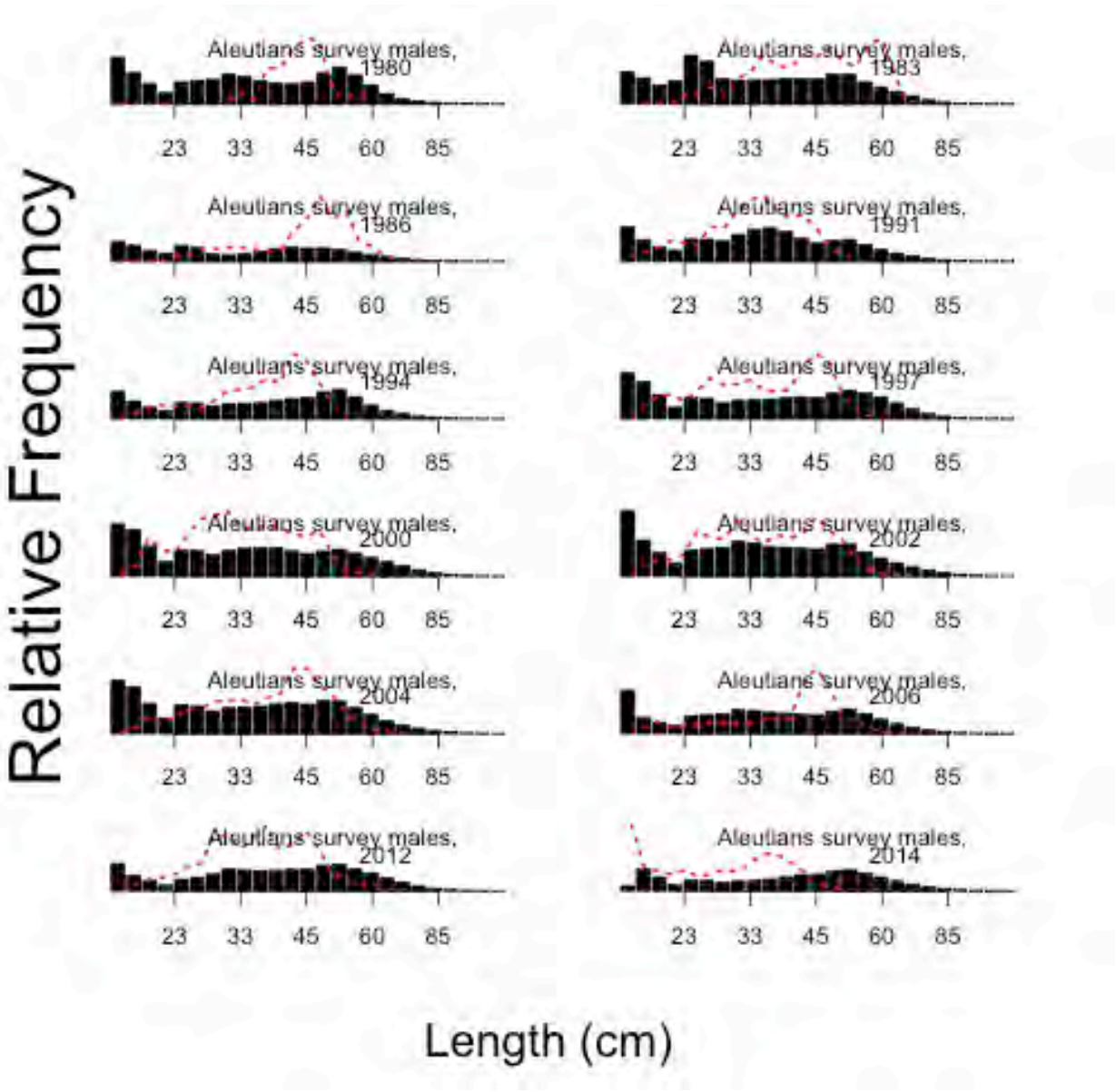

Figure 6.10 (cont'd). Model fit (dotted lines) to Aleutian Islands survey observed length composition (bar plots).

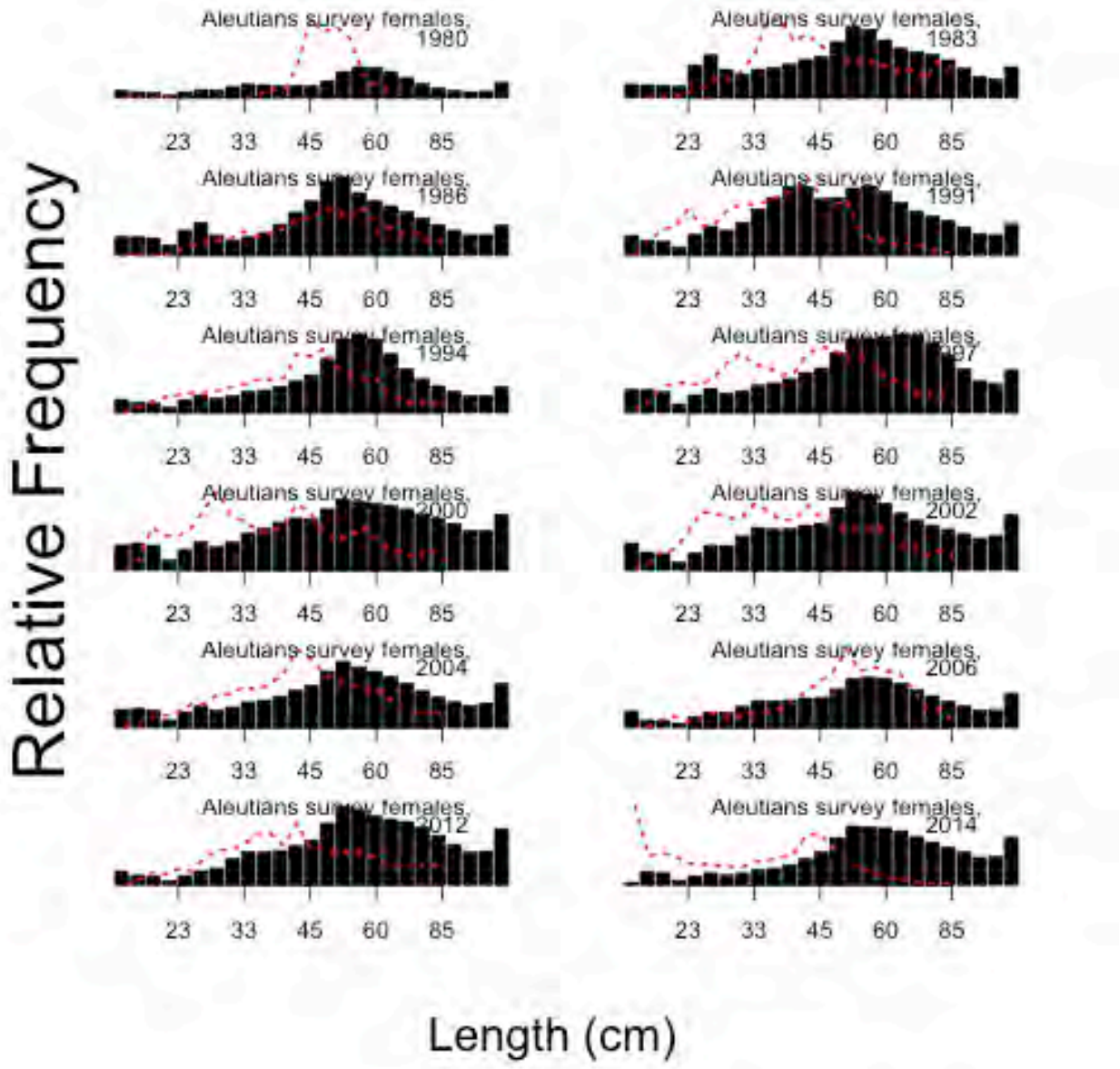

Figure 6.10 (cont'd). Model fit (dotted lines) to Aleutian Islands survey observed length composition (bar plots).

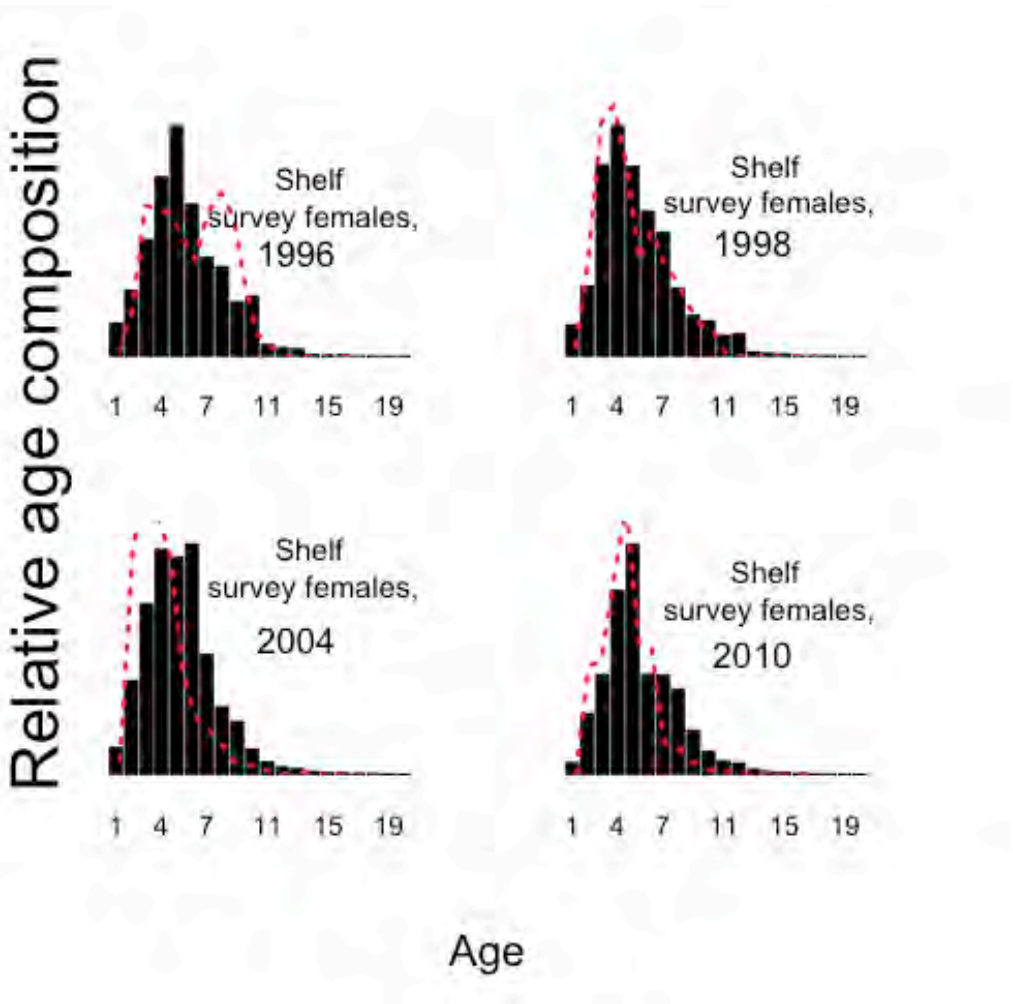

Figure 6.10 (cont'd). Model fit (dotted lines) to Bering Sea shelf survey observed age composition (bar plots).

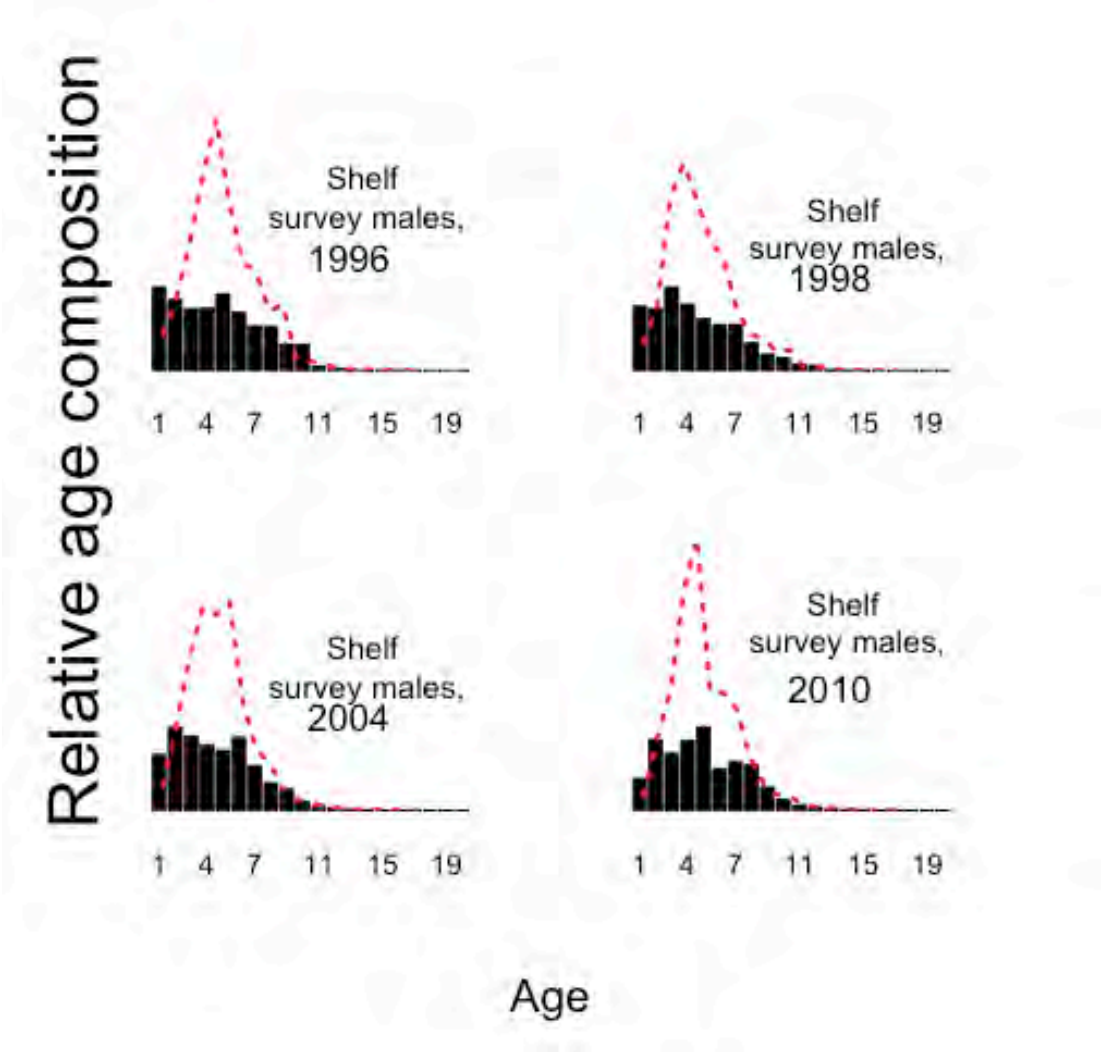

Figure 6.10 (cont'd). Model fit (dotted lines) to Bering Sea shelf survey observed age composition (bar plots).

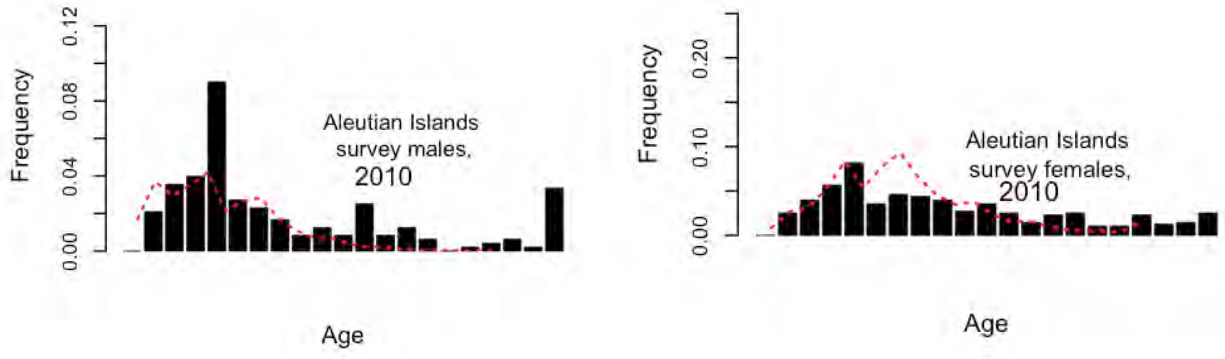

Figure 6.10 (cont'd). Model fit (dotted lines) to Aleutian Islands survey observed age composition (bar plots), males (left) and females (right).

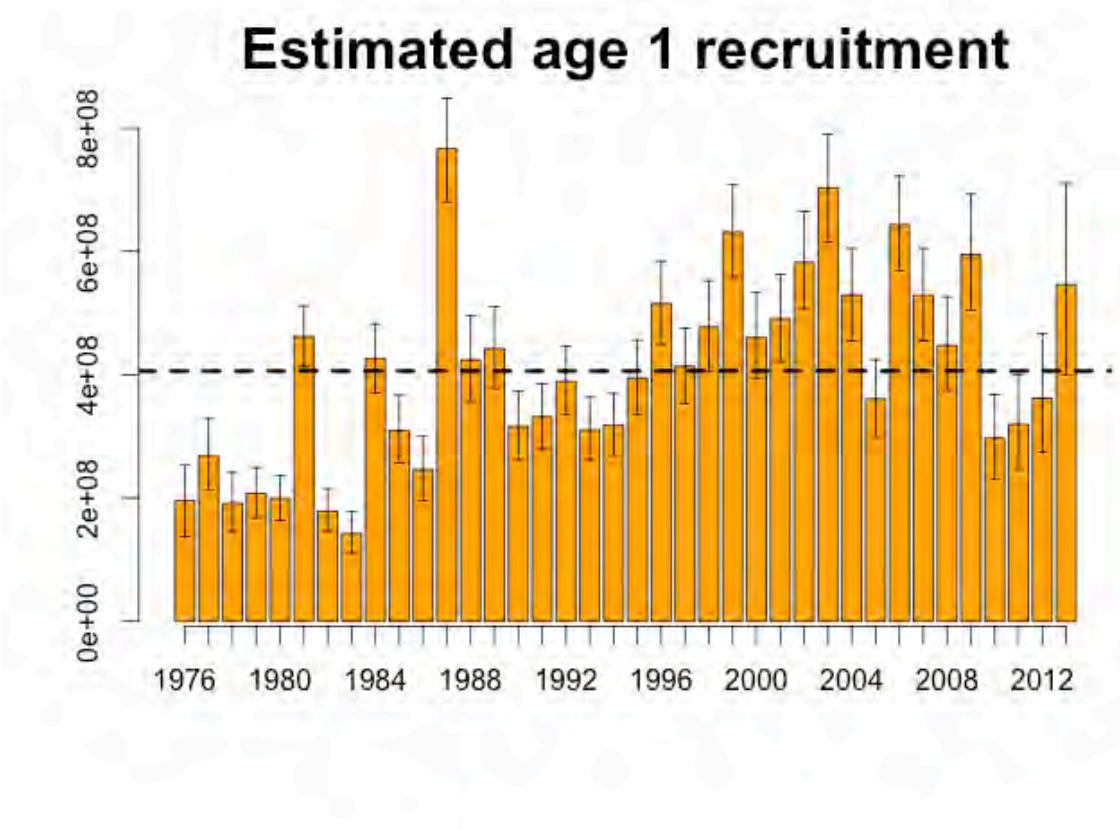

Figure 6.11. Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model.

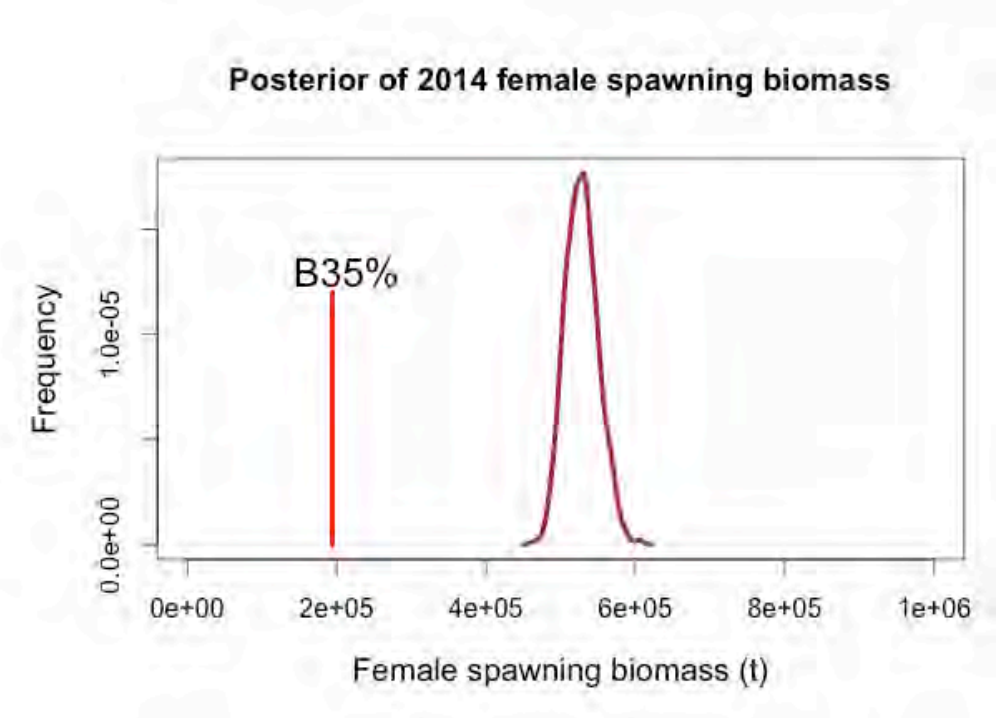

Figure 6.12. Posterior distribution of the estimate of female spawning biomass (t) from the preferred stock assessment model run, compared with the model estimate of $B_{35\%}$, 244,616 t.

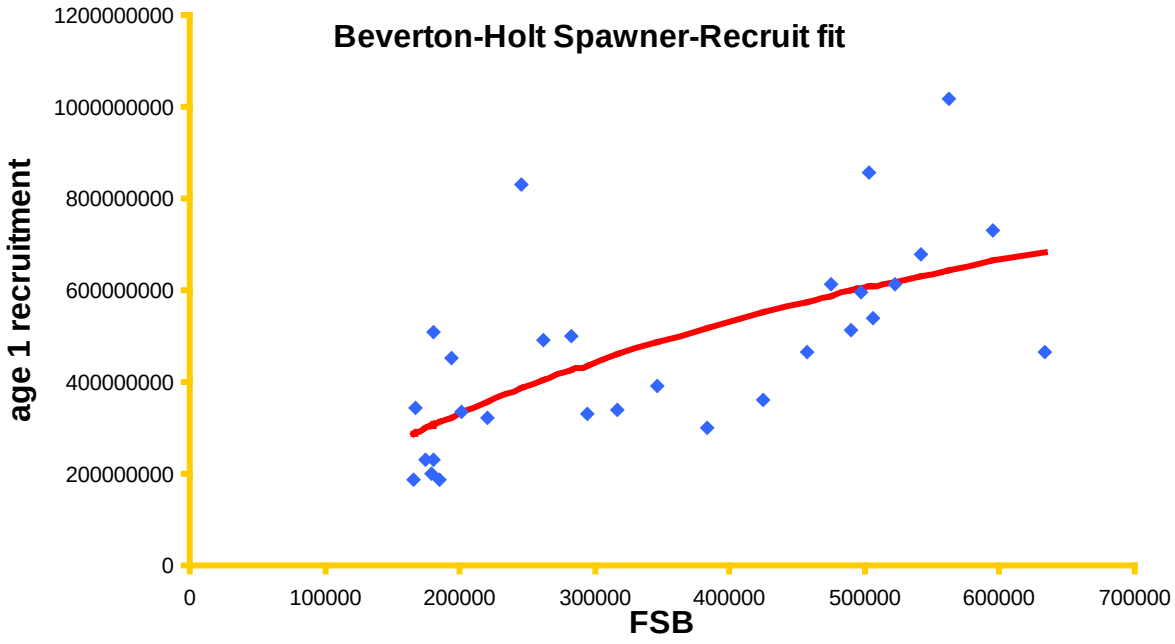

Figure 6.13. Beverton and Holt spawner recruit model fit to the age 1 recruitment data for Bering Sea arrowtooth flounder.

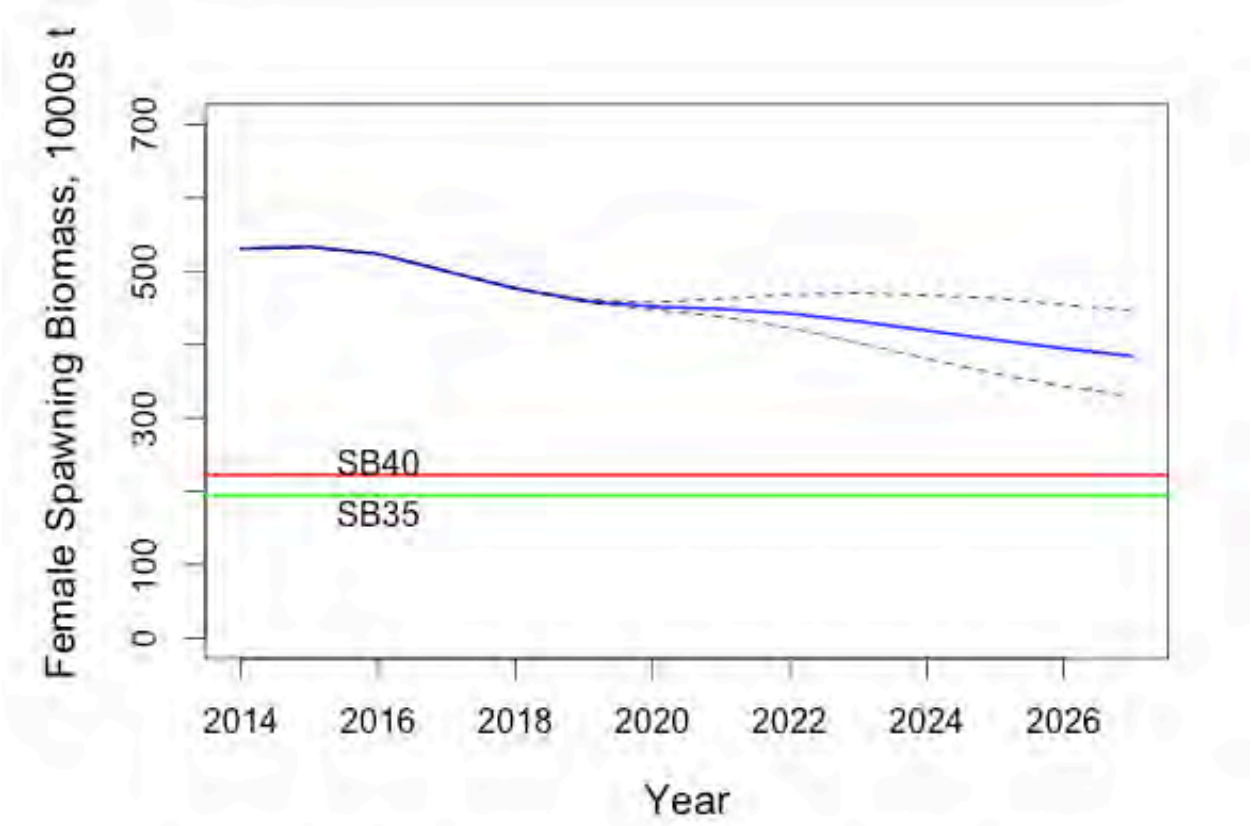

Figure 6.14. Projected female spawning biomass (1,000s t) of arrowtooth flounder if future harvest is at the same fishing mortality rate as the past five years.

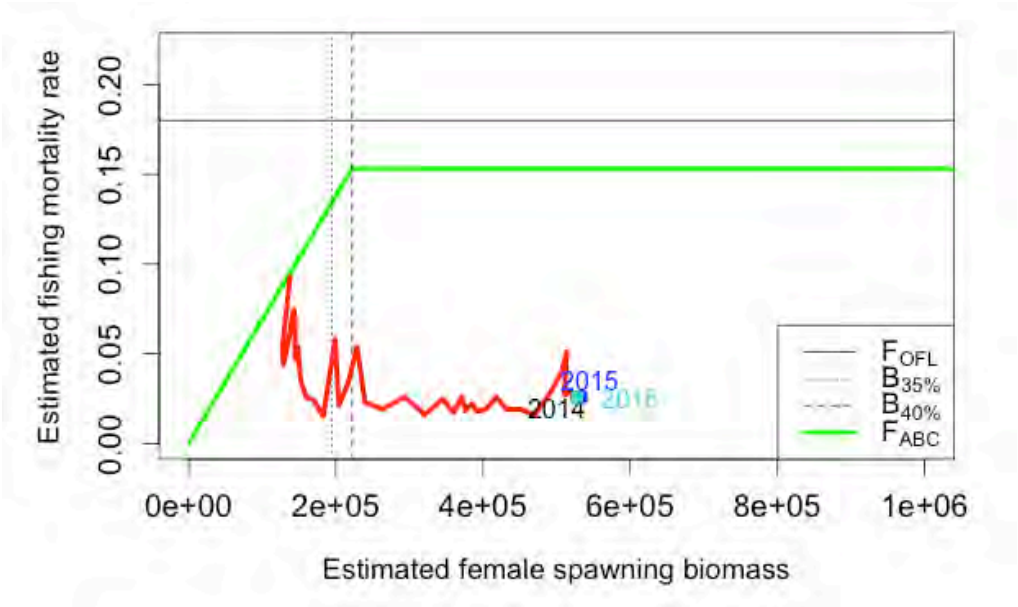

Figure 6.15. Phase plane diagram showing the time-series of stock assessment model estimates of female spawning biomass relative to the harvest control rule, with projection model results for 2015 and 2016.

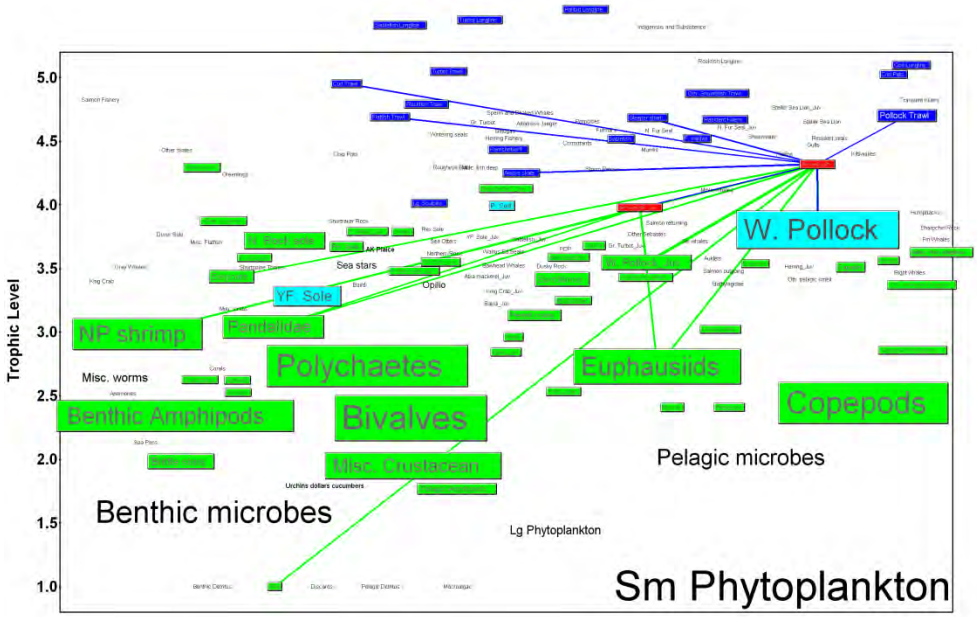

Figure 6.16. Adult and juvenile arrowtooth flounder in the EBS food web. Box size is proportional to biomass, and lines between boxes represent the most significant energy flows. Predators of arrowtooth are dark blue, prey of arrowtooth are green, and species that are both predators and prey of arrowtooth are light blue.

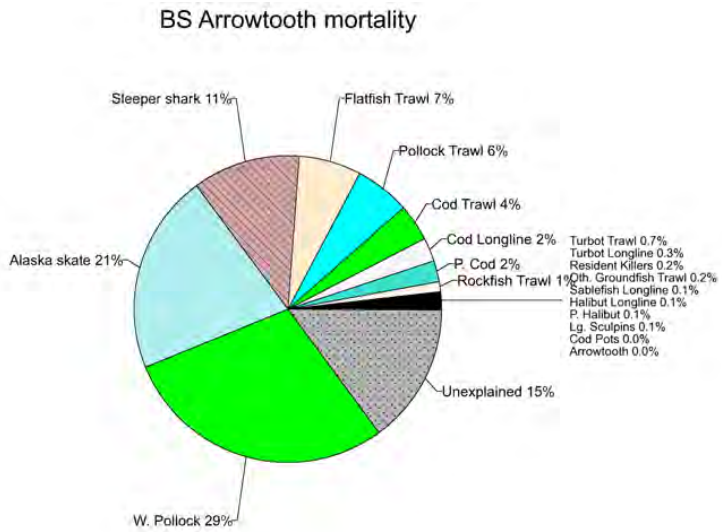

Figure 6.17. Mortality of Bering Sea arrowtooth flounder >20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. "Unexplained" mortality is the difference between the stock assessment mortality and total predation; high unexplained mortality may indicate a top predator in an ecosystem. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good diet coverage within the time period and region; striped hatching indicates limited data from literature sources; cross-hatching indicates estimate derived from ecosystem model (poor data quality).

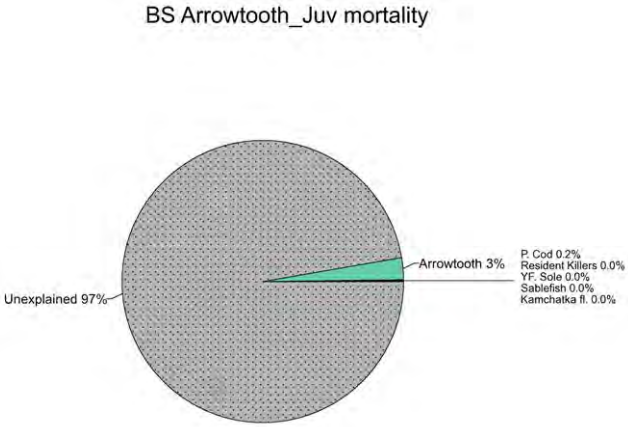

Figure 6.18. Mortality of Bering Sea arrowtooth flounder <20cm fork length by predator or fishery as from predator ration and diet estimates, and fisheries catch data, 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. "Unexplained" mortality is the difference between the stock assessment mortality and total predation; high unexplained mortality may indicate a top predator in an ecosystem. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good diet coverage within the time period and region; striped hatching indicates limited data from literature sources; cross-hatching indicates estimate derived from ecosystem model (poor data quality).

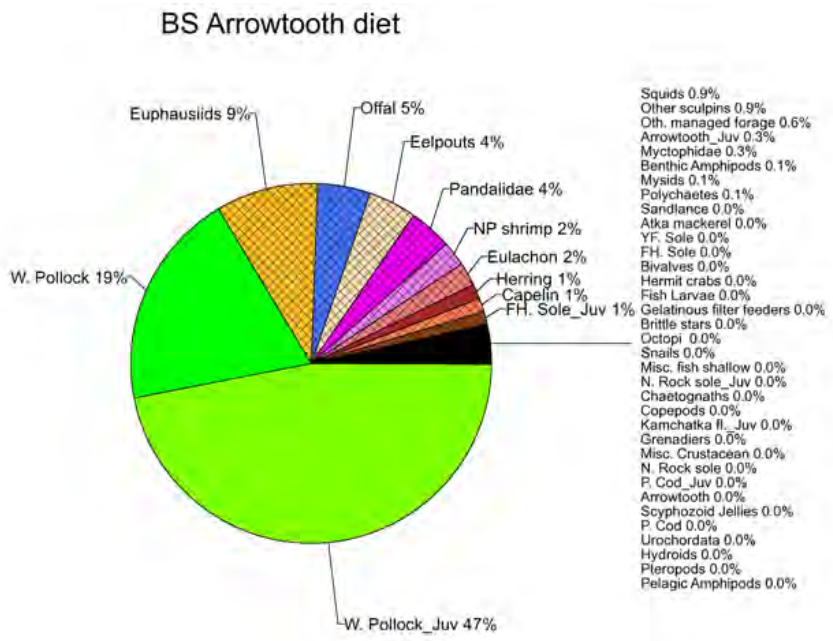

Figure 6.19. Diet of Bering Sea arrowtooth flounder >20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good diet coverage within the time period and region; striped hatching indicates limited data from literature sources; cross-hatching indicates estimate derived from ecosystem model (poor data quality).

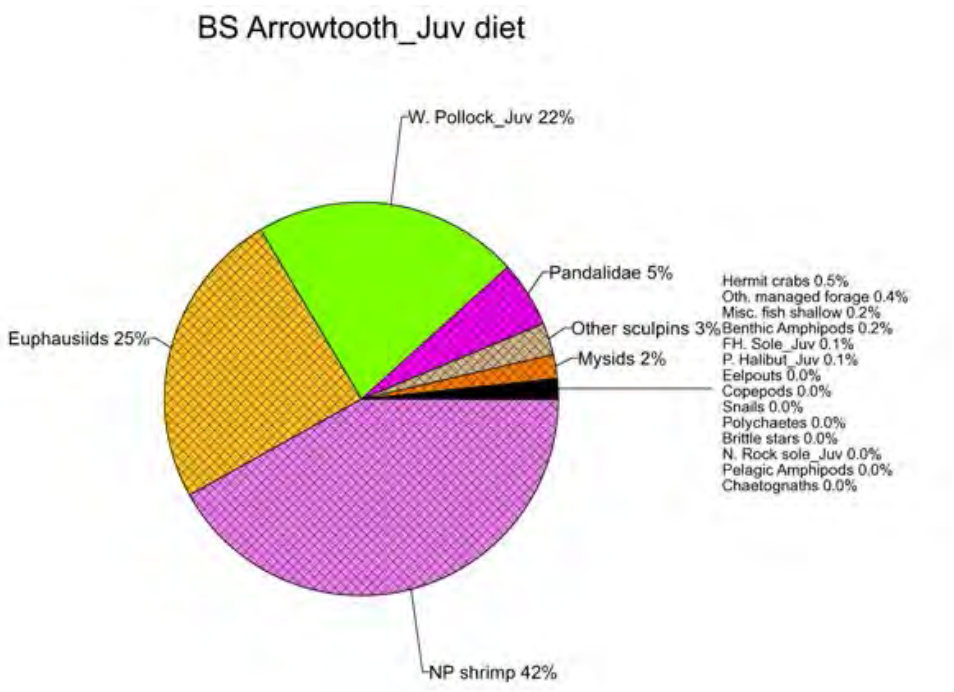

Figure 6.20. Diet of Bering Sea arrowtooth flounder <20cm fork length, 1991-1994 from AFSC food habits data 1990-94, as described in Appendix 1 of the Ecosystem Considerations chapter. Hatching in each wedge indicates qualitative data confidence: no hatching indicates value came from species with good diet coverage within the time period and region; striped hatching indicates limited data from literature sources; cross-hatching indicates estimate derived from ecosystem model (poor data quality).

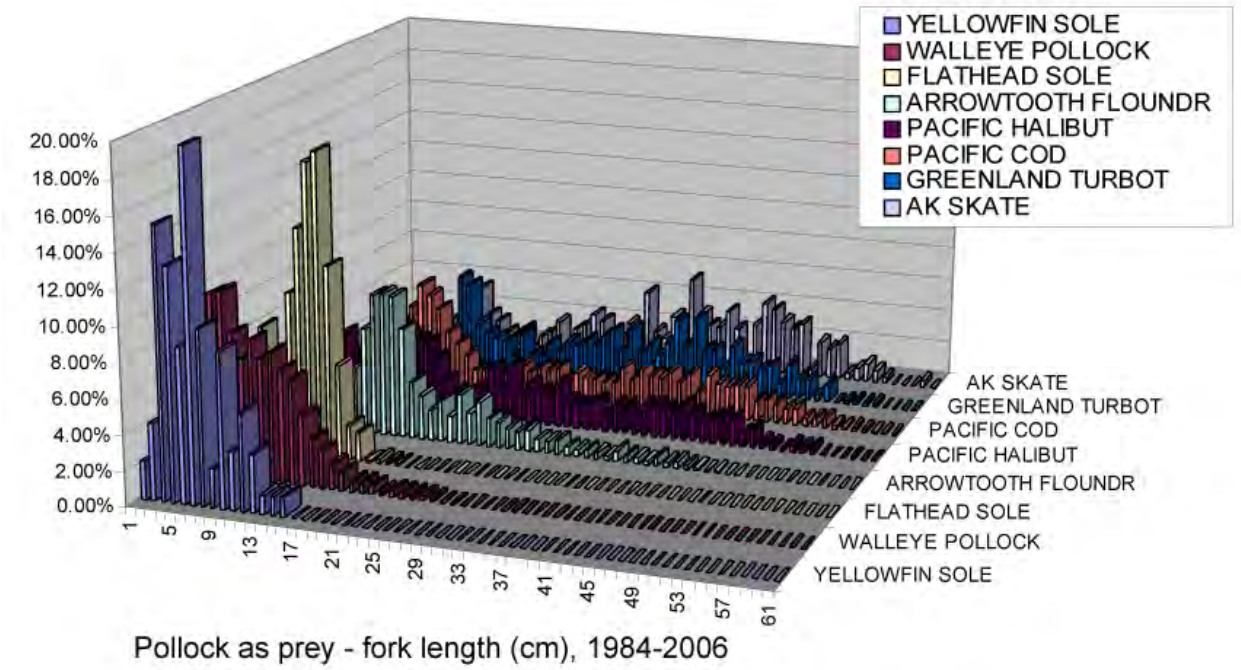

Figure 6.21. Length frequency of pollock found in stomachs, from groundfish food habits collected from 1984-2006 on AFSC summer trawl surveys in the eastern Berng Sea. Predators are sorted by median prey length of pollock in their stomachs. All lengths of predators are combined.

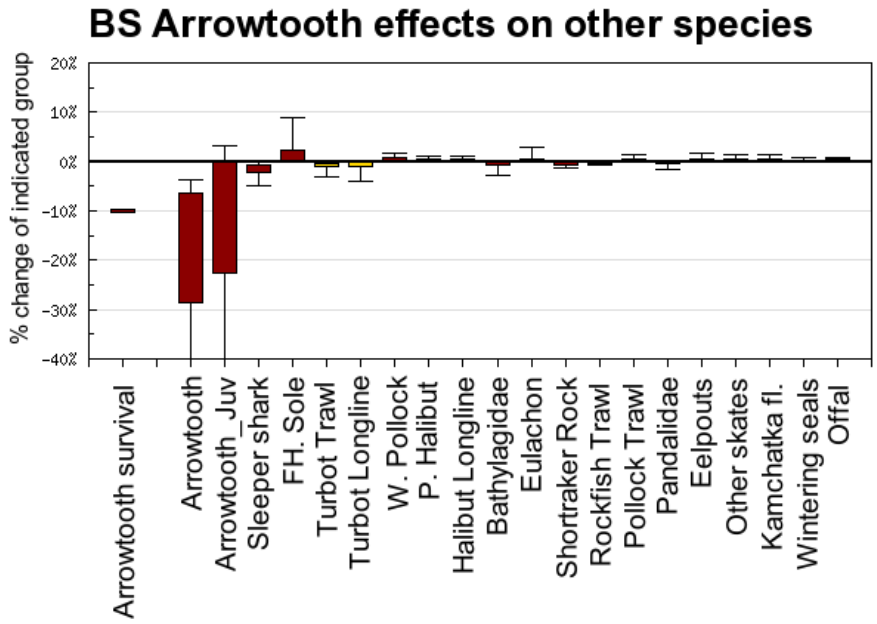

Figure 6.22. Effect of changing arrowtooth > 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting percent change in the biomass of each species on the x axis after 30 years for 50% of feasible ecosystems, error bars show results for 95% of feasible ecosystems (see Aydin et al. in press for detailed Sense methods).

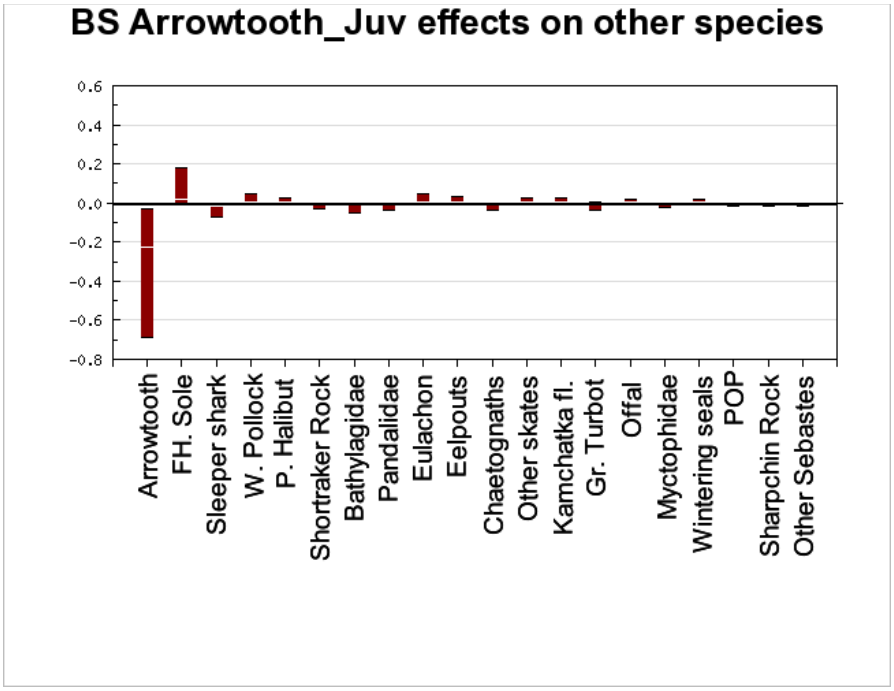

Figure 6.23. Effect of changing arrowtooth < 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the EBS, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting percent change in the biomass of each species on the x axis after 30 years for 50% of feasible ecosystems, error bars show results for 95% of feasible ecosystems (see Aydin et al. in press for detailed Sense methods).

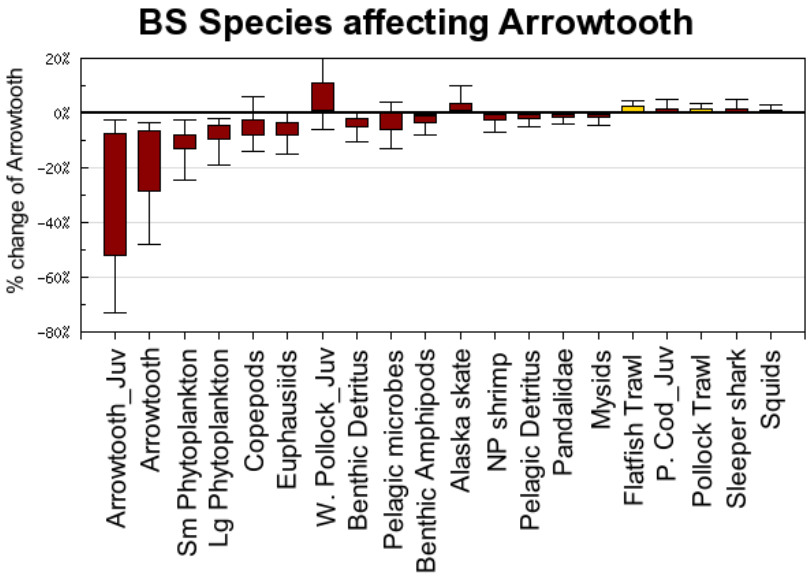

Figure 6.24. Effect of reducing fisheries catch (yellow) and other species survival (dark red) on arrowtooth > 20 cm biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting percent change in the biomass of adult arrowtooth after 30 years for 50% of feasible ecosystems, error bars show results for 95% of feasible ecosystems (see Aydin et al. in press for detailed Sense methods).

Appendix:

An exploration of alternative assessment models for arrowtooth flounder in the Bering Sea and Aleutian Islands

Ingrid Spies, Thomas K. Wilderbuer, Daniel G. Nichol and Kerim Aydin

Alaska Fisheries Science Center
National Marine Fisheries Service

Introduction

This document presents responses to comments made by the BSAI Plan team and the SSC with regard to the 2013 BSAI arrowtooth assessment. The SSC requested that the 2014 assessment compare alternative maturity curves (Zimmerman 1997 and Stark 2011), along with their uncertainty. This year an attempt was made to standardize the GOA and BSAI arrowtooth models, and the discrepancy between the methods for estimating selectivity in the fishery was noted. The September 2014 meeting of the BSAI plan team suggested that both methods for estimating fishery selectivity be explored in the 2014 BSAI arrrowtooth flounder assessment, as well as likelihood weights for the non-parametric fishery selectivity model. In the BSAI arrowtooth flounder model, sex-specific "domed-shaped" selectivity has been assumed for males and females in the shelf survey due to age distributions observed there. In addition, an asymptotic selectivity pattern has been assumed for both sexes for the fishery, the slope surveys, and the Aleutian Islands surveys, through 2013. In the GOA model, fishery selectivity has been estimated non-parametrically for each age, and the shape of the selectivity curve has been constrained to be a smooth, monotonic function.

The author's preferred BSAI model incorporated non-parametric fishery selectivity. This appendix includes model results that incorporate logistic fishery selectivity, compared with non-parametric fishery selectivity. In addition, alternatives to the current likelihood weighting system on monotonicity and smoothness of these selectivity values are explored. Finally, assessment results comparing maturity values based on the Stark (2011) and Zimmerman (1997) analysis are presented.

In December 2013 the SSC accepted the author's and Plan Team's recommended ABCs and OFLs for 2014 and 2015 under Tier 3a using the current model updated with female maturity information based on research by Stark (2011). The SSC looks forward to a full analysis of the model results with the old and new data in next year's stock assessment. The assessment should compare the alternative maturity curves, along with their uncertainty.

In September 2014, the BSAI Plan Team recommended that the arrowtooth flounder assessment bring forward a model that explores selectivity shapes for both the survey and the fishery, including a model with non-parametric selectivity-by-age as an alternative to the logistic model. For the selectivity-by-age model, the weightings used in the smoothing penalties should also be explored.

Author's response: The 2014 BSAI arrowtooth assessment is based on the author's preferred model, which incorporates non-parametric fisheries selectivity as an alternative to the logistic model, as well as the Stark (2011) female maturity values. The logistic model is compared with the non-parametric fishery selectivity model and results of the logistic model are included in this Appendix. Weightings used in the

smoothing penalties are also explored in this Appendix. Assessment results using old maturity values are considered here as well.

Data and Analytic Approach

Model Structures

Three models are considered here:

Model 1: Logistic fishery selectivity. This model is the same as the 2013 accepted model (Spies et al. 2013). The same weightings were used in the smoothing penalties as those used in the GOA model (Table A1). This model uses Stark (2011) maturity values (Table A2).

Model 2: Non-parametric fishery selectivity with equal weights for the monotonic and smoothness likelihood components. This is the same as the 2014 preferred model, with logistic weights as shown in Table A1. This model uses Stark (2011) maturity values (Table A2).

Model 3: The author's preferred model with Zimmerman (1997) female maturity values, rather than Stark (2011) maturity-at-age (Table A2).

Calculating AIC from the hessian and objective function value (ADMB output)

The hessian, the matrix of second mixed derivatives in transformed space, is created as output from each ADMB model run. Transformed parameters (bounded parameters estimated using a logit transform) were back-transformed by taking the log of the determinant of the hessian, and the marginal likelihood ($Likelihood_{MAR}$) was estimated as in Thorson et al. (2014), where OFV is the objective function value from the ADMB .par file:

$$Likelihood_{MAR} \approx -0.5 Hess_T - OFV.$$

The marginal likelihood can be used to calculate AIC, as follows:

$AIC = 2k - 2 * likelihood_{MAR}$, where k is the number of parameters used in the model.

Results

Models 1 and 2:

The non-parametric method for estimating fishery selectivity (Model 2) resulted in a lower Akaike information criterion (AIC) when applied to the BSAI model; and is therefore the preferred model. The non-parametric method (Model 2) for estimating fishery selectivity adds 38 new parameters to the model, but results in a lower AIC, 9,818 for the non-parametric model vs. 9,990 for the logistic method (Model 1; Table A3). However, the effective number of parameters may be smaller than 38 due to the non-parametric method applied. If this were the case, the AIC would still be lower with the non-parametric method; therefore, the non-parametric model (Model 2) is preferred by the authors and is presented in the main document. The most notable improvement in the new method for estimating fishery selectivity is in the fit to fishery lengths (Table A3).

Model 1 reference values are summarized in Table A4. Reference values are very similar to those using Model 2,the non-parametric fishery selectivity.

Selectivity curves estimated by the two models are shown in Figures A1 (Model 1) and A2 (Model 2). The survey selectivity curves are not affected by changes to fishery selectivity. The non-parametric selectivity estimates are dome shaped for both sexes, and descend more steeply for males.

Tables 6.8, 6.9, 6.10, 6.11, and 6.12 and from the assessment were recreated using model output with logistic fishery selectivity and are presented in Tables A5, A6, A7, A8, and A9. In addition, Figures A3 and A4 are provided for comparison with Figures 6.9 and 6.11 respectively. Both are similar to the results for the preferred model.

When equal weightings were applied to the smoothness and monotonicity likelihood components for male and female fishery selectivity in Model 2, the model estimates for fishery selectivity changed. Fishery selectivity was not smooth for either sex (Figure A5). However, results did not change significantly; male selectivity peaked at a higher level than female selectivity and declined more quickly for older ages in males. Although this was not a thorough analysis of alternatives for likelihood weights, the original weightings in Table A1 were used in all further analyses.

Model 3:
In 2011 a study was published which estimated maturity-at-age of arrowtooth flounder in the Bering Sea (Stark 2011). The Bering Sea and Aleutian Islands (BSAI) stock assessment uses parameters from Zimmerman (1997), which estimated maturity-at-length (Figure A6). In 2012 the BSAI Plan Team requested an analysis of the different maturity-at-age and length parameters in order to determine the best parameters to use in the BSAI ATF stock assessment. The 2011 maturity-at-age parameters are recommended to replace Zimmerman (1997) parameters in the BSAI ATF stock assessment because maturity-at-age is less variable than maturity-at-length and the sample is taken in the Bering Sea rather than the Gulf of Alaska.

Estimates of female spawning biomass and total biomass with both maturity estimates are shown in Figure A7. The Model 3 2014 estimate of total biomass is 877,781 t (95% CI: 807,366, 948,196) and female spawning biomass is 656,643 t (95% CI: 613,098, 700,188).

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Tables

Table A1. Weightings used in the smoothing and monotonicity penalties in the GOA model. Values in parentheses were tested.

	Fishery female	Fishery male
Smooth selectivity likelihoods	10 (1)	40 (1)
Monotonicity constraint	200 (1)	100 (1)

Table A2. Arrowtooth flounder female female maturity at age, based on Zimmerman (2007) and Stark (2011).

age	female maturity at age (Zimmerman 2007)	female maturity at age (Stark 2011)
1	0	0.00
2	0	0.00
3	0	0.01
4	0.02	0.02
5	0.39	0.06
6	0.84	0.16
7	0.97	0.34
8	1.00	0.59
9	1.00	0.80
10	1	0.97
11	1	0.99
12	1	1
13	1	1
14	1	1
15	1	1
16	1	1
17	1	1
18	1	1
19	1	1
20	1	1
21	1	1

Table A3. Likelihood components for the Bering Sea and Aleutian Islands arrowtooth flounder model run with two configurations: fishery selectivity estimated separately (non-parametrically) for each age (Model 1), and fishery selectivity estimated as an increasing logistic function (Model 2). Lower values indicate a better fit; green is the lower value and red is higher, for each row of the table.

	Non-parametric selectivity (Model 1)	Logistic fishery selectivity (Model 2)
Shelf survey biomass	133.9	134.4
Slope survey biomass	62.6	64.0
AI biomass	47.6	47.2
Shelf survey lengths	1852.0	1854.1
Slope survey lengths	1046.0	1042.5
AI survey lengths	1087.3	1083.0
Fishery lengths	280.114	301.2
Recruitment	27.4	27.8
Catch	0.001106	0.001257
Sex ratio	46.6	46.7
Shelf survey ages	140.4	140.4
Total Obj. Fun. value	4753.54	4759.74
Number of Parameters	158	120
AIC	9818.488	9990.455

Table A4. Summary of results if the fishery selectivity were modeled as logistic.

	Last year		This year*	
Quantity/Status	2014	2015	2015	2016
M (natural mortality – Male, Female)	0.35, 0.2	0.35, 0.2	0.35, 0.2	0.35, 0.2
Specified/recommended Tier	3a	3a	3a	3a
Projected biomass (ages 1+)	1,023,440	995,494	908,644	912,220
Female spawning biomass (t)				
Projected	626,319	632,319	533,246	527,257
$B_{100\%}$	577,538	577,538	551,587	551,587
$B_{40\%}$	231,015	231,015	220,635	220,635
$B_{35\%}$	202,138	202,138	193,055	193,055
F_{OFL}	0.186	0.186	0.163	0.163
$maxF_{ABC}$ (maximum allowable = F40%)	0.156	0.156	0.138	0.138
Specified/recommended F_{ABC}	0.156	0.156	0.138	0.138
Specified/recommended OFL (t)	125,642	125,025	97,286	98,757
Specified/recommended ABC (t)	106,599	106,089	84,300	83,043
Is the stock being subjected to overfishing?	no	no	no	no
Is the stock currently overfished?	no	no	no	no
Is the stock approaching a condition of being overfished?	no	no	no	no

*Using logistic fishery selectivity.

Table A5 (Table 6.8 with logistic fishery selectivity). Model estimates of arrowtooth flounder fishing mortality and exploitation rate (catch/total biomass).

year	Full selection F	Exploitation rate
1976	0.115	0.068
1977	0.068	0.041
1978	0.057	0.035
1979	0.077	0.048
1980	0.099	0.061
1981	0.092	0.056
1982	0.060	0.037
1983	0.070	0.043
1984	0.046	0.028
1985	0.034	0.021
1986	0.030	0.019
1987	0.019	0.012
1988	0.075	0.045
1989	0.026	0.016
1990	0.044	0.026
1991	0.069	0.040
1992	0.030	0.018
1993	0.024	0.016
1994	0.035	0.023
1995	0.021	0.015
1996	0.032	0.022
1997	0.022	0.015
1998	0.032	0.022
1999	0.022	0.015
2000	0.027	0.018
2001	0.028	0.018
2002	0.022	0.015
2003	0.024	0.016
2004	0.032	0.021
2005	0.024	0.016
2006	0.024	0.016
2007	0.021	0.014
2008	0.036	0.024
2009	0.049	0.033
2010	0.064	0.043
2011	0.033	0.023
2012	0.036	0.025
2013	0.033	0.023
2014	0.033	0.023

Table A6 (Table 6.9 with logistic fishery selectivity). Model estimates of arrowtooth flounder age-specific fishery and survey selectivities, by sex.

	Fishery		**shelf survey**		**slope survey**		**Aleutians survey**	
Age	**females**	**males**	**females**	**males**	**females**	**males**	**females**	**males**
1	0.01	0.01	0.05	0.11	0.00	0.03	0.03	0.07
2	0.02	0.03	0.16	0.18	0.00	0.05	0.06	0.12
3	0.06	0.06	0.42	0.27	0.00	0.08	0.13	0.18
4	0.15	0.13	0.80	0.40	0.00	0.12	0.24	0.26
5	0.32	0.25	1.00	0.56	0.06	0.19	0.41	0.37
6	0.57	0.43	0.95	0.71	0.91	0.27	0.61	0.49
7	0.78	0.63	0.81	0.82	1.00	0.38	0.77	0.62
8	0.91	0.79	0.65	0.83	1.00	0.51	0.88	0.73
9	0.96	0.89	0.52	0.75	1.00	0.63	0.94	0.81
10	0.99	0.95	0.40	0.60	1.00	0.74	0.97	0.88
11	1.00	0.98	0.31	0.44	1.00	0.82	0.99	0.92
12	1.00	0.99	0.23	0.31	1.00	0.88	0.99	0.95
13	1.00	1.00	0.18	0.20	1.00	0.93	1.00	0.97
14	1.00	1.00	0.13	0.13	1.00	0.95	1.00	0.98
15	1.00	1.00	0.10	0.08	1.00	0.97	1.00	0.99
16	1.00	1.00	0.07	0.05	1.00	0.98	1.00	0.99
17	1.00	1.00	0.06	0.03	1.00	0.99	1.00	1.00
18	1.00	1.00	0.04	0.02	1.00	0.99	1.00	1.00
19	1.00	1.00	0.03	0.01	1.00	1.00	1.00	1.00
20	1.00	1.00	0.02	0.01	1.00	1.00	1.00	1.00
21	1.00	1.00	0.02	0.00	1.00	1.00	1.00	1.00

Table A7 (Table 6.10 with logistic (Model 1) and non-parametric fishery selectivity (preferred model), and Zimmerman (1997) maturity at age (Model 3)). Model estimates of arrowtooth flounder 1+ total biomass (t) and female spawning biomass (FSB, t) from the 2012 and 2014 assessments.

	Assessment – Year and specifications							
	2012		2014 - logistic fishery selectivity (Model 1)		2014 – non-parametric fishery selectivity (preferred model)		2014 – Zimmerman (1997) maturity (Model 3)	
	Total biomass	FSB	Total biomass	FSB	Total biomass	FSB	Total biomass	FSB
1976	261,843	145,079	264,056	133,980	269,581	137,913	269,581	173,333
1977	259,394	135,957	262,121	123,565	267,323	127,605	267,323	175,020
1978	265,437	140,201	268,235	124,872	273,114	128,654	273,114	184,953
1979	274,039	149,543	276,615	132,758	281,156	136,179	281,156	192,187
1980	278,544	155,185	280,479	139,542	284,669	142,697	284,669	190,820
1981	282,838	154,787	283,547	141,544	287,394	144,561	287,394	189,593
1982	289,105	154,463	288,163	141,810	291,738	144,598	291,738	191,786
1983	304,256	160,634	301,258	146,066	304,652	148,601	304,652	197,742
1984	319,243	165,944	313,872	149,797	317,146	152,209	317,146	201,440
1985	338,135	176,108	330,491	157,560	333,697	159,777	333,697	215,974
1986	360,542	190,169	350,689	168,113	353,901	170,170	353,901	236,432
1987	389,916	207,577	377,811	180,864	381,113	182,853	381,113	247,589
1988	423,607	226,675	409,441	197,255	412,852	199,211	412,852	262,481
1989	450,671	231,305	434,105	201,979	437,638	204,155	437,638	271,692
1990	491,982	248,134	473,581	214,875	477,253	216,960	477,253	289,596
1991	526,128	264,652	506,758	226,742	510,536	228,980	510,536	314,053
1992	546,661	279,076	527,758	237,127	531,547	239,547	531,547	345,015
1993	571,926	310,864	555,514	260,883	559,302	263,221	559,302	379,741
1994	592,011	346,248	579,651	291,359	583,417	293,761	583,417	408,124
1995	601,598	371,401	594,349	318,281	598,051	320,825	598,051	423,307
1996	614,404	391,549	612,430	343,276	616,089	345,783	616,089	440,068
1997	621,046	398,706	623,890	356,942	627,504	359,496	627,504	449,474
1998	635,335	404,618	641,961	368,595	645,562	371,083	645,562	457,834
1999	649,181	402,715	657,897	373,112	661,463	375,655	661,463	460,931
2000	670,513	404,531	680,318	378,959	683,861	381,405	683,861	473,362
2001	695,086	407,830	703,805	383,243	707,317	385,656	707,317	487,465
2002	721,321	415,548	728,041	389,353	731,488	391,757	731,488	500,318
2003	755,958	430,045	757,761	401,379	761,140	403,703	761,140	521,503
2004	792,770	448,107	787,765	415,913	791,072	418,167	791,072	545,164
2005	827,972	467,148	812,922	429,639	816,099	431,908	816,099	560,603
2006	869,734	491,079	842,848	448,765	845,881	450,913	845,881	581,116
2007	909,359	516,763	868,078	468,126	870,942	470,156	870,942	608,386
2008	948,231	548,056	892,574	489,122	895,262	491,018	895,262	638,824
2009	980,823	580,548	905,333	503,901	907,756	505,908	907,756	648,982
2010	1,002,620	608,551	903,157	511,655	905,159	513,829	905,159	646,995
2011	1,017,650	630,021	888,164	508,374	889,634	510,566	889,634	641,469
2012	1,023,890	652,156	887,486	516,069	888,498	517,672	888,498	649,475
2013			880,840	521,099	881,413	522,331	881,413	654,377
2014			877,625	526,780	877,781	527,622	877,781	656,643

Table A8 (Table 6.11 with logistic fishery selectivity). Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

females	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	98,634	36,674	84,221	70,500	76,130	28,181	15,765	10,915	8,387	6,829
1977	133,932	80,679	29,950	68,492	56,758	60,075	21,622	11,799	8,051	6,147
1978	96,310	109,593	65,955	24,423	55,520	45,466	47,328	16,785	9,081	6,173
1979	103,831	78,816	89,615	53,820	19,831	44,637	36,050	37,068	13,052	7,039
1980	101,050	84,956	64,419	73,039	43,569	15,839	34,985	27,787	28,295	9,920
1981	231,602	82,666	69,405	52,438	58,942	34,560	12,264	26,517	20,801	21,063
1982	89,429	189,477	67,543	56,518	42,357	46,851	26,858	9,343	19,966	15,580
1983	71,989	73,182	154,924	55,105	45,867	34,015	37,074	20,978	7,242	15,424
1984	213,283	58,906	59,824	126,320	44,654	36,715	26,764	28,730	16,113	5,540
1985	155,023	174,557	48,180	48,849	102,734	36,029	29,295	21,145	22,568	12,625
1986	124,957	126,887	142,808	39,368	39,797	83,205	28,940	23,359	16,789	17,885
1987	387,187	102,281	103,817	116,714	32,089	32,268	66,967	23,140	18,607	13,350
1988	214,014	316,953	83,706	84,903	95,292	26,113	26,136	54,018	18,621	14,957
1989	221,331	175,113	259,067	68,230	68,751	76,156	20,488	20,175	41,303	14,177
1990	158,440	181,172	143,287	211,780	55,648	55,817	61,434	16,434	16,129	32,971
1991	166,372	129,674	148,187	117,012	172,280	44,924	44,578	48,600	12,929	12,658
1992	196,123	136,137	106,005	120,833	94,834	137,950	35,367	34,573	37,364	9,901
1993	156,911	160,533	111,386	86,638	98,498	76,902	111,049	28,286	27,547	29,720
1994	159,906	128,442	131,363	91,065	70,680	80,016	62,101	89,205	22,652	22,030
1995	198,983	130,883	105,079	107,332	74,180	57,228	64,239	49,484	70,770	17,936
1996	260,327	162,885	107,108	85,924	87,604	60,322	46,296	51,730	39,741	56,768
1997	209,614	213,082	133,264	87,526	70,016	70,983	48,491	36,956	41,126	31,537
1998	241,870	171,587	174,373	108,969	71,433	56,927	57,408	39,034	29,668	32,974
1999	319,782	197,974	140,383	142,494	88,794	57,880	45,763	45,827	31,033	23,543
2000	234,968	261,768	162,008	114,787	116,287	72,184	46,799	36,825	36,773	24,871
2001	249,945	192,334	214,192	132,435	93,615	94,400	58,219	37,529	29,431	29,346
2002	297,076	204,591	157,373	175,079	107,987	75,962	76,079	46,637	29,957	23,456
2003	360,419	243,181	167,422	128,677	142,873	87,778	61,409	61,205	37,413	24,002
2004	269,641	295,029	198,994	136,881	104,982	116,076	70,897	49,342	49,030	29,930
2005	185,492	220,706	241,378	162,616	111,543	85,071	93,326	56,607	39,237	38,918
2006	332,646	151,838	180,604	197,348	132,676	90,630	68,720	75,001	45,356	31,396
2007	273,741	272,293	124,248	147,656	161,004	107,786	73,193	55,209	60,071	36,278
2008	234,419	224,083	222,834	101,603	120,527	130,951	87,226	58,968	44,364	48,215
2009	315,252	191,870	183,319	182,059	82,752	97,556	105,072	69,450	46,740	35,093
2010	159,547	258,003	156,919	149,657	147,988	66,691	77,681	82,779	54,376	36,493
2011	172,736	130,557	210,935	127,990	121,379	118,685	52,650	60,477	63,924	41,838
2012	198,124	141,386	106,813	172,363	104,282	98,324	95,364	42,001	48,044	50,687
2013	305,145	162,163	115,664	87,265	140,371	84,390	78,865	75,893	33,273	37,981
2014	409,222	249,764	132,671	94,515	71,102	113,717	67,816	62,926	60,302	26,388

Table A8 (cont'd). Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

	females				numbers at age (1,000s)						
	11	12	13	14	15	16	17	18	19	20	21
1976	5,748	4,947	4,305	3,772	3,325	2,940	2,594	2,295	2,010	1,756	4,012
1977	4,991	4,197	3,611	3,142	2,753	2,427	2,146	1,894	1,675	1,467	4,210
1978	4,705	3,819	3,211	2,762	2,403	2,106	1,856	1,641	1,448	1,281	4,342
1979	4,779	3,641	2,955	2,484	2,137	1,859	1,629	1,436	1,270	1,120	4,350
1980	5,340	3,623	2,760	2,239	1,883	1,619	1,409	1,235	1,088	962	4,146
1981	7,368	3,963	2,688	2,047	1,661	1,396	1,201	1,045	916	807	3,789
1982	15,745	5,503	2,960	2,007	1,529	1,240	1,043	897	780	684	3,432
1983	12,020	12,141	4,243	2,281	1,547	1,178	956	804	691	602	3,173
1984	11,782	9,176	9,266	3,238	1,741	1,181	899	730	613	528	2,880
1985	4,337	9,218	7,178	7,248	2,533	1,362	924	703	571	480	2,666
1986	9,997	3,433	7,297	5,682	5,737	2,005	1,078	731	557	452	2,490
1987	14,212	7,942	2,727	5,796	4,513	4,557	1,592	856	581	442	2,336
1988	10,727	11,418	6,380	2,191	4,656	3,626	3,661	1,279	688	466	2,232
1989	11,368	8,148	8,671	4,845	1,664	3,536	2,753	2,780	971	522	2,049
1990	11,311	9,068	6,499	6,915	3,864	1,327	2,820	2,196	2,217	775	2,051
1991	25,850	8,864	7,106	5,092	5,419	3,028	1,040	2,209	1,720	1,737	2,214
1992	9,678	19,753	6,772	5,428	3,890	4,139	2,313	794	1,688	1,314	3,018
1993	7,870	7,691	15,696	5,381	4,313	3,091	3,289	1,838	631	1,341	3,442
1994	23,755	6,289	6,146	12,542	4,300	3,446	2,470	2,628	1,468	504	3,822
1995	17,430	18,789	4,974	4,860	9,919	3,400	2,725	1,953	2,078	1,161	3,421
1996	14,381	13,972	15,061	3,987	3,896	7,950	2,726	2,185	1,566	1,666	3,673
1997	45,016	11,400	11,075	11,938	3,160	3,088	6,302	2,160	1,732	1,241	4,232
1998	25,274	36,069	9,134	8,873	9,564	2,532	2,474	5,049	1,731	1,387	4,385
1999	26,148	20,036	28,592	7,240	7,034	7,581	2,007	1,961	4,002	1,372	4,575
2000	18,859	20,942	16,046	22,897	5,798	5,632	6,071	1,607	1,570	3,205	4,762
2001	19,836	15,038	16,697	12,793	18,255	4,623	4,491	4,840	1,281	1,252	6,352
2002	23,374	15,795	11,974	13,294	10,186	14,535	3,681	3,575	3,854	1,020	6,054
2003	18,784	18,714	12,646	9,586	10,643	8,155	11,636	2,947	2,862	3,085	5,664
2004	19,191	15,016	14,959	10,108	7,662	8,507	6,518	9,301	2,355	2,288	6,993
2005	23,740	15,218	11,906	11,861	8,014	6,075	6,745	5,168	7,374	1,867	7,358
2006	31,124	18,982	12,167	9,519	9,482	6,407	4,857	5,392	4,132	5,896	7,376
2007	25,098	24,876	15,170	9,723	7,607	7,578	5,120	3,881	4,309	3,302	10,606
2008	29,104	20,132	19,952	12,167	7,799	6,101	6,078	4,107	3,113	3,456	11,154
2009	38,108	22,996	15,906	15,763	9,613	6,161	4,820	4,802	3,244	2,459	11,543
2010	27,370	29,710	17,926	12,398	12,286	7,492	4,802	3,757	3,742	2,529	10,913
2011	28,038	21,017	22,809	13,761	9,517	9,432	5,751	3,686	2,884	2,873	10,319
2012	33,149	22,209	16,646	18,065	10,899	7,537	7,470	4,555	2,920	2,284	10,448
2013	40,038	26,177	17,536	13,143	14,263	8,605	5,951	5,898	3,596	2,305	10,052
2014	30,100	31,722	20,738	13,892	10,412	11,299	6,817	4,714	4,672	2,849	9,789

Table A8 (cont'd). Model estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

males	numbers at age (1,000s)									
	1	2	3	4	5	6	7	8	9	10
1976	98,634	31,566	62,393	44,953	41,781	13,312	6,410	3,819	2,526	1,770
1977	133,932	69,398	22,168	43,647	31,203	28,603	8,930	4,204	2,459	1,607
1978	96,310	94,293	48,806	15,554	30,484	21,615	19,577	6,031	2,808	1,630
1979	103,831	67,816	66,336	34,269	10,880	21,177	14,866	13,315	4,064	1,881
1980	101,050	73,092	47,680	46,517	23,905	7,519	14,438	9,983	8,830	2,673
1981	231,602	71,113	51,357	33,390	32,358	16,432	5,079	9,566	6,509	5,698
1982	89,429	163,004	49,976	35,979	23,246	22,279	11,131	3,379	6,269	4,224
1983	71,989	62,968	114,662	35,083	25,154	16,135	15,300	7,554	2,271	4,186
1984	213,283	50,682	44,280	80,440	24,495	17,415	11,032	10,318	5,036	1,503
1985	155,023	150,205	35,666	31,114	56,347	17,064	12,035	7,556	7,014	3,408
1986	124,957	109,193	105,742	25,080	21,828	39,371	11,852	8,303	5,185	4,796
1987	387,187	88,020	76,878	74,372	17,603	15,265	27,387	8,196	5,714	3,556
1988	214,014	272,776	61,992	54,109	52,278	12,346	10,670	19,071	5,689	3,958
1989	221,331	150,660	191,793	43,476	37,755	36,148	8,424	7,173	12,665	3,749
1990	158,440	155,914	106,086	134,929	30,532	26,430	25,188	5,840	4,952	8,718
1991	166,372	111,585	109,728	74,549	94,536	21,279	18,278	17,269	3,975	3,355
1992	196,123	117,130	78,471	76,984	52,058	65,466	14,556	12,334	11,523	2,633
1993	156,911	138,150	82,467	55,192	54,037	36,409	45,545	10,068	8,489	7,906
1994	159,906	110,537	97,282	58,024	38,769	37,846	25,391	31,610	6,960	5,854
1995	198,983	112,631	77,814	68,403	40,703	27,083	26,277	17,509	21,675	4,755
1996	260,327	140,181	79,320	54,760	48,068	28,530	18,912	18,273	12,134	14,988
1997	209,614	183,369	98,689	55,781	38,425	33,598	19,828	13,060	12,552	8,307
1998	241,870	147,669	129,135	69,449	39,196	26,930	23,457	13,784	9,048	8,676
1999	319,782	170,368	103,961	90,813	48,732	27,397	18,716	16,199	9,469	6,194
2000	234,968	225,279	119,978	73,157	63,809	34,150	19,124	13,008	11,218	6,542
2001	249,945	165,520	158,627	84,404	51,373	44,666	23,793	13,255	8,977	7,720
2002	297,076	176,067	116,543	111,584	59,261	35,949	31,102	16,477	9,137	6,170
2003	360,419	209,282	123,990	82,010	78,401	41,525	25,090	21,612	11,408	6,311
2004	269,641	253,901	147,374	87,241	57,609	54,915	28,963	17,418	14,944	7,868
2005	185,492	189,931	178,751	103,641	61,219	40,270	38,169	20,004	11,967	10,234
2006	332,646	130,672	133,748	125,773	72,806	42,882	28,090	26,501	13,835	8,256
2007	273,741	234,335	92,017	94,105	88,350	50,994	29,907	19,498	18,322	9,541
2008	234,419	192,849	165,032	64,758	66,136	61,937	35,620	20,806	13,519	12,676
2009	315,252	165,112	135,754	116,032	45,421	46,188	42,984	24,547	14,255	9,228
2010	159,547	222,007	116,183	95,366	81,240	31,614	31,870	29,373	16,640	9,614
2011	172,736	112,333	156,147	81,538	66,637	56,328	21,672	21,572	19,675	11,072
2012	198,124	121,670	79,082	109,803	57,209	46,567	39,133	14,958	14,809	13,460
2013	305,145	139,547	85,648	55,599	77,009	39,948	32,309	26,958	10,244	10,103
2014	409,222	214,936	98,241	60,228	39,011	53,818	27,756	22,303	18,510	7,009

Table A8 (cont'd). Estimates of arrowtooth flounder population number-at-age, by sex, 1976-2014.

males	numbers at age (1,000s)										
	11	12	13	14	15	16	17	18	19	20	21
1976	1,282	950	712	537	407	310	235	179	135	102	123
1977	1,119	808	598	447	337	256	195	148	113	85	141
1978	1,061	738	532	393	294	222	168	128	97	74	149
1979	1,089	708	491	354	262	196	148	112	85	65	148
1980	1,232	712	462	321	231	171	128	96	73	56	139
1981	1,716	788	455	295	205	148	109	82	62	47	124
1982	3,679	1,105	507	292	190	132	95	70	52	40	110
1983	2,812	2,444	734	337	194	126	87	63	47	35	99
1984	2,760	1,850	1,607	482	221	127	83	57	41	31	88
1985	1,014	1,860	1,246	1,082	325	149	86	56	39	28	80
1986	2,326	692	1,268	849	737	221	101	58	38	26	73
1987	3,284	1,591	473	867	581	504	151	69	40	26	68
1988	2,461	2,272	1,100	327	599	401	349	105	48	28	65
1989	2,597	1,612	1,486	719	214	392	262	228	68	31	61
1990	2,577	1,784	1,107	1,020	494	147	269	180	156	47	63
1991	5,893	1,740	1,204	746	688	333	99	181	121	105	74
1992	2,214	3,881	1,145	792	491	452	219	65	119	80	118
1993	1,804	1,515	2,655	783	541	336	309	150	45	82	135
1994	5,444	1,241	1,042	1,826	538	372	231	213	103	31	149
1995	3,992	3,709	845	710	1,243	367	253	157	145	70	122
1996	3,284	2,755	2,559	583	490	858	253	175	108	100	133
1997	10,242	2,242	1,880	1,746	398	334	585	173	119	74	159
1998	5,735	7,067	1,547	1,297	1,204	274	230	404	119	82	160
1999	5,929	3,916	4,823	1,055	885	822	187	157	275	81	166
2000	4,274	4,089	2,699	3,324	727	610	566	129	108	190	170
2001	4,496	2,935	2,807	1,853	2,281	499	418	389	89	74	247
2002	5,298	3,083	2,012	1,924	1,270	1,564	342	287	266	61	220
2003	4,257	3,653	2,125	1,386	1,326	875	1,077	236	198	184	194
2004	4,347	2,930	2,514	1,462	954	912	602	741	162	136	259
2005	5,378	2,969	2,000	1,716	998	651	622	411	506	111	270
2006	7,051	3,703	2,044	1,377	1,181	687	448	428	283	348	262
2007	5,686	4,852	2,548	1,406	947	812	472	308	295	194	419
2008	6,594	3,927	3,351	1,759	971	654	561	326	213	203	424
2009	8,635	4,487	2,671	2,279	1,196	660	444	381	222	145	426
2010	6,206	5,800	3,012	1,793	1,529	802	443	298	256	149	383
2011	6,373	4,107	3,835	1,991	1,185	1,010	530	293	197	169	351
2012	7,560	4,348	2,801	2,615	1,357	807	689	361	199	134	355
2013	9,164	5,142	2,956	1,904	1,777	922	549	468	246	136	332
2014	6,900	6,253	3,507	2,016	1,298	1,212	629	374	319	167	319

Table A9 (Table 6.12 with logistic fishery selectivity). Estimated age 2 recruitment of arrowtooth flounder (thousands of fish) from the 2012 and 2014 stock assessments. Average over all years from 2014 assessment = 310,216.

Year class	2012 Assessment	2014 Assessment
1974	230,069	68,240
1975	297,213	150,077
1976	245,370	203,886
1977	260,994	146,632
1978	466,116	158,049
1979	278,861	153,779
1980	279,797	352,481
1981	295,261	136,150
1982	261,457	109,587
1983	512,622	324,762
1984	300,425	236,080
1985	424,330	190,301
1986	454,913	589,729
1987	228,364	325,773
1988	469,933	337,086
1989	570,669	241,259
1990	346,025	253,267
1991	608,477	298,683
1992	709,081	238,979
1993	533,246	243,514
1994	590,261	303,066
1995	484,687	396,451
1996	422,013	319,256
1997	461,524	368,342
1998	440,673	487,047
1999	501,638	357,854
2000	439,534	380,658
2001	375,534	452,463
2002	369,206	548,930
2003	381,796	410,637
2004	327,427	282,510
2005	322,479	506,628
2006	346,488	416,932
2007	389,187	356,982
2008		480,010
2009		242,890

Figures

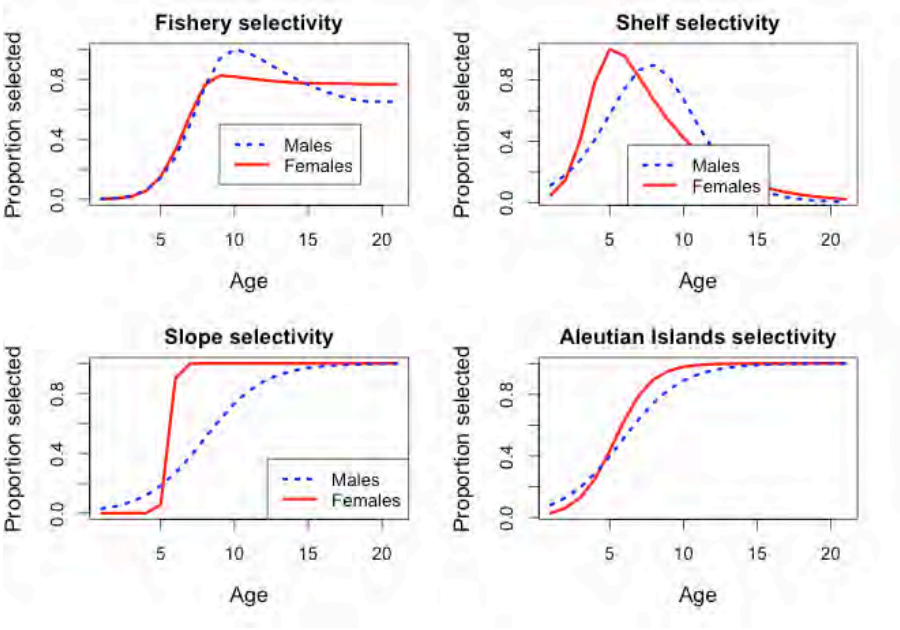

Figure A1. Age-specific fishery selectivity (top left panel), shelf survey selectivity (top right panel) slope survey selectivity (bottom left panel) and Aleutian Islands survey selectivity (bottom right panel), by sex, estimated within the stock assessment model. Fishery selectivity estimated non-parametrically for all ages.

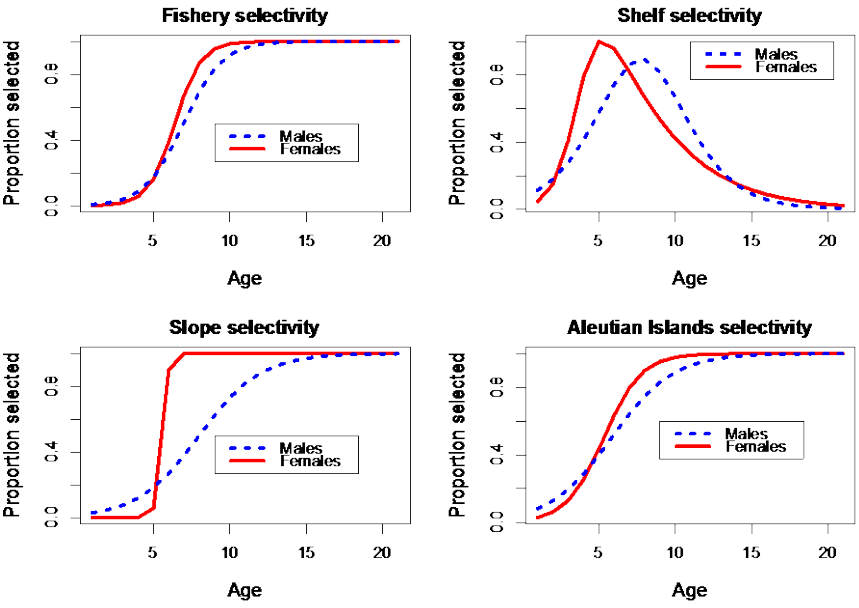

Figure A2. (Figure 6.8 with logistic fishery selectivity) Age and sex-specific fishery selectivity (top left panel), shelf survey selectivity (top right panel) slope survey selectivity (bottom left panel) and Aleutian Islands survey selectivity (bottom right panel), by sex, estimated within the stock assessment model. Selectivity is estimated using a two parameter ascending logistic function.

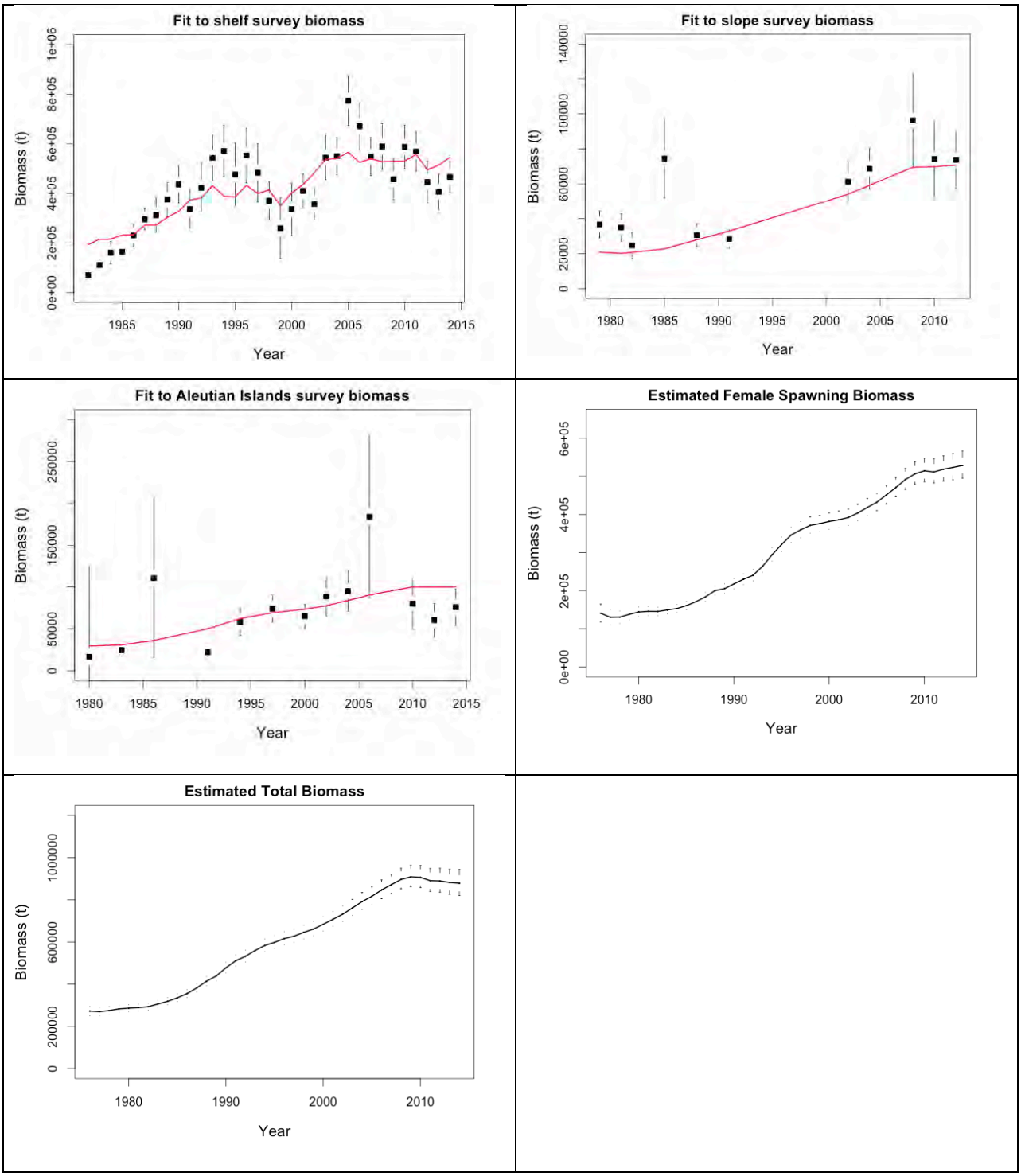

Figure A3 (Figure 6.9 with logistic fishery selectivity). Stock assessment model results of the fit to the shelf survey biomass time-series (upper left panel), slope survey biomass (upper right panel), estimate of female spawning biomass with $B_{35\%}$ and $B_{40\%}$ indicated (middle right panel), the fit to the Aleutian Islands survey (middle left panel) and the estimate of total biomass (bottom panel). Credible intervals on model estimates of female spawning biomass and total biomass are from 5% and 95% quantiles of MCMC posterior values.

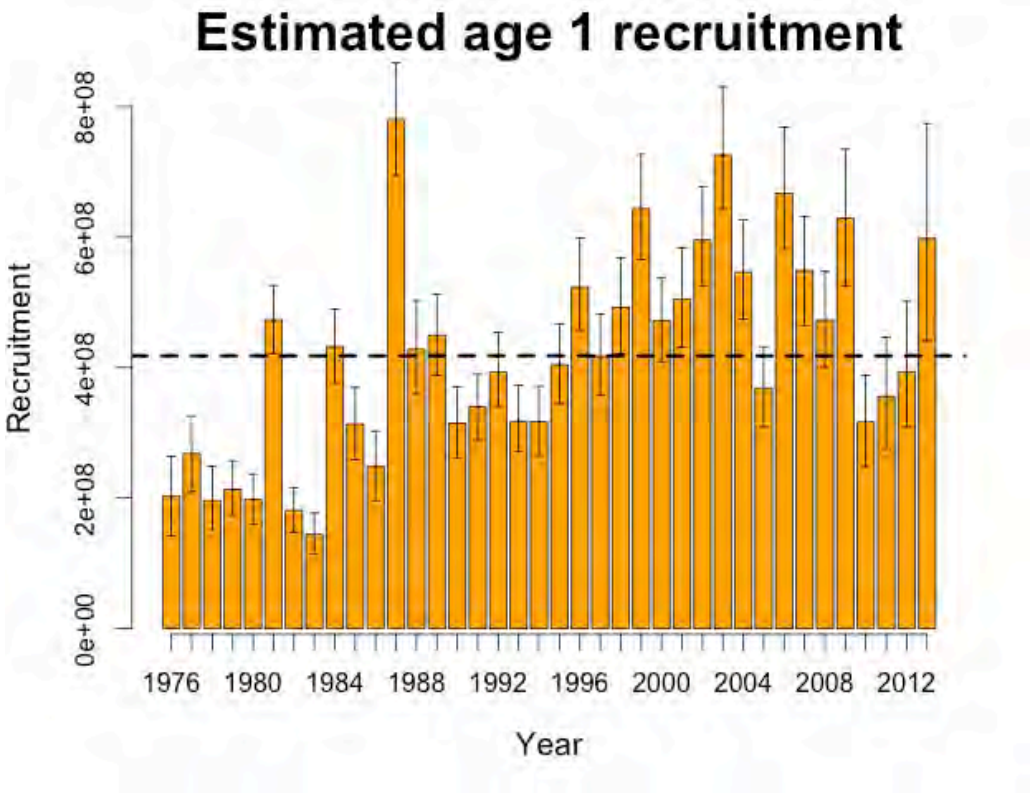

Figure A4 (Figure 6.11 using logistic fishing selectivity). Estimates of arrowtooth flounder age 1 recruitment from the stock assessment model.

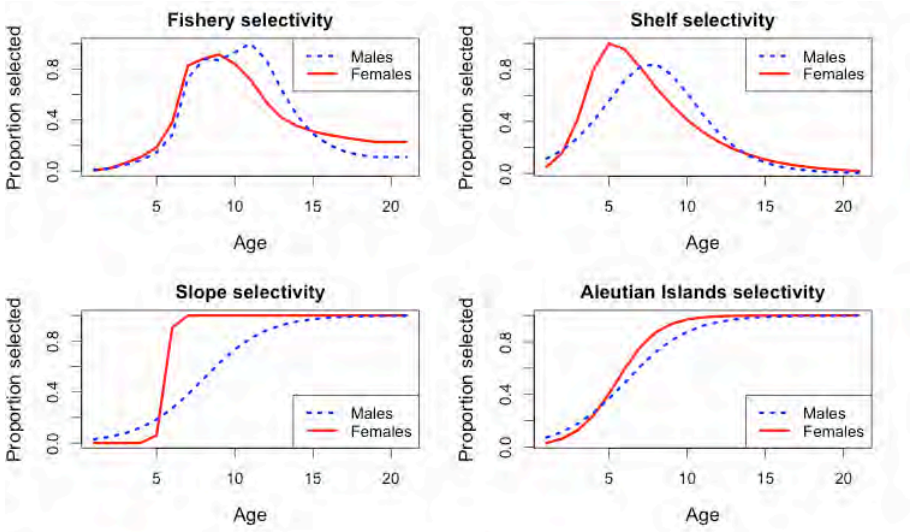

Figure A5 (Figure 6.8 with non-parametric fishery selectivity and equal weights on smoothing likelihood components). Selectivity estimated by the model when non-parametric selectivity was used, and all weights were equal to 1.

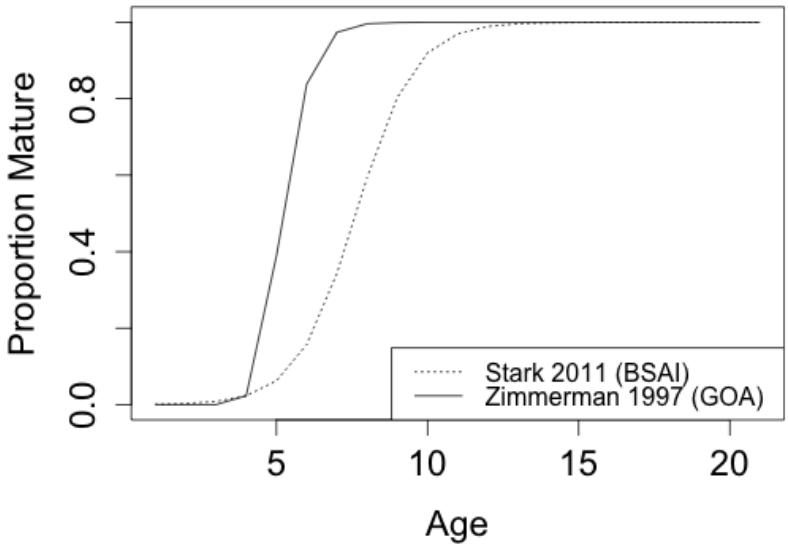

Figure A6. Stark (2011) parameters indicate that ATF mature at a younger age than estimates from the Zimmermann (1997) study.

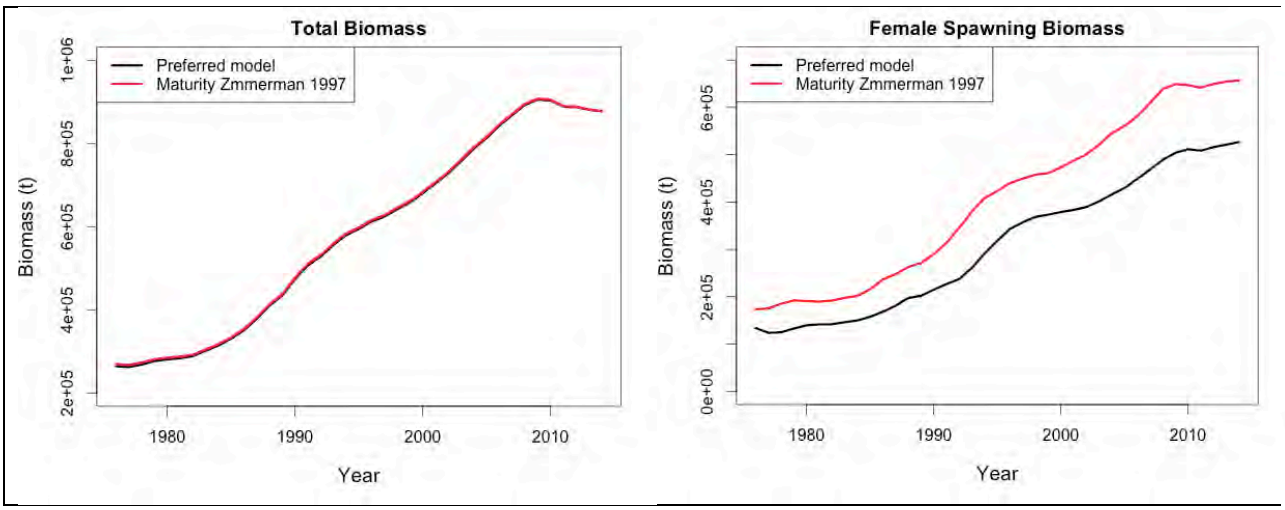

Figure A7. Total biomass (left) and female spawning biomass (right) for maturity estimated by Stark (2011) as in the preferred model, and by Zimmerman (1997).

Chapter 7

Assessment of the Kamchatka Flounder stock in the Bering Sea and Aleutian Islands

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Executive Summary

This assessment is a full update of the 2012 stock assessment. The 2013 assessment was an off-cycle assessment that did not re-run an updated assessment model, but instead the projection model was run with updated catch information only to provide estimates of 2014 and 2015 ABC and OFL without re-estimating the stock assessment model parameters and biological reference points.

Summary of changes in assessment input

1) Estimate of catch for 2012-2014.

2) 2012 and 2013 fishery length composition.

3) 2013 and 2014 shelf survey length composition

4) 2013 and 2014 shelf survey biomass and standard error estimates.

5) 2014 Aleutian Islands survey biomass and standard error.

6) 2014 Aleutian Islands survey length composition.

7) 2012 slope survey age composition.

No changes were made to the assessment methodology.

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Summary of Results

	Tier 3 assessment model			
	As estimated last year for		As estimated this year for	
Quantity	2014	2015	2015	2016
M (natural mortality rate)	0.11	0.11	0.11	0.11
Tier	3	3	3	3
Projected total (age 1+) biomass (t)	136,600	138,700	174,500	181,000
Projected female spawning biomass				
Projected	50,400	50,100	**60,100**	61,200
$B_{100\%}$	115,200	115,200	**132,500**	132,500
$B_{40\%}$	46,100	46,100	**53,000**	53,000
$B_{35\%}$	40,300	40,300	**46,400**	46,400
F_{OFL}	0.073	0.073	**0.076**	0.076
$maxF_{ABC}$	0.063	0.063	**0.065**	0.065
F_{ABC}	0.063	0.063	**0.065**	0.065
OFL (t)	8,270	8,500	**10,500**	11,000
maxABC (t)	7,100	7,300	**9,000**	9,500
ABC (t)	7,100	7,300	**9,000**	9,500
	As determined *last* year for:		As determined *this* year for:	
Status	2012	2013	2013	2014
Overfishing	no	n/a	no	n/a
Overfished	n/a	no	n/a	no
Approaching overfished	n/a	no	n/a	no

	Alternative Tier 5 model			
	As estimated or		As estimated or	
Quantity	*specified last* year for:		*recommended this* year for:	
	n/a	n/a	2015	2016
M (natural mortality rate)	n/a	n/a	0.11	0.11
Tier	n/a	n/a	5	5
Biomass (t)	n/a	n/a	136,000	136,000
F_{OFL}	n/a	n/a	0.11	0.11
$maxF_{ABC}$	n/a	n/a	0.0825	0.0825
F_{ABC}	n/a	n/a	0.0825	0.0825
OFL (t)	n/a	n/a	14,200	14,200
maxABC (t)	n/a	n/a	10,700	14,200
ABC (t)	n/a	n/a	10,700	10,700
Status	As determined *last* year for:		As determined *this* year for:	
	2013	2014	2014	2015
Overfishing	n/a	n/a	n/a	n/a

Responses to SSC and Plan Team Comments on Assessments in General

From the December 2013 SSC minutes: The SSC asks assessment authors project the reference points for the future two years (e.g., 2014 and 2015) on the phase diagrams.

From the September 2013 Joint Plan Team minutes:
***Accounting for total catch removals*: The Teams recommended that SAFE chapter authors continue to include "other" removals as an appendix. Optionally, authors could also calculate the impact of these removals on reference points and specifications, but are not required to include such calculations in final recommendations for OFL and ABC.**

***Retrospective analyses*: In conformity with the main recommendations of the Retrospective Working Group, the Team recommended the following:**

1. **Assessment authors should routinely do retrospective analyses extending back 10 years, plot spawning biomass estimates and error bars, plot relative differences, and report Mohn's rho (revised).**
2. **If a model exhibits a retrospective pattern, try to investigate possible causes.**
3. **Communicate the uncertainty implied by retrospective variability in biomass estimates.**
4. **For the time being, do not disqualify a model on the grounds of poor retrospective performance alone.**
5. **Do consider retrospective performance as one factor in model selection.**

***Total Current Year Removals*: The Teams recommended that each stock assessment model incorporate the best possible estimate of the current year's removals.**

Responses to SSC and Plan Team Comments Specific to this Assessment

SSC comments from December 2013.

Therefore, the SSC supports the ABCs and OFLs for 2014 and 2015, respectively, as recommended by the authors and Plan Team using the new Tier 3 assessment. The SSC requests that the authors bring forward a full assessment under both Tier 3 and Tier 5 for review during next year's assessment.

Tier 5 template included above for alternative management values.

Introduction

In 2013 a Tier 3 approach was used to describe the stock status of Kamchatka flounder using survey and fishery age and length structured modeling. The assessment previously used Tier 5 methodology reliant upon trawl survey biomass from the Bering Sea shelf, slope and the Aleutian Islands and an estimate of natural mortality. ABC and OFL were determined from a 7-year averaging technique of survey biomass.

The Kamchatka flounder (*Atheresthes evermanni*) is a relatively large flatfish which is distributed from Northern Japan through the Sea of Okhotsk to the Western Bering Sea north to Anadyr Gulf (Wilimovsky et al. 1967) and east to the eastern Bering Sea shelf and south of the Alaska Peninsula (there is also a catch record from California). In U.S. waters they are found in commercial concentrations in the Aleutian

Islands where they generally decrease in abundance from west to east (Zimmerman and Goddard 1996). They are also present in Bering Sea slope waters but are absent in survey catches east of Chirikof Island.

In the eastern part of their range, Kamchatka flounder overlap with arrowtooth flounder (*Atheresthes stomias*), a species that is very similar in appearance but was not routinely distinguished in the commercial catches until 2007. Until about 1991, these species were also not consistently separated in trawl survey catches (Fig. 7-1) and were combined in the arrowtooth flounder stock assessment (Wilderbuer et al. 2009). However, managing the two species as a complex became undesirable in 2010 due to the emergence of a directed fishery for Kamchatka flounder in the BSAI management area. Since the ABC was determined by the large amount of arrowtooth flounder relative to Kamchatka flounder (complex is about 93% arrowtooth flounder) the possibility arose of an overharvest of Kamchatka flounder as the *Atheresthes sp*. ABC exceeded the Kamchatka flounder biomass. Arrowtooth and Kamchatka flounder have been managed separately since 2011. There is no evidence of stock structure.

Fishery

Catch History

Historical Kamchatka flounder catch is combined in catch records of arrowtooth flounder and Greenland turbot from the 1960s. The fisheries for Greenland turbot intensified during the 1970s and the bycatch of arrowtooth flounder and Kamchatka flounder is assumed to have also increased. Catches of these species decreased after implementation of the MFCMA and the Kamchatka flounder resource remained lightly exploited with the combined catches with arrowtooth flounder averaging 12,831 t from 1977-2008 (Table 7-1). It is estimated that only a small fraction (<10%) of this catch was Kamchatka flounder. This decline resulted from catch restrictions placed on the fishery for Greenland turbot and phasing out of the foreign fishery in the U.S. EEZ. Catches in Table 7-1 through 2006 are for arrowtooth flounder and Kamchatka flounder combined, catches thereafter are those estimated for Kamchatka flounder only. The total combined catch estimated for arrowtooth and Kamchatka flounder reported by the Alaska Regional Office (catches were not differentiated by species until 2011), is a blend of vessel reported catch and observer at-sea sampling of the catch. However, observers have separately identified the two species from catches aboard trawl vessels since 2007 and their sampling has indicated that the proportion of Kamchatka flounder in the combined catch has steadily increased from 10% in 2007 to 55% in 2010.

year	Percent of combined catch
2007	10%
2008	31%
2009	45%
2010	55%

The increased harvest was the result of a recently developed foreign market for Kamchatka flounder which has now become a fishery target. Based on the above observer derived percentages, the 2010 estimated catch of Kamchatka flounder was 21,153 t, taken primarily in area 514 and to a lesser extent in area 518. The 2011 catch of 9,935 is less than half of the 2010 combined total (TAC and ABC = 17,700, OFL = 23,600) and was evenly split between area 541 in the central Aleutian Islands (51%) and area 524 in the northern Bering Sea (34%). Based on this result in 2011, area apportionment has not been pursued in the assessment. The 2012 catch of 9,514 t was about the same as the 2011 and has declined since then to 7,772 t in 2013 and 6,220 t 2014 (through October 4). The 2014 catch is 87% of the ABC of 7,100 t (Table 7-1). The Kamchatka catch by week in 2014 (Fig. 7-1) shows that targeting for Kamchatka flounder began May 1and continued throughout the summer with peak weekly amounts in July and August.

Data

The data used in this assessment includes estimates of total fishery catch, bottom trawl survey biomass estimates and length composition from the Bering Sea shelf, slope and Aleutian Islands surveys. Age data are available from the 2010 Aleutian Islands survey and from the 2002 and 2012 slope surveys. All survey length-weight observations were included.

Fishery catch

Fishery catch from 2007-2014 were included in the model as listed above. Catches from 1991-2006, years when Kamchatka and arrowtooth flounder were not identified to species were calculated by assuming that Kamchatka flounder comprised 10% of the catch during that time period. The 2014 catch used the current estimate from the Alaska Regional Office at the time of the assessment, assuming the fishery is finished for 2014.

Absolute Abundance from Trawl Surveys

Biomass estimates (t) for Kamchatka flounder from the standard shelf survey area in the eastern Bering Sea, slope surveys and the Aleutian Islands region are shown in Table 7-2. Reliable estimates of Kamchatka flounder became available in 1991 and they were estimated at an average biomass of 45,500 t through 1994 on the Bering Sea shelf (Fig. 7-2). During the following 10 years the biomass was estimated at a lower level (25,000 t average) before increasing to high and stable levels the past 10 years (52,000 t average). On the continental shelf they are usually found in highest concentrations at depths greater than 200 meters around the Pribilof Islands and also in the large shelf area west of St. Matthew Island (Fig. 7-3) and were present in 185 of the 376 stations in the standard survey area (Table 7.3, Fig. 7-2). Trends of abundance from the slope and Aleutian Islands surveys also indicate an increasing resource. They are common in the deeper waters of the slope area (500 to 800 meters, Zimmerman and Goddard 1996) in both the Aleutian Islands and the eastern Bering Sea slope (Figs. 7-3 and 7-4).

An estimate of total BSAI biomass for the years in which Aleutian Islands and slope surveys were not conducted was calculated by averaging the years in closest temporal (before and after) proximity. Population length composition estimates for the three trawl surveys are shown by year and sex in Figure 7-5 and Tables 7.4-7.6.

Analytic Approach

Model Structure

This stock assessment utilizes the AD Model Builder software to model the population dynamics of Bering Sea and Aleutian Islands Kamchatka flounder starting in 1991. The model is a sex-specific length and age-based approach where survey and fishery length composition observations are used to calculate estimates of population numbers-at-age by the use of a length-age (growth) matrix. The model simulates the dynamics of the population and compares the expected values of the population characteristics to those observed from surveys and fishery sampling programs. This is accomplished by the simultaneous estimation of the parameters in the model using the maximum likelihood estimation procedure. The fit of the simulation values to the observed characteristics is optimized by maximizing the log(likelihood) function given the following distributional assumptions about the observed data (see Tables 7-8 and 7-9).

The suite of parameters estimated by the base model are classified by the following likelihood components:

Data Component	Distribution assumption
Trawl fishery size composition	Multinomial
Shelf survey population size composition	Multinomial
Slope survey population size composition	Multinomial
Slope survey age composition (2002 and 2012)	Multinomial
Aleutian Islands survey size composition	Multinomial
Aleutian Islands age composition (2010)	Multinomial
Trawl survey biomass estimates and S.E.	Log normal
Slope survey biomass estimates and S.E.	Log normal
Aleutian Islands biomass estimates and S.E.	Log normal

The total log likelihood is the sum of the likelihoods for each data component. The model allows for the individual likelihood components to be weighted by an emphasis factor. Equal emphasis was placed on fitting all data components for this assessment with the exception that a large emphasis was placed on fitting the fishery catch. The number of parameters estimated for the base configuration of the model are presented below:

Fishing mortality	Selectivity	Shelf and Aleutian survey *q*	Year class strength	Total
25	16	2	48	91

The recruitment parameters are comprised of the 24 initial ages in 1991 (ages 2-25), the 24 subsequent recruitment deviation estimates from 1992-2014 and the mean log of all recruitment. Fishing mortality (*F*) parameters include the log of average *F* and the 24 annual fishing mortality deviations. Selectivity parameters are from the logistic model for 3 surveys and a single fishery, for each sex. It was assumed that the shelf, slope and Aleutian Islands surveys measure non-overlapping segments of the Kamchatka flounder stock. Biomass was apportioned between the three areas by calculating the average of the annual proportions estimated from the trawl surveys (Fig 7-8). The resulting proportions are (37% shelf, 18% slope and 45% in the Aleutian Islands) were used as starting values in the area-specific catchability estimation. The length-age conversion matrices (sex-specific) were constructed using fitted von Bertalanffy growth curves to the available age data. The variability in length at age was estimated to reflect a *CV* of about 8% (in cm). This provided the variance in growth for the length-age conversions.

In addition, two more parameters can be estimated in a later stage to estimate the annual relationship between bottom water temperature and shelf survey catchability and bottom water temperature and the overall value of catchability which relates to the capture process and availability of the stock (discussed in the next section).

Parameters Estimated Outside of the Assessment Model

Length-weight, length and weight at age, maturity and natural mortality

All length-weight measurements collected during RACE surveys (1,074 total, 483 males and 591 females) were used to describe the Kamchatka flounder length (cm)-weight (g) relationship (Fig 7.6) by the equation:

Males: $W = 4.73 \times 10^{-6} L^{3.757}$

Females $W = 2.08 \times 10^{-3} L^{3.393}$

Length at age calculations from the ageing of 450 otoliths from the 2010 Aleutian Islands survey were fit to a von Bertalanffy growth model to obtain male and female length at age. These data were then multiplied by the sex-specific length-weight data to obtain estimates of weight-at-age for the assessment model. Weight-at-age data indicate that females and males grow at a similar rate until about the age of maturation after which females continue to grow to a larger size (Fig 7.7). Maturity was determined in a study by Stark (2011) from a histological examination of ovary samples collected in the Bering Sea (Table 7.7).

Both sexes have been found in relatively equal numbers and the oldest fish have been aged at 35 years indicating that Kamchatka flounder are similar in life history to other Bering Sea flatfish. The assessment model was used to explore estimates of natural mortality.

Parameters Estimated Inside the Assessment Model

Catchability

Examination of Bering Sea shelf survey biomass estimates indicate that some of the annual variability seemed to positively co-vary with bottom water temperature. Variations in shelf survey biomass were particularly evident during the coldest year (1999) and the warm trend that occurred from 2001-2005. The relationship between average annual bottom water temperature collected during the survey and annual survey biomass estimates can be better understood by modeling survey catchability as:

$$q = e^{-\alpha+\beta T}$$

where q is catchability, α and β are a parameters estimated by the model, and T_t is the average annual bottom water temperature for year t. The catchability equation has two parts. The e^{α} term is a constant or time-independent estimate of q. The second term, $e^{\beta T}$ is a time-varying (annual) q which relates to the metabolic aspect of herding or distribution (availability) which can vary annually with bottom water temperature.

Year class strengths

The population simulation specifies the number-at-age in the beginning year of the simulation, the number of recruits in subsequent years as deviations from overall mean log recruitment, and the survival rate for each cohort as it moves through the population calculated from the population dynamics equations (see Table 7-8 and Table 7-9).

Fishing Mortality

The fishing mortality rates for each age and year are calculated to approximate the catch weight by solving for F while still allowing for observation error in catch measurement. A large emphasis (300) was placed on the catch likelihood component.

Selectivity

Survey results indicate that fish less than about 4 years old (< 30 cm) are found mostly on the Bering Sea shelf and to a lesser extent in the Aleutian Islands. Males and females from 30-50 cm are found on the shelf and in deeper waters of the Aleutian Islands and Bering Sea slope waters, and males and females > 50 cm are mainly found at depths below 200 meters. Sex specific "domed-shaped" selectivity was freely estimated for males and females in the shelf survey due to the lack of larger fish there. We assumed an asymptotic selectivity pattern for both sexes in the slope surveys and the Aleutian Islands surveys. Selectivity was assumed constant over all survey years.

Up to the present, the low level of length measurements collected from the fishery may not provide sufficient information for the model to reliably estimate fishery selectivity. The input sample size for fitting this data was set at a low level (25) and may be overemphasized. This results in sample size

problems which make estimates of fishery selectivity unreliable. The shape of the selectivity curve was fixed asymptotic for older fish in the fishery since the directed fishery for Kamchatka flounder presumably targets the larger fish.

Results

Model Evaluation

1) Started with *q*'s (catchability) apportioned by their relative survey biomass estimates for the three survey areas.
2) Examination of the results from the initial model run indicated that fishery selectivity is poorly determined (presumably due to the low sample sizes,) and that there are males present in the length records that are larger than those observed in any survey data. It is suspected that this is the result of some mis-sexing of Kamchatka flounder in the commercial fishery sampling. This was resolved by fixing the slope of the logistic curve (age at 50% selection is still estimated for each sex) which produced more sensible results (Fig. 7-9) and estimated reference *F* values similar to other Bering Sea flatfish species.
3) Based on selectivity patterns, the shelf survey showed big differences in the ages of fish available to these different surveys (Fig. 7-10). The slope survey selectivity estimates seemed most stable hence: Alternative values of *q* were fixed for the slope survey and *q* values for the shelf and Aleutian Islands surveys were freely estimated.
4) Since *q* is confounded with natural mortality, *M* was estimated as a free parameter and returned estimates similar to that obtained from profiling over *M* with catchability fixed for the three surveys (~0.11). *M* was fixed at 0.11 for subsequent model runs.

Estimates of *q* from the slope survey profile and the associated likelihood indicated that slope q is less than 0.3, but flat from about 0.2-0.05. Estimates of female spawning biomass derived from slope $q = 0.1$ and $q = 0.18$ are shown in figure 7-12. The difference in total likelihood between these models was only 1.95, with the q=0.1 model being favored (in terms of total log likelihood) since the best fit to the overall likelihood is a low slope *q* (Fig. 7-13). Since the likelihood surface was so flat between q=0.1 and 0.18, the fixed value of 0.18 was retained for slope *q*. With the model configured in this way (slope survey q=0.18, $M = 0.11$ and fishery selectivity logistic slope fixed) the model was run to estimate the status and the population dynamics of the Kamchatka flounder stock over the period 1991-2014.

Time Series Results

Model results estimate that the total biomass of Kamchatka flounder steadily increased from 1991 to 2009 to about 175,000 t and has since declined by 8,000 t (Fig. 7-14). The female spawning biomass trend mirrors the total biomass with a parallel trend that peaks at 63,000 t in 2009 and has declined by 3,000 t to the 2014 estimate (Fig. 7-15 and Table 7.10). The model estimates of shelf, slope and Aleutian Islands surveys fit the trends estimated by those data sources reasonably well (Fig. 7-16). Selectivity, as previously discussed, were constrained for the fishery and were freely estimated for the surveys. It is clear that the shelf survey samples a younger portion of the population than those surveys conducted on the Bering Sea slope and in the Aleutian Islands (Fig. 7-10). Model estimates of male and female numbers-at-age are shown in Table 7.11 and estimated female spawning biomass-at-age in Table 7.12.

Model estimates of fishing mortality indicate that the stock was lightly harvested from 1991 to 2007 with an average annual full selection F of 0.014 (Fig 7-17). As the fishery developed for Kamchatka flounder in 2008 the fishing mortality was much higher, peaking at 0.129 in 2010. For the last 4 years fishing mortality has averaged 0.54.

Examination of the model fit to the survey length composition data was made by comparing the average observed proportion at length from the time-series to the average predicted proportion at length from the model (Fig. 7-18). Overall the model fits the general shape of the length compositions but has some residual trends for large fish on the slope and the Aleutian Islands. Fits to the individual annual length compositions, by sex, are shown in Figure 7.19.

Projections and Harvest Recommendations

The reference fishing mortality rate for Kamchatka flounder is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $B_{40\%}$, $F_{40\%}$, and $SPR_{40\%}$ were obtained from a spawner-per-recruit analysis. Assuming that the average recruitment from 1989-2011 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{40\%}$ is calculated as the product of $SPR_{40\%}$ * equilibrium recruits (=53,000 t). The 2015 spawning biomass is estimated at 60,100 t. Since reliable estimates of 2015 spawning biomass (B), $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and $B>B_{40\%}$ (60,100 t > 53,000 t shown in Fig. 7.15 and Fig. 7.20), Kamchatka flounder reference fishing mortality is defined in tier 3a of Amendment 56. For this tier, F_{ABC} is constrained to be $\leq F_{40\%}$, and F_{OFL} is defined as $F_{35\%}$. The values of these quantities are:

2015 SSB estimate (B)	=	60,100 t
$B_{40\%}$	=	53,000 t
$F_{40\%}$	=	0.065
F_{ABC}	=	0.065
$F_{35\%}$	=	0.076
F_{OFL}	=	0.076

The estimated catch level for year 2015 associated with the overfishing level of F = 0.076 is 10,500 t. **The 2015 recommended ABC associated with F_{ABC} of 0.065 is 9,000 t.** Projections of Kamchatka flounder female spawning biomass (described below) at a harvest rate equal to the average fishing mortality rate of the past five years indicate that the stock could increase to a stable level of over 65,000 t from 2020-2027 (Fig. 7.15).

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2014 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2015 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2014. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment.

Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2015, are as follows ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2015 recommended in the assessment to the *max* F_{ABC} for 2015. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 2010-2014 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, and five-year projections of the mean Alaska plaice harvest and spawning stock biomass for the remaining four scenarios are shown in Table 10.11.

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the Alaska plaice stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY level in 2015 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2027 under this scenario, then the stock is not approaching an overfished condition.)

The results of these two scenarios indicate that Kamchatka flounder are neither overfished nor approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2014 of scenario 6 is well above its $B_{35\%}$ value of 124,300 t. With regard to whether the stock is likely to be in an overfished condition in the near future, the expected stock size in the year 2027 of scenario 7 is also greater than its $B_{35\%}$ value. Figure 7.20 shows the relationship between the estimated time-series of female spawning biomass and fishing mortality and the tier 3 control rule for Kamchatka flounder. The simulation results for the 7 harvest scenarios are shown in Table 7.13.

Scenario Projections and Two-Year Ahead Overfishing Level

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2015, it does not provide the best estimate of OFL for 2016, because the mean 2016 catch under Scenario 6 is predicated on the 2015 catch being equal to the 2015 OFL, whereas the actual 2015 catch will likely be less than the 2015 ABC. Therefore, the projection model was re-run with the 2016 catch fixed at the 2015 level.

Year	Catch	ABC	OFL
2015	6,220	9,000	10,500
2016	6,220	9,500	11,000

Ecosystem Considerations

Predators of Kamchatka flounder

Kamchatka flounder have rarely been found in the stomachs of other groundfish species in samples collected by the Alaska Fisheries Science Center. Their presence has only been documented in 17 stomach samples from the BSAI where the predators included Pacific cod, pollock, Pacific halibut, arrowtooth flounder and two sculpin species.

Kamchatka flounder predation

The prey of Kamchatka flounder can be discerned from 152 stomachs collected in 1983 (Yang and Livingston 1986). The principle diet was composed of walleye pollock, shrimp (mostly Crangonidae) and euphausids. Pollock was the most important prey item for all sizes of fish, ranging from 56 to 86% of the total stomach content weight. An examination of diet overlap with arrowtooth flounder indicated that these two congeneric species basically consume the same resources. Therefore the following sections are from the arrowtooth flounder assessment but pertain to Kamchatka flounder.

Ecosystem Effects on the stock

Prey availability/abundance trends

Arrowtooth flounder diet varies by life stage as indicated in the previous section. Regarding juvenile prey and its associated habitat, information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not be re-sampled since. Information on pollock abundance is available in Chapter 1 of this SAFE report. It has been hypothesized that predators on pollock, such as adult arrowtooth flounder, may be important species which control (with other factors) the variation in year-class strength of juvenile pollock (Hunt et al. 2002). The populations of arrowtooth flounder which have occupied the outer shelf and slope areas of the Bering Sea over the past twenty years for summertime feeding do not appear food-limited. These populations have fluctuated due to the variability in recruitment success which suggests that the primary infaunal food source has been at an adequate level to sustain the arrowtooth flounder resource.

Predator population trends

As juveniles, it is well-documented from studies in other parts of the world that flatfish are prey for shrimp species in near shore areas. This has not been reported for Bering Sea arrowtooth flounder due to a lack of juvenile sampling and collections in near shore areas, but is thought to occur. As late juveniles

they are found in stomachs of pollock and Pacific cod, mostly on small arrowtooth flounder ranging from 5 to 15 cm standard length..

Past, present and projected future population trends of these predator species can be found in their respective SAFE chapters in this volume. Encounters between arrowtooth flounder and their predators may be limited as their distributions do not completely overlap in space and time.

Changes in habitat quality

Changes in the physical environment which may affect Kamchatka flounder distribution patterns, recruitment success, migration timing and patterns are catalogued in the Ecosystem Considerations Appendix of this SAFE report. Habitat quality may be enhanced during years and warmer bottom water temperatures with reduced ice cover (higher metabolism with more active feeding). Environmental factors important to juvenile survival are presently not well known.

Fishery Effects on the Ecosystem

Ecosystem effects on Kamchatka flounder			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Benthic infauna	Stomach contents	Stable, data limited	Unknown
Predator population trends			
Fish (Pollock, Pacific cod)	Stable	Possible increases to Kamchatka mortality	
Changes in habitat quality			
Temperature regime	Cold years Kamchatka catchability and herding may decrease	Deeper water species so less likely to affect surveyed stock	No concern (dealt with in model)
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability

***Arrowtooth flounder* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Minor contribution to mortality	No concern
Forage (including Pollock, shrimp and euphausids)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	No concern
HAPC biota	Low bycatch levels of (spp)	Bycatch levels small relative to HAPC biota	No concern
Marine mammals and birds	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Recent high exploitation rate	Little detrimental effect	No concern
Fishery effects on amount of large size target fish	Recent high exploitation rate, but unknown effect	Natural fluctuation	No concern
Fishery contribution to discards and offal production	Stable trend	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	Unknown	NA	Possible concern

Data Gaps and Research Priorities

A significant improvement in the estimate of fishery selectivity would likely result from an increase in the amount of Kamchatka flounder length data collected when Kamchatka flounder are targeted in the commercial fishery.

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Table 7-1. Total combined catch (t) of arrowtooth and Kamchatka flounder in the eastern Bering Sea and Aleutian Islands region[a], 2001-2006. Catches from 2007 to present, when the two species were differentiated in commercial catches, are reported for Kamchatka flounder only in this table.

year	catch	TAC	ABC	OFL
1991	22,052			
1992	10,382			
1993	9,338			
1994	14,366			
1995	9,280			
1996	14,652			
1997	10,054			
1998	15,241			
1999	10,573			
2000	12,929			
2001	13,908			
2002	11,540			
2003	12,834			
2004	17,809			
2005	13,685			
2006	13,309			
2007	1,183			
2008	6,819			
2009	12,802			
2010	21,153			
2011	9,935	17,700	17,700	23,600
2012	9,514	17,700	18,600	24,800
2013	7772	10,000	12,200	16,300
2014	6,220	7,100	7,100	8,270

Table 7-2. Estimated Kamchatka flounder biomass and coefficient of variation (*CV*) from the three BSAI bottom trawl surveys (shelf, slope, and Aleutian Islands). Reliable estimates of Kamchatka flounder biomass are only available after 1991 when Kamchatka and arrowtooth flounder were differentiated.

	shelf	shelf CV	slope	slope CV	Aleutian Islands	Aleutian Islands CV
1982	0					
1983	17,299				1,034	
1984	20,695					
1985	31					
1986	0				565	
1987	40					
1988	13,723					
1989	17,108					
1990	32,799					
1991	37,152	0.11			16,255	0.27
1992	50,081	0.11				
1993	38,376	0.09				
1994	56,268	0.12			49,156	0.38
1995	28,393	0.10				
1996	24,196	0.10				
1997	18,282	0.10			37,664	0.25
1998	23,474	0.09				
1999	18,974	0.14				
2000	21,551	0.11			28,535	0.23
2001	31,120	0.09				
2002	25,213	0.12	18,645	0.11	49,035	0.28
2003	27,531	0.11				
2004	29,663	0.09	14,740	0.10	39,219	0.24
2005	46,084	0.07				
2006	61,644	0.08			45,369	0.24
2007	65,191	0.08				
2008	53,967	0.10	24,822	0.19		
2009	47,252	0.11				
2010	51,927	0.08	27,875	0.10	49,069	0.38
2011	46,094	0.09				
2012	40,951	0.08	32,787	0.22	35,100	0.40
2013	46,380	0.08				
2014	58,036	0.02			45,157	0.37

Table 7.3. Kamchatka flounder sample sizes from the Eastern Bering Sea shelf survey. The hauls columns refer to the number of hauls from which either lengths or otoliths were obtained.

Year	Total Hauls	Hauls w/Lengths	Number lengths	Hauls w/otoliths	Hauls w/ages	Number otoliths	Number ages
1982	334						
1983	353	13	692				
1984	355	27	741				
1985	357						
1986	354						
1987	357	1	5				
1988	373	18	142				
1989	374	33	424				
1990	371	51	643				
1991	372	92	1056				
1992	356	98	1039	20		165	
1993	375	146	1117	15		148	
1994	375	122	1241				
1995	376	100	816	7		74	
1996	375	136	826	9		103	
1997	376	100	698	2		31	
1998	375	138	1099				
1999	373	94	805				
2000	372	124	1054				
2001	375	127	1111				
2002	375	118	1053				
2003	376	158	1530				
2004	375	165	3034				
2005	373	182	3582				
2006	376	141	4126				
2007	376	132	2954				
2008	375	154	2724				
2009	376	132	2074				
2010	376	160	3219				
2011	376	189	2130				
2012	376	136	2953				
2013	376	151	2954	62		519	
2014	376	185	2490	31		314	

Table 7-4. Bering Sea shelf survey female size composition estimates (1,000s of fish).

Female size composition estimates from the shelf surveys (1,000s of fish)

year/size (cm)	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
1991	68	203	725	354	80	155	0	226	158	745	718	624	183 7	642	103 0	569	184 2	341 4	286 8
1992	256	148	131 8	221	354	0	50	318	568	494	663	146	267	715	232	205 2	119 0	106 9	122 1
1993	239	166	463	884	151	274	116	284	735	1047	436	620	274	239	327	301	111 5	199	533
1994	74	219	221	168	40	211	271	566	417	597	770	809	898	692	962	901	976	116 3	821
1995	0	56	55	0	115	59	27	53	199	56	107	113	63	215	190	498	575	978	471
1996	0	123	48	185	63	90	23	66	126	173	224	184	249	220	127	154	152	224	248
1997	100	402	200	570	190	239	338	172	142	308	149	149	243	58	81	58	59	99	60
1998	292	314	352	345	299	214	380	250	585	1012	713	675	583	739	392	419	275	354	169
1999	195	220	273	192	146	110	145	163	167	405	636	904	674	518	705	312	116 4	653	701
2000	141	201	0	66	0	92	215	376	732	1052	740	689	410	200	558	612	504	882	699
2001	189	64	205	318	306	422	222	309	789	451	240	137	163	454	936	147 8	179 2	125 0	148 9
2002	551	886	901	455	383	170	171	226	426	764	364	193	447	394	537	620	347	471	254
2003	86	146	318	686	795	681	814	743	1254	1263	116 6	985	663	506	348	347	387	403	520
2004	830	198 4	407 0	7817	7175	6595	4630	3755	2096	1210	142 0	254 9	139 2	214 7	138 6	149 5	160 8	182 3	152 2
2005	7	123 3	127 3	2161	1729	2570	2342	4279	2417	4199	598 0	819 1	852 5	656 5	681 6	502 3	357 9	282 2	274 9
2006	282	425	313	428	368	953	547	526	1016	1756	272 3	463 6	446 8	582 8	883 2	687 7	569 9	723 9	567 3
2007	351	123 3	152 8	1456	566	213	134	265	529	640	363	768	733	115 8	197 6	284 0	289 1	498 8	490 5
2008	214	513	714	627	586	872	920	1874	1356	706	465	314	700	852	651	113 6	131 4	124 0	145 8
2009	141	449	705	617	138	218	346	464	630	484	871	956	777	874	103 1	883	139 3	623	611
2010	101 8	364 0	387 4	3340	1154	1279	1557	2453	2387	1294	116 8	877	866	106 4	101 6	941	129 8	126 1	122 1
2011	450	687	840	543	574	343	1300	1119	2382	2352	216 8	127 0	220 9	104 7	141 9	122 5	117 2	996	724
2012	154 2	133 2	137 1	2258	1382	1685	1331	1917	1704	2523	145 7	195 8	247 7	260 8	236 9	277 7	170 4	176 4	100 1
2013	393	792	379	1301	332	395	752	2027	2519	2904	340 8	303 7	213 6	216 4	196 6	206 7	203 5	371 8	286 3
2014	867	124 6	102 7	2452	1037	763	705	636	326	1393	104 8	129 8	102 0	140 4	245 0	353 4	402 1	435 0	343 5

Table 7-4. Continued.

year/size (cm)	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
1991	1873	2059	2215	1964	2991	1933	780	1052	1002	543	486	339	1502	606	175	384	416	682	425	202	45
1992	1462	1334	730	1315	2028	2309	2075	2487	2236	2491	1476	1320	1467	514	799	211	669	568	315	1158	94
1993	471	606	983	639	844	424	1464	913	1258	1241	2060	1471	1065	915	1136	798	636	1011	254	468	407
1994	501	686	721	547	760	883	743	1349	877	1082	1180	2089	1239	1231	1041	1185	955	1585	1068	544	712
1995	380	553	857	317	654	427	254	490	601	394	221	643	399	658	562	580	614	448	430	463	344
1996	469	469	272	402	851	730	289	404	590	312	495	389	219	363	347	321	421	408	479	544	744
1997	173	276	59	88	115	59	267	413	522	473	642	574	607	334	208	116	212	61	275	191	404
1998	295	319	254	123	96	473	144	273	454	717	458	472	392	524	249	308	601	139	338	254	133
1999	442	173	583	226	327	406	413	180	192	127	419	85	128	126	114	320	258	257	213	408	364
2000	1152	558	420	455	659	255	315	617	143	63	152	31	129	209	98	172	203	203	77	185	368
2001	529	618	697	1148	988	1074	878	586	537	806	498	382	457	279	264	475	251	176	57	285	46

2002	414	554	1041	1002	841	294	367	418	414	491	807	620	781	774	447	151	545	91	255	154	109
2003	564	638	505	332	518	581	286	1111	474	227	608	268	377	320	321	233	308	194	236	29	48
2004	1220	736	979	604	473	849	189	1031	298	287	231	264	338	219	267	176	240	212	326	250	110
2005	2551	2146	2598	2160	781	1673	760	498	349	229	284	131	394	92	513	137	491	151	193	172	149
2006	6141	5321	4762	3063	3697	2665	1184	1465	633	557	390	515	229	173	247	272	27	27	29	88	210
2007	5214	4622	5165	6456	5419	4120	3755	2137	2344	879	1062	518	310	707	59	372	226	524	166	90	62
2008	2962	2428	2548	2968	4291	3005	4431	3825	3956	2345	1492	953	964	303	939	145	369	430	62	166	130
2009	524	1053	857	1462	1762	2310	2399	2053	2331	2612	2974	2340	1667	1450	1426	438	329	288	159	78	113
2010	2271	1945	828	972	363	1513	913	901	1775	1373	1527	1892	2244	1869	2115	1699	1605	508	557	551	192
2011	736	968	736	705	813	759	401	830	518	479	661	745	1241	1120	1675	1199	1328	1035	1283	917	569
2012	945	598	837	297	935	697	818	559	794	468	757	425	726	575	605	621	1171	734	757	840	904
2013	3022	2257	1661	1544	974	1028	828	494	766	483	904	734	427	455	478	388	499	434	643	880	401
2014	2388	2071	1534	2045	1723	3054	1173	2385	983	958	605	1575	309	448	653	472	181	325	519	482	436

Table 7-4. Continued.

year/size (cm)	**55**	**56**	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70+**
1991	103	205	136	33	45	0	0	206	178	37	33	0	43	0	0	0
1992	613	222	228	384	288	282	0	0	68	123	0	35	0	0	0	37
1993	435	306	416	400	299	150	0	94	136	0	57	28	116	28	164	116
1994	679	118	454	376	595	146	185	527	190	299	35	88	0	0	52	123
1995	469	611	353	50	30	140	236	66	25	0	27	66	0	62	0	0
1996	332	212	418	331	103	159	143	32	174	189	150	0	65	0	0	148
1997	135	180	165	232	179	77	27	0	98	32	58	89	57	0	29	98
1998	90	288	328	168	140	239	153	75	184	148	135	86	131	0	0	288
1999	114	139	67	97	0	0	128	328	213	62	32	33	0	84	150	334
2000	179	174	307	29	228	57	49	82	0	43	167	271	57	58	229	612
2001	257	120	193	167	213	176	124	23	374	172	29	256	731	73	143	293
2002	105	209	469	82	337	78	112	0	166	0	0	161	247	164	75	175
2003	237	62	0	114	327	104	200	56	58	223	0	81	280	110	127	394
2004	188	46	179	53	82	0	46	66	169	53	169	47	102	28	18	582
2005	295	0	305	0	146	108	35	107	149	92	128	0	25	0	45	611
2006	54	55	29	27	28	144	123	29	27	0	53	0	103	28	84	110
2007	123	30	592	106	479	120	131	57	29	222	178	286	234	0	145	192
2008	167	59	62	73	0	31	148	78	28	102	92	0	86	0	165	297
2009	200	83	84	104	55	0	95	112	29	417	36	0	51	84	383	622
2010	125	29	64	60	61	165	30	29	58	124	41	187	0	32	101	929
2011	423	561	552	87	0	92	0	34	20	88	46	100	0	52	122	562
2012	412	417	225	52	49	0	74	34	0	28	25	84	29	118	24	398
2013	373	665	333	414	166	71	148	0	85	20	0	0	27	57	0	438
2014	227	563	369	623	464	83	96	193	0	0	56	26	0	0	0	425

Table 7-4. Bering Sea shelf survey male size composition estimates (1,000s of fish).

Male size composition estimates from the shelf surveys (1,000s of fish)

year/size (cm)	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
1991	75	217	160	15	168	0	28	267	291	670	253	117 5	277	759	777	976	204 4	269 0	224 4
1992	156	770	1094	1225	217	41	144	490	220	710	577	294	169	399	511	898	113 2	863	456
1993	98	934	790	1246	384	92	28	402	764	475	435	213	369	243	586	713	623	313	418
1994	28	314	86	179	369	164	389	212	403	875	101 3	100 8	125 9	925	159 5	102 5	142 0	119 3	107 0
1995	46	181	83	90	82	135	142	269	89	109	304	140	168	246	653	435	121 9	530	101 1
1996	75	64	61	269	92	100	61	133	131	356	260	410	186	188	96	335	328	391	265
1997	28	821	582	789	619	459	578	229	576	309	420	211	313	173	106	31	102	120	124
1998	168	591	470	628	582	166	330	459	385	662	875	118 0	111 4	558	500	530	393	535	528
1999	151	500	1716	732	954	58	134	333	300	596	156 6	122 4	801	615	407	945	767	144 1	106 1
2000	204	186	58	95	0	213	345	659	887	150 2	133 1	984	630	349	421	133 0	119 7	157 8	632
2001	70	23	36	183	59	169	137	279	207	550	693	521	157	473	105 1	162 7	174 5	157 4	940
2002	732	724	859	531	859	254	105	194	268	404	633	498	631	328	467	604	442	715	636
2003	32	202	470	640	972	872	673	858	1220	156 8	133 8	120 5	129 1	122 0	843	586	296	898	570
2004	967	280 8	4598	8840	9036	8040	5753	2798	1910	156 6	147 4	188 3	109 9	195 0	109 2	150 8	105 4	143 3	156 9
2005	6	145 8	1849	1846	2349	2219	3493	3751	2522	583 5	610 6	640 4	701 2	670 0	495 0	319 4	269 7	185 1	298 5
2006	111	302	364	694	1043	667	866	978	1549	216 1	446 2	513 2	556 2	859 0	734 9	582 8	743 3	806 1	657 3
2007	671	255 6	2003	1155	570	95	187	368	335	537	656	103 3	625	991	201 3	250 6	353 9	482 6	527 9
2008	314	689	964	704	890	1109	1470	1964	1414	862	493	392	692	881	826	124 7	118 8	108 3	165 4
2009	199	410	631	644	357	364	662	277	961	616	119 5	486	115 7	112 2	138 6	934	656	523	785
2010	166 8	496 9	4829	4354	2098	1877	3207	3932	2393	173 6	794	723	569	144 0	101 1	120 1	199 6	106 8	171 8
2011	385	512	1312	434	953	487	686	941	3030	180 8	266 9	203 5	162 1	163 7	205 9	750	509	485	711
2012	114 2	163 5	1831	2085	1452	1001	1644	1775	2176	181 9	175 3	226 9	208 6	324 4	267 2	297 0	202 1	182 8	138 3
2013	340	772	663	408	306	372	489	1265	1688	243 4	322 4	290 3	254 2	214 4	205 2	293 3	211 4	304 7	315 0
2014	130 3	142 8	1756	1738	1300	1000	1043	975	1529	138 0	142 3	176 3	152 8	197 9	283 5	513 1	443 0	507 4	378 5

Table 7-4. Continued.

year/size (cm)	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
1991	2676	3162	1969	2161	1788	1714	718	661	889	1258	301	778	513	389	156	414	268	177	115	92	0
1992	1177	2682	1988	1676	1836	2425	1827	1696	1627	1491	938	2131	456	831	820	478	1001	904	79	108	87
1993	367	841	1156	1130	1031	985	1899	1817	1530	1428	1147	1171	1260	600	579	437	246	548	67	260	175
1994	589	291	507	589	1294	704	1373	1508	1889	1599	1117	1395	2074	1974	866	1186	688	879	167	597	259
1995	855	768	924	550	246	392	235	252	458	709	407	254	902	865	630	633	618	840	1068	326	297
1996	119	406	451	441	846	571	741	771	628	466	535	273	632	244	487	504	457	591	210	169	0
1997	198	86	60	222	204	309	962	415	791	831	592	517	703	360	388	476	214	170	156	83	115

1998	608	170	102	120	216	261	305	359	612	510	365	801	486	291	410	213	534	337	258	155	287
1999	441	406	226	140	264	124	203	47	250	80	149	260	390	466	122	340	239	0	213	181	56
2000	795	343	1100	695	847	704	490	664	214	387	204	185	181	203	259	221	192	68	51	120	233
2001	521	1418	906	1411	818	1272	908	1213	833	574	532	436	340	270	130	82	310	282	168	208	174
2002	869	790	1039	1255	431	277	606	589	525	563	206	282	468	308	602	16	301	199	109	0	420
2003	1016	465	527	592	1085	801	854	807	760	586	570	669	446	252	337	202	240	337	100	226	341
2004	1089	756	478	735	343	439	457	218	242	310	334	335	278	239	389	138	272	53	27	189	63
2005	2264	1736	1205	973	818	696	157	536	186	132	296	237	69	165	130	213	121	28	274	0	97
2006	6496	5580	4950	2522	1745	1192	1297	708	877	440	438	173	420	111	195	191	56	240	75	226	28
2007	5668	4680	6341	5592	4836	3292	3396	652	1550	351	632	661	131	389	64	240	133	519	36	176	0
2008	3380	4088	4862	3586	4822	4049	4799	3247	3200	1230	1307	1016	1059	116	544	132	189	129	153	341	156
2009	557	577	1152	2148	1405	1820	1549	2505	2335	2633	1659	1147	911	720	451	150	226	0	51	56	0
2010	1558	1183	1110	641	824	498	1063	1597	2493	2714	2839	2082	2469	717	1362	344	329	120	212	20	0
2011	626	1320	1232	1047	529	840	798	575	653	820	1138	1209	1817	1288	1426	894	464	138	144	181	65
2012	953	1278	1122	593	1223	795	1040	253	701	454	951	479	1091	520	779	687	467	233	123	185	125
2013	3567	2246	2071	1544	1088	522	650	851	662	815	510	890	455	702	348	481	447	203	196	80	46
2014	3081	2679	1737	1810	2367	2262	2163	1581	550	771	421	1677	348	633	196	936	787	153	583	126	78

Table 7-4. Continued.

year/size (cm)	**55**	**56**	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70+**
1991	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	94	0	123	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	24	24	0	24	0	0	0	0	0	0	0	0	0	0	0	0
1994	106	52	283	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	177	80	210	68	0	0	133	0	0	0	0	0	0	0	0	0
1996	30	42	89	30	90	90	38	0	0	0	0	0	0	0	0	0
1997	20	102	0	29	0	0	0	0	0	0	102	0	0	0	0	0
1998	51	28	37	0	74	0	64	0	0	0	0	0	0	0	0	27.016
1999	93	0	0	64	0	28	0	0	0	0	0	0	0	0	0	0
2000	208	17	21	0	0	26	0	26	0	0	0	0	0	0	0	0
2001	338	0	42	69	27	0	0	27	0	0	0	0	0	0	0	0
2002	256	76	0	27	0	0	0	0	0	0	0	0	0	0	0	0
2003	195	114	157	130	41	32	29	0	0	0	0	0	0	0	0	0
2004	75	239	76	20	0	0	0	0	0	0	0	0	0	0	0	0
2005	325	25	0	0	65	159	0	0	0	0	0	0	0	0	0	0
2006	56	27	47	0	75	0	19	28	0	0	0	0	0	0	0	0
2007	57	118	85	28	0	50	36	0	0	0	0	0	0	0	0	0
2008	29	256	29	109	0	35	0	0	0	0	0	0	0	0	0	0
2009	84	55	0	0	134	0	55	0	0	0	0	0	0	0	0	0
2010	78	69	103	99	0	0	0	0	0	0	0	0	0	0	0	0

2011	117	79	80	103	0	32	0	0	0	0	0	0	0	0	0	0
2012	182	127	0	114	0	0	55	0	0	0	0	0	0	0	0	0
2013	0	28	175	0	67	0	51	0	0	0	0	0	0	0	0	0
2014	96	154	299	58	88	56	0	28	0	161	0	30	0	0	0	0

Table 7-5. Bering Sea slope survey female size composition estimates (1,000s of fish).

year/size (cm)	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
2002	0	0	0	0	0	0	0	0	0	5	0	0	0	6	19	37	35	12	83	78
2004	5	0	9	4	3	12	15	5	29	30	36	45	34	35	30	80	48	68	60	64
2008	0	8	0	0	0	4	0	4	0	4	0	15	13	71	102	118	199	216	202	412
2010	0	0	0	5	0	4	4	0	0	0	4	11	0	21	21	14	21	54	40	144
2012	0	0	10	0	0	7	24	0	15	38	11	5	5	0	0	8	4	39	29	5

Table 7-5. Continued.

year/size (cm)	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
2002	78	105	111	194	196	152	213	122	152	145	81	58	58	172	158	141	120	153	196	199
2004	47	55	69	93	92	75	83	73	103	100	80	68	97	124	100	103	91	68	78	77
2008	454	497	473	337	307	284	279	191	189	191	145	194	118	144	154	98	169	127	178	94
2010	168	249	314	395	428	790	698	846	598	461	498	393	352	310	313	152	178	213	117	170
2012	16	0	55	93	0	16	32	66	64	140	59	294	32	64	122	209	70	79	18	23

Table 7-5. Continued.

year/size (cm)	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
2002	163	164	153	155	201	159	145	177	98	159	96	156	91	67	59	39	26	52	38	12
2004	74	64	66	92	88	102	81	106	79	56	70	43	54	55	50	40	49	33	23	47
2008	122	92	110	65	97	126	79	130	107	103	124	90	74	72	63	61	69	28	52	16
2010	118	92	95	118	58	90	81	103	67	104	82	34	52	31	59	51	48	57	33	34
2012	22	10	12	19	10	9	4	13	0	45	9	0	9	33	14	11	0	0	0	4

Table 7-5. Bering Sea slope survey male size composition estimates (1,000s of fish).

year/size (cm)	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
2002	0	0	0	0	0	0	0	0	0	0	0	0	6	38	42	68	51	77	186	169
2004	4	0	3	16	12	33	21	58	72	109	120	114	85	138	135	181	228	144	112	92
2008	4	0	0	0	0	0	4	0	16	25	31	68	115	220	314	333	641	619	767	1001
2010	6	0	0	4	4	0	5	16	10	20	18	57	36	64	58	87	130	190	214	390
2012	0	0	5	0	14	20	5	0	39	52	41	26	31	5	26	76	0	221	21	31

Table 7-5. Continued.

year/size (cm)	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
2002	269	295	285	230	216	155	133	125	299	222	246	350	290	305	323	238	143	174	78	72
2004	158	229	196	229	217	270	224	372	363	352	403	278	318	283	267	231	164	101	81	87
2008	1171	1100	767	506	539	451	537	342	473	487	524	384	468	234	285	198	220	211	119	87
2010	576	805	1130	1058	1182	1083	817	679	479	539	330	339	283	291	224	319	195	257	130	123
2012	10	14	39	94	0	49	139	78	92	85	9	46	18	9	16	158	27	37	26	0

Table 7-5. Continued.

year/size (cm)	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
2002	66	27	0	12	21	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0
2004	28	27	7	8	3	6	4	3	0	0	3	0	0	0	0	5	0	0	0	0
2008	59	62	30	7	13	4	0	0	0	0	0	4	4	4	0	0	0	0	0	0
2010	101	75	39	18	9	12	19	5	0	0	0	0	0	0	0	0	0	0	0	0
2012	13	10	4	0	0	0	4	7	0	0	0	0	0	0	0	0	0	0	0	0

Table 7-6. Aleutian Islands survey female size composition estimates (1,000s of fish).

Female size composition estimates from the Aleutian Islands surveys (1,000s of fish)

year/size (cm)	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
1991	17	75	242	330	393	308	436	576	628	363	430	325	511	581	631	603	746	719	662
1994	18	111	287	330	530	539	619	616	652	803	627	809	653	766	890	895	1025	1098	1137
1997	157	295	630	868	1068	1099	924	1177	986	963	1033	1093	1523	2045	1550	2611	1530	1477	1855
2000	112	273	608	1229	1821	1281	1140	1199	1362	1203	2140	2515	2166	3029	2782	2198	2004	2220	1464
2002	41	162	483	728	833	1067	681	1476	1672	2264	2482	2570	2140	2201	2213	2059	2282	2847	2698
2004	254	258	264	854	907	924	791	789	973	1072	1367	1166	1264	1670	1661	1700	1825	2124	1910
2006	40	159	182	658	1045	1340	1037	972	847	1416	1146	1716	1558	1442	1298	1542	1117	1308	1615
2010	34	96	320	673	714	745	716	920	959	1044	1015	1057	1499	1441	1494	1582	1619	1417	1786
2012	8	14	71	92	116	138	95	198	118	180	177	300	278	259	182	319	298	230	224
2014	256	500	634	1123	1546	1464	1321	1333	1127	1258	1495	1484	1688	1777	1812	2032	1856	1710	2054

Table 7-6. Continued.

year/size (cm)	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
1991	724	767	830	773	890	918	847	784	503	527	452	605	398	584	390	498	551	406	262	250	245
1994	1163	1327	1296	1255	1228	1358	1331	1567	1452	1365	1528	1414	1763	1492	1676	1154	1170	1220	1216	1195	980

1997	1707	1508	1496	1200	1383	1321	1395	1296	1340	1384	1583	1579	1661	1356	1348	1084	1060	1545	1312	1121	1358
2000	1822	1234	1479	1182	1618	1675	1383	1860	1424	1342	1516	1155	979	1055	962	702	771	916	821	1087	804
2002	2777	2356	2430	1944	2464	1900	1945	2152	1587	1587	1607	1586	1558	1265	1478	1183	1415	1014	1287	1072	1240
2004	1866	1790	2105	2266	2327	2784	2267	2773	2317	2070	2371	2140	2120	1634	1505	1532	1334	1384	1157	1528	1444
2006	1476	1512	1631	1875	2046	2791	2248	2263	2132	2595	2491	3067	3492	2900	3421	4398	5088	3884	3293	3524	2920
2010	1650	2091	1801	1808	1591	1807	1618	1640	1322	1280	1007	1242	754	974	1293	1160	1494	1355	1500	1502	1579
2012	261	227	189	237	141	146	119	170	89	96	62	82	49	105	36	74	89	87	139	87	110
2014	1778	1528	1628	1588	1365	1565	1286	1368	1193	1456	1347	1288	1332	1431	1345	995	1203	1116	1386	1382	1710

Table 7-6. Continued.

year/size (cm)	**55**	**56**	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70+**
1991	120	198	194	168	167	160	187	193	129	171	175	154	72	102	80	1239
1994	1066	1018	1029	1095	1211	1038	992	1108	603	605	577	500	416	360	238	1844
1997	1500	1284	1002	1149	973	1024	936	833	914	780	766	515	543	640	445	2384
2000	1157	1025	1006	708	876	807	567	616	566	634	487	450	398	369	338	3726
2002	1333	1180	1526	1341	1221	1512	930	1102	1218	1228	1334	1017	956	982	1149	5780
2004	1198	1142	1496	1041	1518	1286	1198	1131	775	937	787	800	787	660	493	4314
2006	3558	3470	3384	4034	2788	3106	3064	3064	3245	2451	2740	1590	1796	1288	1005	5896
2010	1094	1374	914	844	690	982	769	752	707	677	420	756	527	554	415	4188
2012	153	108	158	72	174	120	36	92	79	82	113	61	54	88	74	1416
2014	1309	1326	1441	2032	1770	2063	1554	2085	1691	2053	1930	1946	1634	1861	1503	14208

Table 7-6. Aleutian Islands survey male size composition estimates (1,000s of fish).

year/size (cm)	Male size composition estimates from the Aleutian Islands surveys (1,000s of fish)																		
	15	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
1991	95	115	182	237	207	336	298	297	312	188	346	561	508	422	640	585	109 2	785	109 7
1994	82	181	357	548	423	533	493	477	428	464	527	468	488	737	824	101 0	119 7	119 5	124 7
1997	20 5	589	792	894	1045	1120	907	536	893	123 1	113 0	163 3	162 5	134 4	129 5	127 9	141 9	135 8	166 5
2000	16 5	302	467	1454	1345	1090	1107	910	1015	137 7	185 3	202 2	234 6	257 5	224 4	258 1	241 3	185 3	182 4
2002	91	316	617	626	535	516	675	612	999	143 2	183 6	147 5	134 4	107 1	176 1	186 9	221 1	176 0	152 3
2004	73	205	510	880	1171	630	851	838	790	889	969	110 5	114 2	132 1	138 9	136 8	172 2	166 9	122 6
2006	96	379	738	995	958	658	623	911	1018	112 0	127 8	125 5	147 7	144 1	115 0	138 9	891	108 0	995
2010	22	165	249	893	882	1185	867	754	705	727	106 7	131 7	159 0	183 1	183 0	227 1	230 2	248 1	268 1
2012	13	20	3	58	144	153	161	170	226	260	183	194	168	327	473	402	430	338	321
2014	37 9	640	957	1758	1726	2050	1567	1514	1507	169 7	157 6	177 0	225 7	252 6	279 3	306 9	309 8	260 2	248 9

Table 7-6. Continued.

year/size (cm)	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
1991	1054	1021	731	928	837	577	731	401	436	304	346	369	159	235	133	184	157	204	186	154	175
1994	1350	1165	1560	1524	1419	1429	1751	1799	1611	1492	1966	1575	1138	1177	1066	871	987	723	1024	1174	1513
1997	1136	1248	934	1341	1134	1293	1299	1250	1676	1389	1975	1790	1728	1549	1217	1378	953	819	827	636	872
2000	1967	1664	1729	1850	1987	1489	1190	1010	1179	1013	926	1302	1551	1298	1354	893	802	608	609	635	463
2002	1308	1463	1800	1832	1560	1617	1415	1464	1173	1767	1912	1704	1635	1186	1172	1229	1233	1043	855	667	447
2004	1180	1332	1432	1404	1578	1464	1453	1559	1849	1506	1508	1680	1150	1208	1311	1182	1128	1092	806	684	773
2006	1223	1219	1218	1490	1069	1374	1858	2562	3559	3416	3518	3212	2615	2952	2233	1913	1230	1416	1340	738	1092
2010	2051	3100	2751	2615	2442	1974	2010	3485	2277	2516	2244	2400	2041	1448	1083	1081	818	718	749	618	869
2012	341	370	350	309	362	231	177	115	161	130	128	101	181	175	227	276	272	404	278	171	247
2014	2447	2525	2407	2855	2463	2324	2539	2655	2629	2729	2561	3010	2570	2905	3006	3490	3642	4016	4272	4063	5569

Table 7-6. Continued.

year/size (cm)	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70+
1991	100	169	122	183	111	145	71	83	94	43	7	4	15	4	0	5
1994	1488	1278	1745	1030	1037	729	703	552	327	122	51	96	3	11	0	14
1997	908	873	699	788	675	789	563	402	251	225	175	78	30	14	16	4
2000	579	467	601	566	586	626	536	395	372	200	242	86	23	69	65	338
2002	416	416	438	336	462	451	451	473	384	501	498	132	157	101	55	521
2004	875	726	790	757	917	797	1009	660	672	423	282	186	126	81	85	323
2006	750	597	804	818	882	834	794	614	728	524	515	198	210	116	105	951
2010	498	816	1052	1109	911	1179	1554	1354	1031	974	552	540	216	302	51	491
2012	471	453	298	293	537	572	563	804	599	774	521	359	259	226	109	31
2014	5307	5252	6169	5641	6177	6546	6501	5541	4950	4324	2840	1932	1152	868	547	163

Table 7.7. Estimated maturity at age for female Kamchatka flounder (Stark 2011).

age	proportion mature
2	0.00
3	0.01
4	0.01
5	0.02
6	0.05
7	0.10
8	0.18
9	0.31
10	0.48
11	0.66
12	0.80
13	0.89
14	0.94
15	0.97
16	0.99
17	0.99
18	1.00
19	1.00
20	1.00
21	1.00
22	1.00
23	1.00
24	1.00
25	1.00

Table 7-8. Key equations used in the population dynamics model.

$N_{t,1} = R_t = R_0 e^{\tau},\ \tau_t \sim N\left(0, \delta_R^2\right)$	Recruitment t=1969-1990
$N_{t,1} = R_t = R_y e^{\tau},\ \tau_t \sim N\left(0, \delta_R^2\right)$	Recruitment t=1991-2012
$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}\left(1 - e^{-z_{t,a}}\right)N_{t,a}$	Catch in year t for age a fish
$N_{t+1,a+1} = N_{t,a}e^{-z_{t,a}}$	Numbers of fish in year $t+1$ at age a
$N_{t+1,A} = N_{t,A-1}e^{-z_{t,A-1}} + N_{t,A}e^{-z_{t,A}}$	Numbers of fish in the "plus group"
$S_t = \sum N_{t,a}W_{t,a}\phi_a$	Spawning biomass
$Z_{t,a} = F_{t,a} + M$	Total mortality in year t at age a
$F_{t,a} = s_a \mu^F \exp^{\varepsilon^F{}_t},\ \varepsilon^F{}_t \sim N(o, \sigma^{2}{}_F)$	Fishing mortality
$s_a = \frac{1}{1 + \left(e^{-\alpha+\beta a}\right)}$	Age-specific fishing selectivity
$C_t = \sum C_{t,a}$	Total catch in numbers
$P_{t,a} = {}^{C_{t,a}}\!/_{C_t}$	Proportion at age in catch
$SurB_t = q\sum N_{t,a}W_{t,a}v_a$	Survey biomass
$reclike = \lambda(\sum_{i=1965}^{endyear} \bar{R} - R_i)^2 + \sum_{a=1}^{20}(\bar{R}_{init} - R_{init,a})^2$	Recruitment likelihood
$catchlike = \lambda \sum_{i=startyear}^{endyear}(\ln C_{obs,i} - \ln C_{est,i})^2$	catch likelihood
$surveylike = \lambda \frac{(\ln B - \ln \hat{B})^2}{2\sigma^2}$	survey biomass likelihood
$SurvAgelike = \sum_{t,a} n_t P_{t,a}(\ln \hat{P}_{t,a} + 0.001) - \sum_{t,a} n_t P_{t,a}(\ln P_{t,a} + 0.001)$	survey age comp likelihood
$SurvLengthlike = \sum_{t,a} n_t P_{t,a}(\ln \hat{P}_{t,a} + 0.001) - \sum_{t,a} n_t P_{t,a}(\ln P_{t,a} + 0.001)$	survey length comp likelihood

Table 7-9. Variables used in the population dynamics model.

Variables	
R_t	Age 1 recruitment in year *t*
R_0	Geometric mean value of age 1 recruitment, 1956-75
R_γ	Geometric mean value of age 1 recruitment, 1976-96
τ_t	Recruitment deviation in year *t*
$N_{t,a}$	Number of fish in year *t* at age *a*
$C_{t,a}$	Catch numbers of fish in year *t* at age *a*
$P_{t,a}$	Proportion of the numbers of fish age *a* in year *t*
C_t	Total catch numbers in year *t*
$W_{t,a}$	Mean body weight (kg) of fish age *a* in year *t*
ϕ_a	Proportion of mature females at age *a*
$F_{t,a}$	Instantaneous annual fishing mortality of age *a* fish in year *t*
M	Instantaneous natural mortality, assumed constant over all ages and years
$Z_{t,a}$	Instantaneous total mortality for age *a* fish in year *t*
s_a	Age-specific fishing gear selectivity
μ^F	Median year-effect of fishing mortality
ε_t^F	The residual year-effect of fishing mortality
ν_a	Age-specific survey selectivity
α	Slope parameter in the logistic selectivity equation
β	Age at 50% selectivity parameter in the logistic selectivity equation
σ_t	Standard error of the survey biomass in year *t*

Table 7.10. Estimated total biomass (ages 2+), female spawning biomass, and recruitment (age 2 fish).

	Female Spawning Biomass (t)	Total Biomass (t)	age 2 recruitment (millions)
1991	25247	83104	10520
1992	27250	88453	15409
1993	30229	94444	9544
1994	33837	99688	6321
1995	37720	103522	9084
1996	41966	107236	14319
1997	45603	110107	22896
1998	48724	113289	19883
1999	50786	116043	21335
2000	52407	119182	12098
2001	53381	122114	16446
2002	53968	125530	31616
2003	54603	130434	45514
2004	55375	137636	69248
2005	56312	145365	23169
2006	57907	154235	13387
2007	59888	163393	18470
2008	62347	172417	20075
2009	62963	174841	22787
2010	61932	171790	63762
2011	57908	159940	36877
2012	58644	160983	54133
2013	59266	162905	19155
2014	59990	167803	44664
2015	60083	174500	

Table 7.11. Estimated numbers at age (thousands) from the stock assessment model for ages 2-24.

	females												
	2	3	4	5	6	7	8	9	10	11	12	13	14
1991	5260	4722	5868	10639	10365	5697	3664	3098	2881	761	2163	1489	742
1992	7705	4705	4213	5210	9373	9060	4954	3178	2684	2496	659	1873	1289
1993	4772	6897	4208	3760	4635	8311	8016	4379	2807	2371	2204	582	1655
1994	3161	4273	6171	3758	3349	4117	7369	7101	3877	2486	2099	1951	515
1995	4542	2829	3820	5503	3338	2964	3633	6495	6256	3415	2189	1849	1719
1996	7160	4067	2531	3413	4905	2969	2631	3223	5761	5548	3029	1941	1640
1997	11448	6409	3637	2258	3034	4345	2623	2322	2844	5081	4893	2671	1712
1998	9941	10251	5735	3249	2013	2697	3857	2327	2059	2521	4504	4338	2368
1999	10668	8899	9166	5116	2888	1783	2384	3404	2053	1816	2224	3973	3826
2000	6049	9552	7963	8189	4560	2568	1583	2114	3018	1820	1610	1971	3522
2001	8223	5416	8544	7109	7290	4047	2275	1401	1870	2670	1610	1424	1744
2002	15808	7362	4844	7627	6327	6468	3583	2012	1238	1653	2360	1423	1259
2003	22757	14155	6587	4327	6797	5624	5740	3178	1784	1098	1466	2092	1261
2004	34624	20375	12663	5883	3854	6038	4988	5086	2815	1580	972	1298	1852
2005	11585	30995	18220	11298	5230	3414	5336	4403	4487	2483	1393	857	1145
2006	6694	10373	27729	16273	10063	4646	3028	4728	3899	3974	2199	1234	759
2007	9235	5993	9280	24771	14501	8945	4123	2685	4191	3456	3522	1949	1094
2008	10038	8270	5364	8294	22094	12907	7951	3662	2384	3721	3069	3127	1730
2009	11394	8972	7367	4745	7256	19114	11084	6804	3130	2036	3177	2620	2670
2010	31881	10166	7956	6449	4070	6099	15851	9133	5591	2569	1671	2607	2150
2011	18438	28361	8948	6848	5361	3266	4782	12290	7048	4308	1978	1286	2006
2012	27067	16459	25181	7855	5907	4542	2735	3982	10209	5850	3574	1641	1067
2013	9577	24165	14620	22127	6787	5017	3815	2285	3318	8501	4870	2975	1366
2014	22332	8556	21498	12892	19245	5821	4264	3228	1930	2801	7174	4109	2510

Table 7.11. (continued).

	Females										
	15	16	17	18	19	20	21	22	23	24	25
1991	547	445	389	336	303	282	272	263	263	264	585
1992	643	474	385	337	291	262	244	236	228	228	735
1993	1139	568	419	340	298	257	232	216	208	201	851
1994	1465	1008	503	371	301	264	227	205	191	184	931
1995	454	1290	888	443	326	265	232	200	181	168	982
1996	1524	403	1144	787	392	290	235	206	178	160	1020
1997	1446	1344	355	1009	694	346	255	208	182	157	1041
1998	1518	1282	1192	315	895	616	307	226	184	161	1062
1999	2089	1339	1131	1051	278	789	543	271	200	162	1079
2000	3392	1851	1187	1002	932	246	699	481	240	177	1100
2001	3115	3000	1638	1050	887	824	218	619	426	212	1129
2002	1541	2754	2652	1448	928	784	728	192	547	376	1186
2003	1116	1366	2441	2350	1283	822	695	646	171	485	1385
2004	1117	988	1210	2161	2081	1136	728	615	572	151	1655
2005	1634	985	872	1067	1906	1836	1002	642	543	504	1593
2006	1014	1447	872	772	945	1688	1626	887	569	480	1857
2007	673	898	1282	773	684	837	1496	1441	786	504	2072
2008	971	597	798	1139	686	607	744	1328	1279	698	2287
2009	1477	829	510	681	972	586	518	635	1134	1092	2549
2010	2190	1212	680	418	559	797	481	425	521	930	2987
2011	1654	1686	933	523	322	430	614	370	327	401	3015
2012	1664	1372	1398	774	434	267	357	509	307	272	2833
2013	888	1385	1142	1164	644	361	222	297	424	255	2584
2014	1152	749	1169	964	982	543	305	188	250	357	2396

Table 7.11. (continued).

Males

	2	3	4	5	6	7	8	9	10	11	12	13	14
1991	5260	4722	5868	10639	10365	5697	3664	3098	2881	761	2163	1489	742
1992	7705	4710	4224	5238	9453	9141	4984	3187	2688	2497	659	1874	1289
1993	4772	6900	4217	3778	4676	8413	8108	4410	2817	2374	2205	582	1655
1994	3161	4274	6179	3773	3375	4167	7475	7189	3907	2495	2102	1953	516
1995	4542	2831	3826	5525	3366	3000	3688	6599	6338	3442	2197	1852	1720
1996	7160	4068	2535	3424	4938	3001	2668	3275	5855	5621	3053	1949	1642
1997	11448	6412	3642	2267	3056	4391	2659	2358	2891	5165	4958	2693	1719
1998	9941	10254	5742	3259	2026	2724	3905	2361	2092	2563	4579	4396	2387
1999	10668	8904	9180	5135	2909	1802	2414	3452	2084	1846	2261	4039	3877
2000	6049	9555	7973	8215	4589	2593	1602	2143	3062	1848	1636	2005	3581
2001	8223	5418	8555	7133	7336	4087	2302	1420	1897	2709	1635	1447	1773
2002	15808	7365	4851	7653	6369	6532	3627	2039	1256	1677	2395	1445	1279
2003	22757	14159	6595	4341	6838	5678	5808	3219	1808	1113	1487	2122	1281
2004	34624	20383	12678	5901	3878	6093	5045	5151	2853	1602	986	1316	1879
2005	11585	31010	18248	11339	5266	3449	5400	4459	4547	2517	1413	870	1161
2006	6694	10376	27767	16327	10130	4693	3064	4789	3951	4027	2229	1251	770
2007	9235	5995	9291	24846	14589	9030	4172	2720	4247	3503	3570	1975	1109
2008	10038	8272	5369	8316	22211	13015	8039	3709	2416	3771	3110	3170	1754
2009	11394	8985	7395	4786	7364	19459	11273	6908	3175	2065	3221	2656	2706
2010	31881	10193	8020	6565	4197	6333	16390	9359	5695	2609	1695	2643	2179
2011	18438	28493	9074	7072	5670	3505	5101	12876	7263	4396	2011	1305	2035
2012	27067	16498	25444	8064	6219	4901	2975	4275	10725	6034	3649	1668	1083
2013	9577	24220	14735	22619	7097	5384	4170	2501	3573	8941	5025	3038	1389
2014	22332	8572	21643	13117	19973	6184	4625	3547	2117	3018	7547	4240	2563

Table 7.11. (continued).

Males

	15	16	17	18	19	20	21	22	23	24	25
1991	547	445	389	336	303	282	272	263	263	264	585
1992	643	474	385	337	291	262	244	236	228	228	735
1993	1139	568	419	340	298	257	232	216	208	201	851
1994	1465	1008	503	371	301	264	227	205	191	184	931
1995	454	1290	888	443	327	265	232	200	181	168	982
1996	1525	403	1144	787	392	290	235	206	178	160	1020
1997	1448	1345	355	1009	695	346	255	208	182	157	1041
1998	1524	1284	1192	315	895	616	307	226	184	161	1062
1999	2105	1344	1132	1052	278	789	543	271	200	162	1079
2000	3437	1866	1191	1004	932	246	699	481	240	177	1100
2001	3167	3040	1651	1054	888	825	218	619	426	212	1129
2002	1567	2800	2687	1459	931	785	729	192	547	376	1186
2003	1134	1389	2481	2382	1293	826	696	646	171	485	1385
2004	1134	1004	1230	2197	2109	1145	731	616	572	151	1655
2005	1658	1000	886	1085	1938	1860	1010	645	543	505	1593
2006	1028	1468	886	784	961	1716	1647	894	571	481	1858
2007	682	911	1301	785	695	851	1521	1460	793	506	2073
2008	985	606	809	1155	697	617	756	1350	1296	704	2290
2009	1498	841	517	691	986	595	527	645	1153	1107	2556
2010	2220	1229	690	424	567	809	488	432	530	946	3005
2011	1677	1709	946	531	327	436	623	376	333	408	3040
2012	1688	1391	1417	784	440	271	362	516	312	276	2860
2013	901	1405	1158	1180	653	366	226	301	430	259	2610
2014	1172	760	1185	977	995	551	309	190	254	363	2421

Table 7.12. Estimate of the spawning biomass at age (t) from the stock assessment model.

	2	3	4	5	6	7	8	9	10	11	12	13	14
1991	1	3	12	76	223	335	532	986	1737	744	2985	2615	1551
1992	1	3	9	37	202	533	720	1011	1618	2440	910	3290	2694
1993	1	4	9	27	100	489	1165	1393	1692	2318	3041	1022	3457
1994	0	2	13	27	72	242	1070	2259	2337	2430	2897	3427	1077
1995	1	2	8	39	72	174	528	2066	3771	3339	3021	3247	3591
1996	1	2	5	24	106	175	382	1025	3473	5424	4179	3410	3425
1997	1	3	8	16	65	256	381	739	1714	4968	6752	4691	3577
1998	1	6	12	23	43	159	560	740	1241	2465	6215	7618	4947
1999	1	5	19	37	62	105	346	1083	1237	1776	3068	6978	7993
2000	1	5	17	59	98	151	230	673	1819	1779	2222	3462	7359

2001	1	3	18	51	157	238	330	446	1128	2610	2221	2501	3643
2002	2	4	10	55	136	381	521	640	747	1617	3257	2499	2630
2003	3	8	14	31	147	331	834	1011	1075	1073	2022	3674	2635
2004	4	11	27	42	83	355	725	1618	1697	1544	1341	2279	3870
2005	1	17	39	81	113	201	775	1401	2705	2427	1923	1506	2392
2006	1	6	59	116	217	273	440	1504	2351	3885	3034	2167	1586
2007	1	3	20	177	313	526	599	854	2526	3379	4860	3422	2285
2008	1	4	11	59	476	760	1155	1165	1437	3638	4234	5492	3615
2009	1	5	16	34	156	1125	1610	2165	1887	1991	4384	4602	5578
2010	4	5	17	46	88	359	2303	2905	3371	2512	2306	4579	4491
2011	2	15	19	49	116	192	695	3910	4249	4211	2729	2259	4192
2012	3	9	53	56	127	267	397	1267	6154	5719	4931	2882	2229
2013	1	13	31	158	146	295	554	727	2000	8311	6719	5225	2853
2014	3	5	46	92	415	343	619	1027	1163	2738	9898	7216	5244

Table 7.12. (continued).

	15	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
1991	1305	1179	1126	1047	1009	997	1013	1026	1070	1118	2558
1992	1532	1255	1114	1051	969	926	910	919	927	962	3217
1993	2714	1503	1211	1062	992	907	862	842	847	850	3721
1994	3491	2670	1453	1156	1004	931	846	800	778	779	4074
1995	1082	3416	2567	1380	1088	938	864	781	735	711	4298
1996	3632	1066	3308	2455	1307	1023	876	803	723	677	4464
1997	3446	3559	1026	3146	2314	1223	951	810	739	662	4555
1998	3617	3394	3445	981	2980	2175	1142	883	749	681	4645
1999	4977	3545	3269	3277	925	2787	2021	1056	813	686	4718
2000	8083	4902	3431	3125	3104	869	2604	1878	976	748	4812
2001	7424	7943	4734	3273	2953	2911	810	2414	1733	897	4941
2002	3673	7291	7666	4513	3091	2768	2712	751	2226	1591	5189
2003	2659	3617	7056	7328	4274	2905	2586	2519	694	2049	6058
2004	2661	2616	3497	6739	6933	4014	2711	2400	2327	638	7242
2005	3894	2608	2520	3327	6351	6485	3730	2507	2208	2132	6971
2006	2416	3831	2522	2406	3148	5963	6051	3462	2315	2031	8126
2007	1604	2379	3707	2410	2279	2958	5569	5622	3201	2131	9065
2008	2314	1582	2306	3550	2287	2145	2768	5183	5206	2952	10007
2009	3520	2195	1475	2123	3238	2070	1930	2477	4616	4617	11151
2010	5220	3209	1966	1305	1861	2817	1790	1660	2119	3933	13068
2011	3942	4463	2696	1632	1073	1519	2285	1444	1332	1694	13190
2012	3966	3633	4042	2412	1446	944	1328	1986	1249	1148	12395
2013	2116	3668	3302	3629	2145	1277	828	1158	1724	1080	11306
2014	2746	1983	3379	3005	3271	1919	1135	732	1019	1511	10481

Table 7.13. Projections of spawning biomass (1,000s t), catch (1,000s t), and fishing mortality rate for each of the seven scenarios. The value of $B_{40\%}$ and $B_{35\%}$ are 53,000 t and 46,400 t, respectively.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	FSB	catch	F
2014	59212	6220	0.047
2015	60083	**8998**	0.065
2016	59968	9302	0.065
2017	60440	9568	0.065
2018	61750	9771	0.065
2019	63673	9907	0.065
2020	65700	9972	0.065
2021	67379	9978	0.065
2022	68520	9944	0.065
2023	69105	9885	0.065
2024	69208	9810	0.065
2025	68934	9723	0.065
2026	68401	9630	0.065
2027	67711	9534	0.065

Scenario 3
1/2 maximum ABC harvest

Year	FSB	catch	F
2014	59212	6220	0.047
2015	60248	**4500**	0.032
2016	62116	5051	0.034
2017	64539	5336	0.034
2018	67932	5589	0.034
2019	72106	5803	0.034
2020	76509	5975	0.034
2021	80587	6107	0.034
2022	84048	6207	0.034
2023	86798	6282	0.034
2024	88869	6337	0.034
2025	90340	6375	0.034
2026	91323	6398	0.034
2027	91929	6409	0.034

Scenario 4
Harvest at avg F over the past five years

Year	**FSB**	**catch**	**F**
2014	59212	6220	0.047
2015	60083	8998	0.065
2016	59944	9980	0.070
2017	60124	10220	0.070
2018	61134	10393	0.070
2019	62742	10495	0.070
2020	64444	10525	0.070
2021	65800	10494	0.070
2022	66632	10424	0.070
2023	66934	10331	0.070
2024	66786	10225	0.070
2025	66296	10111	0.070
2026	65581	9993	0.070
2027	64740	9876	0.070

Scenario 5
No fishing

Year	**FSB**	**catch**	**F**
2014	59212	6220	0.05
2015	60408	0	0
2016	64295	0	0
2017	69044	0	0
2018	75065	0	0
2019	82233	0	0
2020	89964	0	0
2021	97586	0	0
2022	104671	0	0
2023	111008	0	0
2024	116546	0	0
2025	121297	0	0
2026	125333	0	0
2027	128745	0	0

Table 7.13. (continued).

Scenario 6

Determination of overfishing

Year	FSB	catch	F
2014	59212	6220	0.047
2015	60028	10489	**0.076**
2016	59255	10739	0.076
2017	59074	10942	0.076
2018	59713	11074	0.076
2019	60937	11133	0.076
2020	62253	11118	0.076
2021	63239	11043	0.076
2022	63735	10931	0.076
2023	63744	10801	0.076
2024	63348	10660	0.076
2025	62654	10515	0.076
2026	61778	10370	0.076
2027	60815	10213	0.076

Scenario 7

Determination of approaching overfishing

Year	FSB	catch	F
2014	59212	6220	0.047
2015	60084	8995	0.065
2016	59969	9302	0.065
2017	60385	11157	0.076
2018	61015	11278	0.076
2019	62230	11323	0.076
2020	63523	11293	0.076
2021	64464	11201	0.076
2022	64892	11074	0.076
2023	64814	10927	0.076
2024	64321	10771	0.076
2025	63526	10613	0.076
2026	62550	10456	0.076
2027	61491	10295	0.076

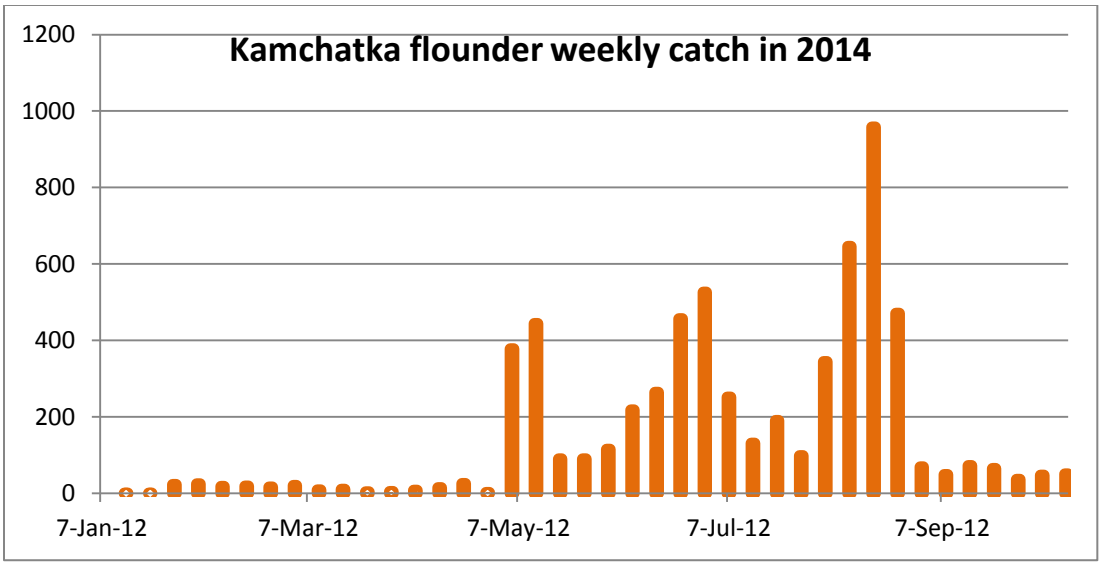


Figure 7-1. 2014 Kamchatka flounder catch (t) by week from Alaska Regional Office catch reports.

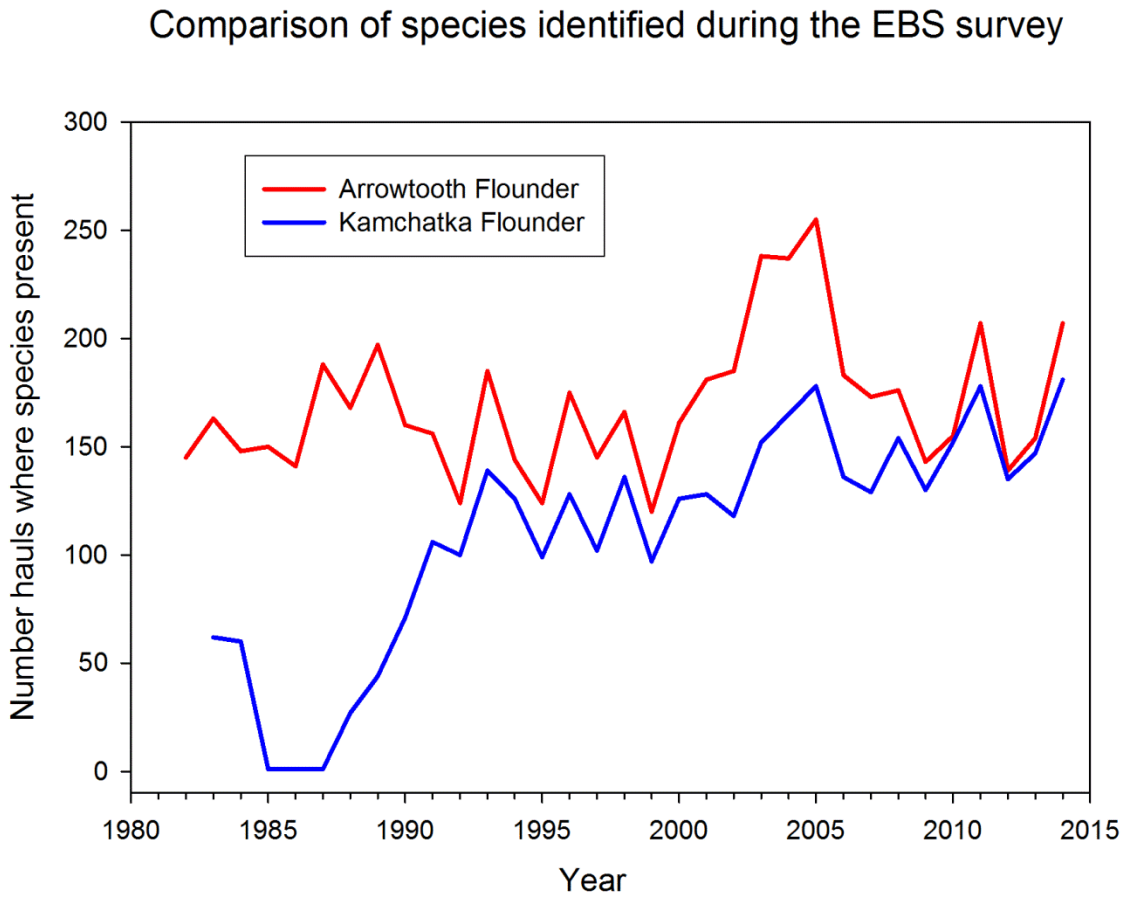


Figure 7.2—Number of hauls where arrowtooth flounder and Kamchatka flounder were identified during the annual Bering Sea shelf surveys, 1982-2014.

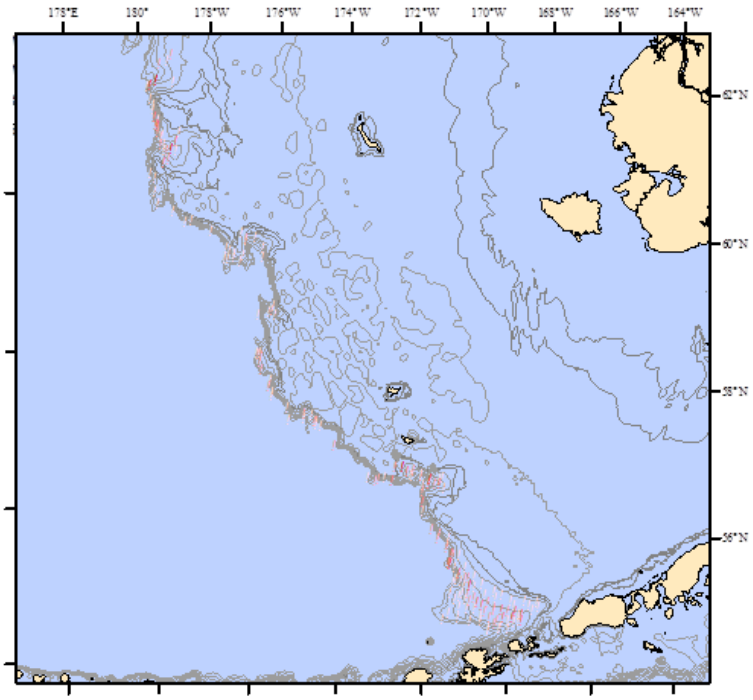


Figure 7-3. Distribution and relative of abundance of Kamchatka flounder from the 2010 slope survey.

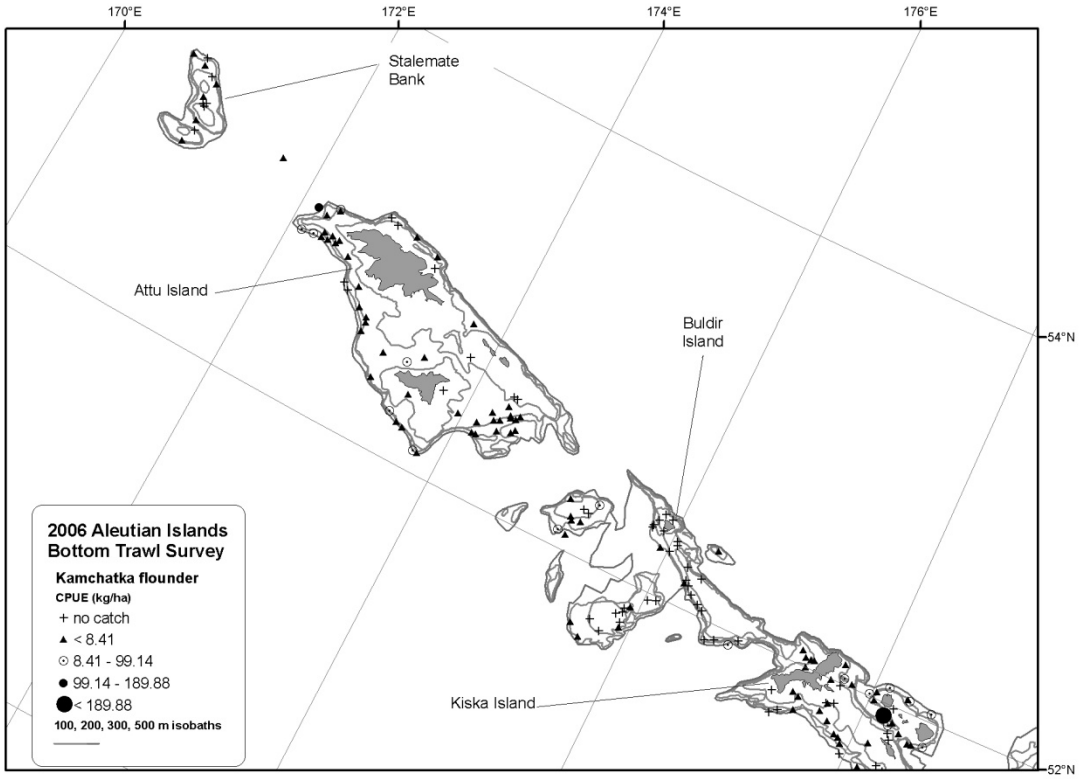


Figure 7-4. Distribution and relative abundance of Kamchatka flounder from the 2006 Aleutian Islands survey.

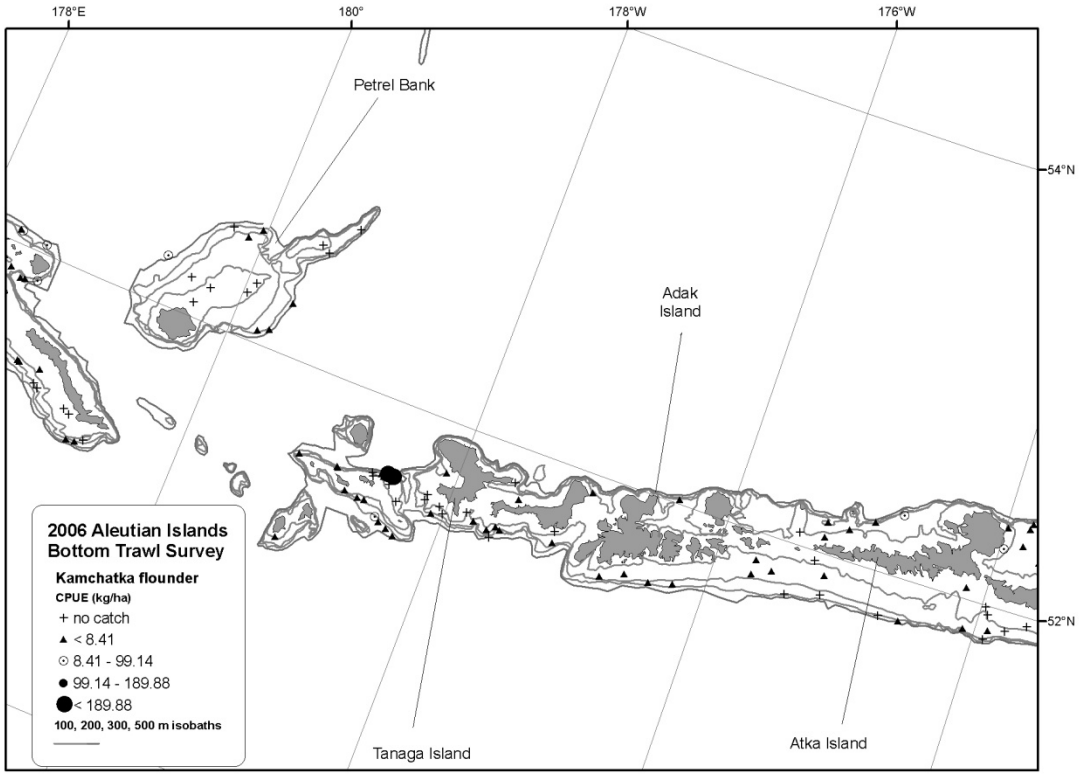


Figure 7-4 (continued).

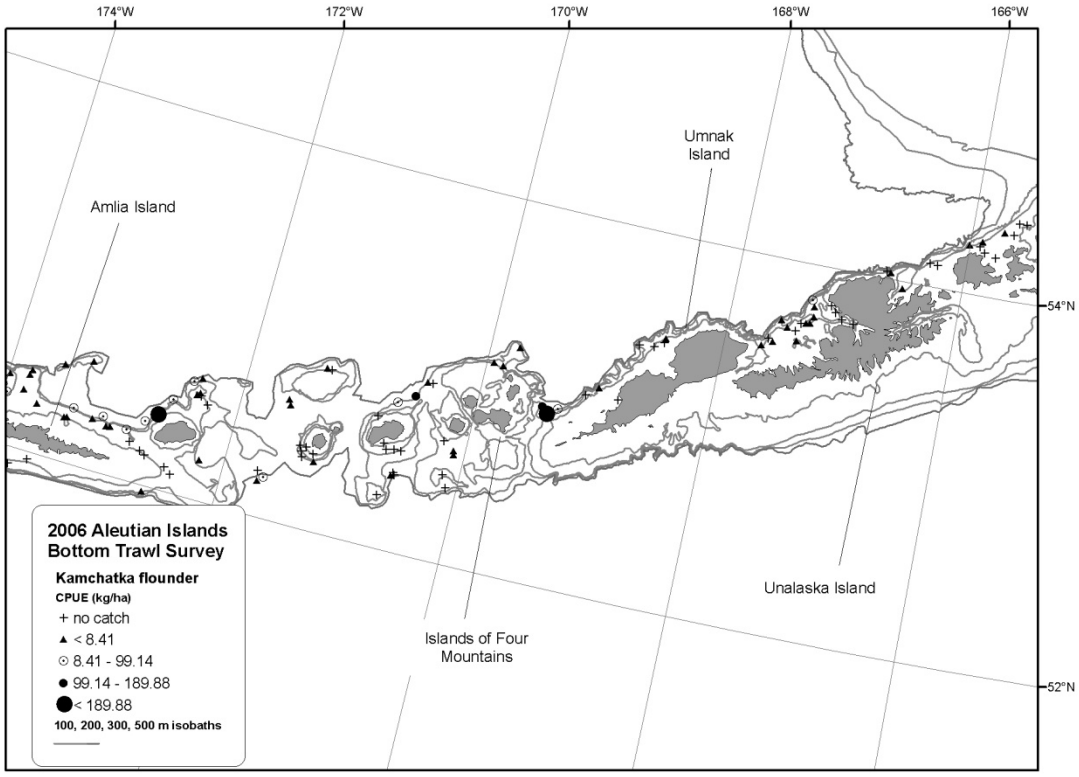


Figure 7-4 (continued).

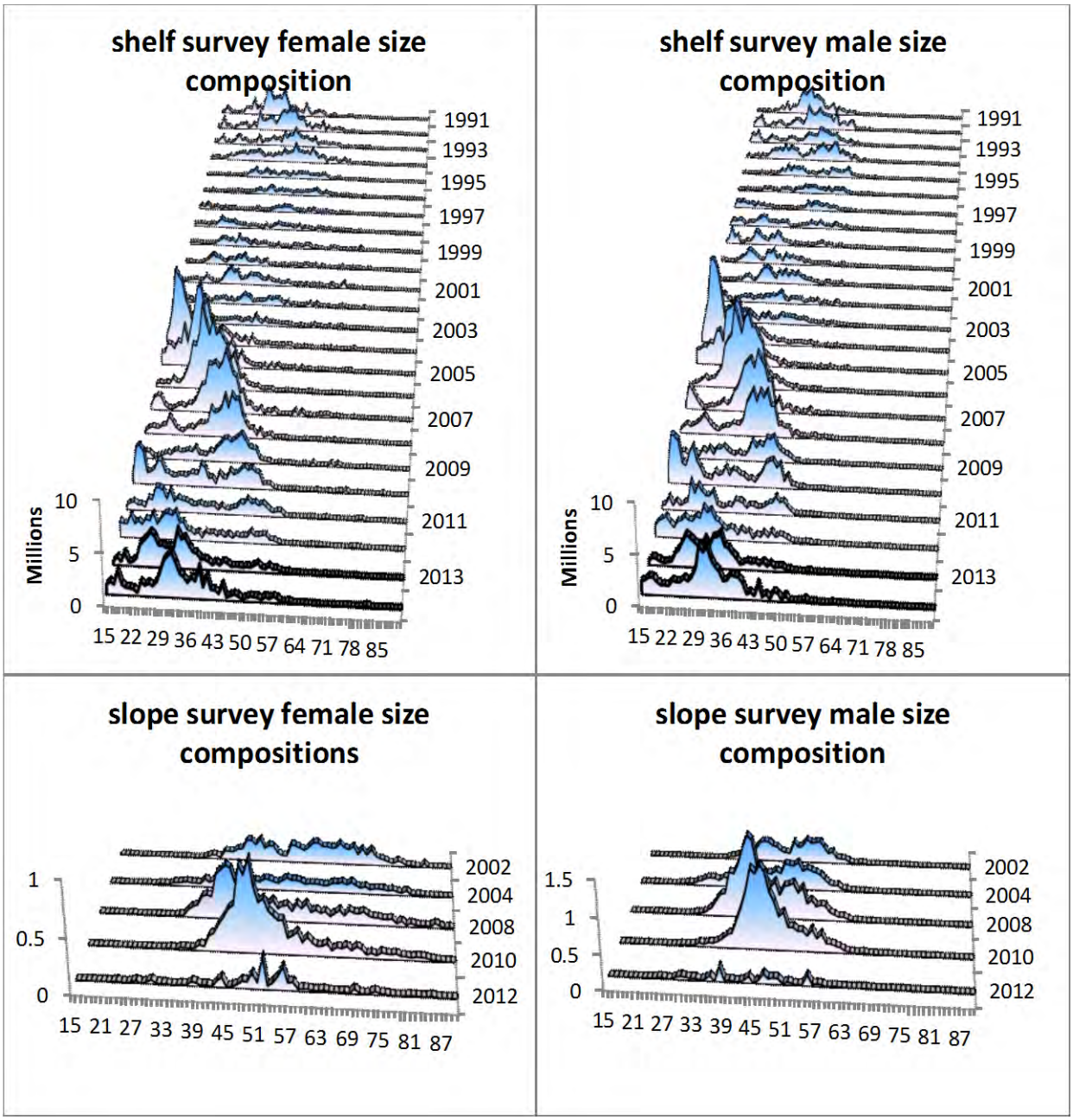


Figure 7.5. Kamchatka flounder population length composition estimates from the shelf, slope and Aleutian Islands survey for males and females.

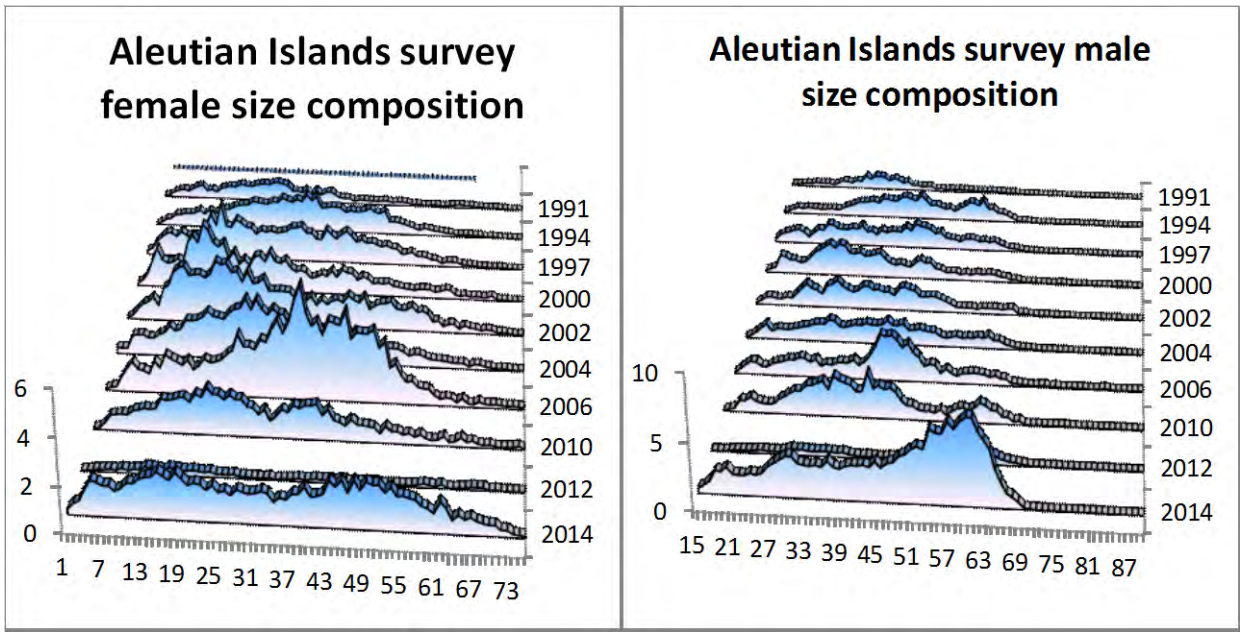
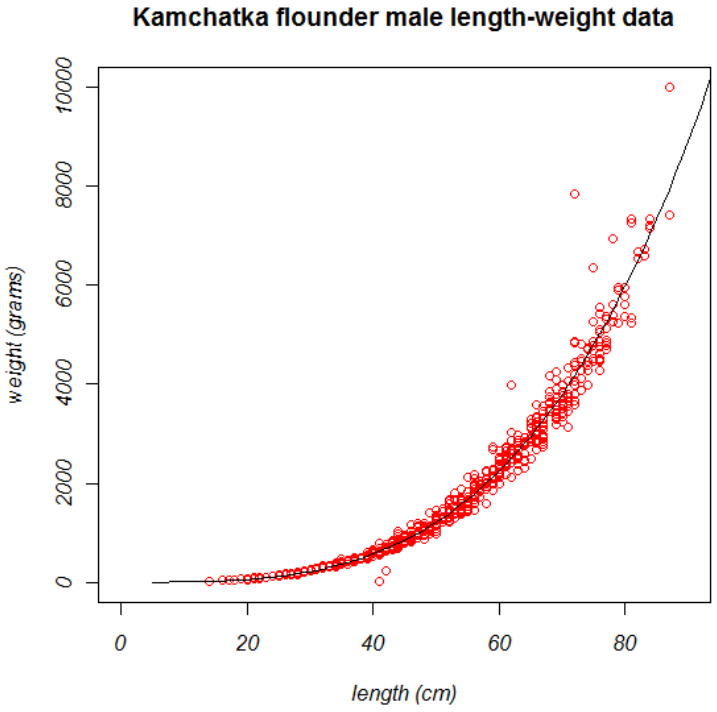


Figure 7.5. (continued).



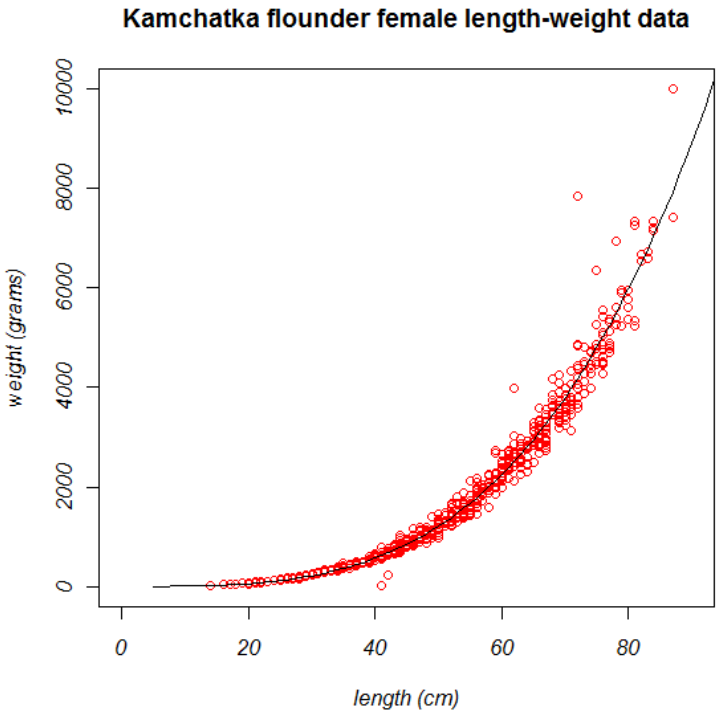


Figure 7-6 Kamchatka flounder length-weight plots for male and females.

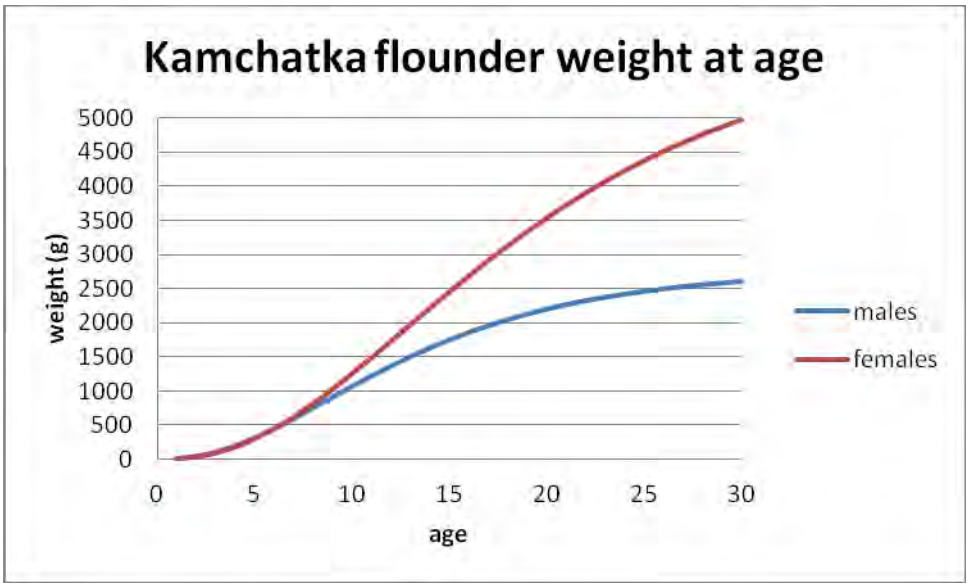


Figure 7-7 Estimated weight-at-age for male and female Kamchatka flounder from a 2010 age sample from the Aleutian Islands.

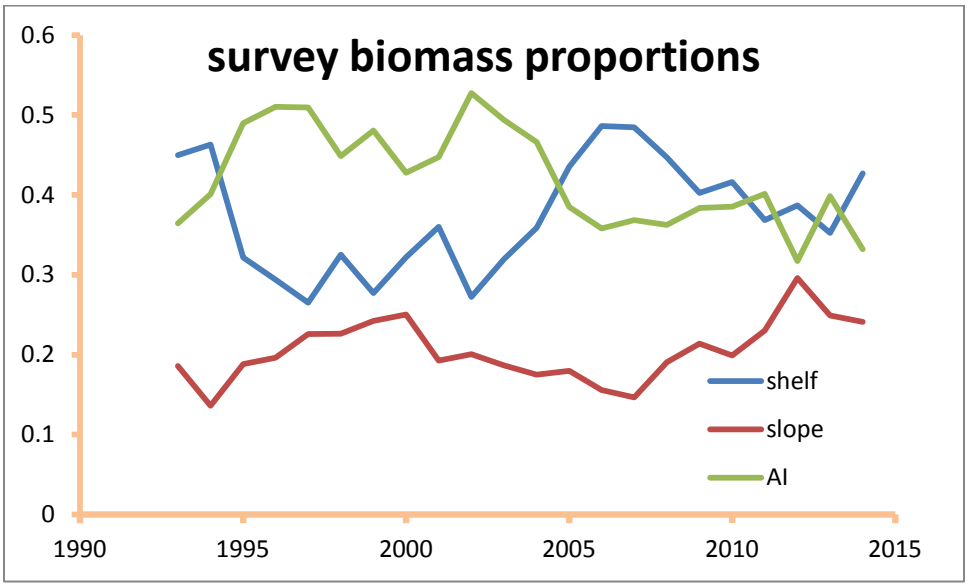


Figure 7-8 Initial area-specific catchability values were assigned in the assessment model according to the proportion of the average biomass from the time-series of each trawl survey (shelf, slope and Aleutian Islands).

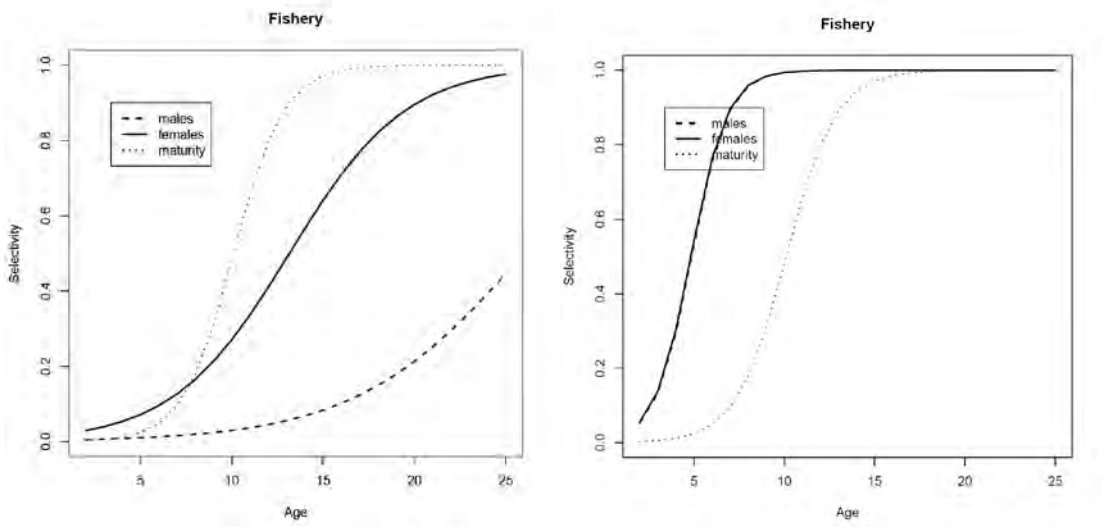


Figure 7-9 Estimated fishery selectivity from two model runs, unconstrained (left panel) and estimated with slope parameter fixed (right panel). Maturity curve is also plotted.

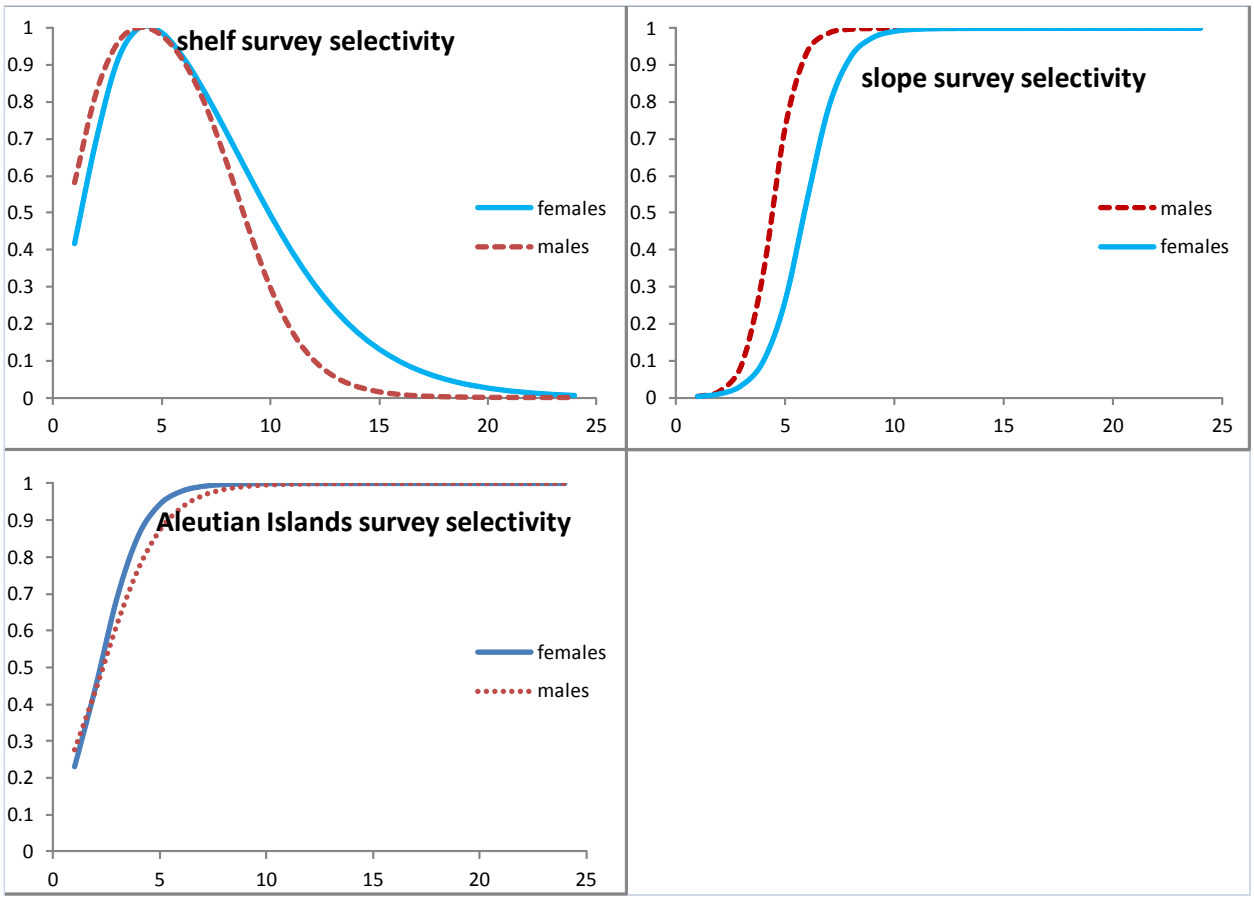


Figure 7-10 Model estimates of survey selectivity, males and females, for the shelf, slope and Aleutian Islands surveys.

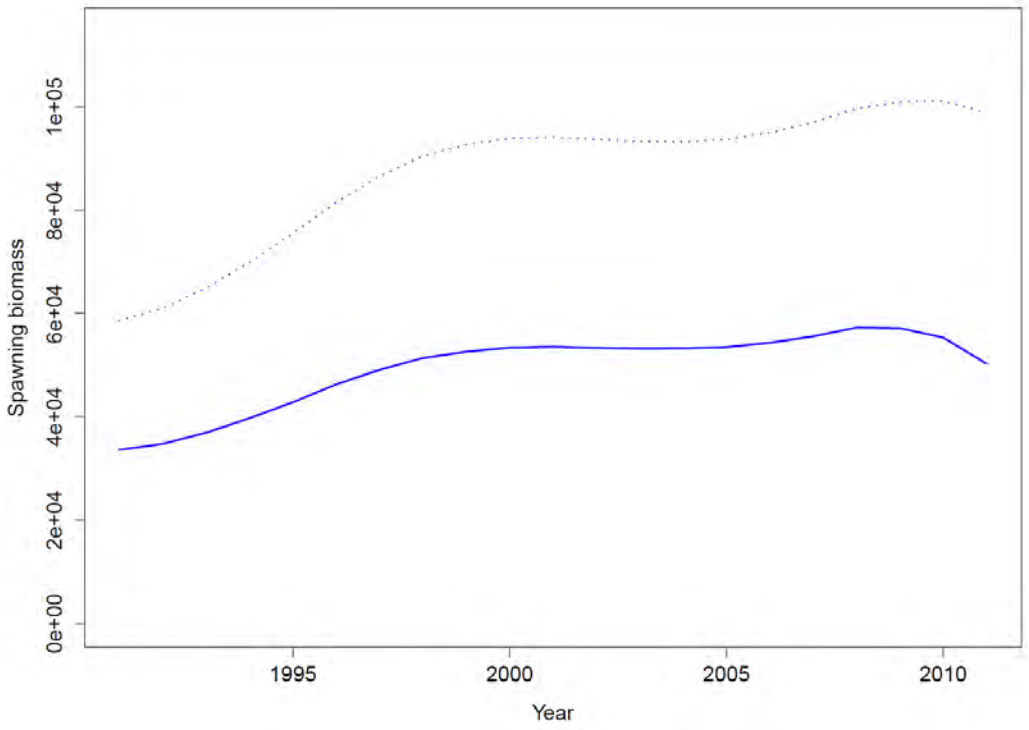


Figure 7-12 Comparison of spawning biomass estimates with slope survey catchability fixed at 0.18 (solid line) and 0.1 (dotted line). The difference in total likelihood between these models was 1.95 (with the higher biomass model being favored).

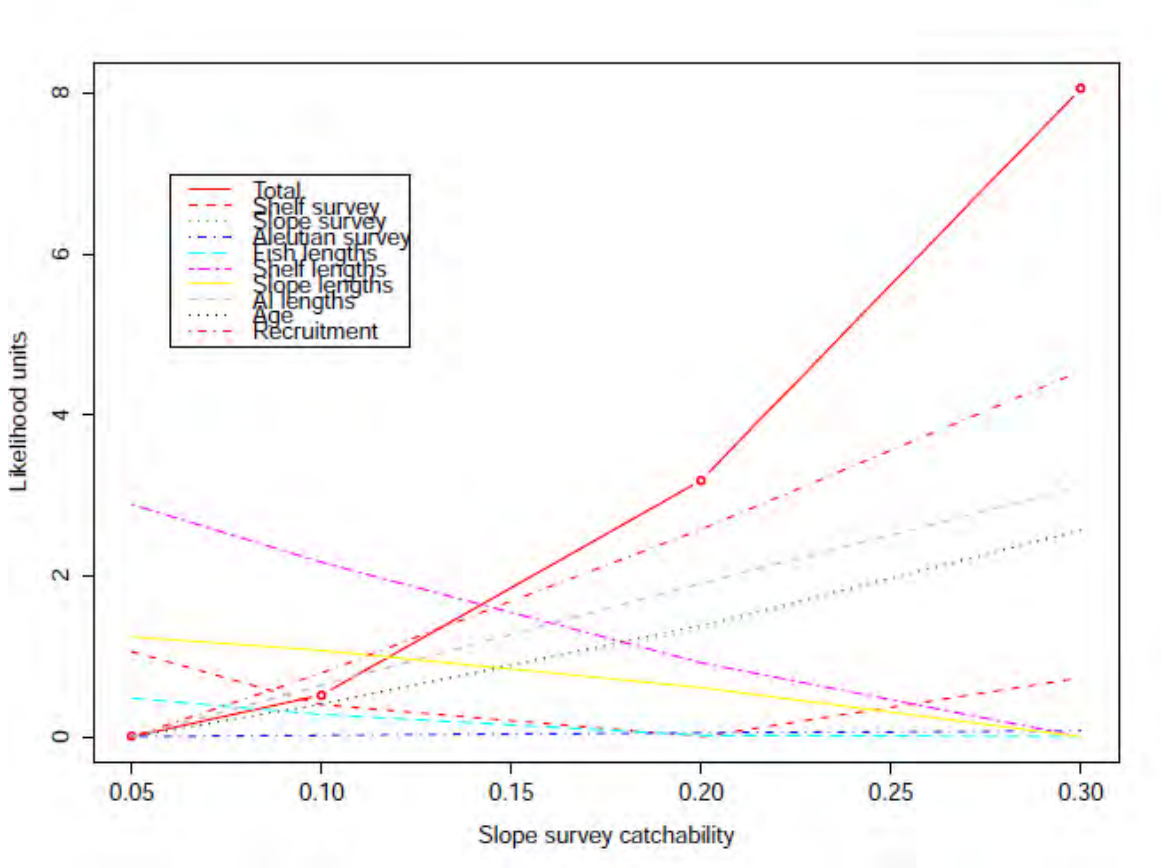


Figure 7-13 Plot of –log(likelihood) values for model components when profiling over values of slope survey q ranging from 0.05 to 0.3.

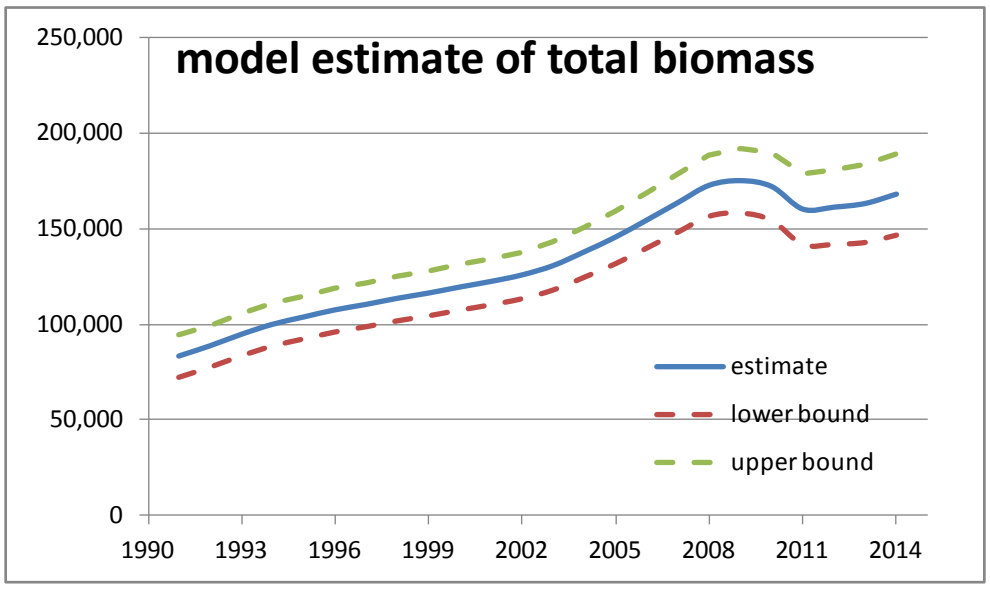


Figure 7-14 Assessment model estimate of total Kamchatka flounder biomass (t) and 95%(?) confidence bounds from 1991-2014.

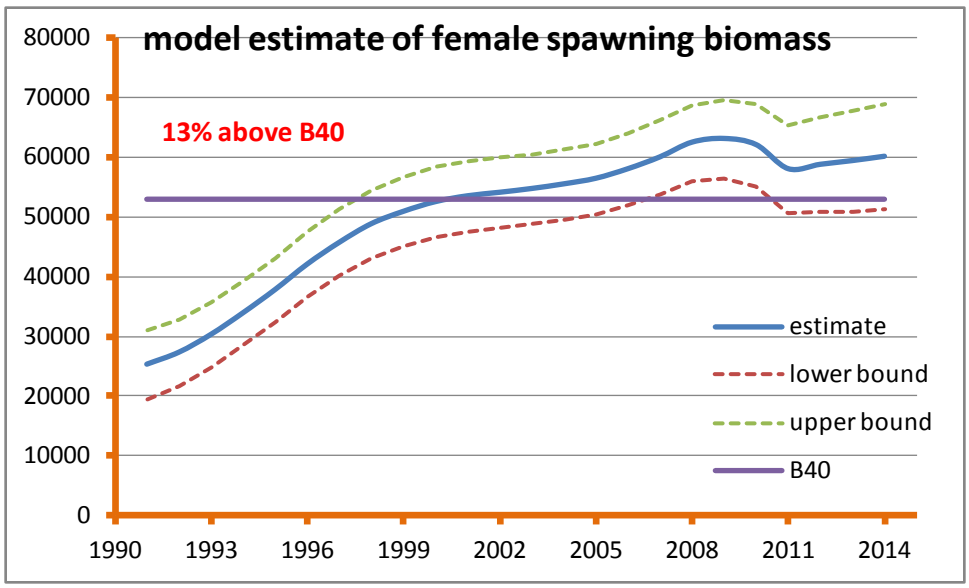


Figure 7-15 Assessment model estimate of female spawning biomass (t) and 95%(?) confidence bounds.

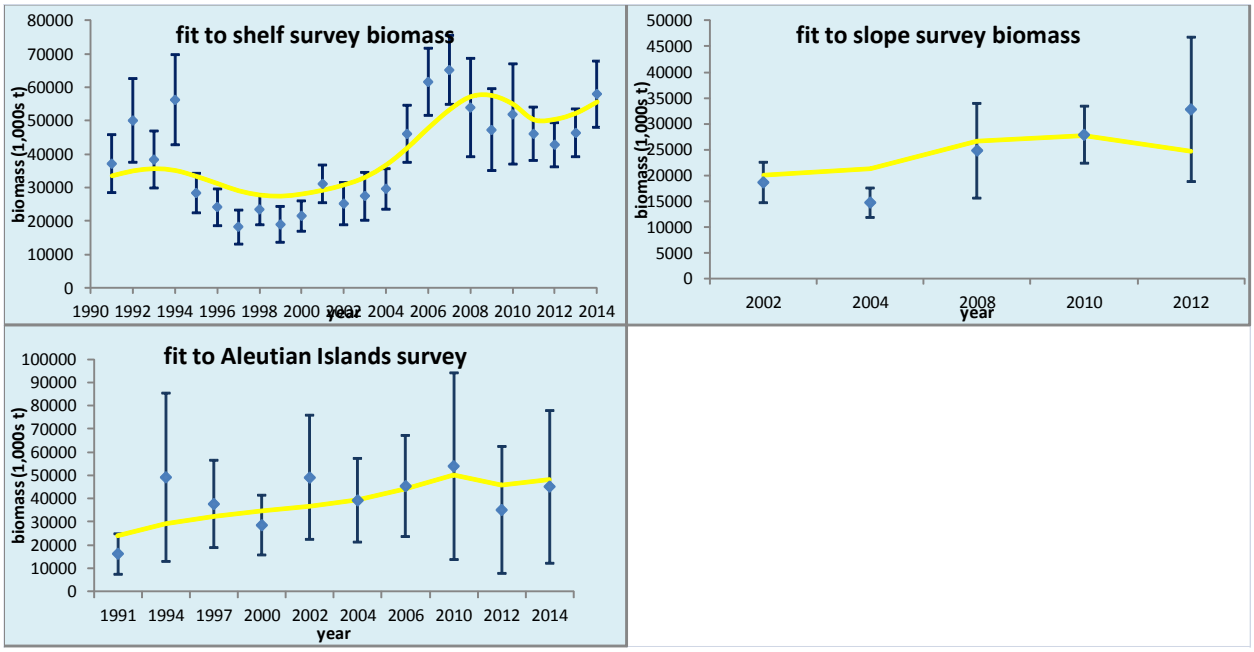


Figure 7-16 Assessment model fit (yellow line) to the shelf, slope and Aleutian Islands surveys (shown with 95% confidence intervals).

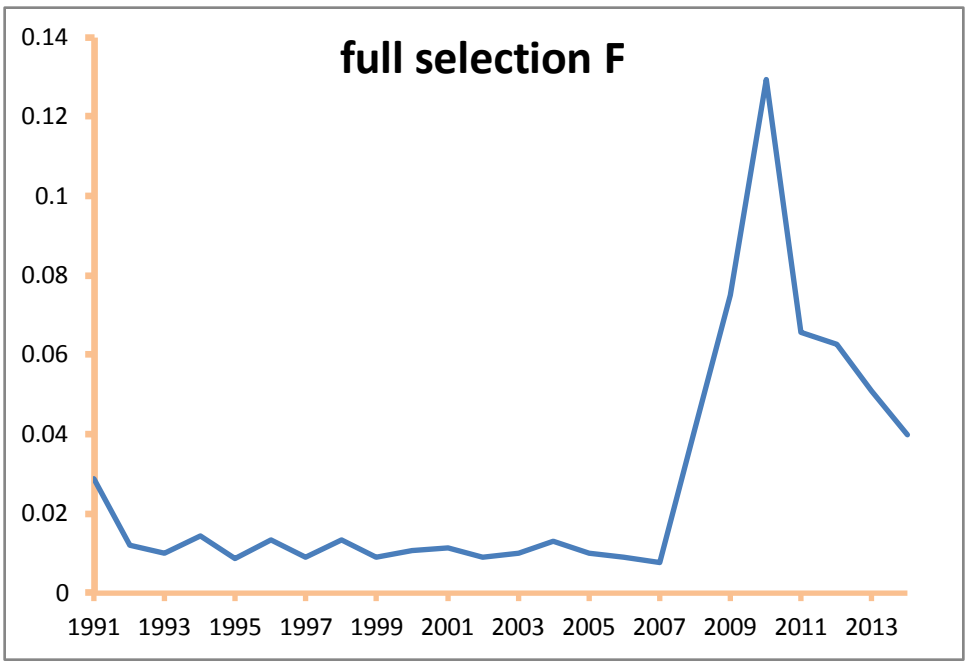


Figure 7-17. Assessment model estimates of full selection *F*s for 1991-2014.

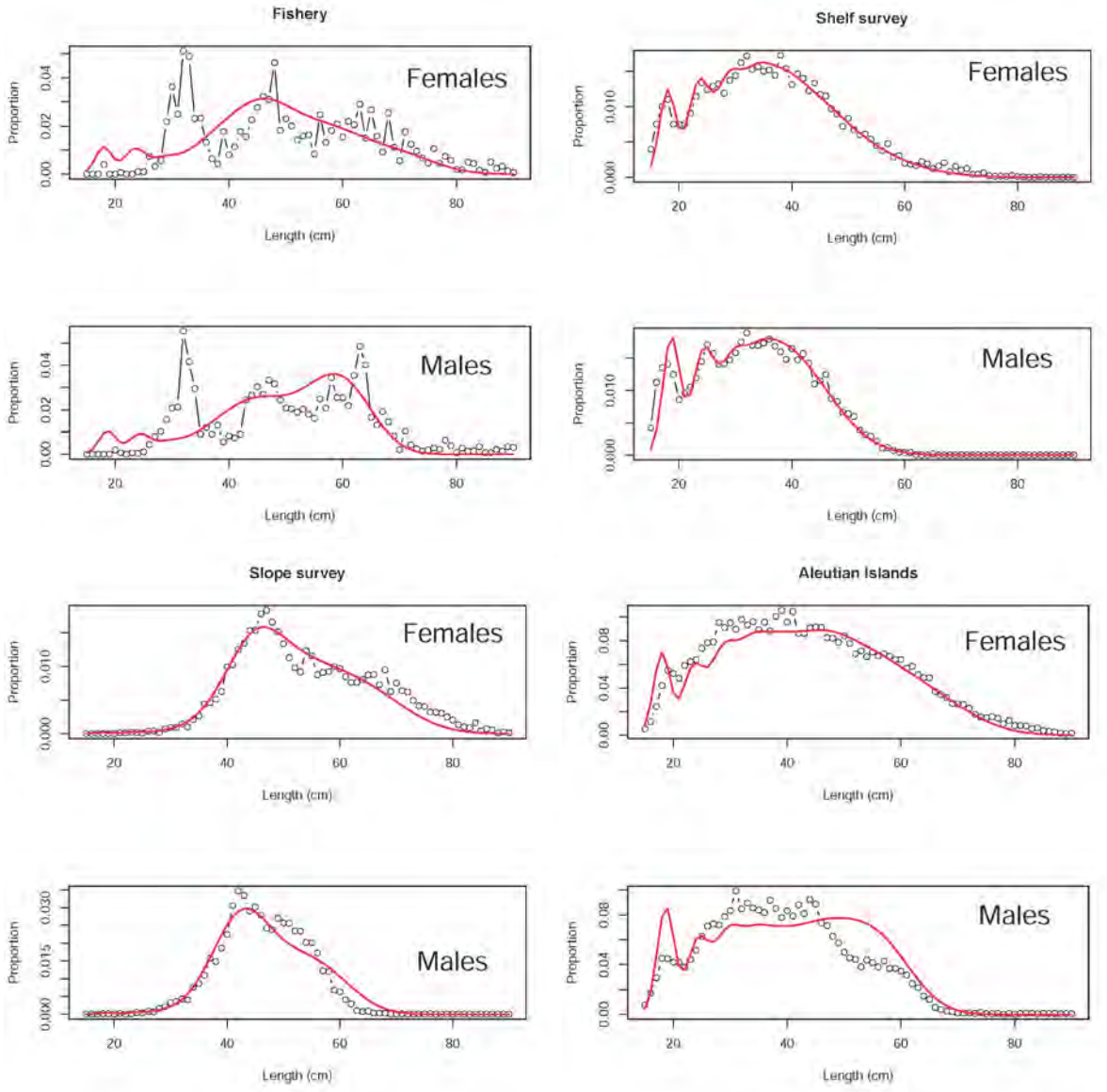


Fig. 7-18 Comparison of the average observed (open circles) proportion at length from the time-series to the average predicted (solid line) proportion at length from the model for the fishery, and the three surveys on the Bering Sea shelf, slope and the Aleutian Islands.

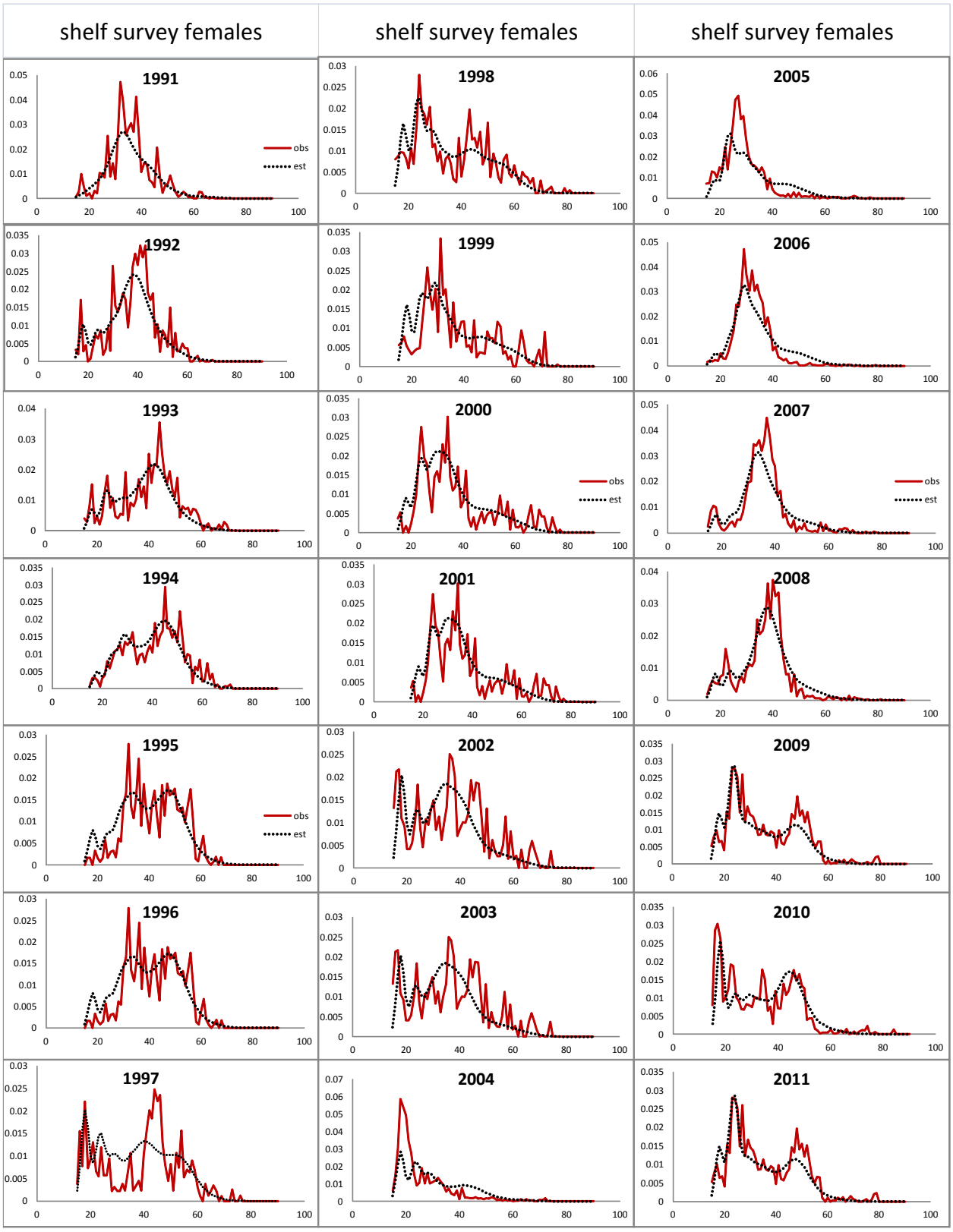


Figure 7-19 Assessment model fit (black dotted line) to the shelf, slope and Aleutian Islands survey size compositions (red solid line).

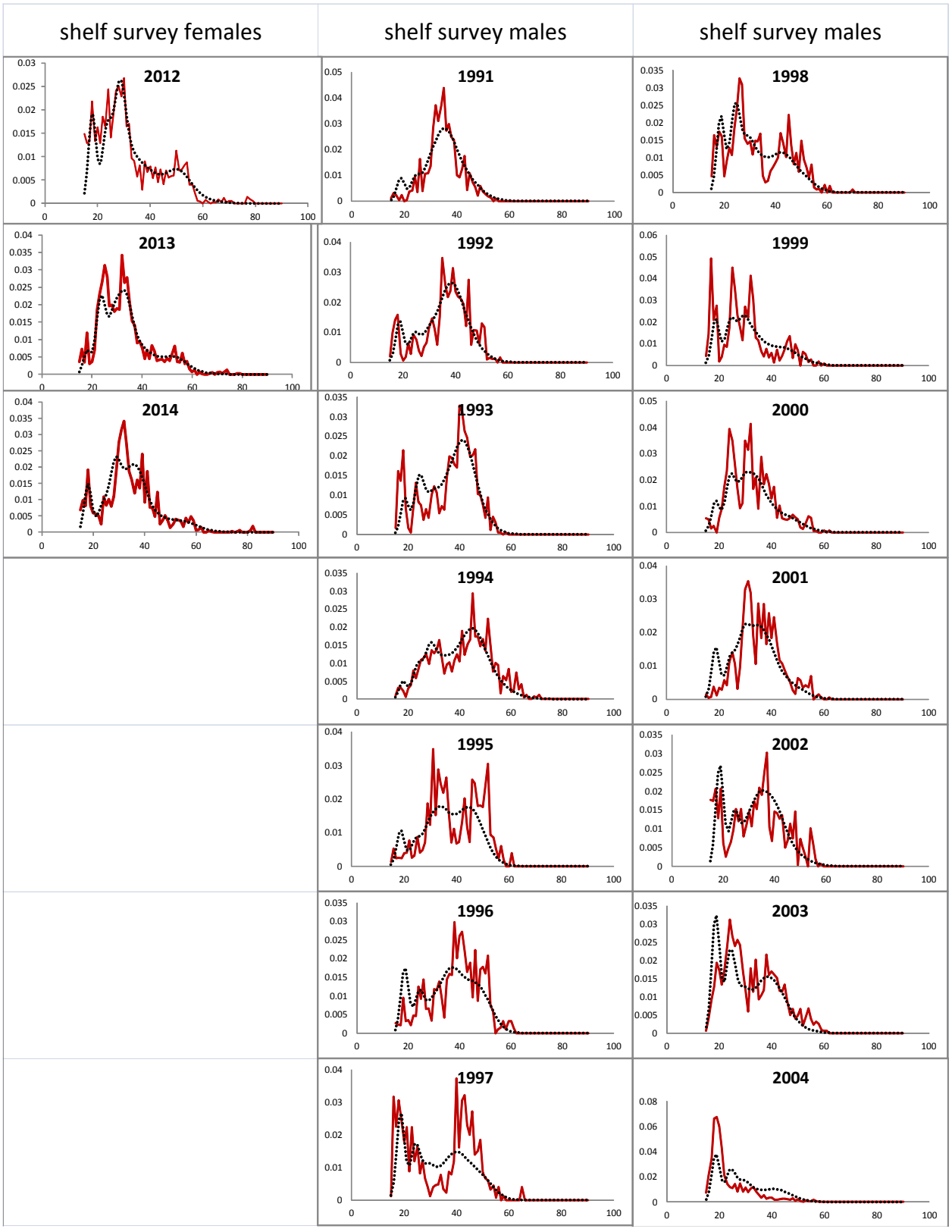


Figure 7-19 continued.

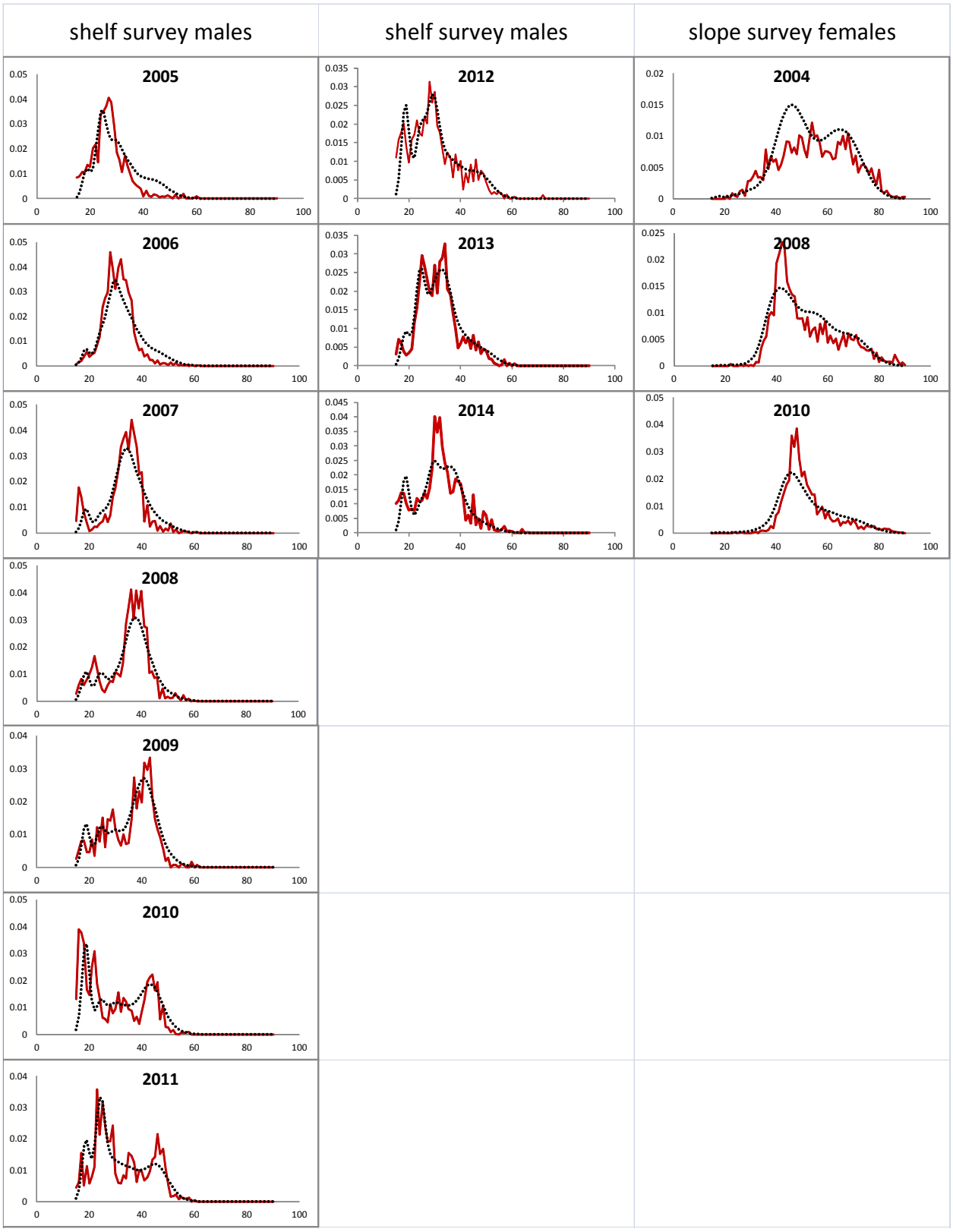


Figure 7-19 continued.

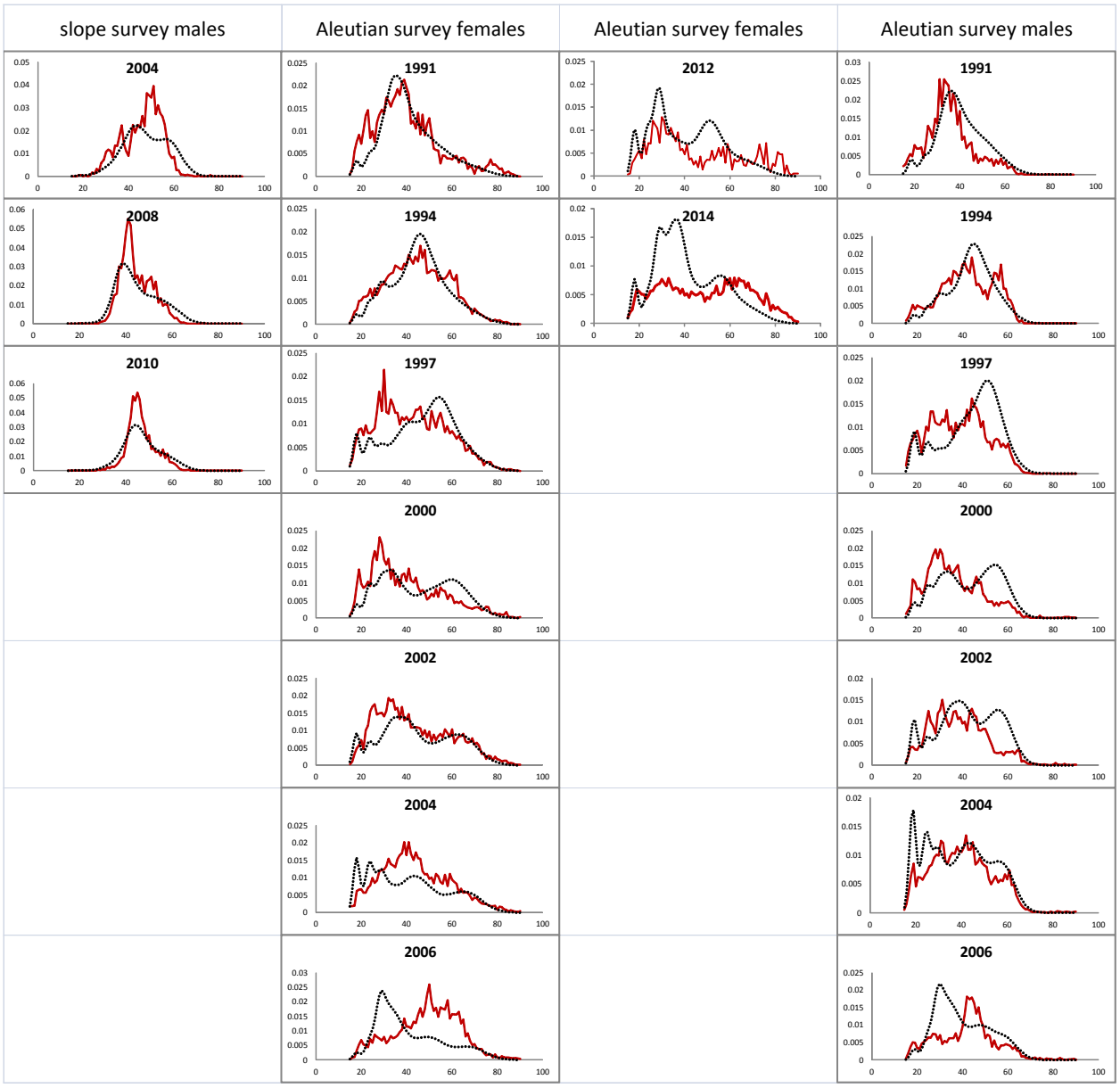


Figure 7.19 (continued).

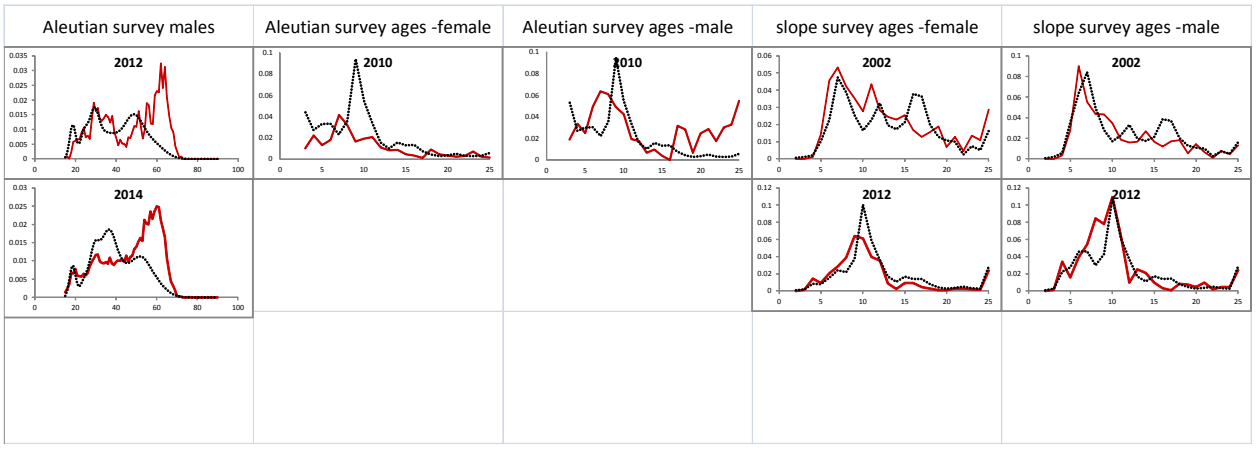


Figure 7.19 (continued).

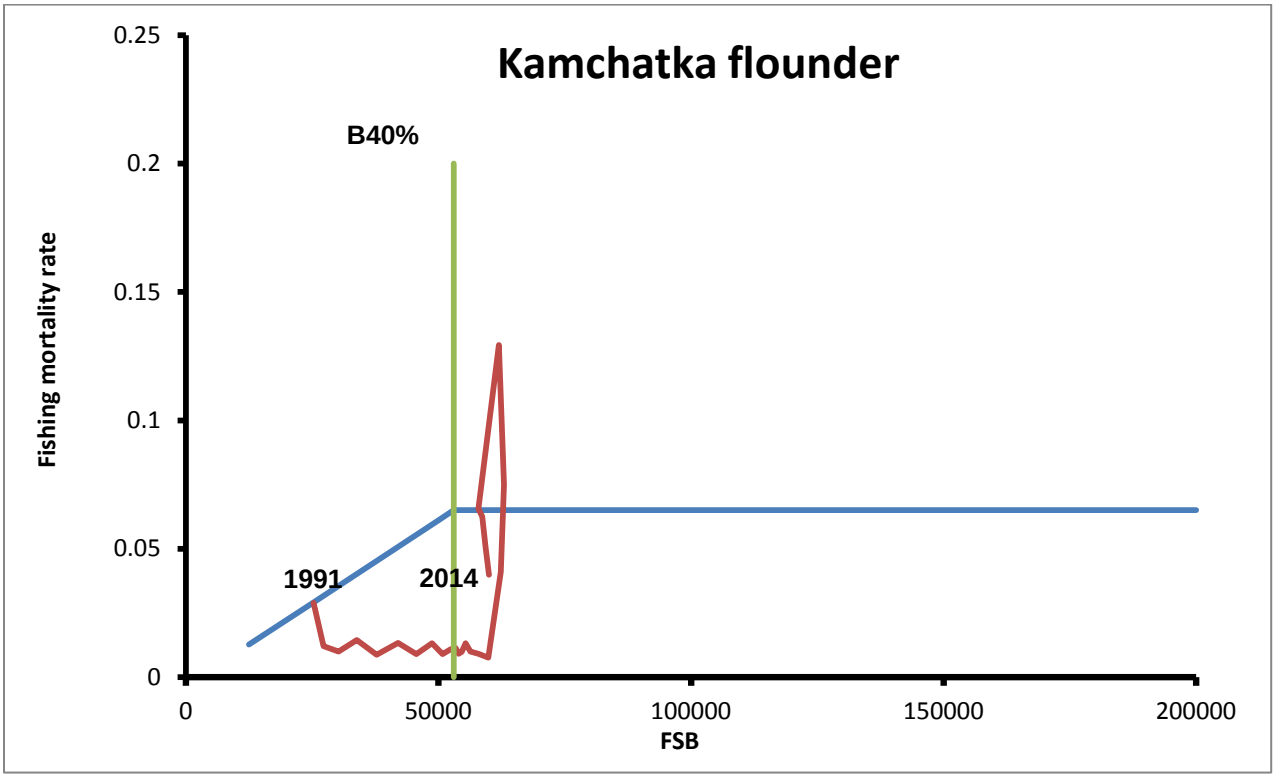


Figure 7.20. Phase plane figure of Kamchatka flounder female spawning biomass (t) and annual fishing mortality rate.

Chapter 8

Assessment of the Northern Rock Sole stock in the Bering Sea and Aleutian Islands

Thomas K. Wilderbuer and Daniel G. Nichol

Executive Summary

The following changes have been made to this assessment relative to the last full assessment in November 2012:

Summary of changes to the assessment input

1) 2012 and 2013 fishery age composition.
2) 2012 and 2013 survey age composition.
3) 2013 and 2014 trawl survey biomass point estimates and standard errors.
4) Estimate of catch (t) and discards for 2013 and 2014.
5) Estimate of retained and discarded portions of the 2013 catch.

Summary of Results

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2016
M (natural mortality rate)	0.15	0.15	0.15	0.15
Tier	1a	1a	1a	1a
Projected total (age 6+)	1,555,700	1,456,600	1,233,400	1,118,700
Female spawning biomass (t)	713,200	698,800	622,300	589,800
Projected				
B_0	694,500		694,500	
B_{MSY}	260,000	260,000	260,000	260,000
F_{OFL}	0.16	0.16	0.152	0.152
$maxF_{ABC}$	0.143	0.143	0.143	0.143
F_{ABC}	0.143	0.143	0.143	0.143
OFL (t)	249,000	233,100	187,600	170,100
maxABC (t)	222,500	208,300	181,700	164,800
ABC (t)	222,500	208,300	181,700	164,800
Status	As determined *last* year for: 2012	2013	As determined *this* year 2013	2014
Overfishing	No	No	No	No
Overfished	No	No	No	No
Approaching overfished	No	No	No	No

This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Marine Fisheries Service and should not be construed to represent any agency determination or policy.

Responses to SSC and Plan Team Comments to Assessments in General

There were no general comments relative to the northern rock sole assessment.

Responses to the SSC and Plan Team Comments specific to this assessment

The SSC agrees with the Plan Team and recommends applying the base model for this year's assessment for setting ABCs and OFLs for 2014 and 2015. While the SSC anticipates ultimately accepting the alternative model with the temperature relationship, the SSC would like to see a more complete analysis of the performance of the two models in a full assessment next year.

For November 2014, the Team recommended that the authors provide a full assessment including the temperature-dependent model with new data. At that time the Team requests that the model details be written out for documentation of change of model; the documentation should include a graph to compare the temperature-dependent Model 7 to the currently used Model 1.

Last year a full model was not implemented due to the time constraint imposed by the furlough. Thus this year there were two surveys and 4 age compositions (2 fishery and 2 survey) input into the assessment models to refit all the parameters. The model run which estimates q as a function of the annual bottom temperature (Model 7) during the surveys (with male and female M fixed at 0.15) sets q at 1.4 by fixing the alpha value in the temperature-q equation and then allows the beta value to co-vary with annual bottom temperature. The result is an improved fit to the survey biomass time-series and fits the experimental value of q better than models which estimate q as a free parameter (with M fixed for both sexes and is part of the likelihood) since the effect of the penalty is greater in Model 7 since it's applied in every year rather than only for 1 q in each year as in model 4. Model 7 gives similar results to Model 1 but does not fit the observed age compositions as well and is not selected as the model of choice from an AIC analysis. This result is different from two years ago.

INTRODUCTION

Northern rock sole (Lepidopsetta polyxystra n. sp.) are distributed primarily on the eastern Bering Sea continental shelf and in much lesser amounts in the Aleutian Islands region. Two species of rock sole are known to occur in the North Pacific Ocean, a northern rock sole (L. polyxystra) and a southern rock sole (L. bilineata) (Orr and Matarese 2000). These species have an overlapping distribution in the Gulf of Alaska, but the northern species comprise the majority of the Bering Sea and Aleutian Islands populations where they are managed as a single stock.

Centers of abundance for rock soles occur off the Kamchatka Peninsula (Shubnikov and Lisovenko 1964), British Columbia (Forrester and Thompson 1969), the central Gulf of Alaska, and in the southeastern Bering Sea (Alton and Sample 1975). Adults exhibit a benthic lifestyle and seem to occupy separate winter (spawning) and summertime feeding distributions on the southeastern Bering Sea continental shelf. Northern rock sole spawn during the winter-early spring period of December-March.

CATCH HISTORY

Rock sole catches increased from an average of 7,000 t annually from 1963-69 to 30,000 t from 1970-1975. Catches (t) since implementation of the MFCMA in 1977 are shown in Table 8.1, with catch data for 1980-88 separated into catches by non-U.S. fisheries, joint venture operations and Domestic Annual Processing catches (where available). Prior to 1987, the classification of rock sole in the "other flatfish" management category prevented reliable estimates of DAP catch. Catches from 1989-2014 (domestic only) have averaged 50,200 t annually, well below ABC values. The size composition of the 2014 catch from observer sampling, by sex and management area, are shown in Figure 8.1 and the locations of the 2014 catch by month through September are shown in Figure 8.3.

The management of the northern rock sole fishery changed significantly in 2008 with the implementation of Amendment 80 to the BSAI Fisheries Management Plan. The Amendment directly allocated fishery resources among BSAI trawl harvesters in consideration of their historic harvest patterns and future harvest needs in order to improve retention and utilization of fishery resources by the non-AFA trawl catcher/processor fleet. This was accomplished by extending the groundfish retention standards to all H&G vessels and also by providing the ability to form cooperatives within the newly formed Amendment 80 sector. In addition, Amendment 80 also mandated additional monitoring requirements which included observer coverage on all hauls, motion-compensating scales for weighing samples, flow scales to obtain accurate catch weight estimates for the entire catch, with the added stipulation of no mixing of hauls and no on-deck sorting.

Northern rock sole are important as the target of a high value roe fishery occurring in February and March which accounted for 63% of the annual catch in 2014 (Fig 8.2). About 67% of the 2014 catch came from management area 509 with the rest from areas 513, 514, 516, 517 and 521 (Fig 8.2). The 2014 catch is estimated at 52,250 t based on the Alaska regional office estimate through mid September projected forward to the end of the year by applying the catch rates from the previous 5 weeks for September through December. The projected catch is 26% of the 2014 ABC of 203,800 t and 61% of the 85,000 t TAC. Thus, rock sole remain lightly harvested in the Bering Sea and Aleutian Islands. The fishery in the past has been affected by seasonal and annual closures to prevent exceeding halibut bycatch allowances specified for the trawl rock sole, flathead sole, and “other flatfish” fishery category by vessels participating in this sector in the BSAI. There were no closures in 2014.

Northern rock sole are usually headed and gutted, frozen at sea, and then shipped to Asian countries for further processing (see “market profile” in the economic SAFE report for details). In 2010, following a comprehensive assessment process, the northern rock sole fishery was certified under the Marine Stewardship Council environmental standard for sustainable and well-managed fisheries. The certification also applies to all the major flatfish fisheries in the BSAI and GOA.

Although female rock sole are highly desirable when in spawning condition, large amounts of rock sole were discarded overboard in the various Bering Sea trawl target fisheries in the past. Estimates of retained and discarded catch from at-sea sampling for 1987-2013 are shown in Table 8.2. From 1987 to 2000, more rock sole were discarded than were retained. However since 2000 retention has trended upward and since 2008, the first year of Amendment 80 mandated fishing practices, retention has been at least 90%. Details of the 2013 northern rock sole catch by fishery designation are shown in Table 8.3.

DATA

The data used in this assessment include estimates of total catch, trawl fishery catch-at-age, trawl survey age composition, trawl survey biomass estimates and sampling error, maturity observations from observer sampling and mean weight-at-age.

Fishery Catch and Catch-at-Age

Available information include fishery total catch data through September 2014 (Table 8.1) and fishery catch-at-age numbers from 1980-2013 (Table 8.4). The 2014 catch total used in the model is based on the 2014 catch rates from August through mid-September applied to fishing through the end of the year to provide an estimate of 2014 annual catch.

Survey CPUE

Since rock sole are lightly exploited and are often taken incidentally in target fisheries for other species, CPUE from commercial fisheries are considered an unreliable method for detecting trends in abundance. It is therefore necessary to use research vessel survey data to assess the condition of these stocks.

Abundance estimates from the 1982 AFSC survey were substantially higher than from the 1981 survey data for a number of bottom-tending species such as flatfishes. This is coincident with the change in research trawl to the 83/112 with better bottom tending characteristics. The increase in survey CPUE was particularly large for rock sole (6.5 to 12.3 kg/ha, Figure 8.4). Allowing the stock assessment model to fit these early survey estimates would most likely underestimate the true pre-1982 biomass, thus exaggerating the degree to which biomass increased during that period. Consequently, CPUE and biomass from the 1975-81 surveys are not used in the assessment model.

The CPUE trend indicates a significantly increasing population from 1982-92 when the mean CPUE more than tripled. The population leveled-off from 1994-98 when CPUE values indicated a high level of abundance. The 1999 value of 36.5 kg/ha was the lowest observed since 1992, possibly due to extremely low water temperatures. Since that time the trend had been stable with 2007 and 2008 values of 41.0 kg/ha. The 2010 through 2014 estimates are nearly the same and indicate that the stock remains at a stable level.

Absolute Abundance

Rock sole biomass is also estimated from the AFSC surveys using stratified area-swept expansion of the CPUE data (Table 8.5). These biomass estimates are point estimates from an "area-swept" bottom trawl survey. Some assumptions add uncertainty to these estimates. Survey estimates assume that the sampling plan covers the distribution of the fish and that all fish in the path of the footrope of the trawl are captured. That is, there are no losses due to escape or gains due to gear herding effects. Due to sampling variability alone, the 95% confidence interval for the 2014 point estimate of the Bering Sea surveyed area is 1,601,380 – 2,113,525 t.

Survey sampling indicates that northern rock sole biomass was at low levels through 1985, but then increased substantially in the following years to 2.8 million t in 1994. In the 20 years since the peak estimate of 1994, the survey estimates have averaged 2.065 million t with a peak value of 2.433 million t in 2001 and a low of 1.539 million t in 2009. The 2014 estimate of 1.857 million t is a 6% increase from

2013. Overall, the survey indicates that the northern rock sole stock has been at a high and stable level since the mid-1990s.

The 2014 Aleutian Islands biomass estimate of 43,259 t is less than 3% of the combined BSAI total. Since it is such a low proportion of the total biomass for this area, the Aleutian Islands biomass is not used in this assessment. The total tonnage of northern rock sole caught annually in the Bering Sea shelf surveys from 1977-2014 is listed in Table 8.6 and an Appendix where other non-commercial catch is shown.

Weight-at-age and Maturity-at-age

In conjunction with the large and steady increase in the rock sole stock size in the early 1980s, it was found that there was also a corresponding decrease in size-at-age for both sexes (Figure 8.5). This also caused a resultant decrease in weight-at-age as the population increased and expanded northwestward toward the shelf edge (Walters and Wilderbuer 2000). These updated values of combined-sex weight-at-age were applied to the populations in 2001-2007 in past assessments to model the population dynamics of the rock sole population.

The 2012 assessment re-analyzed the time trend of size-at-age and weight-at-age available from the survey data. Northern rock sole growth (mean length-at-age) indicates that males and females grow similarly until about age 6 after which females grow faster and larger than males (Fig. 8.6). The length-at-age time series exhibits periods of slow and fast growth from 1982-2011 (shown for 8 year old fish in Figure 8.7). Accordingly, the length-at-age time series was partitioned into periods of faster (1982-1991, 2004-2008) and slower (1992-2003) growth to capture the time-varying differences in growth. In order to produce a growth matrix which was not too abrupt between change point years (1991-1992 and 2003-2004) a three year running average of weight-at-age was used, working backwards from 2008 (Table 8.7). Predicted and observed biomasses match better (does not underestimate the 1980s biomass or overestimate the 1992-2003 biomass) compared to previous assessments which used the average weight-at-age from all years. This method was continued for this assessment.

The length-weight relationship available from 4,469 (2,564 females, 1,905 males) survey samples collected since 1982 indicate that this value did not change significantly over this time period. The following parameters have been calculated for the length (cm)-weight (g) relationship:

$$W = a * L^{b}$$

Males		Females	
a	b	a	b
0.005056	3.224	0.006183	3.11747

The maturity schedule for northern rock sole was updated in the 2009 assessment from a histological analysis of 162 ovaries collected from the Bering Sea fishery in February and March 2006 (Stark 2012) and is shown in Table 8.8 and Figure 8.8. Compared to the maturity curve from anatomical scans used previously, the length-based model of Stark indicates nearly the same age at 50% maturity (7.8 years).

Survey and Fishery Age composition

Northern rock sole otoliths have been routinely collected during the trawl surveys since 1979 to provide estimates of the population age composition (Fig. 8.8, Table 8.10). For this assessment all fishery and

survey age compositions (1979-2013) were calculated to estimate age composition by sex. Fishery size composition data from 1979-89 (prior to 1990 observer coverage was sparse for this species and the small age collections did not reflect the catch-at-age composition) were applied to age-length keys from the same-year surveys to provide a time-series of catch-at-age assuming that the mean length-at-age from the trawl survey was the same as the fishery in those years. Estimation of the fishery age composition since 1990 use age-length keys derived from age structures collected annually from the fishery. Northern rock sole occurrence in trawl survey hauls and associated collections of lengths and age structures since 1982 are shown in Table 8.9.

ANALYTIC APPROACH

Model Structure

The abundance, mortality, recruitment and selectivity of northern rock sole were assessed with a stock assessment model using the AD Model builder software. The conceptual model is a separable catch-age analysis that uses survey estimates of biomass and age composition as auxiliary information (Fournier and Archibald 1982). The model simulates the dynamics of the population and compares the expected values of the population characteristics to the characteristics observed from surveys and fishery sampling programs. This is accomplished by the simultaneous estimation of the parameters in the model using the maximum likelihood estimation procedure. The fit of the simulated values to the observable characteristics is optimized by maximizing a log(likelihood) function given some distributional assumptions about the data.

Since the sex-specific weight-at-age for northern rock sole diverges after about age 6, with females growing larger than males, the current assessment model is coded to accommodate the sex-specific aspects of the population dynamics of northern rock sole. The model allows for the input of sex-specific estimates of fishery and survey age composition and weight-at-age and provides sex-specific estimates of population numbers, fishing mortality, selectivity, fishery and survey age composition and allows for the estimation of sex-specific natural mortality and catchability. The model retains the utility to fit combined sex data inputs.

The parameters estimated in the stock assessment model are classified by three likelihood components:

Data Component	Distribution assumption
Trawl fishery catch-at-age	Multinomial
Trawl survey population age composition	Multinomial
Trawl survey biomass estimates and S.E.	Log normal

The total log likelihood is the sum of the likelihoods for each data component (Table 8.11). The likelihood components may be weighted by an emphasis factor, however, equal emphasis was placed on fitting each likelihood component in the rock sole assessment except for the catch weight which was weighted more/less. The AD Model Builder software fits the data components using automatic differentiation (Griewank and Corliss 1991) software developed as a set of libraries (AUTODIFF C++ library). Table 8.11 presents the key equations used to model the rock sole population dynamics in the Bering Sea and Table 8.12 provides a description of the variables used in Table 8.11. The model of rock

sole population dynamics was evaluated with respect to the observations of the time-series of survey and fishery age compositions and the survey biomass trend since 1982, and the estimates of natural mortality, catchability and sex ratio.

Parameters Estimated Outside the Assessment Model

Rock sole maturity schedules were estimated independently as discussed in a previous section (Table 8.8) as were length at age and length-weight relationships.

Parameters Estimated Inside the Assessment Model

The parameters estimated by the model are presented below:

Fishing mortality	Selectivity	Year class strength	Spawner-recruit	Catchability	M	Total
41	168	80	2	0, 1 or 2 (optional)	0, 1 or 2 (optional)	291-295 depending on model run

The increase in the number of parameters estimated in this assessment compared to last year (6) can be accounted for by the input of another year of fishery data (annual fishing mortality), sex-specific estimates of fishery selectivity (4) and the entry of another year class into the observed population.

Year class strengths

The population simulation specifies the numbers-at-age in the beginning year of the simulation, the number of recruits in each subsequent year, and the survival rate for each cohort as it progresses through the population using the population dynamics equations given in Table 7-11.

Selectivity

Fishery and survey selectivity was modeled separately for males and females using the two parameter formulation of the logistic function (Table 7-11). The model was run with an asymptotic selectivity curve for the older fish in the fishery and survey, but still was allowed to estimate the shape of the logistic curve for young fish. The oldest year classes in the surveys and fisheries were truncated at 20 and allowed to accumulate into the age category 20+ years. Sex-specific selectivity curves were fit for all years of survey data.

Given that there have been annual changes in management, vessel participation and most likely gear selectivity, time-varying fishing selectivity curves are estimated. A logistic equation was used to model fishery selectivity and is a function of time-varying parameters specifying the age and slope at 50% selection, φ_t and η_t, respectively. The fishing selectivity (S^f) for age a and year t is modeled as,

$$S^f_{a,t} = \left[1 + e^{\eta_t (a - \varphi_t)}\right]^{-1}$$

where η_t and φ_t are time-varying and partitioned (for estimation) into parameters representing the mean and a vector of deviations (log-scale) conditioned to sum to zero. The deviations are constrained by a lognormal prior with a variance that was iteratively estimated. The process of iterating was to first set the variance to a high value (diffuse prior) of 0.5^2 and estimate the deviations. The next step was to compare

the variability of model estimates. These values were then rounded up slightly and fixed for subsequent runs.

Fishing Mortality

The fishing mortality rates (F) for each age, sex and year are calculated to approximate the catch weight by solving for F while still allowing for observation error in catch measurement. A large emphasis (300) was placed on the catch likelihood component, which results in predicted catches closely matching observed catches.

Natural Mortality

Assessments for rock sole in other areas assume M = 0.20 for rock sole on the basis of the longevity of the species. In a past BSAI assessment, a model was used to entertain a range of M values to evaluate the fit of the observable population characteristics over a range of natural mortality values (Wilderbuer and Walters 1992). The best fit occurred at M = 0.18 with the survey catchability coefficient (q) set equal to 1.0. In this assessment natural mortality was estimated for both sexes as free parameters with values of 0.159 and 0.19, for males and females respectively, when survey catchability was fixed at 1.5. The base assessment model fixes M at 0.15 for both sexes and catchability at 1.5.

Survey Catchability

Unusually low estimates of flatfish biomass were obtained for Bering Sea shelf flatfish species during the very cold year of 1999 and again in 2009, another cold year. Results were also a bit lower for 2012, the second coldest year in the survey time-series. These results may suggest a relationship between bottom water temperature and trawl survey catchability, which are documented for yellowfin sole, flathead sole and arrowtooth flounder in the BSAI SAFE document. To better predict how water temperature may affect the catchability of rock sole to the survey trawl, we estimated catchability in a non-linear model for each year within the stock assessment model as:

$$q = e^{-\alpha+\beta T}$$

where q is the annual catchability, T is the average annual bottom water temperature at survey stations less than 100 m, and α and β are parameters estimated by the model. Past attempts to model catchability using this formulation resulted in values of α and β at -1.028 and 0.0296, respectively. These values indicate that temperature may have some effect on trawl catchability of rock sole where bottom temperatures anomalies ranging from -2 to 2 degrees Celsius would affect the value of the estimate of q by 0.4. However the estimated mean value of q in the absence of any temperature effect was estimated at 2.8, an unrealistic value indicating that 64% of the fish caught were herded into the trawl path. To constrain the estimates of q to more realistic values, the catchability of northern rock sole was formulated as discussed below while still allowing annual effects on q as a function of water temperature.

Experiments conducted in recent years on the standard research trawl used in the annual trawl surveys indicate that rock sole are herded by the bridles (in contact with the seafloor) from the area outside the net mouth into the trawl path (Somerton and Munro 2001). Rock sole survey trawl catchability was estimated at 1.4 from these experiments (standard error = 0.056) which indicate that the standard area-swept biomass estimate from the survey is an overestimate of the rock sole population biomass.

These experimental results, in combination with the results of the bottom temperature analysis above, provided a compelling reason to consider an alternative model where survey catchability is estimated. As in past assessments we use the value of q from the herding experiment to constrain survey catchability and then estimate survey catchability as follows:

$$qprior = 0.5\left[\frac{q_{\exp} - q_{\mathrm{mod}}}{\sigma_{\exp}}\right]^2$$

where *qprior* is the survey catchability prior value, q_{mod} is the survey catchability parameter estimated by the model, q_{exp} is the estimate of area-swept q from the herding experiment, and σ is the standard error of the experimental estimate of q.

Model evaluation

The model evaluation for this stock assessment first evaluates the productivity of the northern rock sole stock by an examination of which data sets to include for spawner-recruit fitting and then evaluates various combinations of natural mortality and catchability estimates using a preferred set of spawner-recruit time-series data.

The SSC determined in December 2006 that northern rock sole would be managed under the Tier 1 harvest guidelines, and therefore future harvest recommendations would be based on MSY and F_{MSY} values calculated from a spawner-recruit relationship. MSY is an equilibrium concept and its value is dependent on both the spawner-recruit estimates which are assumed to represent the equilibrium stock size-recruitment relationship and the model used to fit the estimates. In the northern rock sole stock assessment model, a Ricker form of the stock-recruit relationship was fit to these data inside the model using a value of 0.6 to allow variability in the fitting process. Estimates of F_{MSY} and B_{MSY} were calculated assuming that the fit to the stock-recruitment data represents the long-term productivity of the stock.

This analysis was not repeated for this assessment, but is summarized as follows: Three different stock-recruitment time-series were investigated including the full time-series 1978-2006 (Model A, preferred method based on guidance from a recent Plan Team stock recruitment workshop and report), the years of consecutive poor recruitment events (1989-2001) (Model B), and the period of high recruitment during the 1980s, 1978-90 (Model C) (Fig. 8.14). Estimates of the harvest rates which would ensure the long-term sustainability of the stock ranged from F_{MSY} values of 0.1 – 0.144, depending on which years of stock-recruitment data points were included in the fitting procedure. High values are estimated for F_{MSY} when the full time series is used (Model A) and lower values were obtained (as expected) when the poor recruitment time-series (Model B) was used. Model C (the most productive time series 1978-1990) was data limited and does not have enough contrast in spawning stock size to fit the spawner-recruit data, does not converge properly, and gives an unrealistic estimate of B_{msy}. Large recruitments of northern rock sole that occurred at a low spawning stock size in the 1980s determine that the stock is most productive at a smaller stock size (B_{MSY} = 260,000 t) with the result that F_{MSY} is highest when fitting the full data set. Since the time-series is only available for 27 years now, we use the full time-series (Model A) for our estimate of the productivity of the stock.

For this assessment model runs were made to explore different states of nature by examining combinations of fixing and/or estimating male M, female M and q to discern the range of their values and their effect on the resulting estimates of 2015 female spawning biomass, ABC and SPR rates ($F_{40\%}$).

For the runs where q was fixed, it was set at 1.5 since this value was close to the value from the herding experiment (Models 1, 2 and 3). In runs where q is estimated, a strong prior was used to constrain q to the value from the trawl herding study.

Model exploration	q	female M	male M	2015 FSB	2015 ABC	F_{ABC}
Model 1 q fixed at 1.5, male and female M fixed at 0.15	1.5	0.15	0.15	622,300	181,700	0.147
Model 1a q fixed at 1.4, male and female M fixed at 0.15	1.4	0.15	0.15	676,500	195,000	0.146
Model 2 q fixed at 1.5, female M fixed at 0.15 and male M estimated	1.5	0.15	0.18	692,700	186,000	0.155
Model 3 q fixed at 1.5, female M and male M estimated	1.5	0.164	0.194	648,000	175,400	0.153
Model 4 q estimated, Female and male M fixed at 0.15	2.21	0.15	0.15	385,800	122,600	0.157
Model 5 q estimated, female M fixed at 0.15 and male M estimated	1.96	0.15	0.179	481,000	162,000	0.158

Model 6 q, female M and male M all estimated as free parameters	2.10	0.145	0.173	464,300	134,300	0.163
Model 7 q estimated with the bottom temperature relationship, male and female M fixed at 0.15	1.4	0.15	0.15	673.41	193.500	0.146

These model runs indicate that fixing q at 1.5 provides a constraint on the estimates of natural mortality with males estimated at a little higher value than females (Models 2 and 3). Fixing the female or both the male and female M (Models 4 and 5) has less of a constraint on q and values are estimated as high as 2.21 (Model 4) and 1.96 (Model 5). Allowing all three parameters to be freely estimated results in estimates of q and female stock size in-between Models 4 and 5 (Model 6). The model run which estimates q as a function of the annual bottom temperature (Model 7) during the surveys (with male and female M fixed at 0.15) sets q at 1.4 by fixing the alpha value in the temperature-q equation and then allows the beta value to co-vary with annual bottom temperature. The result is an improved fit to the survey biomass time-series and fits the experimental value of q better than model 4 (also with M fixed for both sexes) since the effect of the penalty is greater in Model 7 since it's applied in every year rather than only for 1 q in each year as in model 4. The results of Model 7 are very similar to Model 1.

Models 4-6 provide estimates of survey catchability which range from 1.96 to 2.21. These estimates represent a large difference in the estimate of q compared to what was estimated from the herding experiment (1.4). These results would indicate that 55% (Model 4) and 50% (Model 5) of the northern rock sole present in trawl survey catches were herded into the net from the areas between where the sweep lines contact the bottom, compared to a value of 29% from the catchability experiment. The reason for this difference in the q estimate is the trade-off in the model in reconciling the survey biomass trend with the population age composition and is not related to changes in fish behavior in the trawl path. Regarding fitting M as a free parameter in the model (males only or both sexes), both models 2 and 3 gave similar results in the level of M and abundance estimates, but they do not fit the observed sex ratio from the observed survey age composition as well as using the fixed M values in Model 1 (Fig. 8.9). Therefore, the model of choice for this assessment is Model 1 where q is constrained at a value close to the experimental result, M is fixed at values close to those estimated for each sex, and the model run results in a better fit to the observed population sex ratio. Model 7 gives similar results to model 1 but does not fit the observed age compositions as well and is not selected as the model of choice from an AIC analysis. A slightly modified version of base Model 1 that sets q at the experimental value (1.4 instead of 1.5) is also introduced for consideration in this assessment (from an SSC member's review of the SAFE document). This model, Model 1a, gives similar results as the base model (7% higher ABC due to lower q).

MODEL RESULTS

The 2014 bottom trawl survey point estimate is a 6% increase over the 2013 estimate and the stock abundance is at the same levels estimated for the past 12 years in the trawl surveys. The stock assessment model fits the 2014 survey value but is higher than the 7 previous estimates. The model results indicate that the stock condition has been stable to increasing. This is the result of the combination of strong recruitment from the 2001-2003 and 2005 year classes which are presently at the age of maximum cohort biomass and light fishery exploitation.

Fishing Mortality and Selectivity

The assessment model estimates of the annual fishing mortality on fully selected ages and the estimated annual exploitation rates (catch/total biomass) are given Table 8.13. The exploitation rate has averaged 3.5% from 1975-2014, indicating a lightly exploited stock. Age and sex-specific selectivity estimated by the model (Table 8.14, Fig. 8.10) indicate that male and female rock sole are 50% selected by the fishery at about ages 8 and 9, respectively, and are nearly fully selected by ages 12 and 13.

Abundance Trend

The stock assessment model indicates that rock sole total biomass was at low levels during the mid 1970s through 1982 (200,000 - 400,000 t, Fig. 8.11 and Table 8.15). From 1985-95, a period characterized by sustained above-average recruitment (1980-88 year classes, Fig. 8.11) and light exploitation, the estimated total biomass rapidly increased at a high rate to nearly 1.7 million t by 1997. Since then, the model indicates the population biomass declined 11% to 1.5 million t in 2004 before increasing to 1.7 million t in 2007 and declining slightly to the present level of 1.4 million t. The decline from 1995-2003 was attributable to the below average recruitment to the adult portion of the population during the 1990s. The increase the past three years is the result of increased recruitment in 2001-2005. The female spawning biomass is estimated to be at a high level (632,500 in 2014) and has been increasing after a low of 491,000 t in 2007. As the strong year classes spawned in 2001-2004 are now maturing the female spawning biomass is increasing (Table 8.15). The model provides good fits to most of the strong year classes observed in the fishery and surveys during the time-series (Fig. 8.12).

The model estimates of survey biomass (using trawl survey age-specific selectivity and the estimate of q applied to the total biomass, Fig. 8.11) correspond fairly well with the trawl survey biomass trend with the exception of the cold year of 1999 and also 2009. Although 2006 through 2013 have been relatively cold years in the eastern Bering Sea, the northern rock sole survey biomass estimate remained steady, which may indicate the lack of a relationship between survey catchability and bottom temperatures, as shown for other flatfish species. Both the trawl survey and the model indicate the same increasing biomass trend from the late 1970s to the mid 1990s but the survey does not indicate the declining trend after the mid 1990s that the model estimates. The model fit is within the 95% confidence intervals of the survey biomass point estimates for 27 of the 33 annual surveys. Posterior distributions of some selected model parameters from the preferred stock assessment model (Model 1) are presented in Figure 8.13.

Total Biomass

The stock assessment projection model estimates total biomass (mid-year population numbers multiplied by mid-year weight at age) for 2015 at **1,233,400** t (including the 2014 catch estimated at 52,250 t).

Recruitment Trends

Increases in abundance for rock sole during the 1980s can be attributed to the recruitment of a series of strong year classes (Figs. 8.5 and 8.9, Table 8.16). The 8-12 year old fish are the dominant age classes in the fishery (by numbers). Recruitment during the 1990s, with the exception of the 1990 year class, was below the 34 year average and has resulted in a flat survey age composition for ages 10+. The 2001-2005 year classes are estimated to be strong (2004 is average) as discerned from the last 6 survey age samples and are now contributing to an increased spawning stock size.

The stock assessment model estimates of the population numbers at age for each sex, estimated number of female spawners, selected parameter estimates and their standard deviations and estimated annual fishing mortality by age and sex are shown in Tables 8.17-8.20, respectively.

ACCEPTABLE BIOLOGICAL CATCH

The SSC has determined that northern rock sole qualify as a Tier 1 stock and therefore the 2015 ABC is calculated using Tier 1 methodology. Using this approach the 2015 fishing mortality recommendation is $F_{ABC} = F_{\text{harmonic mean}} = 0.147$. The Tier 1 harvest level is calculated as the product of the harmonic mean of F_{MSY} and the geometric mean of the 2015 6+ biomass estimate, as follows:

$B_{gm} = e^{\ln \hat{B} - \frac{cv^2}{2}}$, where B_{gm} is the geometric mean of the 2015 6+ biomass estimate, $\hat{B}$ is the point estimate of the 2015 6+ biomass from the stock assessment model and cv^2 is the coefficient of variation of the point estimate;
and

$\bar{F}_{har} = e^{\ln \hat{F}_{msy} - \frac{\ln sd^2}{2}}$, where $\bar{F}_{har}$ is the harmonic mean, $\hat{F}_{msy}$ is the peak mode of the F_{MSY} distribution and sd^2 is the square of the standard deviation of the F_{MSY} distribution. **This calculation gives a Tier 1 ABC harvest recommendation of 181,700 t and an OFL of 187,600 t for 2015**. The projection of 2015 ABC from last year's assessment was 208,300 t and the OFL was projected at 233,100 t.

These ABC and OFL values represent a 3% (6,000 t) buffer between ABC catch and overfishing.

The stock assessment analysis must also consider harvest limits, usually described as overfishing fishing mortality levels with corresponding yield amounts. Amendment 56 to the BSAI FMP sets the Tier 1 harvest limit at the F_{MSY} fishing mortality value. The overfishing fishing mortality values, ABC fishing mortality values and their corresponding yields are given as follows:

Harvest level	F value	2015 Yield
Tier 1 $F_{OFL} = F_{MSY}$	**0.152**	**187,600 t**
Tier 1 $F_{ABC} = F_{\text{harmonic mean}}$	**0.147**	**181,700 t**

BIOMASS PROJECTIONS

Status Determination

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2014 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2015 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2014. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2015, are as follows ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2015 recommended in the assessment to the *max* F_{ABC} for 2015. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 2010-2014 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY level in 2014 and above its MSY level in 2026 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, F is set equal to $max\ F_{ABC}$, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2027 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 8.21 indicate that northern rock sole are currently not overfished and are not approaching an overfished condition. If harvested at the average F from 2010-2014, northern rock sole female spawning biomass is projected to decrease slowly due to the ageing of the strong recruitment from 2001-2005 that has built the FSB in recent years (Fig. 8.16). The ABC and TAC values that have been used to manage the northern rock sole resource since 1989 are shown in Table 8.22 and a phase plane diagram showing the estimated time-series of female spawning biomass and fishing mortality relative to the harvest control rule is in Figure 8.17.

Scenario Projections and Two-Year Ahead Overfishing Level

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. The 2014 numbers at age from the stock assessment model are projected to 2015 given the 2014 catch and then a 2015 catch of 65,000 t is applied to the projected 2015 population biomass to obtain the 2016 OFL.

Tier 1 Projection

Year	Catch	FSB	Geometric mean 6+ total biomass	ABC	OFL
2015	65,000	622,300	1,233,400	181,700	187,600
2016	65,000	589,800	1,118,700	164,800	170,100

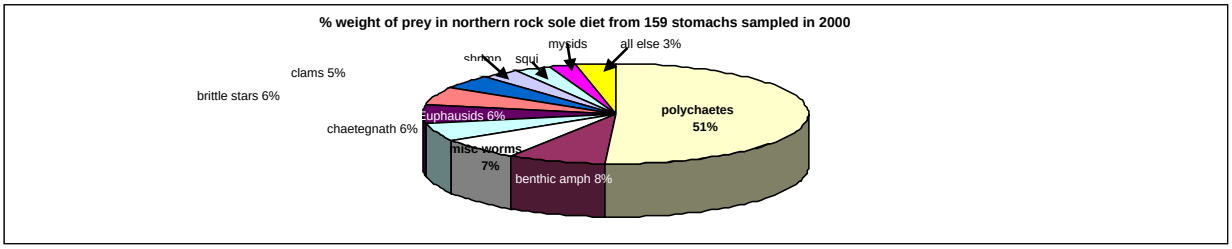
ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the stock

1) Prey availability/abundance trends

Rock sole diet by life stage varies as follows: Larvae consume plankton and algae, early juveniles consume zooplankton, late juvenile stage and adults prey includes bivalves, polychaetes, amphipods, mollusks and miscellaneous crustaceans. Information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not be re-sampled since. The large populations of flatfish which have occupied the middle shelf of the Bering Sea over the past thirty years for summertime feeding do not appear food-limited. These populations have

fluctuated due to the variability in recruitment success which suggests that the primary infaunal food source has been at an adequate level to sustain the northern rock sole resource.



2) Predator population trends

As juveniles, it is well-documented from studies in other parts of the world that flatfish are prey for shrimp species in near shore areas. This has not been reported for Bering Sea northern rock sole due to a lack of juvenile sampling and collections in near shore areas, but is thought to occur. As late juveniles they are found in stomachs of pollock, Pacific cod, yellowfin sole, skates and Pacific halibut; mostly on small rock sole ranging from 5 to 15 cm standard length.

Past, present and projected future population trends of these predator species can be found in their respective SAFE chapters in this volume. Encounters between rock sole and their predators may be limited as their distributions do not completely overlap in space and time.

3) Changes in habitat quality

Changes in the physical environment which may affect rock sole distribution patterns, recruitment success, migration timing and patterns are catalogued in the Ecosystem Considerations Appendix of this SAFE report. Habitat quality may be enhanced during years of favorable cross-shelf advection (juvenile survival) and warmer bottom water temperatures with reduced ice cover (higher metabolism with more active feeding).

Fishery Effects on the ecosystem

1) The rock sole target fishery contribution to the total bycatch of other target species is shown for 1991-2013 in Table 8.23 and the catch of non-target species from the rock sole fishery is shown in Table 8.24. The northern rock sole target fishery contribution to the total bycatch of prohibited species is shown for 2011 and 2012 in Table 13 of the Economic SAFE (Appendix C) and is summarized for 2012 as follows:

Prohibited species	Rock sole fishery % of total bycatch
Halibut mortality	12
Herring	<1
Red King crab	51
C. bairdi	14
Other Tanner crab	2
Salmon	< 1

2) Relative to the predator needs in space and time, the rock sole target fishery is not very selective for fish between 5-15 cm and therefore has minimal overlap with removals from predation.

3) The target fishery is not perceived to have an effect on the amount of large size target fish in the population due to the history of very light exploitation (3%) over the past 30 years.

4) Rock sole fishery discards are presented in the Catch History section.

5) It is unknown what effect the fishery has had on rock sole maturity-at-age and fecundity.

6) Analysis of the benthic disturbance from the rock sole fishery is available in the Essential Fish Habitat Environmental Impact Statement

Ecosystem effects on rock sole			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Benthic infauna	Stomach contents	Stable, data limited	Unknown
Predator population trends			
Fish (Pollock, Pacific cod, halibut, yellowfin sole, skates)	Stable	Possible increases to rock sole mortality	
Changes in habitat quality			
Temperature regime	Cold years rock sole catchability and herding may decrease	Likely to affect surveyed stock	No concern (dealt with in model)
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability

Rock sole effects on ecosystem			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Minor contribution to mortality	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	No concern
HAPC biota	Low bycatch levels of (spp)	Bycatch levels small relative to HAPC biota	No concern
Marine mammals and birds	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Low exploitation rate	Little detrimental effect	No concern
Fishery effects on amount of large size target fish	Low exploitation rate	Natural fluctuation	No concern
Fishery contribution to discards and offal production	Stable trend	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	unknown	NA	Possible concern

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Table 8.1--Rock sole catch (t) from 1977 - September 30, 2014.

Year	Foreign	Joint-Venture	Domestic	Total
1977	5,319			5,319
1978	7,038			7,038
1979	5,874			5,874
1980	6,329	2,469		8,798
1981	3,480	5,541		9,021
1982	3,169	8,674		11,843
1983	4,479	9,140		13,619
1984	10,156	27,523		37,679
1985	6,671	12,079		18,750
1986	3,394	16,217		19,611
1987	776	11,136	28,910	40,822
1988		40,844	45,522	86,366
1989		21,010	47,902	68,912
1990		10,492	24,761	35,253
1991			60,587	60,587
1992			56,998	56,998
1993			63,953	63,953
1994			59,606	59,606
1995			58,870	58,870
1996			46,928	46,928
1997			67,564	67,564
1998			33,642	33,642
1999			40,510	40,510
2000			49,264	49,264
2001			29,255	29,255
2002			41,331	41,331
2003			35,395	35,395
2004			47,637	47,637
2005			35,546	35,456
2006			36,411	36,411
2007			36,768	36,768
2008			51,275	51,275
2009			48,649	48,649
2010			53,221	53,221
2011			60,401	60,401
2012			76,099	76,099
2013			59,773	59,773
2014			52,250	52,250

Table 8.2 Retained and discarded catch (t) in Bering Sea fisheries, 1987-2013.

Year	Retained (t)	Discarded (t)	% Retained
1987	14,209	14,701	49
1988	22,374	23,148	49
1989	23,544	24,358	49
1990	12,170	12,591	49
1991	25,406	35,181	42
1992	21,317	35,681	37
1993	22,589	45,669	33
1994	20,951	39,945	34
1995	21,761	33,108	40
1996	19,770	27,158	42
1997	27,743	39,821	41
1998	12,645	20,999	38
1999	15,224	25,286	38
2000	22,151	27,113	45
2001	19,299	9,956	66
2002	23,607	17,724	57
2003	19,492	15,903	55
2004	26,600	21,037	56
2005	23,172	12,376	65
2006	28,577	7,834	78
2007	27,826	8,942	76
2008	45,945	5,330	90
2009	43,478	5,172	89
2010	50,160	3,061	94
2011	56,105	4,527	93
2012	70,772	5,327	93
2013	56,784	2,989	95

Table 8.3--Discarded and retained rock sole catch (t), by target fishery, in 2013.

	Discarded	Retained
Atka Mackerel	7	33
Pollock - bottom	227	4,143
Pacific Cod	338	660
Alaska Plaice	2	45
Other Flatfish		
Halibut		
Rockfish	11	65
Flathead Sole	39	2,050
Other Species		
Pollock - midwater	1,079	910
Rock Sole	1,193	41,206
Sablefish		
Greenland Turbot		
Arrowtooth Flounder	1	25
Yellowfin Sole	284	7,453
Total catch		**59,773**

Table 8.4--Estimated catch numbers at age, 1980-2014 (in millions).
Females

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1980	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.06	0.16	0.22	0.44	0.59	0.89	1.03	1.04	1.04	1.05	1.07	1.08
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.05	0.13	0.18	0.36	0.49	0.72	0.83	0.84	0.82	0.83	1.69
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.05	0.11	0.16	0.28	0.33	0.40	0.42	0.38	0.37	1.13
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.12	0.25	0.35	0.58	0.47	0.43	1.71
1984	0.00	0.00	0.00	0.02	0.02	0.06	0.14	0.45	2.00	2.16	1.16	0.91	0.74	0.57	0.25	0.15	0.06	0.03	0.03	0.13
1985	0.07	0.14	0.35	0.52	1.96	1.42	1.74	1.42	1.65	3.11	1.99	0.84	0.61	0.48	0.37	0.16	0.09	0.04	0.02	0.10
1986	0.15	0.23	0.47	1.16	1.45	3.76	1.75	1.58	1.11	1.22	2.25	1.43	0.60	0.44	0.34	0.26	0.11	0.07	0.03	0.09
1987	0.07	0.22	0.37	0.82	2.06	2.31	5.01	2.07	1.77	1.22	1.33	2.45	1.55	0.66	0.47	0.37	0.29	0.12	0.07	0.13
1988	0.02	0.06	0.18	0.27	0.54	1.33	1.68	4.49	2.15	1.96	1.39	1.52	2.82	1.79	0.75	0.55	0.43	0.33	0.14	0.23
1989	0.10	0.16	0.44	1.08	1.41	2.41	4.84	4.82	10.43	4.47	3.93	2.75	3.01	5.57	3.53	1.49	1.08	0.85	0.65	0.73
1990	0.17	0.57	1.20	3.74	8.40	6.65	5.16	4.53	2.29	3.23	1.12	0.91	0.61	0.66	1.22	0.78	0.33	0.24	0.19	0.30
1991	0.02	0.06	0.23	0.54	1.98	5.47	5.22	4.40	3.94	2.00	2.82	0.98	0.79	0.54	0.58	1.07	0.68	0.29	0.21	0.43
1992	0.33	0.53	1.56	4.31	6.82	13.58	17.80	9.65	6.41	5.38	2.69	3.78	1.31	1.06	0.72	0.78	1.43	0.91	0.38	0.85
1993	0.78	1.45	2.37	6.89	17.50	22.07	31.46	31.66	15.13	9.60	7.93	3.94	5.54	1.92	1.55	1.05	1.14	2.10	1.33	1.81
1994	0.05	0.56	1.29	2.58	8.74	21.68	20.98	22.36	19.27	8.69	5.41	4.44	2.21	3.09	1.07	0.87	0.59	0.64	1.17	1.75
1995	0.05	0.17	1.33	2.36	3.46	7.78	12.11	8.50	8.06	6.77	3.04	1.89	1.56	0.77	1.08	0.38	0.30	0.21	0.22	1.02
1996	0.10	0.11	0.30	1.95	2.86	3.56	7.48	12.68	10.69	11.81	10.78	5.02	3.17	2.62	1.30	1.83	0.64	0.51	0.35	2.11
1997	0.02	0.09	0.10	0.29	2.05	3.19	4.15	8.71	13.64	10.08	9.95	8.52	3.86	2.41	1.98	0.98	1.38	0.48	0.39	1.85
1998	0.01	0.04	0.20	0.24	0.72	5.14	7.83	9.14	15.05	17.10	9.79	8.44	6.84	3.03	1.88	1.54	0.76	1.07	0.37	1.74
1999	0.00	0.01	0.04	0.19	0.23	0.72	5.24	8.00	9.04	13.81	14.51	7.92	6.70	5.38	2.38	1.47	1.21	0.60	0.84	1.65
2000	0.00	0.02	0.03	0.13	0.65	0.74	2.15	13.73	16.73	13.39	14.43	12.17	6.04	4.93	3.92	1.73	1.07	0.87	0.43	1.80
2001	0.00	0.00	0.01	0.02	0.11	0.58	0.68	2.05	12.83	14.19	9.78	9.36	7.43	3.59	2.91	2.30	1.01	0.63	0.51	1.31
2002	0.04	0.05	0.09	0.31	0.38	1.33	4.64	3.51	6.48	24.54	17.70	9.49	8.26	6.43	3.11	2.53	2.01	0.88	0.55	1.59
2003	0.00	0.01	0.01	0.02	0.07	0.09	0.37	1.48	1.27	2.63	10.73	7.92	4.19	3.58	2.73	1.31	1.06	0.83	0.37	0.89
2004	0.00	0.00	0.02	0.03	0.06	0.27	0.40	1.63	6.06	4.16	5.93	16.23	8.81	3.90	3.04	2.23	1.05	0.84	0.66	1.00
2005	0.00	0.01	0.01	0.05	0.09	0.21	0.93	1.30	4.53	12.38	6.00	6.62	15.77	8.06	3.48	2.69	1.97	0.92	0.74	1.46
2006	0.02	0.03	0.06	0.10	0.37	0.58	1.10	3.08	2.37	4.50	7.94	3.05	3.04	6.99	3.52	1.51	1.17	0.85	0.40	0.96
2007	0.02	0.03	0.04	0.11	0.20	0.86	1.39	2.36	5.31	3.38	5.79	9.77	3.68	3.65	8.35	4.21	1.81	1.39	1.02	1.62
2008	0.05	0.11	0.17	0.20	0.46	0.65	2.02	2.13	2.46	4.44	2.59	4.32	7.23	2.72	2.69	6.17	3.11	1.33	1.03	1.95
2009	0.02	0.08	0.18	0.29	0.34	0.81	1.14	3.30	3.11	3.27	5.61	3.20	5.30	8.83	3.32	3.29	7.52	3.79	1.63	3.63
2010	0.02	0.06	0.21	0.46	0.74	0.83	1.72	1.81	3.69	2.62	2.37	3.82	2.13	3.50	5.83	2.19	2.16	4.95	2.50	3.46
2011	0.02	0.04	0.16	0.59	1.41	2.31	2.35	3.64	2.66	4.15	2.59	2.23	3.53	1.96	3.21	5.33	2.00	1.98	4.53	5.45
2012	0.00	0.03	0.07	0.29	1.15	2.85	4.38	3.51	4.07	2.49	3.60	2.19	1.87	2.95	1.63	2.67	4.44	1.67	1.65	8.32
2013	0.00	0.02	0.10	0.23	0.86	3.16	6.88	8.50	5.39	5.44	3.16	4.51	2.73	2.33	3.67	2.04	3.33	5.54	2.08	12.42
2014	0.00	0.01	0.03	0.23	0.57	2.27	7.88	12.89	10.20	4.62	4.01	2.21	3.10	1.87	1.59	2.51	1.39	2.28	3.78	9.90

Males

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1980	0.00	0.00	0.00	0.01	0.04	0.08	0.16	0.39	0.82	1.36	1.36	1.62	1.40	1.37	1.38	1.33	1.32	1.34	1.35	1.35
1981	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.12	0.31	0.65	1.09	1.09	1.31	1.13	1.10	1.11	1.07	1.06	1.08	2.18
1982	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.12	0.28	0.55	0.78	0.63	0.66	0.54	0.52	0.52	0.50	0.49	1.52
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.06	0.16	0.35	0.64	0.75	1.05	0.97	0.97	0.97	0.93	3.73
1984	0.00	0.00	0.00	0.01	0.01	0.03	0.07	0.24	0.95	0.99	0.70	0.54	0.34	0.17	0.06	0.03	0.02	0.01	0.01	0.06
1985	0.13	0.24	0.58	0.79	2.66	1.68	1.10	0.94	1.08	1.63	0.93	0.51	0.36	0.22	0.11	0.04	0.02	0.01	0.01	0.05
1986	0.22	0.39	0.89	2.23	2.36	4.79	1.92	0.95	0.73	0.80	1.18	0.67	0.36	0.26	0.16	0.08	0.03	0.01	0.01	0.04
1987	0.10	0.26	0.34	0.60	1.31	1.50	3.78	1.81	0.98	0.78	0.86	1.28	0.72	0.40	0.28	0.17	0.09	0.03	0.02	0.05
1988	0.04	0.08	0.17	0.18	0.27	0.53	0.61	1.81	1.14	0.80	0.75	0.91	1.42	0.82	0.45	0.32	0.20	0.10	0.04	0.08
1989	0.64	0.83	1.77	3.46	3.52	4.59	7.05	5.67	10.96	4.52	2.30	1.78	1.96	2.91	1.65	0.90	0.64	0.39	0.20	0.23
1990	0.28	1.12	2.66	7.97	13.58	8.03	5.41	4.54	2.30	3.30	1.15	0.54	0.40	0.43	0.64	0.36	0.20	0.14	0.09	0.09
1991	0.06	0.22	0.82	1.85	5.62	10.48	6.71	4.67	3.95	2.01	2.88	1.01	0.47	0.35	0.38	0.56	0.32	0.17	0.12	0.16
1992	0.41	0.75	2.49	7.45	11.38	18.79	20.19	9.95	6.40	5.32	2.69	3.85	1.35	0.63	0.47	0.51	0.75	0.42	0.23	0.37
1993	0.30	0.89	2.28	10.08	32.07	34.90	37.82	32.76	15.02	9.46	7.82	3.94	5.65	1.97	0.93	0.69	0.74	1.10	0.62	0.89
1994	0.11	1.12	2.67	5.36	16.47	31.16	22.84	21.76	18.38	8.40	5.28	4.37	2.20	3.16	1.10	0.52	0.39	0.42	0.61	0.84
1995	0.06	0.26	2.88	6.59	10.10	16.75	16.83	9.04	7.85	6.48	2.94	1.85	1.53	0.77	1.10	0.39	0.18	0.14	0.15	0.51
1996	0.09	0.12	0.46	3.94	7.40	10.60	20.33	24.66	14.58	13.09	10.92	4.98	3.13	2.59	1.30	1.87	0.65	0.31	0.23	1.11
1997	0.02	0.13	0.19	0.70	6.04	10.91	13.70	20.93	21.03	11.42	9.97	8.25	3.75	2.36	1.95	0.98	1.41	0.49	0.23	1.01
1998	0.01	0.05	0.35	0.52	2.03	17.15	25.74	21.65	22.17	18.10	9.14	7.81	6.42	2.92	1.83	1.51	0.76	1.09	0.38	0.96
1999	0.00	0.00	0.03	0.25	0.46	2.17	20.90	30.10	20.90	18.69	14.49	7.21	6.13	5.04	2.28	1.44	1.19	0.60	0.86	1.05
2000	0.00	0.02	0.03	0.15	0.81	0.96	2.91	18.28	19.84	13.30	12.63	10.20	5.17	4.42	3.64	1.65	1.04	0.86	0.43	1.38
2001	0.01	0.02	0.08	0.11	0.47	1.96	1.81	4.13	18.94	15.32	8.50	7.50	5.96	3.02	2.59	2.13	0.97	0.61	0.50	1.06
2002	0.02	0.03	0.08	0.34	0.51	2.21	9.08	7.37	12.67	39.21	21.88	9.45	7.30	5.46	2.69	2.28	1.87	0.85	0.53	1.37
2003	0.00	0.00	0.00	0.01	0.04	0.10	0.63	3.75	3.90	6.86	19.18	9.81	4.05	3.07	2.27	1.12	0.95	0.78	0.35	0.79
2004	0.00	0.00	0.01	0.02	0.05	0.26	0.42	1.85	7.11	4.69	6.14	15.50	7.77	3.20	2.43	1.80	0.89	0.75	0.62	0.91
2005	0.00	0.00	0.01	0.04	0.07	0.20	1.00	1.54	5.43	13.95	6.20	6.39	14.50	6.98	2.84	2.14	1.59	0.78	0.66	1.34
2006	0.01	0.02	0.05	0.08	0.31	0.52	1.07	3.12	2.41	4.52	7.84	2.94	2.85	6.34	3.04	1.23	0.93	0.69	0.34	0.87
2007	0.05	0.10	0.14	0.39	0.67	2.48	2.90	3.43	6.13	3.53	5.83	9.62	3.54	3.41	7.58	3.63	1.47	1.11	0.82	1.44
2008	0.05	0.14	0.28	0.41	1.13	1.61	4.03	3.11	2.90	4.73	2.64	4.32	7.11	2.61	2.52	5.60	2.68	1.09	0.82	1.67
2009	0.04	0.15	0.42	0.84	1.18	2.87	3.14	6.01	4.06	3.61	5.80	3.23	5.27	8.67	3.19	3.07	6.82	3.26	1.32	3.03
2010	0.05	0.18	0.69	1.73	2.93	2.93	4.25	2.92	4.42	2.76	2.40	3.83	2.13	3.47	5.71	2.10	2.02	4.50	2.15	2.87
2011	0.04	0.08	0.28	0.99	2.28	3.48	3.08	4.08	2.70	4.05	2.52	2.19	3.50	1.95	3.18	5.22	1.92	1.85	4.11	4.59
2012	0.02	0.13	0.27	0.98	3.35	6.63	7.38	4.34	4.24	2.43	3.46	2.12	1.83	2.92	1.62	2.65	4.35	1.60	1.54	7.25
2013	0.00	0.02	0.13	0.29	1.08	3.88	8.05	9.24	5.48	5.32	3.03	4.32	2.64	2.28	3.64	2.02	3.30	5.43	1.99	10.96
2014	0.00	0.02	0.09	0.54	1.13	3.78	10.62	14.32	10.23	4.49	3.85	2.11	2.96	1.81	1.56	2.49	1.38	2.25	3.70	8.84

Table 8.5 Bottom trawl survey biomass estimates (t) from the Eastern Bering Sea shelf and the Aleutian Islands for northern rock sole.

year	Bering Sea	Aleutians
1975	175,500	
1979	194,700	
1980	283,800	28,500
1981	302,400	
1982	578,800	
1983	713,000	23,300
1984	799,300	
1985	700,100	
1986	1,031,400	26,900
1987	1,269,700	
1988	1,480,100	
1989	1,138,600	
1990	1,381,300	
1991	1,588,300	37,325
1992	1,543,900	
1993	2,123,500	
1994	2,894,200	54,785
1995	2,175,040	
1996	2,183,000	
1997	2,710,900	45,303
1998	2,168,700	
1999	1,689,100	
2000	2,127,700	37,220
2001	2,135,400	
2002	1,921,400	48,406
2003	2,424,800	
2004	2,182,100	43,052
2005	2,119,100	
2006	2,215,670	69,366
2007	2,032,954	
2008	2,031,612	
2009	1,539,030	
2010	2,064,870	49,177
2011	1,977,086	
2012	1,920,350	62,479
2013	1,752,970	
2014	1,857,450	43,259

Table 8.6—Total tonnage of northern rock sole caught in resource assessment trawl surveys on the Bering Sea shelf, 1977-2014.

year	research catch (t)
1977	10
1978	14
1979	13
1980	20
1981	12
1982	26
1983	59
1984	63
1985	34
1986	53
1987	52
1988	82
1989	83
1990	88
1991	97
1992	46
1993	75
1994	113
1995	99
1996	72
1997	91
1998	79
1999	72
2000	72
2001	81
2002	69
2003	75
2004	84
2005	74
2006	83
2007	76
2008	76
2009	62
2010	80
2011	67
2012	70
2013	63
2014	66

Table 8-7 --Rock sole weight-at-age (grams) by age and year determined from 1983-2011 from length-at-age and length-weight relationships (missing values filled in) from the annual trawl survey in the eastern Bering Sea. Three year running average was used to model rock sole weight-at-age in the assessment.

	females																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1982	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1983	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1984	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1985	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1986	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1987	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1988	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1989	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1990	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1991	9	15	30	59	112	183	267	363	439	489	577	570	612	667	714	790	862	939	889	815
1992	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
1993	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
1994	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
1995	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
1996	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
1997	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
1998	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
1999	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
2000	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
2001	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
2002	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
2003	9	11	26	50	78	110	165	211	278	346	397	452	496	566	571	610	707	709	753	821
2004	9	17	25	54	114	181	272	269	327	387	421	479	462	504	514	523	562	537	626	632
2005	9	17	25	54	114	181	272	269	327	387	421	479	462	504	514	523	562	537	626	632
2006	9	17	25	54	114	181	272	269	327	387	421	479	462	504	514	523	562	537	626	632
2007	9	17	25	54	114	181	272	269	327	387	421	479	462	504	514	523	562	537	626	632
2008	9	15	19	39	52	123	157	326	336	477	437	568	499	0	415	548	573	556	588	714
2009	9	15	16	33	54	101	161	254	313	316	391	432	456	443	545	609	576	600	615	649
2010	9	15	22	49	72	117	151	232	307	347	453	461	449	534	604	520	537	578	456	583
2011	9	15	31	87	123	138	174	221	299	359	421	447	485	537	493	695	690	815	336	621
2012	9	15	31	87	123	138	174	221	299	359	421	447	485	537	493	695	690	815	336	621
2013	9	15	31	87	123	138	174	221	299	359	421	447	485	537	493	695	690	815	336	621
2014	9	15	31	87	123	138	174	221	299	359	421	447	485	537	493	695	690	815	336	621

Table 8.7 continued.

	males																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1982	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1983	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1984	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1985	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1986	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1987	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1988	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1989	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1990	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1991	7	11	13	26	55	100	153	213	256	259	311	301	314	353	367	330	455	342	366	360
1992	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
1993	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
1994	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
1995	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
1996	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
1997	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
1998	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
1999	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
2000	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
2001	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
2002	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
2003	7	10	23	44	67	96	151	185	221	232	273	282	307	301	330	357	393	453	420	438
2004	7	13	23	55	123	149	196	234	241	265	282	308	314	307	297	360	321	348	321	335
2005	7	13	23	55	123	149	196	234	241	265	282	308	314	307	297	360	321	348	321	335
2006	7	13	23	55	123	149	196	234	241	265	282	308	314	307	297	360	321	348	321	335
2007	7	13	23	55	123	149	196	234	241	265	282	308	314	307	297	360	321	348	321	335
2008	7	7	19	29	47	111	146	234	243	234	324	279	360	337	308	526	310	357	303	360
2009	7	7	15	31	54	91	153	206	232	292	285	368	303	285	319	330	398	354	298	290
2010	7	9	27	39	65	103	136	187	240	292	253	315	290	306	409	263	366	325	339	312
2011	7	9	23	56	78	110	163	192	254	223	264	275	360	341	336	340	344	340	390	370
2012	7	9	23	56	78	110	163	192	254	223	264	275	360	341	336	340	344	340	390	370
2013	7	9	23	56	78	110	163	192	254	223	264	275	360	341	336	340	344	340	390	370
2014	7	9	23	56	78	110	163	192	254	223	264	275	360	341	336	340	344	340	390	370

Table 8-8.--Mean length-at-age (cm) from the average of annual mean length at age and proportion mature for female Bering Sea rock sole from histological examination of ovaries collected from the 2006 fishery (Stark In Prep).

age	female length at age	male length at age	proportion mature
1	7.5	8.8	0.00
2	11.3	11.0	0.00
3	14.0	13.6	0.00
4	17.2	17.1	0.00
5	20.7	20.4	0.01
6	23.8	22.9	0.01
7	26.9	25.8	0.06
8	29.0	27.3	0.20
9	31.1	28.1	0.51
10	32.8	29.0	0.75
11	34.3	29.7	0.89
12	35.1	30.1	0.93
13	35.8	30.7	0.96
14	37.0	30.9	0.98
15	37.4	30.9	0.98
16	38.3	32.4	0.99
17	39.5	32.1	0.99
18	39.9	33.1	0.99
19	40.2	32.3	0.99
20	40.3	31.3	0.99

Table 8.9—Survey sample sizes of occurrence of northern rock sole and biological collections.

Year	Total hauls	Hauls with length	# of lengths	hauls with otoliths	# otoliths collected	# otoliths aged
1982	334	139	16874	32	312	312
1983	353	149	16285	14	444	444
1984	355	174	18203	22	458	454
1985	358	229	20891	25	571	571
1986	354	310	26078	14	404	404
1987	360	273	26167	6	422	422
1988	373	295	27671	14	350	350
1989	373	307	27434	22	675	675
1990	371	307	31769	30	634	634
1991	372	300	31059	20	551	551
1992	356	299	27188	17	525	525
1993	375	333	27624	12	443	443
1994	376	326	26793	18	467	466
1995	376	340	26764	14	434	378
1996	375	352	35230	14	500	496
1997	376	351	34927	10	339	336
1998	375	362	44055	22	409	405
1999	373	329	34086	26	490	484
2000	372	336	31953	23	410	403
2001	375	341	30113	24	418	411
2002	375	337	27563	34	503	283
2003	376	321	29520	34	518	506
2004	375	338	33373	12	407	401
2005	373	337	31048	19	417	407
2006	376	317	35470	44	539	539
2007	376	332	28467	46	485	463
2008	375	307	29422	23	370	370
2009	376	310	27994	66	599	579
2010	376	292	19365	61	524	490
2011	376	308	23140	54	390	384
2012	376	289	18192	48	355	348
2013	376	313	21189	44	358	352
2014	376	273	22808	32	283	

Table 8.10--Estimated population numbers-at-age (millions) from the annual Bering Sea trawl surveys, 1982- 2013.

year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1982	0	69	243	525	537	533	546	254	86	78	57	112	64	26	6	9	8	0	1	0
1983	0	65	624	570	644	321	325	368	168	142	56	76	105	54	38	25	5	2	1	0
1984	0	127	521	1,189	709	385	612	268	338	133	55	62	69	41	53	24	9	0	3	3
1985	9	141	353	937	906	423	263	202	116	130	29	13	6	14	37	31	7	7	2	8
1986	0	0	432	1,086	1,299	1,151	508	271	264	53	196	21	20	18	5	19	17	1	0	12
1987	0	17	714	1,014	1,081	848	972	256	251	164	72	206	30	8	10	4	18	4	2	17
1988	0	289	1,077	1,517	1,927	947	896	492	301	67	164	88	70	59	0	7	11	58	23	14
1989	0	108	777	947	1,092	1,256	723	538	399	123	89	89	65	76	25	23	2	2	15	22
1990	0	18	944	2,677	1,634	900	1,101	327	447	304	127	56	64	17	39	1	0	8	0	37
1991	0	12	98	2,717	2,165	1,346	967	830	452	409	254	133	84	61	37	14	0	4	5	27
1992	0	8	300	737	3,021	2,295	860	1,044	549	312	328	196	143	96	50	27	13	0	11	5
1993	0	39	998	1,390	1,256	3,977	2,192	1,025	964	543	158	150	141	98	48	11	0	0	5	10
1994	0	43	517	2,230	1,385	1,395	4,629	2,286	1,098	356	678	302	171	194	92	56	14	12	30	17
1995	0	0	157	942	2,096	932	699	2,533	1,503	524	570	406	164	140	100	0	10	4	4	9
1996	0	36	941	455	720	1,921	566	945	2,237	1,332	387	200	242	72	102	90	33	11	1	9
1997	0	4	539	1,531	590	958	2,693	562	1,000	2,113	707	653	447	273	138	134	66	30	0	15
1998	0	0	246	727	861	600	984	1,798	489	593	1,628	1,069	336	126	163	37	33	12	11	20
1999	0	0	62	105	295	836	116	623	1,473	831	586	1,381	530	239	112	123	27	27	11	2
2000	0	0	41	505	238	369	904	370	942	1,417	746	641	1,057	443	240	208	60	9	11	15
2001	0	22	181	218	637	452	371	938	510	1,178	1,193	512	647	989	416	189	67	53	16	4
2002	0	134	427	202	254	757	268	230	629	322	505	1,007	346	227	791	256	102	69	5	34
2003	11	682	1,108	542	436	209	709	348	199	255	164	539	1,154	257	402	729	204	123	82	38
2004	0	99	1,985	1,201	760	434	193	516	245	60	634	320	209	625	165	73	516	386	4	197
2005	0	213	2,011	2,336	1,616	349	479	326	405	133	161	152	115	476	313	234	274	432	229	205
2006	0	300	2,009	4,173	1,994	1,283	418	302	348	457	273	149	197	109	419	491	287	127	339	264
2007	1	61	710	1,720	2,105	1,632	1,067	493	173	507	211	210	214	207	302	274	161	156	152	153
2008	0	0	780	991	1,525	1,976	1,586	894	227	225	344	254	149	32	93	129	274	287	60	300
2009	0	9	233	1,423	948	1,097	1,314	823	523	81	190	54	186	77	86	84	98	173	193	262
2010	0	20	209	856	1,390	1,099	1,068	1,375	976	498	264	257	113	228	74	121	54	87	193	382
2011	0	0	226	293	729	1,366	899	1,004	1,124	598	412	180	126	88	133	26	39	48	29	292
2012	52	216	305	788	698	1,183	843	503	592	261	170	38	185	94	203	45	83	71	22	587
2013	1	140	37	101	228	434	941	806	786	604	514	267	72	122	19	85	31	54	40	445

Table 8.11--Key equations used in the population dynamics model.

$N_{t,1} = R_t = R_0 e^{\tau_t}, \quad \tau_t \sim N(0, \delta^2{}_R)$	Recruitment 1956-75
$N_{t,1} = R_t = R_\gamma e^{\tau_t}, \ \tau_t \sim N(0, \delta^2{}_R)$	Recruitment 1976-96
$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}\left(1 - e^{-z_{t,a}}\right)N_{t,a}$	Catch in year *t* for age *a* fish
$N_{t+1,a+1} = N_{t,a} e^{-z_{t,a}}$	Numbers of fish in year *t+1* at age *a*
$N_{t+1,A} = N_{t,A-1} e^{-z_{t,A-1}} + N_{t,A} e^{-z_{t,A}}$	Numbers of fish in the "plus group"
$S_t = \sum N_{t,a} W_{t,a} \phi_a$	Spawning biomass
$Z_{t,a} = F_{t,a} + M$	Total mortality in year *t* at age *a*
$F_{t,a} = s_a \mu^F \exp^{\varepsilon^F{}_t}, \ \varepsilon^F{}_t \sim N(o, \sigma^{2}{}_F)$	Fishing mortality
$s_a = \frac{1}{1 + \left(e^{-\alpha + \beta a}\right)}$	Age-specific fishing selectivity
$C_t = \sum C_{t,a}$	Total catch in numbers
$P_{t,a} = {}^{C_{t,a}}\!/_{C_t}$	Proportion at age in catch
$SurB_t = q \sum N_{t,a} W_{t,a} v_a$	Survey biomass
$qprior = \lambda \frac{0.5(\ln q_{est} - \ln q_{prior})^2}{\sigma_q^2}$	survey catchability prior
$mprior = \lambda \frac{0.5(\ln m_{est} - \ln m_{prior})^2}{\sigma_m^2}$	natural mortality prior

$$reclike = \lambda(\sum_{i=1965}^{endyear} \bar{R} - R_i)^2 + \sum_{a=1}^{20}(\bar{R}_{init} - R_{init,a})^2 + \frac{1}{2((\sum_{i=1965}^{endyear} \bar{R} - R_i)\frac{1}{n+1})}$$ recruitment likelihood

$$catchlike = \lambda \sum_{i=startyear}^{endyear}(\ln C_{obs,i} - \ln C_{est,i})^2$$ catch likelihood

$$surveylike = \lambda \frac{(\ln B - \ln \hat{B})^2}{2\sigma^2}$$ survey likelihood

$$SurvAgelike = \sum_{i,t} m_t P_{t,a} \ln \frac{\hat{P}_{t,a}}{P_{t,a}}$$ survey age composition likelihood

$$FishAgelike = \sum_{i,t} m_t P_{t,a} \ln \frac{\hat{P}_{t,a}}{P_{t,a}}$$ fishery age composition likelihood

Table 8.12--Variables used in the population dynamics model.

Variables	
R_t	Age 1 recruitment in year *t*
R_0	Geometric mean value of age 1 recruitment, 1956-75
R_γ	Geometric mean value of age 1 recruitment, 1976-96
τ_t	Recruitment deviation in year *t*
$N_{t,a}$	Number of fish in year *t* at age *a*
$C_{t,a}$	Catch numbers of fish in year *t* at age *a*
$P_{t,a}$	Proportion of the numbers of fish age *a* in year *t*
C_t	Total catch numbers in year *t*
$W_{t,a}$	Mean body weight (kg) of fish age *a* in year *t*
ϕ_a	Proportion of mature females at age *a*
$F_{t,a}$	Instantaneous annual fishing mortality of age *a* fish in year *t*
M	Instantaneous natural mortality, assumed constant over all ages and years
$Z_{t,a}$	Instantaneous total mortality for age *a* fish in year *t*
s_a	Age-specific fishing gear selectivity
μ^F	Median year-effect of fishing mortality
ε_t^F	The residual year-effect of fishing mortality
ν_a	Age-specific survey selectivity
α	Slope parameter in the logistic selectivity equation
β	Age at 50% selectivity parameter in the logistic selectivity equation
σ_t	Standard error of the survey biomass in year *t*

Table 8.13--Model estimates of rock sole fishing mortality and exploitation rate (catch/total biomass).

year	Full selection F	Exploitation rate
1975	0.30	0.06
1976	0.39	0.05
1977	0.30	0.02
1978	1.40	0.03
1979	0.05	0.02
1980	0.04	0.03
1981	0.03	0.03
1982	0.05	0.03
1983	0.06	0.03
1984	0.16	0.07
1985	0.05	0.03
1986	0.05	0.03
1987	0.08	0.05
1988	0.16	0.09
1989	0.12	0.07
1990	0.05	0.03
1991	0.11	0.04
1992	0.11	0.04
1993	0.11	0.04
1994	0.11	0.04
1995	0.10	0.04
1996	0.08	0.03
1997	0.09	0.04
1998	0.04	0.02
1999	0.04	0.02
2000	0.05	0.03
2001	0.02	0.02
2002	0.03	0.03
2003	0.03	0.02
2004	0.04	0.03
2005	0.04	0.02
2006	0.04	0.02
2007	0.04	0.02
2008	0.06	0.03
2009	0.05	0.03
2010	0.06	0.03
2011	0.06	0.04
2012	0.07	0.05
2013	0.05	0.04
2014	0.05	0.04

Table 8.14 --Model estimates of rock sole age-specific fishery and survey selectivities.

	survey selectivity																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
females	0.01	0.04	0.25	0.71	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
males	0.01	0.06	0.39	0.88	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

	Female fishery selectivity																
year / age	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.08	0.22	0.48	0.75	0.91	0.97	0.99	0.99	0.99	0.99
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.17	0.40	0.69	0.88	0.96	0.96	0.96	0.96
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.07	0.21	0.47	0.74	0.91	0.91	0.91	0.91
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.15	0.37	0.37	0.37	0.37
1979	0.00	0.01	0.02	0.06	0.17	0.41	0.70	0.89	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1980	0.11	0.26	0.51	0.76	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1981	0.17	0.40	0.68	0.88	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1982	0.09	0.27	0.57	0.83	0.95	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1983	0.02	0.05	0.14	0.35	0.64	0.85	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1984	0.01	0.04	0.10	0.24	0.48	0.72	0.88	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1985	0.17	0.44	0.75	0.92	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1986	0.03	0.10	0.32	0.67	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1987	0.08	0.23	0.49	0.76	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1988	0.07	0.20	0.47	0.75	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1989	0.04	0.14	0.41	0.75	0.93	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1990	0.04	0.13	0.34	0.63	0.85	0.95	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1991	0.01	0.03	0.07	0.18	0.37	0.61	0.81	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1992	0.00	0.01	0.04	0.10	0.25	0.50	0.74	0.89	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1993	0.00	0.01	0.04	0.11	0.27	0.53	0.77	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1994	0.00	0.01	0.02	0.05	0.13	0.32	0.59	0.82	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1995	0.00	0.01	0.02	0.06	0.15	0.35	0.61	0.82	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00

1996	0.00	0.00	0.01	0.03	0.09	0.22	0.47	0.74	0.90	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1997	0.01	0.02	0.04	0.08	0.16	0.29	0.46	0.65	0.80	0.90	0.95	0.98	0.99	0.99	0.99	0.99	0.99
1998	0.00	0.00	0.01	0.02	0.06	0.13	0.27	0.47	0.69	0.84	0.93	0.97	0.99	0.99	0.99	0.99	0.99
1999	0.00	0.01	0.02	0.05	0.13	0.29	0.52	0.75	0.89	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00
2000	0.00	0.01	0.03	0.08	0.19	0.40	0.66	0.85	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2001	0.02	0.06	0.15	0.33	0.57	0.79	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2002	0.01	0.04	0.11	0.30	0.58	0.82	0.94	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2003	0.02	0.07	0.16	0.35	0.61	0.81	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2004	0.01	0.03	0.09	0.23	0.47	0.72	0.88	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2005	0.02	0.04	0.12	0.28	0.54	0.78	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2006	0.02	0.05	0.14	0.36	0.65	0.86	0.95	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2007	0.01	0.03	0.11	0.32	0.63	0.86	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2008	0.01	0.02	0.07	0.21	0.48	0.76	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2009	0.01	0.02	0.08	0.25	0.56	0.83	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2010	0.00	0.01	0.04	0.11	0.27	0.52	0.76	0.90	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2011	0.00	0.01	0.04	0.12	0.33	0.64	0.86	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2012	0.01	0.02	0.07	0.18	0.42	0.70	0.88	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2013	0.02	0.07	0.21	0.46	0.74	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2014	0.01	0.02	0.06	0.18	0.40	0.68	0.87	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

male fishery selectivity

year / age	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	0.00	0.00	0.01	0.02	0.06	0.18	0.44	0.73	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1976	0.00	0.00	0.00	0.00	0.01	0.04	0.14	0.36	0.66	0.87	0.96	0.99	1.00	1.00	1.00	1.00	1.00
1977	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.18	0.44	0.73	0.91	0.97	0.99	1.00	1.00	1.00	1.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.10	0.28	0.59	0.84	0.95	0.95	0.95	0.95
1979	0.00	0.00	0.01	0.04	0.14	0.38	0.69	0.89	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1980	0.16	0.35	0.61	0.82	0.93	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1981	0.33	0.65	0.88	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1982	0.07	0.17	0.37	0.63	0.83	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1983	0.01	0.03	0.06	0.13	0.25	0.45	0.65	0.82	0.91	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00

1984	0.04	0.10	0.20	0.36	0.56	0.75	0.87	0.94	0.97	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1985	0.37	0.73	0.92	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1986	0.09	0.29	0.63	0.88	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1987	0.14	0.38	0.70	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1988	0.10	0.38	0.77	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1989	0.08	0.27	0.62	0.88	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1990	0.12	0.39	0.75	0.93	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1991	0.02	0.08	0.23	0.52	0.80	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1992	0.01	0.04	0.13	0.36	0.68	0.88	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1993	0.01	0.04	0.13	0.37	0.70	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1994	0.00	0.01	0.05	0.19	0.53	0.84	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1995	0.00	0.01	0.03	0.08	0.21	0.45	0.72	0.89	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1996	0.01	0.01	0.03	0.08	0.17	0.35	0.57	0.77	0.89	0.95	0.98	0.99	1.00	1.00	1.00	1.00	1.00
1997	0.01	0.03	0.07	0.16	0.34	0.58	0.79	0.91	0.96	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1998	0.00	0.00	0.01	0.04	0.15	0.41	0.74	0.92	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1999	0.00	0.01	0.02	0.06	0.15	0.35	0.61	0.82	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2000	0.00	0.01	0.03	0.08	0.23	0.49	0.75	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2001	0.02	0.05	0.14	0.32	0.58	0.80	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2002	0.04	0.13	0.33	0.62	0.85	0.95	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2003	0.05	0.16	0.41	0.72	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2004	0.03	0.12	0.33	0.64	0.87	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2005	0.06	0.17	0.42	0.72	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2006	0.03	0.08	0.22	0.48	0.75	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2007	0.03	0.10	0.27	0.54	0.80	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2008	0.01	0.03	0.09	0.25	0.53	0.80	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2009	0.01	0.04	0.14	0.34	0.63	0.85	0.95	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2010	0.02	0.05	0.13	0.29	0.54	0.77	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2011	0.01	0.04	0.12	0.29	0.57	0.81	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2012	0.02	0.06	0.15	0.32	0.57	0.79	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2013	0.01	0.04	0.16	0.44	0.77	0.93	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2014	0.01	0.05	0.14	0.36	0.66	0.87	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 8-15.--Model estimates of rock sole age 2+ total biomass (t) and female spawning biomass (t) from the 2012 and 2014 assessments.

	2012 Assessment		2014 Assessment	
	Age 2+ Total biomass	Female Spawning biomass	Age 2+ Total biomass	Female Spawning biomass
1975	198,784	54,945	198,899	54,981
1976	218,249	57,877	218,372	57,923
1977	238,163	66,165	238,286	66,221
1978	263,790	83,185	263,901	83,256
1979	287,631	103,695	287,712	103,785
1980	318,327	119,611	318,359	119,711
1981	357,635	128,381	357,587	128,483
1982	401,896	133,105	401,734	133,199
1983	454,728	139,778	454,421	139,853
1984	524,744	148,715	524,223	148,762
1985	587,442	147,651	586,621	147,657
1986	691,435	164,635	690,207	164,584
1987	819,992	182,373	818,083	182,250
1988	964,896	203,498	961,817	203,273
1989	1,048,540	219,892	1,044,210	219,523
1990	1,168,080	249,352	1,162,060	248,804
1991	1,382,610	298,961	1,373,810	298,166
1992	1,477,340	315,365	1,465,840	314,314
1993	1,516,200	332,776	1,502,390	331,375
1994	1,520,980	350,317	1,504,870	348,414
1995	1,596,670	426,510	1,577,880	423,511
1996	1,652,150	524,322	1,630,870	519,733
1997	1,703,390	613,114	1,679,970	606,877
1998	1,686,930	664,778	1,662,050	657,017
1999	1,680,830	723,035	1,655,470	713,595
2000	1,649,630	762,671	1,624,200	751,620
2001	1,597,120	770,869	1,571,890	758,648
2002	1,560,730	759,095	1,536,690	746,323
2003	1,532,460	736,902	1,508,400	723,959
2004	1,527,440	686,888	1,503,700	674,688
2005	1,536,600	611,461	1,513,470	600,925
2006	1,635,500	549,547	1,612,060	540,763
2007	1,744,210	518,370	1,717,400	510,399
2008	1,738,660	499,869	1,712,850	492,339
2009	1,688,750	500,065	1,660,160	491,611

2010	1,634,890	524,317	1,600,600	514,981
2011	1,650,160	563,512	1,607,390	553,163
2012	1,626,770	603,935	1,567,350	592,949
2013			1,495,960	616,945
2014			1,416,990	632,502

Table 8.16--Estimated age 4 recruitment of rock sole (thousands of fish) from the 2012 and 2014 assessments.

Year class	2012 Assessment	2014 Assessment
1971	199,824	199,931
1972	157,253	157,327
1973	196,587	196,661
1974	203,140	202,916
1975	473,120	472,798
1976	266,300	265,918
1977	426,326	425,678
1978	424,174	423,444
1979	563,032	562,054
1980	1,026,604	1,024,776
1981	1,006,494	1,004,258
1982	923,376	920,720
1983	1,388,382	1,383,296
1984	1,342,432	1,335,520
1985	1,269,452	1,260,214
1986	2,242,280	2,220,560
1987	3,498,720	3,455,780
1988	1,240,766	1,221,982
1989	1,036,376	1,017,938
1990	2,306,440	2,260,820
1991	1,165,866	1,139,984
1992	601,308	586,572
1993	914,752	893,456
1994	480,346	475,446
1995	466,196	465,716
1996	632,204	642,982
1997	380,952	382,006
1998	577,568	581,976
1999	586,710	575,988
2000	1,241,580	1,196,848
2001	1,847,268	1,854,508
2002	2,198,500	2,133,280
2003	1,681,994	1,631,880
2004	1,199,502	1,259,950
2005	1,622,094	1,645,976
2006		745,802

Table 8.17—Model estimates of population number by age, year and sex.

	Females (millions of fish)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	159	133	91	100	187	120	51	37	30	23	11	8	5	5	5	4	4	4	4	5
1976	371	137	114	79	86	161	104	44	32	25	20	9	6	4	3	3	3	3	3	6
1977	209	319	118	98	68	74	139	89	38	28	22	17	7	5	3	2	2	2	2	5
1978	334	179	275	101	85	58	64	119	77	33	24	19	14	6	4	2	1	1	1	4
1979	333	288	154	236	87	73	50	55	103	66	28	20	16	12	5	3	1	1	1	3
1980	442	287	248	133	203	75	63	43	47	87	55	23	17	13	10	4	3	1	1	3
1981	804	380	246	213	114	173	63	52	36	39	72	45	19	14	11	8	4	2	1	3
1982	788	692	327	212	182	97	146	53	44	30	32	60	38	16	12	9	7	3	2	3
1983	724	678	596	281	181	155	81	121	44	36	24	27	49	31	13	9	7	6	2	4
1984	1086	623	584	512	242	156	132	68	100	36	29	20	21	40	25	11	8	6	5	5
1985	1050	935	536	502	440	207	132	109	54	76	26	21	14	16	29	18	8	6	4	7
1986	992	903	804	460	429	371	172	109	90	45	63	22	18	12	13	24	15	6	5	9
1987	1745	854	778	692	396	367	314	143	89	74	37	51	18	14	10	11	19	12	5	12
1988	2713	1502	735	668	591	334	303	254	114	71	58	29	41	14	11	8	8	15	10	13
1989	959	2335	1291	630	568	493	267	232	189	84	52	43	21	30	10	8	6	6	11	17
1990	799	825	2009	1110	540	481	404	211	179	145	64	40	33	16	23	8	6	4	5	22
1991	1773	687	710	1728	953	462	407	337	173	147	119	53	33	27	13	19	6	5	4	21
1992	894	1526	591	611	1485	818	394	343	278	139	115	92	41	25	21	10	14	5	4	19
1993	460	769	1314	509	526	1277	701	335	287	227	111	90	71	31	19	16	8	11	4	18
1994	701	396	662	1130	438	452	1094	596	280	233	179	86	70	55	24	15	12	6	9	17
1995	373	603	341	570	973	377	388	937	506	233	188	141	67	54	42	19	12	9	5	20
1996	365	321	519	293	490	837	324	332	794	420	188	149	110	52	42	33	14	9	7	19
1997	504	314	276	447	252	422	720	278	284	671	348	153	119	88	41	33	26	12	7	21
1998	300	434	271	238	384	217	362	615	236	238	555	283	123	95	70	33	26	21	9	22
1999	456	258	374	233	205	331	187	311	528	202	203	468	236	102	78	57	27	22	17	26
2000	452	393	222	321	200	176	284	160	266	449	170	169	387	195	84	65	47	22	18	35
2001	939	389	338	191	277	172	151	244	137	225	375	141	139	319	161	69	53	39	18	44
2002	1455	808	335	291	164	238	148	129	207	115	190	315	118	117	268	135	58	45	33	52

2003	1673	1252	695	288	250	141	204	126	109	173	96	158	262	98	97	223	112	48	37	70
2004	1280	1440	1078	598	248	215	121	174	106	92	145	80	132	219	82	81	186	94	40	90
2005	988	1102	1239	927	515	213	184	103	146	89	76	120	66	109	180	68	67	153	77	107
2006	1291	851	948	1067	798	442	182	157	87	123	74	63	99	55	90	150	56	56	127	153
2007	585	1111	732	816	918	685	379	155	132	72	102	61	52	82	46	75	124	47	46	232
2008	313	503	956	630	702	789	587	322	130	110	60	84	51	43	68	38	62	103	38	230
2009	170	270	433	823	542	603	676	499	269	107	89	49	68	41	35	55	31	50	83	218
2010	108	147	232	373	708	466	517	574	418	222	88	73	40	56	34	29	45	25	41	246
2011	323	93	126	200	321	609	400	442	487	349	183	72	60	32	45	27	23	37	20	233
2012	376	278	80	109	172	276	523	342	373	404	285	149	58	48	26	37	22	19	30	206
2013	571	323	239	69	93	148	236	445	286	307	327	230	120	47	39	21	30	18	15	190
2014	599	492	278	206	59	80	126	199	369	236	252	269	189	98	38	32	17	24	15	168

Males (millions of fish)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1975	159	78	59	65	98	56	32	24	17	12	7	7	6	6	6	6	5	6	6	6
1976	371	137	67	51	56	84	48	27	20	13	9	5	5	4	4	4	4	3	4	7
1977	209	319	118	58	44	48	72	42	23	17	11	7	3	3	2	2	2	2	2	6
1978	334	179	275	101	50	38	41	62	36	20	14	9	5	2	2	1	1	1	1	5
1979	333	288	154	236	87	43	33	36	54	31	17	12	7	4	1	1	0	0	0	1
1980	442	287	248	133	203	75	37	28	30	45	26	14	10	6	3	1	1	0	0	1
1981	804	380	246	213	114	173	63	31	23	25	37	21	12	8	5	3	1	0	0	1
1982	788	692	327	211	181	96	144	53	25	19	21	31	18	10	7	4	2	1	0	1
1983	724	678	595	281	181	155	81	121	44	21	16	17	26	14	8	6	3	2	1	1
1984	1086	623	584	512	242	156	133	69	102	36	17	13	14	21	12	6	5	3	1	2
1985	1050	934	536	501	438	205	130	108	54	78	27	13	10	10	15	9	5	3	2	2
1986	992	903	803	458	424	364	169	107	88	45	64	22	10	8	8	12	7	4	3	3
1987	1745	854	777	690	393	359	304	139	88	72	37	52	18	9	6	7	10	6	3	5
1988	2713	1502	734	667	587	328	292	243	110	69	57	29	41	14	7	5	5	8	5	7
1989	959	2335	1292	630	564	476	250	216	179	81	51	42	21	30	11	5	4	4	6	8
1990	799	825	2009	1109	537	471	381	194	166	137	62	39	32	16	23	8	4	3	3	11

1991	1773	687	710	1726	949	453	390	312	158	136	112	51	32	26	13	19	7	3	2	11
1992	894	1526	591	611	1482	810	380	316	246	123	105	86	39	25	20	10	15	5	2	10
1993	460	769	1314	509	525	1270	687	314	253	192	95	81	66	30	19	16	8	11	4	10
1994	701	396	662	1130	438	450	1077	567	251	197	149	73	62	51	23	15	12	6	9	11
1995	373	603	341	570	973	376	385	908	460	196	152	114	57	48	39	18	11	9	5	15
1996	365	321	519	293	490	836	323	329	764	378	157	120	89	44	37	31	14	9	7	15
1997	504	314	276	447	252	422	718	276	279	640	311	127	96	71	35	30	24	11	7	18
1998	300	434	271	238	384	217	361	610	231	229	515	247	101	76	56	28	23	19	9	20
1999	456	258	374	233	205	331	186	310	521	195	190	425	204	83	62	46	23	19	16	23
2000	452	393	222	322	200	176	284	160	265	442	164	158	352	168	68	51	38	19	16	32
2001	939	389	338	191	277	172	151	244	136	223	368	135	130	289	138	56	42	31	15	40
2002	1455	808	335	291	164	238	148	129	207	115	188	309	114	109	243	116	47	36	26	46
2003	1673	1252	695	288	250	141	202	125	108	172	96	156	257	94	91	202	97	39	30	60
2004	1280	1440	1077	598	247	214	120	171	104	90	144	80	131	215	79	76	169	81	33	75
2005	988	1102	1239	927	514	212	182	100	141	86	74	119	66	107	177	65	63	139	67	89
2006	1291	850	948	1066	796	440	180	152	83	117	72	62	99	55	89	147	54	52	116	129
2007	585	1111	732	816	917	683	375	152	127	69	97	59	51	82	45	74	122	45	43	202
2008	313	503	956	630	701	786	582	316	127	106	57	81	49	42	67	37	61	101	37	203
2009	170	270	433	823	542	603	673	493	264	104	86	47	65	40	34	55	30	50	82	195
2010	108	147	232	373	708	465	515	569	411	217	85	71	38	53	33	28	45	25	41	226
2011	323	93	126	200	321	607	398	436	475	339	178	69	57	31	43	26	23	36	20	217
2012	376	278	80	109	172	275	519	336	363	390	276	144	56	47	25	35	21	19	30	192
2013	571	323	239	69	93	147	235	437	278	296	315	222	116	45	37	20	28	17	15	178
2014	599	492	278	206	59	80	126	198	363	229	243	259	183	95	37	31	17	23	14	159

Table 8.18—Stock assessment model estimates of the number of female spawners (millions).

Estimate of the number of female spawners (millions of fish).

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	0	0	0	0	0	8	191	1493	7524	13014	8324	6504	4392	4557	4491
1976	0	0	0	0	0	10	385	1767	8188	14250	15586	7662	5545	3447	3162
1977	0	0	0	0	0	5	516	3565	9696	15535	17156	14578	6813	4695	2555
1978	0	0	0	0	0	4	237	4771	19561	18403	18731	16126	13164	6024	3822
1979	0	0	0	0	0	5	187	2194	26182	37134	22202	17636	14640	11833	5118
1980	0	0	0	0	0	5	233	1722	11935	48664	43224	19986	15268	12588	9757
1981	0	0	0	0	0	11	236	2092	9112	21801	56445	39130	17467	13270	10496
1982	0	0	0	0	0	6	542	2116	11107	16720	25415	51370	34384	15263	11124
1983	0	0	0	0	0	10	302	4830	11125	20163	19282	22881	44651	29720	12657
1984	0	0	0	0	0	10	491	2730	25443	20002	22896	17056	19527	37887	24191
1985	0	0	0	0	0	13	490	4367	13846	42875	20873	18432	13195	14997	27898
1986	0	0	0	0	0	24	639	4346	22892	25093	49375	18766	16000	11390	12420
1987	0	0	0	0	0	23	1169	5719	22808	41404	28816	44258	16241	13770	9404
1988	0	0	0	0	1	21	1129	10158	29101	39959	46031	25000	37068	13526	11002
1989	0	0	0	0	1	32	995	9282	48271	47372	41211	37028	19411	28620	10018
1990	0	0	0	0	1	31	1503	8426	45660	81608	50817	34500	29927	15601	22068
1991	0	0	0	0	1	30	1514	13461	44228	82481	93521	45439	29781	25689	12847
1992	0	0	0	0	1	52	1466	13730	70870	78395	90896	79489	37090	24122	19946
1993	0	0	0	0	1	82	2609	13409	73290	127437	87233	77674	65106	30126	18778
1994	0	0	0	0	0	29	4071	23847	71424	131297	141282	74358	63520	52824	23431
1995	0	0	0	0	1	24	1444	37471	128969	130883	148338	121497	60944	51512	41026
1996	0	0	0	0	0	54	1204	13283	202377	236121	148144	128204	100231	49767	40289
1997	0	0	0	0	0	27	2678	11112	72408	377510	274532	131735	108702	84067	39971
1998	0	0	0	0	0	14	1347	24602	60151	134084	437569	244465	111809	90990	67200
1999	0	0	0	0	0	21	694	12451	134657	113530	159862	403622	215666	97409	75756
2000	0	0	0	0	0	11	1058	6410	67937	252478	133944	145850	353407	187246	81040
2001	0	0	0	0	0	11	563	9754	34867	126615	295591	121384	127069	305657	155265
2002	0	0	0	0	0	15	550	5169	52800	64959	149485	272101	107831	112233	258981
2003	0	0	0	0	0	9	759	5039	27807	97469	75911	136185	239239	94268	94125
2004	0	0	0	0	0	14	450	6944	27148	51508	114364	69440	120218	209973	79369
2005	0	0	0	0	1	14	686	4122	37323	49917	59758	103248	60454	104035	174297
2006	0	0	0	0	1	28	679	6283	22194	68934	58317	54396	90679	52786	87140

2007	0	0	0	0	1	44	1409	6195	33620	40746	80141	52864	47591	78884	44053
2008	0	0	0	0	1	50	2185	12874	33164	61704	47348	72619	46235	41388	65814
2009	0	0	0	0	1	39	2515	19960	68638	60152	70476	42078	62245	39398	33831
2010	0	0	0	0	1	30	1925	22977	106485	124990	69206	63188	36407	53551	32516
2011	0	0	0	0	0	39	1489	17693	124122	196129	144285	61858	54339	31094	43856
2012	0	0	0	0	0	18	1946	13679	95246	227015	225004	128524	53110	46372	25453
2013	0	0	0	0	0	9	880	17782	72949	172418	257941	198521	109281	44879	37585
2014	0	0	0	0	0	5	469	7964	94192	132650	198661	231803	172203	94259	37136

Table 8.19—Selected parameter estimates and their stand deviations from the preferred stock assessment model run.

	name	value	standard deviation		name	value	standard deviation
	mean_log_recruitment	0.18	0.12	1985	total biomass	586.62	12.73
	sel_slope_fishery_female	1.15	0.06	1986	total biomass	690.21	13.54
	sel50_fishery_female	8.33	0.48	1987	total biomass	818.08	14.57
	sel_slope_fsh_males	1.22	0.06	1988	total biomass	961.82	16.02
	sel50_fsh_males	7.47	0.43	1989	total biomass	1044.20	17.54
	sel_slope_survey_females	2.00	0.12	1990	total biomass	1162.10	19.31
	sel50_survey_females	3.56	0.06	1991	total biomass	1373.80	21.70
	sel_slope_survey_males	0.18	0.08	1992	total biomass	1465.80	22.74
	sel50_survey_males	-0.11	0.02	1993	total biomass	1502.40	23.41
	F40	0.16	0.10	1994	total biomass	1504.90	23.85
	F35	0.19	0.13	1995	total biomass	1577.90	25.74
	F30	0.24	0.17	1996	total biomass	1630.90	27.41
	Ricker_logalpha	-4.16	0.20	1997	total biomass	1680.00	28.87
	Ricker_logbeta	-5.85	0.16	1998	total biomass	1662.00	29.71
	Fmsyr	0.15	0.03	1999	total biomass	1655.50	30.07
	logFmsyr	-1.90	0.18	2000	total biomass	1624.20	30.12
	ABC_biomass 2014	1466.80	60.81	2001	total biomass	1571.90	29.82
	ABC_biomass 2015	1394.70	64.69	2002	total biomass	1536.70	29.24
	msy	252.37	44.01	2003	total biomass	1508.40	28.81
	Bmsy	260.22	29.63	2004	total biomass	1503.70	28.64
1975	total biomass	198.90	9.63	2005	total biomass	1513.50	29.04
1976	total biomass	218.37	10.38	2006	total biomass	1612.10	31.35
1977	total biomass	238.29	11.02	2007	total biomass	1717.40	34.34
1978	total biomass	263.90	11.50	2008	total biomass	1712.90	35.28
1979	total biomass	287.71	11.74	2009	total biomass	1660.20	35.68
1980	total biomass	318.36	11.88	2010	total biomass	1600.60	36.08
1981	total biomass	357.59	12.00	2011	total biomass	1607.40	38.15
1982	total biomass	401.73	12.01	2012	total biomass	1567.30	39.74
1983	total biomass	454.42	12.18	2013	total biomass	1496.00	41.35
1984	total biomass	524.22	12.42	2014	total biomass	1417.00	43.13

Table 8.20. Stock assessment model estimates of average age-specific fishing mortality, by gender, 1975-2012.

females

	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.14	0.22	0.27	0.29	0.30	0.30	0.30	0.30
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.07	0.16	0.27	0.35	0.38	0.38	0.38	0.38
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.14	0.23	0.27	0.27	0.27	0.27
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.07	0.21	0.54	0.54	0.54	0.54
1979	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1980	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1981	0.01	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
1982	0.00	0.01	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1983	0.00	0.00	0.01	0.02	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1984	0.00	0.01	0.02	0.04	0.08	0.12	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
1985	0.01	0.02	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1986	0.00	0.00	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1987	0.01	0.02	0.04	0.06	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
1988	0.01	0.03	0.07	0.12	0.14	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
1989	0.00	0.02	0.05	0.09	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
1990	0.00	0.01	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1991	0.00	0.00	0.01	0.02	0.04	0.07	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1992	0.00	0.00	0.00	0.01	0.03	0.05	0.08	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1993	0.00	0.00	0.00	0.01	0.03	0.06	0.08	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1994	0.00	0.00	0.00	0.01	0.01	0.04	0.07	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1995	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
1996	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
1997	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.06	0.07	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09
1998	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1999	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2000	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2001	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2002	0.00	0.00	0.00	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2003	0.00	0.00	0.00	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2004	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2005	0.00	0.00	0.00	0.01	0.02	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2006	0.00	0.00	0.01	0.01	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2007	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2008	0.00	0.00	0.00	0.01	0.03	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2009	0.00	0.00	0.00	0.01	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2010	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

2011	0.00	0.00	0.00	0.01	0.02	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2012	0.00	0.00	0.00	0.01	0.03	0.05	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2013	0.00	0.00	0.01	0.02	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2014	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

males

	4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1975	0.00	0.00	0.00	0.01	0.02	0.05	0.13	0.22	0.27	0.29	0.30	0.30	0.30	0.30	0.30	0.30	0.30
1976	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.14	0.26	0.34	0.38	0.39	0.39	0.39	0.39	0.39	0.39
1977	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.13	0.22	0.28	0.29	0.30	0.30	0.30	0.30	0.30
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.15	0.42	0.87	1.23	1.40	1.40	1.40	1.40
1979	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1980	0.01	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1981	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
1982	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1983	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1984	0.01	0.02	0.03	0.06	0.09	0.12	0.14	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
1985	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1986	0.00	0.01	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1987	0.01	0.03	0.06	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
1988	0.02	0.06	0.12	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
1989	0.01	0.03	0.07	0.10	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
1990	0.01	0.02	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1991	0.00	0.01	0.03	0.06	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1992	0.00	0.00	0.01	0.04	0.07	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1993	0.00	0.00	0.01	0.04	0.08	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1994	0.00	0.00	0.01	0.02	0.06	0.09	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1995	0.00	0.00	0.00	0.01	0.02	0.05	0.08	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
1996	0.00	0.00	0.00	0.01	0.01	0.03	0.04	0.06	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08
1997	0.00	0.00	0.01	0.01	0.03	0.05	0.07	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1998	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1999	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2000	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2001	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2002	0.00	0.00	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2003	0.00	0.00	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2004	0.00	0.01	0.01	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2005	0.00	0.01	0.01	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2006	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2007	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2008	0.00	0.00	0.01	0.02	0.03	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2009	0.00	0.00	0.01	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

2010	0.00	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2011	0.00	0.00	0.01	0.02	0.03	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2012	0.00	0.00	0.01	0.02	0.04	0.05	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2013	0.00	0.00	0.01	0.02	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2014	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table 8.21--Projections of rock sole female spawning biomass (1,000s t), future catch (1,000s t) and full selection fishing mortality rates for seven future harvest scenarios.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2014	632437	52297	0.05
2015	616780	157568	0.16
2016	534355	131346	0.16
2017	443806	107937	0.16
2018	364449	89355	0.16
2019	303188	69315	0.14
2020	264748	55801	0.12
2021	250231	52571	0.12
2022	252055	56689	0.12
2023	270493	67064	0.13
2024	290825	76778	0.13
2025	315402	86272	0.14
2026	335338	93286	0.15
2027	349670	97811	0.15

Scenario 3
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2014	632437	52297	0.05
2015	620878	78778	0.08
2016	581377	70066	0.08
2017	522062	62127	0.08
2018	462341	55071	0.08
2019	410426	49882	0.08
2020	370632	46850	0.08
2021	349055	45920	0.08
2022	343094	47375	0.08
2023	356232	50351	0.08
2024	373738	53520	0.08
2025	402623	57157	0.08
2026	429860	60519	0.08
2027	453198	63289	0.08

Scenario 4
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2014	632437	52297	0.05
2015	622030	55604	0.05
2016	596134	33561	0.04
2017	556468	30913	0.04
2018	511847	28387	0.04
2019	470377	26487	0.04
2020	437180	25422	0.04
2021	419929	25211	0.04
2022	417084	26103	0.04
2023	433465	27711	0.04
2024	452949	29399	0.04
2025	487271	31427	0.04
2026	520300	33353	0.04
2027	549710	35020	0.04

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2014	632437	52297	0.05
2015	624707	0	0
2016	628701	0	0
2017	606112	0	0
2018	575369	0	0
2019	544105	0	0
2020	517877	0	0
2021	505627	0	0
2022	506722	0	0
2023	527219	0	0
2024	548930	0	0
2025	589606	0	0
2026	629250	0	0
2027	665631	0	0

Table 8.21—continued.

Scenario 6
Determination of whether northern rock sole are currently overfished

B35=299,000

Year	Female spawning biomass	catch	F
2014	632437	52297	0.05
2015	615132	187738	0.19
2016	516482	151665	0.19
2017	415866	120949	0.19
2018	331585	96213	0.19
2019	270157	66512	0.15
2020	236714	54190	0.13
2021	226185	52377	0.13
2022	230959	58146	0.13
2023	251124	70813	0.14
2024	272191	82718	0.15
2025	295455	93873	0.16
2026	313165	101728	0.17
2027	324845	106354	0.17

Scenario 7
Determination of whether the stock is approaching an overfished condition

B35=299,000

Year	Female spawning biomass	catch	F
2014	632437	52297	0.05
2015	616780	157580	0.16
2016	534348	131344	0.16
2017	442588	128565	0.19
2018	351982	103240	0.19
2019	284636	73465	0.16
2020	245915	58156	0.14
2021	232110	54846	0.13
2022	234705	59747	0.13
2023	253381	71789	0.14
2024	273374	83198	0.15
2025	296062	94083	0.16
2026	313428	101789	0.17
2027	324929	106347	0.17

Table 8.22—Northern rock sole ABC and TAC used to manage the resource since 1989.

	TAC	ABC
1989	90,762	171,000
1990	60,000	216,300
1991	90,000	246,500
1992	40,000	260,800
1993	75,000	185,000
1994	75,000	313,000
1995	60,000	347,000
1996	70,000	361,000
1997	97,185	296,000
1998	100,000	312,000
1999	120,000	309,000
2000	137,760	230,000
2001	75,000	228,000
2002	54,000	225,000
2003	44,000	110,000
2004	41,000	139,000
2005	41,500	132,000
2006	41,500	126,000
2007	55,000	198,000
2008	75,000	301,000
2009	90,000	296,000
2010	90,000	240,000
2011	85,000	224,000
2012	87,000	208,000
2013	92,380	214,000
2014	85,000	203,800

Table 8.23—Catch and bycatch in the rock sole target fisheries, 1993-2013, from blend of regional office reported catch and observer sampling.

Species	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Walleye Pollock	18,583	15,784	7,766	7,698	9,123	3,955	5,207	5,481	4,577	9,942	4,643
Arrowtooth Flounder	1,143	1,782	507	1,341	411	300	69	216	835	314	419
Pacific Cod	8,160	6,358	9,796	6,965	8,947	3,529	3,316	4,219	3,391	4,366	3,195
Groundfish, General	3,091	3,266	1,605	1,581	1,381	909	537	1,186	1,198	692	978
Rock Sole	39,857	40,139	29,241	18,380	32,477	13,092	16,047	29,042	14,437	20,168	18,681
Flathead Sole	2,140	1,702	1,147	1,302	2,373	1,223	575	1,806	1,051	771	744
Sablefish	4	16	3	3	1	0	2	5	12	4	2
Atka Mackerel	15	0		0	0	9	0	38	3	0	1
Pacific Ocean Perch	15	62	4	2		1	0	0	0	0	
Rex Sole	79	145	108	48	11	12	5	4	18	7	
Flounder, General	2,221	2,756	1,636	1,591	1,498	342	362	1,184	726	307	783
Shortraker/Rougheye	2	21				1					
Butter Sole	38	11	1	5	79	53	38	156	72	94	
Starry Flounder	230	85	0	1	99	72	34	214	152	329	
Northern Rockfish		29					2			1	
Yellowfin Sole	6,277	5,690	6,876	6,030	7,601	1,358	1,421	2,976	3,951	3,777	6,546
Greenland Turbot	28	50	3	3	2	1	0	1	15	0	1
Alaska Plaice	2,561	931	173	71	408	250	63	385	75	621	375
Sculpin, General								9	2	271	
Kamchatka flounder											
Octopus											
Other rockfish											
Skate, General								1	5	306	

Species	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Walleye Pollock	8,937	7,240	6,922	3,212	4,995	6,124	6,016	7,091	6,779	7,372
Arrowtooth Flounder	346	599	516	220	464	600	1,841	448	101	683
Pacific Cod	5,648	5,192	4,901	3,238	3,927	3,608	6,659	7,332	9,777	8,599
Groundfish, General	801	910	1,605	1,807	3			6		

Rock Sole	24,287	16,667	20,129	21,217	35,180	29,703	37,311	39,682	58,178.00	42,433
Flathead Sole	881	850	1,691	1,061	1,945	1,770	3,446	2,028	769	2,019
Sablefish	9			3	1					
Atka Mackerel	16	48	87	210	4	<1	<1	<1	<1	<1
Pacific Ocean Perch				<1			<1	1	<1	45
Rex Sole					33					
Flounder, General	820	937	620	1,009	2	691	517	411	1144	313
Shortraker/Rougheye										
Butter Sole					560					
Starry Flounder					622					
Northern Rockfish				4	<1	<1	<1		<1	1
Yellowfin Sole	3,888	7,579	9,983	8,916	12,903	6,608	12,038	9,827	9557	8,477
Greenland Turbot	4	1	27	8		7	3	1	<1	3
Alaska Plaice	1,111	1,352	1,828	1,810	2,710	2,299	2,446	3,162	1653	4,339
Sculpin, General					1,104			905	969	1,288
Kamchatka flounder									17	109
Octopus									1	
Other rockfish									10	<1
Skate, General					559			711	653	529

Table 8.24—Non-target species catch in the northern rock sole fishery.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Benthic urochordata	118678	220868	318778	105544	12759	30837	9764	58513	5801	17201	8125
Birds		0	0	0	0		0	0		0	0
Bivalves	4700	339	206	365	397	299	288	477	383	175	192
Brittle star unidentified	32	865	1774	7290	1539	1103	262	1398	83	72	79
Capelin	1	388	24	4	6	22	43	103	316	57	4
Corals Bryozoans	690	693	16	1347	21	100	19	1984	105	348	168
Eelpouts	1000	4296	2156	3245	6906	136	150	4900	1861	85	2385
Eulachon		14			2	4	2	33	93	4	5
Giant Grenadier					4573			3331			
Greenlings	1150	334	429	335	268	45		18	35		
Grenadier	0	503									
Hermit crab unidentified	19169	7150	7588	10401	5765	2683	637	4087	2308	3606	1939
Invertebrate unidentified	105866	3129	84181	6938	24240	1582	2392	14526	6897	3423	36890
Misc crabs	18830	6424	9293	6508	13622	8922	3263	6369	2877	6348	3905
Misc crustaceans	380	152	45	500	199	180	257	1046	174	365	87
Misc fish	12857	16944	22422	17281	70990	25202	11690	14957	16736	17865	6267
Misc inverts (worms etc)	1	52		24	100	8	11	121	16	11	6
Other osmerids	3716	64	726	268	185	627	82	22	124	24	44
Pacific Sand lance	16	45	7	33	42	31	105	15	6	7	
Pandalid shrimp	201	86	30	20	53	22	59	60	58	53	34
Polychaete unidentified	2	7		1	103	21	19	15	4	12	8
Scypho jellies	257847	304925	393491	73281	94520	185158	233299	348530	264225	314919	135754
Sea anemone unidentified	18449	13291	6456	8995	6346	6735	2560	8770	9462	4749	13290
Sea pens whips		19	36	0		29	50	201	28	79	65
Sea star	1171098	333433	555351	731041	711347	206605	30565	174184	67505	89062	112089
Snails	23795	23967	12923	28386	24402	9313	2694	11207	9698	14138	6883
Sponge unidentified	198371	67555	69937	40985	19246	19270	64699	139966	115985	64410	152707
Stichaeidae	42	1	3		0	4	1	3	6		2
urchins dollars cucumbers	13420	8890	9280	3900	32200	6035	1105	4173	3449	1607	419

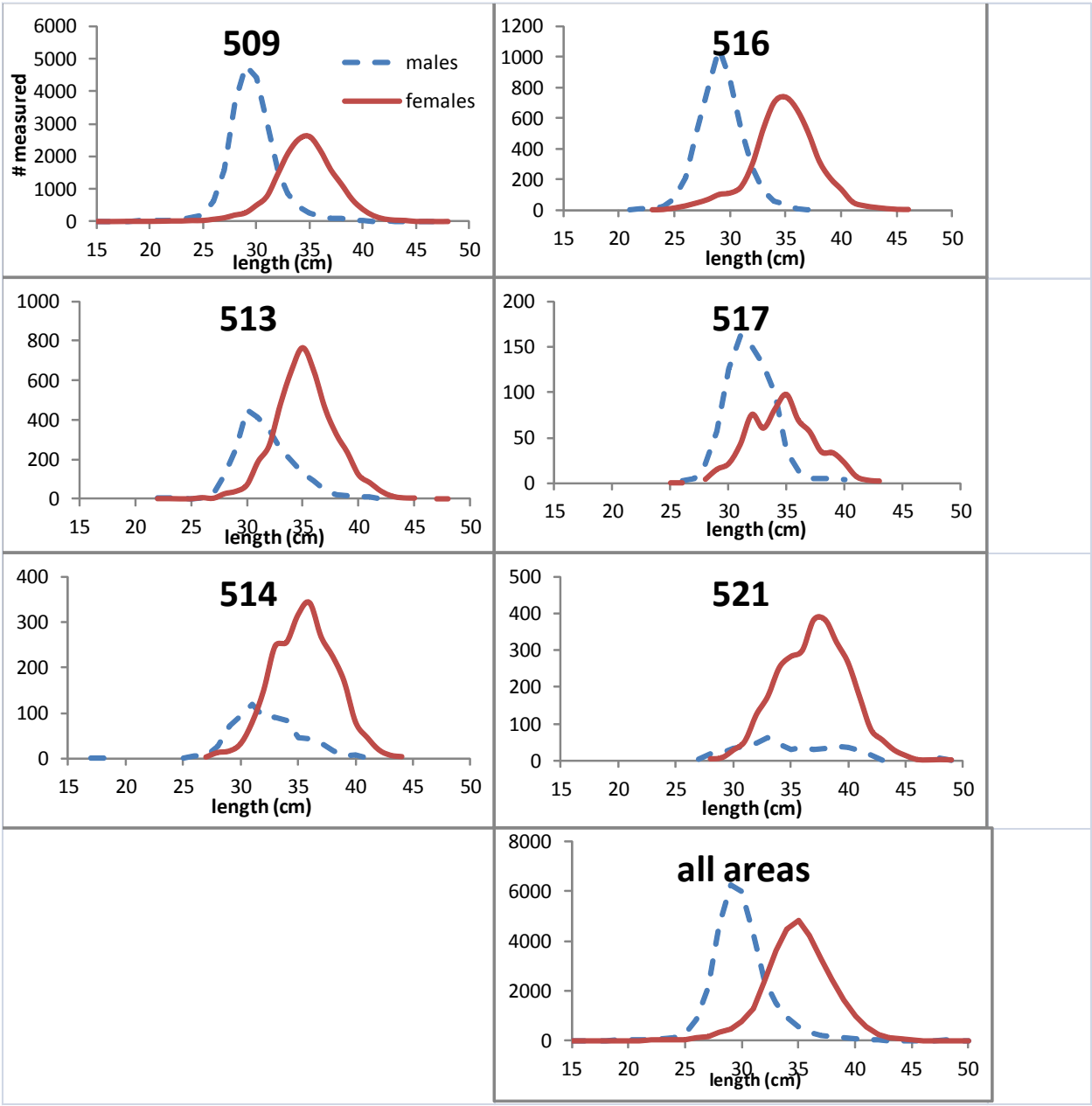


Figure 8.1—Size composition of rock sole, by sex and area, in the 2014 catch as determined from observer sampling.

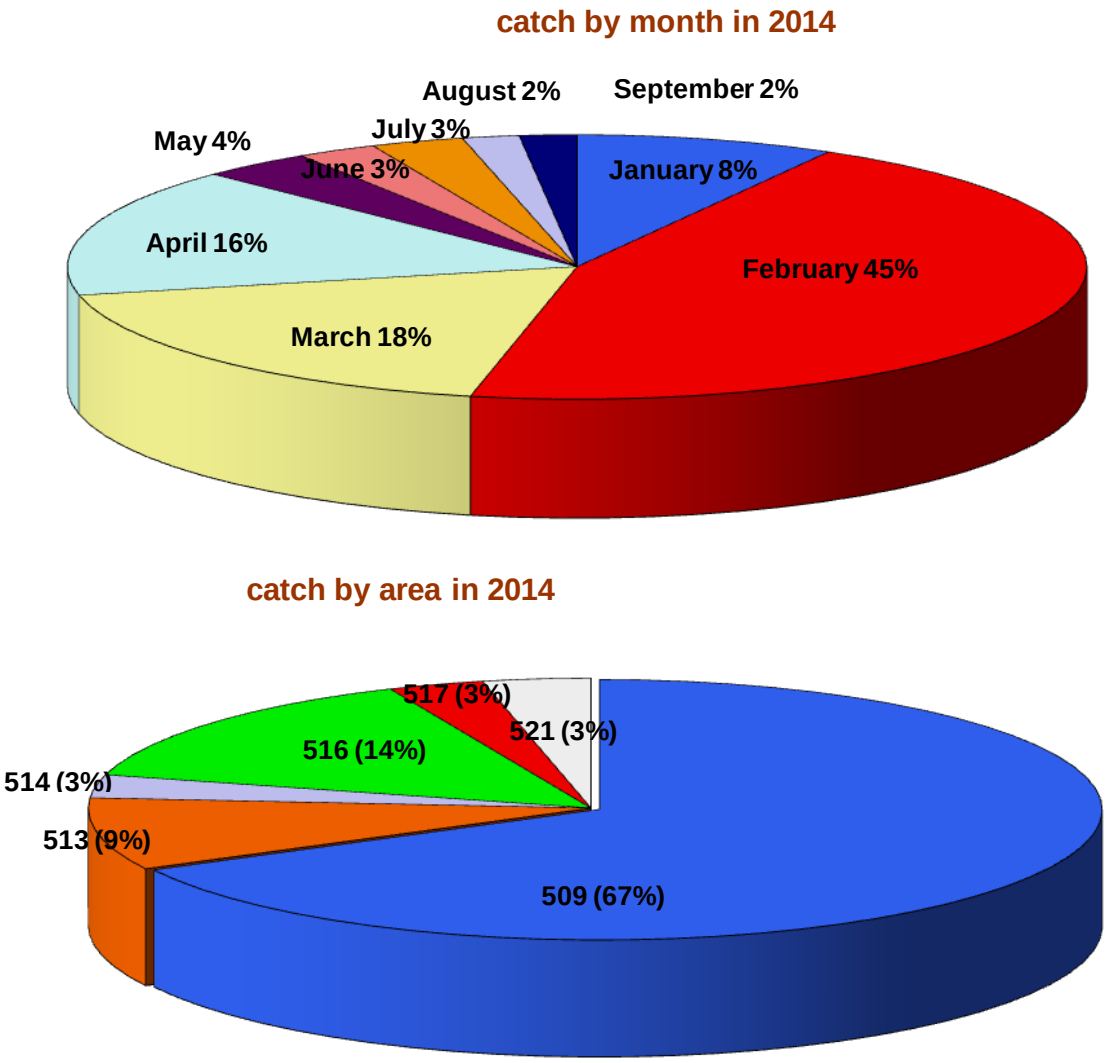


Figure 8.2—Bering Sea northern rock sole fishery catch by month and area in 2014 (percent of total).

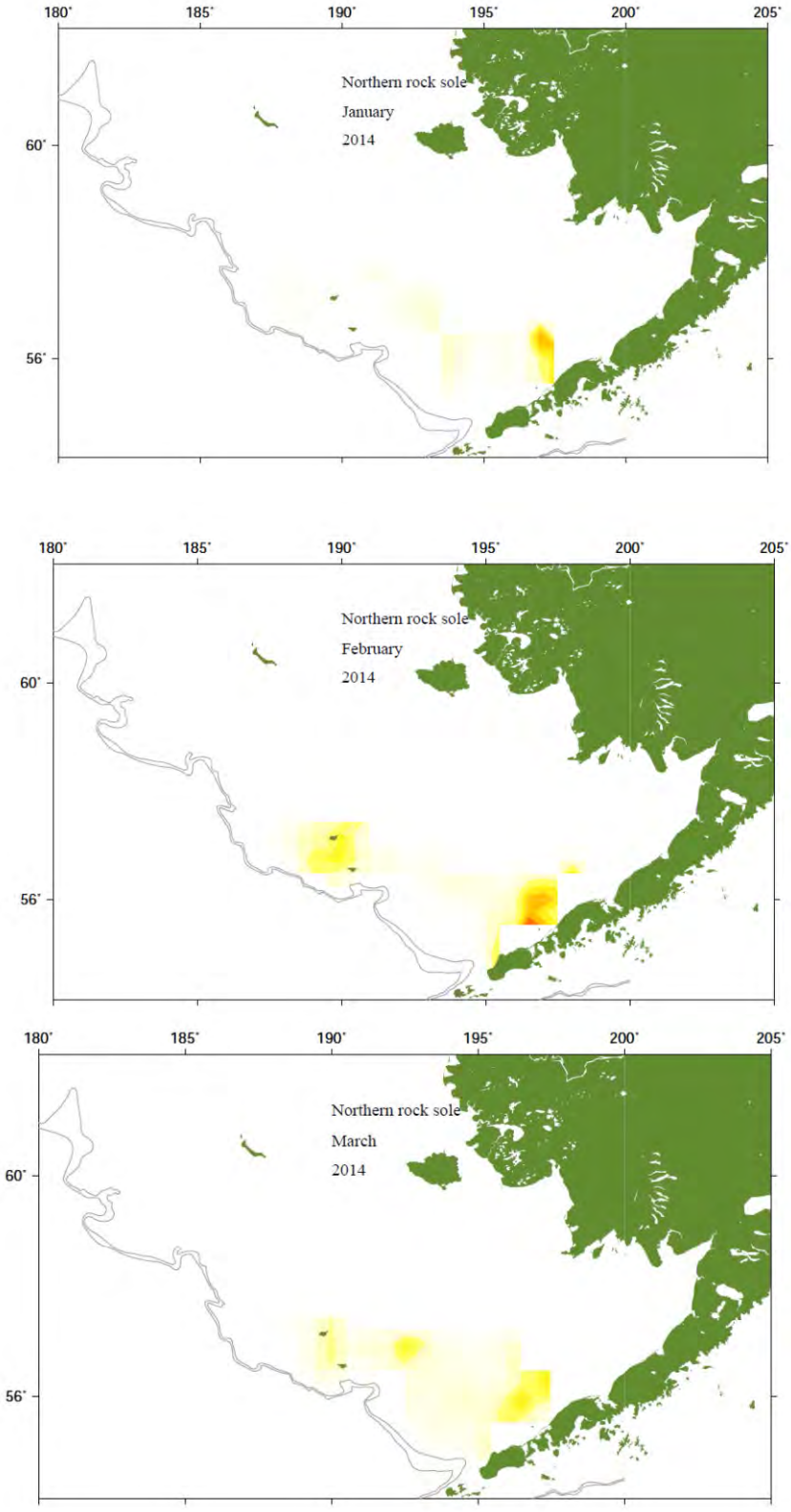


Figure 8.3—Catch locations, by month, of northern rock sole.

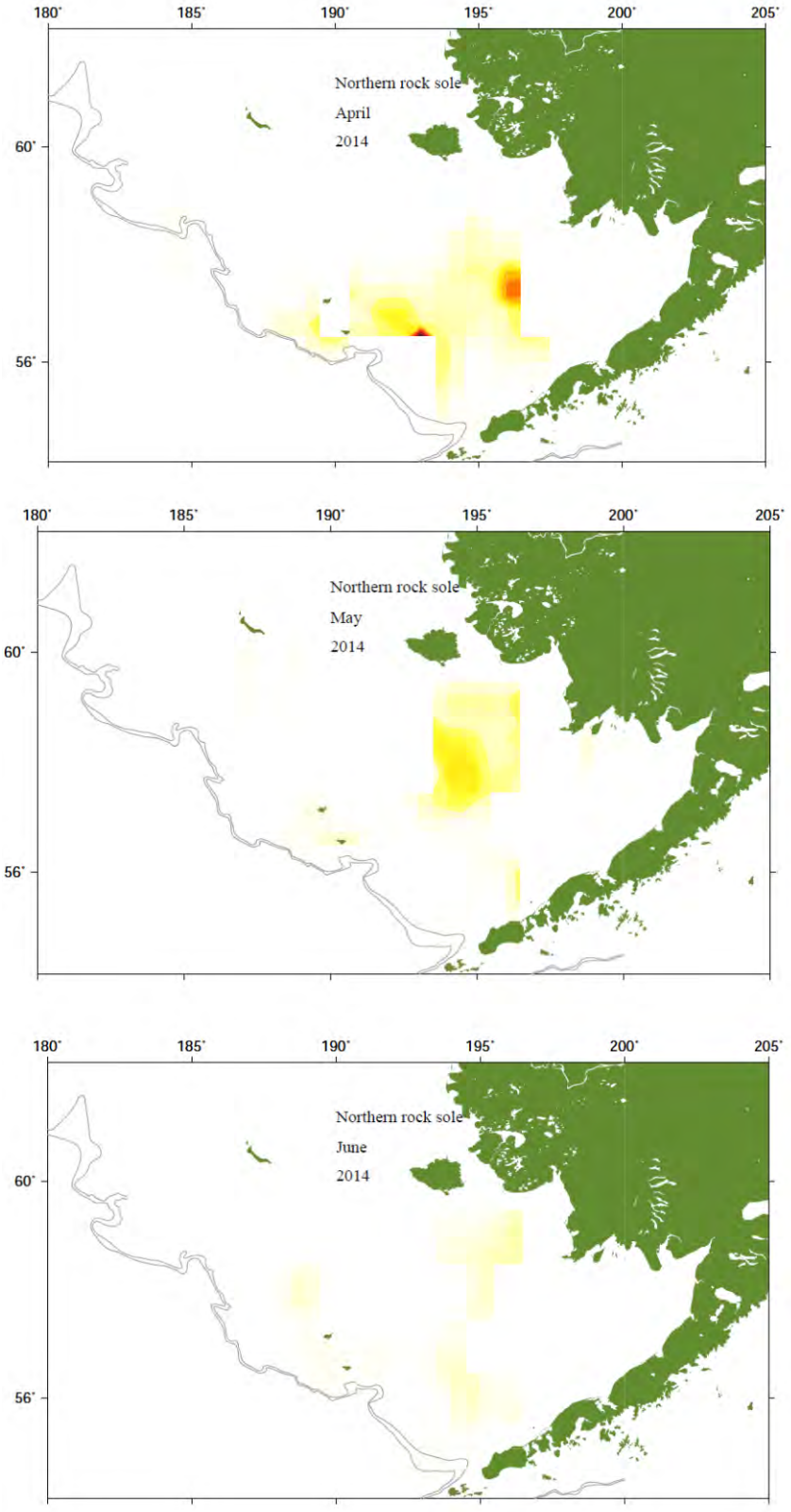


Figure 8.3—Continued.

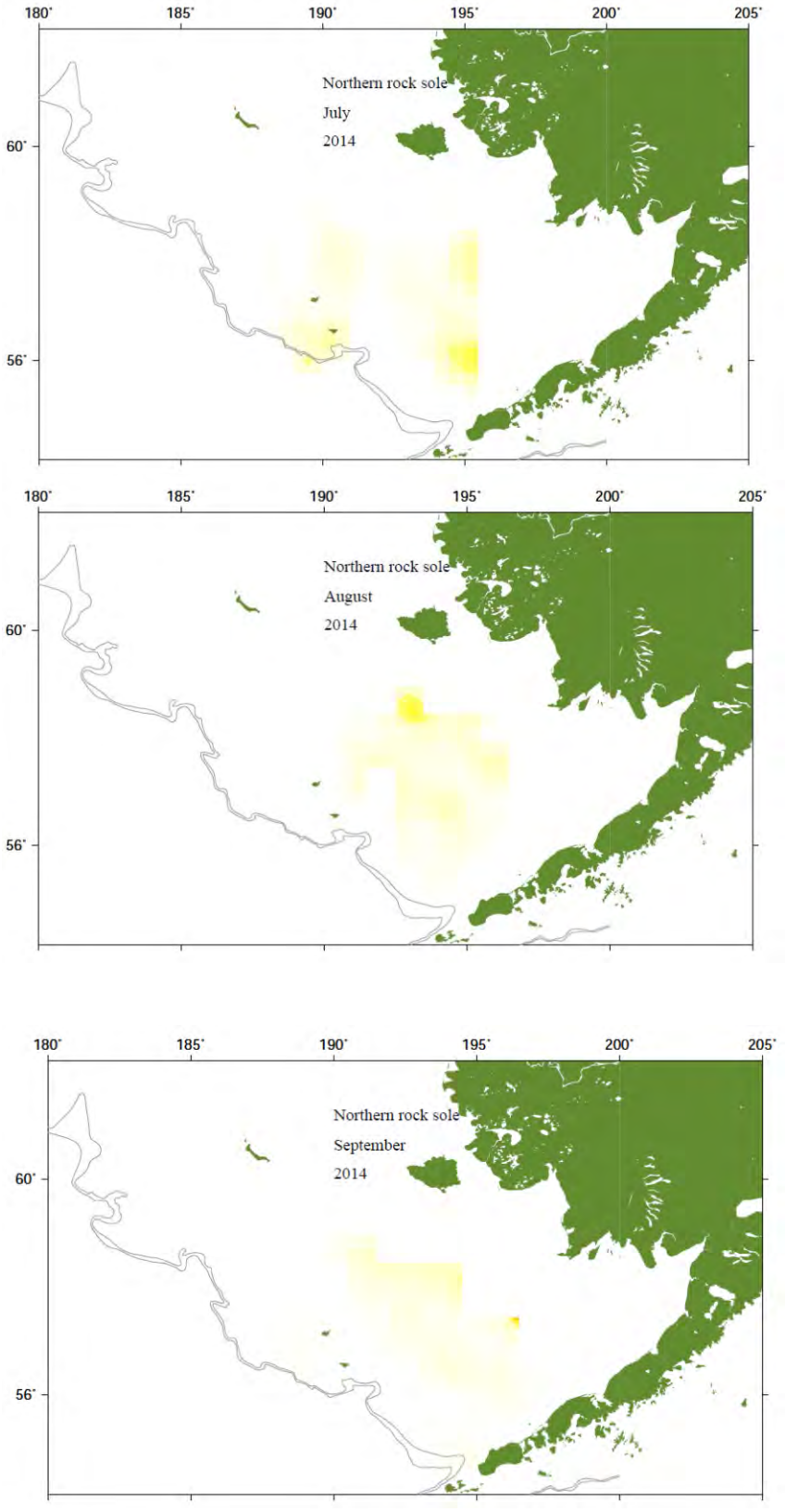


Figure 8.3—Continued.

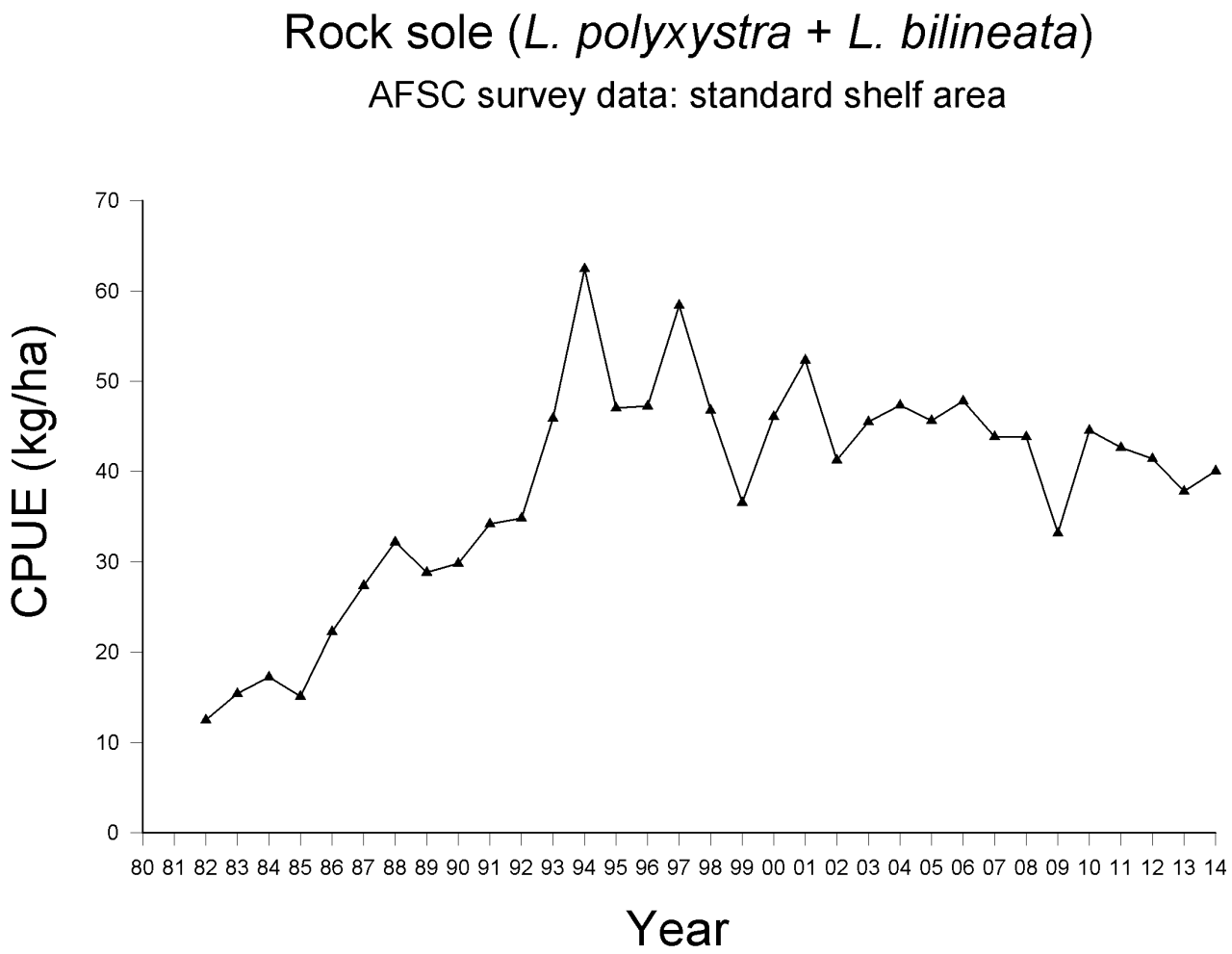


Figure 8.4—Catch per unit effort of *Lepidopsetta polyxystra* and *Lepidopsetta bilineata* (kg/ha) from Bering Sea shelf trawl surveys, 1982-2014.

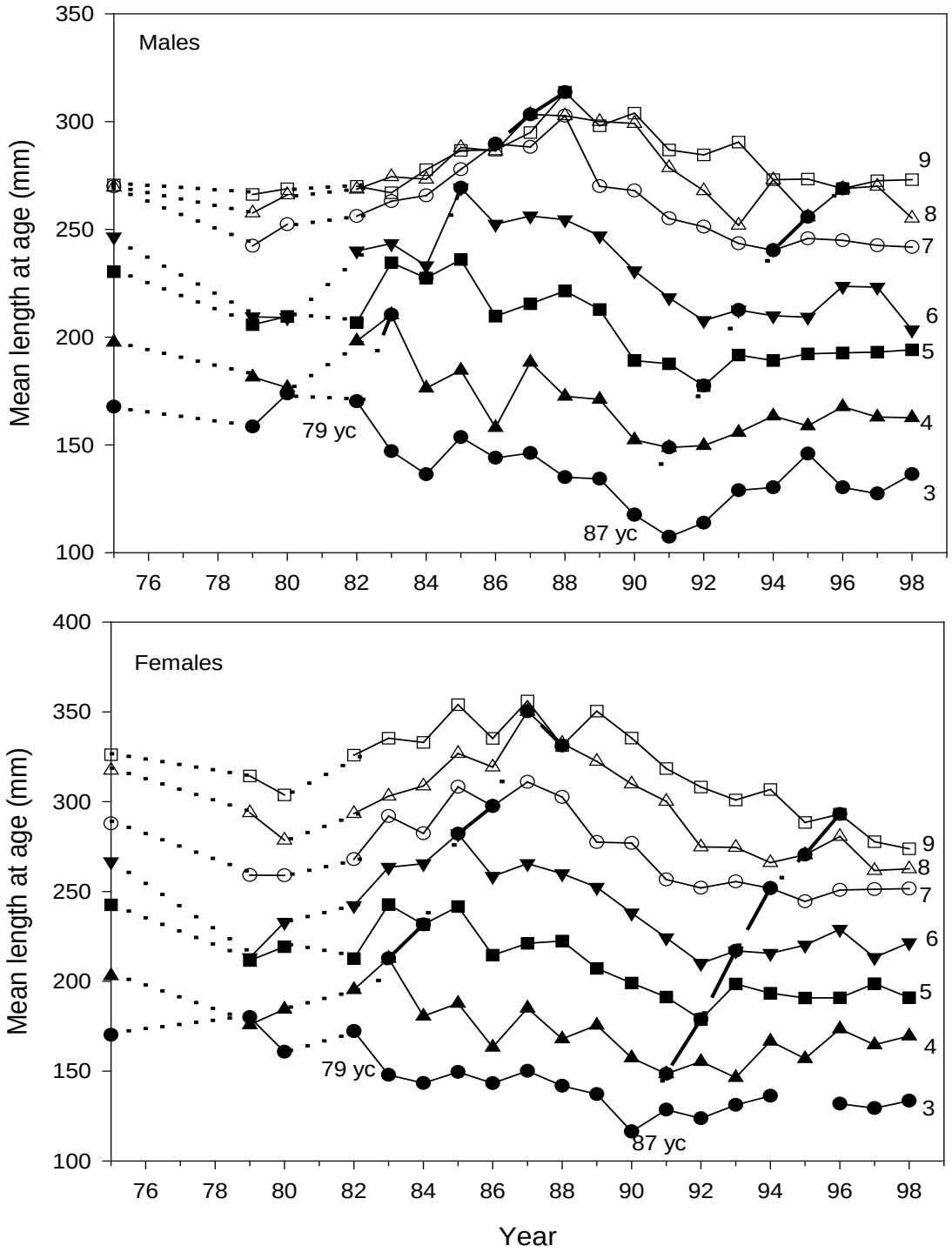


Fig. 8.5. Mean lengths at age (mm) by year of survey for eastern Bering Sea northern rocksole ages 3-9 for each sex during 1975-1998. Growth curves are shown for the 1979 (79yc) and 1987 (87yc) year classes. Dotted lines indicate no data during the period.
(From Walters and Wilderbuer, 2000, p.20)

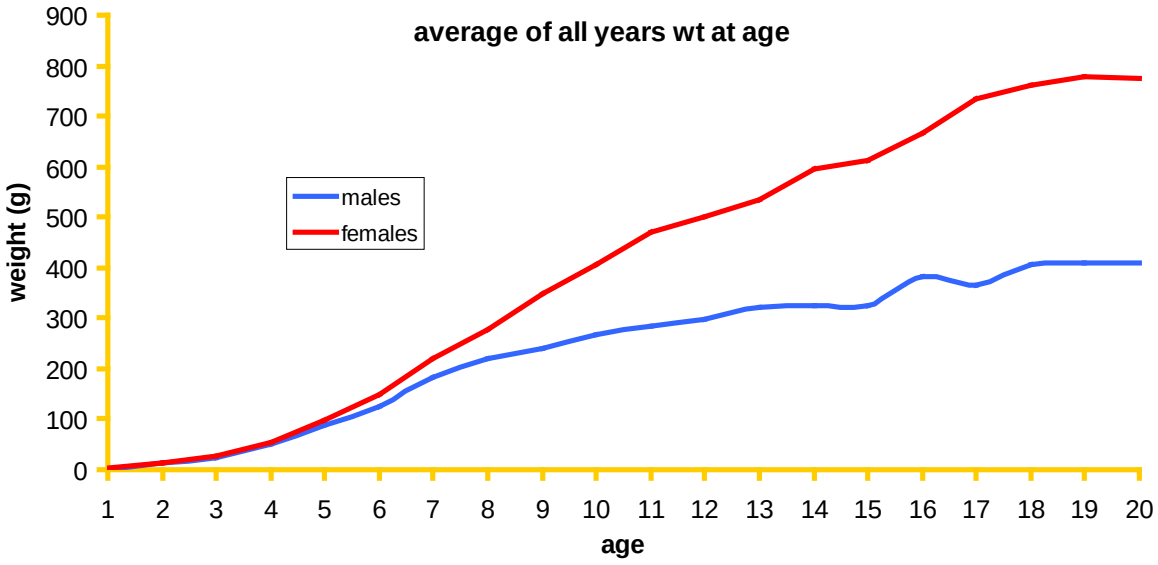


Figure 8.6-Mean weight-at-age for northern rock sole averaged over all years of survey age data.

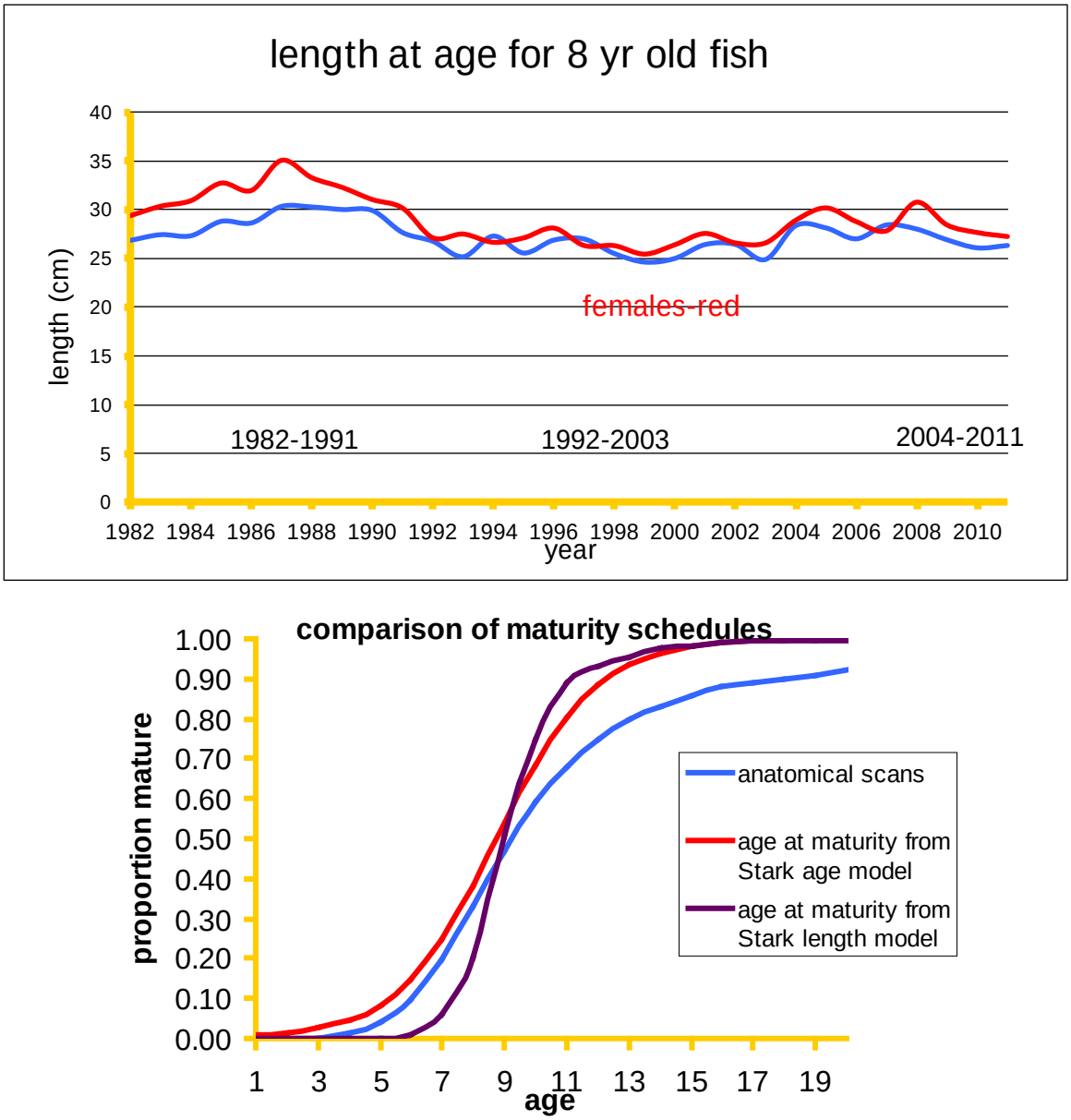
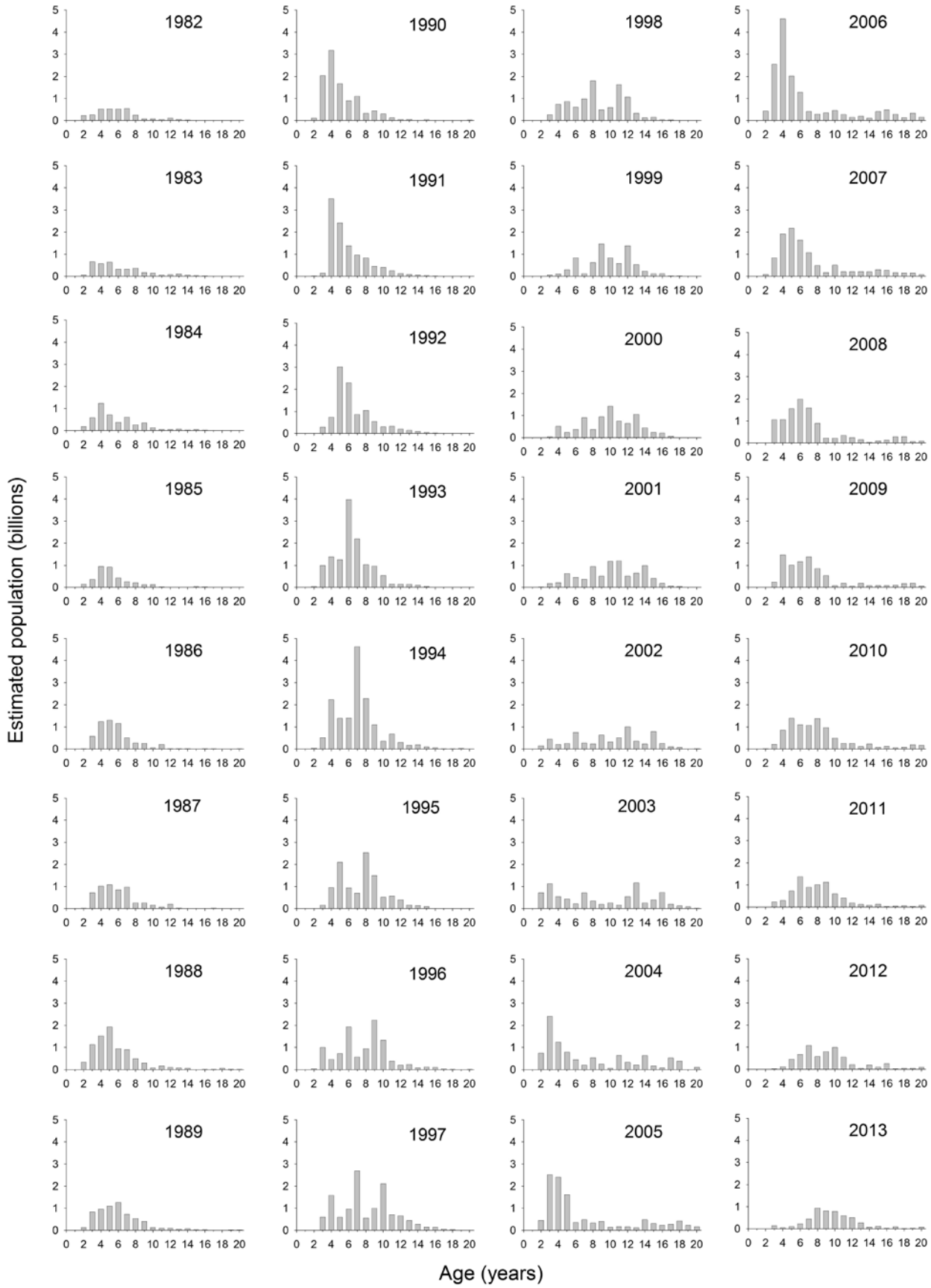


Fig. 8.7-Time-varying length-at-age for 8 year old northern rock sole with 3 time periods identified for modeling growth differently (top panel). Maturity schedule for northern rock sole from three methods (bottom panel). Stark (2012) length model, based on histology, is used in the stock assessment replacing the curve from anatomical scanning of fish used in past assessments.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2008
2009
2010
2011
2012
2013
Estimated population (billions)
Age (years)

Figure 8.8—Age composition of northern rock sole from the AFSC annual trawl survey.

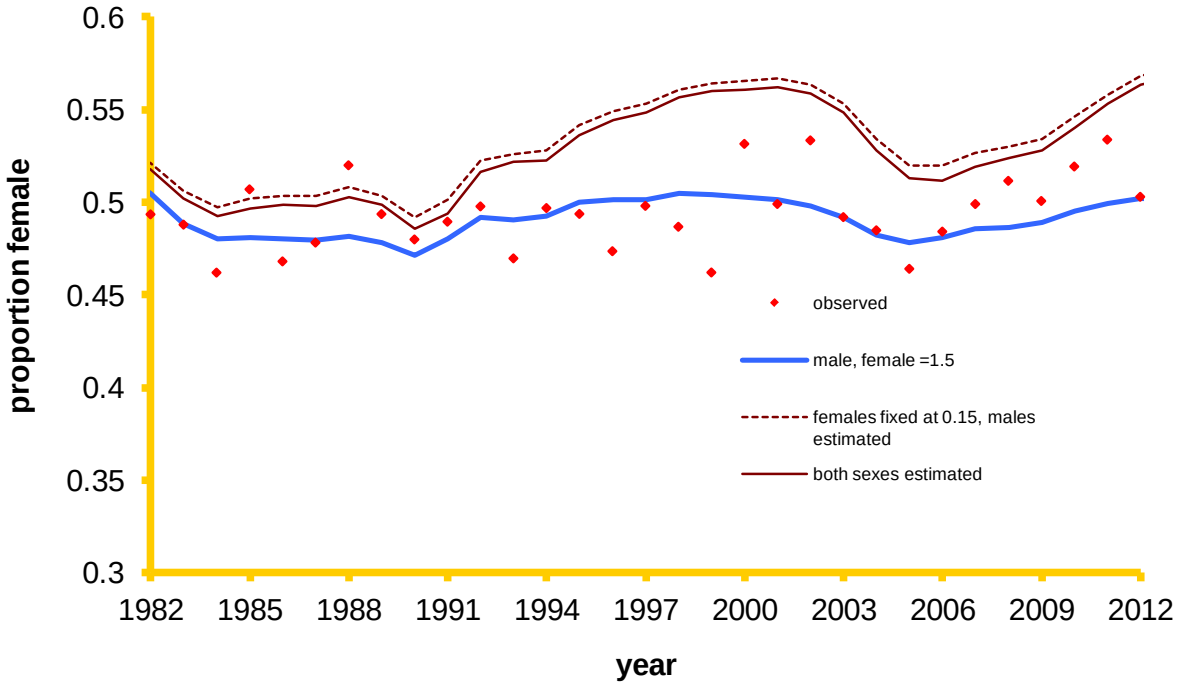


Figure 8.9—Fits to the population sex ratio from the results of Models 1, 2 and 3.

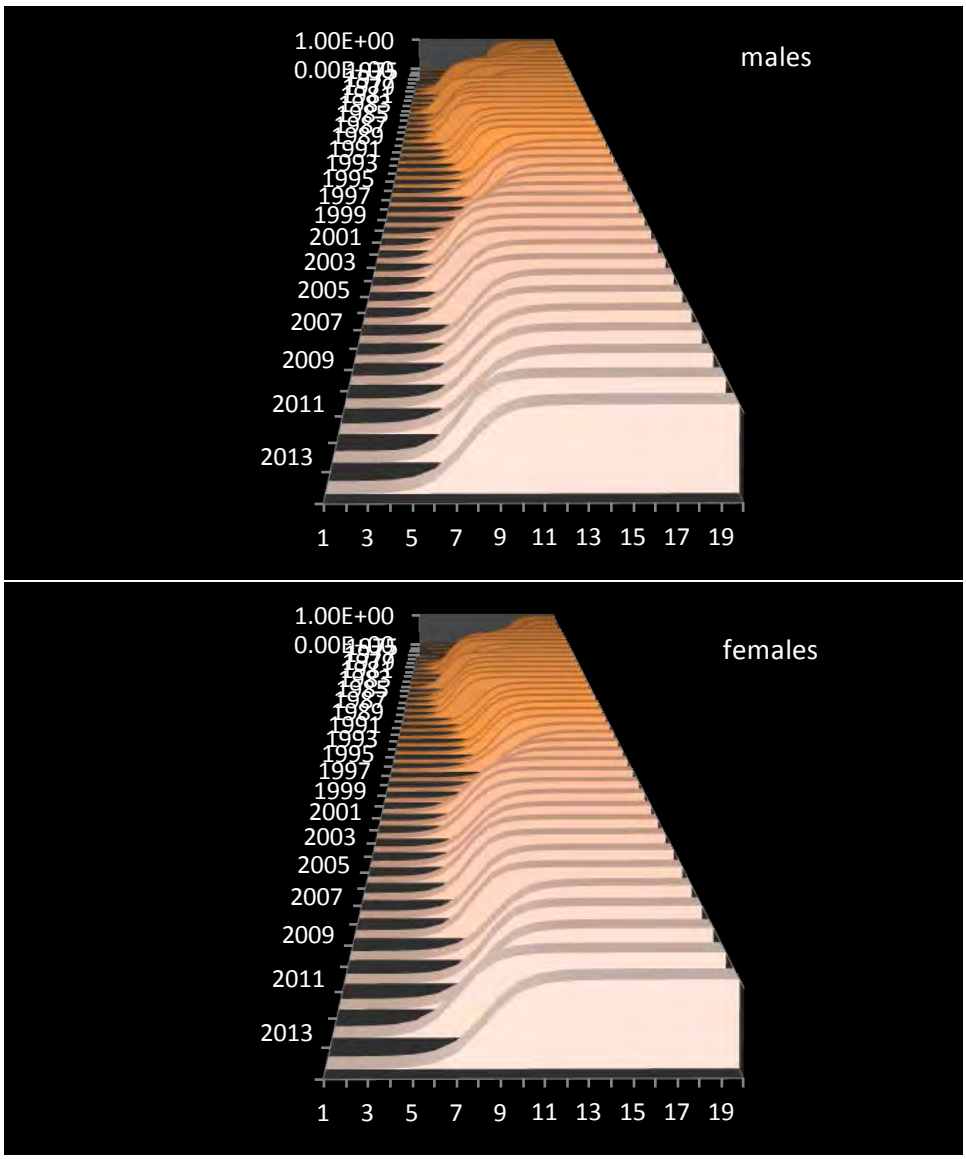


Figure 8.10—Stock assessment model estimates of fishery selectivity at age, by year and gender.

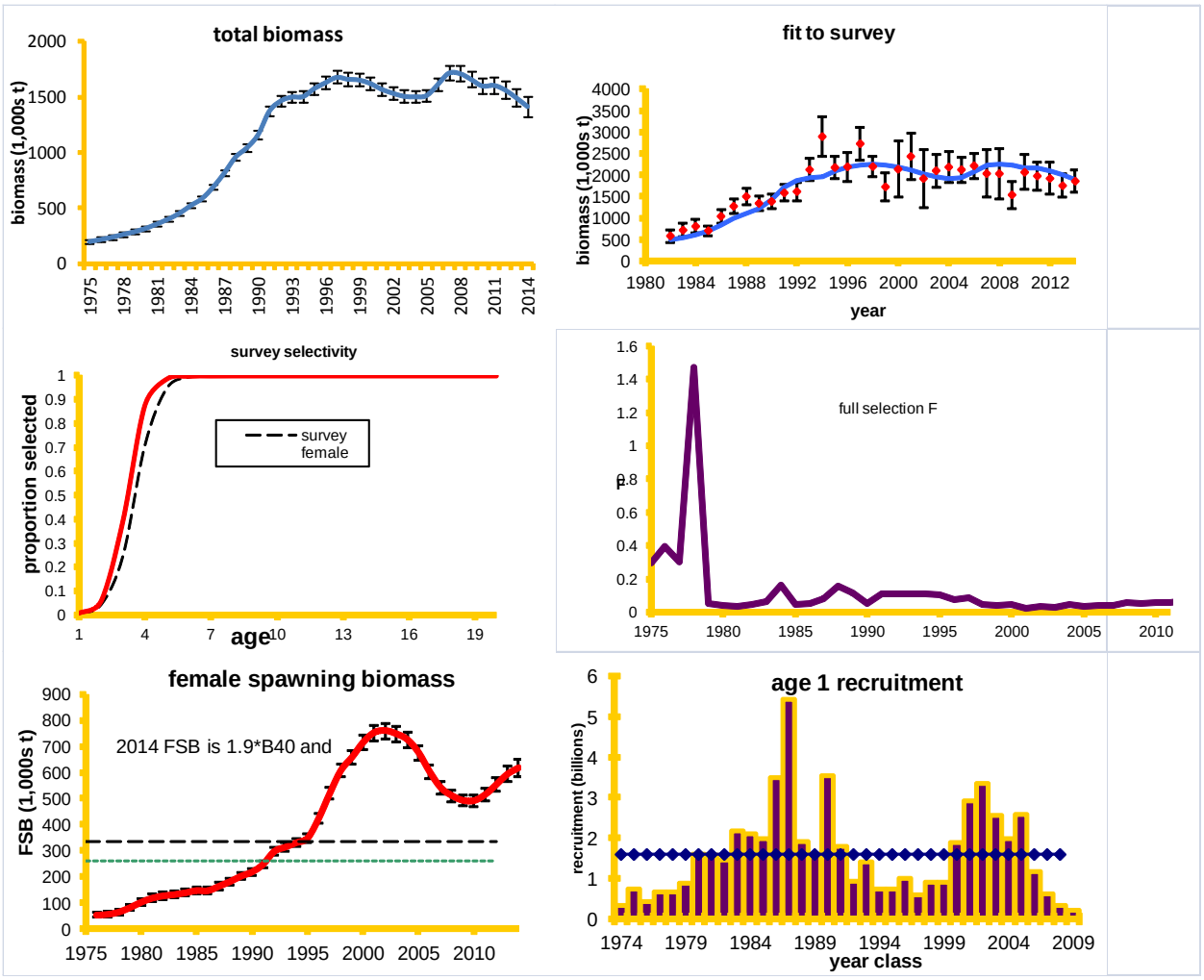


Figure 8.11--Stock assessment model estimates of total 2+ biomass (top left panel), fit to trawl survey biomass (top right panel), age-specific fishery and survey selectivity (middle left panel) and average annual fishing mortality rate (middle right panel), female spawning biomass (bottom left panel) and estimated age 1 recruitment (bottom right panel).

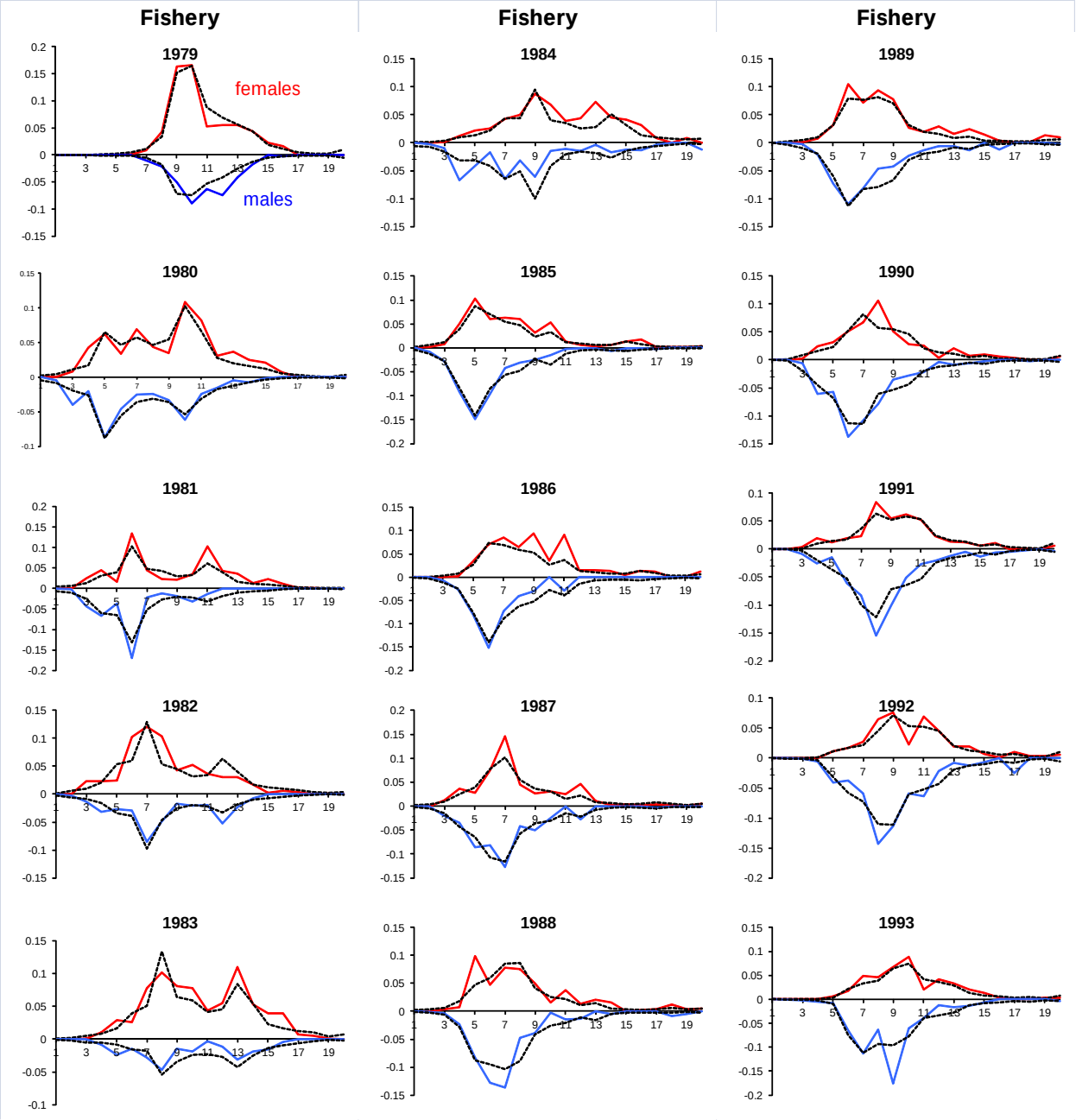
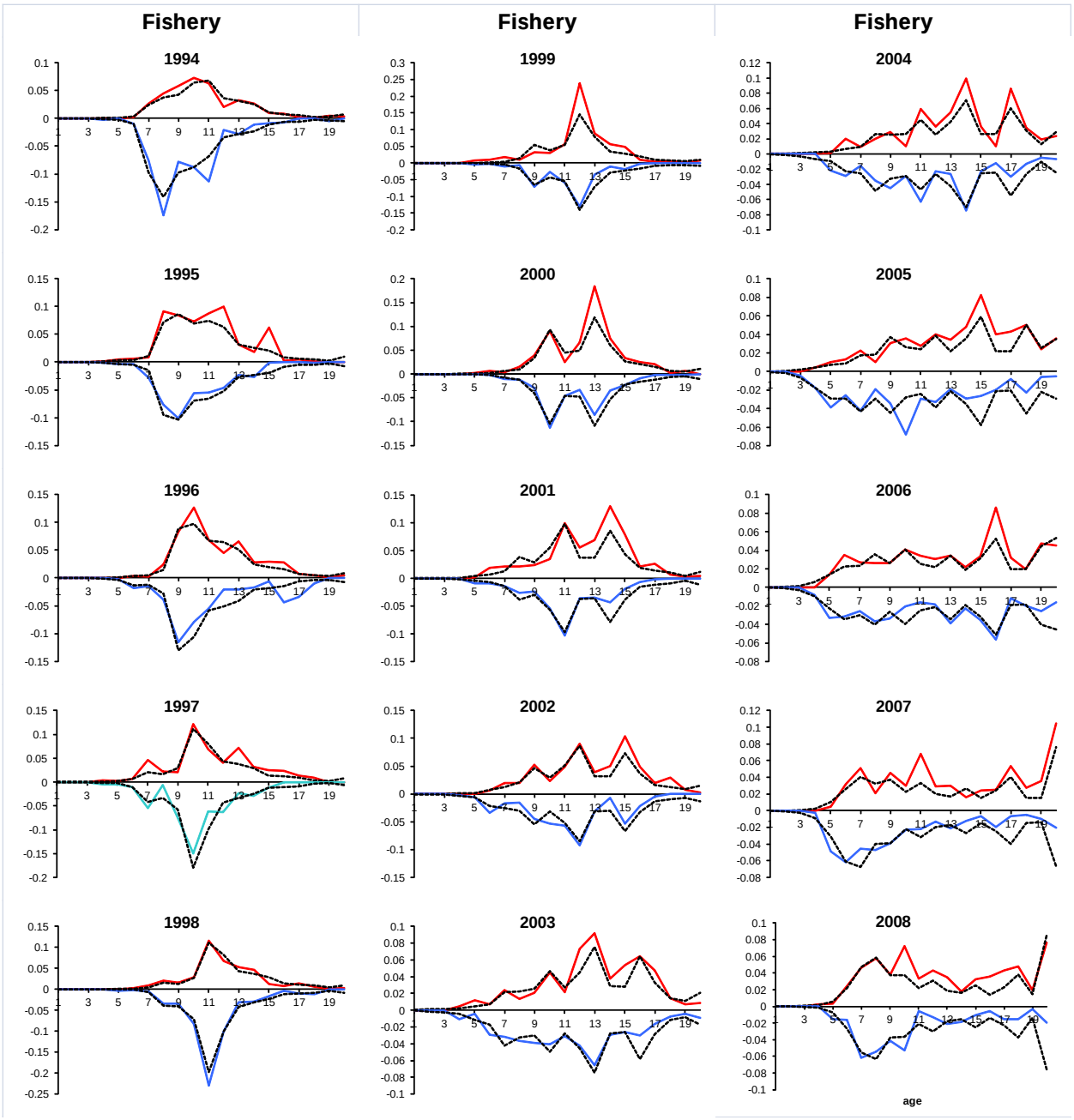


Figure 8.12—Stock assessment model fit to the fishery and survey age compositions, by sex.


Fishery
Fishery
Fishery
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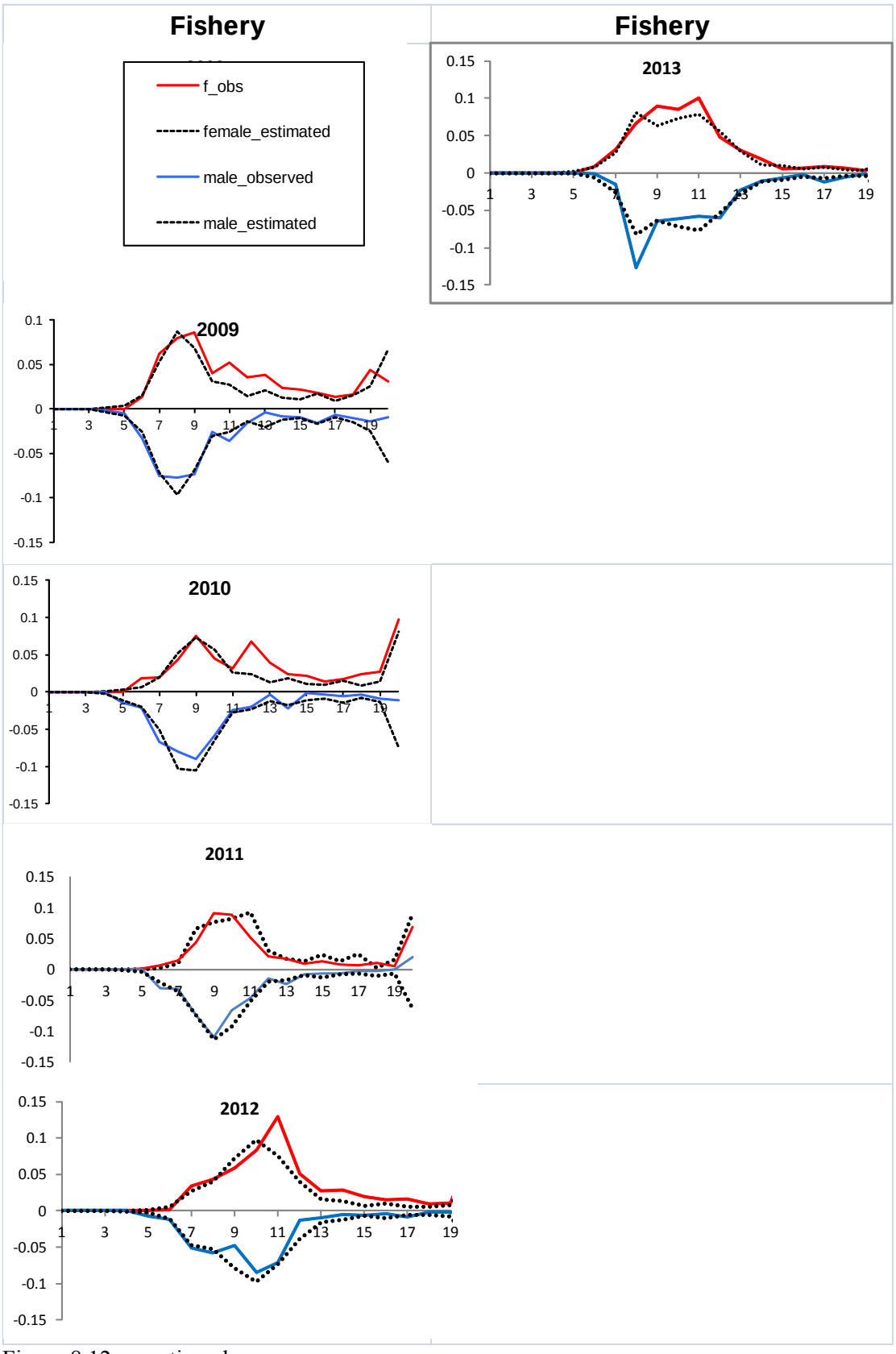


Figure 8.12—continued.

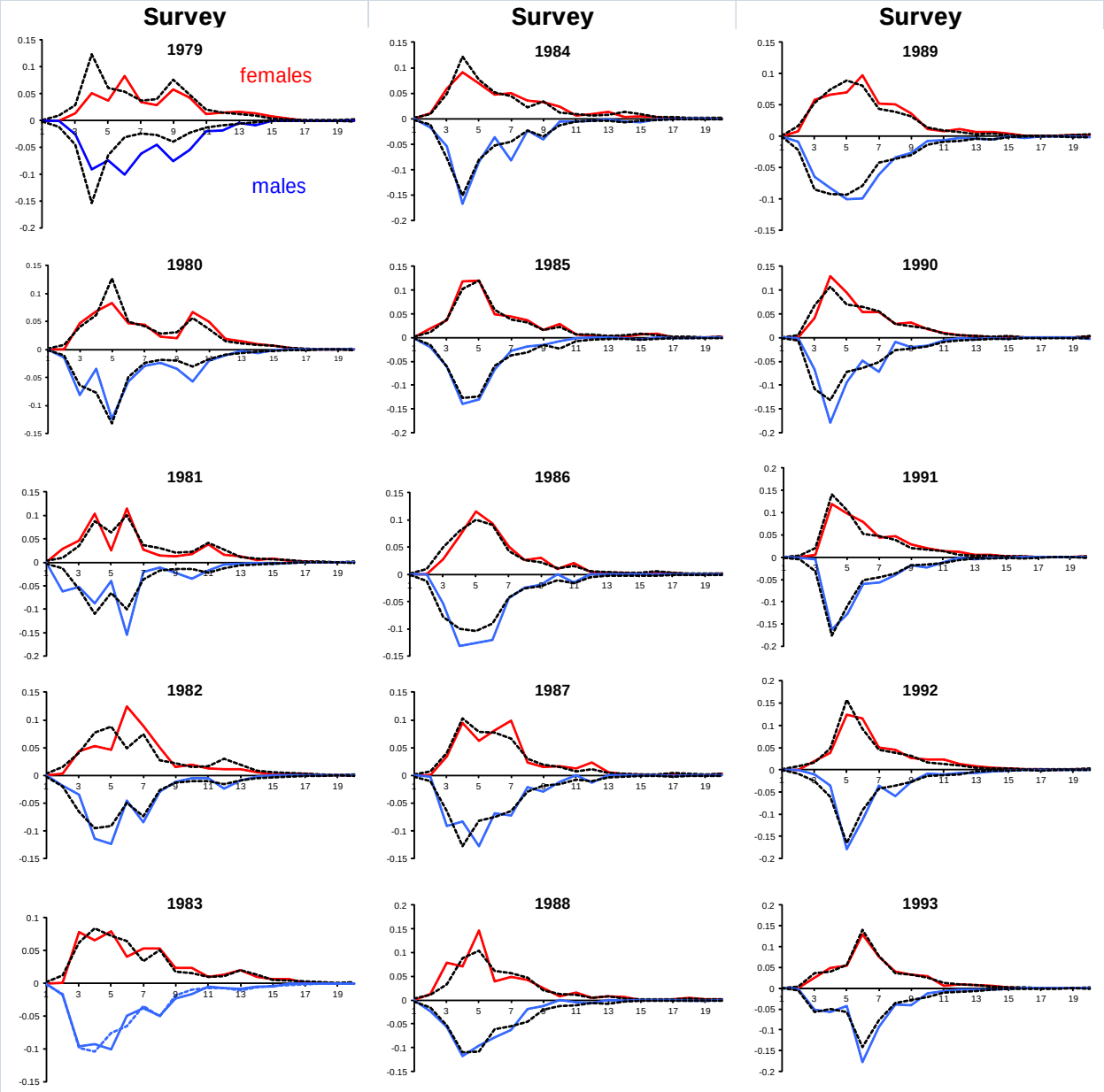


Figure 8.12—continued.

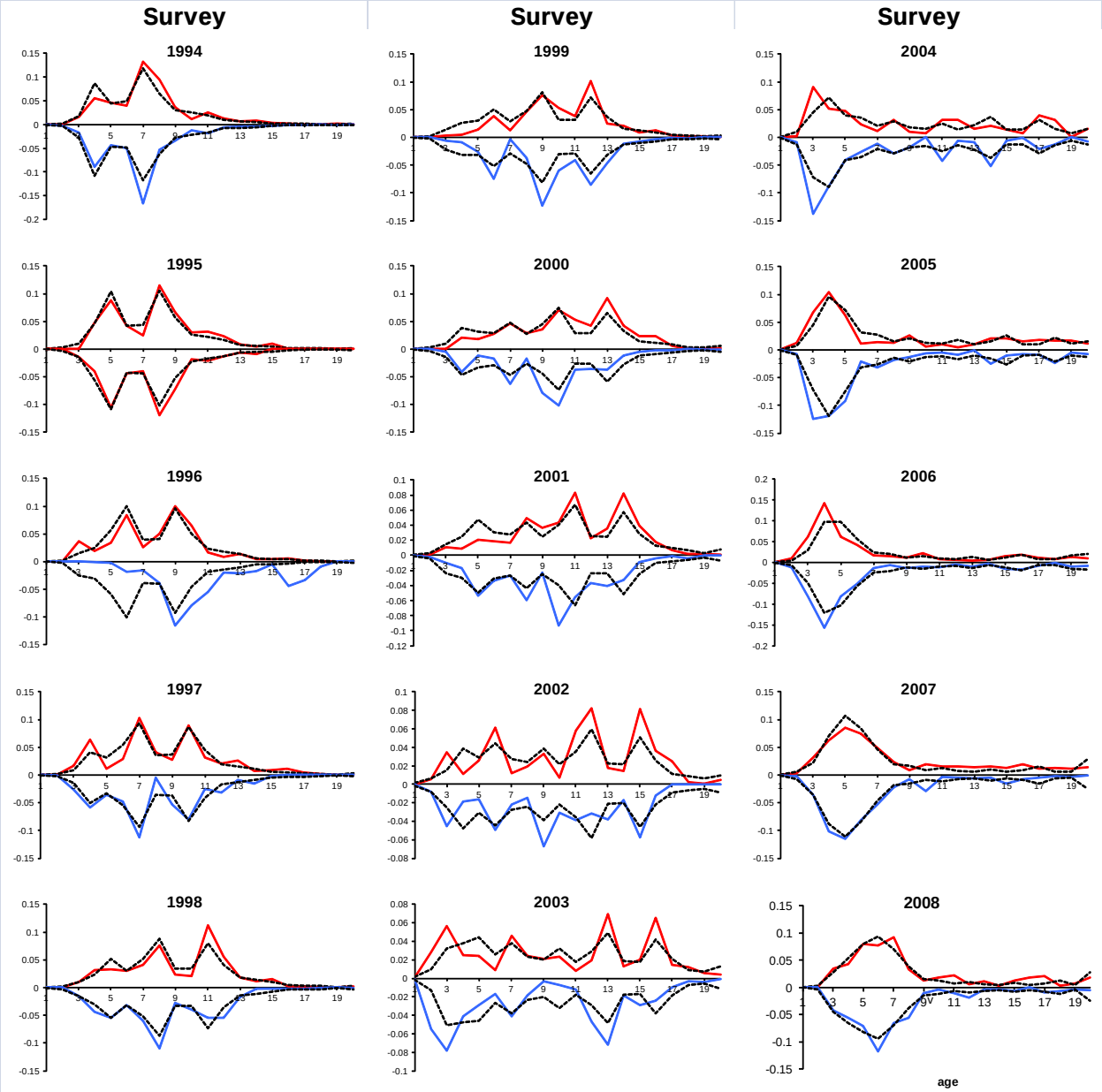
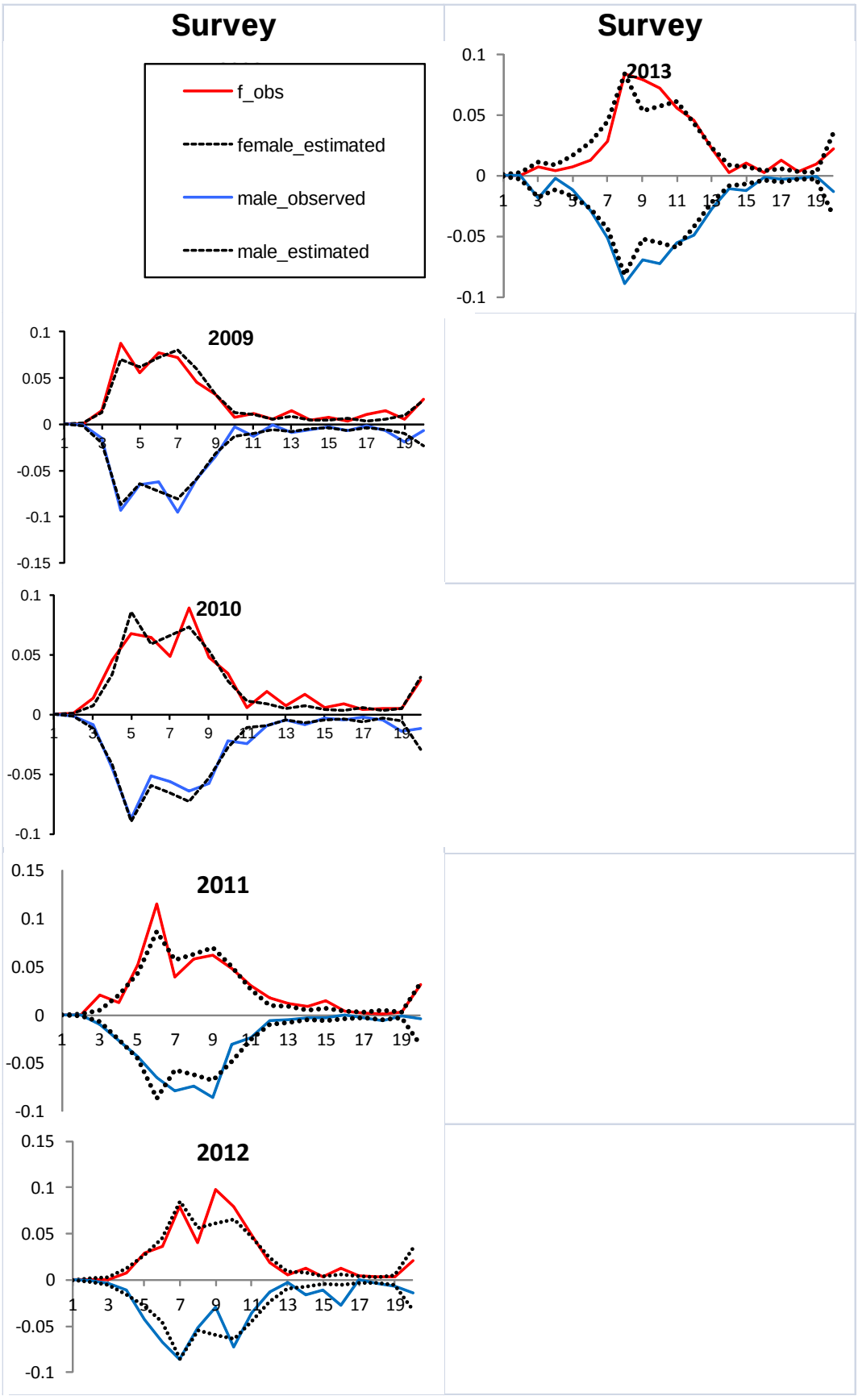


Figure 8.12—continued.


Survey
f_obs
female_estimated
male_observed
male_estimated
Survey
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2009
2010
2011
2012

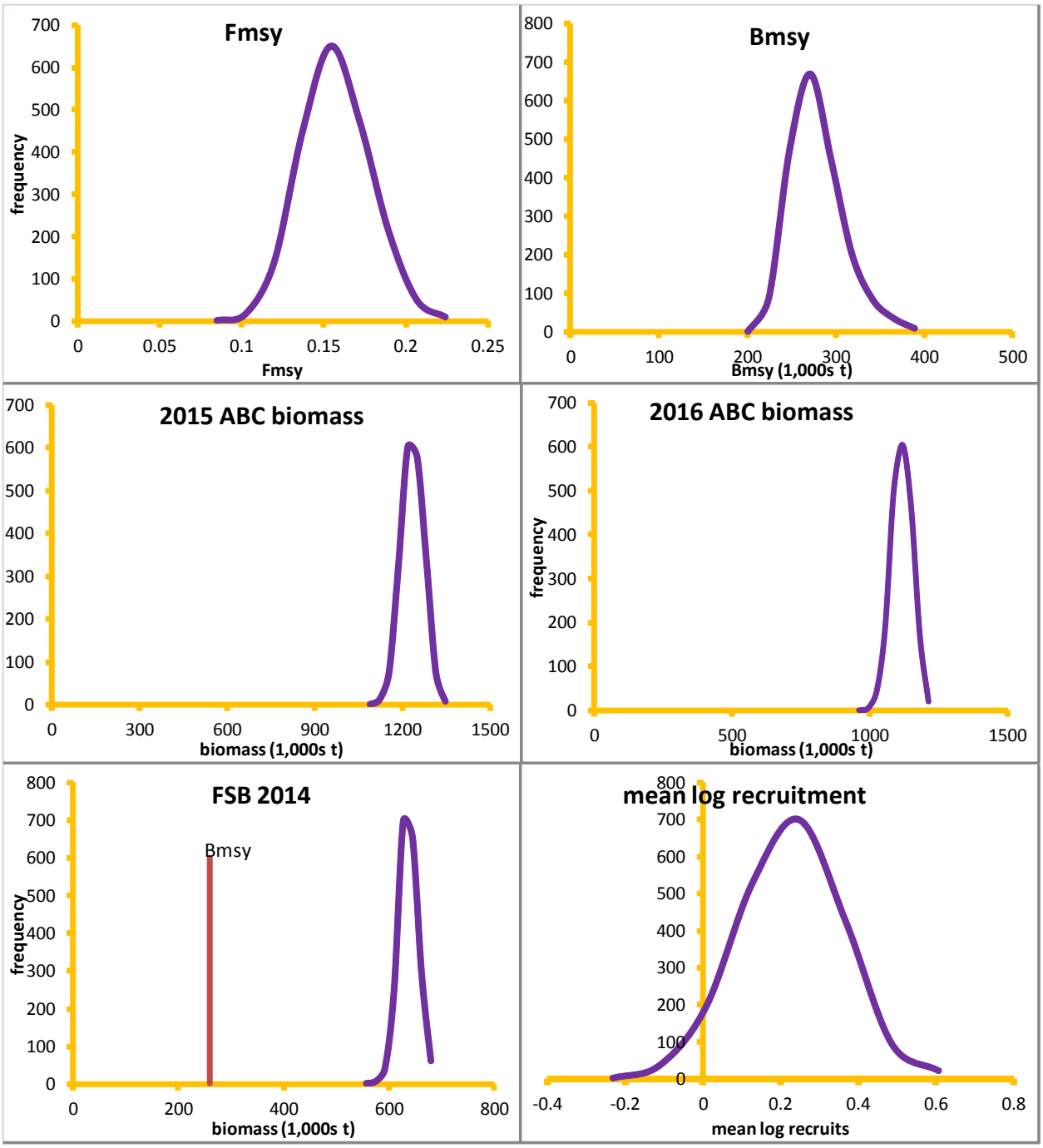

Figure 8.13—Posterior distributions of some selected model estimates from the preferred stock assessment model.

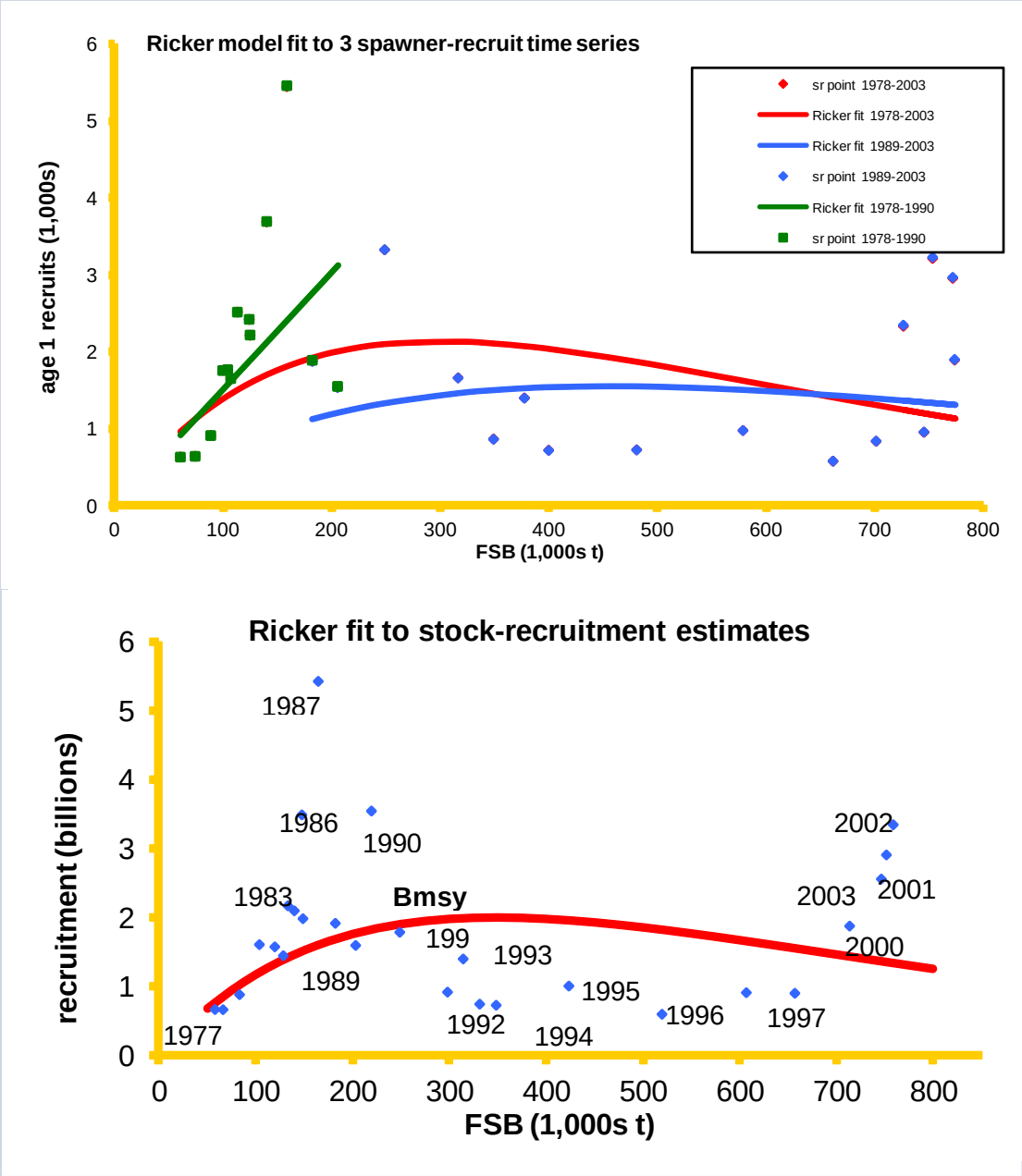

Figure 8.14—Ricker (1958) model fit to spawner-reruit estimates from three time periods; 1978-2003, 1989-2003 and 1978-90 (top panel), and the fit to the spawner-recruit estimates from Model 1 (bottom panel).

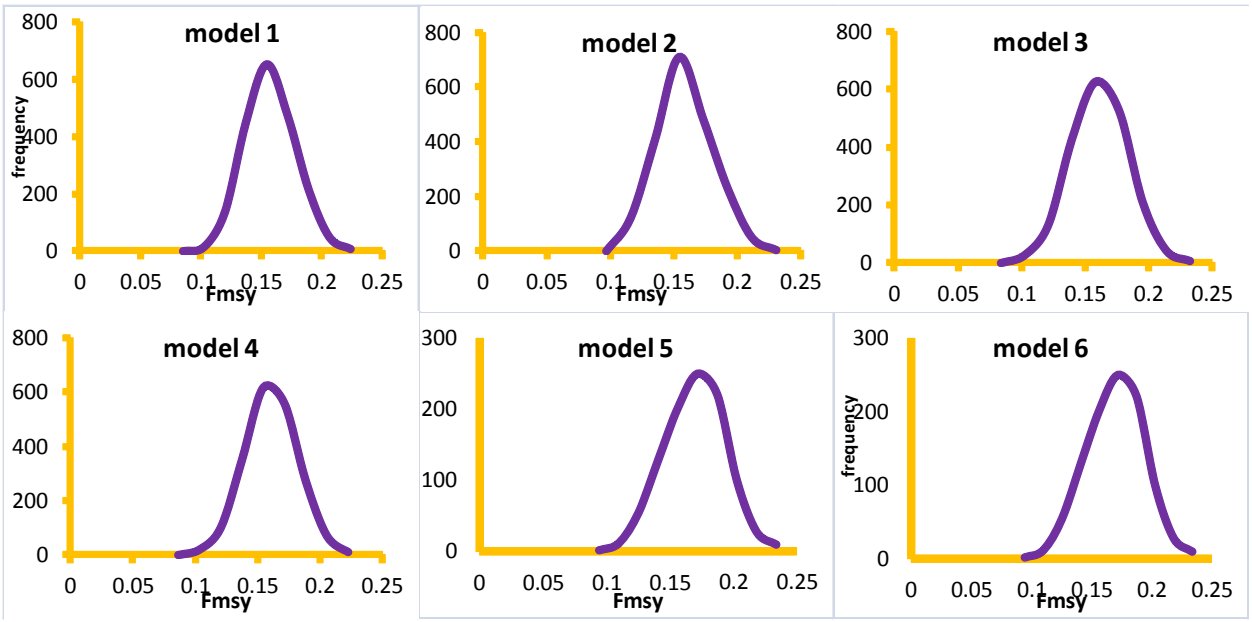

Figure 8.15—Posterior distributions of F_{msy} from 6 of the models considered in the analysis.

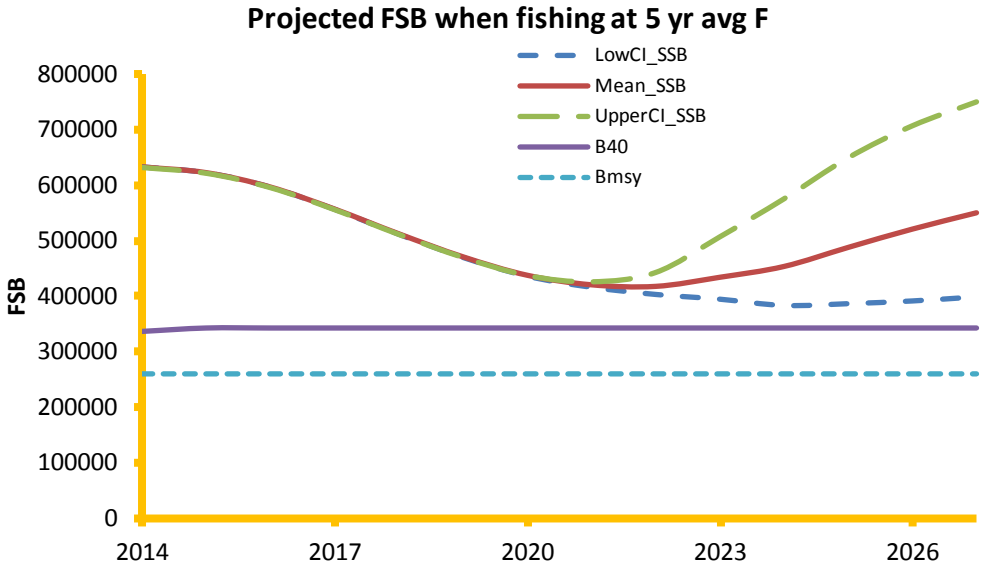

Figure 8.16—Projection of rock sole female spawning biomass when fishing each future year at the average F of the past five years.

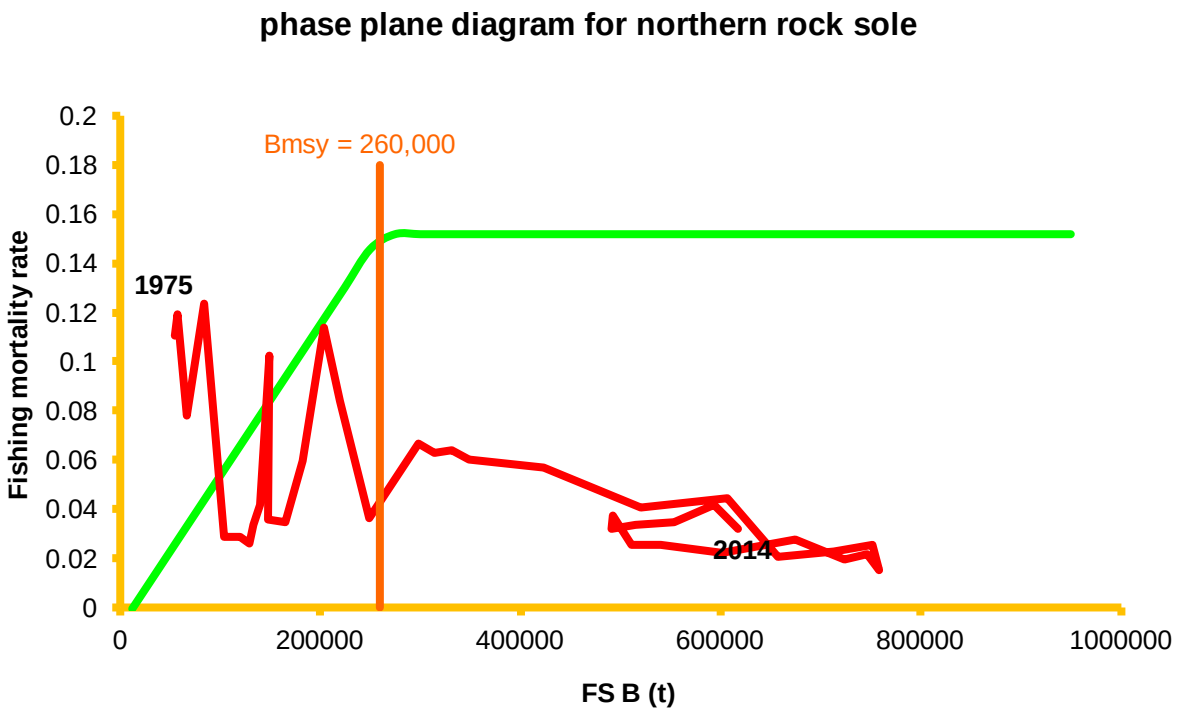

Figure 8.17—Phase-plane diagram of female spawning biomass relative to the harvest control rule.

Appendix

International Pacific halibut Commission survey catch (kg)

2001	0	0	0	0
2002	0	0	0	0
2003	0	0	0	0
2004	0	0	0	0
2005	0	0	0	0
2006	0	0	0	0
2007	0.707	0.502	0.707	0.502
2008	0	0	0	0
2009	0	0	0	0
2010	0.898	0.741	0.898	0.741

southern rock sole

	biomass (t)	CV
1997	65	1
1998	701	0.87
1999	126	0.89
2000	3	1.00
2001	86	1.00
2002	23	1.00
2003	166	0.71
2004	152	0.82
2005	428	0.75
2006	942	0.71
2007	3401	0.70
2008	1322	0.81
2009	2465	0.99
2010	209	1.00
2011	800	0.63
2012	746	0.91
2013	613	0.71
2014	730	1.00

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9. Assessment of the Flathead Sole-Bering flounder Stock in the Bering Sea and Aleutian Islands

By

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Executive Summary

Summary of Changes in Assessment Inputs

(1) 2014 catch biomass was added to the model
(2) 2013 catch biomass was updated to reflect October – December 2013 catches
(3) 2012 fishery age composition data were added and 2011 fishery age composition data were updated to reflect changes made to the observer database.
(4) 2013-2014 fishery length composition data were added to the model
(5) 2013-2014 Eastern Bering Sea (EBS) shelf survey biomass and 2014 Aleutian Islands (AI) survey biomass were added to the linear regression used to determine estimates of AI survey biomass in years when no AI survey occurred; a new survey biomass index was added to the assessment model for 1982-2014 based on updated linear regression results.
(6) 2013-2014 survey bottom temperatures were added to the model.
(7) 2013 survey age composition data were added to the model.
(8) 2014 survey length composition data were added to the model
(9) Minor changes in the historical survey catch were made to the eastern Bering Sea shelf bottom trawl survey database, as a result of Pacific halibut data reconciliation between RACE and the IPHC. The most common error was an incorrect application of an expansion factor to the Pacific halibut catch sample. In hauls where the catch was subsampled, this change in expansion for halibut affected the catch proportion of the other species in the catch to a minor degree.

Summary of Changes in Assessment Methodology

No changes were made to the assessment methodology.

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Summary of Results

The key results of the assessment, based on the author's preferred model, are compared to the key results of the accepted 2013 update assessment in the table below.

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2014	2015	2015*	2016*
M (natural mortality rate)	0.2	0.2	0.2	0.2
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	745,237	744,631	736,947	741,446
Projected Female spawning biomass (t)	239,985	224,112	233,736	221,982
$B_{100\%}$	320,714	320,714	319,206	319,206
$B_{40\%}$	128,286	128,286	127,682	127,682
$B_{35\%}$	112,250	112,250	111,722	111,722
F_{OFL}	0.348	0.348	0.35	0.35
$maxF_{ABC}$	0.285	0.285	0.28	0.28
F_{ABC}	0.285	0.285	0.28	0.28
OFL (t)	79,633	77,023	79,419	76,504
maxABC (t)	66,293	64,127	66,130	63,711
ABC (t)	66,293	64,127	66,130	63,711
Status	As determined in 2013 for:		As determined in 2014 for:	
	2012	2013	2013	2014
Overfishing	no	n/a	no	n/a
Overfished	n/a	no	n/a	no
Approaching overfished	n/a	no	n/a	no

* Projections are based on estimated catches of 16,661t used in place of maximum permissible ABC for current year + 1 and current year + 2. These projected catches were calculated as the current catch of BSAI flathead sole as of October 19, 2014 divided by the ratio of catches to date in the same week of 2013 to the total catches for 2013.

Responses to SSC and Plan Team Comments on Assessments in General

SSC Dec 2013: "The SSC supports the GOA Plan Team recommendation that there should be an investigation into the use of different survey averaging methods, particularly with respect to estimates for species complexes."

Future BSAI flathead sole assessments will investigate use of survey averaging methods to estimate Aleutian Islands survey biomass between survey years.

SSC Dec 2013: "During public testimony, it was proposed that assessment authors should consider projecting the reference points for the future two years (e.g., 2014 and 2015) on the phase diagrams. It was suggested that this forecast would be useful to the public. The SSC agrees. The SSC appreciated this suggestion and asks the assessment authors to do so in the next assessment."

An additional two projection years were included on the phase plot diagram in the current assessment.

GPT, Sept 2013: The Teams recommend retaining use of the mean to estimate the central tendency in recruitment, at least for the time being.

The mean is used to estimate the central tendency in recruitment in this assessment.

GPT, Sept. 2013: The Teams recommend that authors choose a method <for catch estimation when doing stock projections> that appears to be appropriate for their stock, and this method be clearly documented. The Teams recommend authors establish their best available estimate of catch in the current year and the next two years. The Teams recommend that authors should also document how those projected catches were determined in the Harvest Recommendations section (ideally Scenario 2).

The methods for catch estimation used for the projections used in this update are based on the author's best available estimate in the current year and next two years. The methods for catch estimation are documented in the text of this update.

Responses to SSC and Plan Team Comments on Assessments specific to This Assessment

SSC Dec. 2012: "The SSC agrees with the authors' and Team's recommendations for ABC and OFL for 2014 and 2015. In next year's assessment, the SSC would like to see a more complete description of the new catch estimation method"

Additional text was added to the executive summary and harvest projection sections of the assessment to carefully describe catch estimation for 2014. Text was added throughout the document to clarify methods in general.

SSC Dec. 2012: For the next full assessment, the SSC reiterates its request from 2012 that the authors prepare an alternative assessment of flathead sole under Tier 1. The fitted stock-recruit model suggests that Tier 1 status may be appropriate as with yellowfin sole.

The 2016 BSAI flathead sole assessment will evaluate an alternative assessment model of flathead sole under Tier 1. The current assessment presents only Tier 3 results. A future Tier 1 (or Tier 3) assessment should explore alternative options for estimating fishery and survey selectivity, growth (updated data and estimation within the assessment model), and ageing error (i.e. Punt et al. 2008) to improve fits to length composition data as a first priority.

Introduction

"Flathead sole" as currently managed by the North Pacific Fishery Management Council (NPFMC) in the Bering Sea and Aleutian Islands (BSAI) represents a two-species complex consisting of true flathead sole (*Hippoglossoides elassodon*) and its morphologically-similar congener Bering flounder (*H. robustus*). "Flathead sole" was formerly a constituent of the "other flatfish" SAFE chapter. Based on changes in the directed fishing standards to allow increased retention of flatfish, in June 1994 the Council requested the BSAI Plan Team to assign a separate Acceptable Biological Catch (ABC) and Overfishing Limit (OFL) to "flathead sole" in the BSAI, rather than combining them into the "other flatfish" recommendations as in previous assessments. Subsequent to this request, stock assessments for "flathead sole" have been generated annually to provide updated recommendations for ABC and OFL.

Flathead sole are distributed from northern California off Point Reyes northward along the west coast of North America and throughout Alaska (Hart 1973). In the northern part of its range, this species overlaps with its congener, Bering flounder, whose range extends north to the Chukchi Sea and into the western

Bering Sea. Bering flounder typically represent less than 3% of the combined biomass of the two species in annual groundfish surveys conducted by the Alaska Fisheries Science Center (AFSC) in the eastern Bering Sea (EBS). The two species are very similar morphologically, but differ in demographic characteristics and spatial distribution. Differences between the two species in the EBS have been described by Walters and Wilderbuer (1997) and Stark (2011). Bering flounder exhibit slower growth and acquire energy more slowly when compared with flathead sole. Individual fish of the same size and sex can be 10 years different in age for the two species, while fish of the same age can differ by almost 10 cm in size. These differences are most pronounced for intermediate-aged fish (5-25 years old) because asymptotic sizes, by sex, are similar for the two species. Thus, whereas age at 50% maturity is similar for both species (8.7 years for Bering flounder, 9.7 years for flathead sole), size at 50% maturity is substantially smaller for Bering flounder than for flathead sole (23.8 cm vs. 32.0 cm, respectively; Stark, 2004 and Stark, 2011). Stark (2011) hypothesized that the difference in growth rates between the two species might be linked to temperature, because Bering flounder generally occupy colder water than flathead sole and growth rates are typically positively-correlated with temperature.

Walters and Wilderbuer (1997) illustrated the possible ramifications of combining demographic information from the two species. Although Bering flounder typically represent less than 3% of the combined survey biomass for the two species, lumping the two species increases the uncertainties associated with estimates of life-history and population parameters. Accurate identification of the two species occurs in the annual EBS trawl survey. The fisheries observer program also provides information on Bering flounder in haul and port sampling for fishery catch composition. It may be possible in the near future to consider developing species-specific components for ABC and OFL for this complex. Current biological, fishery, and survey information for Bering flounder was discussed in Appendix C of last year's assessment (Stockhausen et al., 2010).

For the purposes of this report, Bering flounder and flathead sole are combined under the heading "*Hippoglossoides* spp." and, where necessary, flathead sole (*H. elassodon*) is used as an indicator species for the complex. Where the fishery is discussed, the term "flathead sole" will generally refer to the two-species complex rather than to the individual species.

Fishery

Prior to 1977, catches of flathead sole (*Hippoglossoides* spp.) were combined with several other flatfish species in an "other flatfish" management category. These catches increased from around 25,000 t in the 1960s to a peak of 52,000 t in 1971. At least part of this apparent increase was due to better species identification and reporting of catches in the 1970s. After 1971, catches declined to less than 20,000 t in 1975. Catches during 1977-89 averaged 5,286 t. Since 1990, annual catches have averaged approximately 17,000 t (Table 9.1, Figure 9.1). The catch in 2008 (24,539 t) was the highest since 1998. The average catch from 2011-2014 (14,547 t) was smaller than that from the previous time period (2006-2010; 20,181 t), but the catch in 2013 (17,358 t) and 2014 (15,906 t as of October 18, 2014) was larger than the catch in 2011 and 2012 (13,566 t and 11,366 t).

The majority of the catch is taken by non-pelagic trawl gear (81-82% in 2013 and 2014 and 63-64% in 2011 and 2012) and pelagic trawl gear (15% and 17% in 2013 and 2014; 35% and 33% in 2011 and 2012; Table 9.2). In addition, almost all of the catch is taken from NMFS statistical areas 509, 513, 517, and 521 in each year; 19%, 17%, 25%, and 36% of the catch was taken in each of these four reporting areas, respectively, in 2014 (as of October 18, 2014; Table 9.3, Figure 9.2).

Using observer-reported species-specific catches and extrapolating to the total *Hippoglossoides* spp. catch within each area yields disaggregated estimates of total catch of flathead sole and Bering flounder (Table

9.4, Figure 9.2). Bering flounder constitutes only a small percentage of the total Hippoglossoides species catch each year (0.46% and 0.23% in 2013 and 2014, respectively, Figure 9.2).

Although flathead sole receives a separate ABC and TAC, until 2008 it was managed in the same Prohibited Species Catch (PSC) classification as rock sole and "other flatfish" and it received the same apportionments and seasonal allowances of incidental catch of prohibited species as these other stocks. In July, 2007, however, the NPFMC adopted Amendment 80 to the BSAI Fishery Management Plan (FMP). The purpose of this amendment was, among other things, to: 1) improve retention and utilization of fishery resources by the non-American Fisheries Act (non-AFA) trawl catcher/processor fleet by extending the AFA's Groundfish Retention Standards to all vessels and 2) establish a limited access privilege program for the non-AFA trawl catcher/processors and authorize the allocation of groundfish species to cooperatives to encourage lower discard rates and increased value of harvested fish while lowering costs. In addition, Amendment 80 also mandated additional monitoring requirements which include observer coverage on all hauls, motion-compensating scales for weighing samples, flow scales to obtain accurate catch weight estimates for the entire catch, no mixing of hauls and no on-deck sorting. Amendment 80 applies to catcher/processors and creates three designations for flatfish trawlers: Amendment 80 cooperatives, Amendment 80 limited access, and BSAI limited access (i.e., all others not covered by Amendment 80). Under Amendment 80, allocations of target species and PSC are based on individual fishing history. Vessels may form cooperatives, with each cooperative being assigned cooperative-level allocations of target species and PSC. Catcher/processors that do not participate in a cooperative fall under the Amendment 80 limited access designation. Target species and PSC allocations are made to the limited access sub-sector, not to individual vessels within it. Thus, vessels within the Amendment 80 limited access sub-sector function as in a traditional TAC-based fishery (i.e., they compete amongst each other for limited harvests). Additionally, PSC in the Amendment 80 limited access sector is managed in the same manner as it was managed prior to 2008: the Amendment 80 limited access flathead sole fishery is managed in the same PSC classification as Amendment 80 limited access fisheries for rock sole and "other flatfish" and it receives the same apportionments and seasonal allocation as these fisheries. Once TAC and PSC have been allocated to the two Amendment 80 sectors, any remaining allocations of target species and PSC are made to the (non-Amendment 80) BSAI limited access sector. At present, flathead sole is 100% allocated to the Amendment 80 cooperative and limited access sectors, so directed fishing for flathead sole is prohibited in the BSAI limited access sector.

Prior to the implementation of Amendment 80 in 2008, the flathead sole directed fishery was often suspended or closed prior to attainment of the TAC for exceeding halibut bycatch limits; no such closures have occurred since 2007 (Table 9.5).

Substantial amounts of flathead sole have been discarded in various eastern Bering Sea target fisheries, although retention standards have improved since the implementation of Amendment 80 in 2008 (

Table 9.6). Based on data from the NMFS Regional Office Catch Accounting System, about 30% of the flathead sole catch was discarded prior to 2008. Subsequent to Amendment 80 implementation, the average discard rate has been less than 15% (Table 9.6).

Data

The following data were used in the assessment:

Source	Data	Species Included	Years
NMFS Aleutian Islands Groundfish Trawl Survey	Survey biomass (linear regression used to interpolate AI survey estimates in missing years for a single, combined AI + EBS shelf survey biomass index)	Flathead only; no Bering flounder were caught in the Aleutian Islands	1980, 1983, 1986, 1991-2000 (triennial), 2002-2006 (biennial), 2010-2014 (biennial)
NMFS Bering Sea Shelf Groundfish Survey (standard survey area only[1])	Survey biomass (linear regression used to interpolate AI survey estimates in missing years for a single, combined AI + EBS shelf survey biomass index)	Flathead sole and Bering flounder combined	1982-2014
	Age Composition	Flathead sole only	1982, 1985, 1992-1995, 2000-2011, 2013
	Length Composition	Flathead sole only	1983, 1984, 1986-1991, 1996-1999, 2012, 2014
U.S. trawl fisheries	Catch (Bering Sea and Aleutian Islands; pelagic and non-pelagic trawl[2])	Flathead sole and Bering flounder combined	1977-2014
	Age Composition (Bering Sea only; non-pelagic trawl only)	Flathead sole only	1994-1995, 1998, 2000-2001, 2004-2007, 2009-2012
	Length Composition (Bering Sea only; non-pelagic trawl only)	Flathead sole only	1977-1993, 1996-1997, 1999, 2002-2003, 2008, 2013-2014

1. Excludes survey strata 70, 81, 82, 90, 140, 150, and 160
2. A very small amount of catch is taken with hook and line and is included in the total catch biomass

Fishery:

This assessment used fishery catches for flathead sole and Bering flounder combined (*Hippoglossoides spp.*) from 1977 through October 18, 2014 (Table 9.1, Figure 9.1). Fishery age and length composition data were used for flathead sole caught in the Bering Sea by non-pelagic trawl (and excluding Bering flounder catches, pelagic trawl catches, and Aleutian Islands catches). Fishery age compositions for 2000, 2001, 2004-2007 and 2009-2012 were included in the assessment model (Figure 9.3; Table 9.8). The sample sizes for age compositions are small for years 1994, 1995, and 1998 (Table 9.7) and they were excluded from the assessment model. Size compositions were available for 1977-2014 (Figure 9.4, Table 9.9, Table 9.10). To avoid double-counting data used to estimate parameters in the assessment model, the size composition data were excluded in the model optimization when the age composition data from the

same year were included. Thus, only the flathead sole fishery size compositions for 1977-1999, 2002-2003, 2008 and 2013-2014 were included in the assessment model.

Survey:

Groundfish surveys are conducted annually by the Resource Assessment and Conservation Engineering (RACE) Division of the AFSC on the continental shelf in the EBS using bottom trawl gear. These surveys are conducted using a fixed grid of stations and have used the same standardized research trawl gear since 1982. The "standard" survey area has been sampled annually since 1982, while the "northwest extension" has been sampled since 1987 (Figure 9.5). In 2010, RACE extended the groundfish survey into the northern Bering Sea (Figure 9.5) and conducted standardized bottom trawls at 142 new stations. The data generated by this survey extension may have important implications for the future management of Bering flounder (Stockhausen et al. 2012). Unfortunately, only the standard and northwest extension areas were sampled in 2011-2014. RACE also conducts bottom trawl surveys in the Aleutian Islands (AI) on a triennial basis from 1980 to 2000 and on a biennial basis since 2002 (although no survey was conducted in 2008). Bering flounder are caught in small amounts on the EBS shelf (0-6% of *Hippoglossoides spp.* catch; Table 9.11, Figure 9.6, Figure 9.9), but have not been recorded in any year of the AI survey.

Survey-based estimates of total biomass use an “area-swept” approach and implicitly assume a catchability of 1. Following Spencer et al. (2004), EBS surveys conducted prior to 1982 were not included in the assessment because the survey gear changed after 1981. To maintain consistent spatial coverage across time, only survey strata that have been consistently sampled since 1982 (i.e., those comprising the "standard" area) are included in the EBS biomass estimates.

This assessment used a single survey index of "total" *Hippoglossoides spp.* biomass that included the EBS “standard” survey areas and AI survey areas for the years 1982-2014 (Table 9.11, Figure 9.7). A single linear regression is used to estimate a relationship between EBS shelf *Hippoglossoides spp.* survey biomass estimates and AI survey biomass estimates; this relationship is used to estimate AI survey biomass in years when no AI survey occurred (by using the linear equation to find an AI biomass estimate in a particular year based on the EBS biomass estimate for that year). Based on these surveys, *Hippoglossoides* spp. biomass approximately quadrupled from the early 1980s to a maximum in 1997 (819,365 t). Estimated biomass then declined to 407,001 t in 2000 before increasing to a recent high of 645,419 t in 2006. The 2014 estimate was 532,886 t, a 38% increase from the 2012 estimate of 387, 043 t.

Although survey-based estimates of total biomass assume a catchability (and size-independent selectivity) of 1, previous assessments for flathead sole and other BSAI flatfish have identified a relationship between bottom temperature and survey catchability (e.g., Wilderbuer et al. 2002; Spencer et al., 2004; Stockhausen et al., 2011). Bottom temperatures are hypothesized to affect survey catchability by affecting the stock distribution and/or the activity level of flatfish. The spatial distribution of flathead sole has been shown to shift location in conjunction with shifts in the location of the so-called “cold pool” on the EBS shelf. This relationship was investigated in previous assessments for flathead sole (Spencer et al., 2004) by using annual temperature anomalies from data collected at all survey stations as a covariate of survey catchability. Model results from that assessment indicated the utility of this approach and it has been used subsequently (e.g., Stockhausen et al., 2011). EBS shelf mean bottom temperatures were particularly warm from 2002-2005 and cold from 2006-2009 (Table 9.11, Figure 9.8). Bottom temperatures were colder than average and survey biomass lower than average in 2012 (1.9 deg. C and 387,043 t, respectively); bottom temperatures were warmer than average and survey biomass higher than average in 2014 (3.2 deg C and 532,886 t, respectively; Figure 9.7, Figure 9.8, Figure 9.9, Table 9.11). During the cold period from 2006-2009, the cold pool extended well to the south along the so-called “middle domain” of the continental shelf, which would be expected to have a substantial effect on survey catchability for these years. Flathead sole appear to have been constrained to the outer domain of the shelf in response to the extended cold pools in 2006-2010 and 2012 (Stockhausen et al. 2012). Spatial distribution of flathead sole and Bering flounder biomass and mean bottom temperatures from the EBS

shelf survey in 2013 and 2014 are shown in Figure 9.9 for flathead sole and Bering flounder. The extent of the cold pool in summer 2013 was much greater than in 2014; CPUE of flathead sole at 0 deg C and below was low in in both years, with many survey stations catching 0 flathead sole. In addition, no flathead sole were caught at many survey stations in the northeastern part of the EBS, where temperatures are the greatest. Areas with the highest flathead sole CPUE were similar in 2013 and 2014. As in previous years, Bering flounder survey CPUE was highest in the northwestern (and coldest) part of the EBS, with few catches of Bering flounder in warmer areas (Figure 9.9). However, the distribution of Bering flounder was similar in 2013 and 2014, despite differences in the extent of the cold pool (Figure 9.9).

Sex-specific survey age and size composition data for flathead sole only from the EBS shelf survey only ("standard" survey areas) were included in the assessment. Survey age composition data for 1982, 1985, 1992-1995, 2000-2011, and 2013 were used (Table 9.13, Table 9.14). Survey size composition data were available for 1982-2014, but were excluded from the model optimization in years when survey age composition data were available for the same year. Thus, only the survey size compositions for 1984-91, 1996-99, 2012, and 2014 were included in the model optimization, using 2 cm size bins (Table 9.15, Table 9.16).

Analytical approach

Model Structure

No changes were made to the model; the model structure from the accepted 2012 assessment was used to conduct the 2014 assessment.

The assessment for flathead sole is conducted using a split-sex, age-based model with length-based formulations for fishery and survey selectivity. The model structure (see Appendix A for details) was developed following Fournier and Archibald's (1982) methods for separable catch-at-age analysis, with many similarities to Methot (1990). The assessment model simulates the dynamics of the stock and compares expected values of stock characteristics with observed values from survey and fishery sampling programs in a likelihood framework, based on distributional assumptions regarding the observed data. Model parameters are estimated by minimizing an associated objective function (the negative total log-likelihood plus imposed penalty functions) that describes the error structure between model estimates and observed quantities.

The model was implemented AD Model Builder, automatic differentiation software developed as a set of C++ libraries. AD Model Builder can estimate a large number of parameters in a non-linear model using automatic differentiation software extended from Greiwank and Corliss (1991). This software provides the derivative calculations needed for finding the minimum of an objective function via a quasi-Newton function minimization routine (e.g., Press et al. 1992). It also gives simple and rapid access to these routines and provides the ability to estimate the variance-covariance matrix for all parameters of interest, as well as to perform Markov Chain Monte Carlo (MCMC) analysis.

Age classes included in the model run from age 3 to 21. Age at recruitment was set at 3 years in the model because few fish are caught at younger ages in either the survey or the fishery. The oldest age class in the model (21 years) serves as a plus group in the model; the maximum age of flathead sole in the BSAI, based on otolith age determinations, is 32 years. Details of the population dynamics and estimation equations, description of variables and likelihood components are presented in Appendix A of this chapter. Model parameters that are typically fixed (estimated outside the model) are described in Tables A.2 and A.10 and discussed below. A total of 81 parameters were estimated in the preferred model.

Parameters estimated outside the assessment model

Parameters estimated independently include the log-scale mean survey catchability α_q, natural mortality rates (M_x), the age-based maturity ogive, the ageing error matrix, sex-specific length-at-age conversion matrices ($\mathbf{\Phi}_{x,l,a}$), weights-at-length ($W_{x,l}$), and individual weights-at-age for the survey ($W^S_{x,a}$) and the fishery ($W^F_{x,a}$) (see Appendix A for definitions of coefficients). The log-scale mean survey catchability parameter α_q was fixed at 0.0, producing a mean survey catchability of 1.0. The natural mortality rates M_x were fixed at 0.2 for both sexes, consistent with previous assessments. The maturity ogive for flathead sole was based on Stark (2004), who found a length at 50% maturity of 320.2 mm using a logistic curve. The ageing error matrix was taken directly from the Stock Synthesis model used in assessments prior to 2004 (Spencer et al., 2004).

Sex-specific length-at-age curves were previously estimated from survey data using a procedure designed to reduce potential sampling-induced biases (Spencer et al., 2004). Mean lengths-at-age did not exhibit consistent temporal trends, so sex-specific von Bertalanffy growth curves were fit to mean length-at-age data using all years available at the time (1982, ’85, ’92, ’94, ’95 and 2000). The parameters values are given in the following table:

	von Bertalanffy growth parameters		
Sex	t_0	L_∞	K
Male	-0.27	37.03	0.19
Female	-1.24	50.35	0.10

The L_∞ estimates of 37 cm and 50 cm for males and females, respectively, are somewhat lower than those obtained using a potentially biased approach in previous assessments (40 cm and 55 cm, respectively; Spencer et al., 2003). The resulting growth curves are illustrated in Figure 9.10 (top graph). Age is converted to size in the model assuming that size-at-age is normally-distributed with sex-specific mean size-at-age given by the von Bertalanffy equation using the parameters given above and a constant cv of 0.13 (Figure 9.10, bottom graphs).

A length–weight relationship of the form $W = a\,L^b$ was fit to survey data from 1982-2004, with parameter estimates a = 0.00326 and b = 3.3 applying to both sexes (weight in g, length in cm). Application of the length-weight relationship to the predicted size-at-age from the von Bertalanffy relationships yielded weight-at-age relationships for the fishery and survey (Figure 9.11).

Parameters estimated inside the assessment model

The majority of parameters estimated inside the model are associated with annual estimates of fishing mortality and recruitment. The other parameters estimated inside the model include historical fishing mortality, historical mean recruitment, fishery and survey length selectivity parameters, and survey temperature-dependent catchability. Details are described in Appendix A. The number of estimable parameters associated with different model components is summarized for the model in the following table:

Parameter type	Number of Parameters
Mean fishing mortality	1
Fishing mortality deviations	38
Mean recruitment	1
Recruitment deviations	38
Historical fishing mortality	1
Historical mean recruitment	1
Logistic fishery selectivity-at-length	2
Logistic survey selectivity-at-length	2
Temperature-dependent catchability coefficient	1
Total parameters	**85**

Parameter estimates are obtained by minimizing the overall sum of a weighted set of negative log-likelihood components derived from fits to the model data described above and a set of penalty functions used to improve model convergence and impose various constraints (Appendix A, this chapter). Fits to observed annual fishery size and age compositions, as well as survey biomass estimates and size and age compositions are included among the set of likelihood components. A likelihood component based on recruitment deviations from the mean is also included. Penalties are imposed to achieve good fits to annual fishery catches (biomass) and the assumed historical fishery catch. The functions used are described in more detail in Appendix A of this chapter.

Results

Model Evaluation

Model fits to the survey biomass time series are within the 95% asymptotic confidence intervals of the data in most years (Figure 9.12). Exceptions are predicted survey biomass in 2012 and 1999-2000, where observed survey biomass was particularly low, and in 1988 when survey biomass was higher than in the surrounding years. Corresponding EBS mean bottom temperatures in 2012 and 1999-2000 were particularly low relative to the mean (especially in 1999 and 2012), but the relationship in the model between temperature and catchability only partially explains the extremely low survey biomass observations those years.

Fits to survey age composition data for flathead sole in the EBS shelf survey are reasonable in most years (Figure 9.13, Figure 9.14). The model predicted a smaller proportion of older (age (10-15) males and females than were observed in 1993 (Figure 9.13). Figure 9.15 and Figure 9.16 shows fits to survey length composition data of EBS flathead sole. A greater concentration of males in the 30-35cm size range are observed than are predicted in many years; this type of mismatch may indicate that the growth model (estimated outside of the assessment) or survey selectivity may be mis-specified. In addition, growth is sex-specific in the model, but survey and fishery selectivity curves are not sex-specific. Estimating an ageing error matrix with updated methods (i.e. Punt et al. 2008) may improve fits to age and length composition data as well. These hypotheses should be explored in future assessments.

Figure 9.17 and Figure 9.18 show model fits to fishery age composition data. In recent years (2004-2012), the fishery caught a greater proportion of male fish of ages 5-10 than predicted by the model. Likewise, fits to fishery length composition data show that a greater concentration of male fish in the 30-40 cm

length category were observed than were predicted by the model (Figure 9.19 and Figure 9.20); this is a similar pattern as observed in the survey length composition data. As mentioned above, mis-specification of selectivity curves, growth, and/or ageing error may contribute to systematic mismatches between observed and predicted age and length compositions (especially mis-matches that occur in fits to both the survey and fishery length composition data). The model fits to female fishery age and length composition data are reasonable in most years. Exceptions are 1983, 1993, 1995, and 2012, when a greater concentration of larger fish (35-45 cm) were observed than were predicted by the model, which may be due to variation over time in fishery selectivity.

Estimates of length-based logistic selectivity (Figure 9.21, Figure 9.23, Table 9.17) suggest that the survey captures smaller fish (L_{50} = 27.766 cm for the survey) than are captured by the fishery (L_{50} = 34.89). In addition, the slope of the survey selectivity curve (k = 0.122) is lower than the slope of the fishery selectivity curve (k = 0.330). The value estimated for the temperature-dependent catchability parameter (0.059) is positive, which acts to increase catchability such that it is greater than 1 in years where the mean bottom temperature is above the average of mean bottom temperatures over the years 1977-2014, and decreases catchability such that it is below 1 when mean bottom temperature in a particular year is below the long-term average (Figure 9.23, Table 9.17). Posterior distributions for time-invariant parameters and derived quantities are shown in Figure 9.23; all posterior distributions show one defined mode, indicating that parameter estimates and estimates of derived quantities, such as 2014 spawning biomass and recruitment, are stable and are not local minima.

Time series results

Time series of estimated total biomass, spawning biomass, and recruitment are shown in Figure 9.24 and estimated numbers-at-age are shown in Table 9.21 and Table 9.22. Estimates of total biomass were below 200,000 t in 1977, increased steadily until the mid-1990s and show a slow decrease since the mid-1990s. Uncertainty bounds on spawning biomass are particularly small; several parameters are fixed in the model (including natural mortality and catchability) and therefore uncertainty about these parameters is ignored in the model. Uncertainty bounds corresponding to derived quantities such as spawning biomass would almost certainly be larger if uncertainty in the fixed parameters were represented in the model.

Model estimates of age-3 recruitment (lagged 3 years) in 2004-2010 are relatively low (Figure 9.24). The model estimates a large recruitment of age 3 fish in 2014 (shown as 2011 in Figure 9.24) and very low recruitment of age-3 fish in 2013 (shown as 2010 in Figure 9.24). However, these recruitments may be based on little information, as these cohorts have been observed only partially (due to low selectivity at small lengths) and only for a year or two.

Although relatively large at the start of the model time period (1977), estimated fully-selected fishing mortality has been small since the fishery became completely domestic in 1990, averaging $F = 0.052$ yr^{-1} over the past 10 years (2005-2014; Figure 9.22). Estimated fishing mortality is plotted against spawning stock biomass relative to the harvest control rule in Figure 9.25. The stock has been below its estimated $F_{35\%}$ level and above its $B_{35\%}$ level since 1987. The stock is currently well above its $B_{35\%}$ level and is being fished well below its $F_{35\%}$ level.

Retrospective Analysis

Retrospective analyses were conducted by running this year's assessment model iteratively, each time removing one additional year of data, starting with the most recent year of data. Retrospective model estimates for recent spawning biomass and total biomass are slightly higher than in models for subsequent years for the 2006-2012 models (Figure 9.26 and Figure 9.27). Exceptions are retrospective model runs for 2004 and 2005, in which spawning and total biomass are estimated to be lower than in subsequent retrospective analyses, but estimates of historical spawning and total biomass are 20% and 10% higher than in models for subsequent years (Figure 9.26 and Figure 9.27). Estimates of fishing mortality and recruitment deviations are nearly identical among retrospective models (Figure 9.28 and Figure 9.29);

there is a slightly positive retrospective bias in estimates of recruitment deviations and a slightly negative retrospective bias in fishing mortality rates (~5-10% difference in both recruitment deviations and fishing mortality rates from the 2014 model) for model years 2006-2012. Table 9.23 shows estimates of the time-invariant model parameters for each retrospective model, with conditional formatting to highlight any systematic changes in estimates. Estimates of the temperature dependent catchability parameter are higher in 2004 and 2005, and average recruitment is estimated to be lower in those years. Small, systematic changes in estimates occur among most model parameters from 2006 to 2014 (i.e. fishery and survey selectivity slopes, survey selectivity L50, average F, average recruitment, historical F, historical R, and temperature-dependent catchability). Mohn's rho for the retrospective analyses is 0.021.

Harvest Recommendations

The reference fishing mortality rate for the flathead sole/Bering flounder complex is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{40\%}$, $F_{35\%}$, and $SPR_{40\%}$ were obtained from a spawner-per recruit analysis. Assuming that the average recruitment from the 1980-2012 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{40\%}$ is calculated as the product of $SPR_{40\%}$ times the equilibrium number of recruits. Since reliable estimates of the 2013 spawning biomass (B), $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and $B>B_{40\%}$, the flathead sole/Bering flounder reference fishing mortality is defined in Tier 3a. For this tier, F_{ABC} is constrained to be $\leq F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. The values of these quantities are:

SSB 2014	233,736
$B_{40\%}$	127,682
$F_{40\%}$	0.28
max$Fabc$	0.28
$B_{35\%}$	111,722
$F_{35\%}$	0.35
F_{OFL}	0.35

Because the flathead sole/Bering flounder stock complex has not been overfished in recent years and the stock biomass is relatively high, it is not recommended to adjust F_{ABC} downward from its upper bound.

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). For each scenario, the projections begin with the vector of 2014 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2015 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2014. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective

harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2014, are as follows ("max F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, *F* is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, *F* is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2014 recommended in the assessment to the *max*F_{ABC} for 2014. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, *F* is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, *F* is set equal to the 2008-2013 average *F*. (Rationale: For some stocks, TAC can be well below ABC, and recent average *F* may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, *F* is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.) The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, so scenarios 1 and 2 yield identical results. The 12-year projections of the mean spawning stock biomass, fishing mortality, and catches for the five scenarios are shown in Table 8.15Table 8.17.

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the flathead sole stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as *B35%*):

Scenario 6: In all future years, *F* is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY level in 2014, then the stock is not overfished.)

Scenario 7: In 2014 and 2015, *F* is set equal to *max* F_{ABC}, and in all subsequent years, *F* is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2026 under this scenario, then the stock is not approaching an overfished condition.)

The results of these two scenarios indicate that the stock is not overfished and is not approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2015 of scenario 6 is 232,141 t, more than 2 times *B35%* (111,722t). Thus the stock is not currently overfished. With regard to whether the stock is approaching an overfished condition, the expected spawning stock size in the year 2027 of scenario 7 (131,732t) is greater than *B35%*; thus, the stock is not approaching an overfished condition.

Ecosystem Considerations

Ecosystem effects on the stock

Prey availability/abundance trends

Results from an Ecopath-like model (Aydin et al., 2007) based on stomach content data collected in the early 1990's indicate that flathead sole occupy an intermediate trophic level in the eastern Bering Sea ecosystem (Figure 9.30). They feed upon a variety of species, including juvenile walleye pollock and other miscellaneous fish, brittlestars, polychaetes, and crustaceans (Figure 9.31). The proportion of the diet composed of fish appears to increase with flathead sole size (Lang et al., 2003). The population of walleye pollock has fluctuated but has remained relatively stable over the past twenty years. Information about the abundance trends of the benthic infauna of the Bering Sea shelf is sparse, although some benthic infauna are caught in the EBS groundfish trawl survey. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not been re-sampled since.

Over the past 20 years, many of the flatfish populations that occupy the middle shelf of the eastern Bering Sea have increased substantially in abundance, leading to concern regarding the action of potential density-dependent factors. Walters and Wilderbuer (2000) found density-dependent changes in mean length for age-3 northern rock sole during part of that stock's period of expansion, but similar trends in size have not been observed for flathead sole (Spencer et al., 2004). These populations have fluctuated primarily due to variability in recruitment success, in which climatic factors or pre-recruitment density dependence may play important roles (Wilderbuer et al., 2002). Evidence for post-recruitment density dependent effects on flathead sole is lacking, which suggests that food limitation has not occurred and thus the primary infaunal food source has been at an adequate level to sustain the flathead sole resource.

McConnaughy and Smith (2000) compared the diet between areas with high survey CPUE to that in areas with low survey CPUE for a variety of flatfish species. For flathead sole, the diet in high CPUE areas consisted largely of echinoderms (59% by weight; mostly ophiuroids), whereas 60% of the diet in the low CPUE areas consisted of fish, mostly pollock. These areas also differed in sediment types, with the high CPUE areas consisting of relatively more mud than the low CPUE areas. McConnaughy and Smith (2000) hypothesized that the substrate-mediated food habits of flathead sole were influenced by energetic foraging costs.

Predator population trends

The dominant predators of adult flathead sole are Pacific cod and walleye pollock (Figure 9.32). Pacific cod, along with skates, also account for most of the predation upon flathead sole less than 5 cm (Lang et al. 2003). Arrowtooth flounder, Greenland turbot, walleye pollock, and Pacific halibut comprised other predators. Flathead sole contributed a relatively minor portion of the diet of skates from 1993-1996, on average less than 2% by weight, although flatfish in general comprised a more substantial portion of skates greater than 40 cm. A similar pattern was seen with Pacific cod, where flathead sole generally contribute less than 1% of the cod diet by weight, although flatfish in general comprised up to 5% of the diet of cod greater than 60 cm. The 2013 stock assessment for BSAI Pacific cod indicates that cod biomass has increased by approximately 750,000 t to 1,500,00 t since 2008 (Thompson et al. 2013). Biomass of skates appears to have remained stable since the 1980s (Ormseth 2012). However, there is a good deal of uncertainty concerning predation on flathead sole given that, according to the model, almost 80% of the mortality that flathead sole experience is from unexplained sources.

There is some evidence of cannibalism for flathead sole. Stomach content data collected from 1990 indicate that flathead sole were the most dominant predator, and cannibalism was also noted in 1988 (Livingston et al. 1993).

Changes in habitat quality

The habitats occupied by flathead sole are influenced by temperature, which has shown considerable variation in the eastern Bering Sea in recent years. For example, the timing of spawning and advection to nursery areas are expected to be affected by environmental variation. Flathead sole spawn in deeper waters near the margin of the continental shelf in late winter/early spring and migrate to their summer distribution of the mid and outer shelf in April/May. The distribution of flathead sole, as inferred by summer trawl survey data, has been variable. In 1999, one of the coldest years in the eastern Bering Sea, the distribution was shifted further to the southeast than it was during 1998-2002. Bottom temperatures during the 2006-2010 and 2012-2013 summertime EBS Trawl Surveys were colder than average, and 2014 were very warm (Table 9.11).

In 2010, as noted previously, RACE extended the groundfish survey into the northern Bering Sea (Figure 9.5). No flathead sole were found in the northern Bering Sea area, but a substantial abundance of Bering flounder was found. Bering flounder biomass in the northern Bering Sea area was estimated at 12,761 t, larger than that in the standard survey area (12,360 t). This is consistent with the view that Bering flounder in the BSAI fishery are a marginal stock on the edge of their species range in the eastern Bering Sea. Unfortunately, this area has not been surveyed since 2010. Potential management implications of the northern Bering Sea survey for Bering flounder were discussed in more detail in Appendix C of the 2010 SAFE document (Stockhausen et al., 2010).

Data Gaps and Research Priorities

A main research priority is to investigate the potential causes of systematic mismatches between observed and estimated male survey and fishery length composition. These systematic mismatches may be the result of mis-specification of growth, selectivity, or ageing error. The paragraphs below describe future work that would improve the current assessment model. Stock Synthesis (SS3) is a flexible assessment framework that would allow for many of the topics below to be explored without the need for an extensive expansion of the current model code. SS3 or some other flexible assessment framework should be considered for use to conduct future assessments such that improvements to the assessment can be made in a timely manner.

Future research should be conducted to estimate growth using updated data; currently, the most recent year of data used in growth estimates is 2000. Estimating growth within the assessment model using raw age data within each length bin (conditional age-at-length) should be considered in future assessments, such that uncertainty in growth is propagated through the model and represented in uncertainty bounds for quantities such as spawning biomass and reference points. Use of conditional age-at-length data provides allows for use of both length and age data in the assessment without “double counting.”

Alternative methods for estimating selectivity should be explored. The current assessment uses logistic, length-based selectivity curves that are not sex-specific and are time-invariant. Age-based, sex-specific, or dome-shaped selectivity could be considered. Also, it is possible that time-varying fishery selectivity occurs, which can be seen as changes in the fishery age and length compositions among years. In addition, halibut bycatch rates fell after changes to fisheries management in 2008, indicating fishing behavior (and thus potentially selectivity) may have changed. Up to 30% of the catch was taken by pelagic trawls in some years; future assessments could model the pelagic trawl fishery as a separate fleet, which may have different selectivity than non-pelagic trawls.

A new ageing error matrix should be estimated using updated data and methods described in Punt et al. (2008).

Estimation of natural mortality and mean catchability, perhaps with development of a prior for each of these two parameters should be explored in future assessments to better represent uncertainty in biomass

and management quantities. Uncertainty bounds are small in the current and overstate our knowledge of stock status.

Further future research priorities include the following ideas. An analysis of appropriate effective sample sizes could be conducted for weighting data within and among data sources. Early recruitment deviations could be estimated to inform initial estimates of age composition. An exploration of the use of stock-recruitment relationships (Ricker, Beverton-Holt) could be considered, in response to previous GPT and SSC comments. Lastly, an exploration of alternative ways to incorporate Aleutian Islands data into the assessment could be conducted. Aleutian Islands data could be used as a second survey, and AI length- and age-composition data could be incorporated. Alternatively, a survey averaging approach could be used instead of the linear regression to interpolate AI survey biomass in years without an AI survey. Advantages would be improved estimates of uncertainty about interpolated AI survey biomass estimates, and the assumption that interpolated biomass estimates are more closely related to survey biomass in the AI in surrounding years (rather than related to survey biomass in the EBS in those years). However, the contribution of AI biomass to the survey biomass index is a very small fraction of the total biomass and therefore alternative methods for including AI data may not have a large influence on results.

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Tables

Table 9.1. Combined catch (in tons) of flathead sole and Bering flounder (*Hippoglossoides spp.*) in the Bering Sea and Aleutian Islands as of October 18, 2014.

Year	total	non-CDQ	CDQ	Year	total	non-CDQ	CDQ
1977	7,909	7,909		2000	20,422	19,983	439
1978	6,957	6,957		2001	17,809	17,586	223
1979	4,351	4,351		2002	15,572	15,108	464
1980	5,247	5,247		2003	14,184	13,792	392
1981	5,218	5,218		2004	17,394	16,849	545
1982	4,509	4,509		2005	16,151	15,260	891
1983	5,240	5,240		2006	17,947	17,545	402
1984	4,458	4,458		2007	18,744	17,673	1,071
1985	5,636	5,636		2008	24,539	24,039	500
1986	5,208	5,208		2009	19,549	19,041	508
1987	3,595	3,595		2010	20,125	19,182	943
1988	6,783	6,783		2011	13,556	12,882	674
1989	3,604	3,604		2012	11,366	10,859	507
1990	20,245	20,245		2013	17,358	16,661	697
1991	14,197	14,197		2014	15,906	15,213	693
1992	14,407	14,407					
1993	13,574	13,574					
1994	17,006	17,006					
1995	14,713	14,713					
1996	17,344	17,344					
1997	20,681	20,681					
1998	24,597	24,597					
1999	18,555	18,555					

Table 9.2. Proportion of combined catch of flathead sole and Bering flounder (*Hippoglossoides spp.*) by gear type in recent years. Proportions are shown on a scale of white to dark gray, with the lowest proportions in white and the highest proportions in dark grey.

Year	Non-pelagic Trawl	Pelagic Trawl	Hook and Line
1998	0.92	0.06	0.02
1999	0.88	0.10	0.02
2000	0.86	0.12	0.02
2001	0.86	0.12	0.02
2002	0.86	0.12	0.02
2003	0.86	0.11	0.03
2004	0.84	0.12	0.03
2005	0.82	0.14	0.04
2006	0.81	0.16	0.03
2007	0.76	0.22	0.02
2008	0.81	0.17	0.01
2009	0.76	0.23	0.01
2010	0.77	0.20	0.01
2011	0.63	0.35	0.03
2012	0.64	0.33	0.03
2013	0.81	0.17	0.02
2014	0.82	0.15	0.03

Table 9.3. Combined proportions of catch of flathead sole and Bering flounder (*Hippoglossoides spp.*) by NMFS reporting area in recent years. Only NMFS reporting areas with greater than 1% of the catch in one or more years are included in the table. Proportions are shown on a scale of white to dark gray, with the lowest proportions in white and the highest proportions in dark grey.

Year	509	511	513	514	516	517	519	521	524
1992	0.00	0.36	0.00	0.00	0.01	0.44	0.00	0.19	0.00
1995	0.19	0.00	0.39	0.01	0.01	0.28	0.01	0.11	0.00
1996	0.36	0.00	0.30	0.00	0.01	0.25	0.01	0.06	0.00
1997	0.17	0.00	0.38	0.00	0.00	0.35	0.01	0.08	0.00
1998	0.20	0.00	0.24	0.00	0.00	0.31	0.00	0.24	0.00
1999	0.12	0.00	0.36	0.00	0.02	0.26	0.01	0.24	0.00
2000	0.21	0.00	0.34	0.00	0.00	0.18	0.00	0.25	0.01
2001	0.13	0.00	0.25	0.00	0.02	0.13	0.01	0.41	0.04
2002	0.09	0.00	0.23	0.00	0.01	0.12	0.01	0.50	0.04
2003	0.11	0.00	0.33	0.01	0.02	0.07	0.01	0.40	0.04
2004	0.11	0.00	0.19	0.00	0.02	0.11	0.03	0.53	0.01
2005	0.13	0.00	0.27	0.00	0.01	0.13	0.02	0.29	0.15
2006	0.18	0.00	0.18	0.00	0.01	0.13	0.01	0.44	0.04
2007	0.15	0.00	0.20	0.00	0.01	0.20	0.01	0.39	0.03
2008	0.27	0.00	0.23	0.00	0.01	0.16	0.00	0.27	0.06
2009	0.28	0.00	0.21	0.00	0.01	0.16	0.00	0.30	0.03
2010	0.23	0.00	0.25	0.00	0.03	0.11	0.00	0.37	0.00
2011	0.26	0.00	0.27	0.00	0.01	0.17	0.00	0.27	0.01
2012	0.17	0.00	0.17	0.02	0.01	0.19	0.01	0.41	0.02
2013	0.19	0.00	0.16	0.00	0.01	0.29	0.00	0.34	0.00
2014	0.19	0.00	0.17	0.00	0.01	0.25	0.00	0.36	0.00

Table 9.4. Catch (in tons) of combined flathead sole and Bering flounder (*Hippoglossoides spp.*), flathead sole only, and Bering flounder only in the Bering Sea and Aleutian Islands as of October 18, 2014. Observer data on species-specific extrapolated weight in each haul was summed over hauls within each year and used to calculate the proportion of the total Hippoglossoides spp. catch that was flathead sole or Bering flounder. Proportions were multiplied by the total Hippoglossoides spp. (flathead sole and Bering flounder combined) catches reported by AKFIN to obtain total catch of flathead sole separately from that of Bering flounder.

Year	Total *(Hippoglossoides spp)*	Flathead sole	Bering Flounder
1977	7,909	7,909.00	0.00
1978	6,957	6,891.61	65.39
1979	4,351	4,350.69	0.31
1980	5,247	4,897.00	350.00
1981	5,218	5,213.00	5.00
1982	4,509	4,498.40	10.60
1983	5,240	5,231.69	8.31
1984	4,458	4,394.75	63.25
1985	5,636	5,626.04	9.96
1986	5,208	5,145.85	62.15
1987	3,595	3,478.97	116.03
1988	6,783	6,697.08	85.92
1989	3,604	3,593.61	10.39
1990	20,245	19,263.85	981.15
1991	14,197	14,175.93	21.07
1992	14,407	14,346.72	60.28
1993	13,574	13,462.77	111.23
1994	17,006	16,987.43	18.57
1995	14,713	14,708.58	4.42
1996	17,344	17,339.24	4.76
1997	20,681	20,675.87	5.13
1998	24,597	24,590.40	6.60
1999	18,555	18,534.64	20.36
2000	20,422	20,389.10	32.90
2001	17,809	17,792.62	16.38
2002	15,572	15,546.78	25.22
2003	14,184	14,165.74	18.26
2004	17,394	17,369.90	24.10
2005	16,151	16,120.18	30.82
2006	17,947	17,941.22	5.78
2007	18,744	18,738.18	5.82
2008	24,539	24,524.78	14.22
2009	19,549	19,360.02	188.98
2010	20,125	19,898.93	226.07
2011	13,556	13,474.99	81.01
2012	11,366	11,360.28	5.72
2013	17,358	17,277.76	80.24
2014	15,906	15,869.67	36.33

Table 9.5. BSAI flathead sole fishery status from 2002-2014. Unless otherwise indicated, the closures were applied to the entire BSAI management area. Zone 1 consists of areas 508, 509, 512, and 516; zone 2 consists of areas 513, 517, and 521. "Incidental catch allowance" means stock allowed as incidental catch. "Open" means the directed fishery is allowed. "Bycatch" means that the directed fishery is closed, and only incidental catch allowed.

Year	Dates	Fishery Status
2002	2/22 – 12/31	Red King crab cap (Zone 1 closed)
	3/1 – 3/31	1st seasonal halibut cap
	4/20 – 6/29	2nd seasonal halibut cap
	7/29 – 12/31	Annual halibut allowance
2003	2/18 – 3/31	1st seasonal halibut cap
	4/1 – 6/21	2nd seasonal halibut cap
	7/31 – 12/31	Annual halibut allowance
2004	2/24 – 3/31	1st seasonal halibut cap
	4/16 – 6/30	2nd seasonal halibut cap
	7/31 – 9/3	Bycatch status
	9/4 – 12/31	Prohibited species status
2005	3/1 – 3/31	1st seasonal halibut cap
	4/22 – 6/4	2nd seasonal halibut cap
	8/18 – 12/31	Annual halibut allowance
2006	2/21 – 3/31	1st seasonal halibut cap
	4/13 – 6/30	2nd seasonal halibut cap
	8/8 – 12/31	Annual halibut allowance
2007	2/17-3/31	1st seasonal halibut cap
	4/9-6/30	2nd seasonal halibut cap
	8/6-	Annual halibut allowance
2008	1/1-	Incidental catch allowance
	1/20-	Open: Amend. 80 cooperatives
	1/20-11/22	Open: Amend. 80 limited access
	1/20-	Bycatch: BSAI trawl limited access
	11/22-	Bycatch: Amend. 80 limited access
2009	1/1-	Incidental catch allowance
	1/20-	Open: Amend. 80 cooperatives
	1/20-	Open: Amend. 80 limited access
	1/20-	Bycatch: BSAI trawl limited access
2010	1/1-	Incidental catch allowance

	1/20-	Open: Amend. 80 cooperatives
	1/20-5/28	Open: Amend. 80 limited access
	1/20-	Bycatch: BSAI trawl limited access
	5/28-	Bycatch: Amend. 80 limited access
2011	1/1-	Incidental catch allowance
	1/20-	Open: Amend. 80 cooperatives
	1/20-	Bycatch: BSAI trawl limited access
2012	1/1-	Incidental catch allowance
	1/20-	Open: Amend. 80 cooperatives
	1/20-	Bycatch: BSAI trawl limited access
2013	1/1-	Bycatch (Directed fishery closed): All
	1/20-	Open: Amendment 80
2014	1/1-	Bycatch (Directed Fishery Closed): All
	1/20-	Open: Amendment 80

Table 9.6. Retained and discarded catch biomass and catch limits (ABC, TAC, and OFL) as of October 20, 2014.

Year	ABC	TAC	OFL	Total	Retained	Discarded	Percent Retained
1995	138,000	30,000	167,000	14,713	7,520	7,193	51
1996	116,000	30,000	140,000	17,344	8,964	8,380	52
1997	101,000	43,500	145,000	20,681	10,859	9,822	53
1998	132,000	100,000	190,000	24,597	17,438	7,159	71
1999	77,300	77,300	118,000	18,555	13,757	4,797	74
2000	73,500	52,652	90,000	20,422	14,959	5,481	73
2001	84,000	40,000	102,000	17,809	14,436	3,373	81
2002	82,600	25,000	101,000	15,572	11,311	4,236	73
2003	66,000	20,000	81,000	14,184	9,926	3,866	72
2004	61,900	19,000	75,200	17,394	11,658	5,192	69
2005	58,500	19,500	70,200	16,151	12,263	3,888	76
2006	59,800	19,500	71,800	17,947	12,997	4,255	76
2007	79,200	30,000	95,300	18,744	13,349	5,394	71
2008	71,700	50,000	86,000	24,539	22,209	2,330	91
2009	71,400	60,000	83,800	19,549	17,523	2,026	90
2010	69,200	60,000	83,100	20,125	18,311	1,814	91
2011	69,300	41,548	83,300	13,556	11,729	1,827	87
2012	70,400	34,134	84,500	10,380	8,756	1,624	84
2013	67,900	22,699	81,500	17,358	15,793	1,565	91
2014	66,293	24,500	79,633	15,903	14,620	1,282	92

Table 9.7. Sample sizes of fishery lengths and ages measured for flathead sole only from the Bering Sea-Aleutian Islands.

	Size compositions				Age compositions				
Year	Hauls with Lengths	Number Individual Lengths	Females	Males	Hauls with Ages	Number Individual Ages	Females	Males	Otoliths collected
1990	141	10,113	4,499	3,975					843
1991	169	12,207	3,509	4,976					154
1992	62	4,750	381	529					0
1993	136	11,478	2,646	2,183					0
1994	136	10,878	4,729	4,641	15	138	90	48	143
1995	148	11,963	5,464	4,763	13	186	112	74	195
1996	260	14,921	7,075	7,054					0
1997	208	16,374	6,388	5,388					0
1998	454	35,738	14,573	15,098	10	99	48	51	99
1999	845	18,721	9,319	9,302					622
2000	2,448	32,983	17,465	15,465	241	564	349	215	856
2001	1,680	19,710	10,282	9,258	333	620	353	267	642
2002	1,178	16,156	8,411	7,643					558
2003	1,123	20,441	10,681	9,608					531
2004	1,518	23,426	10,879	12,397	241	496	248	248	814
2005	1,148	15,750	7,829	7,810	187	389	195	194	628
2006	1,242	19,164	8,757	10,384	210	538	275	263	546
2007	1,025	11,675	5,461	6,150	174	434	224	210	441
2008	4,163	39,471	19,680	19,708					1,884
2009	3,095	28,920	14,800	14,059	387	594	288	305	1,423
2010	2,655	21,963	11,136	10,812	347	582	289	293	1,081
2011	2,472	15,738	8,636	7,078	474	825	485	338	828
2012	2,263	15,011	8,764	6,229	404	850	540	310	779
2013	3,077	23,925	13,337	10,570					
2014	1,987	18,731	9,807	8,900					

Table 9.8. BSAI catch-at-age estimates for females (top) and males (bottom) based on observer data. Units are in thousands of fish.

		Age (Females)																		
Year	Effective Sample Size	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
2000	200	0	0	0	100	16	228	270	326	316	356	685	312	457	332	406	358	388	134	276
2001	200	0	0	0	4	133	82	118	219	384	333	281	380	293	316	294	175	244	142	292
2004	200	0	27	124	316	194	261	396	308	349	300	401	427	341	271	74	60	116	128	42
2005	200	0	0	0	43	197	254	363	273	435	220	416	369	422	211	156	210	43	114	343
2006	200	0	19	23	60	240	185	349	247	269	198	293	293	250	199	261	142	140	83	284
2007	200	0	12	58	167	112	206	321	217	182	272	196	178	274	112	204	145	152	106	357
2009	200	0	0	0	237	544	701	503	1,243	1,033	1,060	777	854	485	256	387	441	251	186	528
2010	200	9	0	115	115	815	894	1,027	804	982	1,089	822	605	451	305	442	208	165	310	338
2011	200	0	0	23	80	158	438	384	239	321	248	287	421	249	236	175	161	89	192	328
2012	200	0	0	0	30	115	218	496	551	301	319	276	366	448	283	261	189	184	93	495
Average		1	6	34	115	252	347	423	443	457	439	443	420	367	252	266	209	177	149	328

		Age (Males)																		
Year	Effective Sample Size	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
2000	200	0	0	0	21	140	238	308	355	598	288	533	371	362	381	209	121	165	95	159
2001	200	0	17	25	18	84	283	245	346	258	332	247	446	184	208	96	134	159	50	241
2004	200	0	0	154	479	350	541	422	405	292	342	379	235	139	252	216	123	83	138	324
2005	200	0	29	16	111	319	323	492	385	390	162	484	161	212	282	252	156	78	80	441
2006	200	0	42	111	99	425	447	437	338	291	165	147	205	354	207	213	156	125	149	430
2007	200	0	0	101	217	121	402	574	286	426	161	65	204	274	277	229	108	147	31	262
2009	200	0	0	188	451	1,081	867	905	566	1,073	851	285	428	329	298	483	468	182	295	801
2010	200	0	12	0	129	1,475	977	1,127	862	609	810	461	494	325	457	356	335	335	87	766
2011	200	0	0	89	94	298	623	466	317	297	208	203	149	95	127	88	68	119	59	308
2012	200	0	8	15	74	162	317	536	277	333	291	133	163	217	185	144	47	91	104	347
Average		0	11	70	169	445	502	551	414	457	361	294	286	249	267	229	172	148	109	408

Table 9.9. Female catch-at-length estimates from the BSAI observer data. Units are in thousands. Asterisks denote years of catch-at-length data that were omitted from assessment inputs because catch-at-age estimates from observer data were used instead.

		Length (Females)																							
Year	Effective Sample Size	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	43	46	49	52	58+	
1977	200	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
1978	200	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
1979	200	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
1980	200	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1981	200	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	1	0	0	0	0	0	0
1982	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1983	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
1985	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
1986	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	200	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0
1989	200	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0
1990	200	0	0	0	0	0	0	0	0	0	0	1	1	2	4	8	18	24	33	24	10	2	1	0	0
1991	200	0	0	0	0	0	0	0	0	0	0	1	4	6	8	10	12	18	23	16	5	2	0	0	0
1992	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	4	3	1	1	0	0	0
1993	200	0	0	0	0	0	0	0	0	0	1	1	2	5	7	9	11	15	27	21	6	1	0	0	0
1994*	200	0	0	0	0	0	0	0	0	0	2	4	4	9	18	20	30	44	65	52	29	15	3	0	1
1995*	200	0	0	0	0	0	0	0	1	3	2	5	10	16	32	34	47	52	112	120	61	14	3	0	0
1996	200	0	0	0	0	0	0	0	0	0	2	3	5	12	30	63	93	107	162	180	89	18	3	0	0
1997	200	0	0	0	0	0	0	0	0	1	4	5	9	18	30	55	77	91	120	119	61	15	2	0	0
1998*	200	0	0	0	0	0	0	0	0	2	6	12	24	35	69	120	164	196	314	300	222	81	10	0	0
1999	200	0	0	0	0	0	0	0	0	2	7	23	42	106	184	272	337	447	694	560	328	123	15	4	3
2000*	200	0	0	0	0	0	2	0	4	9	25	42	100	228	355	562	659	645	925	747	500	187	31	4	4
2001*	200	0	0	0	0	0	0	4	6	8	15	44	134	130	248	358	511	499	712	575	340	133	24	6	2
2002	200	0	0	0	0	0	0	3	3	8	3	12	36	57	103	223	348	423	664	453	258	88	21	7	5
2003	200	0	0	0	0	1	0	0	4	4	15	38	48	91	134	235	356	438	772	528	222	55	13	0	2
2004*	200	0	0	0	0	0	2	3	3	22	41	90	147	213	286	421	451	508	812	775	341	65	16	3	0
2005*	200	0	0	0	0	0	0	1	3	2	20	48	135	189	282	401	600	544	740	667	368	93	10	0	1
2006*	200	0	0	1	0	0	0	2	8	11	16	33	63	152	245	391	431	403	632	636	452	98	11	2	1
2007*	200	0	0	0	0	0	1	2	5	13	34	49	94	110	176	287	360	395	672	588	378	124	10	1	0
2008	200	0	0	0	0	2	0	1	5	17	53	151	236	505	887	1,457	1,827	1,625	2,103	1,904	1,427	510	62	5	1
2009*	200	0	0	0	0	0	0	1	0	10	27	73	180	402	655	992	1,433	1,463	1,745	1,344	951	322	36		0
2010*	200	0	0	0	0	0	0	0	0	2	16	41	107	384	819	1,097	1,521	1,688	1,860	1,181	752	264	37	7	0
2011*	200	0	0	0	0	1	1	1	3	5	12	13	38	106	230	478	655	689	806	510	350	147	26	6	2
2012*	200	0	0	0	0	0	0	2	1	5	12	27	63	129	265	451	668	657	1,061	778	395	145	10	2	1
2013	200	0	0	0	0	0	0	0	2	8	25	74	101	191	494	833	1,197	1,414	2,008	1,357	819	286	44	1	1
2014	200	0	0	0	0	0	0	1	3	5	34	69	161	247	442	769	907	1,072	1,370	1,140	517	200	14	1	0

Table 9.10. Male catch-at-length estimates from the BSAI observer data. Units are in thousands. Asterisks denote years of catch-at-length data that were omitted from assessment inputs because catch-at-age estimates from observer data were used instead.

		Length (Males)																								
Year	Effective Sample Size	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	43	46	49	52	58+		
1977	200	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	
1978	200	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	
1979	200	0	0	0	0	0	0	0	1	1	0	0	1	1	2	1	0	0	0	0	0	0	0	0	0	
1980	200	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	
1981	200	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	
1982	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1983	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1984	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1985	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1986	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1987	200	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	
1988	200	0	0	0	0	0	0	0	0	0	0	1	1	2	2	1	0	0	0	0	0	0	0	0	0	
1989	200	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	
1990	200	0	0	0	0	0	0	0	0	1	1	2	3	6	13	24	33	29	16	4	2	1	0	0	0	
1991	200	0	0	0	0	0	0	0	0	1	2	4	10	15	23	37	46	30	11	1	0	0	0	0	0	
1992	200	0	0	0	0	0	0	0	1	1	1	1	2	2	3	4	4	3	3	0	0	0	0	0	0	
1993	200	0	0	0	0	0	0	0	0	0	1	2	5	6	12	18	19	10	4	1	0	0	0	0	0	
1994*	200	0	0	0	0	0	0	0	1	2	5	14	27	44	59	69	64	37	20	8	5	4	3	0	0	
1995*	200	0	0	0	0	0	0	0	1	3	5	10	27	41	70	98	99	70	33	14	6	1	0	0	0	
1996	200	0	0	0	0	0	0	0	1	2	5	14	24	75	153	214	204	119	48	9	4	2	1	0	1	
1997	200	0	0	0	0	0	0	0	1	3	9	25	39	64	102	103	90	57	24	2	0	0	0	0	0	
1998*	200	0	0	0	0	0	0	1	2	8	14	43	75	155	265	389	396	279	143	23	7	1	0	0	0	
1999	200	0	0	0	0	0	0	1	4	14	28	71	172	315	487	702	669	488	291	56	18	3	0	0	0	
2000*	200	0	0	0	0	0	1	5	6	18	37	118	222	537	791	947	824	531	282	89	44	17	6	6	4	
2001*	200	0	0	0	0	2	2	3	24	22	33	68	223	374	566	685	662	465	241	41	21	9	4	3	6	
2002	200	0	0	0	1	0	3	3	9	30	42	63	133	229	399	605	672	429	229	46	17	4	1	0	0	
2003	200	0	0	0	0	2	2	1	4	18	41	121	151	207	319	609	657	441	206	32	11	3	1	0	0	
2004*	200	0	0	0	0	1	0	5	6	19	58	180	401	559	712	921	990	729	347	39	10	2	0	0	0	
2005*	200	0	0	0	0	0	0	1	5	16	38	72	288	582	757	867	917	584	303	42	12	3	1	0	0	
2006*	200	0	0	0	0	0	1	10	16	23	48	118	170	447	800	943	830	627	381	50	7	8	1	2	2	
2007*	200	0	0	0	0	0	4	5	12	28	65	105	208	443	657	749	783	486	338	59	42	7	1	0	0	
2008	200	0	0	0	2	1	1	2	21	54	151	342	711	1,470	2,627	2,926	2,546	1,746	1,016	183	71	31	2	0	1	
2009*	200	0	0	1	0	0	0	0	4	20	52	224	558	1,067	1,747	2,185	1,848	1,172	639	131	32	18	1	0	1	
2010*	200	0	0	0	0	0	0	1	8	24	67	169	523	1,371	1,959	2,318	1,796	1,094	660	109	12	5	1	0	0	
2011*	200	0	0	0	0	1	1	4	5	16	21	46	148	376	705	830	732	437	270	53	19	7	2	0	0	
2012*	200	0	0	0	0	0	1	0	7	8	19	49	145	366	601	722	664	528	346	66	21	9	0	0	0	
2013	200	0	0	0	0	0	1	0	4	13	41	107	220	594	1,310	1,821	1,749	1,254	753	120	17	7	1	0	1	
2014	200	0	0	0	1	0	0	0	9	17	54	103	285	519	1,146	1,541	1,407	1,018	626	136	13	1	0	0	0	

Table 9.11. Survey biomass (in tons) of Hippoglossoides spp. combined (flathead sole and Bering flounder) in the Eastern Bering Sea (EBS) shelf survey, flathead sole only in the Aleutian Islands and EBS shelf survey, and Bering flounder only in the EBS shelf survey.

	Hippoglossoides spp. EBS-Aleutian Islands Combined (used in assessment)		Aleutian Islands		EBS *Hippoglossoides spp.* (Flathead Sole and Bering Flounder)		EBS Flathead Sole Only		EBS Bering Flounder Only		EBS Bottom Temperature (deg C)
Year	Biomass	CV	Biomass	CV	Biomass	CV	Biomass	CV	Biomass	CV	
1982	195,685	0.09			192,037	0.09	192,037	0.09	0	0.00	2.269
1983	272,185	0.10	1,213	0.20	270,972	0.10	252,612	0.11	18,359	0.20	3.022
1984	347,709	0.08			341,694	0.08	323,874	0.09	17,820	0.22	2.333
1985	281,333	0.07			276,351	0.07	262,110	0.08	14,241	0.12	2.367
1986	363,208	0.09	5,245	0.16	357,963	0.09	344,002	0.09	13,962	0.17	1.859
1987	400,424	0.09			393,588	0.09	379,394	0.10	14,194	0.14	3.220
1988	583,479	0.09			573,794	0.09	550,273	0.09	23,521	0.22	2.357
1989	543,548	0.08			534,485	0.08	515,435	0.09	19,050	0.20	2.969
1990	638,813	0.09			628,266	0.09	607,049	0.09	21,217	0.15	2.448
1991	552,949	0.08	6,939	0.20	546,010	0.08	518,380	0.08	27,630	0.22	2.697
1992	662,301	0.10			651,388	0.10	635,462	0.10	15,927	0.21	2.014
1993	617,947	0.07			607,724	0.07	585,400	0.07	22,324	0.21	3.058
1994	736,326	0.07	9,935	0.23	726,391	0.07	699,554	0.07	26,837	0.19	1.571
1995	604,433	0.09			594,421	0.09	578,945	0.09	15,476	0.18	1.744
1996	626,821	0.09			616,460	0.09	604,427	0.09	12,034	0.20	3.424
1997	823,955	0.22	11,554	0.24	812,401	0.22	797,991	0.22	14,410	0.19	2.742
1998	703,871	0.21			692,312	0.21	684,401	0.21	7,911	0.21	3.275
1999	409,176	0.09			402,204	0.09	388,973	0.09	13,232	0.18	0.828
2000	406,204	0.09	8,950	0.23	397,254	0.09	388,943	0.09	8,312	0.19	2.158
2001	524,123	0.10			515,362	0.10	503,943	0.11	11,419	0.21	2.575
2002	589,074	0.18	9,898	0.24	579,176	0.18	573,953	0.18	5,223	0.20	3.248
2003	523,622	0.10			514,868	0.10	509,156	0.11	5,712	0.21	3.812
2004	625,587	0.09	13,298	0.14	612,289	0.09	604,186	0.09	8,103	0.31	3.387
2005	622,839	0.09			612,540	0.09	605,424	0.09	7,116	0.28	3.473
2006	645,639	0.09	9,668	0.18	635,970	0.09	622,077	0.09	13,893	0.32	1.874
2007	571,982	0.09			562,475	0.09	552,022	0.09	10,453	0.22	1.787
2008	554,708	0.14			545,470	0.14	535,359	0.15	10,111	0.19	1.290
2009	426,047	0.12			418,812	0.12	412,163	0.12	6,649	0.17	1.384
2010	507,047	0.15	11,812	0.31	495,235	0.15	488,626	0.15	6,610	0.16	1.531
2011	593,136	0.19			583,300	0.19	576,498	0.19	6,802	0.15	2.467
2012	387,043	0.12	5,566	0.15	381,477	0.12	374,842	0.12	6,635	0.14	1.008
2013	499,570	0.17			491,191	0.17	485,486	0.17	5,705	0.14	1.873
2014	532,886	0.14	13,436	0.14	519,450	0.14	509,801	0.14	9,649	0.18	3.224

Table 9.12. EBS survey summary information for flathead sole only on sample sizes of length and age measurements and the number of hauls for which lengths and ages were collected.

	Size compositions					Age compositions					
Year	Total Hauls	Hauls with Lengths	Number Individual lengths	males	females	Number hauls with otoliths	Number Otoliths collected	Number hauls with ages measured	Number Aged	males	females
1982	329	108	11029	5094	4942	15	390	15	390	181	207
1983	353	170	15727	7671	7480						
1984	355	152	14043	6639	6792	34	569				
1985	353	189	13560	6789	6769	23	496	23	496	227	268
1986	354	259	13561	6692	6844						
1987	343	192	13924	7017	6534						
1988	353	202	14049	6729	7068						
1989	354	253	15509	7261	7682						
1990	351	256	15437	7922	7504						
1991	352	267	16151	8063	7774						
1992	336	273	15813	7357	8037	11	419	11	419	191	228
1993	355	288	17057	8227	8438	5	140	5	136	58	78
1994	355	277	16366	8149	8078	7	371	7	371	166	204
1995	356	263	14946	7298	7326	10	396	10	395	179	216
1996	355	290	19244	9485	9606	10	420				
1997	356	281	16339	7932	8006	6	301				
1998	355	315	21611	10352	10634	2	87				
1999	353	243	14172	7080	6966	18	420				
2000	352	277	15905	7536	8054	18	439	18	437	193	243
2001	355	286	16399	8146	8234	21	537	21	536	254	282
2002	355	281	16705	8196	8332	19	471	19	465	200	265
2003	356	276	17652	8854	8396	38	576	34	246	111	135
2004	355	274	18737	9026	8864	16	477	16	473	208	265
2005	353	284	16875	8224	8181	17	465	17	450	227	222
2006	356	255	17618	8755	8798	27	515	27	508	229	277
2007	356	262	14855	7120	7494	39	583	38	560	242	314
2008	355	255	16367	7805	8269	46	588	45	581	244	328
2009	356	236	13866	6619	6864	51	673	51	666	292	369
2010	356	244	12568	6131	6253	62	684	62	668	285	382
2011	356	257	14039	6642	7044	53	743	53	733	318	403
2012	356	234	11376	5405	5538	51	587				
2013	356	258	14257	6566	6377	66	669	66	657	285	347
2014	356	260	13249	5849	5669	57	679				

Table 9.13. Eastern Bering Sea shelf survey age composition data for female flathead sole only. Units are in millions.

		Age (Females)																		
Year	Effective Sample Size	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1982	200	66	95.4	56.1	85.3	58.6	48.2	46.7	15.1	9.32	23.6	12.3	3.28	4.66	0	0	0	0	0	0
1985	200	59	138	90.6	55	74.8	31.1	38	35.6	24.3	32.4	6.56	1.72	6.24	9.8	0.79	0.4	1.2	0	0.8
1992	200	106	35.5	160	153	149	63.2	133	73.4	70.4	121	62.8	26.3	11.3	11	7.53	3.8	0	0	1.5
1993	200	0	41	66.7	110	60	81.3	80.7	56.2	101	167	19.7	34.1	19.9	2.5	0	0	0	0	0
1994	200	66	93.9	82	78	158	103	131	113	63.7	94	68	48.7	28.4	10	6.27	2.2	0	0	0
1995	200	47	58.5	84.8	51.8	94.1	152	66.5	71.7	63	48.8	42.1	31	25.7	17	12.2	6.8	0.8	0	2.7
2000	200	18	52.3	29.3	40.9	24.4	38	60.8	53.7	39.7	30.8	46.4	30.7	18.9	18	25.3	10	9	4.4	10
2001	200	54	58.9	78.7	65.9	54.8	68.8	81.3	47.7	27.5	34.6	30.9	33.9	29	13	32	13	8.8	8.5	18
2002	200	48	55.4	48.4	84	63.1	54.3	45.5	43.8	74.4	28.8	20.1	18.8	25.1	18	14	25	17	16	52
2003	200	33	47.5	97.4	86.7	86	26.9	27.1	51.6	12.5	35.4	8.93	33.9	24.3	45	16.4	40	12	4.6	22
2004	200	112	43.6	108	97	56	54.8	21.9	68.3	53.1	42.8	46.6	20.3	16.1	32	7.61	12	13	3.4	18
2005	200	79	151	27.8	83.9	113	87.4	19.7	46.5	40.6	47.1	40.1	56.3	17.1	4.7	11.7	24	9.1	4.7	40
2006	200	119	103	135	73.7	80.3	67.4	85.7	71.7	25.3	34.4	34.2	21.8	11.9	6	22.6	9.3	5.3	11	41
2007	200	20	148	98.4	90.3	47.1	82.5	61.3	53.5	36.9	30.9	49.3	32.7	24.6	22	16	24	13	4.3	32
2008	200	26	63.1	110	73.9	99.2	80.6	70.3	60.9	52.7	16.5	30.9	11.8	15.2	13	12.3	18	6.6	1.4	29
2009	200	18	42.8	22.3	114	74.8	92.6	46.6	39	15.5	27.2	37.3	27.5	12.8	6.6	8.34	9.8	9	6.5	13
2010	200	39	60.4	60.2	41.9	110	74.6	74	45.4	23.9	33.4	28.3	32.2	5.11	10	5.49	5.1	7.9	1.8	12
2011	200	62	51.7	86.8	78.5	59	79.9	79	42.6	47.8	39.7	34.8	29.9	26	15	26.8	21	8.6	6.2	23
2013	200	28	75	50.8	51.3	42.4	58.7	50.5	93.9	42.2	48.2	25.1	23.3	15.2	14	11	2.8	4.9	5.4	16
Average		53	74.5	78.6	79.8	79.2	70.8	64.2	57.1	43.4	49.3	33.9	27.3	17.8	14	12.4	12	6.6	4.1	17

Table 9.14. Eastern Bering Sea shelf survey age composition data for male flathead sole only. Units are in millions.

		Age (Males)																		
Year	Effective Sample Size	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1982	200	71	79.9	104	97.2	59.1	44	12.5	15.5	23.5	6.47	13.3	12.9	1.26	0	0.74	1.4	0	2.5	0
1985	200	63	150	75.4	78.2	56.8	52.4	55.9	32.9	42	19.8	16.1	10.7	8.44	3.9	0	0	0	0	0
1992	200	137	54.5	239	131	233	124	113	129	54.8	45	55.3	8.33	0	0	9.48	0	0	0	0
1993	200	29	29.4	104	92.3	129	190	126	42	72.5	91.6	26.2	6.34	0	20	0	0	5	0	0
1994	200	65	101	148	62.6	220	107	130	141	61.3	65	69.1	38.8	8.71	33	2.04	0	0	17	10
1995	200	38	118	79.3	105	53.6	129	115	134	87	53.1	8.05	63.8	41.3	18	2.91	2.7	0	4	0
2000	200	21	69.6	58.7	21.2	35.5	76.9	89.7	35.2	24.7	16.3	41.5	10	24.1	14	7.13	20	4.8	8.4	14
2001	200	68	98.9	115	73.2	84.3	74.3	57.7	48.4	39	19.1	32.2	20.4	20.5	27	26	18	5.7	6.6	17
2002	200	65	98.9	54.8	82.9	87.9	62.4	35.7	65.4	49	12.3	32.4	15.8	10.9	24	3.62	27	8.3	21	9
2003	200	46	95.9	83	79.3	67.9	86.8	48.9	73.8	10.4	37.8	9	86.9	9	17	2.03	5.4	4.6	1.2	29
2004	200	128	38.4	146	147	57.6	64.7	26.2	23.7	23.8	23.5	51.5	29	30.9	4.4	35.2	26	11	0	53
2005	200	121	144	16.6	127	106	37.7	75.3	16.7	38.1	66.6	40.2	29.7	18.9	8.3	21.7	17	2.7	13	54
2006	200	126	118	146	99.5	130	95.4	54.1	62.3	24.8	7.04	19.1	30.5	10.5	21	9.43	2.4	21	13	35
2007	200	44	154	111	125	60.4	81.9	26.6	51.3	29.9	32.3	3.84	56.3	19.4	3.6	14.8	17	11	8.8	34
2008	200	36	82.2	116	130	92.8	71.5	51.6	46.9	46.2	20	14.1	21	18.5	7.3	56.7	2.7	29	15	32
2009	200	33	48.8	25.7	122	97.7	86.1	40.6	57	30.1	34.9	17.3	3.47	7.13	6.9	8.73	8.3	6.7	2.8	22
2010	200	40	71.3	89.1	60.6	99.4	104	64.1	37.2	23.4	50.8	30.6	18.2	24.6	14	11.7	15	8.4	25	44
2011	200	65	75.1	77.7	97	64	68.7	93.3	65.2	28.4	25.5	28.6	14.3	22.5	8.4	4.77	15	12	4.6	40
2013	200	32	91.8	48.9	55.7	62.1	52.9	62.1	108	42.7	22.1	24.4	18	7.9	12	18.6	5.7	11	4	27
Average		65	90	97	94	95	85	67	62	40	34	28	26	15	13	12	10	7	8	22

Table 9.15. Eastern Bering Sea shelf survey length composition data for female flathead sole only. Units are in millions. Asterisks denote years of length data that were omitted from assessment inputs because age composition data were used instead.

		Length (Females)																							
Year	Effective Sample Size	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58+
1982*	200	0	0	1	17	24	20	29	47	48	48	53	67	70	55	33	13	7	9	2	0	0	0	0	0
1983	200	0	0	11	37	24	41	53	51	42	48	51	56	68	69	62	29	15	8	2	0	0	0	0	0
1984	200	0	0	6	31	56	82	62	55	67	68	68	77	78	75	74	48	23	12	1	1	0	0	0	0
1985*	200	0	1	1	7	19	31	50	76	66	48	47	51	52	51	46	29	21	13	4	1	0	0	0	0
1986	200	0	0	3	12	12	15	28	44	62	73	64	58	66	67	68	51	38	29	7	2	0	0	0	0
1987	200	0	0	3	16	23	33	33	42	41	53	64	68	70	67	75	56	44	34	14	3	0	0	0	0
1988	200	0	0	3	19	68	86	73	87	58	61	66	73	75	98	99	93	67	62	26	3	1	0	0	0
1989	200	0	0	15	42	26	34	95	92	97	68	55	64	74	65	82	86	64	64	26	8	1	0	0	0
1990	200	0	0	2	13	58	69	45	60	80	79	71	64	59	74	69	80	78	91	40	11	2	0	0	0
1991	200	0	1	4	4	7	30	65	88	81	85	80	74	59	69	82	72	104	124	45	15	1	0	0	0
1992*	200	0	0	4	30	54	41	47	71	96	114	105	105	76	73	81	83	80	94	52	16	2	0	0	0
1993*	200	0	1	5	9	18	47	53	39	62	83	85	98	95	78	69	64	57	94	49	16	3	0	0	0
1994*	200	0	0	2	13	31	47	66	55	44	71	90	104	110	98	86	72	76	100	71	26	4	0	0	0
1995*	200	0	0	1	5	15	29	37	53	49	46	58	75	91	85	75	64	58	69	51	17	6	0	0	0
1996	200	0	0	3	19	27	40	42	56	57	64	62	62	72	85	90	79	50	71	51	23	3	0	0	0
1997	200	0	0	2	6	14	22	27	33	36	43	57	61	77	91	108	105	94	128	109	33	8	1	0	0
1998	200	0	1	13	24	11	20	28	38	39	42	54	68	59	75	93	88	80	88	59	25	12	1	0	0
1999	200	0	0	2	6	15	15	14	20	28	33	39	37	42	48	62	58	44	42	28	15	8	1	0	0
2000*	200	0	0	2	5	9	17	16	20	19	28	34	37	49	57	62	67	49	51	29	13	4	1	0	0
2001*	200	0	0	3	5	9	15	28	45	47	38	38	58	64	75	84	80	57	60	38	19	4	1	0	0
2002*	200	0	1	2	4	11	14	18	26	37	41	41	48	52	73	81	66	60	66	53	44	25	5	1	0
2003*	200	0	0	2	9	11	14	18	25	29	43	59	69	65	70	74	57	61	74	41	11	2	0	0	0
2004*	200	0	1	2	5	17	33	35	35	38	42	52	69	80	80	70	73	52	76	57	30	7	0	0	0
2005*	200	0	1	6	19	23	33	45	49	49	51	61	66	77	86	87	72	51	66	59	34	11	1	0	0
2006*	200	0	1	2	9	25	44	53	58	45	52	65	69	81	89	91	76	60	73	50	28	5	1	0	0
2007*	200	0	2	4	7	8	18	38	68	64	56	62	61	69	78	87	75	55	68	52	27	6	1	0	0
2008*	200	0	0	3	8	9	14	14	23	43	62	69	67	80	83	88	81	51	55	28	16	5	0	0	0
2009*	200	0	0	1	4	13	12	18	17	22	31	52	76	69	69	68	56	46	39	27	11	4	0	0	0
2010*	200	0	0	2	16	19	24	26	24	26	32	34	63	88	79	69	62	45	44	23	11	3	0	0	0
2011*	200	0	0	3	19	19	49	37	38	27	36	42	52	70	83	90	63	51	78	51	31	8	2	0	0
2012	200	0	0	2	4	13	19	32	27	26	26	29	35	55	76	69	54	44	44	19	12	2	0	0	0
2013*	200	0	1	1	4	8	15	33	34	38	40	28	30	48	58	76	70	54	70	36	17	3	1	0	0
2014	200	0	0	2	20	47	36	27	35	36	34	42	38	48	52	78	86	59	60	30	13	6	1	0	0
Avg		0	0	4	14	22	32	39	46	49	53	57	64	69	74	77	67	54	62	37	16	4	1	0	0

Table 9.16. Eastern Bering Sea shelf survey length composition data for female flathead sole only. Units are in millions. Asterisks denote years of length data that were omitted from assessment inputs because age composition data were used instead.

		Length (Males)																							
Year	Effective Sample Size	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58+
1982*	200	0	0	1	19	31	28	34	46	55	64	84	90	73	32	10	3	1	0	0	0	0	0	0	0
1983	200	0	1	16	47	27	48	64	54	48	54	69	84	81	58	24	7	1	0	0	0	0	0	0	0
1984	200	1	1	10	30	55	95	71	65	78	74	81	94	91	70	34	7	4	0	0	0	0	0	0	0
1985*	200	0	3	4	7	21	39	59	83	73	55	68	73	80	61	39	14	3	1	0	0	0	0	0	0
1986	200	0	1	7	23	16	20	37	63	71	81	82	68	87	88	49	21	7	2	0	0	0	0	0	0
1987	200	0	0	6	21	23	39	40	50	60	76	75	88	98	97	55	29	15	4	0	0	0	0	0	0
1988	200	1	2	5	29	72	97	65	73	61	68	74	85	115	137	120	52	18	5	0	0	0	0	0	0
1989	200	0	1	16	68	39	39	122	96	100	70	73	75	75	128	127	58	18	3	0	0	0	0	0	0
1990	200	0	1	5	17	73	76	61	89	109	97	95	96	108	136	132	70	28	5	0	0	0	0	0	0
1991	200	0	0	11	8	10	46	88	121	114	109	109	90	101	95	107	72	21	5	0	0	0	0	0	0
1992*	200	0	0	3	44	73	45	47	89	127	158	143	118	124	136	138	89	32	7	0	0	0	0	0	0
1993*	200	0	1	7	12	17	56	57	53	67	106	136	136	120	128	118	69	27	7	0	0	0	0	0	0
1994*	200	0	1	5	20	43	66	88	75	66	91	125	142	156	154	144	96	32	8	0	0	0	0	0	0
1995*	200	0	0	2	7	18	33	42	59	68	64	104	131	152	139	120	74	32	11	0	0	0	0	0	0
1996	200	0	1	3	20	37	33	53	67	73	76	88	115	138	145	136	85	34	12	1	0	0	0	0	0
1997	200	0	0	3	10	12	24	30	39	53	66	73	91	143	152	145	102	53	24	2	2	0	0	0	0
1998	200	0	1	17	35	17	26	29	37	46	68	77	93	137	163	161	109	61	15	3	0	0	0	0	0
1999	200	0	0	3	7	20	15	17	29	31	48	59	67	80	99	84	46	21	11	1	0	0	0	0	0
2000*	200	0	0	5	7	11	23	20	24	27	41	62	63	86	87	73	49	19	8	1	0	0	0	0	0
2001*	200	0	1	5	6	17	21	37	63	59	45	59	98	120	123	105	60	31	10	2	1	0	0	0	0
2002*	200	0	1	2	6	13	18	22	36	57	59	59	75	109	116	107	63	26	12	2	3	0	0	0	0
2003*	200	0	1	4	10	12	22	28	31	42	69	85	103	113	98	87	65	32	9	2	0	0	0	0	0
2004*	200	0	0	2	9	20	32	46	40	48	58	78	117	133	122	114	71	44	16	2	0	0	0	0	0
2005*	200	0	1	8	24	28	36	49	57	59	59	85	113	137	128	101	61	33	15	2	1	1	0	0	0
2006*	200	1	0	2	12	32	50	58	63	58	65	79	107	129	146	117	77	40	17	2	0	0	0	0	0
2007*	200	0	2	4	6	9	20	47	72	71	72	79	87	111	112	94	60	33	15	1	0	0	0	0	0
2008*	200	0	1	5	13	14	15	18	30	51	81	91	95	121	147	120	58	40	13	1	0	0	0	0	0
2009*	200	0	1	2	7	13	15	19	26	27	44	77	92	90	96	78	46	26	12	1	0	0	0	0	0
2010*	200	0	0	3	16	17	27	38	25	29	44	56	99	132	119	109	74	43	18	0	0	0	0	0	0
2011*	200	0	0	6	24	26	56	46	42	35	32	49	88	116	125	90	56	42	19	2	0	0	0	0	0
2012	200	0	0	2	5	9	19	32	29	34	27	35	70	98	108	68	42	21	10	1	0	0	0	0	0
2013*	200	0	1	2	5	11	19	35	41	44	49	41	54	81	99	93	81	41	21	2	0	0	0	0	0
2014	200	0	0	2	30	67	42	36	36	54	63	58	60	74	112	132	74	39	15	2	0	0	0	0	0
Avg		0	1	5	18	27	38	46	55	60	68	79	93	109	114	98	59	28	10	1	0	0	0	0	0

Table 9.17. Parameter estimates for parameters estimated within the assessment model and corresponding standard deviations from the hessian.

Parameter	Estimate	Std_dev
Fishery selectivity (L_{50})	34.890	0.380
Fishery selectivity (slope)	0.330	0.010
Survey Selectivity (L_{50})	27.766	0.944
SurveySelectivity (slope)	0.122	0.007
Log Mean Recruitment	6.791	0.099
Log Mean Fishing Mortality	-2.950	0.067
Survey Temperature-Dependent Catchability	0.059	0.018
Historical Fishing Mortality	0.065	0.010
Log Historical Mean Recruitment	4.361	0.109

Table 9.18. Estimated recruitment deviations and fishing mortality deviations with corresponding standard devations.

Year	Recruitment Deviations	Std. Dev.	Fishing mortality Deviations	Std. Dev.
1977	0.754	0.158	1.693	0.157
1978	-2.010	2.969	1.595	0.159
1979	0.283	0.293	1.053	0.153
1980	-0.454	0.359	1.015	0.135
1981	-0.022	0.231	0.697	0.119
1982	-0.411	0.244	0.226	0.111
1983	0.514	0.163	0.087	0.107
1984	0.818	0.149	-0.321	0.105
1985	-0.582	0.305	-0.294	0.103
1986	-0.132	0.233	-0.558	0.103
1987	0.127	0.217	-1.094	0.102
1988	0.729	0.167	-0.610	0.102
1989	0.398	0.208	-1.368	0.102
1990	0.574	0.174	0.263	0.103
1991	-0.488	0.299	-0.168	0.103
1992	-0.066	0.208	-0.228	0.102
1993	-0.536	0.293	-0.355	0.102
1994	0.108	0.212	-0.180	0.103
1995	-0.372	0.290	-0.370	0.103
1996	-0.014	0.205	-0.226	0.103
1997	-0.807	0.286	-0.052	0.103
1998	-0.202	0.204	0.144	0.104
1999	0.026	0.185	-0.122	0.103
2000	-0.566	0.276	-0.002	0.103
2001	0.255	0.178	-0.115	0.103
2002	0.003	0.198	-0.221	0.103
2003	-0.978	0.297	-0.283	0.103
2004	0.426	0.152	-0.054	0.103
2005	0.120	0.210	-0.105	0.103
2006	0.531	0.156	0.018	0.103
2007	-0.919	0.311	0.078	0.104
2008	-0.452	0.232	0.360	0.105
2009	-0.414	0.233	0.134	0.105
2010	-0.696	0.256	0.152	0.105
2011	-0.535	0.243	-0.255	0.106
2012	-0.105	0.211	-0.441	0.107
2013	-2.017	0.977	-0.013	0.108
2014	0.632	0.220	-0.080	0.109

Table 9.19. Time series of predicted total biomass, spawning biomass, and associated standard deviations. Std_B and Std_spb are the standard deviation of total biomass and spawning biomass, respectively.

	2012 Assessment				*2014 Assessment*			
Year	**Total Biomass (age 3+)**	**Stdev_B**	**Spawning Biomass**	**Stdev_ SPB**	**Total Biomass (age 3+)**	**Stdev_ B**	**Spawning Biomass**	**Stdev_ SPB**
1977	119,140	10,924	21,205	3,137	118,840	10,823	20,978	3,102
1978	145,700	11,692	18,919	3,087	145,440	11,590	18,695	3,051
1979	197,280	12,697	17,872	3,027	197,670	12,548	17,654	2,991
1980	246,810	14,323	18,809	2,983	247,790	14,133	18,602	2,946
1981	301,750	16,217	22,028	2,953	303,630	15,974	21,852	2,914
1982	350,340	18,117	30,018	3,094	353,070	17,841	29,908	3,054
1983	416,050	20,436	45,178	3,665	420,790	20,136	45,188	3,622
1984	502,540	23,218	66,707	4,625	510,430	22,877	66,906	4,572
1985	566,570	25,538	89,988	5,548	576,490	25,174	90,448	5,477
1986	624,500	27,551	112,080	6,368	635,340	27,142	112,910	6,276
1987	681,300	29,461	133,220	7,158	690,120	28,926	134,520	7,049
1988	753,570	31,666	154,680	7,915	761,280	30,995	156,600	7,794
1989	817,660	33,631	177,570	8,699	823,870	32,812	180,280	8,570
1990	887,610	35,633	203,550	9,595	893,430	34,680	207,170	9,460
1991	919,840	36,911	224,430	10,517	925,030	35,863	228,670	10,373
1992	946,760	37,886	242,550	11,240	951,640	36,764	246,690	11,069
1993	953,480	38,238	257,750	11,764	958,170	37,075	261,040	11,540
1994	957,920	38,492	274,400	12,298	962,580	37,279	276,530	12,001
1995	948,640	38,453	294,250	13,038	952,930	37,191	295,610	12,671
1996	936,260	38,181	309,360	13,581	939,870	36,854	310,460	13,172
1997	909,630	37,567	318,210	13,992	912,820	36,207	319,440	13,564
1998	879,790	36,923	315,680	14,048	882,780	35,529	317,100	13,614
1999	852,210	36,492	306,100	13,897	855,100	35,044	307,620	13,461
2000	823,090	35,878	295,500	13,614	825,890	34,394	297,000	13,173
2001	808,640	35,946	285,090	13,386	811,620	34,374	286,500	12,932
2002	799,530	36,233	276,170	13,183	802,590	34,537	277,410	12,711
2003	779,600	36,095	265,750	12,862	782,550	34,315	266,710	12,369
2004	782,330	37,124	256,430	12,582	785,240	35,138	257,230	12,069
2005	784,990	38,468	247,980	12,405	788,120	36,257	248,690	11,866
2006	804,160	40,947	243,200	12,407	810,970	38,547	244,070	11,844
2007	802,830	42,546	239,090	12,504	812,650	40,035	240,070	11,902
2008	796,710	44,041	236,770	12,771	809,820	41,449	237,900	12,116
2009	779,520	45,255	232,900	13,107	795,050	42,570	234,130	12,384
2010	759,750	46,028	233,180	13,610	776,210	43,236	234,700	12,809
2011	735,410	46,701	236,210	14,334	752,210	43,674	238,390	13,449
2012	726,860	48,476	243,330	15,260	738,030	44,478	246,830	14,305
2013	724,740	50,234	245,199	--	709,700	44,344	252,320	15,074
2014					709,710	47,342	249,980	15,572
2015					712,530	50,078	239,357	--

Table 9.20. Age 3 recruitment (millions) estimated in the 2012 and 2014 assessments and standard deviations about the estimates.

	2012 Assessment		*2014 Assessment*	
Year	**Recruits (Age 3)**	**Std. dev**	**Recruits (Age 3)**	**Std. dev**
1977	1,877.10	249.47	1,890.70	248.58
1978	128.01	355.90	119.16	353.88
1979	1,157.80	321.56	1,179.80	322.81
1980	558.56	199.22	564.59	202.20
1981	853.25	181.55	869.86	184.94
1982	581.30	134.67	589.62	137.11
1983	1,433.00	201.53	1,486.70	206.71
1984	1,944.70	234.54	2,015.50	239.44
1985	501.71	148.90	497.03	148.92
1986	804.63	172.92	779.67	169.81
1987	1,108.60	211.85	1,009.90	203.10
1988	1,825.40	263.54	1,844.70	260.86
1989	1,323.60	254.25	1,323.70	254.59
1990	1,537.80	231.98	1,579.00	233.68
1991	546.47	158.76	545.90	159.47
1992	825.64	155.70	832.46	156.79
1993	516.79	147.09	520.57	148.37
1994	984.62	190.03	990.79	190.21
1995	624.30	175.32	613.42	173.02
1996	889.69	164.18	877.00	162.36
1997	391.98	109.85	396.67	110.81
1998	715.09	134.80	726.74	136.03
1999	907.55	150.08	912.92	150.57
2000	502.54	135.03	504.87	135.72
2001	1,139.00	181.39	1,147.70	181.11
2002	892.32	163.56	891.73	162.72
2003	334.96	98.27	334.59	98.03
2004	1,357.00	179.77	1,361.60	176.83
2005	986.52	198.93	1,002.90	201.03
2006	1,380.80	199.83	1,513.10	206.10
2007	327.70	100.61	354.96	109.71
2008	532.10	120.99	565.82	126.02
2009	580.27	134.46	587.80	131.66
2010	470.15	122.91	443.66	111.11
2011	520.73	164.01	521.04	123.28
2012	1,005.10	281.26	800.91	163.64
2013			118.33	115.28
2014			1,674.00	353.03
Average	890.74		894.46	

Table 9.21. Time series of estimated female numbers-at-age. Units are in millions.

	Age (Females)																		
Year	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21+**
1977	945.4	32.1	26.2	21.4	17.5	14.2	11.5	9.2	7.4	5.9	4.6	3.6	2.8	2.2	1.7	1.3	1.0	0.8	2.8
1978	59.6	773.4	26.2	21.3	17.3	13.9	11.0	8.7	6.8	5.3	4.1	3.2	2.5	1.9	1.5	1.1	0.9	0.7	2.3
1979	589.9	48.7	631.7	21.3	17.2	13.7	10.8	8.4	6.4	4.9	3.7	2.9	2.2	1.7	1.3	1.0	0.8	0.6	1.9
1980	282.3	482.8	39.9	515.3	17.3	13.8	10.9	8.5	6.5	4.9	3.7	2.8	2.1	1.6	1.2	0.9	0.7	0.5	1.8
1981	434.9	231.0	394.7	32.5	418.4	13.9	11.0	8.6	6.6	4.9	3.7	2.8	2.1	1.6	1.2	0.9	0.7	0.5	1.7
1982	294.8	356.0	189.0	322.4	26.5	338.5	11.2	8.8	6.7	5.1	3.8	2.8	2.1	1.6	1.2	0.9	0.7	0.5	1.6
1983	743.3	241.3	291.3	154.5	262.9	21.5	273.6	9.0	7.0	5.4	4.0	3.0	2.2	1.7	1.2	0.9	0.7	0.5	1.7
1984	1007.8	608.5	197.5	238.2	126.1	213.9	17.4	220.4	7.2	5.6	4.2	3.2	2.4	1.8	1.3	1.0	0.7	0.5	1.7
1985	248.5	825.0	498.0	161.5	194.6	102.8	173.8	14.1	177.8	5.8	4.5	3.4	2.5	1.9	1.4	1.0	0.8	0.6	1.8
1986	389.8	203.4	675.2	407.4	132.0	158.6	83.5	140.7	11.4	142.9	4.6	3.6	2.7	2.0	1.5	1.1	0.8	0.6	1.8
1987	504.9	319.1	166.5	552.4	332.9	107.7	129.1	67.8	113.9	9.2	115.1	3.7	2.9	2.2	1.6	1.2	0.9	0.7	2.0
1988	922.3	413.4	261.3	136.3	451.8	272.0	87.8	105.2	55.1	92.5	7.4	93.2	3.0	2.3	1.8	1.3	1.0	0.7	2.1
1989	661.8	755.1	338.4	213.7	111.4	368.7	221.5	71.3	85.2	44.5	74.5	6.0	74.9	2.4	1.9	1.4	1.0	0.8	2.2
1990	789.5	541.8	618.1	276.9	174.9	91.1	301.1	180.7	58.1	69.3	36.2	60.5	4.9	60.7	2.0	1.5	1.1	0.8	2.4
1991	272.9	646.3	443.4	505.2	225.9	142.1	73.6	241.8	144.1	46.1	54.6	28.4	47.3	3.8	47.2	1.5	1.2	0.9	2.5
1992	416.2	223.4	528.9	362.6	412.6	184.0	115.3	59.5	194.6	115.5	36.8	43.5	22.6	37.5	3.0	37.3	1.2	0.9	2.7
1993	260.3	340.7	182.9	432.6	296.2	336.2	149.4	93.3	47.9	156.2	92.4	29.4	34.6	17.9	29.8	2.4	29.5	0.9	2.8
1994	495.4	213.1	278.9	149.6	353.4	241.5	273.3	121.0	75.3	38.6	125.3	74.0	23.5	27.6	14.3	23.7	1.9	23.5	3.0
1995	306.7	405.5	174.4	228.1	122.2	287.9	196.0	221.0	97.5	60.4	30.8	99.9	58.8	18.6	21.9	11.3	18.7	1.5	20.9
1996	438.5	251.1	331.9	142.7	186.4	99.6	234.1	158.8	178.4	78.4	48.5	24.7	79.8	46.9	14.8	17.4	9.0	14.9	17.7
1997	198.3	359.0	205.5	271.5	116.5	151.8	80.9	189.4	128.0	143.2	62.8	38.7	19.6	63.4	37.2	11.7	13.8	7.1	25.7
1998	363.4	162.4	293.8	168.0	221.6	94.9	123.1	65.3	152.1	102.3	114.1	49.8	30.6	15.5	50.0	29.3	9.2	10.8	25.7
1999	456.5	297.5	132.9	240.2	137.1	180.2	76.7	99.1	52.2	121.0	81.0	90.0	39.2	24.0	12.1	39.0	22.8	7.2	28.4
2000	252.4	373.7	243.4	108.7	196.1	111.7	146.2	62.0	79.7	41.8	96.6	64.5	71.4	31.0	19.0	9.6	30.8	18.0	27.9
2001	573.8	206.6	305.8	199.1	88.7	159.6	90.5	117.9	49.8	63.7	33.3	76.6	51.0	56.3	24.4	14.9	7.5	24.1	35.9
2002	445.9	469.8	169.1	250.1	162.5	72.2	129.5	73.1	94.8	39.9	50.8	26.5	60.7	40.3	44.5	19.3	11.7	5.9	47.2
2003	167.3	365.0	384.5	138.3	204.3	132.4	58.7	104.7	58.9	76.1	31.9	40.5	21.1	48.3	32.0	35.2	15.2	9.3	41.9
2004	680.8	137.0	298.7	314.5	113.0	166.5	107.6	47.5	84.5	47.3	61.0	25.5	32.3	16.8	38.3	25.4	27.9	12.1	40.4
2005	501.4	557.3	112.1	244.3	256.7	92.0	135.0	86.8	38.1	67.6	37.7	48.4	20.2	25.5	13.2	30.2	20.0	21.9	41.1
2006	756.5	410.5	456.1	91.7	199.5	209.1	74.6	109.0	69.8	30.5	53.9	30.0	38.4	16.0	20.2	10.4	23.8	15.7	49.5
2007	177.5	619.3	335.9	372.9	74.8	162.3	169.4	60.2	87.5	55.8	24.3	42.7	23.7	30.3	12.6	15.8	8.2	18.6	51.0
2008	282.9	145.3	506.8	274.6	304.3	60.9	131.4	136.5	48.2	69.7	44.2	19.2	33.6	18.6	23.7	9.8	12.4	6.4	54.2
2009	293.9	231.6	118.9	414.2	223.9	247.0	49.1	105.3	108.6	38.1	54.8	34.6	14.9	26.1	14.4	18.3	7.6	9.5	46.4
2010	221.8	240.6	189.5	97.2	337.9	182.1	199.9	39.5	84.3	86.4	30.2	43.2	27.2	11.7	20.4	11.2	14.3	5.9	43.4
2011	260.5	181.6	196.9	154.9	79.3	274.7	147.3	160.8	31.6	67.0	68.4	23.8	34.0	21.3	9.2	15.9	8.8	11.1	38.2
2012	400.5	213.3	148.6	161.0	126.5	64.6	223.2	119.2	129.7	25.4	53.7	54.6	19.0	27.0	16.9	7.3	12.6	6.9	39.0
2013	59.2	327.8	174.6	121.6	131.6	103.2	52.6	181.0	96.3	104.5	20.4	43.0	43.7	15.1	21.5	13.5	5.8	10.0	36.5
2014	837.0	48.4	268.3	142.7	99.2	107.1	83.6	42.4	145.3	77.0	83.1	16.2	34.0	34.5	11.9	16.9	10.6	4.5	36.4

Table 9.22. Time series of estimated male numbers-at-age. Units are in millions.

	Age (Males)																		
Year	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21+**
1977	945.4	32.1	26.2	21.4	17.5	14.2	11.5	9.3	7.5	6.0	4.8	3.9	3.1	2.4	1.9	1.5	1.2	1.0	3.7
1978	59.6	773.5	26.2	21.3	17.3	13.9	11.2	8.9	7.1	5.6	4.5	3.5	2.8	2.2	1.8	1.4	1.1	0.9	3.3
1979	589.9	48.7	631.9	21.3	17.2	13.8	11.0	8.7	6.8	5.4	4.2	3.3	2.6	2.0	1.6	1.3	1.0	0.8	2.9
1980	282.3	482.8	39.9	515.5	17.3	13.9	11.1	8.7	6.8	5.4	4.2	3.3	2.6	2.0	1.6	1.2	1.0	0.8	2.8
1981	434.9	231.0	394.8	32.5	418.9	14.0	11.2	8.8	6.9	5.4	4.2	3.2	2.5	2.0	1.5	1.2	0.9	0.7	2.7
1982	294.8	356.0	189.0	322.4	26.5	339.6	11.3	8.9	7.0	5.5	4.2	3.3	2.5	2.0	1.5	1.2	0.9	0.7	2.7
1983	743.3	241.3	291.3	154.5	263.1	21.6	275.4	9.1	7.2	5.6	4.4	3.4	2.6	2.0	1.6	1.2	0.9	0.7	2.7
1984	1007.8	608.5	197.5	238.2	126.1	214.3	17.5	222.9	7.3	5.8	4.5	3.5	2.7	2.1	1.6	1.2	1.0	0.8	2.7
1985	248.5	825.0	498.0	161.5	194.6	102.9	174.4	14.2	180.7	5.9	4.7	3.6	2.8	2.2	1.7	1.3	1.0	0.8	2.8
1986	389.8	203.4	675.2	407.4	132.0	158.8	83.8	141.7	11.5	146.2	4.8	3.8	2.9	2.3	1.8	1.3	1.0	0.8	2.9
1987	504.9	319.1	166.5	552.5	333.0	107.8	129.4	68.2	115.1	9.3	118.5	3.9	3.1	2.4	1.8	1.4	1.1	0.8	2.9
1988	922.3	413.4	261.3	136.3	451.9	272.2	88.0	105.6	55.6	93.8	7.6	96.3	3.2	2.5	1.9	1.5	1.1	0.9	3.1
1989	661.8	755.1	338.4	213.8	111.4	369.0	221.9	71.6	85.8	45.1	76.0	6.2	78.0	2.6	2.0	1.6	1.2	0.9	3.2
1990	789.5	541.8	618.1	277.0	174.9	91.1	301.5	181.2	58.5	70.0	36.7	61.9	5.0	63.5	2.1	1.6	1.3	1.0	3.3
1991	272.9	646.3	443.4	505.3	226.0	142.3	73.9	243.5	145.8	46.9	56.0	29.3	49.3	4.0	50.3	1.6	1.3	1.0	3.4
1992	416.2	223.4	528.9	362.6	412.8	184.2	115.7	59.9	197.1	117.8	37.8	45.0	23.6	39.6	3.2	40.4	1.3	1.0	3.5
1993	260.3	340.7	182.9	432.6	296.3	336.6	149.9	94.0	48.5	159.3	95.0	30.5	36.2	18.9	31.8	2.6	32.4	1.1	3.7
1994	495.4	213.1	278.9	149.6	353.5	241.7	274.1	121.8	76.2	39.3	128.8	76.7	24.6	29.2	15.2	25.6	2.1	26.0	3.8
1995	306.7	405.6	174.4	228.1	122.2	288.3	196.6	222.5	98.6	61.6	31.7	103.7	61.7	19.7	23.4	12.2	20.5	1.7	23.9
1996	438.5	251.1	331.9	142.7	186.4	99.7	234.8	159.8	180.5	79.9	49.8	25.6	83.6	49.7	15.9	18.9	9.8	16.5	20.5
1997	198.3	359.0	205.5	271.5	116.6	152.0	81.1	190.6	129.5	145.9	64.5	40.1	20.6	67.2	39.9	12.7	15.1	7.9	29.6
1998	363.4	162.4	293.8	168.1	221.7	95.0	123.6	65.8	154.1	104.4	117.4	51.8	32.2	16.5	53.8	31.9	10.2	12.1	29.9
1999	456.5	297.5	132.9	240.2	137.2	180.5	77.1	99.9	53.0	123.8	83.7	93.9	41.3	25.6	13.1	42.8	25.4	8.1	33.3
2000	252.4	373.7	243.4	108.7	196.2	111.8	146.8	62.5	80.9	42.8	99.8	67.3	75.4	33.2	20.6	10.5	34.2	20.3	33.0
2001	573.8	206.6	305.8	199.1	88.7	159.8	90.8	118.9	50.5	65.2	34.4	80.1	53.9	60.3	26.5	16.4	8.4	27.3	42.5
2002	445.9	469.8	169.1	250.1	162.6	72.3	130.0	73.7	96.2	40.8	52.5	27.7	64.3	43.3	48.4	21.2	13.1	6.7	55.7
2003	167.3	365.0	384.5	138.3	204.3	132.6	58.9	105.5	59.7	77.8	32.9	42.3	22.3	51.7	34.7	38.8	17.0	10.5	50.0
2004	680.8	137.0	298.7	314.5	113.0	166.7	107.9	47.8	85.5	48.3	62.8	26.5	34.1	17.9	41.5	27.9	31.2	13.7	48.5
2005	501.4	557.3	112.1	244.3	256.8	92.1	135.5	87.5	38.6	69.0	38.9	50.4	21.3	27.3	14.3	33.2	22.3	24.9	49.6
2006	756.5	410.5	456.1	91.7	199.5	209.3	74.9	109.9	70.8	31.2	55.5	31.2	40.5	17.1	21.9	11.5	26.6	17.8	59.4
2007	177.5	619.3	335.9	373.0	74.8	162.6	170.1	60.7	88.7	57.0	25.1	44.6	25.0	32.4	13.6	17.4	9.2	21.2	61.5
2008	282.9	145.3	506.8	274.7	304.5	61.0	132.0	137.7	49.0	71.4	45.8	20.1	35.6	20.0	25.8	10.9	13.9	7.3	65.7
2009	293.9	231.6	118.9	414.2	224.0	247.5	49.4	106.4	110.6	39.2	57.0	36.4	15.9	28.2	15.8	20.4	8.6	10.9	57.4
2010	221.8	240.6	189.5	97.2	338.1	182.4	200.9	39.9	85.8	88.9	31.4	45.6	29.1	12.7	22.5	12.6	16.2	6.8	54.2
2011	260.5	181.6	196.9	154.9	79.3	275.2	148.0	162.5	32.2	69.0	71.2	25.1	36.4	23.2	10.1	17.9	10.0	12.9	48.3
2012	400.5	213.3	148.6	161.0	126.6	64.7	224.0	120.2	131.6	26.0	55.7	57.4	20.2	29.3	18.6	8.1	14.3	8.0	49.0
2013	59.2	327.8	174.6	121.6	131.6	103.3	52.7	182.2	97.5	106.7	21.1	45.0	46.4	16.3	23.6	15.0	6.5	11.5	45.9
2014	837.0	48.4	268.3	142.7	99.3	107.2	83.9	42.7	147.2	78.6	85.8	16.9	36.1	37.1	13.0	18.8	12.0	5.2	45.7

Table 9.23. Estimates of time-invariant parameters for retrospective model runs. Conditional formatting from white (lowest value of a parameter among years) to dark grey (highest value of a parameter among years) is used within each column to show patterns in changes in parameter values among the retrospective model years.

Year	Fishery selectivity slope	Fishery selectivity L50	Survey selectivity slope	Survey selectivity L50	Log of Average F	Log of Average Recruitment	Historical F	Historical R	Temperature-dependent catchability parameter
2004	0.315	34.912	0.112	28.394	-2.993	6.799	0.055	4.485	0.063
2005	0.318	34.914	0.113	28.612	-3.001	6.827	0.056	4.473	0.072
2006	0.320	34.924	0.115	28.806	-3.008	6.894	0.057	4.457	0.054
2007	0.322	34.916	0.115	28.982	-3.014	6.895	0.058	4.450	0.048
2008	0.324	34.890	0.116	28.890	-2.999	6.877	0.059	4.433	0.045
2009	0.325	34.887	0.118	28.517	-2.975	6.832	0.060	4.417	0.051
2010	0.326	34.869	0.120	28.231	-2.959	6.820	0.061	4.405	0.051
2011	0.327	34.869	0.121	28.217	-2.967	6.827	0.062	4.400	0.051
2012	0.327	34.921	0.122	27.884	-2.955	6.790	0.063	4.385	0.057
2013	0.328	34.942	0.123	27.697	-2.941	6.791	0.065	4.364	0.058
2014	0.330	34.890	0.122	27.766	-2.950	6.791	0.065	4.361	0.059

Table 9.24. Projected spawning biomass for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2014	249,536	249,536	249,536	249,536	249,536	249,536	249,536
2015	233,736	233,736	239,409	239,362	241,107	232,141	233,736
2016	194,515	194,515	227,862	227,565	238,844	186,000	194,515
2017	163,745	163,745	216,771	216,265	235,914	151,432	162,632
2018	141,227	141,227	207,287	206,615	233,308	127,245	135,270
2019	127,604	127,604	202,364	201,556	234,314	113,574	119,061
2020	121,889	121,889	201,941	201,027	238,841	109,882	112,983
2021	123,231	123,231	206,382	205,383	247,454	112,600	114,262
2022	127,222	127,222	214,521	213,430	260,028	117,104	117,905
2023	129,899	129,899	221,086	219,915	270,559	119,693	119,997
2024	131,398	131,398	226,614	225,365	280,053	120,758	120,815
2025	131,734	131,734	229,424	228,121	285,706	120,687	120,629
2026	131,800	131,800	231,884	230,529	290,934	120,365	120,275
2027	131,732	131,732	233,876	232,475	295,459	120,011	119,927

Table 9.25 Projected fishing mortality rates for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2014	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2015	0.28	0.28	0.06	0.07	0.00	0.35	0.28
2016	0.28	0.28	0.06	0.07	0.00	0.35	0.28
2017	0.28	0.28	0.06	0.07	0.00	0.35	0.35
2018	0.28	0.28	0.06	0.07	0.00	0.34	0.35
2019	0.28	0.28	0.06	0.07	0.00	0.31	0.32
2020	0.27	0.27	0.06	0.07	0.00	0.29	0.30
2021	0.27	0.27	0.06	0.07	0.00	0.30	0.31
2022	0.27	0.27	0.06	0.07	0.00	0.31	0.32
2023	0.27	0.27	0.06	0.07	0.00	0.32	0.32
2024	0.27	0.27	0.06	0.07	0.00	0.32	0.32
2025	0.27	0.27	0.06	0.07	0.00	0.32	0.32
2026	0.27	0.27	0.06	0.07	0.00	0.32	0.32
2027	0.27	0.27	0.06	0.07	0.00	0.31	0.31

Table 9.26. Projected catches for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2014	16,661	16,661	16,661	16,661	16,661	16,661	16,661
2015	66,130	66,130	15,954	16,389	-	79,419	66,130
2016	56,923	56,923	15,402	15,806	-	66,218	56,923
2017	49,915	49,915	14,939	15,318	-	56,544	59,984
2018	45,030	45,030	14,603	14,962	-	49,865	52,585
2019	42,136	42,136	14,533	14,881	-	41,509	45,190
2020	39,182	39,182	14,605	14,949	-	39,396	41,439
2021	39,229	39,229	14,769	15,112	-	40,607	41,720
2022	40,013	40,013	15,081	15,427	-	42,586	43,126
2023	40,360	40,360	15,367	15,716	-	43,498	43,723
2024	40,592	40,592	15,660	16,012	-	43,834	43,907
2025	40,583	40,583	15,824	16,178	-	43,760	43,760
2026	40,617	40,617	15,997	16,352	-	43,625	43,598
2027	40,635	40,635	16,149	16,506	-	43,518	43,487

Table 9.27. Non-target catch in the directed flathead sole fishery as a proportion of total bycatch of each species. Conditional highlighting from white (lowest numbers) to green (highest numbers) is applied.

Non-Target Species	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Benthic urochordata	0.043	0.000	0.007	0.039	0.102	0.047	0.002	0.065	0.011	0.007	0.001	0.019
Bivalves	0.016	0.041	0.002	0.010	0.029	0.006	0.005	0.023	0.004	0.005	0.004	0.083
Brittle star unidentified	0.301	0.108	0.023	0.015	0.034	0.016	0.253	0.094	0.004	0.002	0.034	0.034
Capelin	0.000	0.005	0.000	0.000	0.000	0.052	0.026	0.000	0.006	0.000	0.037	0.000
Corals Bryozoans	0.002	0.010	0.009	0.004	0.001	0.000	0.000	0.036	0.000	0.000	0.000	0.000
Eelpouts	0.101	0.209	0.129	0.096	0.040	0.034	0.017	0.100	0.083	0.161	0.271	0.195
Eulachon	0.000	0.001	0.007	0.000	0.000	0.006	0.001	0.007	0.003	0.001	0.122	0.012
Giant Grenadier	0.000	0.005	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.003	0.001	0.000
Greenlings	0.000	0.021	0.005	0.000	0.006	0.007	0.034	0.000	0.000	0.000	0.000	0.000
Grenadier	0.020	0.016	0.002	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.003	0.000
Hermit crab unidentified	0.021	0.133	0.068	0.027	0.122	0.057	0.018	0.063	0.005	0.033	0.048	0.023
Invertebrate unidentified	0.010	0.053	0.032	0.027	0.016	0.183	0.080	0.085	0.009	0.001	0.001	0.003
Lanternfishes (myctophidae)	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Misc crabs	0.216	0.031	0.042	0.022	0.020	0.029	0.006	0.010	0.006	0.005	0.024	0.024
Misc crustaceans	0.067	0.325	0.104	0.026	0.090	0.218	0.034	0.080	0.015	0.008	0.163	0.037
Misc fish	0.024	0.019	0.018	0.020	0.007	0.011	0.014	0.006	0.002	0.000	0.004	0.005
Misc inverts (worms etc)	0.899	0.875	0.882	0.133	0.000	0.571	0.112	0.029	0.055	0.093	0.076	0.025
Other osmerids	0.016	0.031	0.024	0.010	0.000	0.000	0.001	0.001	0.018	0.000	0.010	0.001
Pacific Sand lance	0.009	0.000	0.018	0.000	0.000	0.026	0.000	0.000	0.000	0.000	0.000	0.000
Pandalid shrimp	0.191	0.072	0.286	0.027	0.048	0.112	0.042	0.040	0.007	0.056	0.069	0.065
Polychaete unidentified	0.372	0.277	0.044	0.000	0.032	0.072	0.110	0.006	0.006	0.001	0.004	0.003
Scypho jellies	0.003	0.003	0.001	0.001	0.002	0.001	0.002	0.007	0.001	0.000	0.001	0.005
Sea anemone unidentified	0.074	0.235	0.021	0.069	0.474	0.109	0.030	0.132	0.019	0.017	0.070	0.047
Sea pens whips	0.037	0.017	0.008	0.012	0.022	0.017	0.003	0.001	0.001	0.000	0.001	0.000
Sea star	0.045	0.096	0.047	0.098	0.054	0.097	0.078	0.041	0.028	0.005	0.017	0.046
Snails	0.070	0.195	0.102	0.048	0.100	0.094	0.029	0.063	0.035	0.022	0.045	0.119
Sponge unidentified	0.008	0.004	0.003	0.005	0.000	0.009	0.001	0.014	0.001	0.000	0.015	0.007
Stichaeidae	0.008	0.025	0.215	0.693	0.001	0.028	0.097	0.048	0.002	0.000	0.007	0.004
urchins dollars cucumbers	0.048	0.068	0.009	0.016	0.016	0.062	0.027	0.023	0.034	0.006	0.025	0.007

Table 9.28. Prohibited species catch in the flathead sole directed fishery as a proportion of all prohibited species catch in the BSAI.

	2014		2013	
Prohibited Species	PSCNQ Estimate (*)	Halibut Mortality (mt)	PSCNQ Estimate (*)	Halibut Mortality (mt)
Bairdi Tanner Crab			0.069	
Blue King Crab			0.047	
Chinook Salmon	0.000		0.000	
Golden (Brown) King Crab			0.001	
Halibut	0.022	0.038	0.017	0.035
Herring			0.002	
Non-Chinook Salmon	0.000		0.000	
Opilio Tanner (Snow) Crab			0.096	
Red King Crab			0.007	

Figures

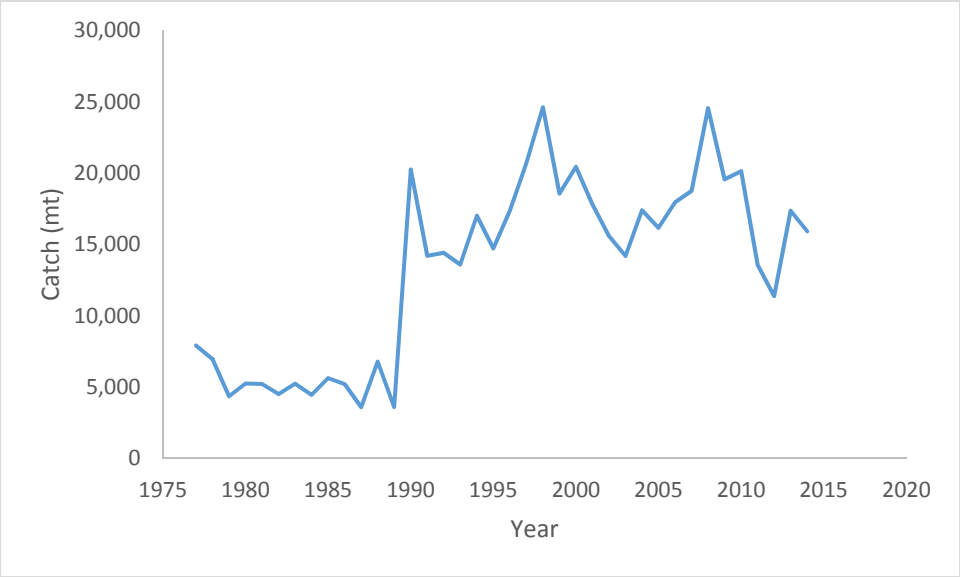


Figure 9.1. Combined catch (in metric tons) of flathead sole and Bering flounder (Hippoglossoides spp.) by year in total and for CDQ and non-CDQ fisheries.

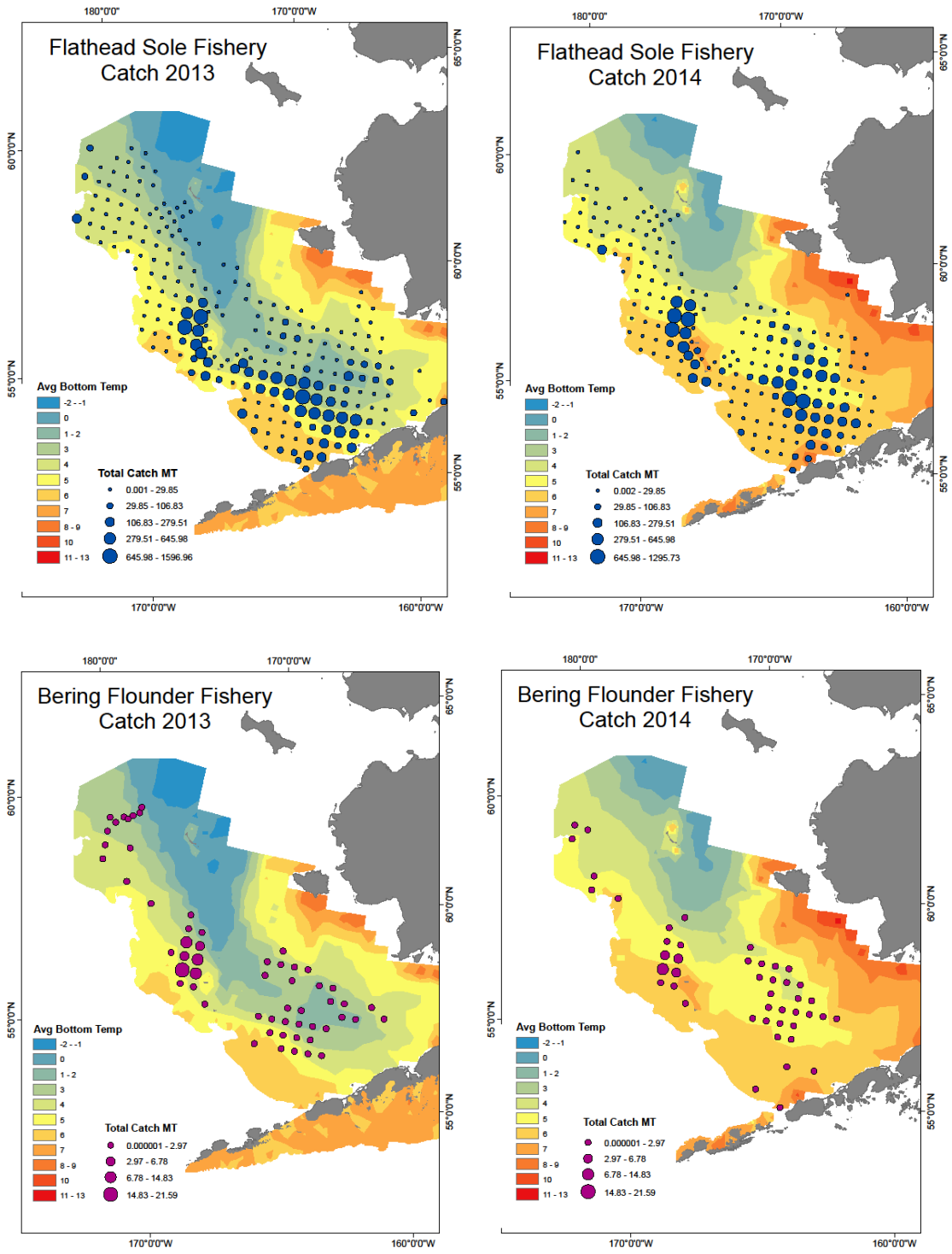


Figure 9.2. Spatial distribution of fishery catches, aggregated by EBS shelf survey stations for flathead sole (top; blue circles) and Bering flounder (bottom; purple circles) in 2013 and 2014. Scale for Bering flounder maps is different from that for flathead sole maps. Catches are overlaid on EBS summer mean bottom temperatures from the EBS shelf survey.

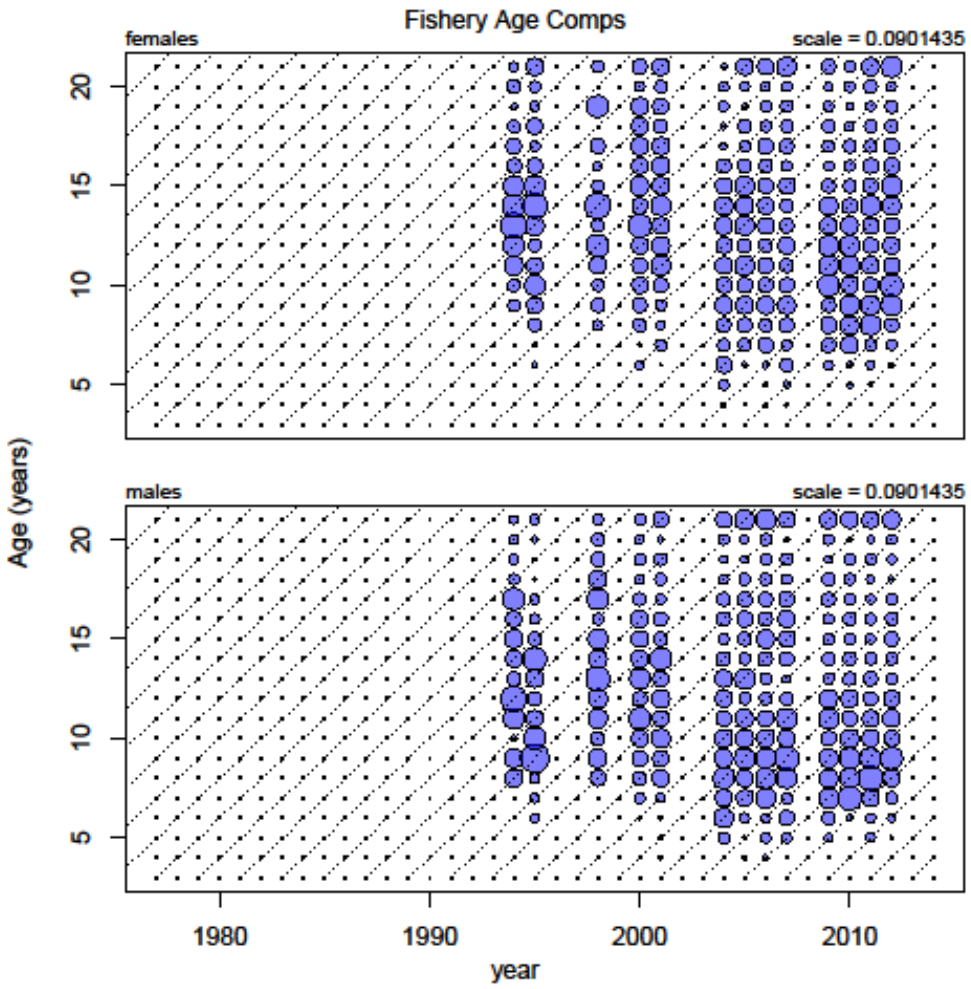


Figure 9.3. Annual age compositions for flathead sole from fishery observer data. Circle area reflects relative numbers-at-age within each year across both sexes. Dotted lines indicate cohort progression. Ages 21+ are grouped together. Age compositions from 1994, 1995 and 1998 were not used in the model due to small sample sizes but are included here for completeness. "Scale" is the maximum observed proportion-at-age.

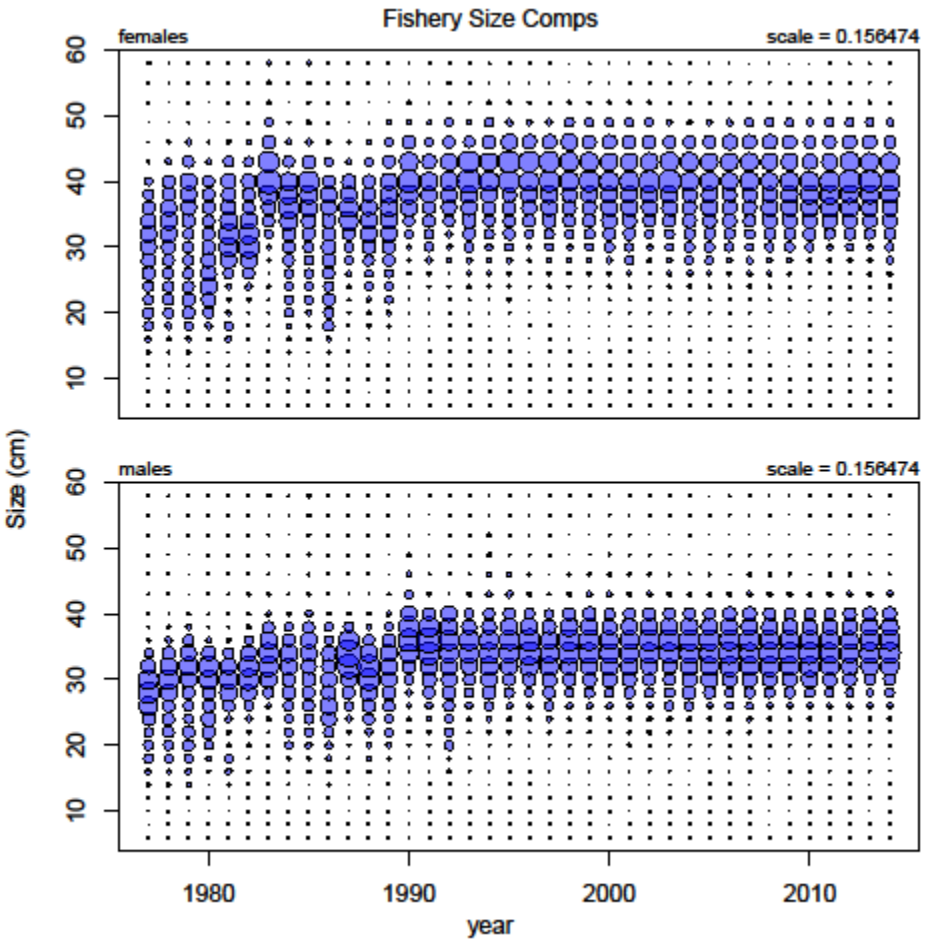


Figure 9.4. Annual size compositions for BSAI *Hippoglossoides* spp. (flathead sole and Bering flounder) from fishery observer data. Circle area reflects relative numbers-at-size within each year, across both sexes. 2 cm size bins are used for sizes 6-40 cm and 3 cm bins are used for sizes > 40 cm. All sizes >= 58cm were grouped into one size bin. The "scale" is the maximum proportion observed.

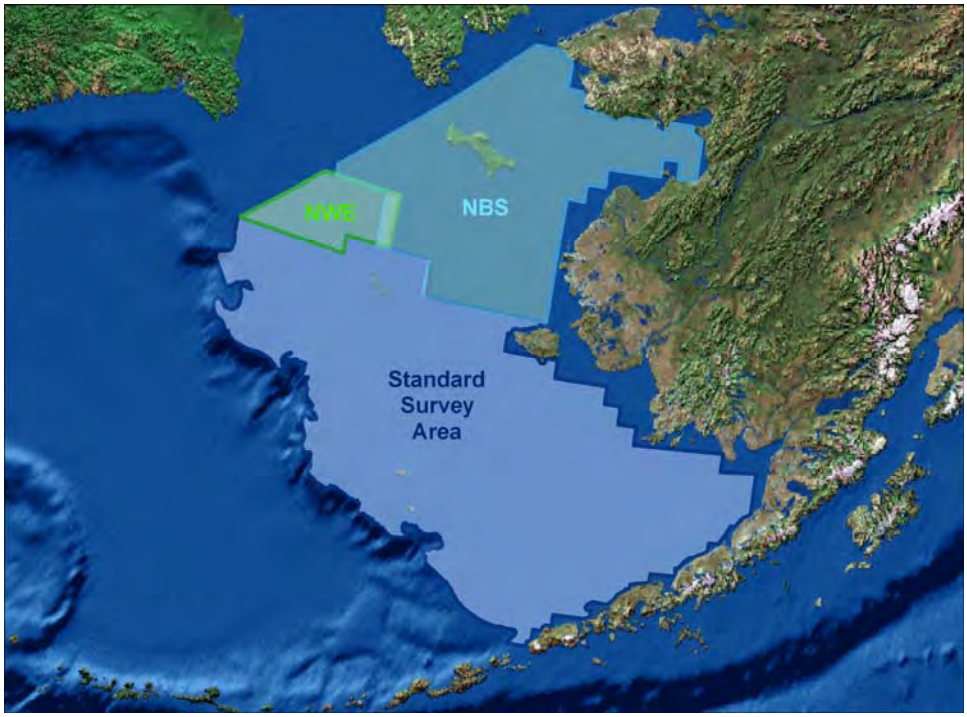


Figure 9.5. Eastern Bering Sea shelf survey areas. Only data from the standard survey area are used in the assessment model; data from the Northwest Extension (NWE) and Northern Bering Sea (NBS) are excluded.

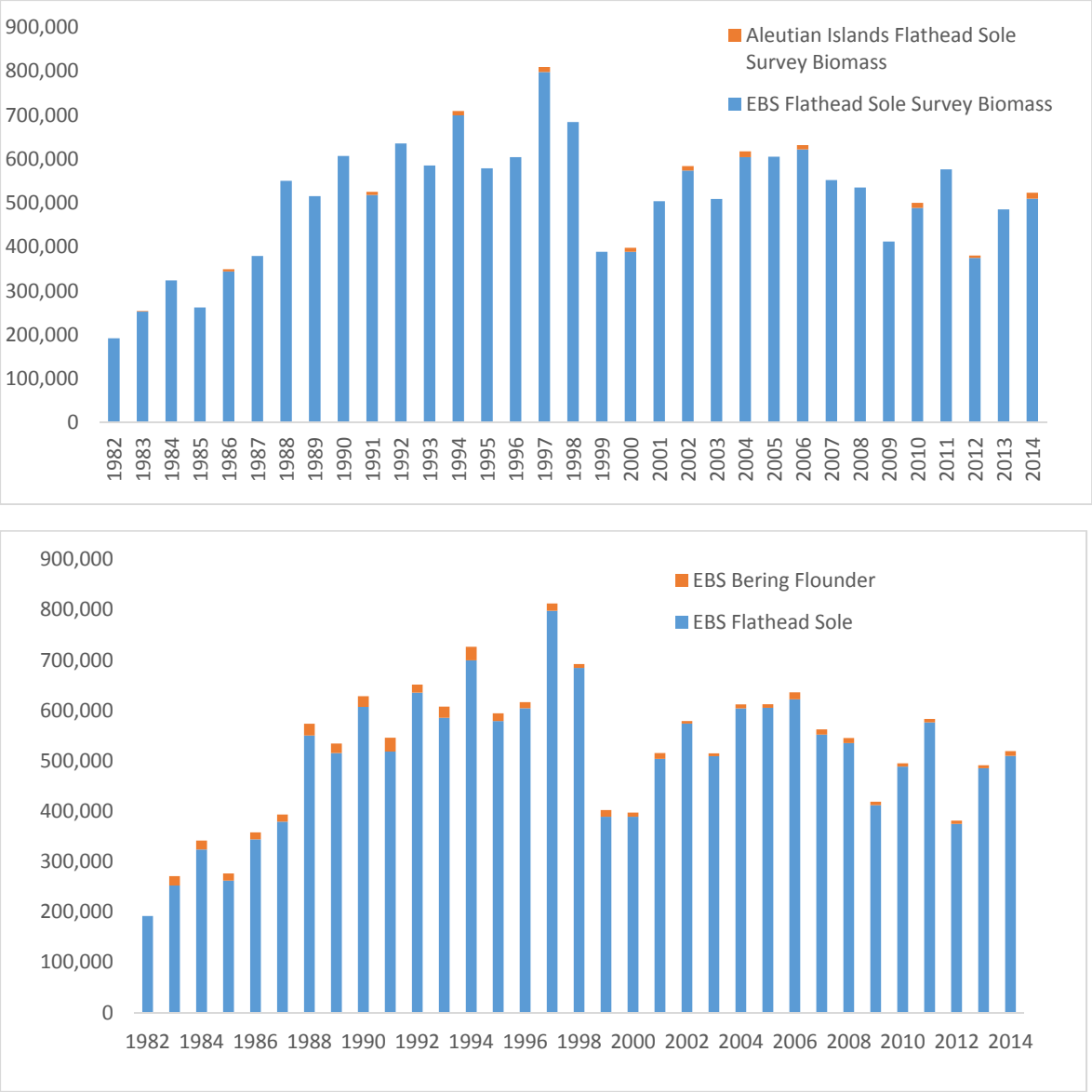


Figure 9.6. Flathead sole (only) survey biomass from the EBS shelf survey and the Aleutian Islands survey (top). Flathead sole and Bering flounder biomass in the EBS shelf survey (bottom).

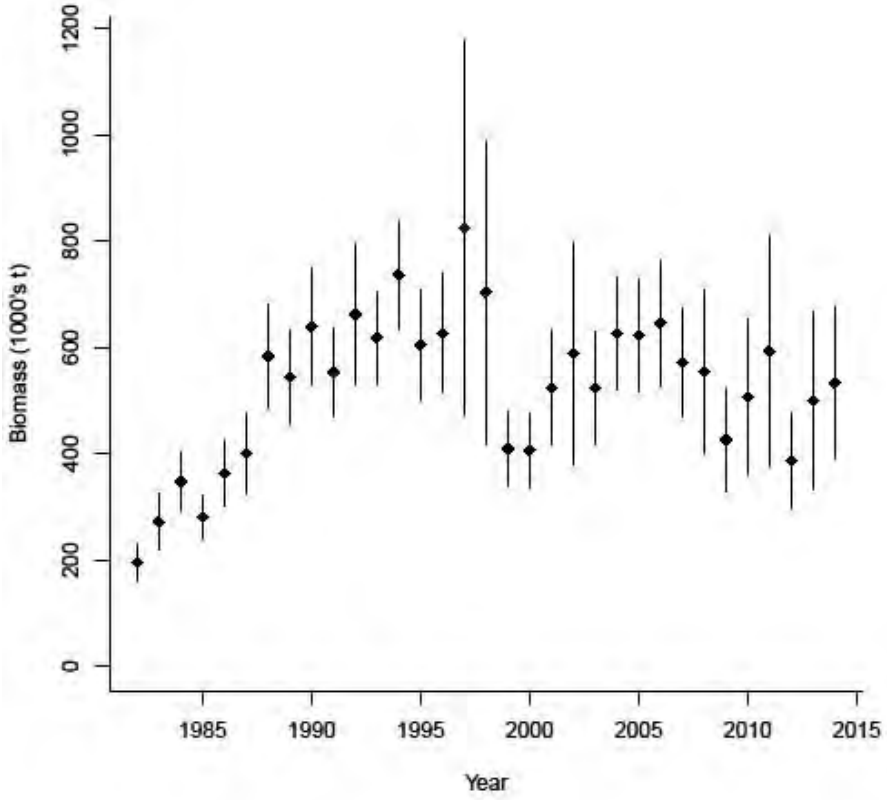


Figure 9.7. Survey biomass estimates (dots) and 95% asymptotic confidence intervals (vertical lines) used in the assessment. The biomass estimates include the Aleutian Islands and EBS shelf survey areas and represent both flathead sole and Bering flounder. A linear regression is used to estimate a relationship between EBS shelf survey biomass and Aleutian Islands survey biomass; the linear relationship is used to estimate Aleutian Islands survey biomass in years without an Aleutian Islands survey.

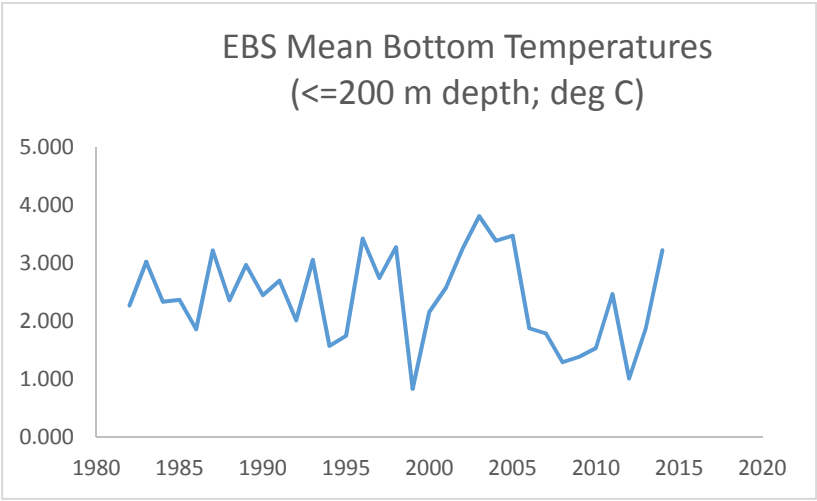


Figure 9.8. Mean bottom temperatures (deg C) from the EBS shelf survey for station depths less than or equal to 200 meters.

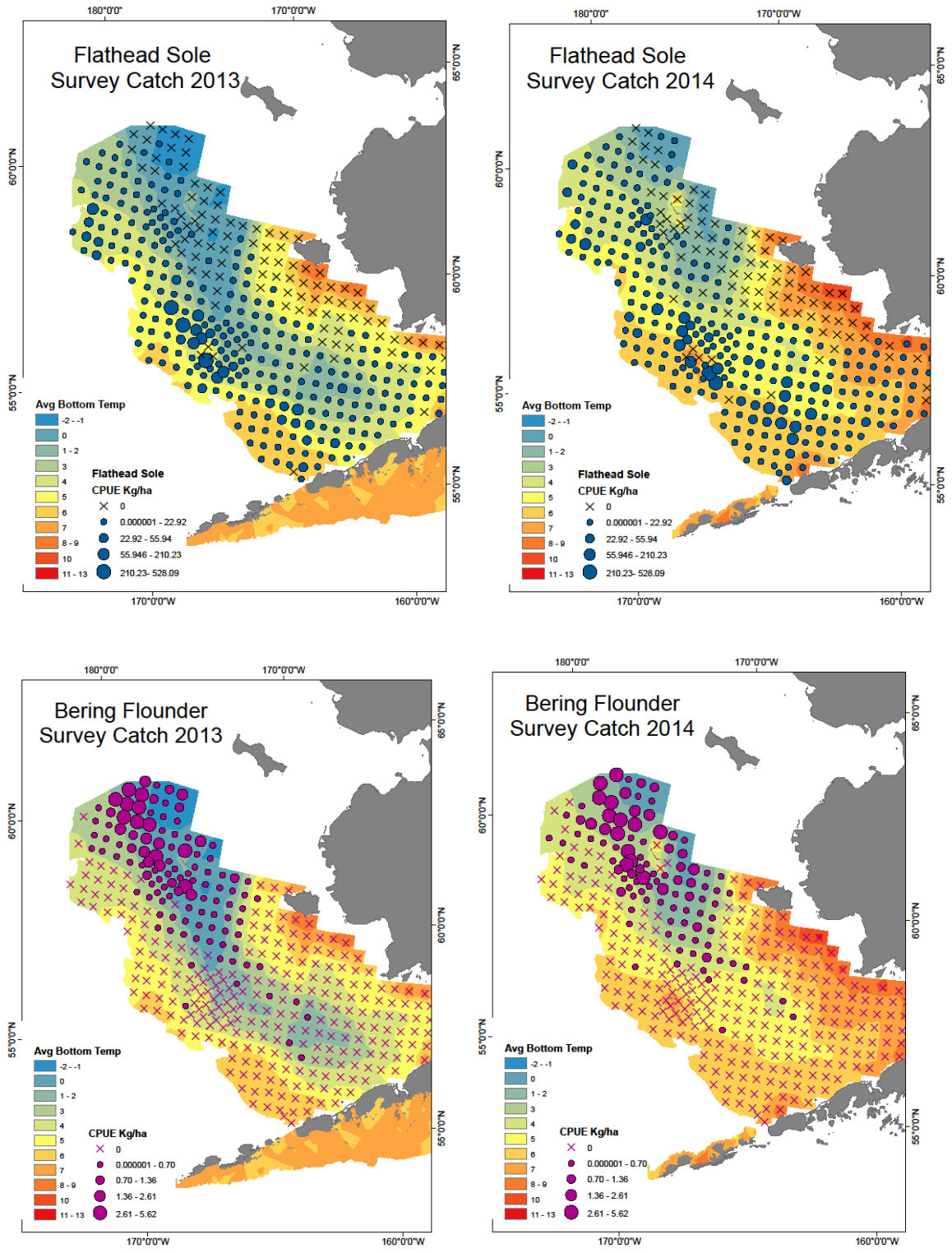
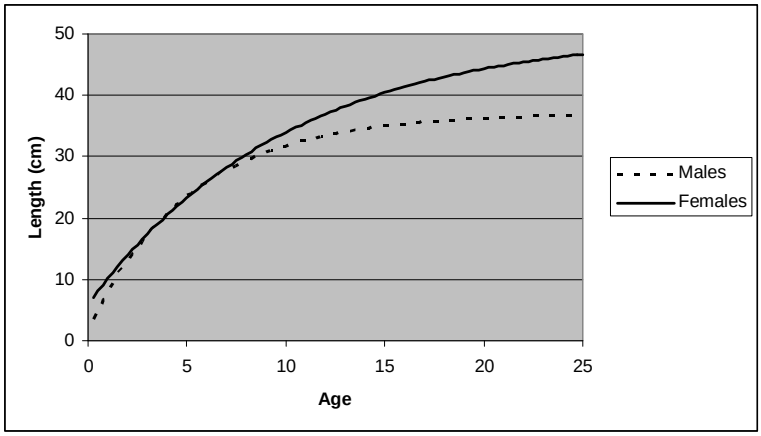


Figure 9.9. Spatial distribution flathead sole (top; blue circles) Bering flounder (bottom; purple circles) catch per unit effort (CPUE) for 2013 and 2014 from the Eastern Bering Sea shelf survey overlaid on a map of mean bottom temperatures measured by the survey.



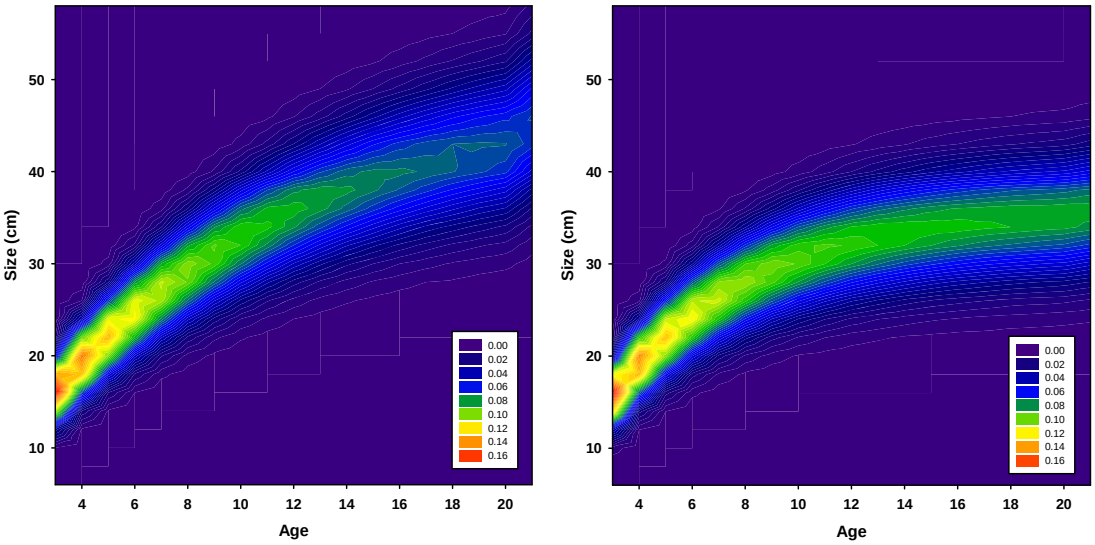


Figure 9.10. Top: sex-specific mean size-at-age used in this assessment (based on EBS groundfish survey data). Females = solid line, males = dotted line. Bottom left: age-size conversion matrix (plotted as density) for females. Bottom right: age-size conversion matrix (plotted as density) for males.

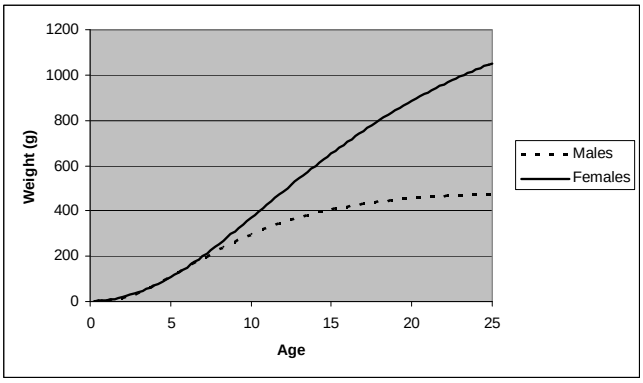


Figure 9.11. Sex-specific weight- at-age used in this assessment (based the EBS groundfish survey data). Females = solid line, males = dotted line.

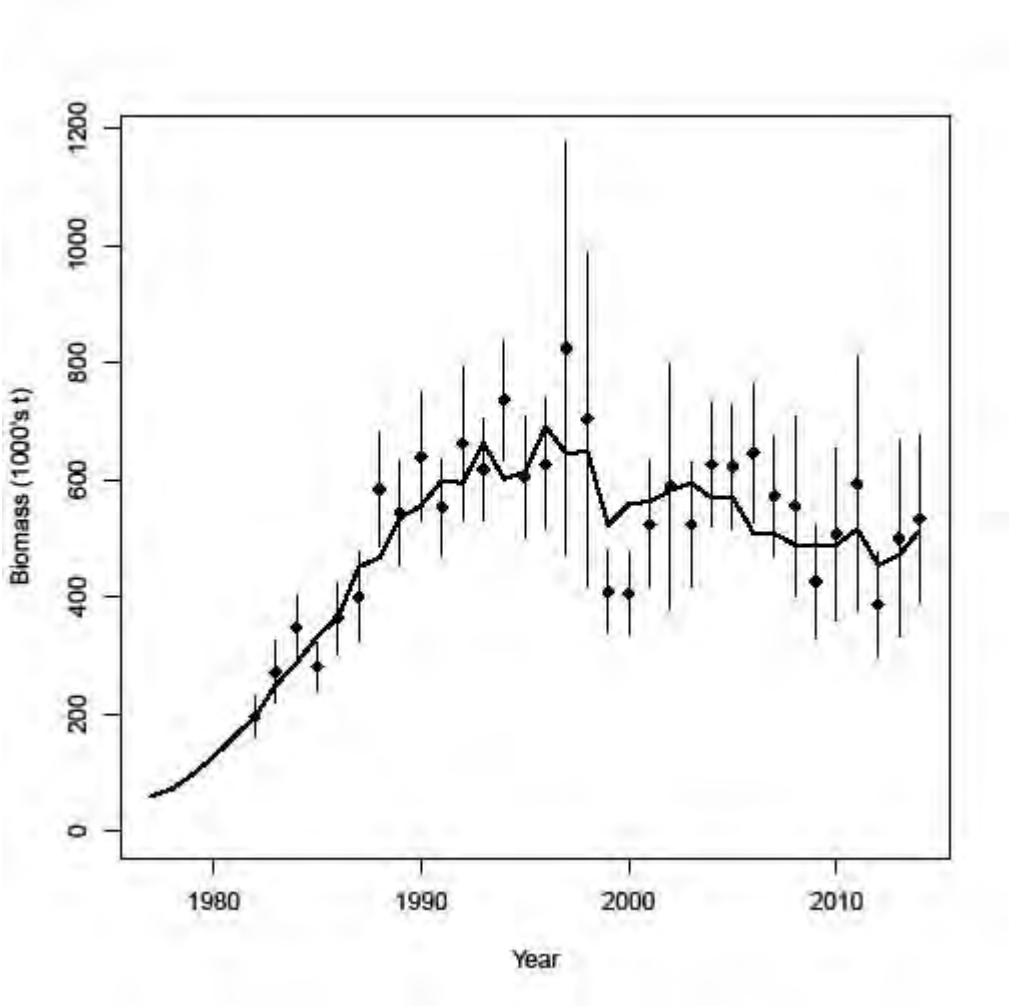


Figure 9.12. Observed (dots) and predicted (solid line) survey biomass (in tons) over time. Vertical lines represent the 95% asymptotic confidence intervals around the survey biomass data.

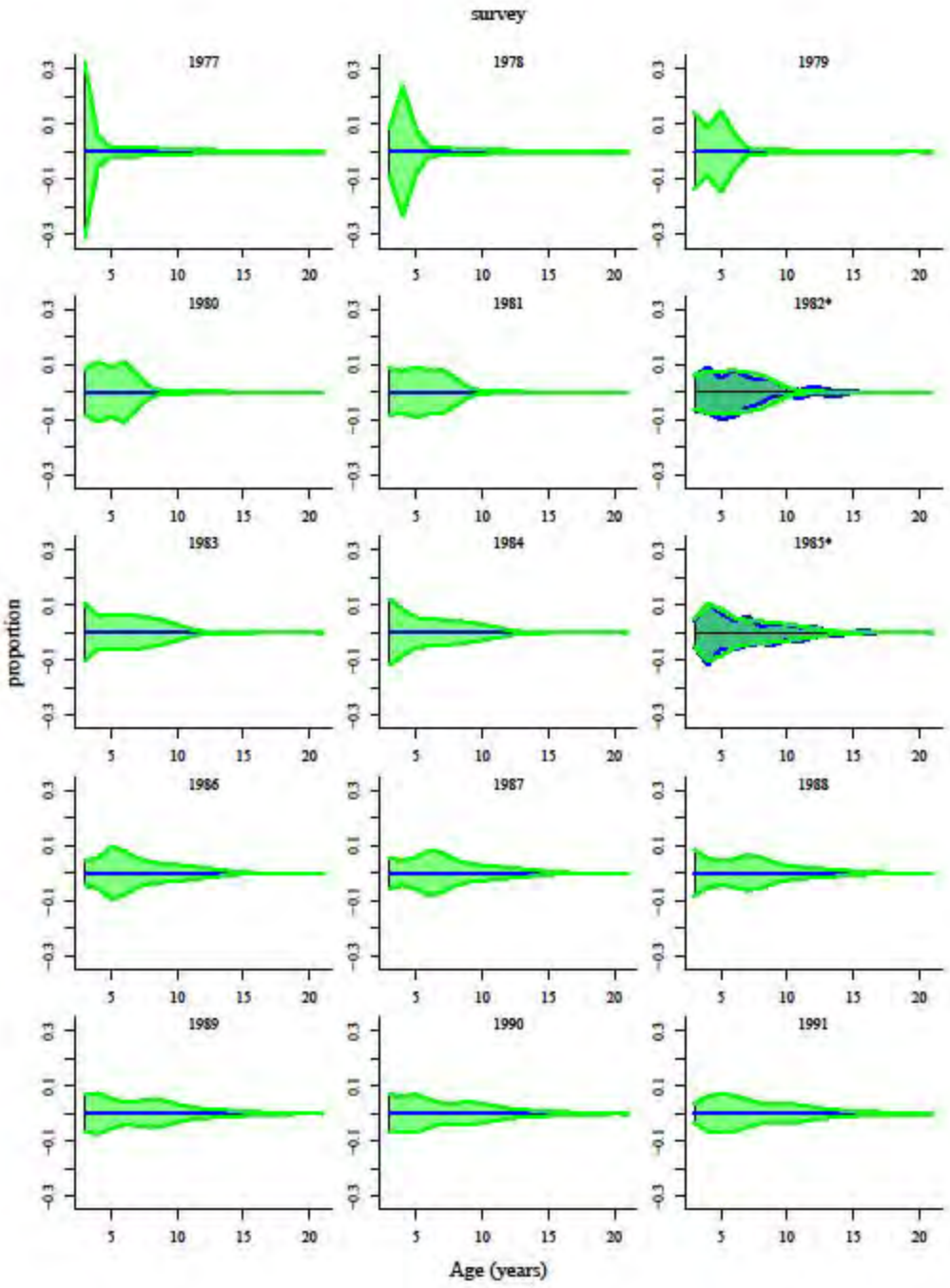


Figure 9.13. Observed (blue) and predicted (green) EBS survey age compositions for flathead sole only (part 1 of 3). Females are shown as positive values, males are shown as negative values. Years with no data are indicated by a horizontal blue line at proportion = 0. Asterisks indicate years included in the model fit.

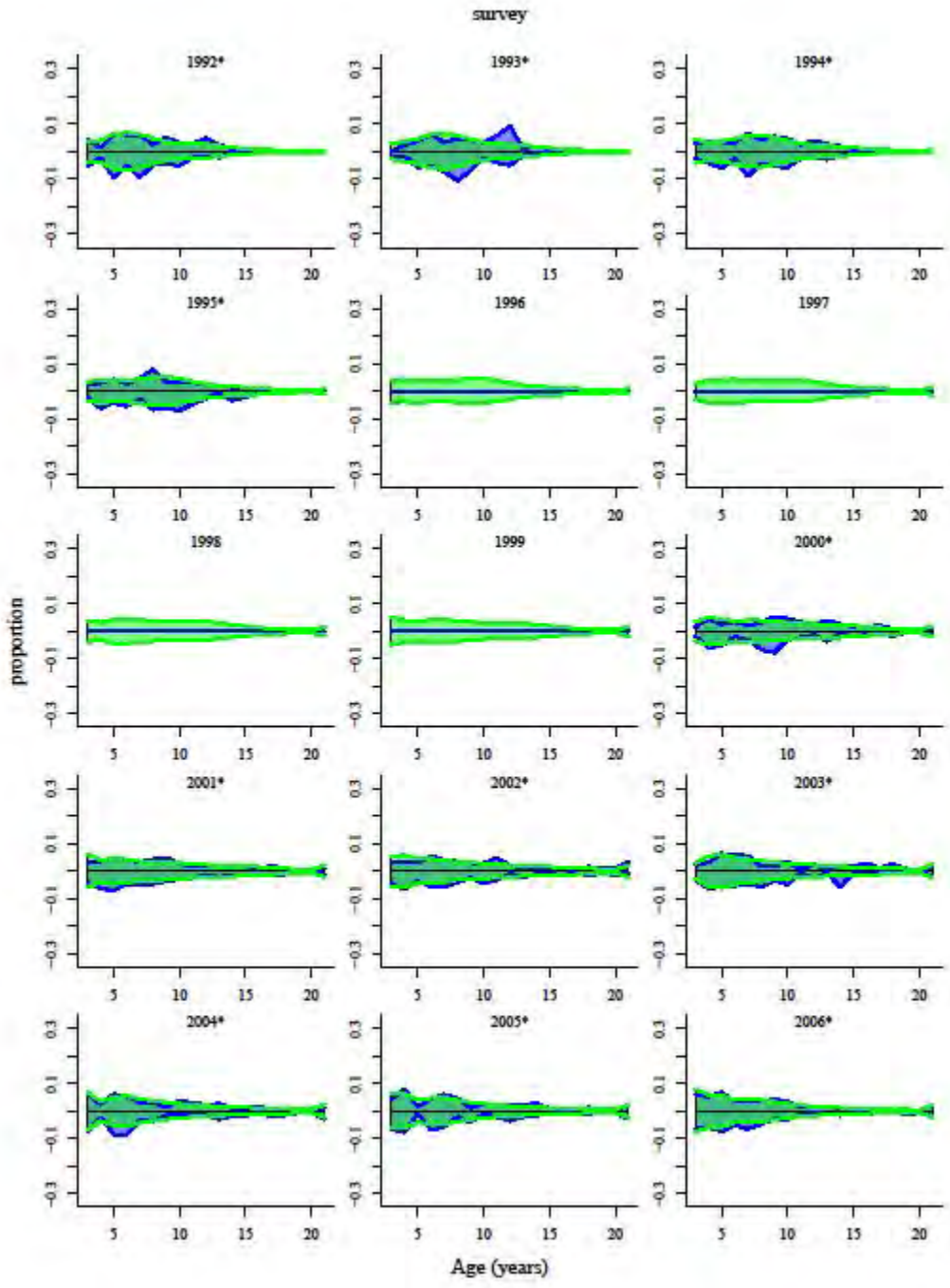


Figure 9.13, continued (part 2 of 3).

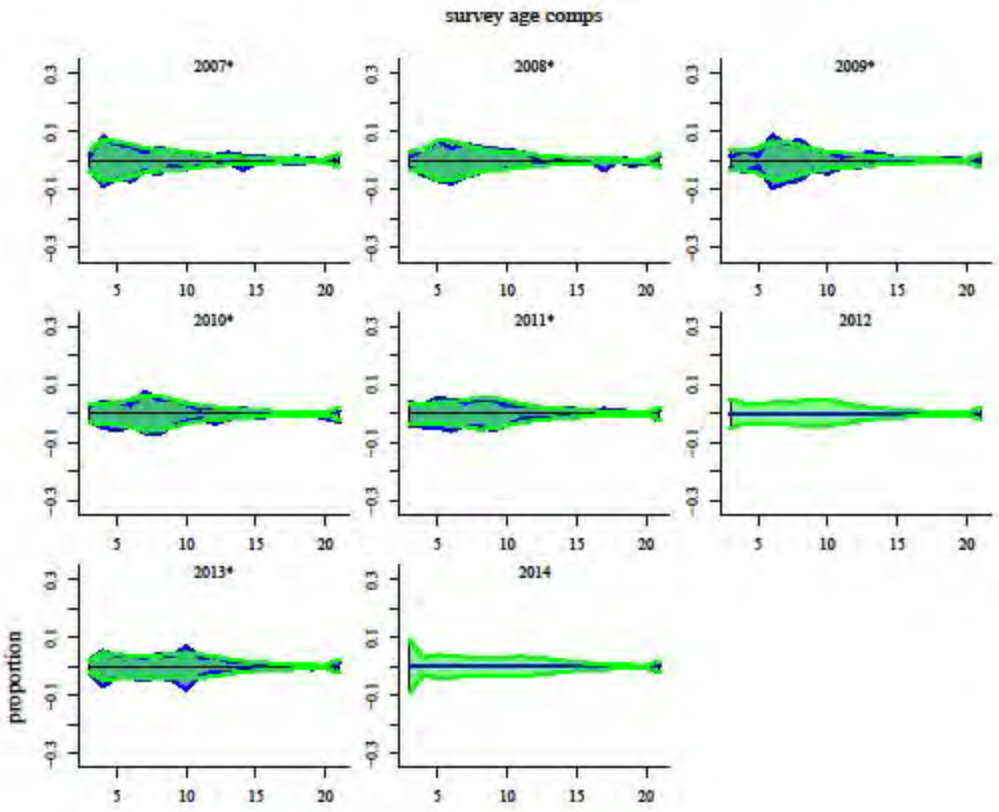


Figure 9.13, continue (part 3 of 3).

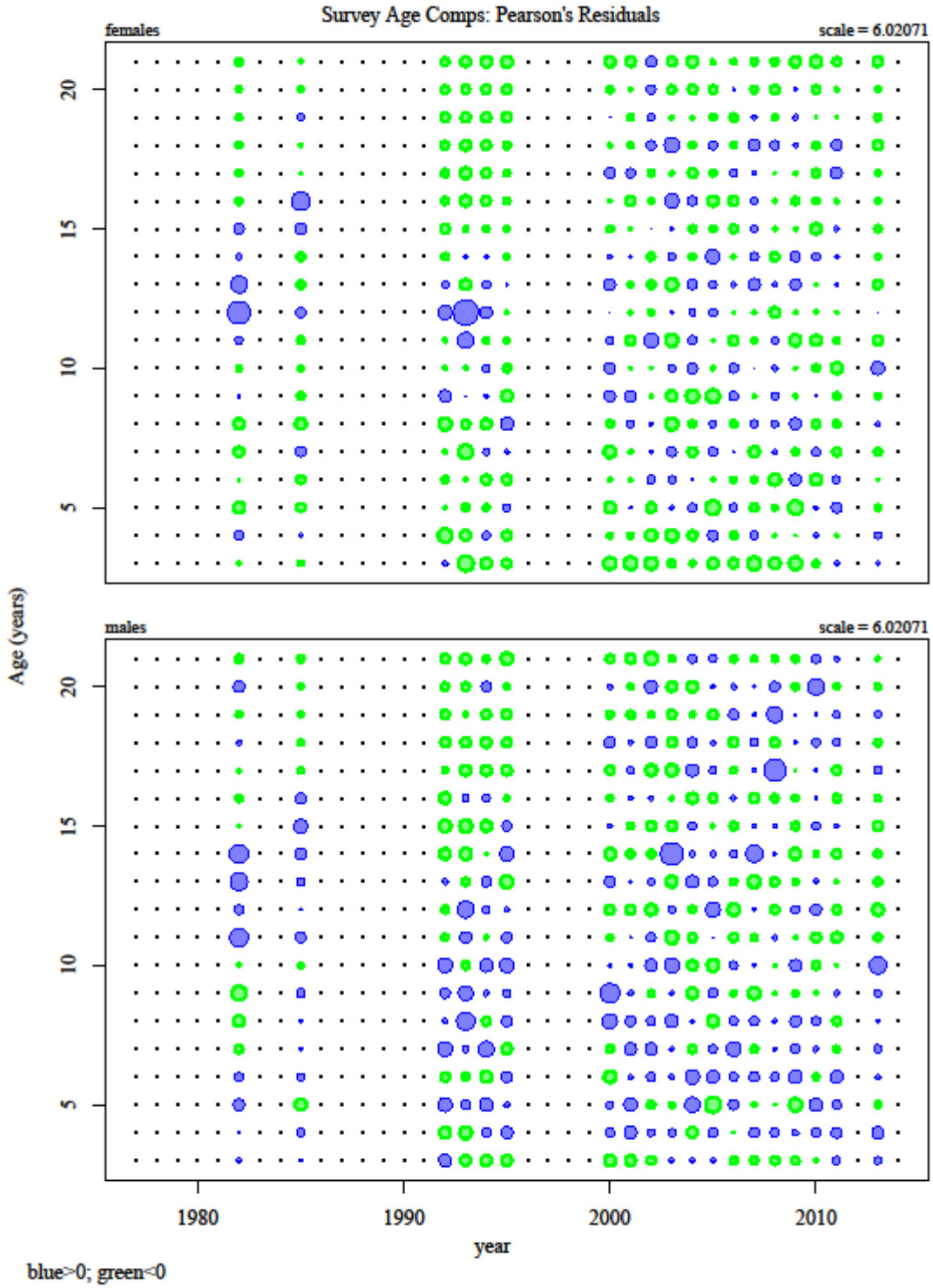


Figure 9.14. Pearson's residuals plots for the EBS flathead sole survey age compositions. Blue circles represent positive residuals, green circles represent negative residuals. Circle area scales with size of the residual.

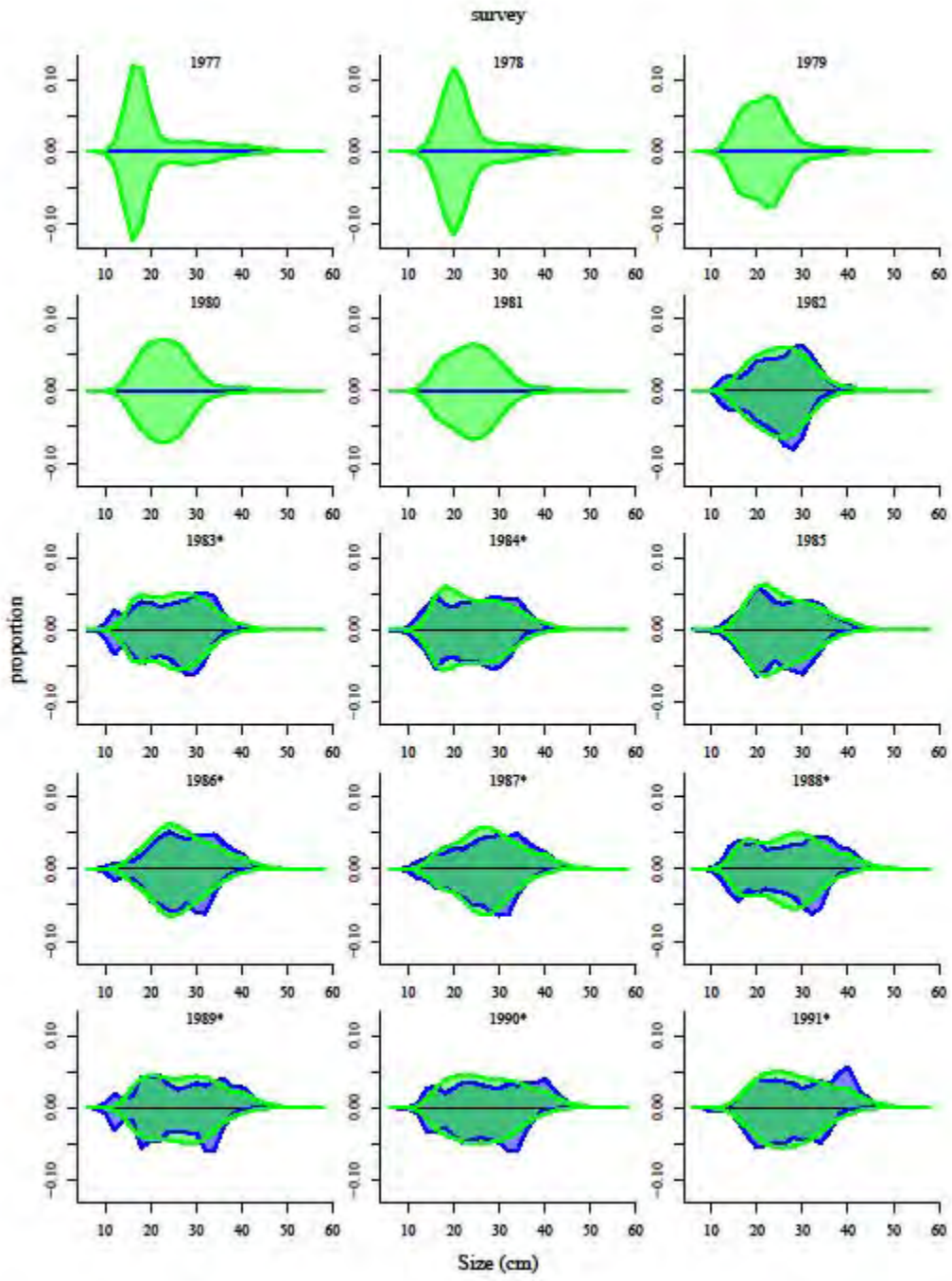


Figure 9.15. Observed (blue) and predicted (green) EBS survey length compositions for flathead sole only (part 1 of 3). Females are shown as positive values, males are shown as negative values. Years with no data are indicated by a horizontal blue line at proportion = 0. Asterisks indicate years included in the model fit.

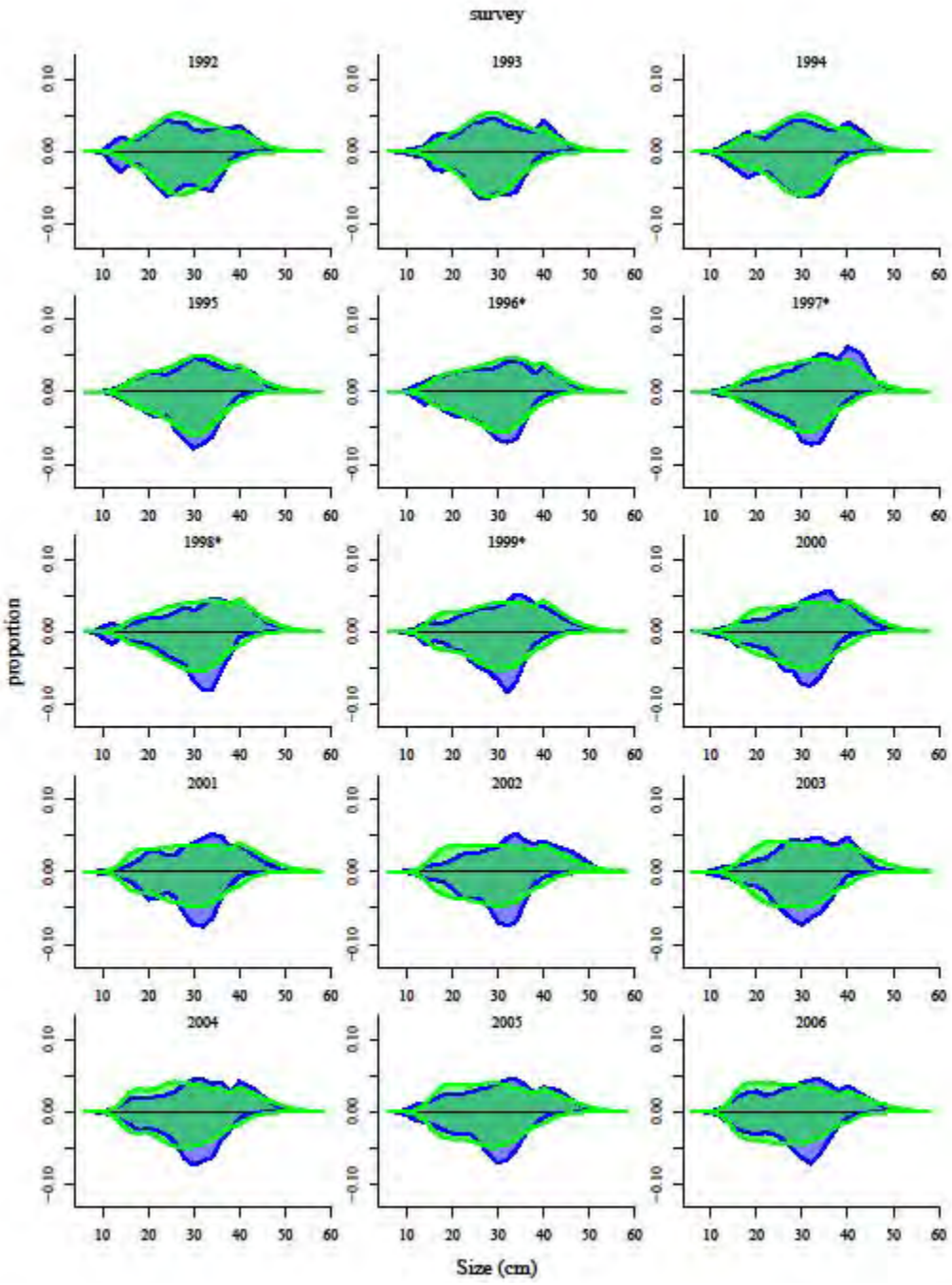
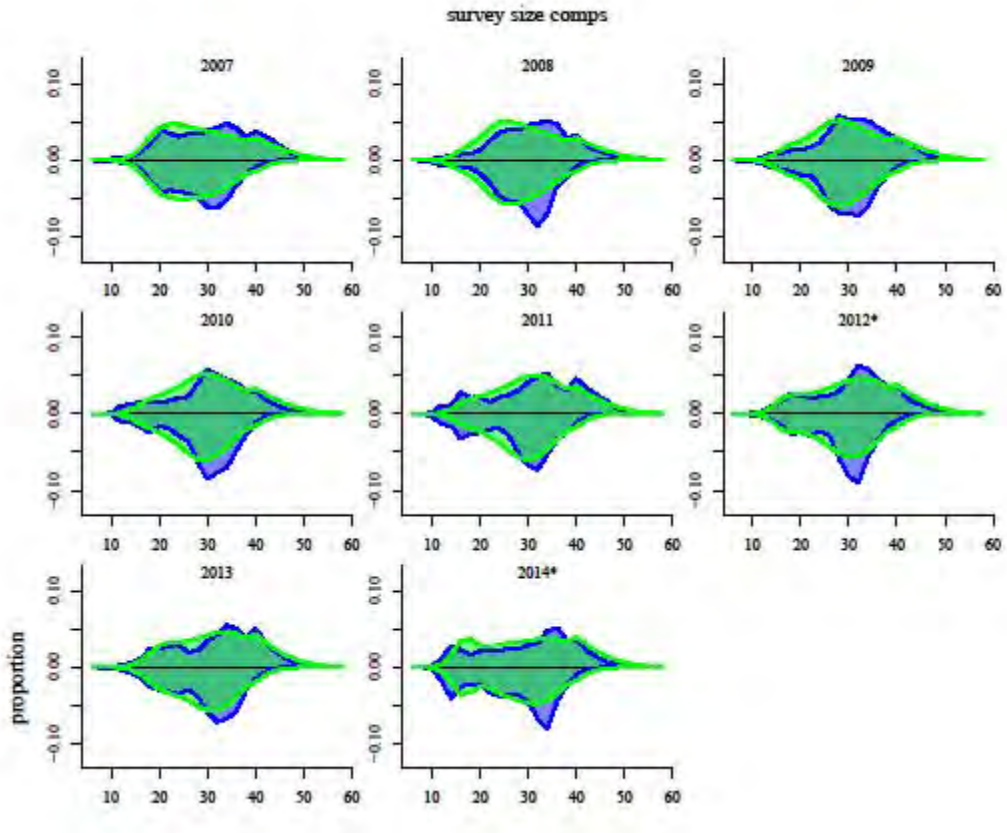


Figure 9.15, continued (part 2 of 3).



Size (cm)

Figure 9.15, continued (part 3 of 3).

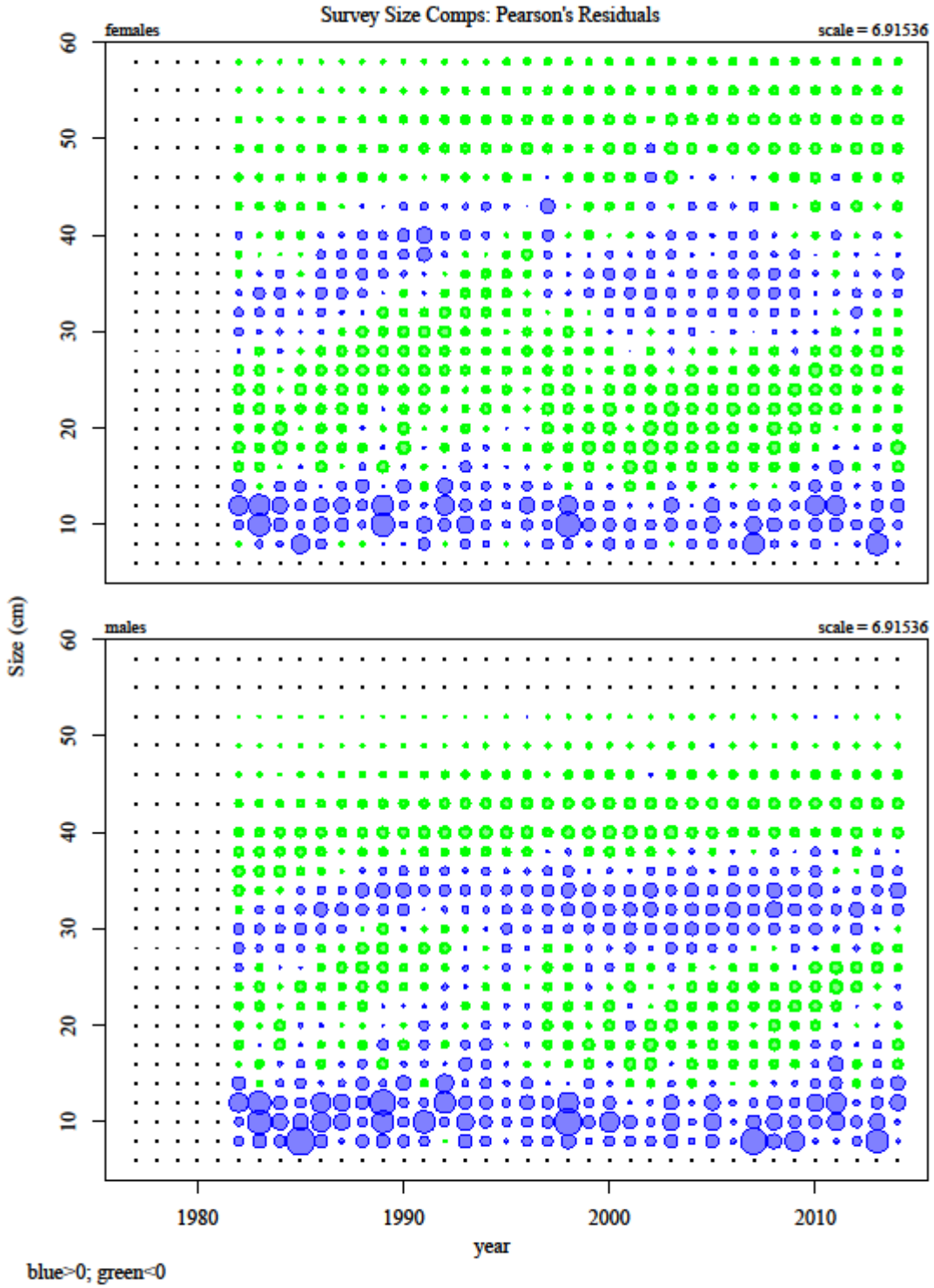


Figure 9.16. Pearson's residuals plots for the EBS flathead sole survey length compositions. Blue circles represent positive residuals, green circles represent negative residuals. Circle area scales with size of the residual.

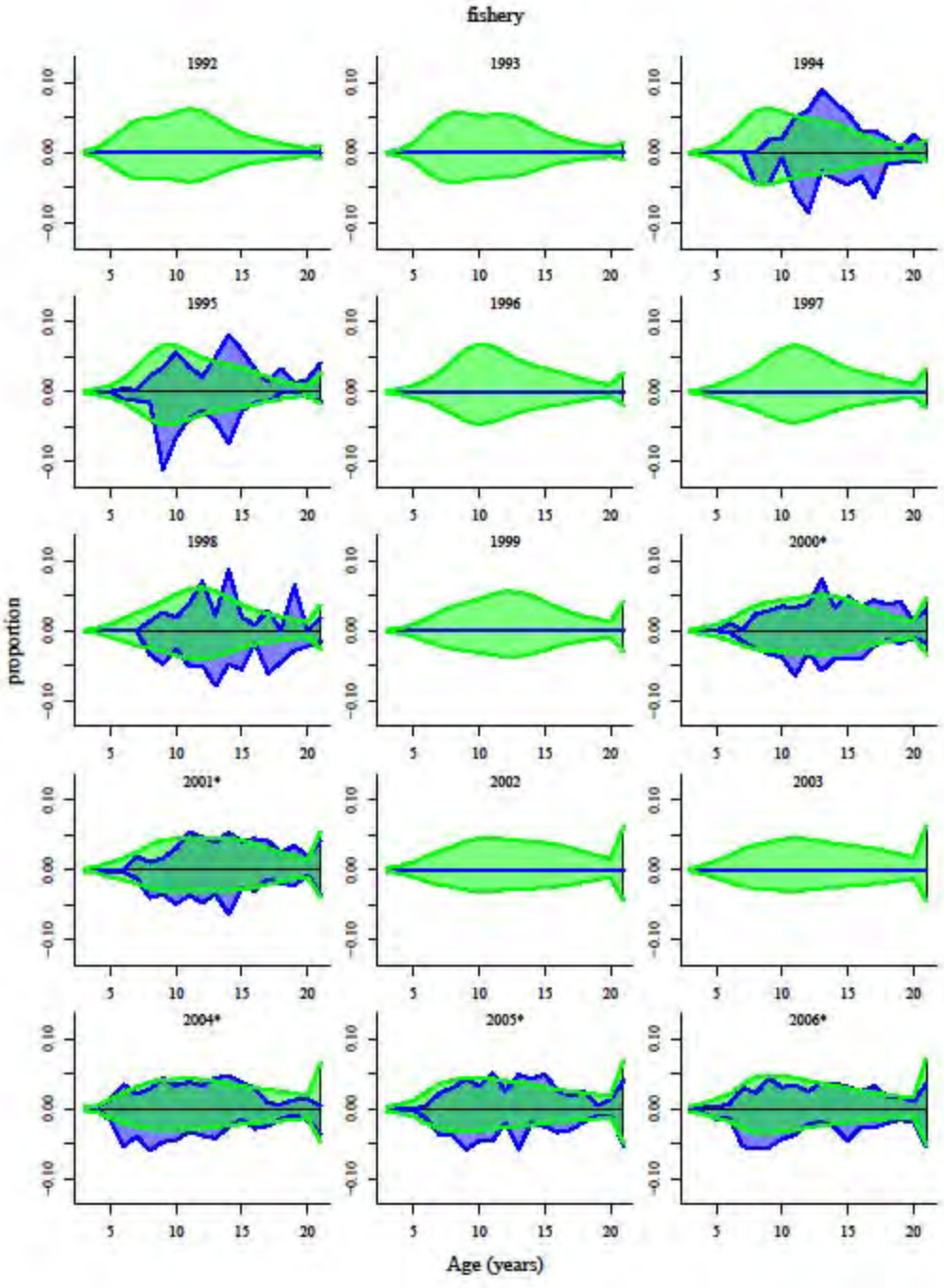


Figure 9.17. Observed (blue) and predicted (green) Bering Sea fishery age compositions for flathead sole only (part 1 of 2). Females are shown as positive values, males are shown as negative values. Years with no data are indicated by a horizontal blue line at proportion = 0. Asterisks indicate years included in the model fit.

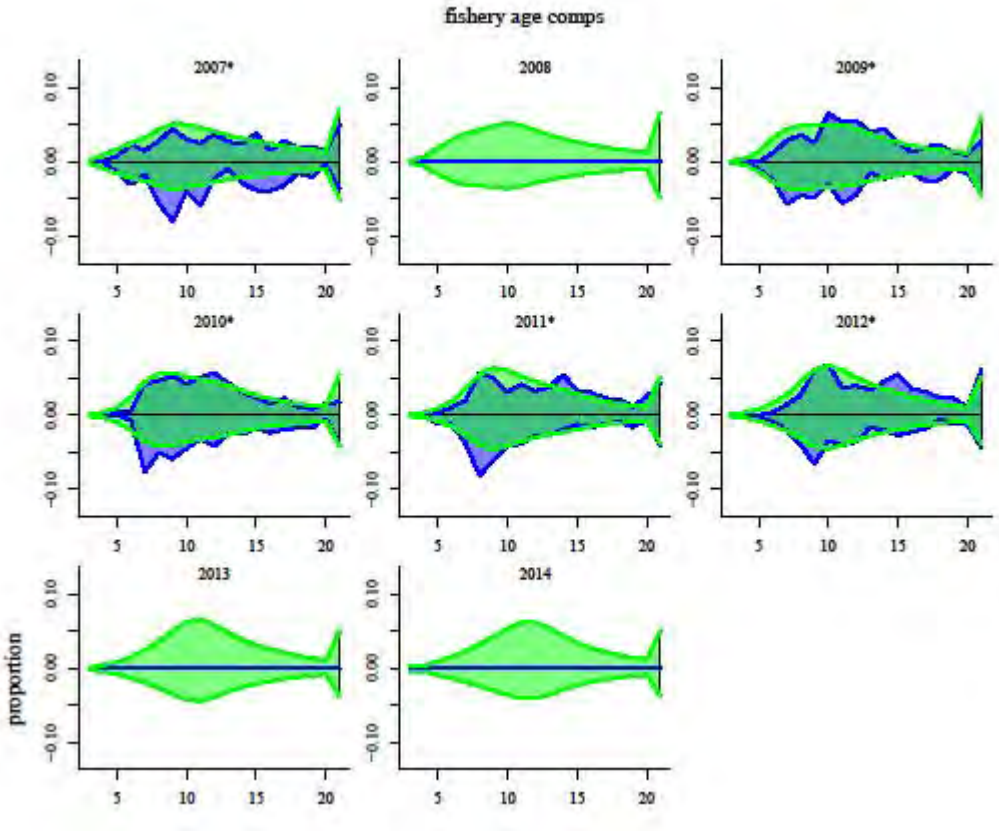


Figure 9.17, continued (part 2 of 2).

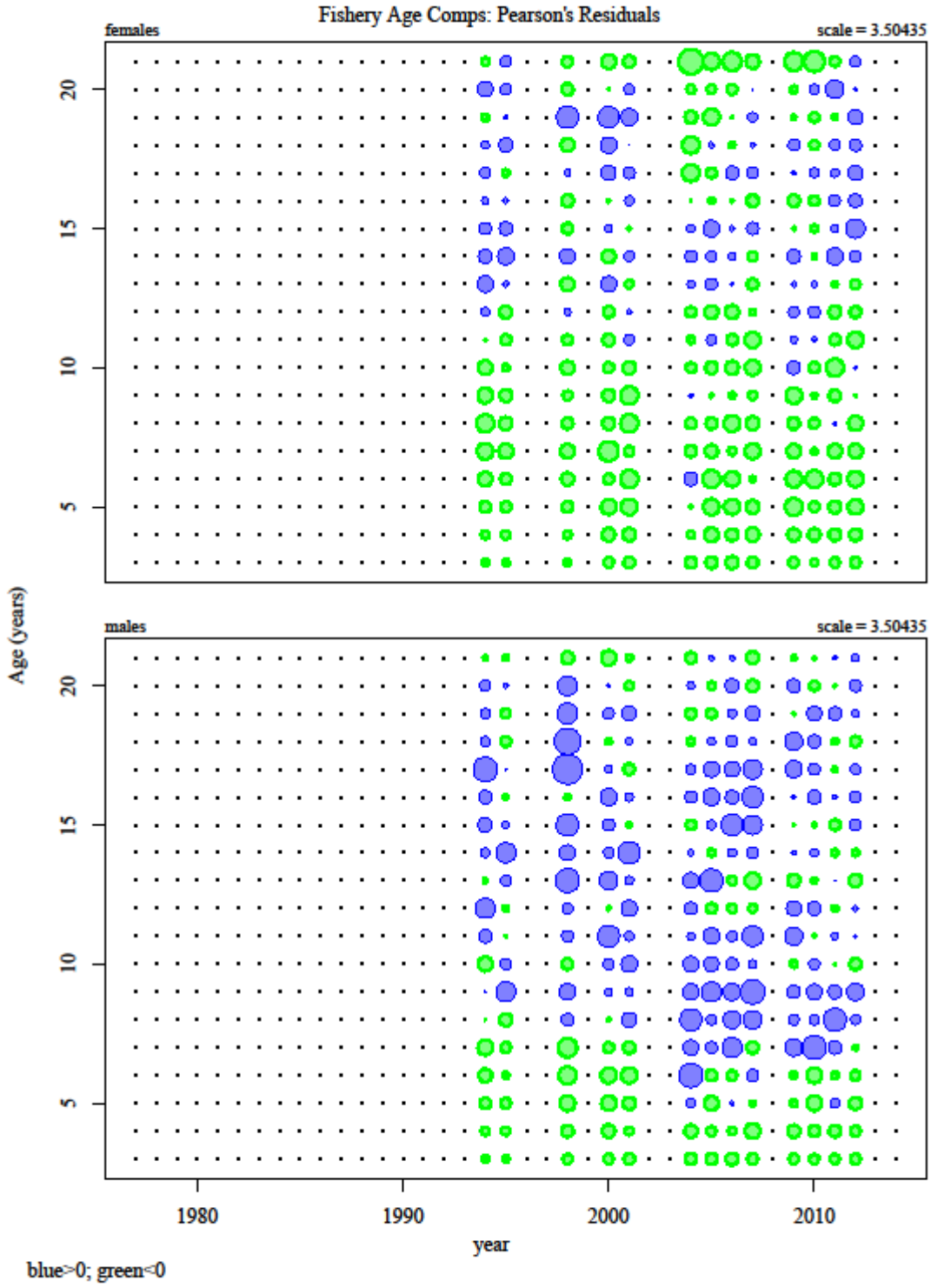


Figure 9.18. Pearson's residuals plots for Bering Sea flathead sole non-pelagic trawl fishery age compositions. Blue circles represent positive residuals, green circles represent negative residuals. Circle area scales with size of the residual.

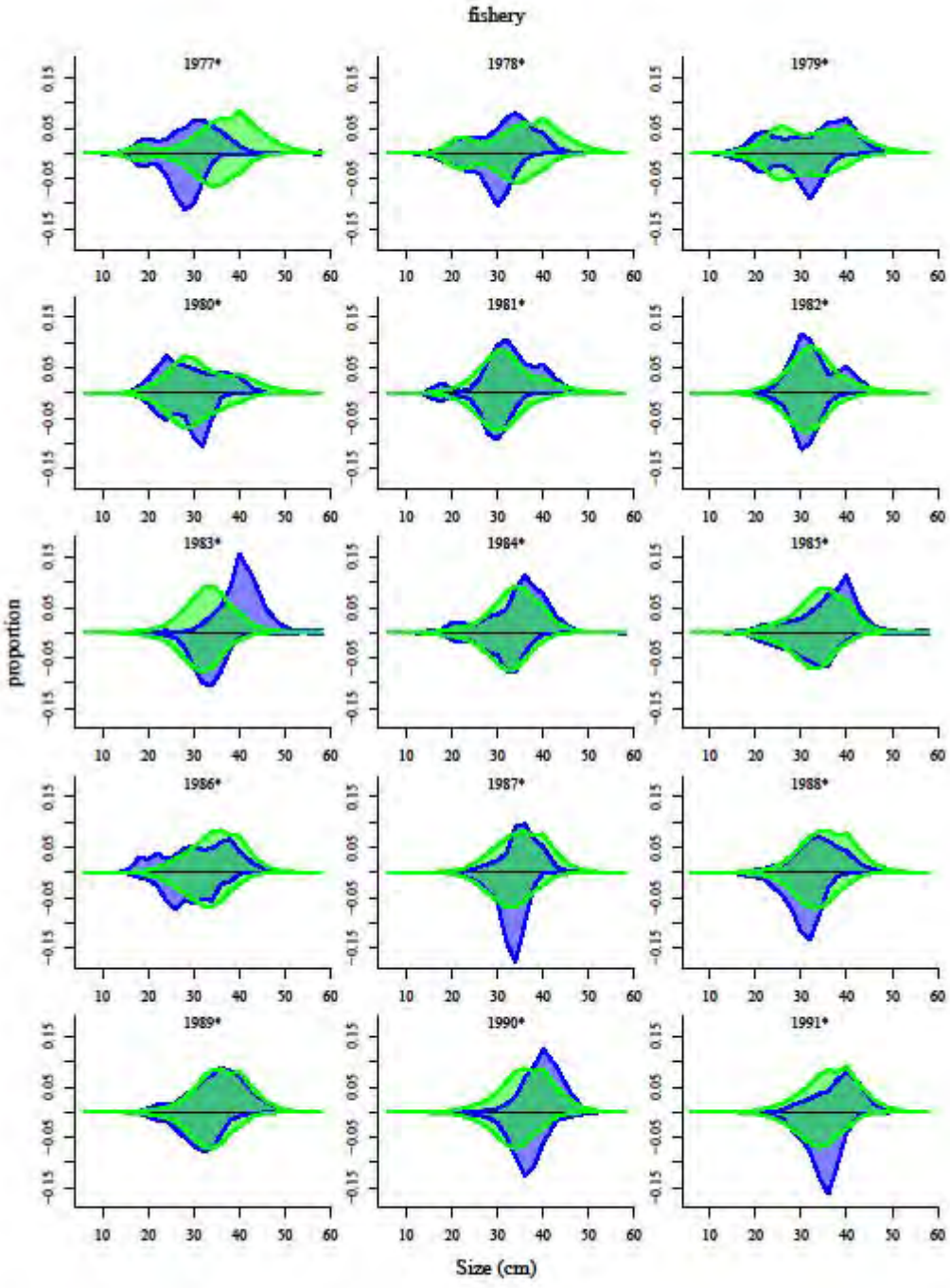


Figure 9.19. Observed (blue) and predicted (green) Bering Sea fishery length compositions for flathead sole only (part 1 of 3). Females are shown as positive values, males are shown as negative values. Years with no data are indicated by a horizontal blue line at proportion = 0. Asterisks indicate years included in the model fit.

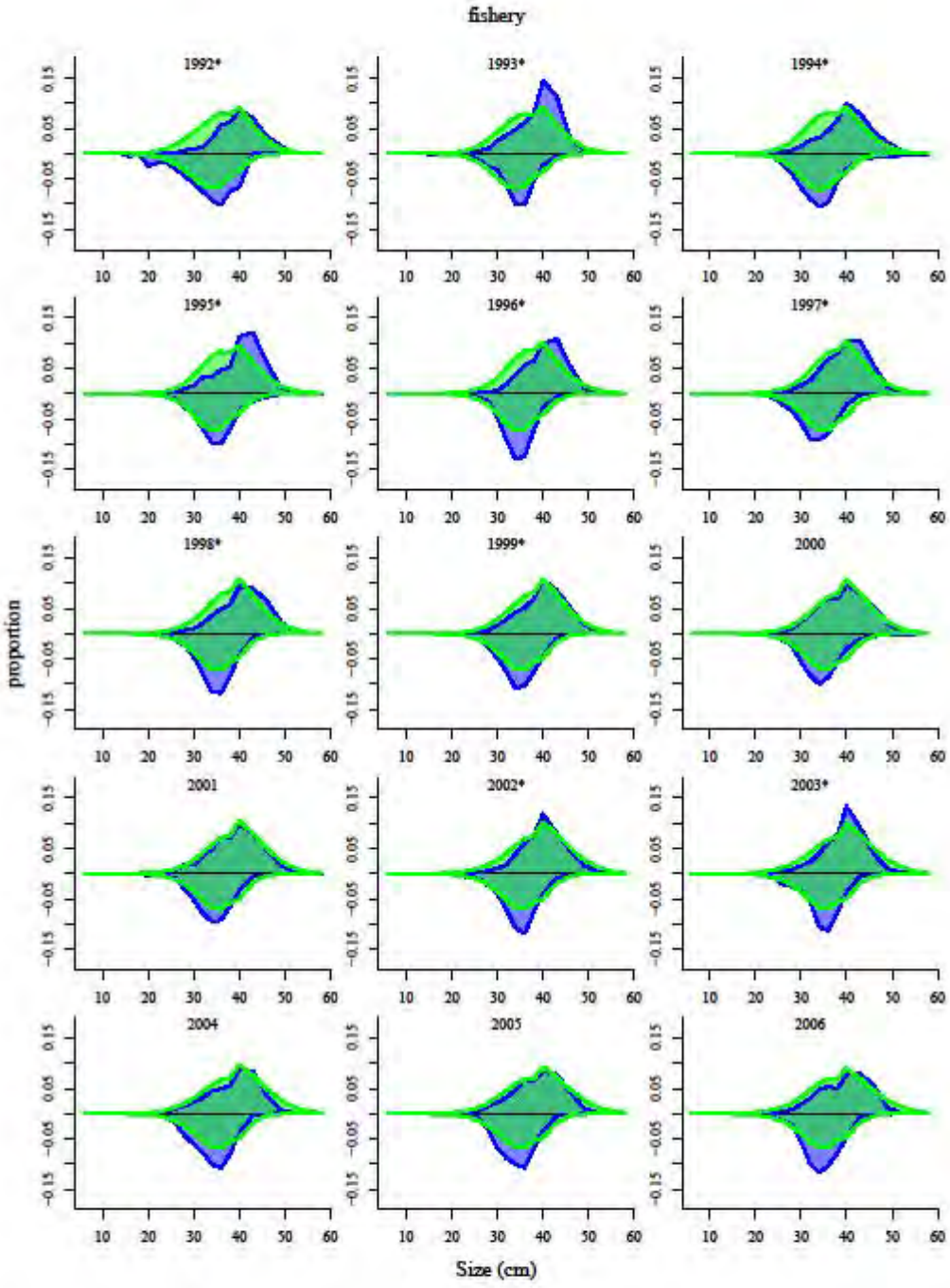


Figure 9.19, continue (part 2 of 3).

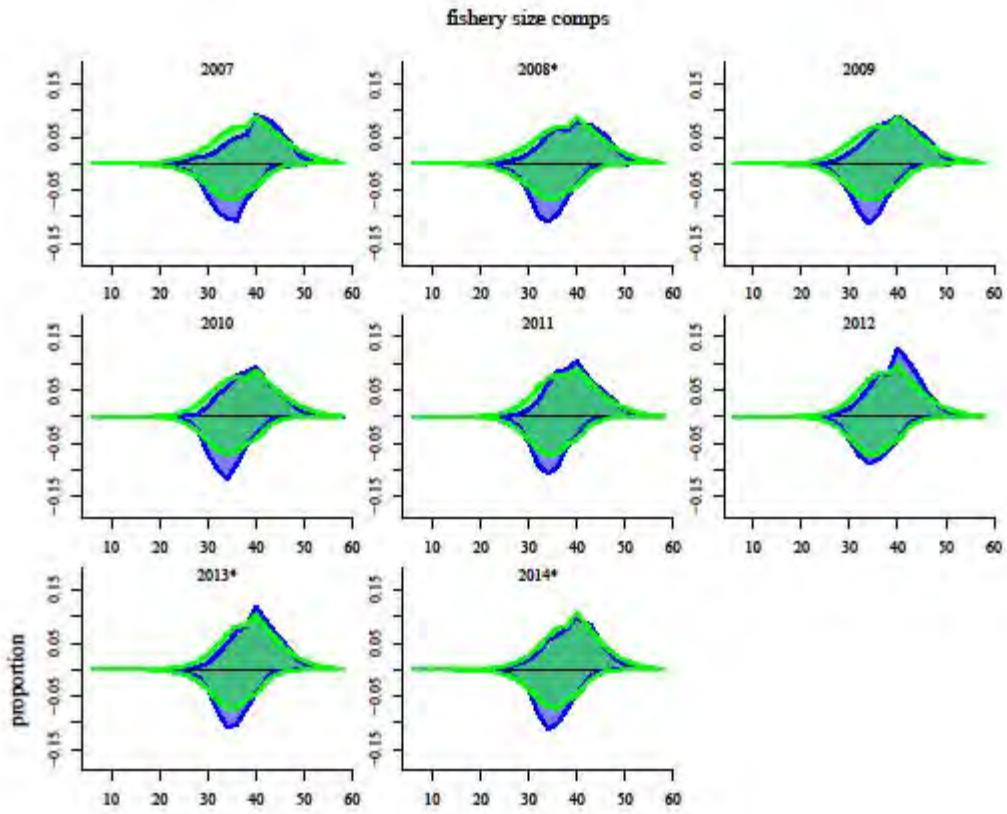


Figure 9.19, continued (part 3 of 3).

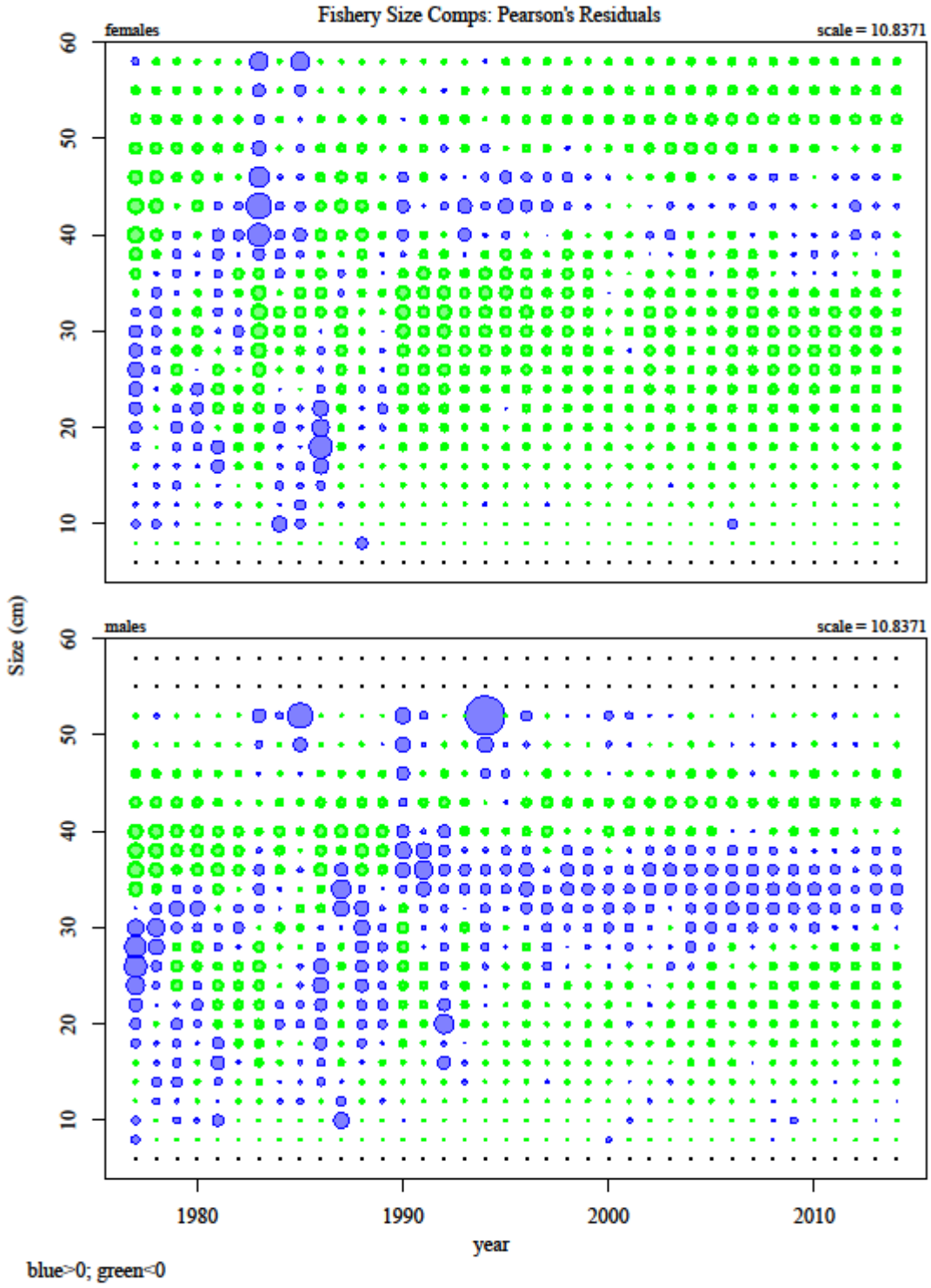


Figure 9.20. Pearson's residuals plots for the Bering Sea flathead sole non-pelagic trawl fishery length compositions. Blue circles represent positive residuals, green circles represent negative residuals. Circle area scales with size of the residual.

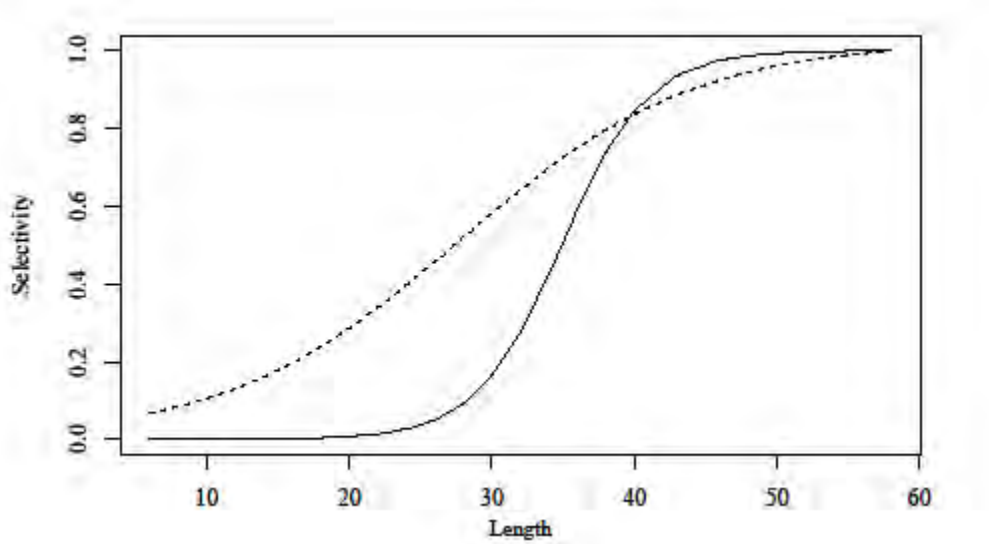


Figure 9.21. Length-based survey (dotted line) and fishery (solid line) selectivity estimated by the assessment model.

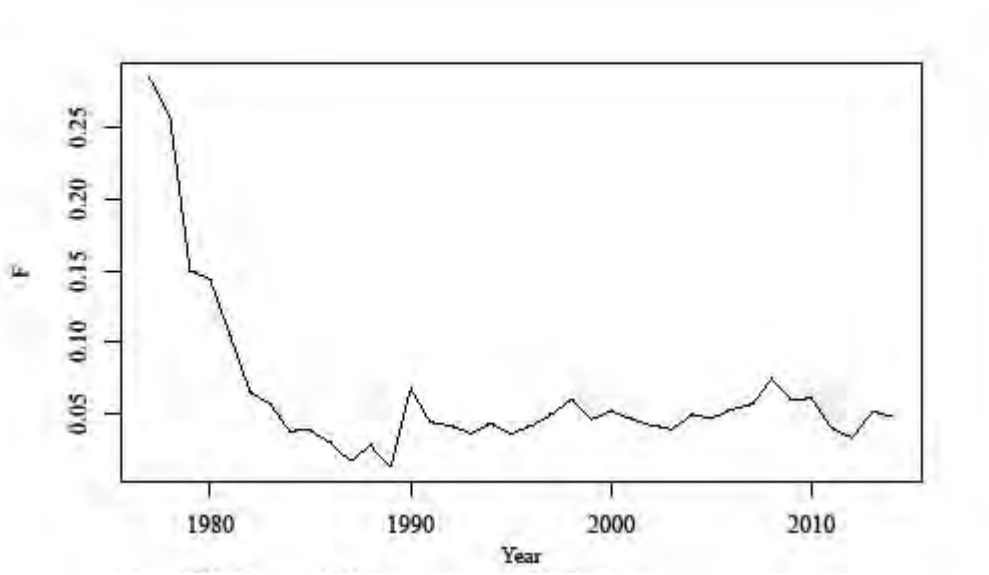


Figure 9.22. Estimates of fishing mortality over time.

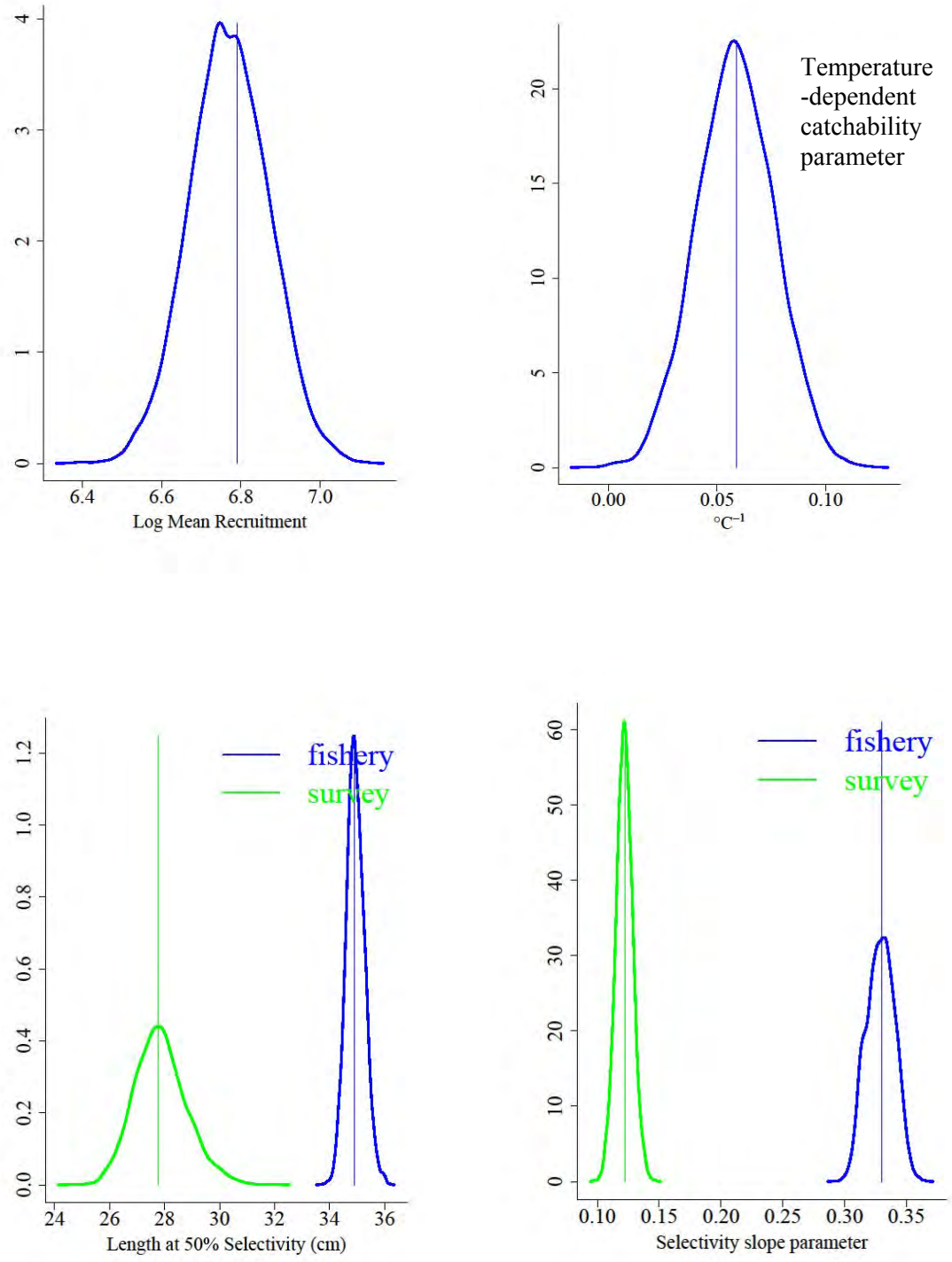


Figure 9.23. Posterior distributions for parameter estimates and derived quantities based on MCMC (part 1 of 2).

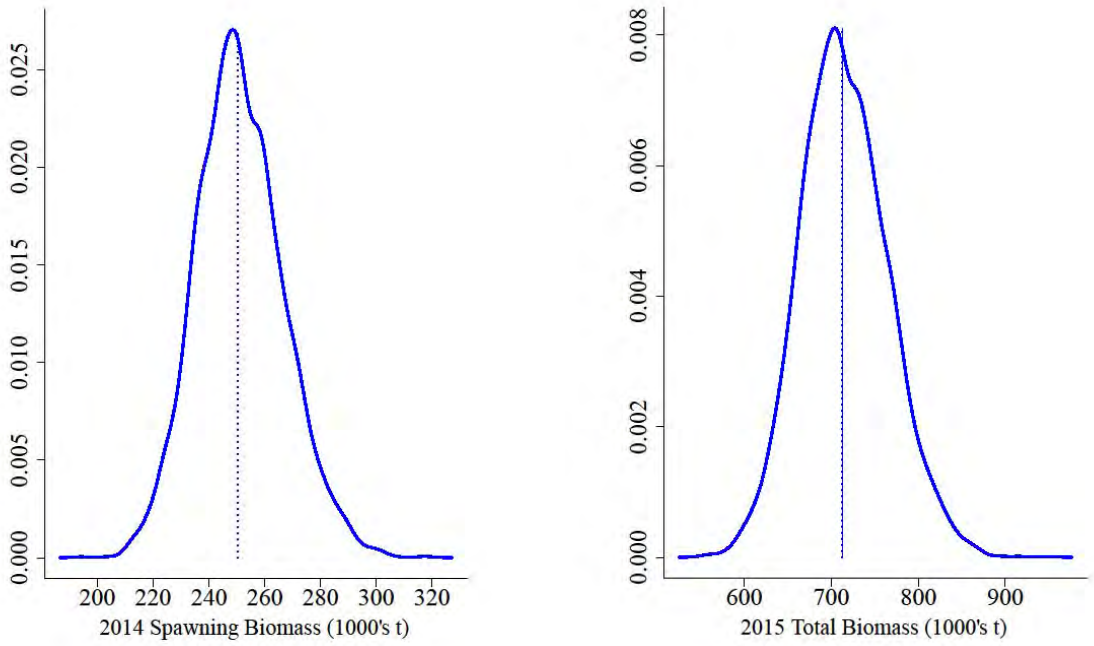


Figure 9.23, continued (part 2 of 2).

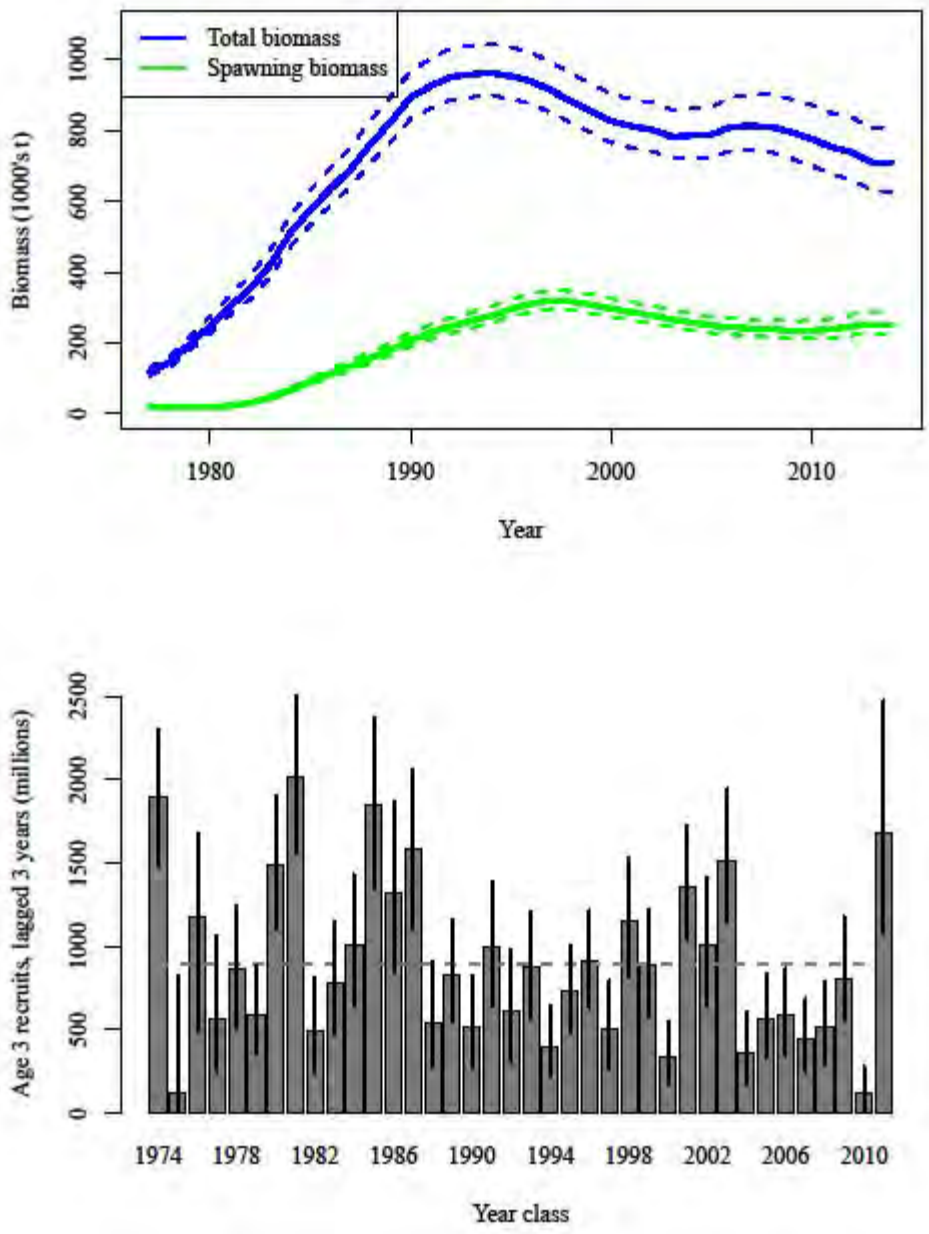


Figure 9.24. (Top) Mean total and spawning biomass (solid lines) and 95% intervals from MCMC integration. (Bottom) Estimated age 3 recruitment, lagged 3 years such that the year shown is the year at which the recruits were age 0 (gray bars) with 95% intervals obtained from MCMC integration (black vertical lines).

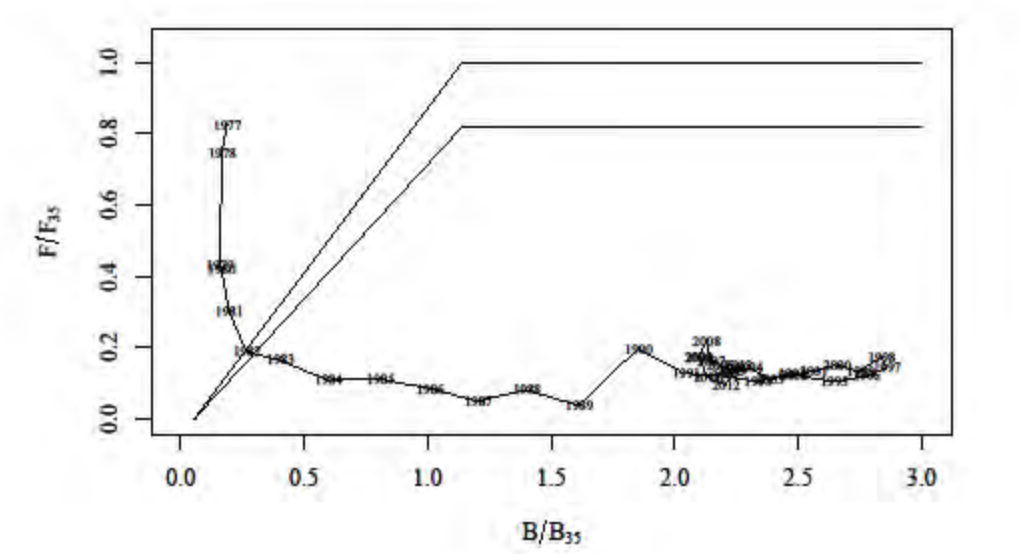


Figure 9.25. Control-rule graph: the ratio of estimated fully-selected fishing mortality (F) to $F_{35\%}$ plotted against the ratio of model spawning stock biomass (B) to $B_{35\%}$. Tier 3 control rules for ABC (lower line) and OFL (upper line) are also shown. Numbers indicate corresponding year.

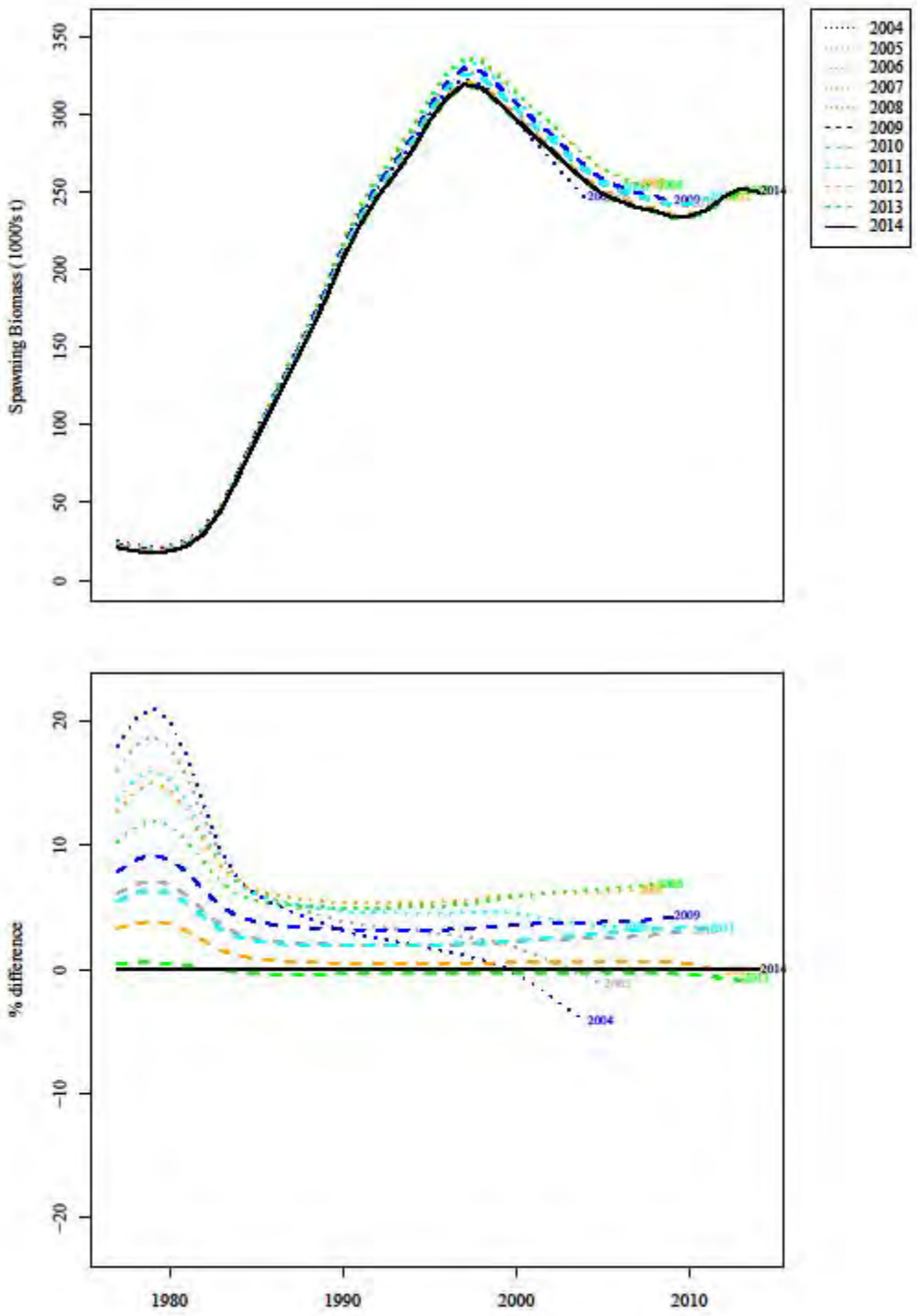


Figure 9.26. Estimated time series of spawning biomass for retrospective analyses for years 200004-2013 conducted using the 2014 assessment model structure (top) and differences in estimates of spawning biomass over time between estimates from each retrospective model and those from the 2014 model (bottom).

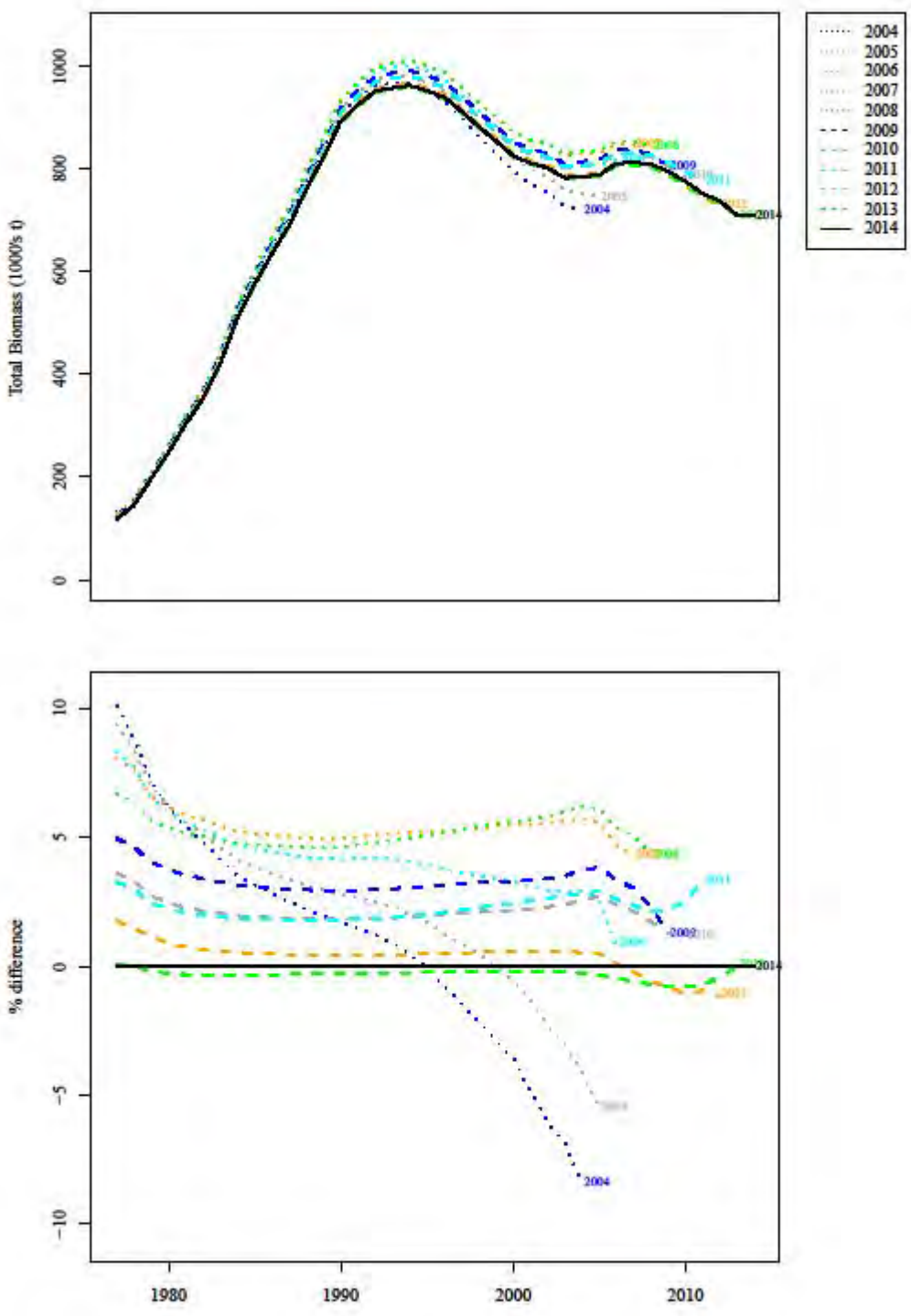


Figure 9.27. As for Figure 9.26, but for total biomass.

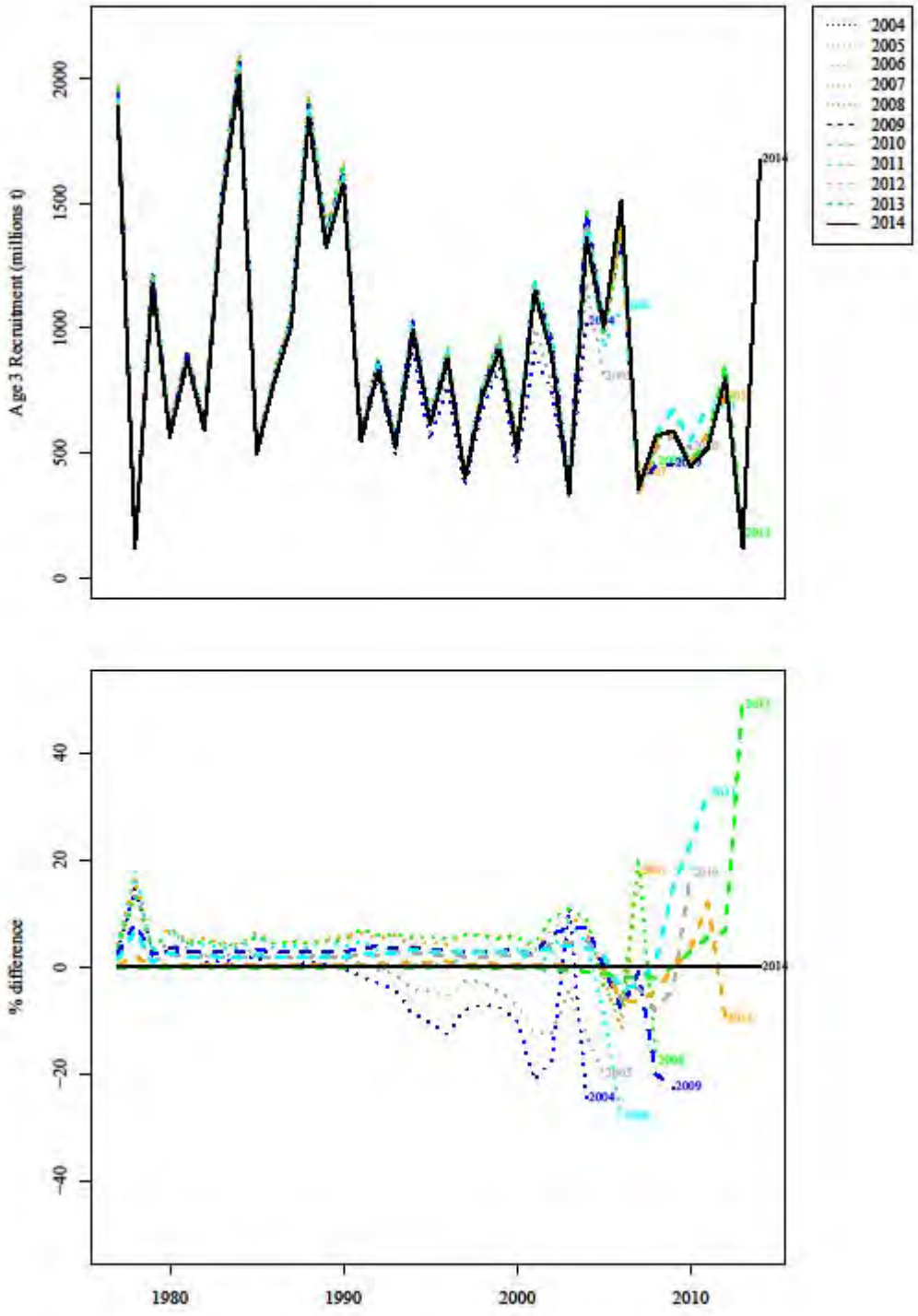


Figure 9.28. As for Figure 9.27, but for age 3 recruitment estimates.

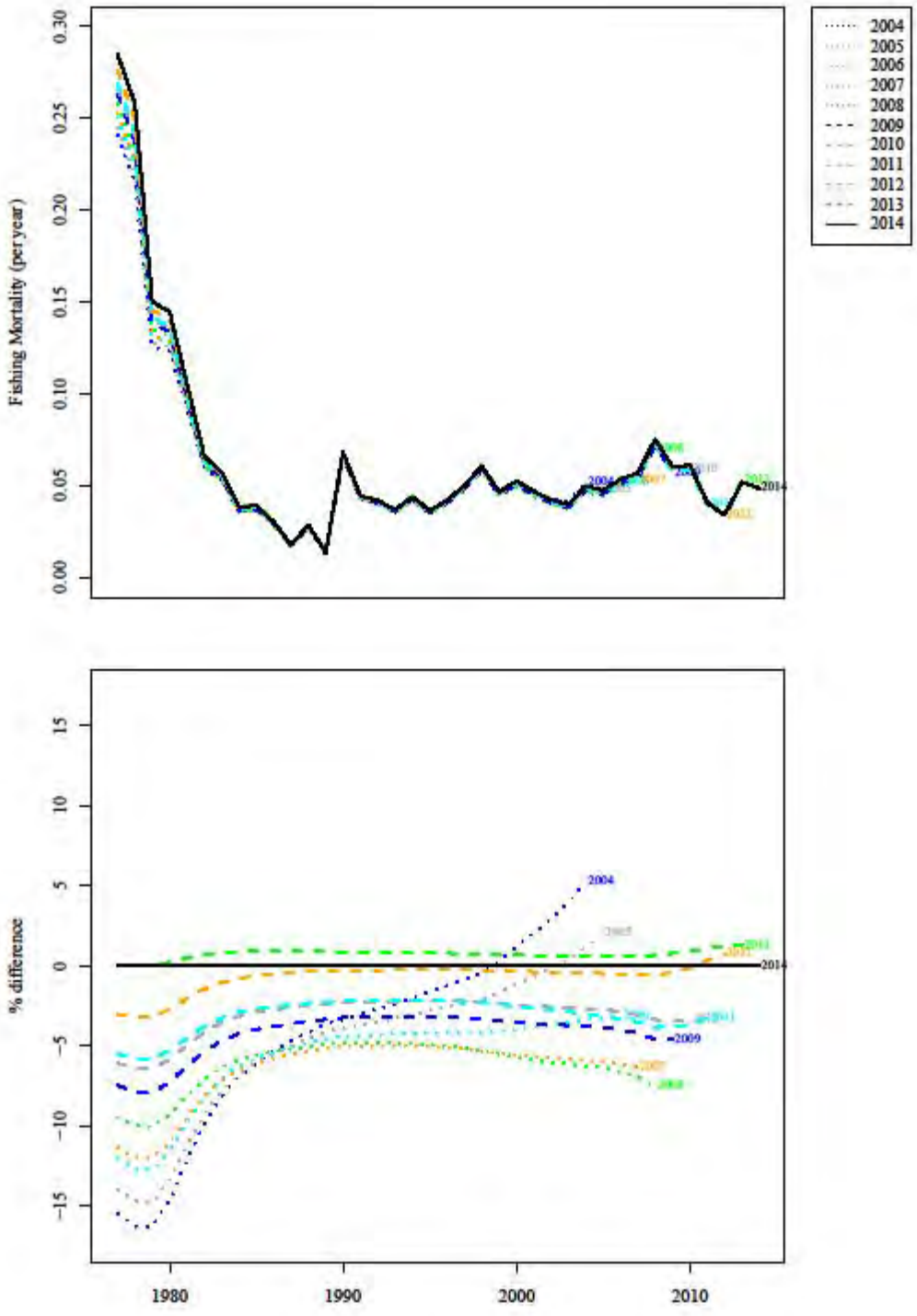


Figure 9.29. As for Figure 9.26, but for fishing mortality estimates.

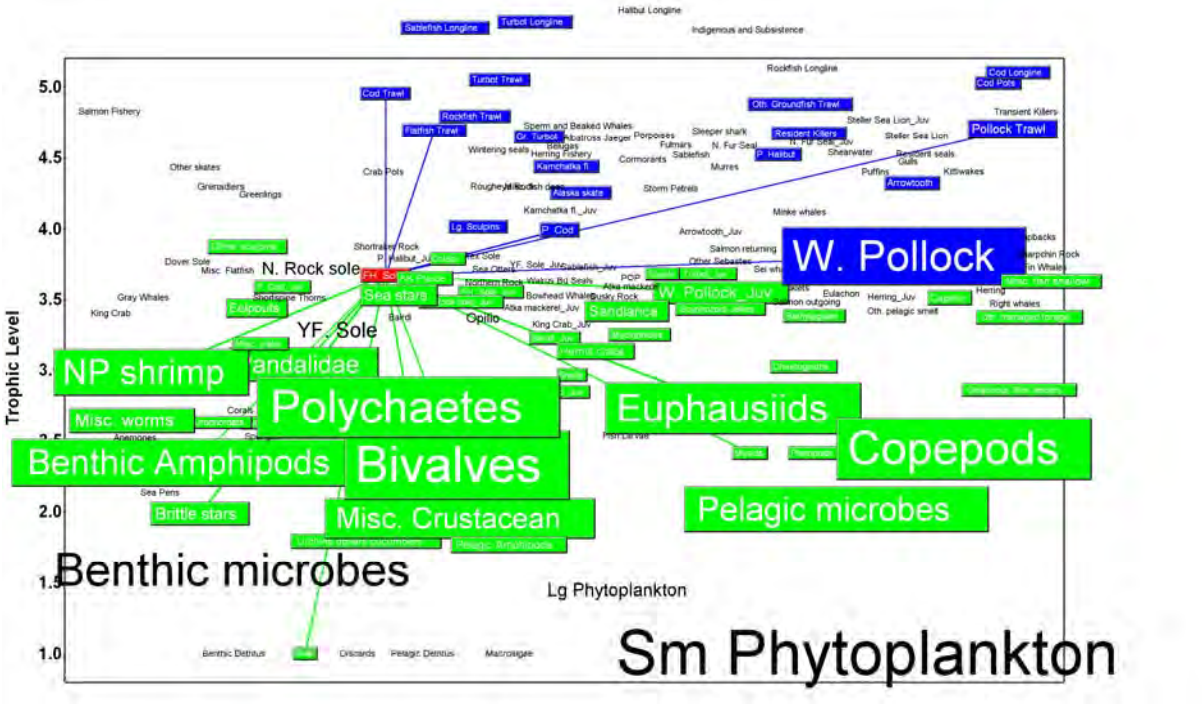


Figure 9.30. Ecosystem links to adult flathead sole in the eastern Bering Sea (based on a balanced ecosystem model for the eastern Bering Sea in the early 1990s; Aydin et al, 2007). Green boxes: prey groups; blue boxes: predator groups. Box size reflects group biomass. Lines indicate significant linkages.

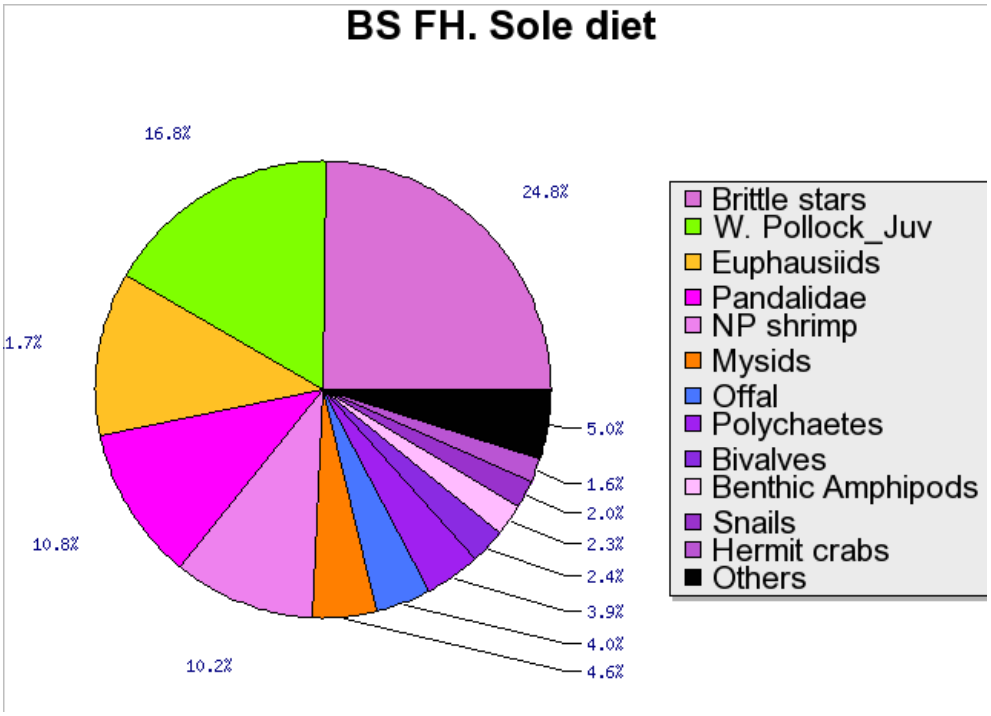


Figure 9.31. Diet composition of adult flathead sole in the eastern Bering Sea (based on a balanced ecosystem model for the eastern Bering Sea in the early 1990s; Aydin et al, 2007).

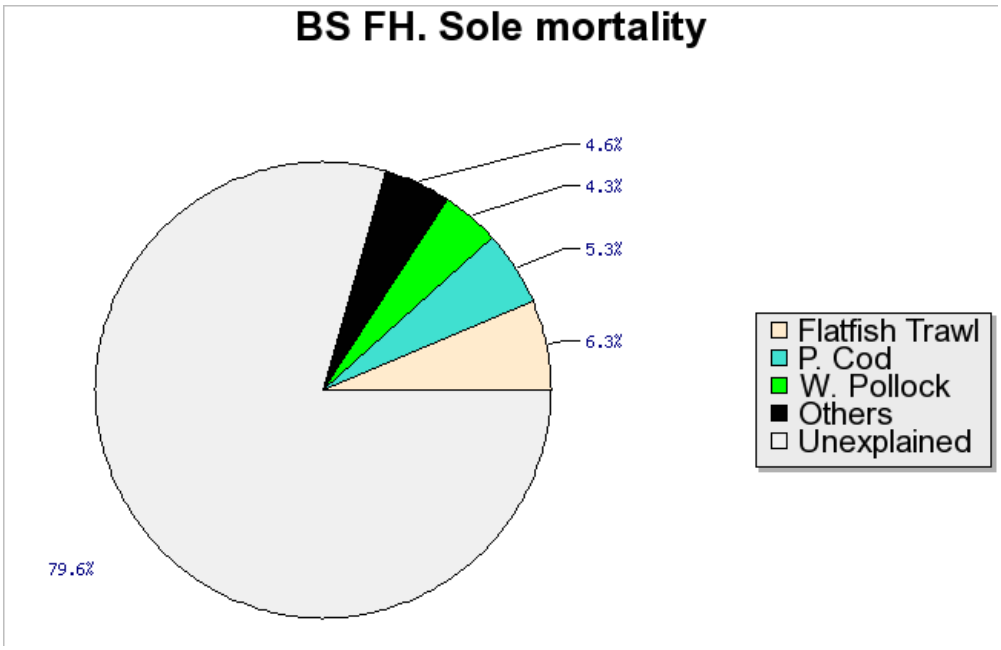


Figure 9.32. Mortality sources for flathead sole in the eastern Bering Sea (based on a balanced ecosystem model for the eastern Bering Sea in the early 1990s; Aydin et al, 2007).

Appendix A: Model Description

The assessment for flathead sole is currently conducted using a split-sex, age-based model with length-based formulations for fishery and survey selectivity. The model structure was developed following Fournier and Archibald's (1982) methods for separable catch-at-age analysis, with many similarities to Methot (1990). The assessment model simulates the dynamics of the stock and compares expected values of stock characteristics with observed values from survey and fishery sampling programs in a likelihood framework, based on distributional assumptions regarding the observed data. Model parameters are estimated by minimizing an associated objective function (basically the negative log-likelihood) that describes the mismatch between model estimates and observed quantities. The model was implemented using AD Model Builder, a software package that facilitates the development of parameter estimation models based on a set of C++ libraries for automatic differentiation.

Basic variables, constants, and indices

Basic variables, constants and indices used in the model are described in the following table:

Table 9A.1. Model constants and indices.

Variable	Description
t	year .
t_{start}, t_{end}	start, end years of model period (1977, 2012).
$t^{sr}_{start}, t^{sr}_{end}$	start, end years for estimating a stock-recruit relationship.
a_{rec}	Age at recruitment, in years (3).
a_{max}	maximum age in model, in years (21).
x	sex index ($1 \le x \le 2$; 1=female, 2=male).
l_{max}	number of length bins.
l	length index ($1 \le l \le l_{max}$).
L_l	length associated with length index l (midpoint of length bin).

Biological data

The model uses a number of biologically-related variables that must be estimated outside the model. These are listed in the following table and include weights-at-age and length for individuals caught in the fishery and by the trawl survey, a matrix summarizing the probability of assigning incorrect ages to fish during otolith reading, sex-specific matrices for the probability of length-at-age, the time of the year at which spawning occurs, and the maturity ogive. Sex-specific growth rates are incorporated in the model via the length-at-age matrices.

Table 9A.2. Input biological data for model.

Variable	Description
$w_{x,a}$	mean body weight (kg) of sex x, age a fish in stock (at beginning of year).
$w^{S}_{x,a}$	mean body weight (kg) of sex x, age a fish from survey.
$w^{F}_{x,a}$	mean body weight (kg) of sex x, age a fish from fishery.
w_l	mean body weight (kg) of fish in length bin l.
$\Theta_{a,a'}$	ageing error matrix.
$\Phi_{x,a,l}$	sex-specific probability of length-at-age.
t_{sp}	time of spawning (as fraction of year from Jan. 1).
ϕ_a	proportion of mature females at age a.

Fishery data
Time series of total yield (catch biomass) from the fishery, as well as length and age compositions from observer sampling of the fishery are inputs to the model and used to evaluate model fit. Under one option for initializing stock numbers-at-age, an historical level of catch (i.e., the catch taken annually prior to the starting year of the model) must also be specified.

Table 9A.3. Input fishery data for model.

Variable	Description
$\{t^F\}$	set of years for which fishery catch data is available.
$\{t^{F,A}\}$	set of years for which fishery age composition data is available.
$\{t^{F,L}\}$	set of years for which fishery length composition data is available.
$\widetilde{Y}^H$	assumed historical yield (i.e., prior to t_{start}; catch in metric tons).
$\widetilde{Y}_t$	observed total yield (catch in metric tons) in year t.
$\widetilde{p}^{F,A}_{t,x,a}$	observed proportion of sex x, age a fish from fishery during year.
$\widetilde{p}^{F,L}_{t,x,l}$	observed proportion of sex x fish from fishery during year t in length bin l.

Survey data
The model also uses time series of observed biomass, length compositions, and age compositions from the AFSC's groundfish surveys on the eastern Bering Sea shelf and in the Aleutian Islands to evaluate model fit. Annual values of spatially-averaged bottom temperature from the eastern Bering Sea trawl surveys are also used to estimate temperature effects on survey catchability.

Table 9A.4. Input survey data for model.

Variable	Description
$\{t^S\}$	set of years for which survey biomass data is available.
$\{t^{S,A}\}$	set of years for which survey age composition data is available.
$\{t^{S,L}\}$	set of years for which survey length composition data is available.
δT_t	survey bottom temperature anomaly in year t (difference from mean bottom temperature in year t)
$\widetilde{B}^S_t$, cv^S_t	observed survey biomass and associated coefficient of variation in year t.
$\widetilde{p}^{S,A}_{t,x,a}$	observed proportion of sex x, age a fish from survey during year t.
$\widetilde{p}^{S,L}_{t,x,l}$	observed proportion of sex x fish from survey during year t in length bin l.

Stock dynamics

The equations governing the stock dynamics of the model are given in the following table. These equations describe the effects of recruitment, growth and fishing mortality on numbers-at-age, spawning biomass and total biomass. Note that the form for recruitment depends on the deviations option selected (standard or "new", see below). Under the standard option, recruitment deviations are about a log-scale mean ($\overline{\ln R}$) while under the new option, the deviations are directly about the stock-recruit relationship.

Table 9A.5. Equations describing model population dynamics.

Variable/equation	Description
b^F, $_{50}L^F$	parameters for length-specific fishery selectivity (slope and length at 50% selected).
$s_l^F = \frac{1}{1+e^{(-b_x^F(L_l - {}_{50}L^F))}}$	length-specific fishery selectivity: 2-parameter ascending logistic.
$s_{x,a}^F = \sum_l \Phi_{x,a,l} \cdot s_l^F$	sex/age-specific fishery selectivity.
$\overline{\ln F}$	log-scale mean fishing mortality.
$\varepsilon_t \sim N(0, \sigma_F^2)$	random log-scale normal deviate associated with fishing mortality.
$F_t = \exp\left(\overline{\ln F} + \varepsilon_t\right)$	fully-selected fishing mortality for year *t*.
$F_{t,l} = F_t \cdot s_l^F$	length-specific fishing mortality for year *t*.
$F_{t,x,a} = F_t \cdot s_{x,a}^F$	sex/age-specific fishing mortality for year *t*.
$Z_{t,x,a} = F_{t,x,a} + M_x$	total sex/age-specific mortality for year *t*.
$\tau_t \sim N(0, \sigma_R^2)$	random log-scale normal deviate associated with recruitment during model time period.
$\overline{\ln R}$	log-scale mean recruitment.
$f(B_t)$	spawner-recruit relationship.
$R_t = \begin{cases} \exp\left(\overline{\ln R} + \tau_t\right) & \text{standard option} \\ f(B_{t-a_{rec}}) \cdot \exp(\tau_t) & \text{new option} \end{cases}$	recruitment during model time period (depends on recruitment deviations option).
$N_{t,x,a_{rec}} = \frac{1}{2} R_t$	recruitment assumed equal for males and females.
$N_{t+1,x,a+1} = N_{t,x,a} \cdot e^{-Z_{t,x,a}}$	numbers at age at beginning of year *t*+1.
$N_{t+1,x,a_{\max}} = N_{t,x,a_{\max}-1} e^{-Z_{t,x,a_{\max}-1}} + N_{t,x,a_{\max}} e^{-Z_{t,x,a_{\max}}}$	numbers in "plus" group at beginning of year *t*+1.
$\overline{N}_{t,x,a} = \frac{(1-e^{-Z_{t,x,a}})}{Z_{t,x,a}} N_{t,x,a}$	mean numbers-at-age for year *t*.
$\overline{N}_{t,x,l} = \sum_a \Phi_{x,a,l} \cdot \overline{N}_{t,x,a}$	mean numbers-at-length for year *t*.
$B_t = \sum_a w_{1,a} \cdot \phi_a \cdot N_{t,1,a} \cdot \exp(-Z_{t,x,a} \cdot t_{sp})$	female spawning biomass in year *t*.
$B_t^T = \sum_x \sum_a w_{x,a} \cdot N_{t,x,a}$	total biomass at beginning of year *t*.

Options for spawner-recruit relationships

Three options for incorporating spawner-recruit relationships are included in the model, but were not used in the 2014 model. These are described in the following table and consist of a relationship where recruitment is independent of stock size, a Beverton-Holt-type relationship, and a Ricker-type relationship (Quinn and Deriso, 1999). The latter two have been re-parameterized in terms of R_0, the expected recruitment for a virgin stock, and h, the steepness of the stock-recruit curve at the origin.

Table 9A.6. Equations describing model spawner-recruit relationships.

Variable/equation	Description
$f(B_t) = \exp(\overline{\ln R})$	no stock-recruit relationship: recruitment is independent of stock level.
$\alpha = \frac{4R_0 h}{5h-1}$ $\beta = \frac{\phi_0 R_0 (1-h)}{5h-1}$ $f(B_t) = \frac{\alpha B_t}{\beta + B_t}$	Beverton-Holt stock-recruit relationship parameterized in terms of equilibrium recruitment with no-fishing, R_0, and the steepness parameter, h. ϕ_0 is the spawning biomass-per-recruit in the absence of fishing.
$\alpha = \frac{(5h)^{5/4}}{\phi_0}$ $\beta = \frac{5\ln(5h)}{4\phi_0 R_0}$ $f(B_t) = \alpha B_t \exp(-\beta B_t)$	Ricker stock-recruit relationship parameterized in terms of equilibrium recruitment with no-fishing, R_0, and the steepness parameter, h. ϕ_0 is the spawning biomass-per-recruit in the absence of fishing.

Options for historical recruitment

The standard option for historical recruitment assumes that recruitment prior to the start of the model time period is independent of stock size. Thus, the stock-recruit model relationship to characterize the model period does not apply to historical recruitment, which is parameterized by $\ln R^H$, the log-scale mean historical recruitment. The "new" option for historical recruitment tested in this assessment assumes that the stock-recruit relationship that characterizes the model period is also operative for historical recruitment. As a consequence, the parameter $\ln R^H$ is no longer estimated when the "new" option is used.

Options for initial numbers-at-age

Under the standard option, initial numbers-at-age are deterministic, with historical recruitment in equilibrium historical fishing mortality F^H, a model-estimated parameter. The model algorithm for this option is given by the following pseudo-code:

$$N_{t_{start},x,a_{rec}} = \tfrac{1}{2} R_{eq}(F^H)$$

$$N_{t_{start},x,a+1} = N_{t_{start},x,a} \cdot \exp(-(F^H \cdot s^F_{x,a} + M_x))$$

$$Y^H = \sum_x \sum_a \frac{F^H \cdot s^F_{x,a}}{F^H \cdot s^F_{x,a} + M_x} \cdot N_{t_{start},x,a} \cdot (1 - \exp(-(F^H \cdot s^F_{x,a} + M_x)))$$

$$\mathcal{P}^H = \lambda^H \cdot \left(\widetilde{Y}^H - Y^H\right)^2$$

$$N_{t_{start},x,a_{rec}} = \begin{cases} \tfrac{1}{2}\exp(\overline{\ln R} + \tau_{t_{start}}) & \text{standard deviations option} \\ \tfrac{1}{2} f(B_{t-a_{rec}}) \cdot \exp(\tau_{t_{start}}) & \text{new deviations option} \end{cases}$$

where $R_{eq}(F)$ is the equilibrium recruitment at fishing mortality F using the selected historic recruitment option and the assumed stock-recruit mode. $\mathcal{P}^H$ is a penalty added to the objective function with a high weight (λ^H) to ensure that the estimated historical catch equals the observed. Recruitment in the first model year is reset to fluctuate stochastically in the final equation above. If the standard option for historical recruitment is used, then historical recruitment is independent of stock size and $R_{eq}(F)$ is given by $\exp(\ln R^H)$. If the new option is used, then $R_{eq}(F)$ is derived from the operative stock-recruit relationship for the model time period (and $\ln R^H$ is not estimated).

Under "option 1", the initial numbers-at-age are assumed to be in stochastic equilibrium with a virgin stock condition (i.e., no fishing). Lognormal deviations from the mean or median stock-recruit relationship during the historical and modeled time periods are taken to be linked. When the standard option for historical recruitment is also used, the initial numbers-at-age are thus given by:

$$N_{t_{start},x,a} = \tfrac{1}{2}\exp(\ln R^H + \tau_{t_{start}-(a-a_{rec})}) \cdot \exp(-M_x \cdot (a - a_{rec})); \quad a = a_{rec} \ldots a_{\max}$$

When the new option for historical recruitment is used, the algorithm for calculating initial numbers-at-age is identical to the equation above, with $\overline{\ln R}$ replacing $\ln R^H$, when recruitment is assumed independent of stock size. When recruitment is assumed to depend on stock size (through either a Ricker or Beverton-Holt relationship), the algorithm for calculating initial numbers-at-age is somewhat more complicated because historical recruitment now depends on historical spawning biomass, which also fluctuates stochastically. Consequently, an attempt is made to incorporate changes to the historical spawning biomass due to stochastic fluctuations in historical recruitment about the stock-recruit curve when calculating the initial numbers-at-age. The algorithm is described by the following pseudo-code:

$$B_t = B_0 \quad \text{for } t \le t_{start} - a_{\max}$$

$$\begin{cases} \text{for j} = 1 \text{ to } a_{\max} \\ N_{t_{start}-a_{\max}+j,x,a_{rec}} = \tfrac{1}{2} f(B_{t_{start}-a_{\max}+j-a_{rec}}) \cdot \exp(\tau_{t_{start}-a_{\max}+j}) \\ N_{t_{start}-a_{\max}+j,x,a+1} = N_{t_{start}-a_{\max}+j-1,x,a} \cdot \exp(-M_x) \\ B_{t_{start}-a_{\max}+j} = \sum_a w_{1,a} \cdot \phi_a \cdot N_{t_{start}-a_{\max}+j,1,a} \cdot \exp(-M_x t_{sp}) \end{cases}$$

where B_0 is the expected biomass for a virgin stock. Conceptually, this option attempts to incorporate the effects of density-dependence implicit in the stock-recruit relationship (if one is being used) when estimating the initial numbers-at-age.

"Option 2" for initial number-at-age represents a subtle variation on "option 1". The equations for "option 2" are identical to those for "option 1" except that the log-scale deviations τ_t over the interval t_{start}-$a_{max} \leq t \leq t_{start}$-1 are replaced by a set of independent log-scale deviations ξ_t. In "option 1", the τ_t are required to sum to 0 over the time interval t_{start}-$a_{max} < t \leq t_{end}$, while in "option 2", the τ_t sum to 0 over $t_{start} \leq t \leq t_{end}$ and the ξ_t sum to 0 over t_{start}-$a_{max} < t \leq t_{start}$-1.

Model-predicted fishery data

In order to estimate the fundamental parameters governing the model, the model predicts annual catch biomass (yield) and sex-specific length and age compositions for the fishery, to compare with the observed input fishery data components. The equations used to predict fishery data are outlined in the following table:

Table 9A.7. Model equations predicting fishery data.

Variable/equation	Description
$C_{t,x,l}=F_{t,l}\ \overline{N}_{t,x,l}$	sex-specific catch-at-length (in numbers) for year *t*.
$C_{t,x,a}=\sum_{a'}\Theta_{a,a'}\,F_{t,x,a'}\,\overline{N}_{t,x,a'}$	sex-specific catch-at-age (in numbers) for year *t* (includes ageing error).
$Y_t=\sum_x\sum_l w_l\,C_{t,x,l}$	total catch in tons (i.e., yield)for year *t*.
$p^{F,L}_{t,x,l}=C_{t,x,l}/\sum_x\sum_l C_{t,x,l}$	proportion at sex/length in the catch.
$p^{F,A}_{t,x,a}=C_{t,x,a}/\sum_x\sum_a C_{t,x,a}$	proportion at sex/age in the catch.

Model-predicted survey data

The model also predicts annual survey biomass and sex-specific length and age compositions from the trawl survey to compare with the observed input survey data components in order to estimate the fundamental parameters governing the model. The equations used to predict survey data are outlined in the following table:

Table 9A.8. Model equations describing survey data.

Variable/equation	Description
$b^S, {}_{50}L^S$	parameters for length-specific survey selectivity (slope and length at 50% selected)
$s_l^S = \frac{1}{1+e^{(-b^S(L_l - {}_{50}L^S))}}$	length-specific survey selectivity: 2-parameter ascending logistic.
$s_{x,a}^S = \sum_l \Phi_{x,a,l}\ s_l^S$	sex/age-specific survey selectivity.
$\sigma_T^2 = \frac{1}{n_T - 1}\sum_t \delta T_t^2$	variance of bottom temperature anomalies.
$q_t = \exp(\alpha_q + \beta_q\ \delta T_{t-y} - \frac{(\beta_q\ \sigma_T)^2}{2})$	temperature-dependent survey catchability in year *t*. *y* is the effect lag (in years). The last term in the exponential implies that the arithmetic mean catchability is exp(α_q).
$N^S{}_{t,x,l} = q_t\ s_l^S \cdot \overline{N}_{t,x,l}$	sex-specific survey numbers-at-length in year *t*.
$N^S{}_{t,x,a} = \sum_{a'} q_t\ \Theta_{a,a'}\ s_{x,a'}^S \overline{N}_{t,x,a'}$	sex-specific survey numbers-at-length in year *t* (includes ageing error).
$B_t^S = \sum_x \sum_a w_l\ N^S{}_{t,x,l}$	total survey biomass in year *t*.
$p_{t,x,l}^{S,L} = N^S{}_{t,x,l} / \sum_x \sum_l N^S{}_{t,x,l}$	proportion at sex/length in the survey.
$p_{t,x,a}^{S,A} = N^S{}_{t,x,a} / \sum_x \sum_a N^S{}_{t,x,a}$	proportion at sex/age in the survey.

Non-recruitment related likelihood components
Model parameters are estimated by minimizing the objective function

$$\mathcal{O} = -\sum_i \lambda_i \cdot \boldsymbol{\ell n \mathcal{L}}_i + \sum_j \mathcal{P}^j$$

where the $\boldsymbol{\ell n \mathcal{L}}_i$ are log-likelihood components for the model, the λ_i are weights put on the different components, and the $\mathcal{P}^j$ are additional penalties to imposed to improve model convergence and impose various conditions (e.g., $\mathcal{P}^H$ defined above to force estimated historic catch to equal input historic catch). One log-likelihood component is connected with recruitment, while the other components describe how well the model predicts a particular type of observed data. Each component is based on an assumed process or observation error distribution (lognormal or multinomial). The likelihood components that are *not* related to recruitment are described in the following table:

Table 9A.9. Non-recruitment related likelihood components (applicable to all model options).

Component	Description
$\boldsymbol{\ell n \mathcal{L}}_C = \sum_{t=1}^{T} \left[\ln(\widetilde{Y}_t + \eta) - \ln(Y_t + \eta)\right]^2$	catch biomass (yield); assumes a lognormal distribution. η is a small value ($<10^{-5}$).
$\boldsymbol{\ell n \mathcal{L}}_{FA} = \sum_{t \in \{t^{F,A}\}} \sum_{x=1}^{2} \sum_{a=1}^{A} \widetilde{n}_t^{F,A} \cdot \widetilde{p}_{t,x,a}^{F,A} \cdot \ln(p_{t,x,a}^{F,A} + \eta) - \Omega^{F,A}$	fishery age composition; assumes a multinomial distribution. $\widetilde{n}_t^{F,A}$ is the observed sample size.
$\boldsymbol{\ell n \mathcal{L}}_{FL} = \sum_{t \in \{t^{F,L}\}} \sum_{x=1}^{2} \sum_{l=1}^{L} \widetilde{n}_t^{F,L} \cdot \widetilde{p}_{t,x,l}^{F,L} \cdot \ln(p_{t,x,l}^{F,L} + \eta) - \Omega^{F,L}$	fishery length composition; assumes a multinomial distribution. $\widetilde{n}_t^{F,L}$ is the observed sample size.
$\boldsymbol{\ell n \mathcal{L}}_{SA} = \sum_{t \in \{t^{S,A}\}} \sum_{x=1}^{2} \sum_{a=1}^{A} \widetilde{n}_t^{S,A} \cdot \widetilde{p}_{t,x,a}^{S,A} \cdot \ln(p_{t,x,a}^{S,A} + \eta) - \Omega^{S,A}$	survey age composition; assumes a multinomial distribution. $\widetilde{n}_t^{S,A}$ is the observed sample size.
$\boldsymbol{\ell n \mathcal{L}}_{SL} = \sum_{t \in \{t^{S,L}\}} \sum_{x=1}^{2} \sum_{l=1}^{L} \widetilde{n}_t^{S,L} \cdot \widetilde{p}_{t,x,l}^{S,L} \cdot \ln(p_{t,x,l}^{S,L} + \eta) - \Omega^{S,L}$	survey length composition; assumes a multinomial distribution. $\widetilde{n}_t^{S,L}$ is the observed sample size.
$\Omega^{\cdot\cdot} = \sum_t \sum_{x=1}^{2} \sum_{a=1}^{A} n_t^{\cdot\cdot} \cdot \widetilde{p}_{t,x,a}^{\cdot\cdot} \cdot \ln(\widetilde{p}_{t,x,a}^{\cdot\cdot} + \eta))$	the offset constants $\{\Omega^{\cdot\cdot}\}$ for age/length composition components are calculated from the appropriate observed proportions and sample sizes.
$\boldsymbol{\ell n \mathcal{L}}_{SB} = \sum_{t \in \{t^S\}} \left[\frac{\ln(\widetilde{B}_t^S + \eta) - \ln(B_t^S + \eta)}{\sqrt{2} \cdot \widetilde{\sigma}_t^S}\right]^2$	Survey biomass; assumes a lognormal distribution.

Recruitment related likelihood components
The exact details of the recruitment-related likelihood components for a given model run depend on whether or not a stock-recruit relationship has been specified and on which of several combinations of model options have been selected. However, the general equation for the recruitment likelihood is

$$\ell n\mathcal{L}_R = \sum_t \left\{ \frac{(\ln(R_t + \eta) - \ln(f(B_{t-a_{rec}}) + \eta) + b)^2}{2\sigma_R^2} + \ln(\sigma_R) \right\} + \gamma \cdot \sum_{t=t_{start}-a_{\max}}^{t_{start}-1} \left\{ \frac{(\xi_t + b)^2}{2\sigma_R^2} + \ln(\sigma_R) \right\}$$

When the standard stock-recruit deviations option is used, $b = \sigma_R^2 / 2$ and the recruitment likelihood fits the *mean* stock-recruit relationship; otherwise b = 0 and the *median* (or log-scale mean) stock-recruit relationship is fit. When the standard initial n-at-age option is used (i.e., the initial n-at-age distribution is in equilibrium with an historic catch biomass and deterministic), γ = 0 and the first sum over *t* runs from t^{sr}_{start} to t^{sr}_{end}, the interval selected over which to calculate the stock-recruit relationship. When option 1 for initial n-at-age is used, the initial n-at-age distribution is regarded as in stochastic equilibrium with a virgin stock and the recruitment deviations (τ_t) are indexed from t_{start}-a_{max} to t_{end}. For this option, γ = 0 again and the first sum over *t* runs from t_{start}-a_{max} to t_{end} so that the stock-recruit relationship is fit over both the modeled and the historical periods. Finally, when option 2 is used, γ = 1 and the first sum over *t* runs from t^{sr}_{start} to t^{sr}_{end} so that recruitment deviation during the historical period and deviations during the model period are not linked.

For the models run in this assessment, the likelihood multipliers are summarized in Table 9A.11. λ_C was assigned a value of 50 to ensure a close fit to the observed catch data while λ_R and λ_B were assigned values of 1. The sample sizes in the age and length composition likelihood components were all set to 200, as in previous assessments. The likelihood components associated with the fishery age and length compositions were de-weighted relative to those from the survey to improve model convergence. Thus, λ_{SA} and λ_{SL} were assigned values of 1 and λ_{FL} and λ_{FA} were assigned values of 0.3.

Table 9A.10. Likelihood multiplier values.

Likelihood Multipliers						
	Fishery			Survey		
catch	age compositions	size compositions	biomass	age compositions	size compositions	Recruitment deviations
λ_C	λ_{FA}	λ_{FL}	λ_B	λ_{SA}	λ_{SL}	λ_R
50	0.3	0.3	1	1	1	1

Model parameters

The following tables describe the potentially estimable parameters for the assessment model.

Table 9A.11. Parameters currently not estimated in the model.

Parameter	Subscript range	Total no. of parameters	Description
M_x	$1 \le x \le 2$	2	sex-specific natural mortality.
σ_R^2	--	1	variance of log-scale deviations in recruitment about spawner-recruit curve.
α_q	--	1	natural log of mean survey catchability.

Table 9A.12. Non recruitment-related parameters estimated in the model.

Parameter	Subscript range	Total no. of parameters	Description
β_q	--	1	temperature-dependent catchability "slope" parameter.
$\ln F^H$	--	1	log-scale fishing mortality prior to model period (i.e., historic).
$\overline{\ln F}$	--	1	log-scale mean fishing mortality during model period.
ε_t	$1977 \le t \le 2012$	36	log-scale deviations in fishing mortality in year t.
b^F, $_{50}\mathrm{L}^F$	--	2	fishery selectivity parameters (slope and length at 50% selected).
b^S, $_{50}\mathrm{L}^S$	--	2	survey selectivity parameters (slope and length at 50% selected).

Table 9A.13. Recruitment-related parameters. Superscripts refer to initial n-at-age options: 1-standard option, 2-option 2, 3-option 3. The standard option was used in the 2014 model.

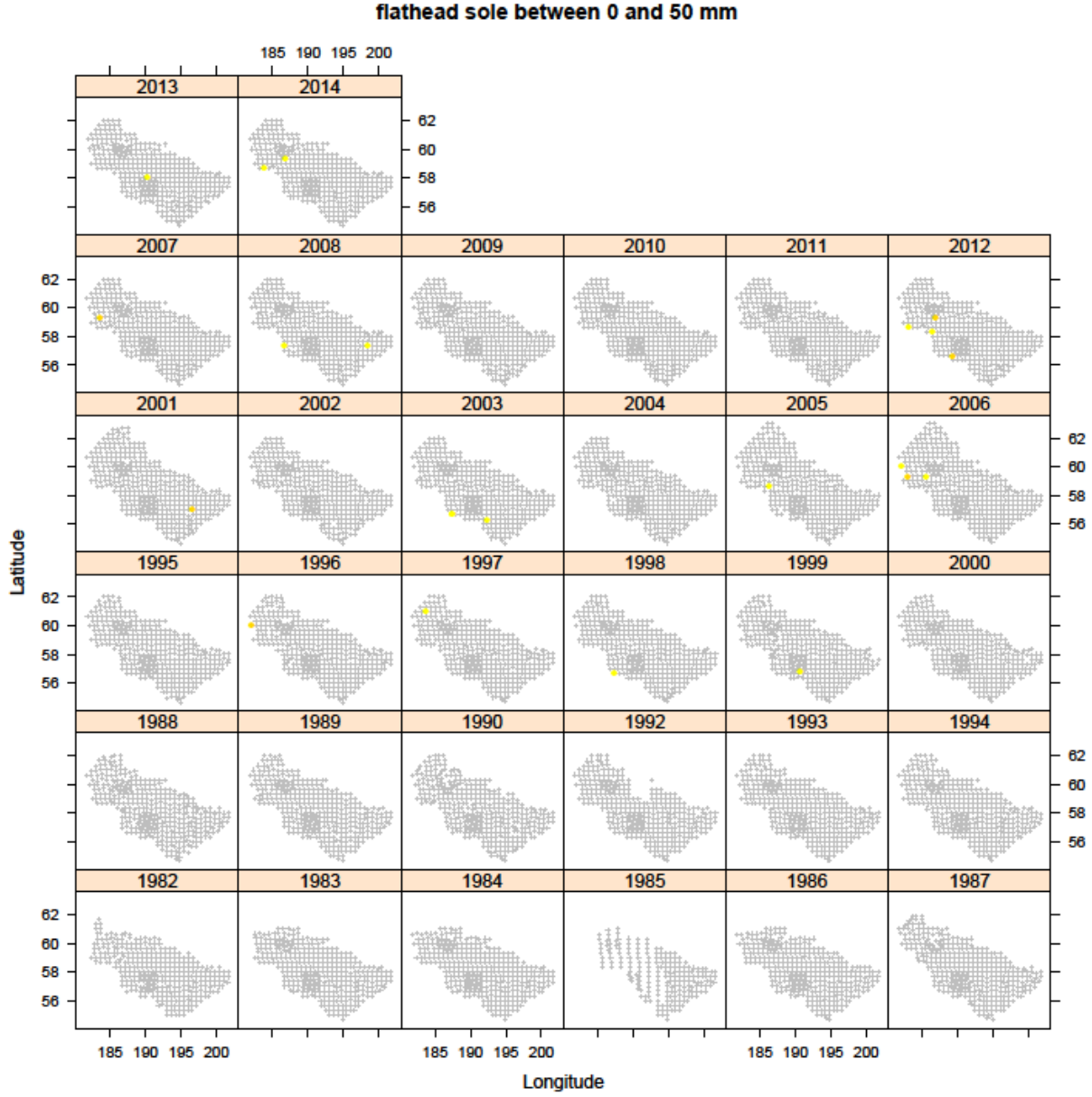
Parameter	Subscript range	Total no. of parameters	Description
$\ln R^H$	--	1	log-scale equilibrium age 3 recruitment prior to model period.
$\overline{\ln R}$	--	1	log-scale mean of age 3 recruitment during the model period.
$\ln R_0$	--	1	natural log of R_0, expected recruitment for an unfished stock (used in Ricker or Beverton-Holt stock-recruit relationships).
h	--	1	steepness of stock-recruit curve (used in Ricker or Beverton-Holt stock-recruit relationships).
τ_t	$1977 \le t \le 2012^{1,3}$ $1957 \le t \le 2012^{2}$	$36^{1,3}$ 56^{2}	log-scale recruitment deviation in year t.
ξ_t	-- $1957 \le t \le 1976$	$0^{1,3}$ 20^{2}	log-scale recruitment deviation in year t.

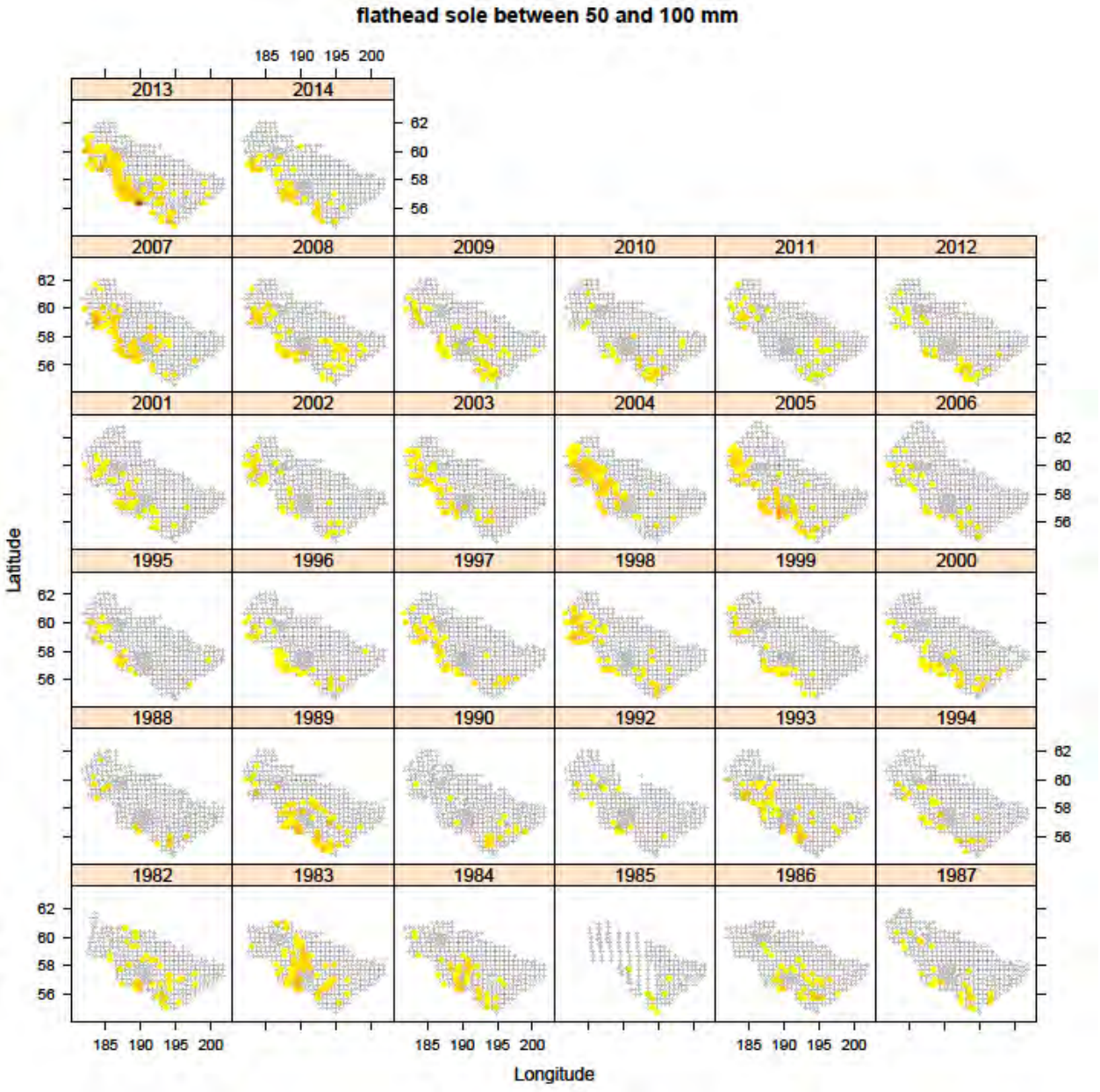
Appendix B: Supplemental Catch Data

Table B.1. Total non-commercial fishery catches not included in the AKFIN estimates of total catch. Units are not known (not identified on the AKFIN website), but may be kg.

Year	ADFG	IPHC	NMFS	Total
2010	3,244	5	27,156	30,406
2011	2,592	13	32,555	35,160
2012	2,814	39	22,284	25,137
2013	2,426		19,647	22,072
2014			23,096	23,096

Appendix C: Distribution of flathead sole by coarse length bins over (a) latitude and longitude and (b) depth and temperature




flathead sole between 50 and 100 mm
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1986
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185 190 195 200
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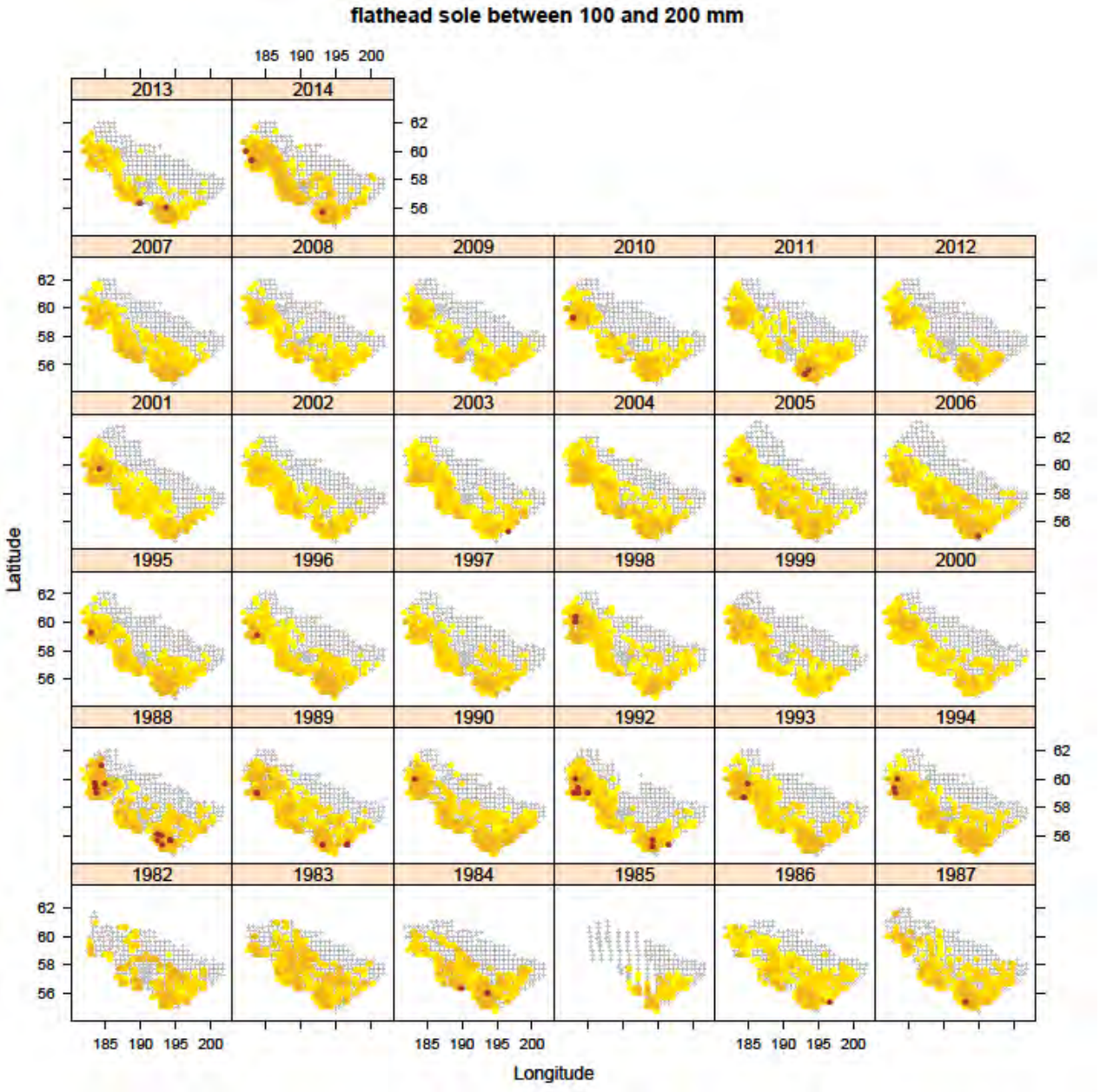
56
Latitude
Longitude


flathead sole between 100 and 200 mm
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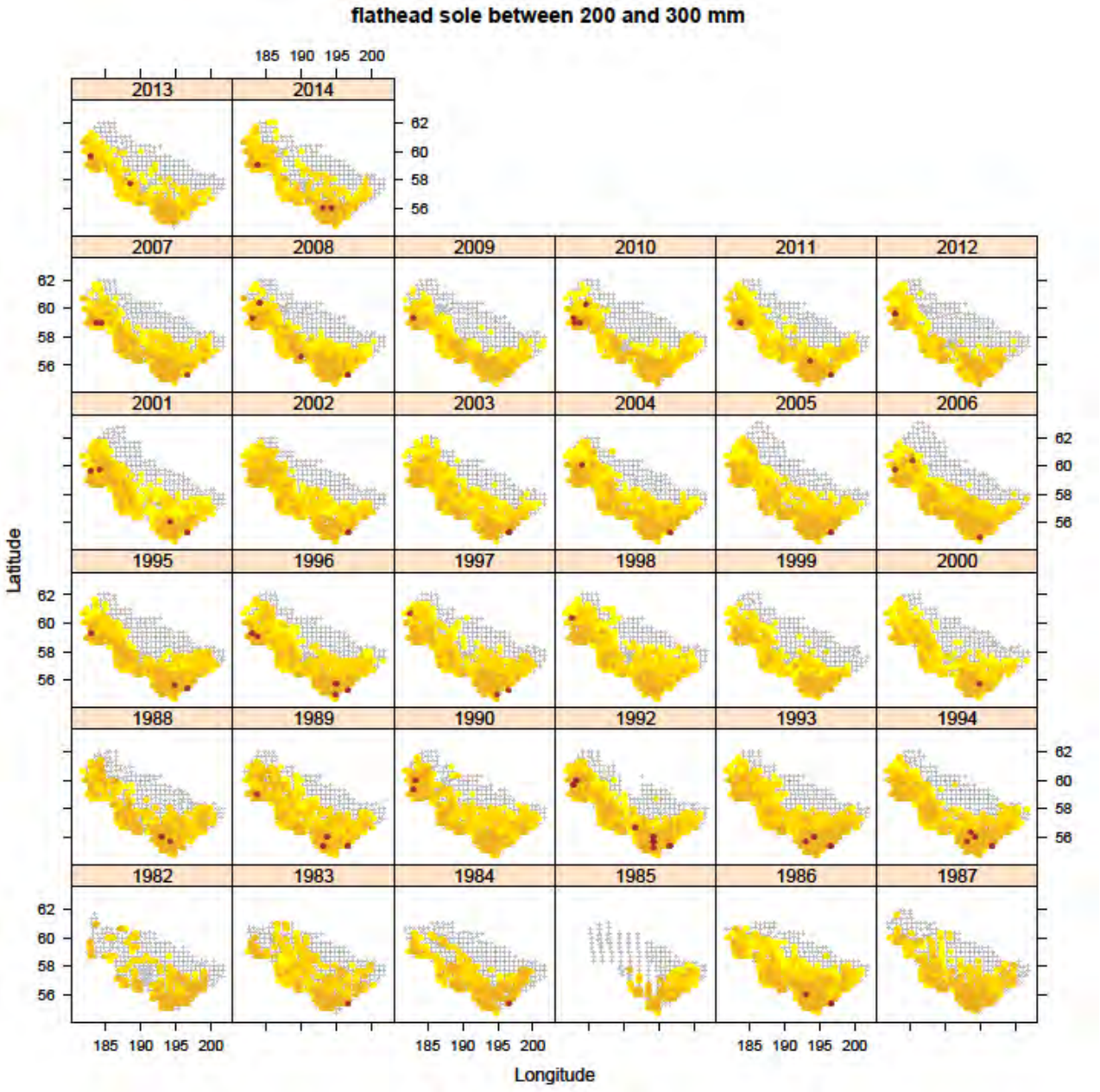
Latitude
Longitude


flathead sole between 200 and 300 mm
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185 190 195 200
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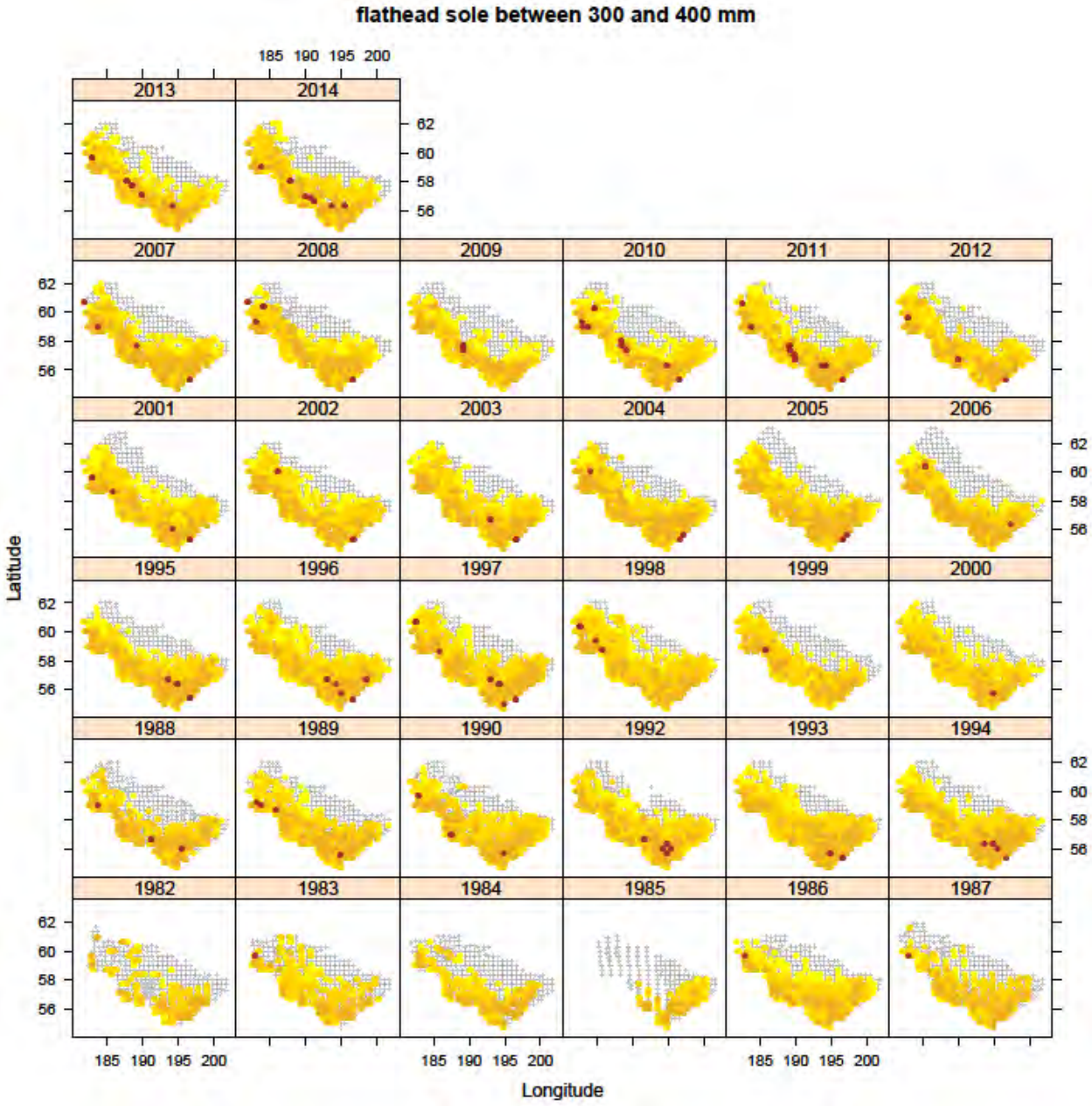
Latitude
Longitude


flathead sole between 300 and 400 mm
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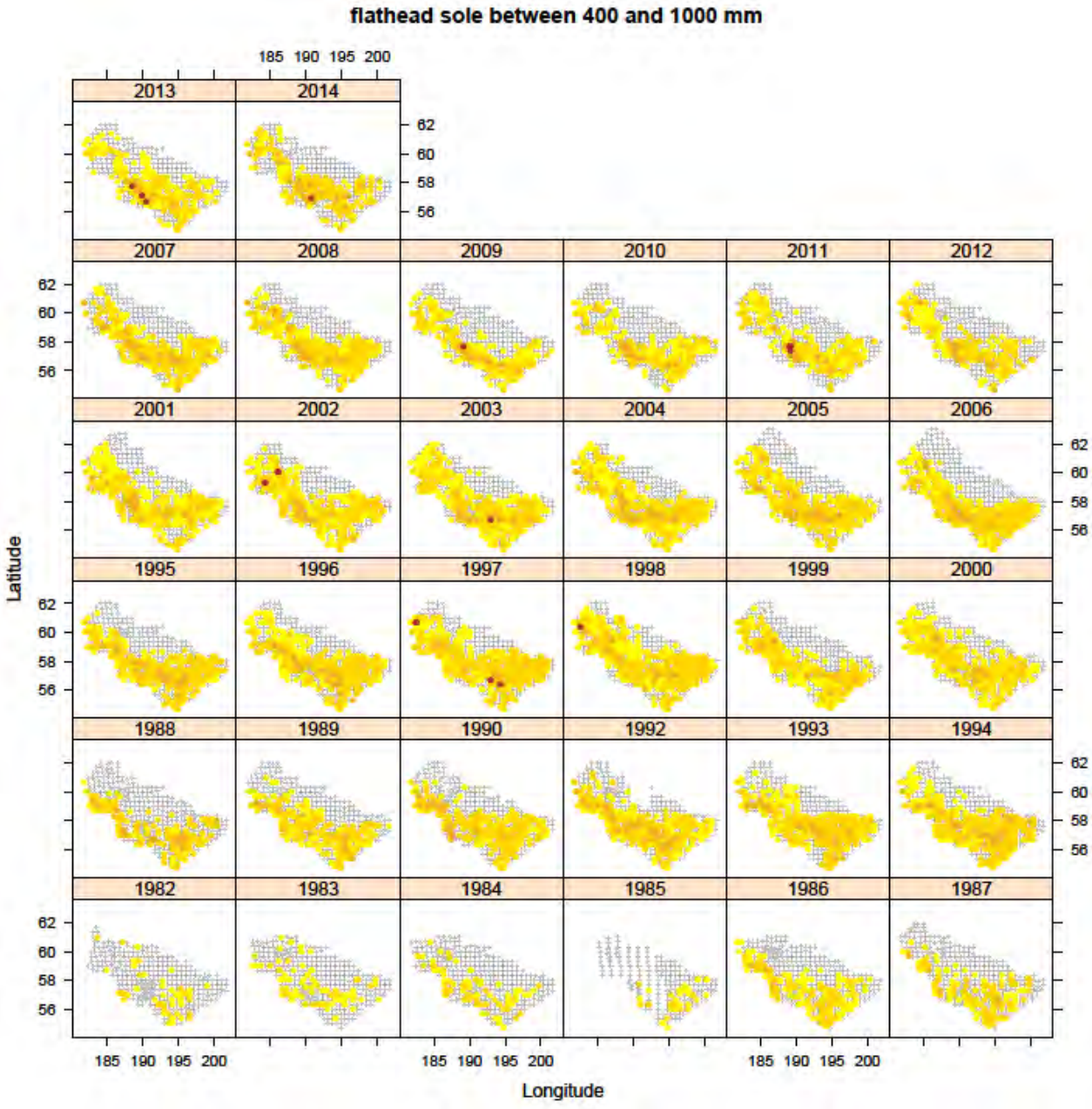
flathead sole between 400 and 1000 mm
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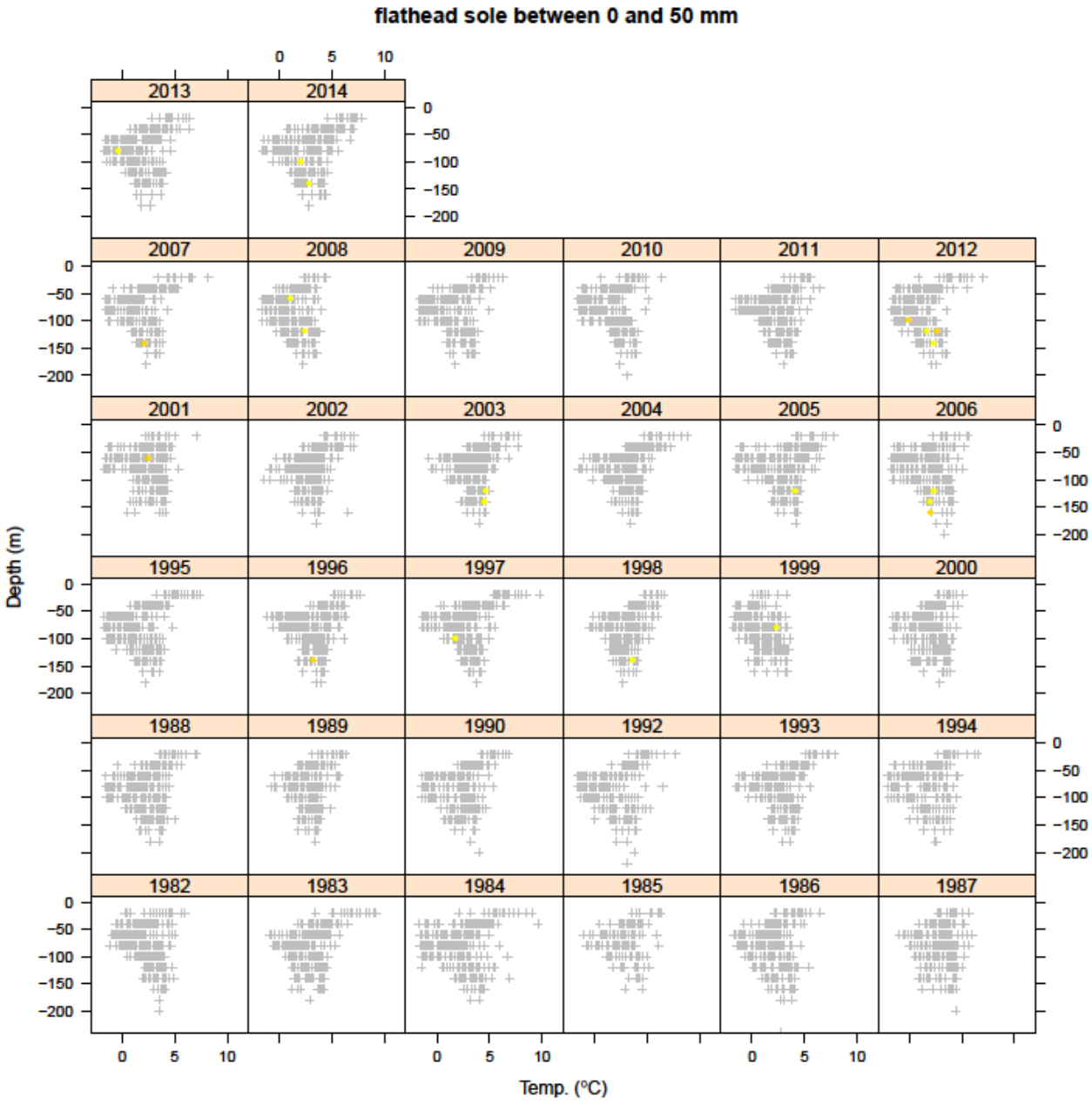
flathead sole between 0 and 50 mm
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Depth (m)
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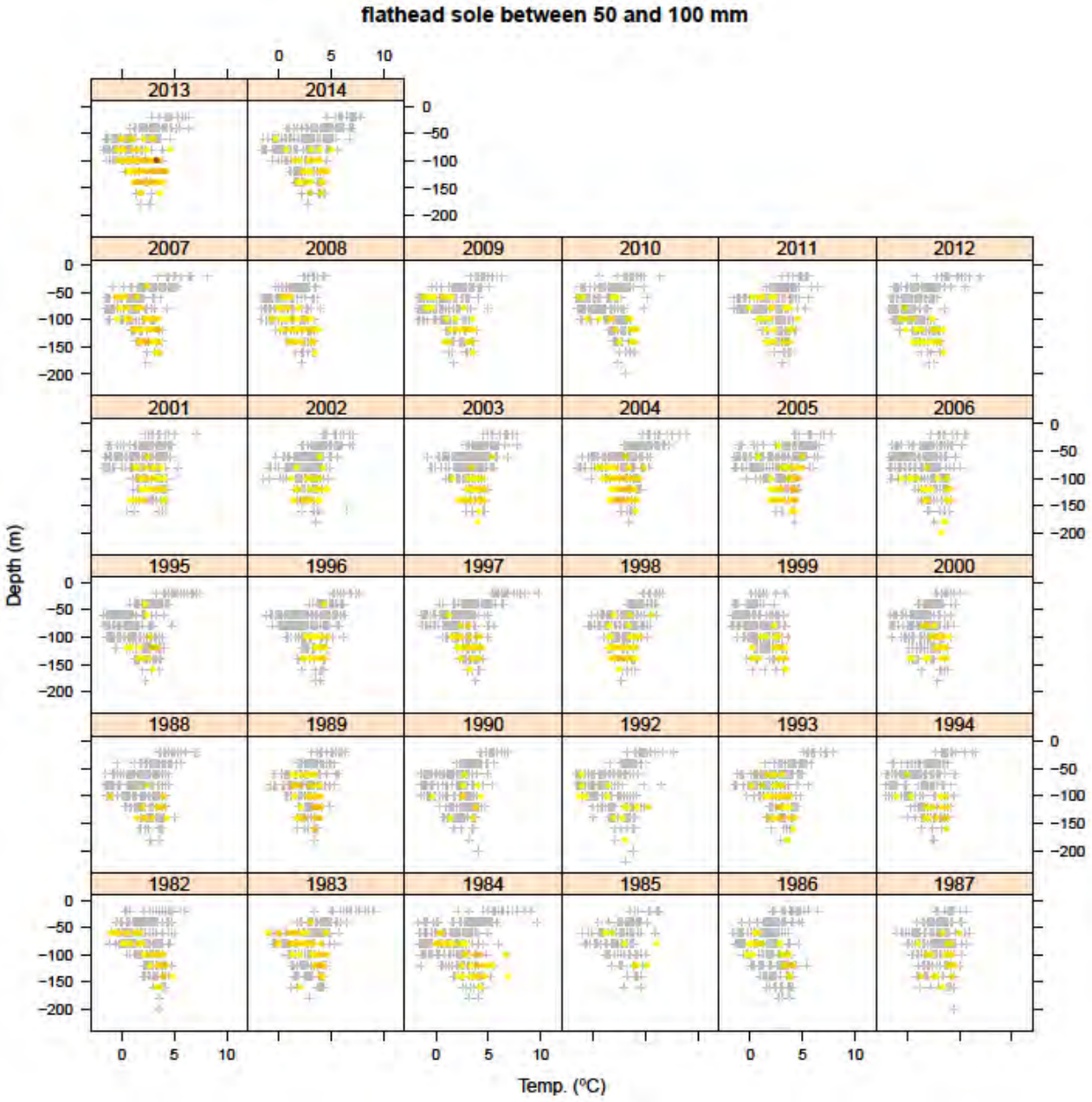
flathead sole between 50 and 100 mm
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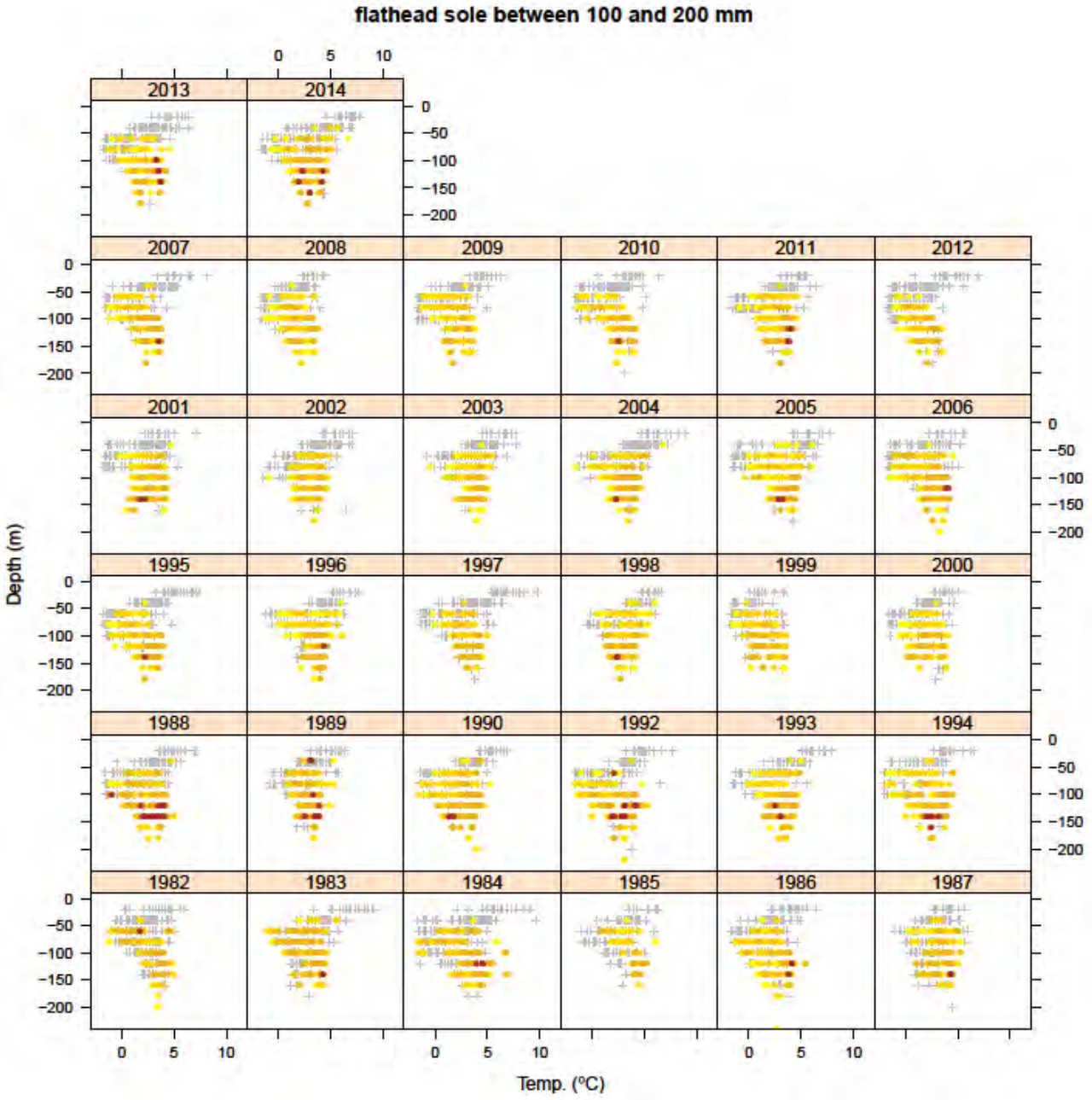
flathead sole between 100 and 200 mm
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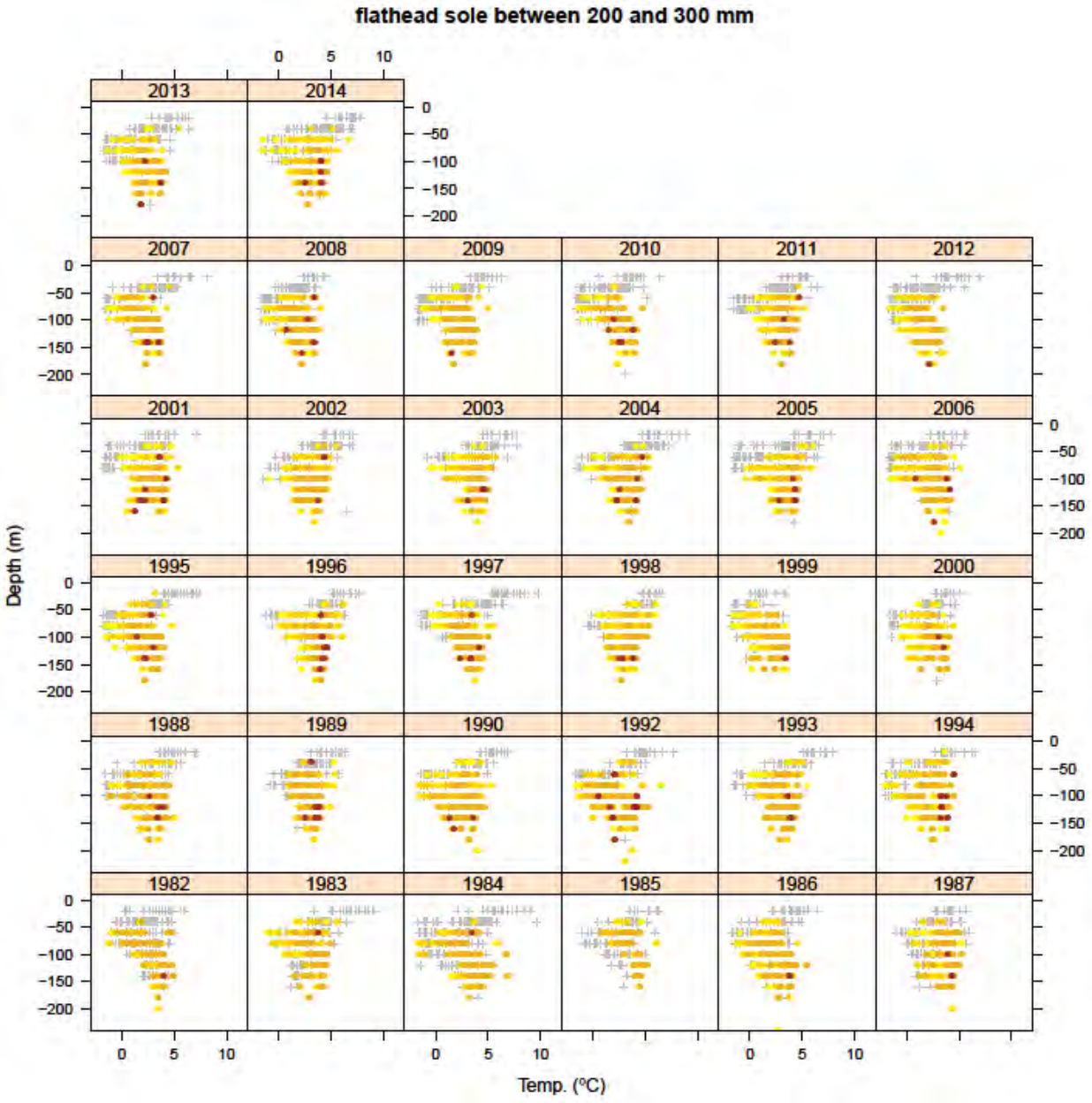
flathead sole between 200 and 300 mm
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Depth (m)
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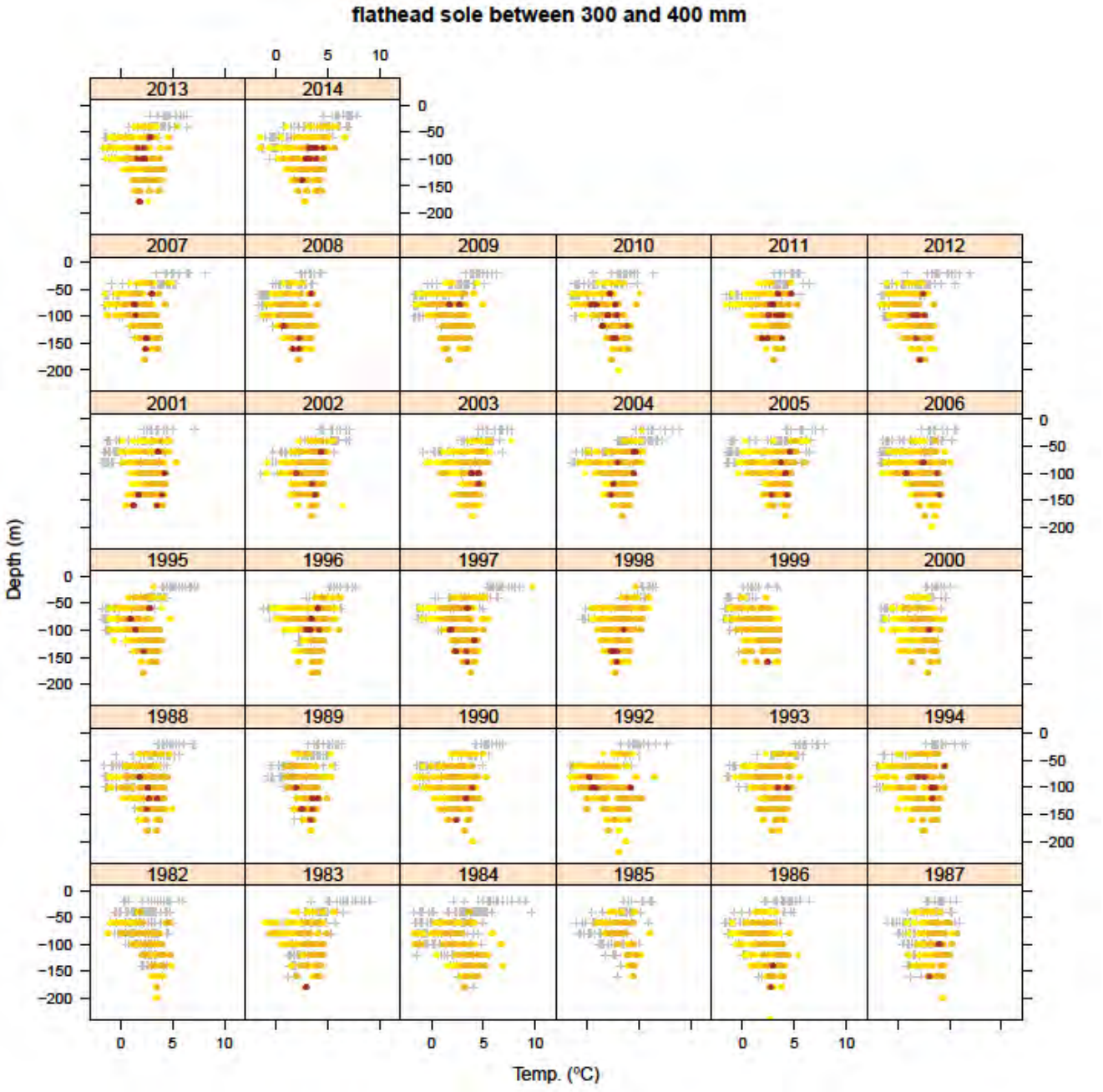
flathead sole between 300 and 400 mm
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Depth (m)
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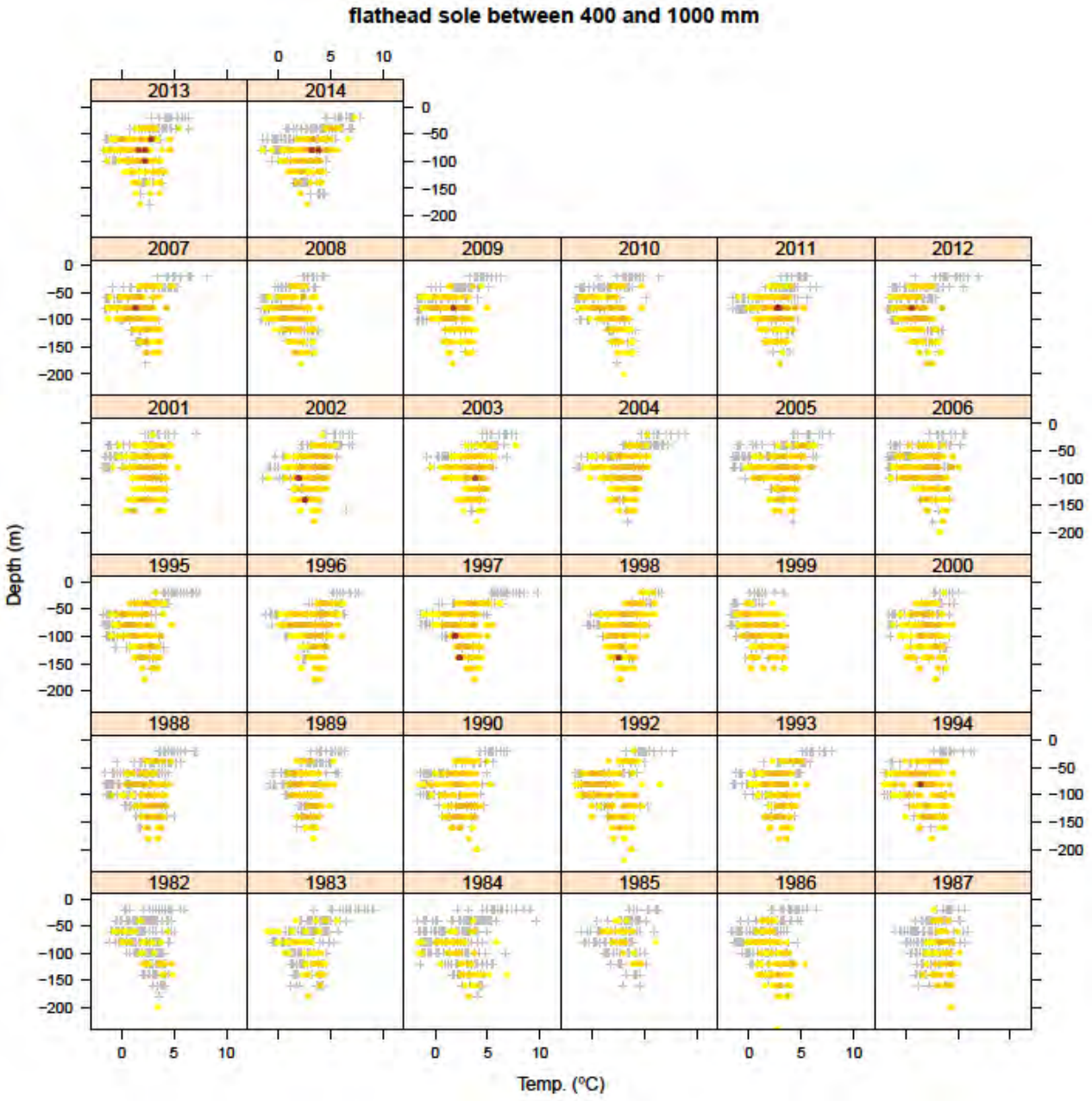
flathead sole between 400 and 1000 mm
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Depth (m)
Temp. (°C)

10. Assessment of the Alaska Plaice stock in the Bering Sea and Aleutian Islands

Thomas K. Wilderbuer, Daniel G. Nichol, and Paul D. Spencer
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National Marine Fisheries Service

Executive Summary

The following changes have been made to this assessment relative to the November 2013 SAFE:

Summary of Changes Assessment Inputs

1) The 2013 catch data was updated, and the 2014 catch was estimated from Alaska Region total catch through September 15, 2014, in consideration of the recent weekly catch pattern for Alaska plaice.
2) The 2013 and 2014 shelf survey biomass estimates and standard errors, and the 2014 survey length composition were included in the assessment.
3) The 2012 and 2013 survey ages were read and their respective survey age compositions were added to the assessment.
4) The 2013 fishery length composition was added as a data component.
5) A new maturity schedule estimated from histological analysis of samples collected in 2012 was implemented in the assessment model.
6) The current assessment does not incorporate 1975, and 1979-1981 survey biomass data.

Changes to the Assessment Methodology

No modifications were made for this assessment.

Summary of Results

1) Estimated 3+ total biomass for 2015 is 471,500 t.
2) Projected female spawning biomass for 2015 is 215,300 t.
3) Recommended ABC for 2015 is 44,900 t based on an $F_{40\%} = 0.143$ harvest level.
4) 2015 overfishing level is 54,000 t based on a $F_{35\%}$ (0.175) harvest level.

This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Marine Fisheries Service and should not be construed to represent any agency determination or policy.

Quantity/Status	Last year 2014	Last year 2015	This year **2015**	This year 2016
M (natural mortality)	0.13	0.13	**0.13**	0.13
Specified/recommended Tier	3a	3a	**3a**	3a
Projected biomass (ages 3+)	576,300	572,900	**471,500**	462,600
Female spawning biomass (t)				
Projected	250,600	246,300	**215,300**	201,300
$B_{100\%}$	380,100		**355,250**	
$B_{40\%}$	152,000		**142,100**	
$B_{35\%}$	133,000		**124,300**	
F_{OFL}	0.19	0.19	**0.175**	**0.175**
$maxF_{ABC}$ (maximum allowable = F40%)	0.158	0.151	**0.143**	**0.143**
Specified/recommended F_{ABC}	0.158	0.151	**0.143**	**0.143**
Specified/recommended ABC (t)	55,100	54,700	**44,900**	42,900
Specified/recommended OFL (t)	66,800	66,300	**54,000**	51,600
Is the stock being subjected to overfishing?	No	No	No	No
Is the stock currently overfished?	No	No	No	No
Is the stock approaching a condition of being overfished?	No	No	No	No

Responses to SSC and Plan Team Comments on Assessments in General

December 2013 SSC Comments:
The SSC noted that different stock assessment scientists often use different methods for catch estimation to estimate catches between late October and December 31 of the current assessment year, as well as catches to be taken during the following two years for use in the catch specification process. The SSC understands that Dana Hanselman will compile the various methods in use. The SSC looks forward to Plan Team advice on the merits of the various alternatives.

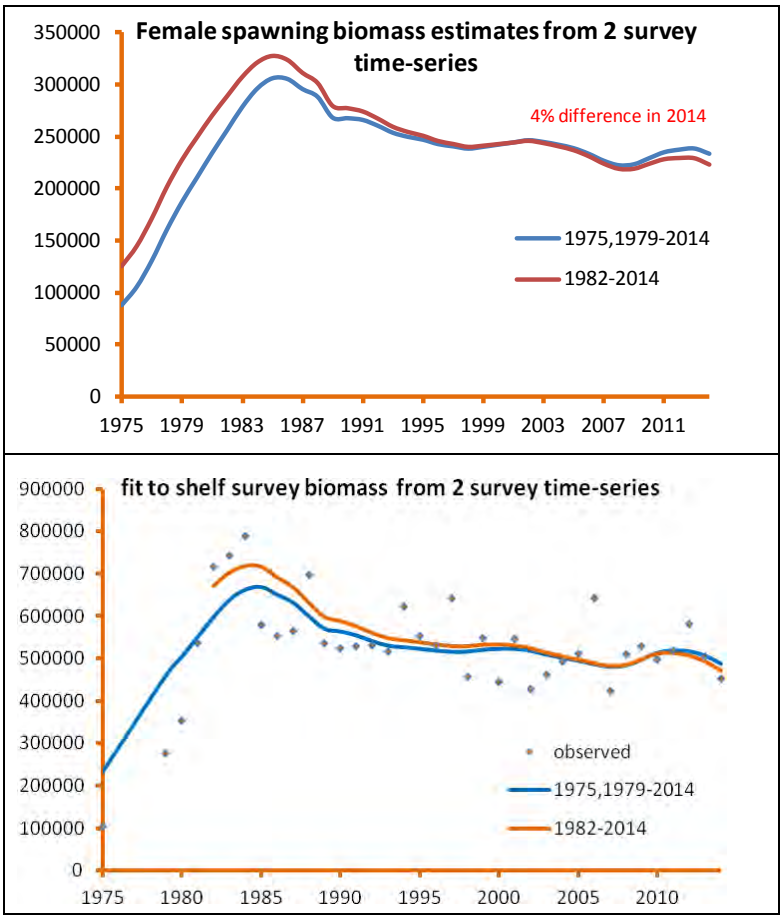
Authors' response: This is described under fisheries data.

The SSC also requested that authors include two years of projections in the phase plane diagram. For example, in 2014, projected values for 2015 and 2016 should be included.

Responses to SSC and Plan Team Comments Specific to this Assessment

SSC Comments from December 2013: In last year's assessment, the authors indicated a desire to remove pre-1982 survey data from the assessment, given changes in catchability associated with the switch in survey gears. The SSC looks forward to an alternative assessment with this modified dataset and reminds the authors to retain a model fit with the full data so that the effect of this change can be evaluated. The SSC also looks forward to any new insights into how best to address the situation that a significant portion of the Alaska plaice biomass resides in the northern Bering Sea.

Authors' response: Both models were run and model output compared in the following figures. Results of estimated female spawning biomass and fit to surveys indicate a small difference (4%) in estimates from the early part of the time series when 4 extra data points were fit in 2014 estimates. Both models produce the same population trends. Given the unknown differences in catchability between the 2 survey trawls (estimates are all treated the same), the current assessment proceeds without the 1975, and 1979-1981 survey estimates (as do most other BSAI flatfish assessments).



Introduction

Alaska plaice (*Pleuronectes quadrituberculatus*) are primarily distributed on the Eastern Bering Sea continental shelf, with only small amounts found in the Aleutian Islands region. In particular, the summer distribution of Alaska plaice is generally confined to depths < 110 m, with larger fish predominately in deep waters and smaller juveniles (<20 cm) in shallow coastal waters (Zhang et al., 1998). The Alaska plaice distribution overlaps with northern rock sole (*Lepidopsetta polyxystra*) and yellowfin sole (*Limanda aspera*), but the center of the distribution is north of the center of the other two species and seems to be positioned further north in warm years and more southern in cold years. Substantial amounts of Alaska plaice were also found between St. Matthew and St. Lawrence Islands in the 2010 northern expansion of the annual Bering Sea shelf trawl survey.

There has been no research on stock structure in this species.

Fishery

Since implementation of the Fishery Conservation and Management Act (FCMA) in 1977, Alaska plaice have been lightly harvested in most years as no major commercial target fishery exists for them. In 2013 68% of the Alaska plaice catch occurred in the yellowfin sole fishery. In 2011, most of the annual TAC for Alaska plaice was harvested by late winter and early spring as bycatch in the yellowfin sole fishery (at levels well-below ABC). This pattern changed in 2012 with much lower catch rates in the early part of

the year but higher catch rates (over 1,000 t per week) in September. The majority of the 2013 catch was also taken early in the year. The 2014 catch is estimated at 19,000 t (less than half the ABC) based on the current catch history (detailed in Table 10.1).

Catches of Alaska plaice increased from approximately 1,000 t in 1971 to a peak of 62,000 t in 1988, the first year of joint venture processing (JVP) (Table 10.1). Part of this apparent increase was due to increased species identification and reporting of catches in the 1970s. Because of the overlap of the Alaska plaice distribution with that of yellowfin sole, much of the Alaska plaice catch during the 1960s was likely caught as bycatch in the yellowfin sole fishery (Zhang et al. 1998). With the cessation of joint venture fishing operations in 1991, Alaska plaice are now harvested exclusively by domestic vessels. Catch data from 1980-89 by its component fisheries (JVP, non-U.S., and domestic) are available in Wilderbuer and Walters (1990).

Alaska plaice are grouped with the rock sole, flathead sole, and other flatfish fisheries under a common prohibited species catch (PSC) limit, with seasonal and total annual allowances of prohibited species bycatch by these flatfish fisheries applied to the fisheries within the group. Prior to 2008, these fisheries were closed prior to attainment of the TAC due to the bycatch of halibut (Table 10.2), and typically were also closed during the first quarter due to a seasonal bycatch cap. Since the implementation of Amendment 80 in 2008 where catch and bycatch shares were assigned to groups of fishing vessels (cooperatives), these fisheries have not been subjected to time and area closures, although there was a rock sole target closure in 2010 (http://www.afsc.noaa.gov/REFM/Docs/2013/BSAIrocksole.pdf).

Substantial amounts of Alaska plaice were discarded in various eastern Bering Sea target fisheries in past years due to low market interest. Retained and discarded catches were reported for Alaska plaice for the first time in 2002, and indicated that of the 12,176 t caught only 370 t were retained, resulting in a retention rate of 3.0% (Table 10.3). Similar patterns were observed for 2003 - 2005 (4%, 5% and 6%, respectively). The discard patterns have now changed, with increased retention each year. The amount of Alaska plaice retained in 2013 was 62%. Examination of the discard data by fishery indicates that 81% - 87% of the discards in 2002 - 2013 can be attributed to the yellowfin sole fishery. Discarding also occurred in the rock sole, flathead sole, Pacific cod and bottom pollock fisheries. The locations where Alaska plaice were caught, by month, in 2014 are shown in Figure 10.1.

Prior to 2002, Alaska plaice were managed as part of the “other flatfish” complex. Since then an age-structured model has been used for the stock assessment allowing Alaska plaice to be managed separately from the “other flatfish” complex as a single species.

Data

In summary, the data available for Alaska plaice are:

Source	Data	Years
NMFS Eastern Bering Sea shelf survey	Survey biomass and standard error	1983-2014
	Age Composition (by sex)	1982, 1988, 1992-1995, 1998, 2000-2002, 2005-2013
	Length Composition (by sex)	1983-1987, 1989-1991, 1996-1997, 1999, 2003, 2004, 2014
Fisheries	Catch	1971-2014
	Age Composition (by sex)	2000, 2002 and 2003
	Length Composition (by sex)	1978-89, 1995, 2001 and 2008-2012

1) Total catch weight, 1971-2014;
2) Proportional fishery catch number at age, 2000, 2002-2003
3) Proportional fishery catch number at length, 1978-89, 1995, 2001, 2008-2012
4) Survey biomass and standard error 1982-2012;
5) Survey age composition, 1982, 1988, 1992-1995, 1998, 2000-2002, 2005-2013
6) Survey length composition, 1983-1987, 1989-1991, 1996-1997, 1999, 2003, 2004, 2014

Fishery:

This assessment uses fishery catches from 1971 through 2014 (Table 10.1). Fishery length compositions from 1978-89, 1995, 2001 and 2008-2012 for each sex were also used, as well as sex-specific age compositions from 2000, 2002 and 2003. The number of ages and lengths sampled from the fishery are shown in Table 10.4.

The catch of Alaska plaice taken in scientific surveys, subsistence fishing, recreational fishing, fisheries managed under other FMPs from 1977 –2014 is shown in Table 10.5.

From August 24-September 30, 2014 the Alaska plaice catch averaged 750 t per week. Yellowfin sole catch is still well below the TAC and fishing is ongoing. Alaska plaice are usually caught as bycatch in the yellowfin sole fishery. Since the fishery was continuing at a good pace, it seemed reasonable to assume that Alaska plaice would continue to be caught at a similar rate to the previous 5 weeks. The catch at Sept. 30 was 16,922 with a TAC of 20,000 t. It was therefore estimated that the Alaska plaice catch could reach 19,000 t for the 2014 fishing season.

Survey:

Because Alaska plaice are usually taken incidentally in target fisheries for other species, CPUE from commercial fisheries is considered unreliable information for determining trends in abundance for these species. It is therefore necessary to use research vessel survey data to assess the condition of these stocks.

Large-scale bottom trawl surveys of the Eastern Bering Sea continental shelf have been conducted in 1975 and 1979-2014 by NMFS. Survey estimates of total biomass and numbers at age are shown in Tables 10.6 and 10.7, respectively. It should be recognized that the resultant biomass estimates are point estimates from an "area-swept" survey. As a result, they carry the uncertainty inherent in the technique. It is assumed that the sampling plan covers the distribution of the fish and that all fish in the path of the trawl are captured. That is, there are no losses due to escape or gains due to gear herding effects.

The trawl gear was changed in 1982 from the 400 mesh eastern trawl to the 83-112 trawl, as the latter trawl has better bottom contact. This may contribute to the increase in Alaska plaice seen from 1981 to 1982, as increases between these years were noticed in other flatfish as well. Due to the differences in catchability between these two survey trawls, this assessment only uses the survey estimates from 1982-2014.

Although calibration between years with different trawl gear has not been accomplished, the survey data since 1982 does incorporate calibration between the two vessels used in the survey. Fishing Power Coefficients (FPC) were estimated following the methods of Kappenman (1992) for 1982-2005. The trend of the biomass estimates is the same as without the calibration between vessels, but the magnitude of the change in 1988 was markedly reduced. In 1988, one vessel had slightly smaller and lighter trawl doors, which may have affected the estimates for several species. With the exception of a high 1988 estimate, Alaska plaice has shown a relatively stable trend since 1985, although abundance was higher in the 1994, 1997 and 2006 surveys (Figure 10.2, Table 10.6). The 2012 estimate of 581,900 t was the highest observed in the five previous years. The past two surveys in 2013 and 2014 have decreased to 505,600 t and 451,600 t, respectively.

Assessments for other BSAI flatfish have suggested a relationship between bottom temperature and survey catchability (Wilderbuer et al. 2002), where bottom temperatures are hypothesized to affect survey catchability by affecting either stock distributions and/or the activity level of flatfish relative to the capture process. Temperature was not expected to affect Alaska plaice catchability since they are a "cold loving" species with an anti-freeze protein that inhibits ice formation in their blood (Knight et al. 1991). This relationship was investigated for Alaska plaice by using the annual temperature anomalies from surveys conducted from 1982 to 2014. Examination of the residuals from the model fit to the bottom trawl survey relative to the annual bottom temperature anomalies did not indicate a correlation between the two data series (Figure 10.3). This was also the result from a past assessment (Spencer et al. 2004) where a fit with a LOWESS smoother indicated that little correspondence exists between the two time series, and the cross-correlation coefficient (-0.17) was not significant at the 0.05 level. Thus, the relationship between bottom temperature and survey catchability was not pursued further.

In 2010 the Alaska Fisheries Science Center had the opportunity to extend the annual bottom trawl survey to the northern Bering Sea past St. Lawrence Island by the additional sampling of 142 stations. Substantial amounts of Alaska plaice were encountered in the northern area with a total biomass estimate of 311,900 t (Figure 10.4). This indicated that for 2010, the combined eastern and northern Bering Sea Alaska plaice biomass was estimated at 810,000 t, of which 38% occurred north of the standard survey area. Since the northern Bering Sea has only been surveyed one time with no plan to repeat the survey and also because the area is closed to fishing, biomass estimates from only the standard survey area are used in this assessment (Table 10.6) and the northern Bering Sea is not included in the assessment.

In this assessment, the estimated population numbers at length from the trawl survey were multiplied by the age-length key in order to produce a matrix of estimated population numbers by age and length, from which an unbiased average length for each age can be determined. These population estimates by length and sex were used to fit the model for years when age composition data were not available. The numbers of age and length samples obtained from the surveys are shown in Table 10.8.

Analytic Approach

Model Structure

This catch at age model was developed with the software program Automatic Differentiation Model Builder (ADMB; Fournier et al. 2012). The age-structured assessment model is configured to accommodate the sex-specific aspects of the population dynamics of Alaska plaice, because the sex-specific weight-at-age diverges after the age of maturity (about age 10 for 50% of the stock) with females growing larger than males (Table 10.9). The model is coded to allow for the input of sex-specific estimates of fishery and survey age composition and weight-at-age and provides sex-specific estimates of population numbers, fishing mortality, selectivity, fishery and survey age composition and allows for the estimation of sex-specific natural mortality and catchability. The catch-at-age population dynamics model was used to obtain estimates of several population variables of the Alaska plaice stock, including recruitment, population size, and catch. Population size in numbers at age a in year t was modeled as

$$N_{t,a} = N_{t-1,a-1} e^{-Z_{t-1,a-1}} \qquad 3 \le a < A, \quad 3 \le t \le T$$

where Z is the sum of the instantaneous fishing mortality rate ($F_{t,a}$) and the natural mortality rate (M), A is the maximum modeled age in the population, and T is the terminal year of the analysis. The numbers at age A are a "pooled" group consisting of fish of age A and older, and are estimated as

$$N_{t,A} = N_{t-1,A-1} e^{-Z_{t-1,A-1}} + N_{t-1,A} e^{-Z_{t-1,A}}$$

Recruitment was modeled as the number of age 3 fish. The efficacy of estimating productivity directly from the stock-recruitment data (as opposed to using an SPR proxy) was examined in a past assessment (Wilderbuer et al. 2008) by comparing results from fitting either the Ricker or Beverton-Holt forms within the model and choosing different time-periods of stock-recruitment productivity. This analysis is described in more detail in the 2008 assessment.

The numbers at age in the first year are modeled with a lognormal distribution

$$N_{1,a} = e^{(meaninit - M(a-1) + \gamma_a)}$$

where *meaninit* is the mean of the recruitments that made up the initial age comp and γ is an age-variant deviation.

The mean numbers at age within each year were computed as

$$\overline{N}_{t,a} = N_{t,a} * (1 - e^{-Z_{t,a}}) / Z_{t,a}$$

Catch in numbers at age in year t ($C_{t,a}$) and total biomass of catch each year (Y_t) were modeled as

$$C_{t,a} = F_{t,a} \overline{N}_{t,a}$$

$$Y_t = \sum_{a=1}^{A} C_{t,a} w_a$$

where w_a is the mean weight at age for Alaska plaice.

A conversion matrix was derived from the von Bertalanffy growth relationship, and used to convert the modeled numbers at age into modeled numbers at length. There are 51 length bins ranging from 10 to 60 cm, and 23 age groups ranging from 3 to 25+. For each modeled age, the transition matrix (TR) consists of a probability distribution of numbers at length, with the expected value equal to the predicted length-at-age from the von Bertalanffy relationship. The variation around this expected value was derived from a linear regression of coefficient of variation (CV) in length-at-age against age, where the CV were obtained from the sampled specimens over all survey years. The estimated linear relationship predicts a

CV of 0.14 at age 3 and a CV of 0.10 at age 25. The conversion matrix, vector of mean numbers at age, and survey selectivity by age were used to compute the estimated survey length composition, by year, as

$$\overline{\mathbf{NL}}_t = (\boldsymbol{srvsel} * \overline{\mathbf{NA}}_t) * \mathbf{TR}^{\mathbf{T}}$$

where ***srvsel*** is a vector of survey selectivity by age.

Estimating certain parameters in different stages enhances the estimation of large number of parameters in nonlinear models. For example, the fishing mortality rate for a specific age and time ($F_{t,a}$) is modeled as the product of an age-specific selectivity function ($fishsel_a$) and a year-specific fully-selected fishing mortality rate. The fully selected mortality rate is modeled as the product of a mean (μ) and a year-specific deviation (ε_t), thus $F_{t,a}$ is

$$F_{t,a} = fishsel_a * e^{(\mu+\varepsilon_t)}$$

In the early stages of parameter estimation, the selectivity coefficients are not estimated. As the solution is being approached, selectivity was modeled with the logistic function:

$$fishsel_a = \frac{1}{1+e^{(-slope(a-fifty)}}$$

where the parameter *slope* affects the steepness of the curve and the parameter *fifty* is the age at which sel_a equals 0.5. The selectivity for the survey is modeled in a similar manner.

Parameters Estimated Independently

The parameters estimated independently include the natural mortality (M) and survey catchability (q_srv). Fish from both sexes have frequently been aged as high as 25 years from samples collected during the annual trawl surveys. Zhang (1987) determined that the natural mortality rate for Alaska plaice is variable by sex and may range from 0.195 for males to 0.27 for females. In past assessments natural mortality was fixed at 0.25 based on an earlier analysis of natural mortality (Wilderbuer and Walters 1997, Table 8.1).

In the 2010 assessment, the natural mortality rate of Alaska plaice was re-estimated using 3 methods from the literature based on the life history characteristics of maximum life span (Hoenig 1983), average age (Chapman and Robson 1960) and the relationship between growth and maximum length (Gislason et al. 2008). The results are summarized below and suggest a range of natural mortality values from 0.08 to 0.13 for males and 0.08 to 0.29 for females.

Method	Males	Females
Hoenig (1983)	0.11	0.11
Chapman and Robson (1960)	0.08	0.08
Gislason et al. 2008	0.12	0.29
Model profiling	0.13	0.13

In this assessment, the model was again run for different combinations of male and female M to discern what value provides the best fit to the data components in terms of –log(likelihood). The best fit to the observable population characteristics occurred at M = 0.13 for both sexes (Figure 10.5). This value of natural mortality is close to those estimated from the other three methods and also is consistent with the natural mortality used in other assessments of Bering Sea shelf flatfish which have similar life histories,

growth and maximum ages. Therefore a value of M = 0.13 was used to model natural mortality for both males and females in this assessment.

Herding experiments in the eastern Bering Sea have demonstrated that many of the flatfish encountered in the area between the outer end of the footrope and where the bridles contact the sea floor (outside the trawl path) are herded into the path of the bottom trawl in varying degrees (Somerton and Munro 2001). Although Alaska plaice were not among the seven species that were explicitly studied, it is assumed that their behavior is similar to the other studied species which all exhibited herding behavior. The mean herding effect from all seven species combined resulted in a bridle efficiency of 0.234. This assessment incorporates a herding effect into the stock assessment model by fixing survey catchability (q) at 1.2, close to the mean value from the combined flatfish species in the herding experiment.

Alaska plaice exhibit sex-specific dimorphic growth after the age of sexual maturity with females attaining a larger size than males. The von Bertalanffy parameters fit to the population length at age and the length-weight relationship of the form $W = aL^b$ were estimated as:

	Length at age fit			Length-weight fit		
	L_{inf}(cm)	k	t_o	a	b	n
males	49.9	0.06	-4.02	0.1249	2.98	866
females	50.1	0.127	0.35	0.0055	3.23	1,381

The combination of the length-weight relationship and the von Bertalanffy growth curve produces an estimated weight-at-age relationship that is similar to that used in previous Alaska plaice assessments. The sex-specific weight-at-age relationship calculated from the average population mean length at age and the length-weight relationship, by sex, are shown in Figure 10.6.

A new maturity schedule is available for this assessment from samples obtained in 2012. These histologically determined estimates of proportion mature at age (TenBrink and Wilderbuer in review) replace the previously used anatomically-derived estimates (Zhang 1987). Both studies estimated similar results differing in estimated 2013 female spawning biomass by only 4%.

Parameters Estimated Conditionally

Parameter estimation is facilitated by comparing the model output to several observed quantities, such as the age compositions of the fishery and survey catches, the survey biomass, and the fishery catches. The general approach is to assume that deviations between model estimates and observed quantities are attributable to observation error and can be described with statistical distributions. Each data component provides a contribution to a total log-likelihood function, and parameter values that maximize the log-likelihood are selected.

The log-likelihoods of the age compositions were modeled with a multinomial distribution. The log of the multinomial function (excluding constant terms) is

$$n\sum_{t,a} p_{t,a} \ln(\hat{p}_{t,a})$$

where n_t is the number of fish aged, and p and $\hat{p}$ are the observed and estimated age proportion at age.

The log-likelihood of the survey biomass was modeled with a lognormal distribution:

$$\lambda_2 \sum_t (\ln(obs_biom_t) - \ln(pred_biom_t))^2 / 2 * cv(t)^2$$

where obs_biom_t and $pred_biom_t$ are the observed and predicted survey biomass at time t, $cv(t)$ is the coefficient of variation of observed biomass in year t, and λ_2 is a weighting factor.
The predicted survey biomass for a given year is

$$q_srv * \sum_a selsrv_a (\overline{N}_a * wt_a)$$

where $selsrv_a$ is the survey selectivity at age and wt_a is the population weight at age.

The log-likelihood of the catch biomass was modeled with a lognormal distribution:

$$\lambda_3 \sum_t (\ln(obs_cat_t) - \ln(pred_cat_t))^2$$

where obs_cat_t and $pred_cat_t$ are the observed and predicted catch. Because the catch biomass is generally thought to be observed with higher precision than other variables, λ_3 is given a very high value (hence low variance in the total catch estimate) so as to fit the catch biomass nearly exactly. This can be accomplished by varying the F levels, and the deviations in F are not included in the overall likelihood function. The overall likelihood function (excluding the catch component) is

$$\lambda_1 \left(\sum_t \varepsilon_t + \sum_a \gamma_a \right) + n \sum_{t,a} p_{t,a} \ln(\hat{p}_{t,a}) + \lambda_2 \sum_t (\ln(obs_biom_t) - \ln(pred_biom_t))^2 / 2 * cv(t)^2$$

For the model run in this analysis, λ_1, λ_2, and λ_3 were assigned weights of 1,1, and 500, respectively. The value for age composition sample size, n, was set to 200 for surveys and 50 for the fishery. The likelihood function was maximized by varying the following parameters:

Parameter type	Number
1) fishing mortality mean (μ)	1
2) fishing mortality deviations (ε_t)	40
3) recruitment mean	1
4) recruitment deviations (ν_t) including initial yr	61
5) fishery selectivity patterns both sexes	4
8) survey selectivity patterns both sexes	4
Total parameters	111

Finally, a Monte Carlo Markov Chain (MCMC) algorithm was used to obtain estimates of parameter uncertainty (Gelman et al. 1995). One and a half million MCMC simulations were conducted, with every 1,000th sample saved for the sample from the posterior distribution. Ninety-five percent confidence intervals were produced as the values corresponding to the 5th and 95th percentiles of the MCMC evaluation. For this assessment, confidence intervals on female spawning biomass, total biomass and age 3 recruitment are presented.

Results

Modeling the Alaska plaice population with M set at 0.13 for both sexes results in population estimates that are 30-40% of the values derived from previous assessments which used M = 0.25. The values of $F_{40\%}$ and $F_{35\%}$ estimated at the reduced natural mortality level (0.143 and 0.195, respectively) are much more consistent with the other Bering Sea flatfish assessments than those that result from the M=0.25 estimates and produce a better fit to the observable population information.

Using the survey catchability value of 1.2, the model results estimate that the total Alaska plaice biomass (ages 3+) increased from 461,300 t in 1975 to a peak of 765,700 t in 1984 (Figure 10.7, Table 10.10). Beginning in 1984, the total biomass steadily declined to 535,600 t by 2003 before increasing again to 558,500 t in 2008. The model estimates a slow decrease thereafter to 484,600 t in 2014. The estimated survey biomass also shows a slow decline since a peak value estimated in 1984 (Figure 10.7). The female spawning biomass has also been very stable since a peak in 1985 and is projected at 215,300 t in 2015, well-above the $B_{40\%}$ value of 142,000 t. The recent increase from 2008-2013 is the result of above average year classes spawned in 2001 and 2002 that contributed to the mature biomass. The female spawning biomass trend is similar to the total biomass trend with a peak level estimated in 1985 and a slow decline thereafter until 2008 after which the spawning stock is estimated to be increasing (Figure 10.9).

As in past assessments, fitting fishery observations was de-emphasized by lowering the input sample sizes from 200 to 50. This contributed in part to producing estimates of 50% fishery selectivity at about 10 years for females and 9 for males (Figure 10.10). The fits to the trawl survey age and length compositions are shown in Figures 10.11 and 10.12 and the fit to the fishery age and length compositions are shown in Figures 10.13 and 10.14.

The modest changes in stock biomass are primarily a function of recruitment variability, as fishing pressure has been light. The fully selected fishing mortality estimates show a maximum value of 0.14 in 1988, and have averaged 0.04 from 1975-2014 (Figure 10.15). Estimated age-3 recruitment indicates high levels from the 1971-1976 year classes which built the stock to its peak level in 1982 (Figure 10.7, Figure 10.16, 10.10). Estimated numbers-at-age are shown in Table 10.11. From 1981-1997 the estimated recruitment declined, averaging 220 million fish. Recruitment is estimated have improved since 1997 with above average recruitment strength in 1998 and exceptionally strong recruitment in 2001 and 2002. These fish have contributed to a high level of female spawning biomass in 2008-2013.

Harvest Recommendations

The reference fishing mortality rate for Alaska plaice is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $B_{40\%}$, $F_{40\%}$, and $SPR_{40\%}$ were obtained from a spawner-per-recruit analysis. Assuming that the average recruitment from 1972-2008 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{40\%}$ is calculated as the product of $SPR_{40\%}$ * equilibrium recruits (=142,100 t). The 2015 spawning biomass is estimated at 215,300 t. Since reliable estimates of 2015 spawning biomass (B), $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and $B>B_{40\%}$ (215,300 t > 142,100 t), Alaska plaice reference fishing mortality is defined in tier 3a of Amendment 56. For this tier, F_{ABC} is constrained to be $\leq F_{40\%}$, and F_{OFL} is defined as $F_{35\%}$. The values of these quantities are:

2015 SSB estimate (B)	=	215,300 t
$B_{40\%}$	=	142,100 t
$F_{40\%}$	=	0.143
F_{ABC}	=	0.143
$F_{35\%}$	=	0.175
F_{OFL}	=	0.175

The estimated catch level for year 2015 associated with the overfishing level of F = 0.175 is 54,000 t. **The 2015 recommended ABC associated with F_{ABC} of 0.143 is 44,900 t.** Projections of Alaska plaice female spawning biomass (described below) at a harvest rate equal to the average fishing mortality rate of

the past five years indicate that the stock could increase to a female spawning biomass in 2027 of over 235,000 t (Fig. 10.17).

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2014 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2015 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2014. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2015, are as follows ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

> *Scenario 1*: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
>
> *Scenario 2*: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2015 recommended in the assessment to the *max* F_{ABC} for 2015. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)
>
> *Scenario 3*: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)
>
> *Scenario 4*: In all future years, F is set equal to the 2010-2014 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
>
> *Scenario 5*: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, and five-year projections of the mean Alaska plaice harvest and spawning stock biomass for the remaining four scenarios are shown in Table 10.13.

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the Alaska plaice stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY level in 2015 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, F is set equal to $max\ F_{ABC}$, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2027 under this scenario, then the stock is not approaching an overfished condition.)

The results of these two scenarios indicate that Alaska plaice are neither overfished nor approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2013 of scenario 6 is well above its $B_{35\%}$ value of 124,300 t. With regard to whether the stock is likely to be in an overfished condition in the near future, the expected stock size in the year 2027 of scenario 7 is also greater than its $B_{35\%}$ value. Figure 10.18 shows the relationship between the estimated time-series of female spawning biomass and fishing mortality and the tier 3 control rule for Alaska plaice.

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2015, it does not provide the best estimate of OFL for 2016, because the mean 2016 catch under Scenario 6 is predicated on the 2015 catch being equal to the 2015 OFL, whereas the actual 2015 catch will likely be less than the 2015 ABC. Therefore, the projection model was re-run with the 2016 catch fixed at the 2015 level.

Year	Catch	ABC	OFL
2015	19,000	44,900	54,000
2016	19,000	42,900	51,600

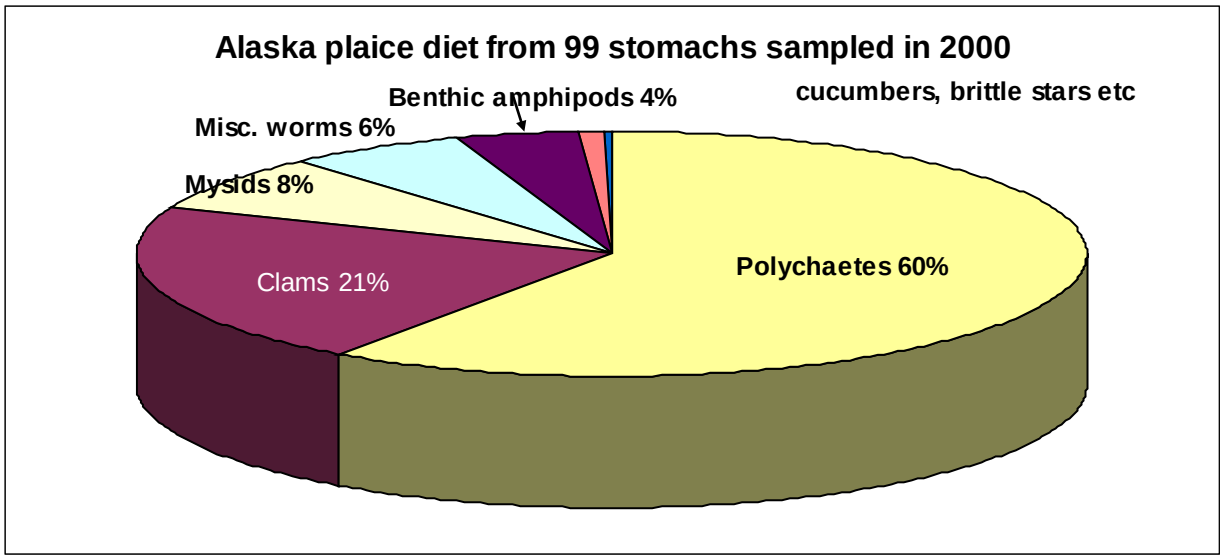
Ecosystem considerations

Ecosystem Effects on the stock

1) Prey availability/abundance trends

The feeding habits of juvenile Alaska plaice are relatively unknown, although the larvae are relatively large at hatching (5.85 mm) with more advanced development than other flatfish (Pertseva-Ostroumova 1961).

For adult fish, Zhang (1987) found that the diet consisted primarily of polychaetes and amphipods regardless of size. For fish under 30 cm, polychaetes contributed 63% of the total diet with sipunculids (marine worms) and amphipods contributing 21.7% and 11.6%, respectively. For fish over 30 cm, polychaetes contributed 75.2% of the total diet with amphipods and echiurans (marine worms) contributing 6.7% and 5.7%, respectively. Similar results were in stomach sampling from 1993-1996, with polychaetes and marine worms composing the majority of the Alaska plaice diet (Lang et al. 2003). McConnaughy and Smith (2000) contrasted the food habits of several flatfish between areas of high and low CPUE, using aggregated data from 1982 to 1994. For Alaska plaice, the diets were nearly identical with 76.5% of the diet composed of polychaetes and unsegmented coelomate worms in the high CPUE areas as compared to 83.1% in the low CPUE areas.



2) Predator population trends

Alaska plaice contribute a relatively small portion of the diets of Pacific cod, Pacific halibut, and yellowfin sole as compared with other flatfish. Total consumption estimates of Alaska plaice from 1993 to 1996 ranged from 0 t in 1996 to 574 t in 1994 (Lang et al. 2003). Consumption by yellowfin sole is upon fish < 2 cm whereas consumption by Pacific halibut is upon fish > 19 cm (Lang et al. 2003).

3) Changes in habitat quality

The habitats occupied by Alaska plaice are influenced by temperature, which has shown considerable variation in the eastern Bering Sea in recent years. For example, the timing of spawning and advection to nursery areas are expected to be affected by environmental variation. Musienko (1970) reported that spawning occurs immediately after the ice melt, with peak spawning occurring at water temperatures from -1.53 to 4.11. In 1999, one of the coldest years in the eastern Bering Sea, the distribution was shifted further to the southeast than it was during 1998-2002. However, in 2003, one of the warmest years in the EBS, the distribution was shifted further to the southeast than observed in 1999.

Fishery effects on the ecosystem

Alaska plaice are not a targeted species and are harvested in a variety of fisheries in the BSAI area. Since 2002, when single-species management for Alaska plaice was initiated, harvest estimates by fishery are available. Most Alaska plaice are harvested by the yellowfin sole fishery, accounting for over 80% of the Alaska plaice catch since 2002. Flathead sole, rock sole, and Pacific cod fisheries make up the remainder of the catch. The ecosystem effects of the yellowfin sole fishery can be found with the yellowfin sole assessment in this SAFE document.

Due to the minimal consumption estimates of Alaska plaice (Lang et al. 2003) by other groundfish predators, the yellowfin sole fishery does not have a significant impact upon those species preying upon Alaska plaice. Additionally, the relatively light fishing mortality rates experienced by Alaska plaice are not expected to have significant impacts on the size structure of the population or the maturity and fecundity at age. It is not known what effects the fishery may have on the maturity-at-age of Alaska plaice. The yellowfin sole fishery, however, does contribute substantially to the total discards in the EBS,

as indicated by the discarding of Alaska plaice discussed in this assessment, and general discards within this fishery discussed in the yellowfin sole assessment.

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Tables

Table 10.1. Harvest (t) of Alaska plaice from 1977-2014.

Year	Harvest
1977	2,589
1978	10,420
1979	13,672
1980	6,902
1981	8,653
1982	6,811
1983	10,766
1984	18,982
1985	24,888
1986	46,519
1987	18,567
1988	61,638
1989	14,134
1990	10,926
1991	15,003
1992	18,074
1993	13,846
1994	10,882
1995	19,172
1996	16,096
1997	21,236
1998	14,296
1999	13,997
2000	14,487
2001	8,685
2002	12,176
2003	9,978
2004	7,888
2005	11,194
2006	17,318
2007	19,522
2008	17,376
2009	13,944
2010	16,165
2011	23,656
2012	16,612
2013	23,523
2014*	19,000

* From August 24-September 30, 2014 the Alaska plaice catch averaged 750 t per week. Yellowfin sole catch is still well below the TAC and fishing is ongoing. Alaska plaice are usually caught as bycatch in the yellowfin sole fishery. Since the fishery was continuing at a good pace, it seemed reasonable to assume that Alaska plaice would continue to be caught at a similar rate to the previous 5 weeks. The catch at Sept. 30 was 16,922 with a TAC of 20,000 t. **It was therefore estimated that the Alaska plaice catch could reach 19,000 t for the 2014 fishing season.**

Table 10.2. Restrictions on the "other flatfish" fishery from 1995 to 2007 in the Bering Sea – Aleutian Islands management area. Unless otherwise indicated, the closures were applied to the entire BSAI management area. Zone 1 consists of areas 508, 509, 512, and 516, whereas zone 2 consists of areas 513, 517, and 521. Since 2008 no management restrictions have occurred.

Year	Dates	Bycatch Closure
1995	2/21 – 3/30	First Seasonal halibut cap
	4/17 – 7/1	Second seasonal halibut cap
	8/1 – 12/31	Annual halibut allowance
1996	2/26 – 4/1	First Seasonal halibut cap
	4/13 – 7/1	Second seasonal halibut cap
	7/31 – 12/31	Annual halibut allowance
1997	2/20 – 4/1	First Seasonal halibut cap
	4/12 – 7/1	Second seasonal halibut cap
	7/25 – 12/31	Annual halibut allowance
1998	3/5 – 3/30	First Seasonal halibut cap
	4/21 – 7/1	Second seasonal halibut cap
	8/16 – 12/31	Annual halibut allowance
1999	2/26 – 3/30	First Seasonal halibut cap
	4/27 – 7/04	Second seasonal halibut cap
	8/31 – 12/31	Annual halibut allowance
2000	¾ – 3/31	First Seasonal halibut cap
	4/30 – 7/03	Second seasonal halibut cap
	8/25 – 12/31	Annual halibut allowance
2001	3/20 – 3/31	First Seasonal halibut cap
	4/27 – 7/01	Second seasonal halibut cap
	8/24 – 12/31	Annual halibut allowance
2002	2/22 – 12/31	Red King crab cap (Zone 1 closed)
	3/1 – 3/31	First Seasonal halibut cap
	4/20 – 6/29	Second seasonal halibut cap
	7/29 – 12/31	Annual halibut allowance
2003	2/18 – 3/31	First Seasonal halibut cap
	4/1 – 6/21	Second seasonal halibut cap
	7/31 – 12/31	Annual halibut allowance
2004	2/24 – 3/31	First Seasonal halibut cap
	4/10 – 12/31	Bycatch status
2005	3/1 - 3/31	First Seasonal halibut cap
	4/22-6/30	Second Seasonal halibut cap
	5/9-12/31	Bycatch status, TAC attained
2006	2/21 - 3/31	First Seasonal halibut cap
	4/5 – 12/31	Red King crab cap (Zone 1 closed)
	4/12 – 5/31	Second seasonal halibut cap
	5/26	TAC attained, 7,000 t reserve released
	8/7 – 12/31	Annual halibut allowance
2007	2/17-3/31	First seasonal halibut cap
	4/1-6/21	Second seasonal halibut cap
	7/31-12/31	Annual halibut allowance

Table 10.3 Discarded and retained BSAI Alaska plaice catch (t) for 2002-2013, from NMFS Alaska regional office 'blend" (2002) and catch accounting system (2003 - 2014) data.

year	Discard	Retained	Total	Proportion discarded
2002	11,806	370	12,176	0.97
2003	9,428	350	9,778	0.96
2004	7,193	379	7,572	0.95
2005	10,293	786	11,079	0.93
2006	14,746	2,564	17,310	0.85
2007	15,481	3,946	19,427	0.8
2008	9,330	8,046	17,376	0.54
2009	5,061	8,882	13,945	0.36
2010	5,845	10,322	16,166	0.36
2011	7,197	16,459	23,656	0.30
2012	3,589	13,023	16,611	0.22
2013	9,053	14,470	23,523	0.38

Table 10.4. Alaska plaice sample sizes from the BSAI fishery. The hauls columns refer to the number of hauls where either lengths or aged otoliths were obtained.

Year	Total Hauls with AK Plaice	Haul Count -- Lengths collected	Number of Lengths	Haul Count -- Otoliths collected	Number of Otoliths	Number of Aged Otoliths
2008	11741	1641	7494	329	381	0
2009	9176	1950	8795	412	443	0
2010	9743	1810	8781	344	398	0
2011	9914	2800	14328	545	686	0
2012	9782	2962	13611	548	600	0
2013	11026	3469	16646	649	787	0
2014	8217	1900	8852	373	456	0

Table 10.5. Research catches (t) of Alaska plaice in the BSAI area from 1977 to 2014.

Year	Research Catch (t)
1977	4.28
1978	4.94
1979	17.15
1980	12.02
1981	14.31
1982	26.77
1983	43.27
1984	32.42
1985	23.24
1986	19.66
1987	19.74
1988	39.42
1989	31.10
1990	32.29
1991	29.79
1992	15.14
1993	19.71
1994	22.48
1995	28.47
1996	18.26
1997	22.59
1998	17.17
1999	18.95
2000	15.98
2001	20.45
2002	15.07
2003	15.39
2004	18.03
2005	22.52
2006	28.50
2007	18.80
2008	17.50
2009	18.40
2010	17.30
2011	17.82
2012	19.26
2013	17.18
2014	15.35

Table 10.6. Estimated biomass and standard deviations (t) of Alaska plaice from the eastern Bering Sea shelf trawl survey, 1982-2014.

Year	Biomass estimate	Standard Deviation
1982	715,400	64,800
1983	743,000	65,100
1984	789,200	35,800
1985	580,000	61,000
1986	553,900	63,000
1987	564,400	57,500
1988	699,400	140,000
1989	534,000	58,800
1990	522,800	50,000
1991	529,000	50,100
1992	530,400	56,400
1993	515,200	50,500
1994	623,100	53,300
1995	552,292	62,600
1996	529,300	67,500
1997	643,400	73,200
1998	452,600	58,700
1999	546,522	47,000
2000	443,620	67,600
2001	540,458	68,600
2002	428,519	53,800
2003	467,326	97,400
2004	488,217	63,800
2005	503,861	55,698
2006	636,971	81,547
2007	421,765	37,831
2008	509,382	47,431
2009	529,729	50,359
2010	498,104	46,867
2011	519,578	72,781
2012	581,894	83,432
2013	505,583	65,596
2014	451,624	48,850

Table 10.7. Alaska plaice population numbers at age (millions) estimated from the NMFS Bering Sea groundfish surveys and age readings of sampled fish.

	females												
Year	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1982	0.41	0.37	22.53	41.28	269	172.3	90.15	57.82	181.37	152.84	337.25	231.75	117.71
1988	0	0.21	3.85	11.7	47.27	35.98	62.44	32.87	62.31	55.98	25.55	77.65	0
1992	0	0	4.21	4.88	7.67	32.47	28.58	20.72	35.2	24.66	16.18	25.8	22.36
1993	0	0	5.45	14.86	30.17	42.06	53.67	5.63	2.43	25.19	42.68	26.55	38.77
1994	0	0	7.69	14.8	45.16	38.83	21.56	45.23	16.55	11.28	55.34	11.75	50.02
1995	0	0	10	31.4	32.78	47.14	34.28	16.81	23.35	16.56	10.15	30.11	30.32
1998	0	0.87	3.72	9.78	35.71	37.29	58.62	28.49	40.13	43.26	17.83	24.84	14.62
2000	0	0.1	3.94	3.86	22.18	27.15	53.22	26.88	33.92	18.95	21.06	15.94	13.8
2001	0	0	4.11	9.46	13.63	48.23	21.59	85.08	30.82	44.56	15.27	16.01	10.5
2002	0	0.04	1.38	13.85	20.02	14.87	31.56	22.2	37.67	15.24	31.42	13.78	22.86
2005	0.86	2.07	13.32	23.35	34.58	31.89	31.31	28.52	24.17	28.67	33.18	19.61	22.53
2006	0.26	4.43	47.24	24.28	54.33	51.8	38.45	27.34	20.18	11.78	31.92	19.4	28.33
2007	0	4.02	43.49	56.53	35.95	24.59	20.18	27.42	29.71	16.8	17.94	16.9	8.71
2008	0	0	12.28	46.14	60.05	42.37	23.47	33.67	32.77	24.79	10.82	13.96	25.29
2009	0	0.55	9.92	14.33	89.06	61.3	24.44	36.06	26.58	17.58	15.89	12.03	18.55
2010	0	0	4.59	10.4	16.1	85.19	55.96	28.89	29.6	26.81	13.44	13.31	17.39
2011	0	0.03	0.61	21.03	34.45	31.66	73.68	60.28	24.6	16.22	26.19	8.6	9.66
2012	0	0	1.35	9.97	19.64	37.37	39.03	63.35	57.44	40.12	22.53	29.85	10.64
2013	0	0	3.47	8.83	12.58	37.11	33.53	22.53	48.73	38.42	42.84	28.05	14.08

Table 10.7 (continued).

	males												
Year	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1982	0.58	0	22.23	73.69	58.78	95.64	113.81	126.18	144.63	170.99	93.5	155.86	99.64
1988	0	0.14	3.66	6.49	37.64	36.15	47.49	32.31	102.5	17.23	6.35	28.89	15.16
1992	0	5.31	16.81	1.29	22.86	29.62	19.29	22.23	46.34	25.41	21.31	19.97	10.93
1993	0	0	2.94	36.76	14.75	25.43	43.65	15.2	17.67	34.2	42.85	6.14	12.04
1994	0.18	2	13.65	13.11	57.64	61.53	15.17	30.2	21.32	14.81	57.29	47.05	31.05
1995	0	0	0	28.54	20.44	84.71	20.96	17.54	38.87	17.38	20.09	17.17	27.44
1998	0	0.3	5.05	22.12	37.94	34.11	51.34	31.63	26.46	27.3	11.56	18.07	15.01
2000	0	0	9.04	0.98	20.94	20.93	75.64	44.57	27.81	30.16	21.56	16.45	3.35
2001	0	0	1.68	17.13	6.41	70.21	46.7	64.95	26.29	52.48	23.07	69.35	5.37
2002	0	1.01	2.18	13.73	15.76	21.47	30.88	45.28	37.32	20.83	32.13	13.55	32.91
2005	0.64	4.19	10.18	32.27	23.25	50.37	14.58	43.1	18.7	32.76	41.25	21.95	10.57
2006	0.09	9.84	46.73	29.28	60.61	61.64	46.65	29.81	24.25	25.34	23.38	55.71	31.55
2007	1.64	3.98	39.18	63.35	46.71	18.93	21.23	41.58	36.97	6.87	12.81	20.21	20.92
2008	0	0	6.71	87.18	60.27	14.47	29.59	52.29	13.51	32.08	15.63	18.74	23.65
2009	0	2.88	6.06	12.58	93.08	83.7	71.81	39.87	23.12	25.57	11.52	39.2	19.17
2010	0	0.48	6.62	17.02	31.68	61.44	65	40.38	48.41	35.67	30.19	24.47	10.99
2011	0	1.08	1.4	17.47	47.71	26.43	56.99	63.27	22.49	33.17	31.88	11.36	13.32
2012	0	0	7.33	3.57	39.68	66.94	25.25	85.81	49.72	33.23	20.86	12.86	9.19
2013	0	0	1.3	7.11	21.61	46.81	35.16	26.77	51.47	72.59	31.89	16.53	19.41

Table 10.7 (continued).

	females													
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16+**
1982	0.41	0.37	22.53	41.28	269	172.3	90.15	57.82	181.37	152.84	337.25	231.75	117.71	0
1988	0	0.21	3.85	11.7	47.27	35.98	62.44	32.87	62.31	55.98	25.55	77.65	0	104.15
1992	0	0	4.21	4.88	7.67	32.47	28.58	20.72	35.2	24.66	16.18	25.8	22.36	134.69
1993	0	0	5.45	14.86	30.17	42.06	53.67	5.63	2.43	25.19	42.68	26.55	38.77	99.41
1994	0	0	7.69	14.8	45.16	38.83	21.56	45.23	16.55	11.28	55.34	11.75	50.02	128.93
1995	0	0	10	31.4	32.78	47.14	34.28	16.81	23.35	16.56	10.15	30.11	30.32	157.67
1998	0	0.87	3.72	9.78	35.71	37.29	58.62	28.49	40.13	43.26	17.83	24.84	14.62	83.19
2000	0	0.1	3.94	3.86	22.18	27.15	53.22	26.88	33.92	18.95	21.06	15.94	13.8	137.91
2001	0	0	4.11	9.46	13.63	48.23	21.59	85.08	30.82	44.56	15.27	16.01	10.5	134.68
2002	0	0.04	1.38	13.85	20.02	14.87	31.56	22.2	37.67	15.24	31.42	13.78	22.86	105.04
2005	0.86	2.07	13.32	23.35	34.58	31.89	31.31	28.52	24.17	28.67	33.18	19.61	22.53	100.02
2006	0.26	4.43	47.24	24.28	54.33	51.8	38.45	27.34	20.18	11.78	31.92	19.4	28.33	145.96
2007	0	4.02	43.49	56.53	35.95	24.59	20.18	27.42	29.71	16.8	17.94	16.9	8.71	91.65
2008	0	0	12.28	46.14	60.05	42.37	23.47	33.67	32.77	24.79	10.82	13.96	25.29	113.03
2009	0	0.55	9.92	14.33	89.06	61.3	24.44	36.06	26.58	17.58	15.89	12.03	18.55	120.89
2010	0	0	4.59	10.4	16.1	85.19	55.96	28.89	29.6	26.81	13.44	13.31	17.39	117.21
2011	0	0.03	0.61	21.03	34.45	31.66	73.68	60.28	24.6	16.22	26.19	8.6	9.66	116.23
2012	0	0	1.35	9.97	19.64	37.37	39.03	63.35	57.44	40.12	22.53	29.85	10.64	162.65
2013	0	0	3.47	8.83	12.58	37.11	33.53	22.53	48.73	38.42	42.84	28.05	14.08	91.81

Table 10.7 (continued).

	males													
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16+**
1982	0.58	0	22.23	73.69	58.78	95.64	113.81	126.18	144.63	170.99	93.5	155.86	99.64	103.54
1988	0	0.14	3.66	6.49	37.64	36.15	47.49	32.31	102.5	17.23	6.35	28.89	15.16	139.34
1992	0	5.31	16.81	1.29	22.86	29.62	19.29	22.23	46.34	25.41	21.31	19.97	10.93	110.33
1993	0	0	2.94	36.76	14.75	25.43	43.65	15.2	17.67	34.2	42.85	6.14	12.04	124.69
1994	0.18	2	13.65	13.11	57.64	61.53	15.17	30.2	21.32	14.81	57.29	47.05	31.05	128.2
1995	0	0	0	28.54	20.44	84.71	20.96	17.54	38.87	17.38	20.09	17.17	27.44	112.23
1998	0	0.3	5.05	22.12	37.94	34.11	51.34	31.63	26.46	27.3	11.56	18.07	15.01	54.87
2000	0	0	9.04	0.98	20.94	20.93	75.64	44.57	27.81	30.16	21.56	16.45	3.35	134.13
2001	0	0	1.68	17.13	6.41	70.21	46.7	64.95	26.29	52.48	23.07	69.35	5.37	132.58
2002	0	1.01	2.18	13.73	15.76	21.47	30.88	45.28	37.32	20.83	32.13	13.55	32.91	62.78
2005	0.64	4.19	10.18	32.27	23.25	50.37	14.58	43.1	18.7	32.76	41.25	21.95	10.57	56.32
2006	0.09	9.84	46.73	29.28	60.61	61.64	46.65	29.81	24.25	25.34	23.38	55.71	31.55	82.37
2007	1.64	3.98	39.18	63.35	46.71	18.93	21.23	41.58	36.97	6.87	12.81	20.21	20.92	72.91
2008	0	0	6.71	87.18	60.27	14.47	29.59	52.29	13.51	32.08	15.63	18.74	23.65	144.92
2009	0	2.88	6.06	12.58	93.08	83.7	71.81	39.87	23.12	25.57	11.52	39.2	19.17	142.87
2010	0	0.48	6.62	17.02	31.68	61.44	65	40.38	48.41	35.67	30.19	24.47	10.99	154.91
2011	0	1.08	1.4	17.47	47.71	26.43	56.99	63.27	22.49	33.17	31.88	11.36	13.32	149.74
2012	0	0	7.33	3.57	39.68	66.94	25.25	85.81	49.72	33.23	20.86	12.86	9.19	121.85
2013	0	0	1.3	7.11	21.61	46.81	35.16	26.77	51.47	72.59	31.89	16.53	19.41	89.16

Table 10.8. Alaska plaice sample sizes from the BSAI trawl survey. The hauls columns refer to the number (Num.) of hauls from which either lengths or aged otoliths were obtained.

Year	Total Hauls	Hauls w/Lengths	Num. lengths	Hauls w/otoliths	Hauls w/ages	Num. otoliths	Num. ages
1982	334	152	14274	27	27	298	298
1983	353	118	11624				
1984	355	151	14026	32		457	
1985	357	168	10914	24		430	
1986	354	236	12349				
1987	357	172	8533				
1988	373	170	7079	10	10	284	284
1989	374	207	7741				
1990	371	215	7739	10		228	
1991	372	235	8163				
1992	356	219	7584	10	10	311	311
1993	375	241	8365	4	4	183	183
1994	375	248	9299	6	6	228	228
1995	376	252	9919	11	11	287	285
1996	375	254	10186	5		250	
1997	376	248	10143	3		82	
1998	375	281	10101	14	14	420	416
1999	373	268	13024	13		297	
2000	372	250	9803	16	16	368	359
2001	375	261	10990	16	16	339	335
2002	375	251	8409	24	24	359	355
2003	376	252	8343	15		320	
2004	375	262	8578	17		325	
2005	373	262	9284	20	20	341	337
2006	376	255	12097	18	18	362	362
2007	376	261	11729	43	42	343	335
2008	375	252	12804	35	35	342	338
2009	376	233	13547	68	68	620	590
2010	376	225	11366	60	51	627	448
2011	376	236	11514	59	59	571	560
2012	376	240	10399	62	62	484	475
2013	376	221	9705	69	69	544	537
2014	376	215	7296	51		502	

Table 10.9 Estimated maturity at age for female Alaska plaice. Anatomical estimates were estimated by Zhang (1987). Histological estimates (TenBrink and Wilderbuer in review) are used in the assessment.

	proportion mature	
age	Anatomical estimate	Histological estimate
3	0	0.00
4	0	0.02
5	0	0.03
6	0.08	0.08
7	0.2	0.16
8	0.43	0.30
9	0.58	0.50
10	0.79	0.70
11	0.88	0.84
12	0.95	0.92
13	0.97	0.97
14	0.98	0.98
15	0.99	1.00
16	1	1
17	1	1
18	1	1
19	1	1
20	1	1
21	1	1
22	1	1
23	1	1
24	1	1
25	1	1

Table 10.10. Estimated total biomass (ages 3+), female spawner biomass, and recruitment (age 3), with comparison to the 2012 SAFE estimates.

	Female spawning biomass		Total biomass (t)		Age 3 recruitment (millions)	
	2012	2014	2012	2014	2012	2014
1975	93,922	124875	376,087	461354	309	301
1976	115,398	144225	427,654	510624	310	297
1977	143,739	170930	484,362	563145	587	563
1978	173,741	201324	540,118	613486	352	341
1979	199,372	227398	584,939	652100	316	309
1980	222,092	249242	622,927	683520	326	322
1981	245,546	270179	660,681	714743	225	223
1982	269,498	288980	689,595	737346	242	240
1983	291,152	307430	713,892	755708	262	259
1984	309,464	321465	729,366	765685	302	299
1985	317,777	327741	727,772	759120	134	134
1986	315,476	323920	713,605	740553	148	147
1987	304,866	311424	675,243	698174	256	254
1988	296,660	301705	661,991	681595	156	155
1989	276,180	279520	604,079	620520	208	206
1990	274,630	277299	598,868	612766	321	319
1991	272,600	274164	595,635	607320	185	185
1992	266,657	267284	590,641	600509	281	284
1993	259,584	259368	583,070	591526	224	229
1994	256,247	254385	583,736	590827	329	323
1995	254,174	250716	587,994	593997	238	239
1996	249,714	245661	584,441	589519	235	236
1997	248,443	242787	581,303	585652	130	132
1998	245,696	239978	570,552	574341	152	154
1999	248,450	241149	564,212	567282	154	146
2000	249,626	242696	555,980	558167	175	167
2001	251,274	244231	546,637	547727	210	201
2002	251,559	245832	543,417	543054	218	205
2003	248,943	243638	537,335	535629	222	223
2004	245,293	240524	541,091	536820	434	390
2005	242,062	236770	557,301	547828	534	438
2006	236,992	230949	570,451	555093	194	162
2007	231,404	223749	580,344	557979	276	232
2008	229,524	218793	588,615	558513	263	216
2009	234,376	218891	594,890	557008	139	104
2010	244,008	223622	600,677	554461	171	111
2011	251,901	228099	598,432	544393		100
2012	257,418	229250	588,499	522533		
2013		229062		505340		
2014		222922		484582		

Table 10.11 Estimated numbers at age (millions) from the stock assessment model for ages 3-25.

	number of females at age (millions)											
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1975	151	125	137	187	163	106	27	25	15	12	11	9
1976	148	132	110	120	164	143	93	23	22	13	10	9
1977	281	130	116	96	106	144	125	81	20	19	11	9
1978	170	247	114	102	84	93	126	109	70	18	16	10
1979	155	149	217	100	89	74	81	109	94	60	15	14
1980	161	136	131	190	88	78	64	69	93	80	51	13
1981	111	141	119	115	167	77	68	56	60	81	69	44
1982	120	98	124	105	101	146	67	59	48	52	69	59
1983	130	105	86	109	92	89	128	59	52	42	45	60
1984	150	114	92	75	95	80	77	111	51	44	36	39
1985	67	131	100	81	66	83	70	67	95	43	38	30
1986	74	59	115	88	71	58	72	60	57	80	36	31
1987	127	65	51	101	77	62	49	61	49	46	64	29
1988	78	111	57	45	88	67	53	43	52	42	39	54
1989	103	68	98	50	39	76	57	44	34	41	32	30
1990	160	91	60	86	43	34	66	49	38	29	35	28
1991	93	140	80	52	75	38	30	58	42	33	25	30
1992	142	81	123	70	46	66	33	26	49	36	28	21
1993	115	125	71	108	61	40	57	28	22	42	30	23
1994	161	101	109	63	95	53	35	49	24	19	36	26
1995	120	142	88	96	55	83	47	30	42	21	16	30
1996	118	105	124	78	84	48	72	40	26	36	18	13
1997	66	104	92	109	68	73	42	62	34	22	30	15
1998	77	58	91	81	95	59	63	36	52	29	18	25
1999	73	68	51	80	71	83	51	55	30	44	24	15
2000	83	64	59	45	70	62	73	44	47	26	38	20
2001	101	73	56	52	39	61	54	63	38	40	22	32
2002	102	88	64	49	46	34	53	47	54	33	34	19
2003	111	90	77	56	43	40	30	46	40	46	28	29
2004	195	98	79	68	49	38	35	26	40	34	40	24
2005	219	171	86	69	60	43	33	30	22	34	30	34
2006	81	192	150	75	61	52	38	29	26	19	29	25
2007	116	71	169	132	66	53	45	32	24	22	16	24
2008	108	102	63	148	115	57	46	39	27	20	18	13
2009	52	95	89	55	130	101	50	39	33	23	17	15
2010	55	46	83	78	48	113	87	43	34	28	19	14
2011	50	49	40	73	69	42	98	75	36	28	23	16
2012	57	44	43	35	64	60	36	83	63	30	23	19
2013	68	50	38	37	31	56	52	31	71	53	25	20
2014	153	59	44	34	33	27	48	44	26	59	44	21

Table 10.11 (continued) Females

	15	16	17	18	19	20	21	22	23	24	25
1975	8	7	7	6	5	5	4	4	4	3	9
1976	8	7	6	6	5	4	4	4	3	3	11
1977	8	7	6	6	5	4	4	3	3	3	12
1978	8	7	6	5	5	4	4	3	3	3	13
1979	8	7	6	5	5	4	4	3	3	3	13
1980	12	7	6	5	4	4	3	3	3	2	13
1981	11	10	6	5	4	4	3	3	3	2	13
1982	38	9	9	5	4	4	3	3	3	2	13
1983	51	33	8	8	5	4	3	3	2	2	14
1984	52	44	28	7	6	4	3	3	2	2	13
1985	33	44	37	24	6	5	3	3	2	2	13
1986	25	27	36	31	20	5	5	3	2	2	13
1987	25	20	22	29	25	16	4	4	2	2	12
1988	24	21	17	18	24	21	13	3	3	2	11
1989	42	19	16	13	14	19	16	10	3	2	10
1990	25	35	16	14	11	12	16	14	9	2	11
1991	24	22	30	14	12	10	10	14	12	7	11
1992	25	20	18	26	12	10	8	9	12	10	15
1993	18	21	17	15	22	10	8	7	7	10	21
1994	20	15	18	14	13	18	8	7	6	6	26
1995	22	17	13	15	12	11	16	7	6	5	28
1996	25	18	14	11	13	10	9	13	6	5	27
1997	11	21	15	12	9	11	9	8	11	5	27
1998	12	9	18	13	10	7	9	7	6	9	26
1999	21	10	8	15	11	8	6	8	6	5	30
2000	13	18	9	7	13	9	7	5	6	5	30
2001	17	11	15	7	6	11	8	6	5	5	30
2002	27	15	9	13	6	5	9	7	5	4	30
2003	16	23	13	8	11	5	4	8	6	4	29
2004	25	14	20	11	7	9	5	4	7	5	28
2005	20	21	12	17	9	6	8	4	3	6	28
2006	29	17	18	10	14	8	5	7	3	3	29
2007	21	24	15	15	8	12	7	4	6	3	26
2008	20	18	20	12	13	7	10	5	3	5	24
2009	11	17	15	17	10	11	6	8	5	3	24
2010	13	9	14	12	14	8	9	5	7	4	23
2011	12	11	8	12	10	12	7	7	4	6	22
2012	13	10	9	6	10	8	10	6	6	3	23
2013	16	11	8	7	5	8	7	8	5	5	22
2014	16	13	9	7	6	4	7	6	7	4	22

Table 10.11 (continued) Male numbers at age (millions)

	3	4	5	6	7	8	9	10	11	12	13	14
1975	151	125	137	187	163	106	27	25	15	12	11	9
1976	148	132	110	120	164	143	93	23	22	13	10	9
1977	281	130	116	96	106	144	125	81	20	19	11	9
1978	170	247	114	102	84	93	126	110	71	18	16	10
1979	155	149	217	100	89	74	81	109	94	61	15	14
1980	161	136	131	190	88	78	64	70	94	81	51	13
1981	111	141	119	115	167	77	68	56	61	81	70	44
1982	120	98	124	105	101	146	67	59	48	52	70	60
1983	130	105	86	109	92	88	128	59	52	42	45	61
1984	150	114	92	75	95	80	77	111	51	45	36	39
1985	67	131	100	81	66	83	70	67	95	43	38	31
1986	74	59	115	88	71	57	72	60	57	81	37	32
1987	127	65	51	101	76	61	49	61	50	47	66	29
1988	78	111	57	45	88	67	53	43	52	43	40	56
1989	103	68	98	49	39	76	56	44	35	42	34	31
1990	160	91	60	85	43	34	66	49	38	30	36	29
1991	93	140	80	52	75	38	30	57	42	33	26	31
1992	142	81	123	70	46	65	33	26	49	36	28	22
1993	115	125	71	108	61	40	57	28	22	42	31	24
1994	161	101	109	63	94	53	35	49	24	19	36	26
1995	120	142	88	96	55	82	46	30	43	21	16	31
1996	118	105	124	77	84	48	72	40	26	36	18	14
1997	66	104	92	109	68	73	41	62	34	22	31	15
1998	77	58	91	81	95	59	63	36	53	29	18	25
1999	73	68	51	80	71	83	51	55	31	45	25	16
2000	83	64	59	45	70	62	72	44	47	26	38	21
2001	101	73	56	52	39	61	54	62	38	40	22	32
2002	102	88	64	49	45	34	53	47	54	33	35	19
2003	111	90	77	56	43	40	30	46	40	46	28	30
2004	195	98	79	68	49	38	35	26	40	35	40	24
2005	219	171	86	69	59	43	33	30	22	34	30	34
2006	81	192	150	75	61	52	38	29	26	19	29	26
2007	116	71	169	132	66	53	45	32	24	22	16	25
2008	108	102	62	148	115	57	46	39	28	21	19	14
2009	52	95	89	55	129	100	50	39	33	23	17	16
2010	55	46	83	78	48	113	87	43	34	28	20	15
2011	50	49	40	73	68	42	98	75	37	29	24	17
2012	57	44	43	35	64	59	36	84	63	31	24	20
2013	68	50	38	37	31	55	52	31	71	54	26	20
2014	153	59	44	34	33	27	48	44	26	60	45	21

Table 10.11 (continued) Males (continued)

	15	16	17	18	19	20	21	22	23	24	25
1975	8	7	7	6	5	5	4	4	4	3	9
1976	8	7	6	6	5	4	4	4	3	3	11
1977	8	7	6	6	5	4	4	3	3	3	12
1978	8	7	6	5	5	4	4	3	3	3	13
1979	8	7	6	5	5	4	4	3	3	3	13
1980	12	7	6	5	4	4	3	3	3	2	13
1981	11	10	6	5	4	4	3	3	3	2	13
1982	38	10	9	5	4	4	3	3	3	2	13
1983	52	33	8	8	5	4	3	3	2	2	14
1984	52	45	28	7	7	4	3	3	2	2	13
1985	33	44	38	24	6	5	3	3	2	2	13
1986	26	28	37	31	20	5	5	3	2	2	13
1987	26	21	22	29	25	16	4	4	2	2	12
1988	25	22	17	19	25	21	13	3	3	2	11
1989	43	19	17	13	14	19	16	10	3	2	10
1990	26	36	16	14	11	12	16	14	9	2	11
1991	25	23	31	14	12	10	10	14	12	7	11
1992	26	21	19	26	12	10	8	9	12	10	16
1993	18	22	17	16	22	10	9	7	7	10	21
1994	20	16	19	15	14	19	8	7	6	6	27
1995	22	17	13	16	13	12	16	7	6	5	28
1996	26	19	14	11	13	11	10	13	6	5	28
1997	12	22	16	12	9	11	9	8	11	5	27
1998	12	10	18	13	10	8	9	7	7	9	27
1999	22	11	8	15	11	8	7	8	6	6	31
2000	13	18	9	7	13	9	7	6	7	5	31
2001	18	11	15	8	6	11	8	6	5	6	30
2002	28	15	10	13	6	5	9	7	5	4	31
2003	16	24	13	8	11	5	4	8	6	4	30
2004	25	14	20	11	7	10	5	4	7	5	29
2005	21	22	12	17	9	6	8	4	3	6	29
2006	29	18	18	10	15	8	5	7	3	3	30
2007	21	25	15	15	9	12	7	4	6	3	27
2008	21	18	20	12	13	7	10	6	4	5	25
2009	11	17	15	17	10	11	6	9	5	3	25
2010	13	10	14	12	14	9	9	5	7	4	23
2011	12	11	8	12	10	12	7	8	4	6	23
2012	14	10	9	7	10	9	10	6	6	3	24
2013	16	11	8	8	5	8	7	8	5	5	23
2014	16	14	9	7	6	4	7	6	7	4	23

Table 10.12 Estimate of the number of female spawners (millions), at age, from the stock assessment model.

	6	7	8	9	10	11	12	13	14
1975	0	2	5	14	26	32	13	17	13
1976	0	2	4	9	26	43	46	16	18
1977	0	2	4	7	17	44	63	56	17
1978	0	4	4	8	13	28	63	76	59
1979	0	2	7	8	14	22	40	76	79
1980	0	2	5	14	14	24	32	48	78
1981	0	2	4	9	27	23	34	39	51
1982	0	1	4	8	16	44	34	41	41
1983	0	2	3	8	15	27	64	41	43
1984	0	2	3	6	15	24	39	77	43
1985	0	2	3	6	10	25	35	47	80
1986	0	1	4	7	11	17	36	42	48
1987	0	1	2	8	12	19	25	42	42
1988	0	2	2	3	14	20	27	30	44
1989	0	1	3	4	6	23	28	31	29
1990	0	1	2	7	7	10	33	34	32
1991	0	2	3	4	12	12	15	40	36
1992	0	1	4	5	7	20	17	18	42
1993	0	2	2	8	10	12	29	20	19
1994	0	2	4	5	15	16	17	34	21
1995	0	2	3	7	9	25	23	21	36
1996	0	2	4	6	13	15	36	28	22
1997	0	2	3	8	11	22	21	43	29
1998	0	1	3	6	15	18	32	25	44
1999	0	1	2	6	11	25	26	38	26
2000	0	1	2	3	11	19	36	31	39
2001	0	1	2	4	6	19	27	44	32
2002	0	1	2	4	7	10	27	33	46
2003	0	1	3	4	7	12	15	32	34
2004	0	1	3	5	8	11	17	18	33
2005	0	3	3	5	9	13	17	21	19
2006	0	3	5	6	10	16	19	20	22
2007	0	1	6	10	10	16	23	23	20
2008	0	2	2	11	18	17	23	27	23
2009	0	1	3	4	21	30	25	27	28
2010	0	1	3	6	8	34	44	30	28
2011	0	1	1	6	11	13	49	52	31
2012	0	1	1	3	10	18	18	58	53
2013	0	1	1	3	5	17	26	22	60
2014	0	1	2	3	5	8	24	31	22

Table 10.12 continued.

	15	16	17	18	19	20	21	22	23	24	25+
1975	8	7	7	6	5	5	4	4	4	3	9
1976	8	7	6	6	5	4	4	4	3	3	11
1977	8	7	6	6	5	4	4	3	3	3	12
1978	8	7	6	5	5	4	4	3	3	3	13
1979	8	7	6	5	5	4	4	3	3	3	13
1980	12	7	6	5	4	4	3	3	3	2	13
1981	11	10	6	5	4	4	3	3	3	2	13
1982	37	9	9	5	4	4	3	3	3	2	13
1983	51	33	8	8	5	4	3	3	2	2	14
1984	51	44	28	7	6	4	3	3	2	2	13
1985	32	43	37	24	6	5	3	3	2	2	13
1986	25	27	36	31	20	5	5	3	2	2	13
1987	25	20	22	29	25	16	4	4	2	2	12
1988	24	21	17	18	24	21	13	3	3	2	11
1989	41	19	16	13	14	19	16	10	3	2	10
1990	25	35	16	14	11	12	16	14	9	2	11
1991	23	22	30	14	12	10	10	14	12	7	11
1992	25	20	18	26	12	10	8	9	12	10	15
1993	18	21	17	15	22	10	8	7	7	10	21
1994	20	15	18	14	13	18	8	7	6	6	26
1995	22	17	13	15	12	11	16	7	6	5	28
1996	25	18	14	11	13	10	9	13	6	5	27
1997	11	21	15	12	9	11	9	8	11	5	27
1998	12	9	18	13	10	7	9	7	6	9	26
1999	21	10	8	15	11	8	6	8	6	5	30
2000	13	18	9	7	13	9	7	5	6	5	30
2001	17	11	15	7	6	11	8	6	5	5	30
2002	27	15	9	13	6	5	9	7	5	4	30
2003	16	23	13	8	11	5	4	8	6	4	29
2004	25	14	20	11	7	9	5	4	7	5	28
2005	20	21	12	17	9	6	8	4	3	6	28
2006	29	17	18	10	14	8	5	7	3	3	29
2007	21	24	15	15	8	12	7	4	6	3	26
2008	20	17	20	12	13	7	10	5	3	5	24
2009	11	17	15	17	10	11	6	8	5	3	24
2010	13	9	14	12	14	8	9	5	7	4	23
2011	12	11	8	12	10	12	7	7	4	6	22
2012	13	10	9	6	10	8	10	6	6	3	23
2013	16	11	8	7	5	8	7	8	5	5	22
2014	16	13	9	7	6	4	7	6	7	4	22

Table 10.13. Projections of spawning biomass (1,000s t), catch (1,000s t), and fishing mortality rate for each of the several scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 142,100 t and 124,300 t, respectively.

Scenarios 1 and 2

Maximum ABC harvest permissible

	Female		
Year	spwn bio	catch	F
2014	222.92	19.00	0.057
2015	211.18	44.89	0.143
2016	186.74	39.83	0.143
2017	164.94	35.25	0.143
2018	147.51	31.54	0.143
2019	135.87	27.69	0.137
2020	130.64	25.49	0.131
2021	130.15	25.24	0.131
2022	131.93	25.91	0.132
2023	134.37	26.82	0.134
2024	136.77	27.68	0.136
2025	138.89	28.41	0.137
2026	140.62	28.98	0.138
2027	141.96	29.41	0.138

Scenario 3

1/2 Maximum ABC harvest permissible

	Female		
Year	spwn bio	catch	F
2014	222.92	19.00	0.057
2015	214.80	22.44	0.069
2016	202.92	20.43	0.067
2017	191.11	19.26	0.067
2018	180.95	18.22	0.067
2019	174.17	17.49	0.067
2020	171.66	17.17	0.067
2021	172.82	17.25	0.067
2022	176.11	17.57	0.067
2023	180.27	18.00	0.067
2024	184.60	18.46	0.067
2025	188.79	18.91	0.067
2026	192.64	19.31	0.067
2027	196.04	19.67	0.067

Scenario 4

Harvest at average F over the past 5 years

	Female		
Year	spwn bio	catch	F
2014	222.92	19.00	0.057
2015	215.51	17.90	0.055
2016	205.94	18.04	0.058
2017	195.35	17.13	0.058
2018	186.14	16.30	0.058
2019	180.09	15.73	0.058
2020	178.15	15.50	0.058
2021	179.78	15.60	0.058
2022	183.50	15.92	0.058
2023	188.07	16.33	0.058
2024	192.81	16.76	0.058
2025	197.39	17.18	0.058
2026	201.62	17.57	0.058
2027	205.38	17.92	0.058

Scenario 5

No fishing

	Female		
Year	spwn bio	catch	F
2014	222.923	19.00	0.0567
2015	218.261	0	0
2016	219.182	0	0
2017	218.458	0	0
2018	217.838	0	0
2019	219.118	0	0
2020	223.498	0	0
2021	230.808	0	0
2022	239.903	0	0
2023	249.692	0	0
2024	259.533	0	0
2025	269.08	0	0
2026	278.11	0	0
2027	286.455	0	0

Table 10.13- continued.

Scenario 6
Determination of overfishing

Year	Female spwn bio	catch (B_{35}=124,300)	F
2014	222.92	19.00	0.057
2015	209.65	**54.04**	0.175
2016	180.29	46.66	0.175
2017	155.16	40.26	0.175
2018	135.92	33.74	0.167
2019	124.14	28.03	0.152
2020	119.59	25.89	0.146
2021	119.68	25.89	0.146
2022	121.85	26.89	0.149
2023	124.44	28.12	0.152
2024	126.77	29.25	0.155
2025	128.65	30.16	0.157
2026	130.04	30.82	0.159
2027	131.00	31.28	0.160

Scenario 7
Determination of whether Alaska plaice are approaching an overfished condition

Year	Female spwn bio	catch (B_{35}=124,300)	F
2014	222.92	19.00	0.057
2015	211.18	44.89	0.143
2016	186.74	39.83	0.143
2017	163.75	42.44	0.175
2018	142.53	36.97	0.175
2019	128.62	30.10	0.158
2020	122.62	27.23	0.150
2021	121.71	26.78	0.149
2022	123.16	27.47	0.151
2023	125.25	28.49	0.153
2024	127.26	29.47	0.155
2025	128.92	30.28	0.157
2026	130.18	30.88	0.159
2027	131.06	31.30	0.160

Figures

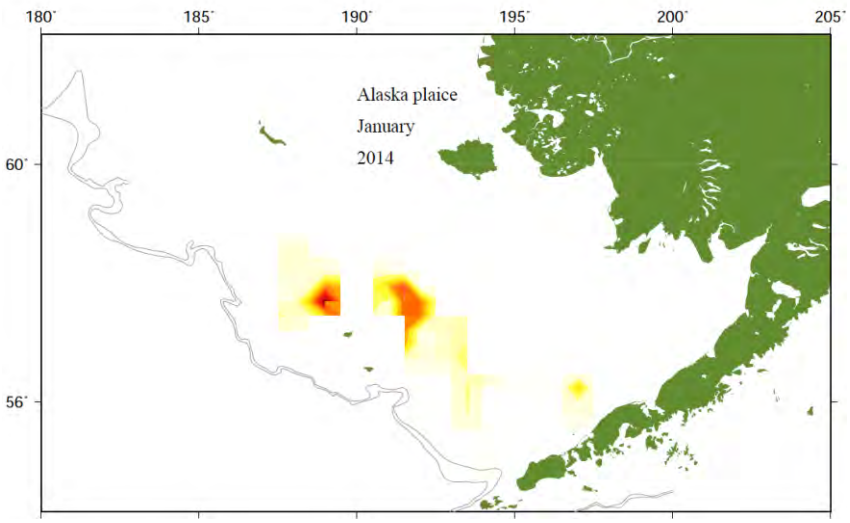

Figure 10.1--Locations of Alaska plaice catch in 2012, by month. The harvest primarily occurred in the yellowfin sole fishery and rock sole fisheries.

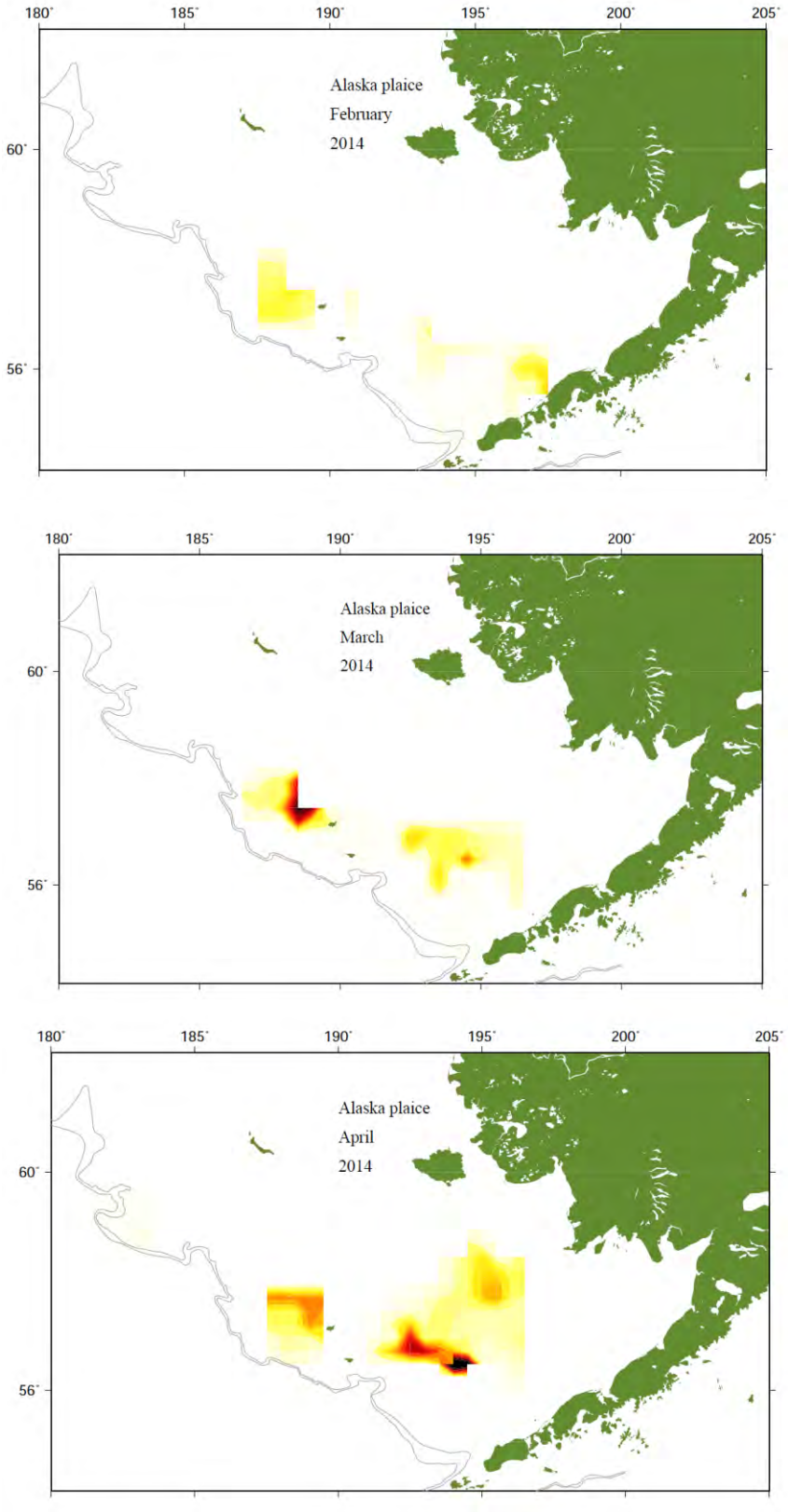

Figure 10.1 (continued).

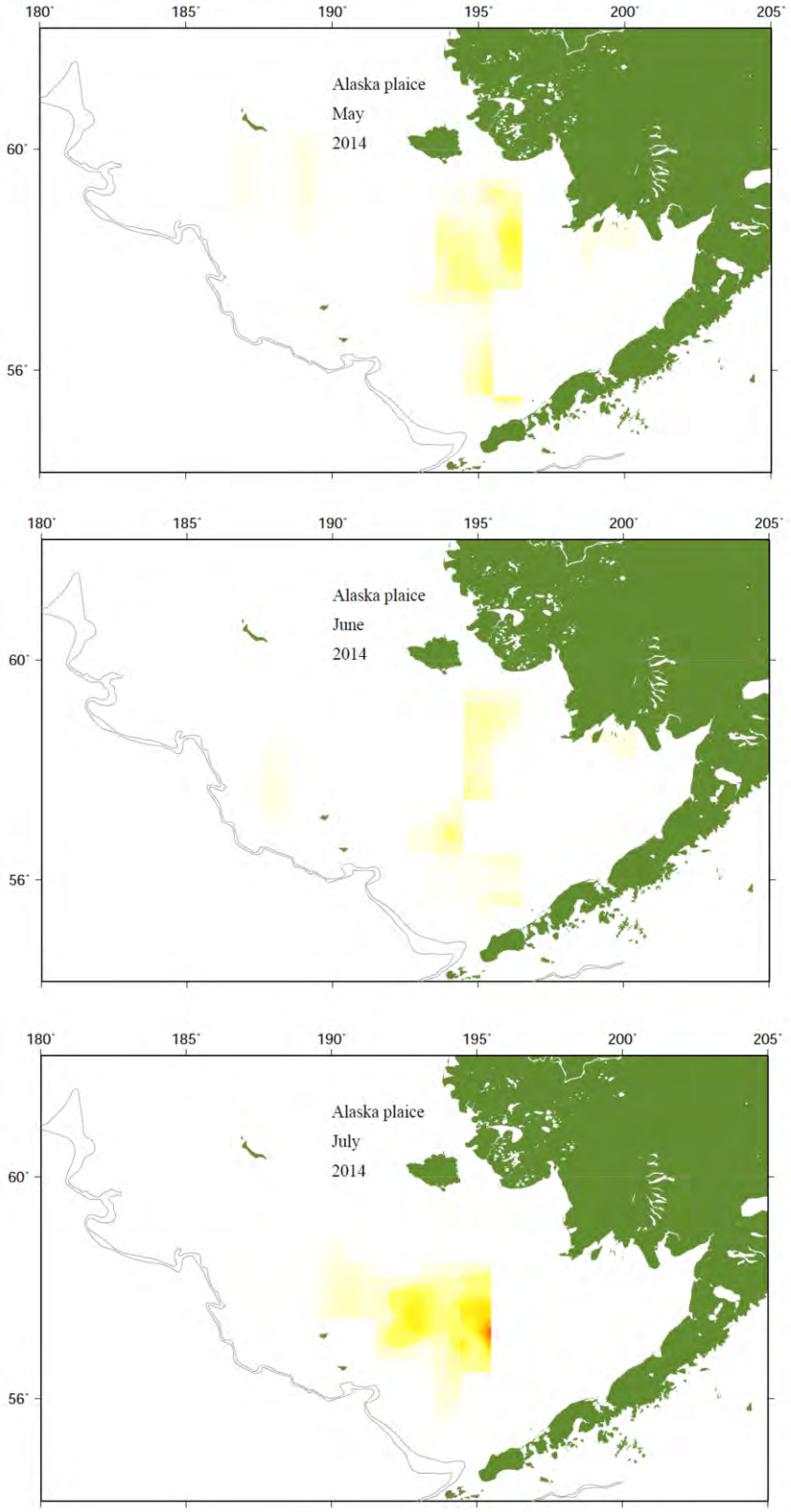

Figure 10.1--(Continued).

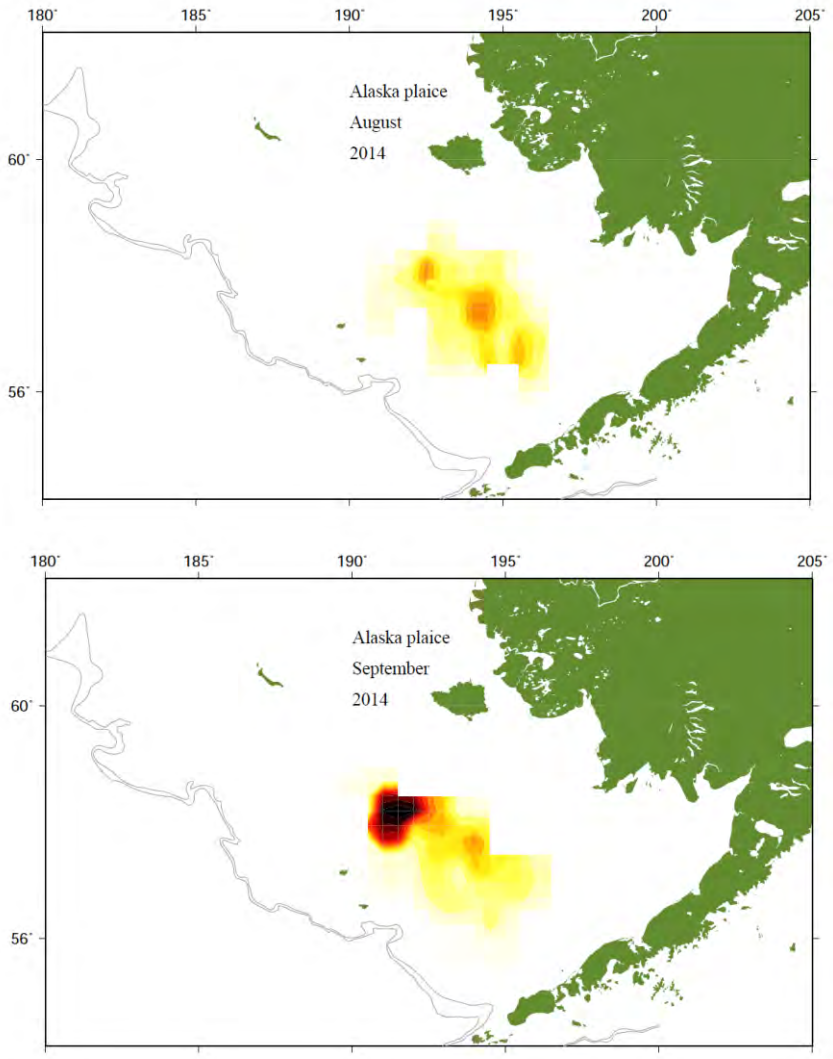

Figure 10.1--(Continued).

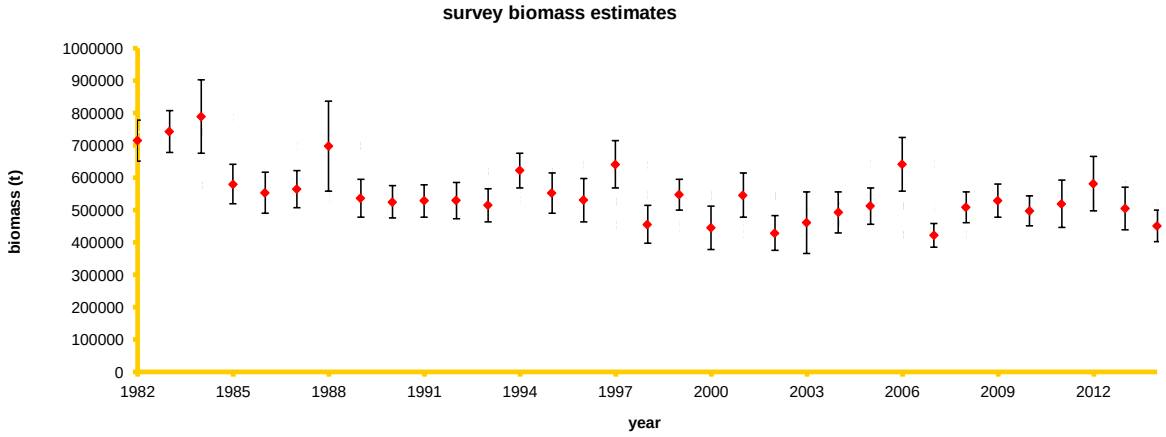

Figure 10.2--Estimated survey biomass and 95% confidence intervals from NMFS eastern Bering Sea bottom trawl surveys.

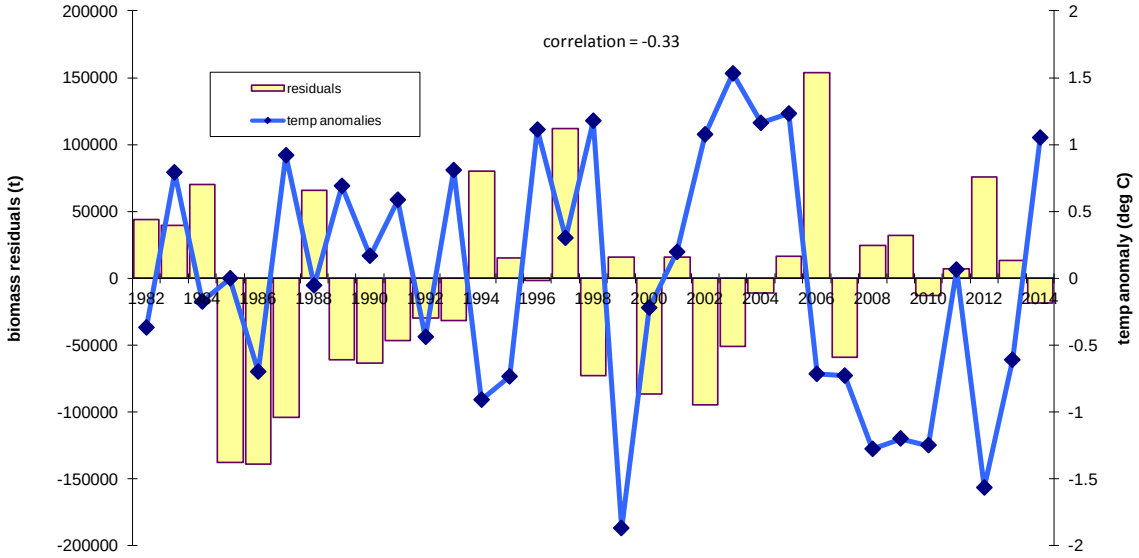

Figure 10.3--Residuals from fitting the trawl survey biomass (bars) compared to the average annual bottom temperature anomalies (degrees Celcius) obtained during the trawl survey.

surveys.

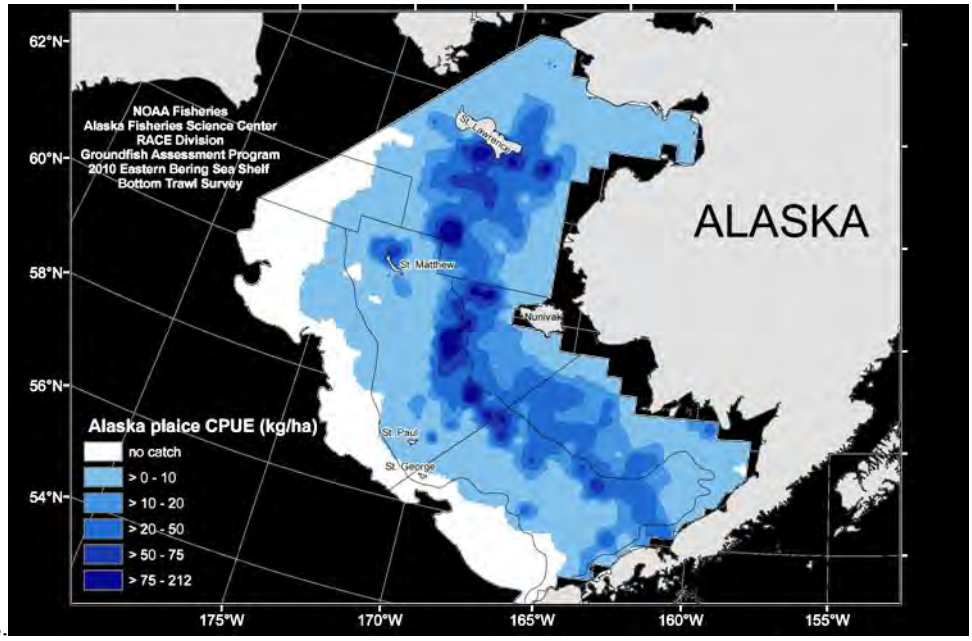

Figure 10.4.--Eastern and northern Bering Sea survey CPUE (kg/ha) of Alaska plaice from 2010.

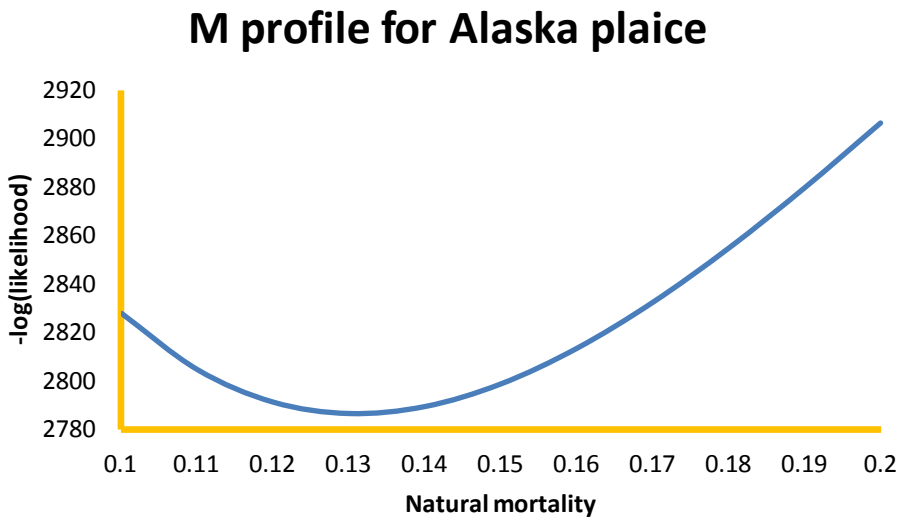

Figure 10.5 -- Stock assessment model fit (in terms of –log(likelihood)) to a range of male and female natural mortality values.

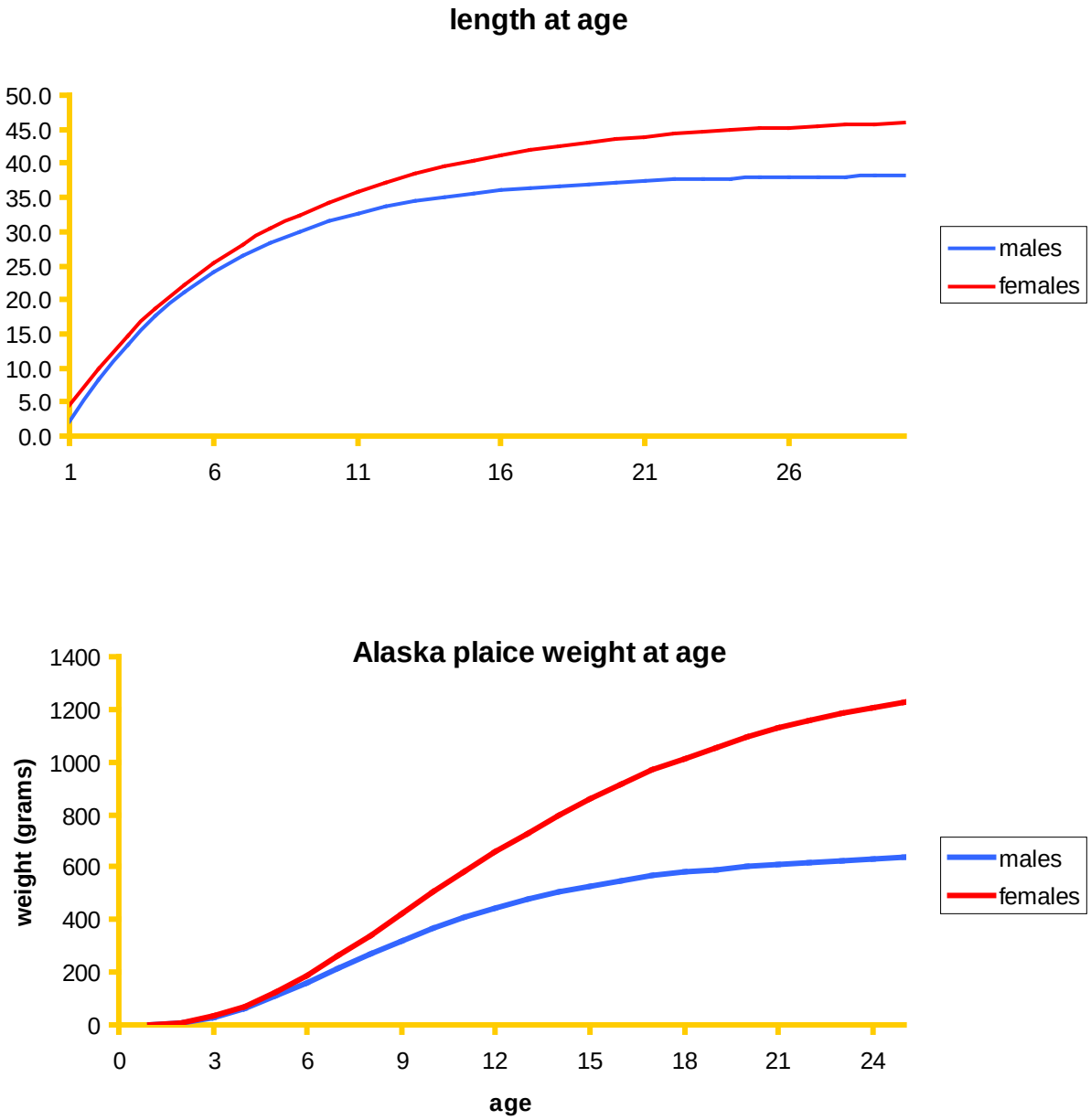

Figure 10.6-- Estimated length and weight-at-age relationships for Alaska plaice used in the 2014 assessment.

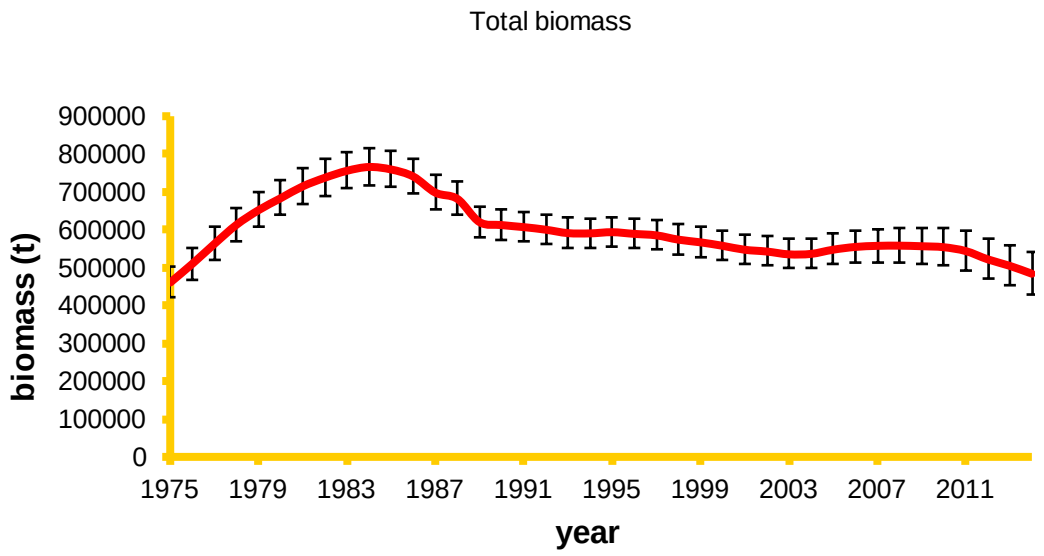

Figure 10.7--Estimated beginning year total biomass of Alaska plaice from the assessment model. 95% percent confidence intervals are from mcmc integration.

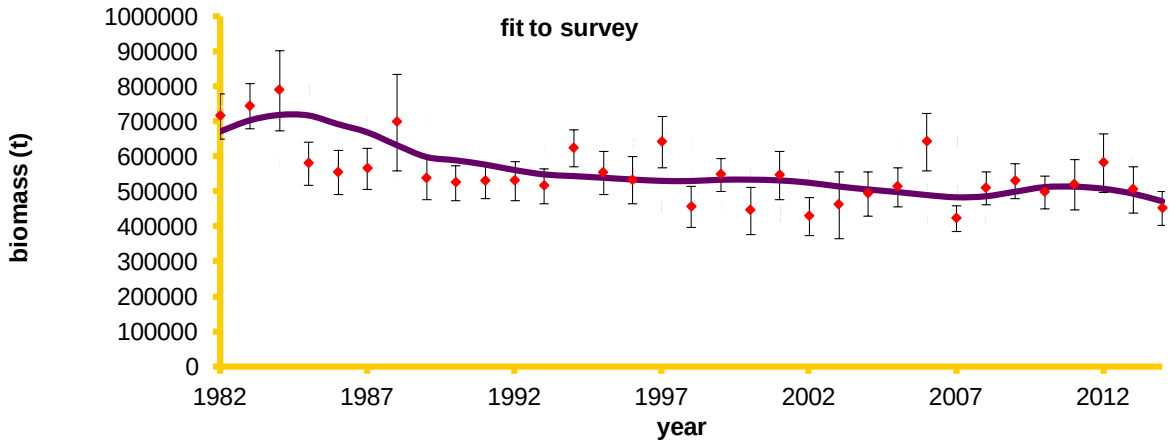

Figure 10.8--Observed (data points) and predicted (solid line) survey biomass of Alaska plaice.

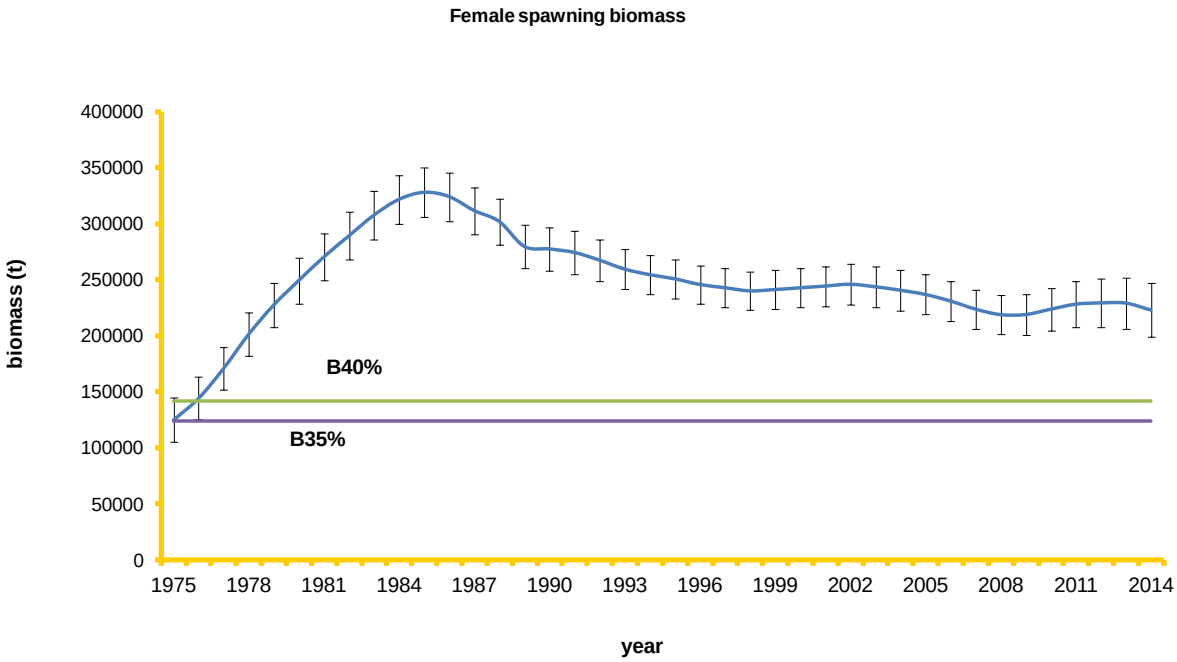

Figure 10.9--Model estimates of Alaska plaice female spawning biomass with estimates of B_{35} and B_{40}. Ninety-five percent credible intervals are from MCMC integration.

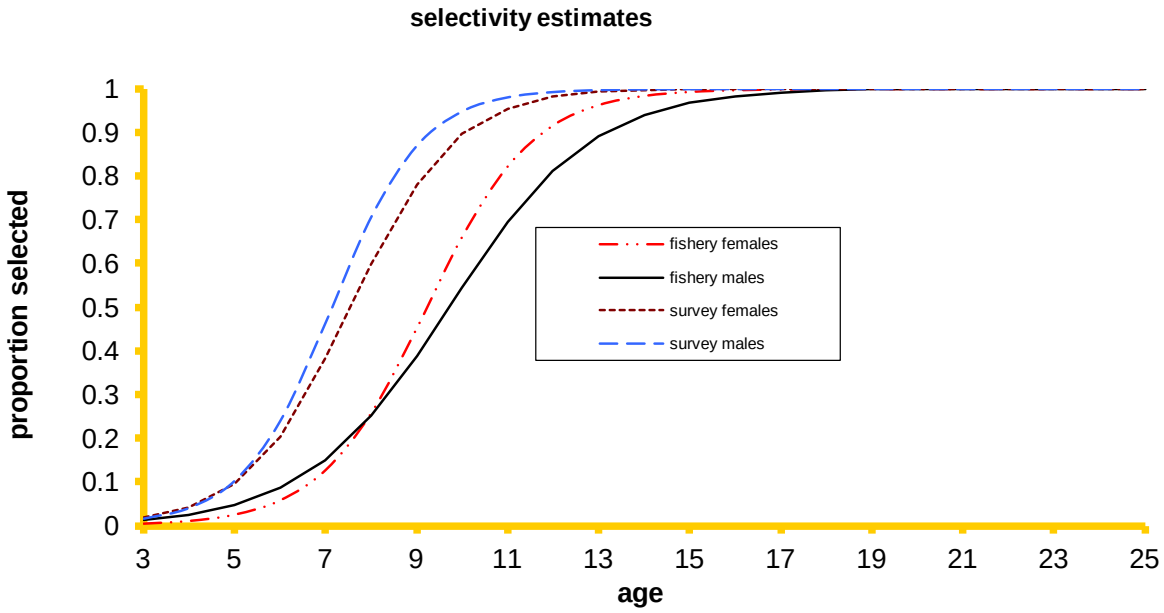

Figure 10.10--Model estimates of survey and fishery selectivity.

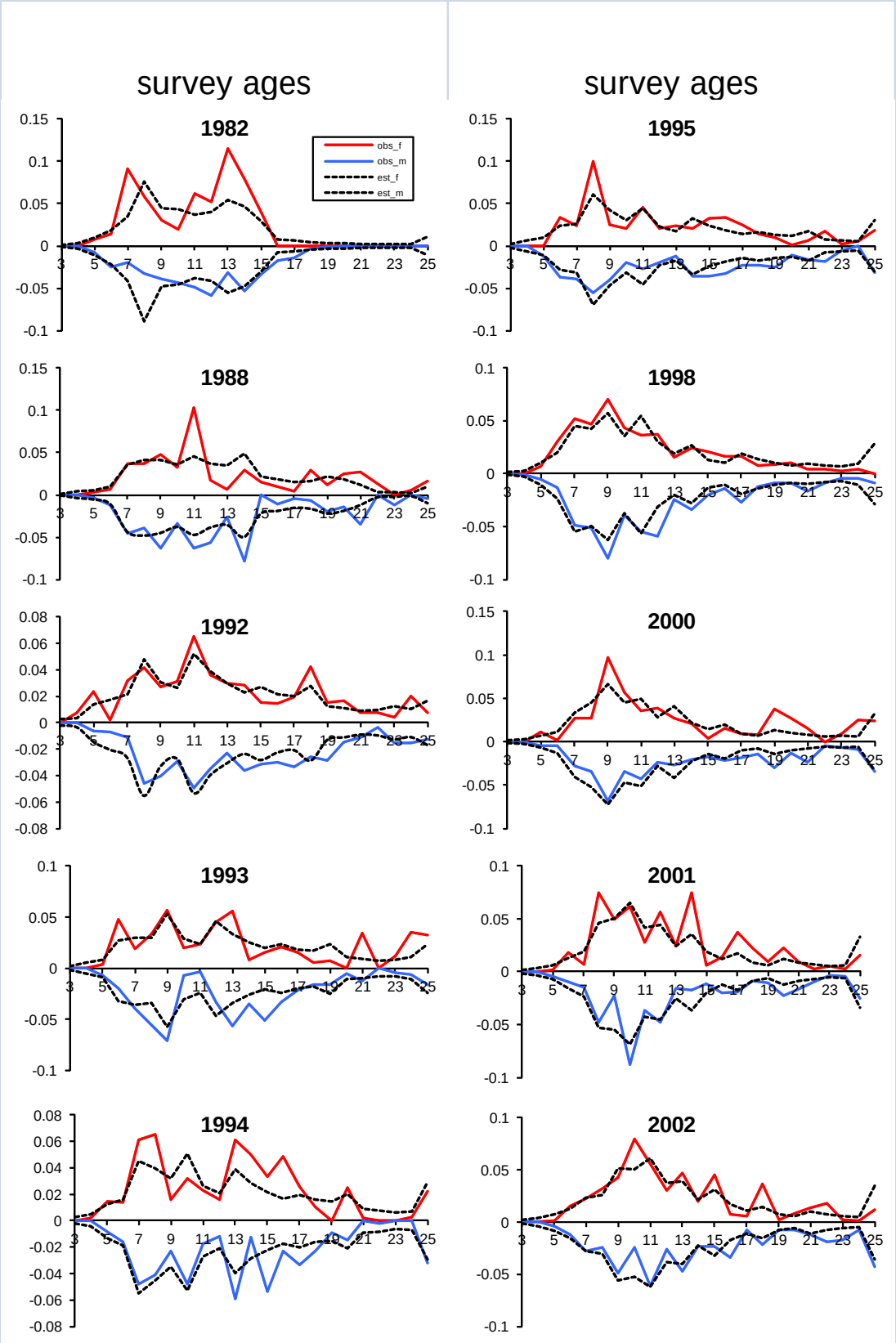

Figure 10.11--Survey age composition (solid line = observed, dotted line = predicted, females above x axis, males below x axis).

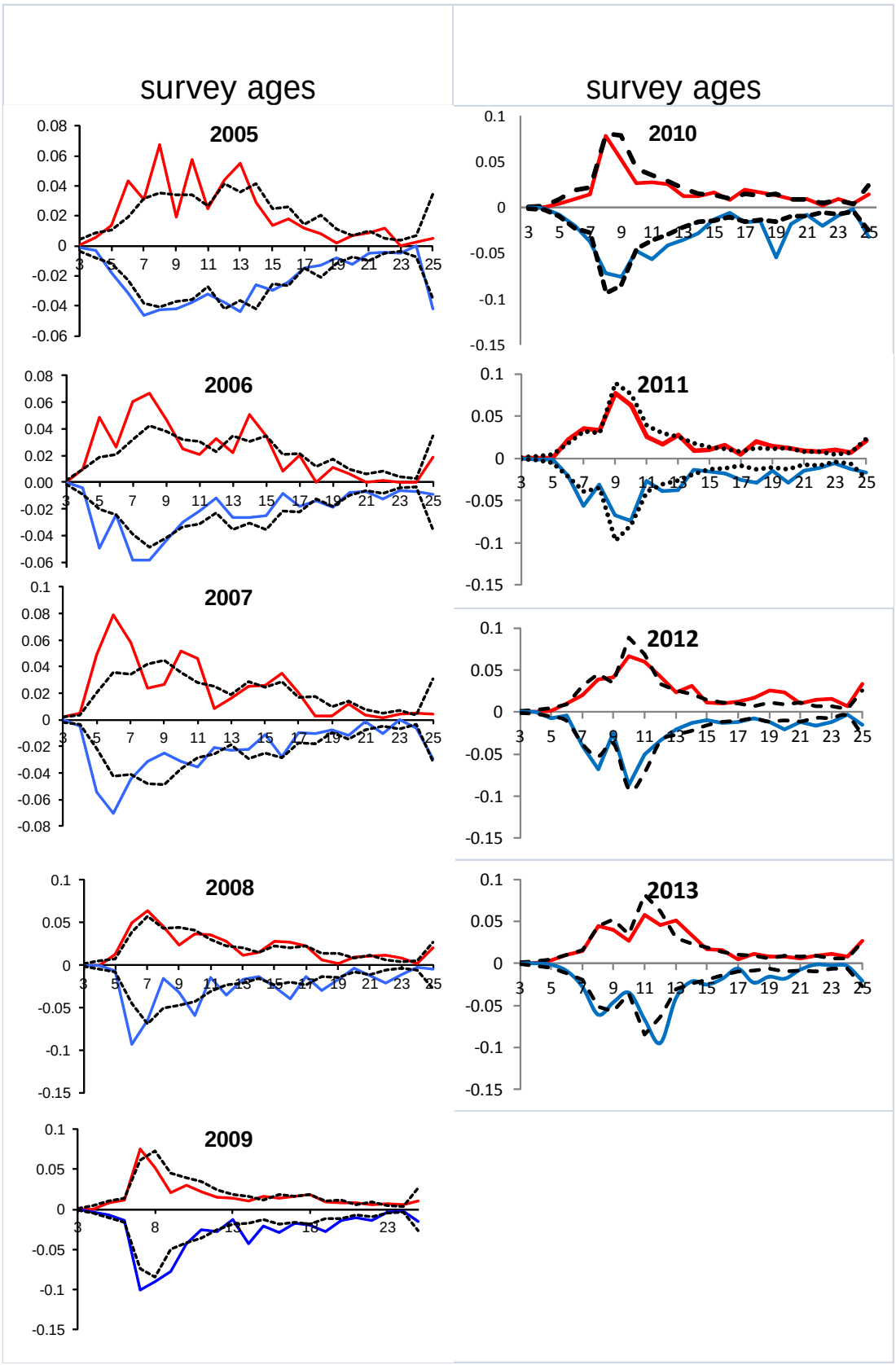

Figure 10.11—(continued).

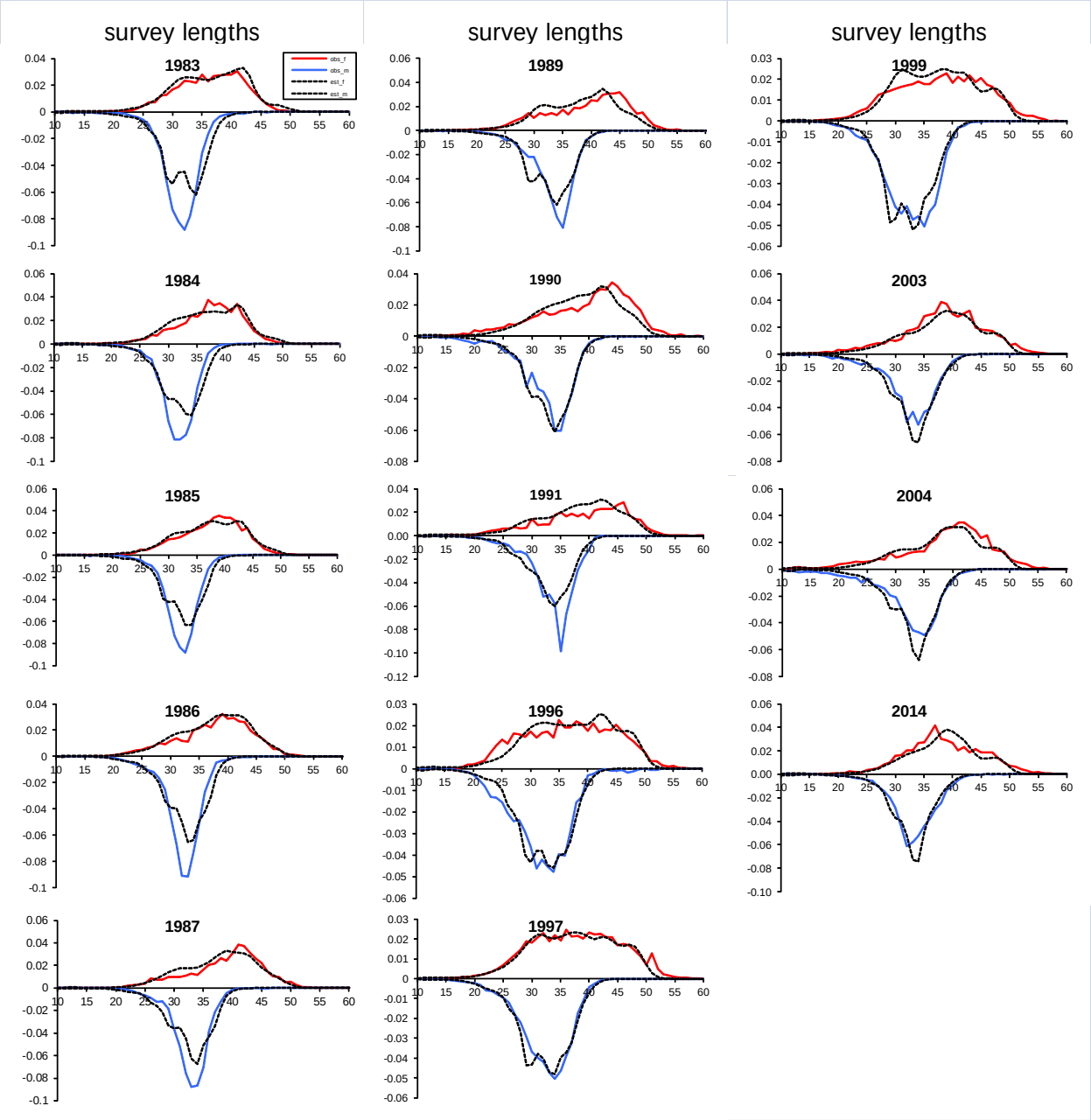

Figure 10.12--Survey length composition by year (solid line = observed, dotted line = predicted, females above x axis, males below x axis).)

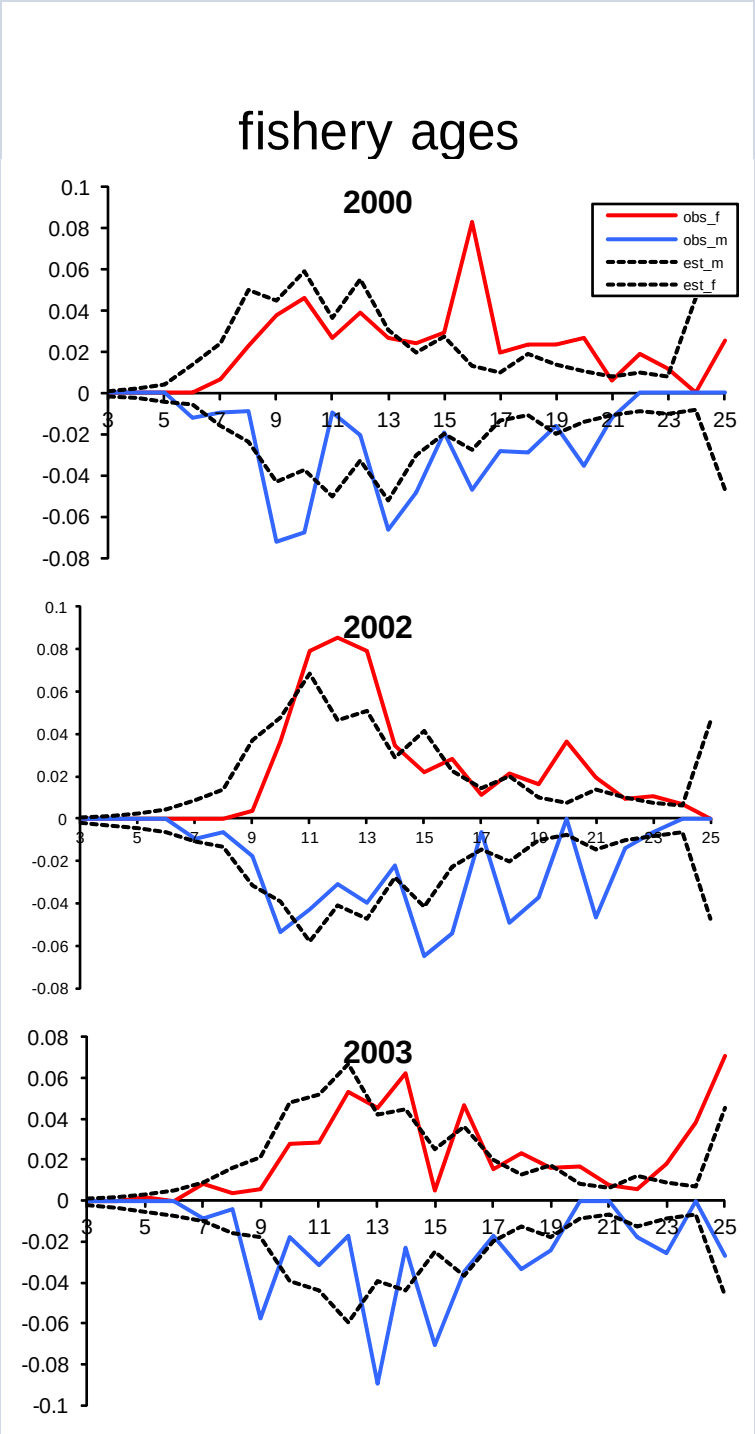

Figure 10.13--Fishery age composition by year (solid line = observed, dotted line = predicted, females above x axis, males below x axis).

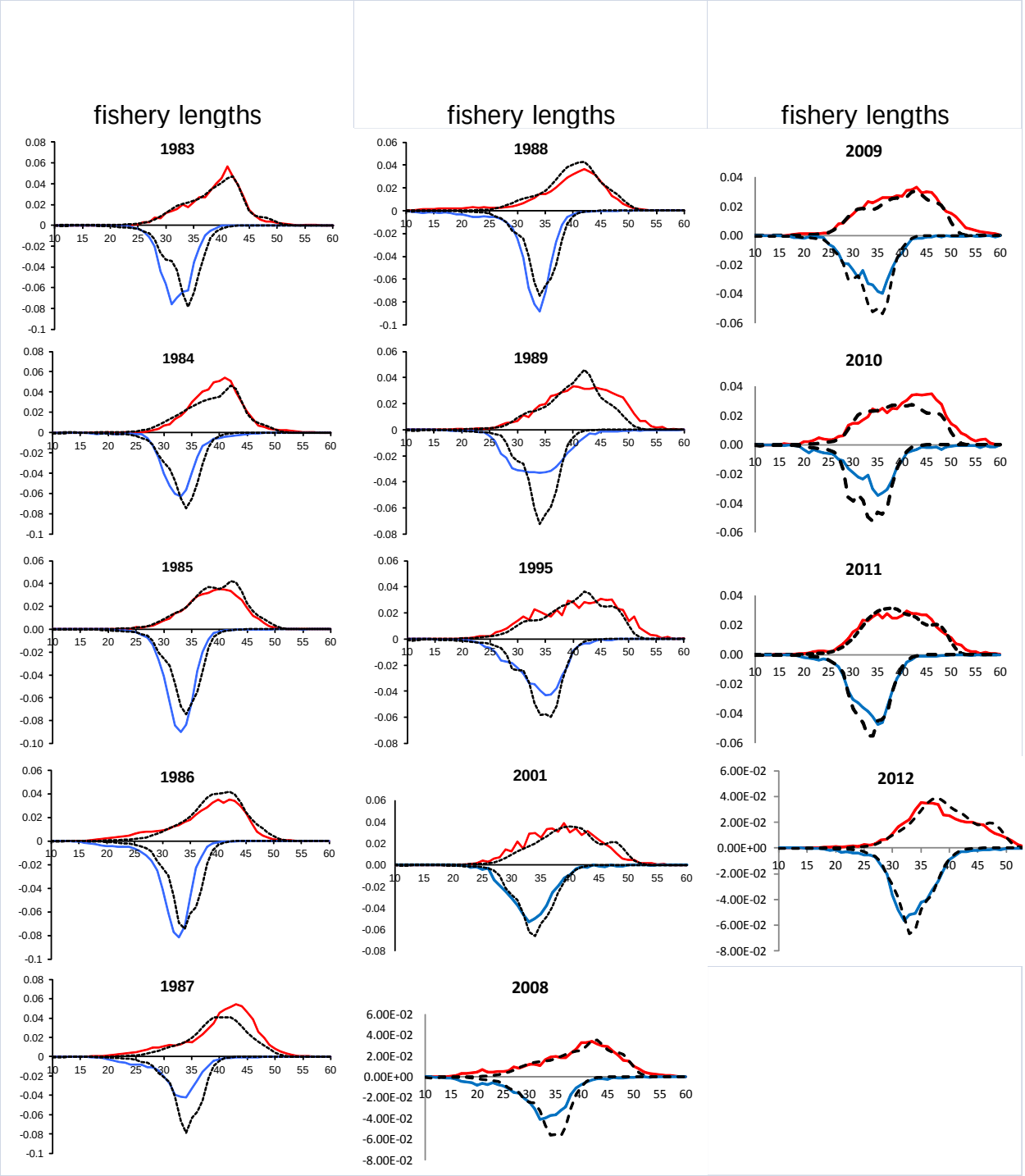

Figure 10.14--Fishery length composition by year (solid line = observed, dotted line = predicted, females above x axis, males below x axis).

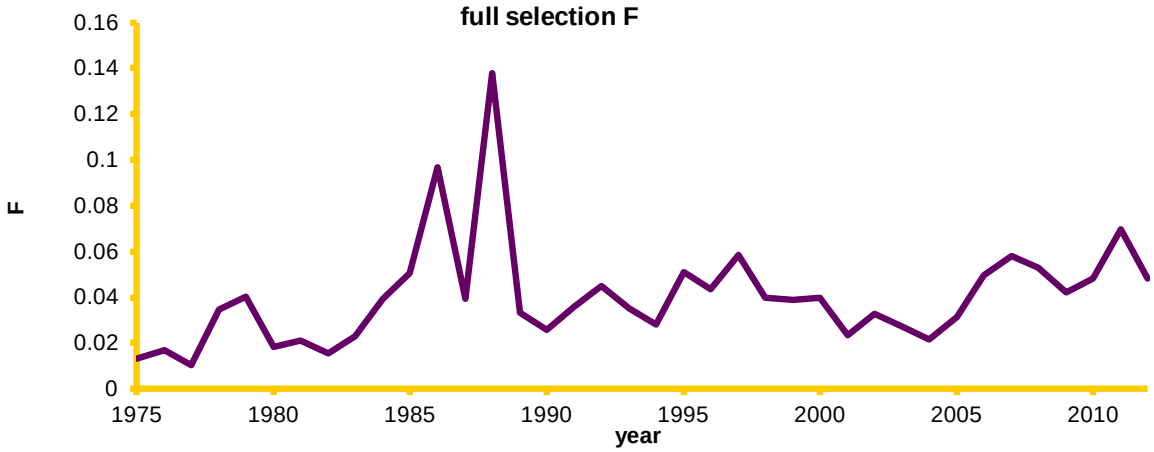

Figure 10.15--Estimated fully selected fishing mortality.

Figure 10.16--Estimated recruitment (age 3) for Alaska plaice. 95% credible intervals are from mcmc integration.

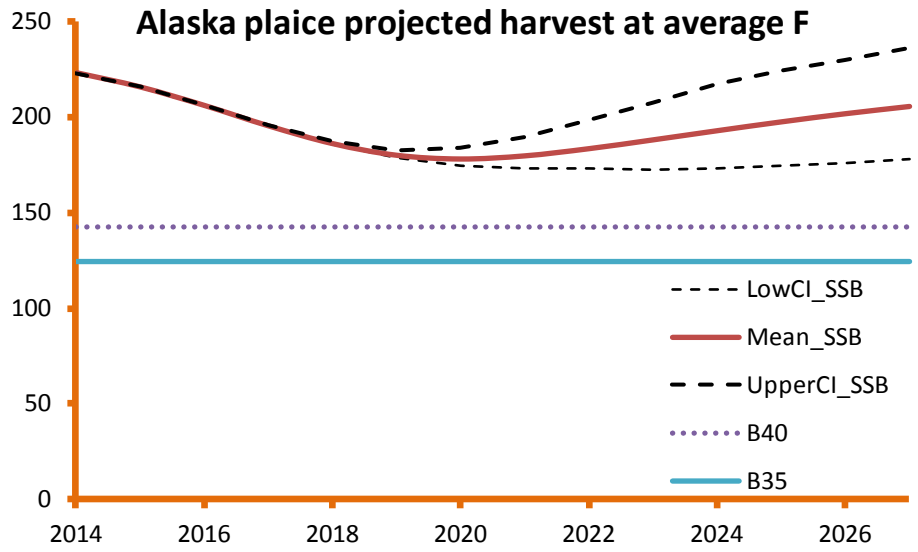

Figure 10.17 Model projection of Alaska plaice at the harvest rate of the average of the past five years assuming the estimated 2011 numbers-at-age from the stock assessment model.

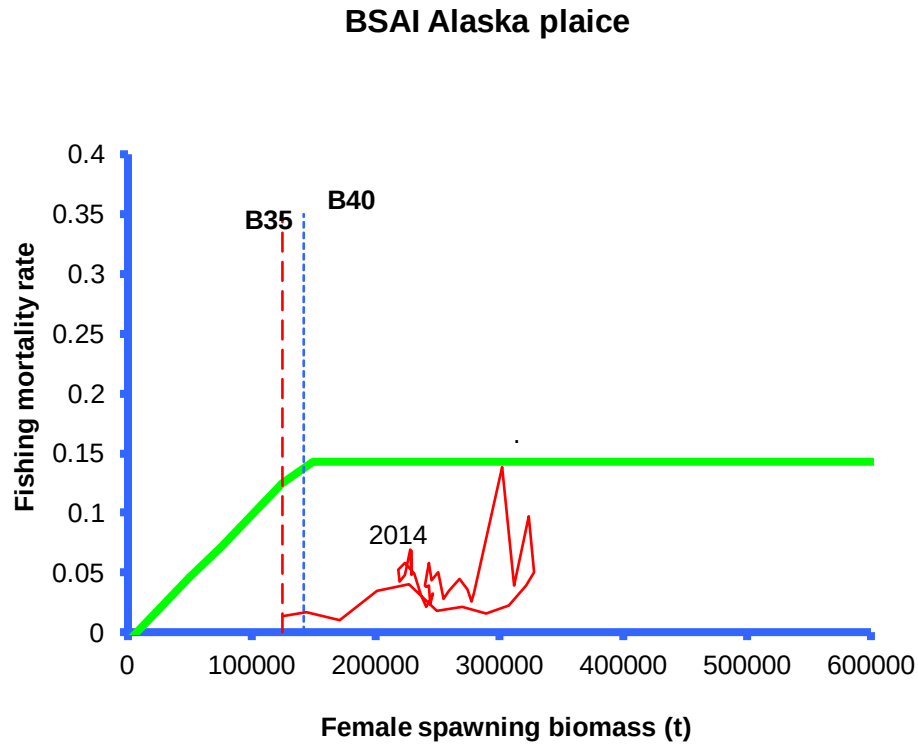

Figure 10.18 Phase-plane diagram of the estimated time-series of Alaska plaice female spawning biomass and fishing mortality relative to the tier 3 control rule.

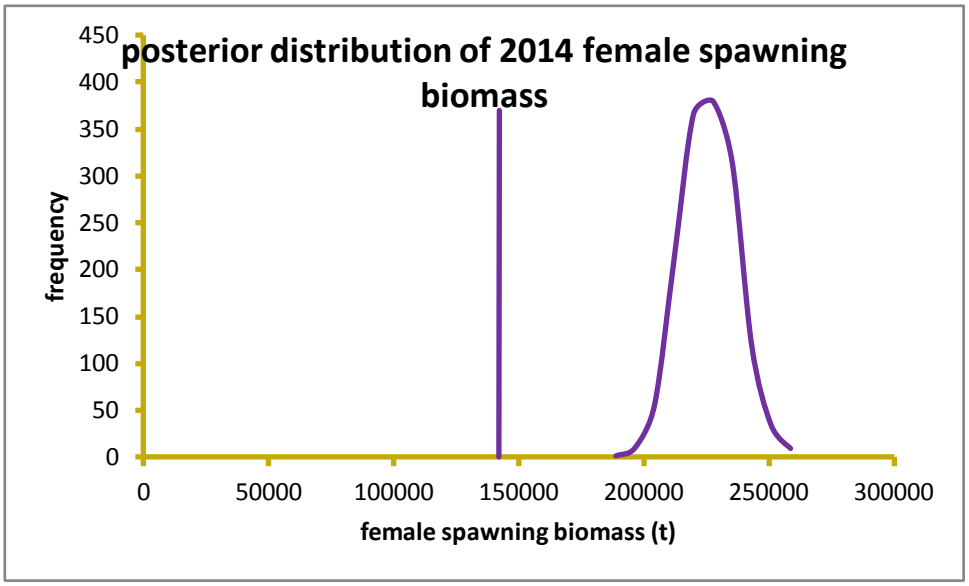

Figure 10.19. Posterior distribution of the 2014 estimate of female spawning biomass (t) from mcmc integration with $B_{40\%}$ =142,100 indicated as a vertical line.

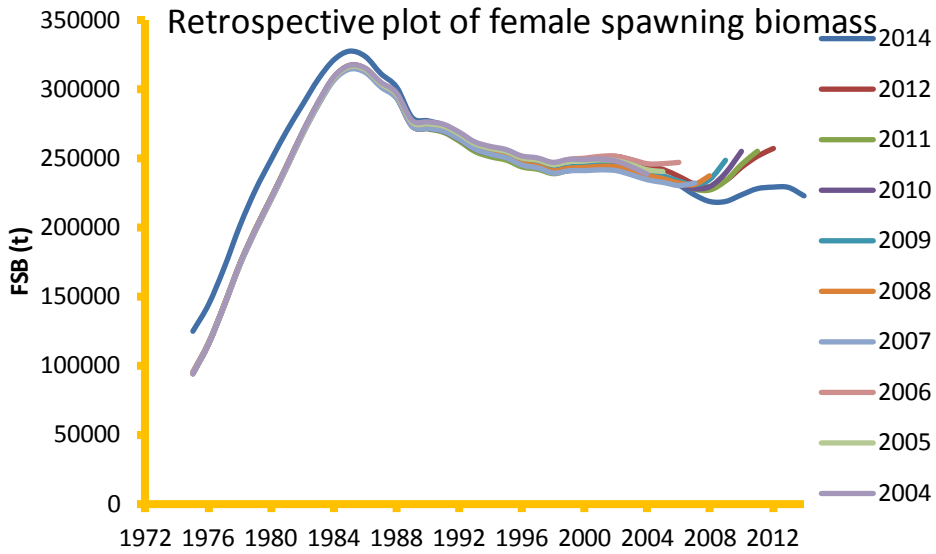

Figure 10.20. Retrospective plot of female spawning biomass (t) from 2004 to 2014.

11. Assessment of the other flatfish stock complex in the Bering Sea and Aleutian Islands

Thomas K. Wilderbuer and Daniel G. Nichol

Executive Summary

Summary of Changes in Assessment Inputs

Changes in the Input Data

1) The 2014 catch (total and discarded) was updated, and catch through 25 October, 2014 were included in the assessment.

2) The 2014 Eastern Bering Sea shelf survey and Aleutian Islands survey biomass estimates and standard errors of other flatfish species are included in the assessment.

Changes in the Assessment Methodology

1) ABC biomass was computed by a random effects model.

Summary of Results

A summary of the 2014 recommended ABCs and OFLs (in bold) relative to the 2012 recommendations for Other flatfish in the Bering Sea/Aleutian Islands (BSAI) is as follows:

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2016
M (natural mortality rate) for rex sole	0.17	0.17	0.17	0.17
M (natural mortality rate) for Dover sole	0.085	0.085	0.085	0.085
M (natural mortality rate) for all others	0.15	0.15	0.15	0.15
Tier	5	5	5	5
Survey Biomass (t)	107,500	107,500	**143,000**	143,000
F_{OFL} (F=M) for rex sole	0.17	0.17	0.17	0.17
F_{OFL} (F=M) for Dover sole	0.085	0.085	0.085	0.085
F_{OFL} (F=M) for all other species	0.15	0.15	0.15	0.15
$maxF_{ABC}$ for rex sole	0.13	0.13	0.13	0.13
$maxF_{ABC}$ for Dover sole	0.064	0.064	0.064	0.064
$maxF_{ABC}$ for all other species	0.113	0.113	0.113	0.113
F_{ABC} for rex sole	0.13	0.13	0.13	0.13
F_{ABC} for Dover sole	0.064	0.064	0.064	0.064
F_{ABC} for all other species	0.113	0.113	0.113	0.113
OFL (t)	16,700	16,700	**17,700**	17,700
maxABC (t)	12,400	12,400	**13,250**	13,250
ABC (t)	12,400	12,400	**13,250**	13,250

This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Marine Fisheries Service and should not be construed to represent any agency determination or policy.

Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	n/a	n/a	n/a	n/a

Responses to SSC and Plan Team Comments to Assessments in General

There were no comments relative to the other flatfish assessment.

Responses to SSC and Plan Team Comments Specific to this Assessment

As requested last year, the SSC requests the reporting of biomass estimates with confidence intervals to help judge trends versus uncertainty. The SSC also looks forward to a future application of a random effects model to these other flatfish data. The authors should consider the merits of applying a random effects model to the aggregate or component species data. The SSC continues to maintain interest in tracking biomass trends of individual species to the extent practical. To the extent possible, the assessment authors are requested to consider the potential effects of temperature on the variance in survey catches of other flatfish.

Figures are provided of survey estimates with confidence intervals for the 5 primary species of the complex. The random effects model was used to calculate ABC biomass for 2015. No work was done on the incorporation of temperature on survey catchability of these species during this assessment cycle.

Introduction

The Bering Sea/Aleutian Islands "other flatfish" group have typically included those flatfish besides northern rock sole, yellowfin sole, arrowtooth flounder, Kamchatka flounder and Greenland turbot. Flathead sole (*Hippoglossoides elassodon*) were part of the other flatfish complex until they were removed in 1995, and Alaska plaice was removed from the complex in 2002, as sufficient biological data exists for these species to construct age-structured population models. In contrast, survey biomass estimates are the principal data source used to assess the remaining other flatfish. Although over a dozen species of flatfish are found in the BSAI area, the other flatfish biomass consists primarily of starry flounder, rex sole, longhead dab, Dover sole and butter sole. A full list of the species in the other flatfish complex is shown in Table 11.1. At present, no evidence of stock structure is evident for these species in the Bering Sea/Aleutian Islands region, although no formal genetic or tagging study has been conducted on these species in this region.

Fishery

The miscellaneous species of the other flatfish species category are listed in Table 11.1, and their catches from 1995-2014 are shown in Table 11.2 (with historical ABC and TAC). These species are not pursued as fishery targets but are captured in fisheries for other flatfish species and Pacific cod. Catch from 1995-2003 were obtained from the NMFS Regional Office "blend" data, and the catch for some species are reported by species and in an aggregate flatfish group. The catch estimates for these years were produced by applying the proportional catch, by species, from fishery observer data to the estimated total catch for the aggregate other flatfish group, and adding this total to the catch that was reported by species. In the current catch accounting system (in use since 2003), catches of other flatfish are reported only in an aggregate group, and the catch estimates for these years were produced by applying the proportional catch, by species, from fishery observer data to the estimated total catch of the aggregate group. In recent years, starry flounder (*Platichthys stellatus*) and rex sole (*Glyptocephalus zachirus*) account for most of the harvest of other flatfish, contributing 97% of the harvest of other flatfish in 2013. The 2014 catch of 4,385 t through late-October is well below the ABC of 13,300 t.

Other flatfish fisheries are grouped with Alaska plaice, rock sole, and flathead sole in a single prohibited species group (PSC) classification, with seasonal and total annual allowances of prohibited bycatch applied to the group. In past years, this group of fisheries was closed due to the bycatch of halibut but since the implementation of Amendment 80 in 2008 there have been no closures.

Data

Fishery

Data from the fishery includes blend estimates of total catch for the combined "other flatfish" species from the Alaska Regional office and species catch data from observer sampling to apportion the total catch to individual species.

Survey

The biomass of the other flatfish complex on the eastern Bering Sea shelf was relatively stable from 1983-1995, averaging 54,274 t, and then increased from 1996 to 2003, averaging 84,137 t (Table 11.3, Fig. 11.1). Since 2003, the biomass estimates have been at a higher level, averaging 125,800 t. The 2014 shelf and Aleutian Islands (slope survey not conducted in 2014) surveys combined estimate of 143,000 t is at the highest level of the past 7 years and third highest overall for the time-series. The estimated increases from the past five years are primarily due to the higher estimates of starry flounder on the Eastern Bering Sea shelf. In years when an AI survey was not conducted, such as 2013, total BSAI biomass was calculated by fitting a linear trend to the observed Aleutian Islands survey data (1991-2012 for this assessment), and then adding the predicted AI biomass estimate to the observed EBS estimate. For this assessment, the linear model estimates were not used to calculate the 2014 biomass since an Aleutian Islands survey was conducted. Individual species biomass estimates for the EBS and AI areas from 1997-2013 are shown in Table 11.4. Notable for 2013 and 2014 is the marked decline in the amount of rex sole on the Bering Sea shelf relative to estimated biomass ten years ago, but the second largest biomass of starry flounder ever observed. Estimates of total BSAI biomass (Table 11.5) were then used to compute species-specific exploitation rates (catch/biomass).

Exploitation rates for starry flounder and rex sole have been low, not exceeding 0.05 from 1997 to 2014 (Table 11.5). The exploitation rates for butter sole have been higher, exceeding 0.14 in 1997, 2000, 2001, and 2003-2009 and 2011-2012 and 2014. In 2008 the butter sole catch exceeded the trawl survey biomass estimate. However these biomass estimates calculated for butter sole have large sampling variances, with coefficients of variation ranging from 0.44 to 0.86 in recent EBS trawl surveys dating back to 1999. The 2013 exploitation rate was only 0.02, as only 29 t are estimated to have been caught through the end of October, but was higher again in 2014 with an exploitation rate of 0.43.

Closer inspection of the butter sole biomass variability suggests that occasional high exploitation rates may be an artifact of survey sampling. The 2003 and 2008 biomass estimates of butter sole were 429 t and 541 t, respectively, unusually low relative to biomass estimates from the past 20 years. These estimates are less than one-fourth the 2002 estimate of 2,382 t, and result in an estimated exploitation rate of nearly 70% in 2003 and 1.14 in 2008. However, butter sole were only captured in four hauls in the 2003 EBS trawl survey and in six hauls in the 2008 survey, causing a large coefficient of variation of 0.61 for the estimated biomass. Thus, it is likely that the population of butter sole is larger than that indicated from the survey, and the comparison of survey biomass to harvest should be interpreted accordingly. Biomass estimates since 2003 have been much higher, and variable. The 2012 biomass estimate of 619 t for butter sole was fairly low relative to the time-series since 1991 (4^{th} lowest) and had a high CV (0.62).

The timing of the butter sole fishery catches do not overlap with survey sampling and came primarily from waters less than 50 m in January and February, a depth and time not covered by the trawl survey. Butter sole are mostly caught by non-pelagic trawl catcher-processors in the rock sole and Pacific cod target fisheries in areas 509 and 516. The center of abundance for butter sole in Alaska is in the Gulf of Alaska whereas the survey and fishery catches on the north side of the Alaska Peninsula represent butter sole captured at the periphery of their distribution, where they are relatively rare.

Several other species in this management category are relatively rare on the EBS shelf, including Dover sole, Sakhalin sole, and English sole, and it is useful to identify whether the EBS represents the edge of the distribution for these species. The distribution of English sole has been identified as Baja California to Unimak Island, and the distribution of Dover sole has been identified as from Baja California to the Bering Sea (Hart 1973). Thus, the eastern Bering Sea can be considered the periphery of the range for these species. They are much more abundant in the Gulf of Alaska. For example, the abundance of Dover sole in the 1984-2011 GOA surveys has fluctuated between 63,000 t and 99,000 t, the abundance of butter sole has ranged between 17,000 t and 31,000 t, and the abundance of English sole has varied between 3,000 t and 18,600 t (Turnock et al. 2011). Dover sole and English sole were most common in the eastern portion of the GOA, consistent with their reported distribution along the west coast of North America. In the case of Sakhalin sole, which prefer colder water and are caught at the northern extent of the survey, their perceived abundance from survey biomass estimates may be related to annual mean bottom water temperature, as they tended to be more abundant in colder years during the 1980s and 1990s. The recent trend from trawl surveys estimates Sakhalin sole at low abundance, however, sampling of the northern Bering Sea in 2010 indicated that their primary distribution is located to the north of the standard survey area (Fig. 11.2). The northern Bering Sea biomass estimate of Sakhalin sole is 2,180 t compared to the 152 t average for the past 5 years estimated for the standard survey area.

Analytic Approach

Model Structure

As Tier 5 constituents, no stock assessment modeling is conducted for the BSAI Other Flatfish.

Parameter Estimates

Natural mortality values for rex and Dover sole are available from age-structured assessments in the Gulf of Alaska SAFE document (Turnock et al. 2005 and Stockhausen et al. 2005) and those published values are used for rex and Dover sole in this stock assessment. For the remaining flatfish species, where less information is available, an assumption of M = 0.15 appears reasonable given the range of values shown above. For the case of starry flounder where estimates are available from a west coast stock assessment (Ralston 2005), the high estimates of M (male = 0.45, female = 0.3) are not used here due to the uncertainty of the estimates and the large spatial difference between the two management areas.

The natural mortality rates used in age-structured BSAI flatfish assessments can be used as guidance and are presented below:

Species	Natural mortality rate used for stock assessment
BSAI yellowfin sole	0.12
BSAI northern rock sole	0.15
BSAI flathead sole	0.20
BSAI Alaska plaice	0.13

GOA rex sole	0.17
GOA Dover sole	0.085

Results

Harvest Recommendations

Other flatfish are assessed under Tier 5 of Amendment 56 to the BSAI groundfish management plan, and thus have harvest recommendations which are directly calculated from estimates of biomass and natural mortality. The estimates of F_{abc} and F_{ofl} under tier 5 are 0.75 x M and M, respectively, and the ABC and OFL levels are the product of the fishing mortality rate and the biomass estimate.

The biomass used to calculate the next year's ABC and OFL has, up to this year, used the sum of the current year point estimates of biomass from each survey for all individual species. This year the ABC methodology has changed to using a random effects model, recommended for all Tier 5 stocks managed by the North Pacific Fisheries Management Council. For the BSAI "other flatfish" complex, the model uses as input the time-series of biomass point-estimates from each survey and their attendant standard errors where the biomass and variances are summed over each species in the complex to calculate an annual ABC biomass (Fig. 11.3). The estimated biomass value in the terminal year of the random effects time series is used for ABC biomass. Runs were made separately for rex sole, Dover sole, and all other species combined (not rex sole and Dover sole).

Given the F_{abc} and F_{ofl} levels listed below and the model estimate of ABC biomass at 125,231 t, the resulting ABC and OFL levels are 14,400 and 19,200 t.

Random Effects Model

	F_{ABC}	F_{OFL}	ABC	OFL
Rex sole	0.13	0.17	3,469	4,626
Dover sole	0.064	0.085	121	162
Others	0.1125	0.15	9,656	12,875
Total Other flatfish			**13,247**	**17,663**

Survey biomass point-estimate of current year method

	F_{ABC}	F_{OFL}	ABC	OFL
Rex sole	0.13	0.17	3,331	4,442
Dover sole	0.064	0.085	105	140
Others	0.1125	0.15	12,959	17,278
Total Other flatfish			**16,395**	**21,860**

Ecosystem Considerations

Data Gaps and Research Priorities

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Turnock, B.J., T.K. Wilderbuer, and E.S. Brown. 2011. Gulf of Alaska flatfish. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Gulf of Alaska Region as Projected for 2012. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage Alaska 99510.

Turnock, B.J., Z. T. A'mar and T. Wilderbuer. 2009. Gulf of Alaska rex sole stock assessment. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Gulf of Alaska Region as Projected for 2006. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage Alaska 99510.

Table 11.1. Flatfish species of the Bering Sea/Aleutian Islands "other flatfish" management complex.

Common Name	Scientific Name
Arctic flounder	*Liopsetta glacialis*
butter sole	*Isopsetta isolepis*
curlfin sole	*Pleuronectes decurrens*
deepsea sole	*Embassichths bathybius*
Dover sole	*Microstomus pacificus*
English sole	*Parophrys vetulus*
longhead dab	*Limanda proboscidea*
Pacific sanddab	*Citharichthys sordidus*
petrale sole	*Eopsetta jordani*
rex sole	*Glyptocephalus zachirus*
roughscale sole	*Clidodoerma asperrimum*
sand sole	*Psettichthys melanostictus*
slender sole	*Lyopsetta exilis*
starry flounder	*Platichthys stellatus*
Sakhalin sole	*Pleuronectes sakhalinensis*

Table 11.2. Harvest (t) of other flatfish from 1995-2014. 2014 catch is through October 25, 2013.

Year	Starry Founder	Rex Sole	Butter Sole	longhead dab	Dover sole	English sole	deep sea sole	Sakhalin sole	Total	ABC	TAC
1995	398	673	157	7	59	26	4	0	1,324	117,000	19,540
1996	1,171	1,148	218	175	6	0	0	30	2,748	102,000	35,000
1997	1,043	687	448	211	53	0	29	6	2,490	97,500	50,750
1998	402	998	229	93	41	0	0	0	1,765	164,000	89,434
1999	725	998	230	56	81	27	0	0	2,117	154,000	154,000
2000	1,151	1,069	458	277	66	4	0	0	3,027	117,000	83,813
2001	755	869	244	62	70	4	6	0	2,028	122,000	28,000
2002	1,075	1,192	222	107	34	0	1	0	2,631	18,100	3,000
2003	887	1,399	296	125	39	2	0	0	2,749	16,000	3,000
2004	2,062	1,858	514	146	82	6	0	0	4,669	13,500	3,000
2005	2,069	2,001	487	25	16	1	0	0	4,599	21,400	3,500
2006	1,663	1,266	261	33	10	0	0	0	3,233	18,100	3,500
2007	4,356	812	579	87	4	2	<1	<1	5,840	21,400	10,000
2008	1,978	968	618	47	10	2	<1	<1	3,623	21,600	21,600
2009	806	1,143	198	7	7	2	0	<1	2,163	17,400	17,400
2010	1,506	510	162	9	5	<1	<1	<1	2,194	17,300	17,300
2011	2,168	860	107	18	10	13	0	<1	3,176	14,500	3,000
2012	2,205	866	191	9	15	5	0	0	3,292	12,700	3,200
2013	906	579	30	15	6	0	0	<1	1,536	13,300	3,500
2014	3,336	769	219	20	10	0	0	0	4,385	13,300	3,500

Table 11.3. Estimated biomass (t) of other flatfish from the eastern Bering Sea (EBS) and Aleutian Islands (AI) AFSC trawl surveys. Species included are Dover sole, longhead dab, rex sole, Sakhalin sole, starry flounder, and butter sole. A linear regression between EBS and AI survey abundance was used to predict AI abundance in years in which an AI survey did not occur.

	Area		
Year	EBS	AI	total
1982	117,763		129,518
1983	66,131	2,700	68,831
1984	59,647		64,956
1985	34,572		37,101
1986	39,517	6,100	45,617
1987	49,764		53,977
1988	44,559		48,195
1989	49,663		53,865
1990	47,126		51,047
1991	72,453	2,144	74,597
1992	53,954		58,632
1993	44,500		48,130
1994	54,368	5,464	59,832
1995	37,891		40,788
1996	60,376		65,766
1997	71,545	7,580	79,125
1998	74,672		81,648
1999	68,557		74,855
2000	70,866	8,149	79,015
2001	78,930		86,378
2002	98,218	8,801	107,019
2003	90,552		99,289
2004	128,740	14,980	143,720
2005	43,970		120,900
2006	132,925	16,367	149,292
2007	133,502		149,507
2008	104,608		121,494
2009	103,575		121,342
2010	114,253	13,076	127,329
2011	94,217		111,060
2012	98,515	15,685	114,200
2013	89,995		107,481
2014	129,025	13,936	142,961

Table 11.4 --Estimated biomass (t) and coefficient of variation (in parentheses) for the miscellaneous species of the "other flatfish" management complex in the Bering Sea trawl and Aleutian Islands surveys.

Eastern Bering Sea Shelf survey

Year	Dover Sole	Rex Sole	longhead dab	Sakhalin sole	starry flounder	butter sole	slender sole	sand sole
1982	--	5,994 (0.16)	103,806 (0.16)	--	7,781 (0.32)	182 (0.82)	--	--
1983	--	7,272 (0.18)	51,386 (0.38)	--	7,436 (0.25)	37 (0.45)	--	1,559(0.94)
1984	--	13,058 (0.28)	35,308 (0.16)	137 (0.43)	8,913 (0.36)	2,231 (0.64)	--	--
1985	10 (1.04)	10,751 (0.20)	9,107 (0.13)	102 (0.37)	12,181 (0.24)	2,421 (0.83)	--	--
1986	15 (1.00)	12,886 (0.22)	10,889 (0.14)	274 (0.48)	9,112 (0.33)	6,341 (0.58)	--	--
1987	81 (0.91)	12,931 (0.19)	11,897 (0.19)	110 (0.58)	22,702 (0.63)	2,043 (0.38)	--	--
1988	38 (0.59)	15,445 (0.15)	16,710 (0.19)	1,061 (0.40)	9,222 (0.30)	2,083 (0.47)	--	1,128(1.0)
1989	--	12,939 (0.15)	13,086 (0.16)	129 (0.57)	22,205 (0.35)	1,304 (0.54)	--	--
1990	47 (0.58)	11,857 (0.21)	18,601 (0.15)	587 (0.36)	15,048 (0.26)	986 (0.60)	--	--
1991	55 (0.70)	16,014 (0.28)	18,680 (0.14)	345 (0.68)	34,303 (0.23)	3,056 (0.50)	--	--
1992	137 (0.58)	14,001 (0.24)	10,827 (0.17)	212 (0.48)	27,544 (0.22)	1,233 (0.70)	--	--
1993	37 (0.75)	14,567 (0.32)	11,690 (0.21)	179 (0.31)	16,510 (0.22)	1,517 (0.75)	--	--
1994	73 (0.72)	15,943 (0.38)	18,533 (0.26)	506 (0.52)	18,218 (0.22)	1,095 (0.97)	--	--
1995	--	10,420 (0.28)	8,402 (0.15)	214 (0.27)	17,652 (0.29)	1,203 (0.54)	--	--
1996	--	10,532 (0.40)	8,567 (0.20)	185 (0.56)	40,409 (0.45)	683 (0.53)	--	--
1997	--	8,233 (0.27)	18,003 (0.21)	1,407 (0.84)	41,018 (0.21)	2,884 (0.43)	--	--
1998	41 (0.44)	7,588 (0.22)	14,737 (0.19)	770 (0.86)	49,605 (0.30)	1,942 (0.38)	--	--
1999	16 (0.65)	8,020 (0.28)	12,087 (0.21)	907 (0.63)	43,375 (0.25)	4,152 (0.62)	--	--
2000	11 (1.02)	9,348 (0.19)	13,511 (0.30)	473 (0.43)	45,810 (0.19)	1,713 (0.56)	--	--
2001	16 (0.84)	21,660 (0.23)	12,764 (0.26)	117 (0.32)	43,026 (0.25)	796 (0.50)	--	--
2002	7 (0.80)	26,053 (0.20)	9,740 (0.22)	173 (0.90)	59,877 (0.23)	2,254 (0.64)	--	--
2003	350 (0.66)	28,023 (0.15)	8,827(0.22)	280 (0.75)	52,893 (0.17)	179 (0.61)	3	
2004	31(0.51)	28,762 (0.19)	11,290 (0.23)	1,118 (0.98)	86,698 (0.38)	841 (0.86)	--	--
2005	157(0.19)	23,171(0.19)	11,556 (0.21)	961(0.97)	71,673(0.26)	958(0.81)	--	--
2006	90(0.53)	21,515(0.28)	13,204(0.25)	125(0.58)	96,900(0.37)	1,091(0.53)	--	--
2007	73(0.53)	17,025(0.25)	16,733(0.24)	30(0.34)	98,623(0.17)	1,018(0.44)	--	--
2008	364(0.90)	18,788(0.31)	10,884(0.22)	77(0.36)	74,077(0.21)	418(0.44)	--	--
2009	469(0.95)	18,142(0.39)	5,011(0.23)	55(0.44)	79,366(0.19)	532(0.60)	--	--
2010	201(0.54)	20,320(0.32)	11,557(0.47)	78(0.49)	80,351(0.25)	1,746(0.82)	--	--
2011	4,08(0.96)	18,525(0.32)	10,348(0.59)	513(0.72)	63,986(0.23)	437(0.69)	--	--
2012	1,921(0.7)	39,695(0.25)	9,065(0.23)	37(0.29)	62,837(0.27)	619(0.62)	--	--
2013	27(1)	9,767(0.18)	5,448(0.45)	625(0.87)	58,942(0.2)	1,306(0.69)	--	--
2014	620 (1)	13,276 (0.32)	3,129 (0.45)	584 (0.79)	110,907 (0.35)	510 (0.65)	--	--

Table 11.4 . continued. Estimated biomass (t) and coefficient of variation (in parentheses) for the miscellaneous species of the "other flatfish" management complex in the Aleutian Islands surveys.

Year	Dover Sole	Rex Sole	longhead dab	Sakhalin sole	starry flounder	butter sole	English sole
1991	174 (0.45)	1,694 (0.18)	--	--	142 (0.85)	86 (0.73)	47 (0.80)
1994	438 (0.41)	4,306 (0.15)	--	--	134 (0.69)	505 (0.98)	83 (0.81)
1997	386 (0.34)	6,378 (0.16)	--	--	459 (0.90)	346 (0.98)	12 (0.72)
2000	630 (0.38)	6,526 (0.18)	--	--	590 (0.71)	310 (0.99)	95 (0.97)
2002	575 (0.28)	7,381 (0.15)	--	--	671 (0.72)	127 (0.83)	47 (0.94)
2004	870 (0.28)	13,717 (0.18)	--	--	123 (0.72)	235 (0.93)	35 (1.00)
2006	2,155 (0.57)	14,230 (0.19)			17 (0.97)	13(0.98)	25 (0.84)
2010	2,853 (0.43)	9,762 (0.14)	--	--	127 (0.14)	180 (0.69)	15 4(0.67)
2012	1,214 (0.24)	14,102(0.24)	--	--	209 (0.6)	134 (0.1)	26 (0.73)
2014	1,025 (0.31)	12,853 (0.13)	--	--	0	0	58 (0.69)

Table 11.5. Estimated biomass (t), harvest amount (t), and exploitation rates of rex sole, starry flounder and butter sole from 1997 to 2014.

	Rex sole			Starry Flounder			Butter sole		
Year	Biomass (t)	Harvest (t)	Exp. Rate	Biomass (t)	Harvest (t)	Exp. Rate	Biomass (t)	Harvest (t)	Exp. Rate
1997	14,611	401	0.03	41,477	814	0.02	3,230	336	0.10
1998	14,250	569	0.04	49,950	242	0.00	2,210	157	0.07
1999	15,415	516	0.03	43,750	597	0.01	4,416	167	0.04
2000	15,874	569	0.04	46,400	770	0.02	2,023	266	0.13
2001	30,524	507	0.02	43,829	479	0.01	1,059	147	0.14
2002	33,411	1,227	0.04	60,633	1,023	0.02	2,382	187	0.08
2003	38,349	1,399	0.04	53,353	887	0.02	429	296	0.69
2004	42,479	1,858	0.04	86,821	2,062	0.02	1,076	514	0.48
2005	34,963	1,830	0.05	72,176	1,892	0.03	1,201	445	0.37
2006	35,745	1,266	0.04	96,917	1,663	0.02	1,104	261	0.24
2007	31,052	812	0.03	98,941	4,356	0.04	1,153	579	0.50
2008	33,613	961	0.03	74,397	1,964	0.03	541	614	1.14
2009	33,766	1,132	0.03	79,688	797	0.01	642	196	0.31
2010	30,082	491	0.02	80,478	1,148	0.02	1,926	156	0.08
2011	32,544	826	0.03	64,218	2,082	0.03	562	103	0.18
2012	39,695	866	0.02	62,837	2,205	0.04	619	191	0.31
2013	9,767	569	0.015	58,942	889	0.015	1,306	29	0.02
2014	26,129	769	0.03	111,116	3,366	0.03	510	219	0.43

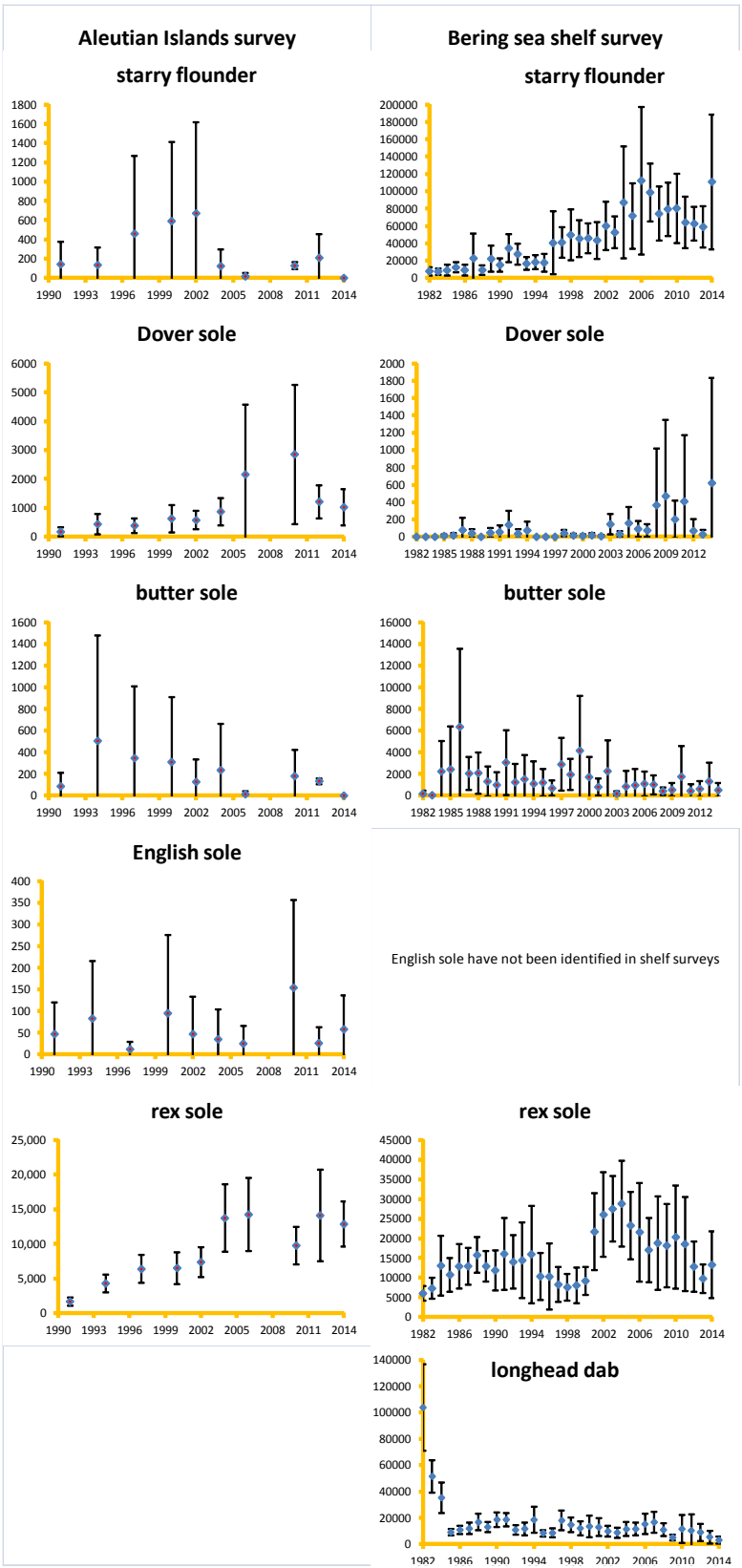

Figure 11.1. BSAI shelf survey and Aleutian Islands survey biomass estimates with 95% confidence intervals.

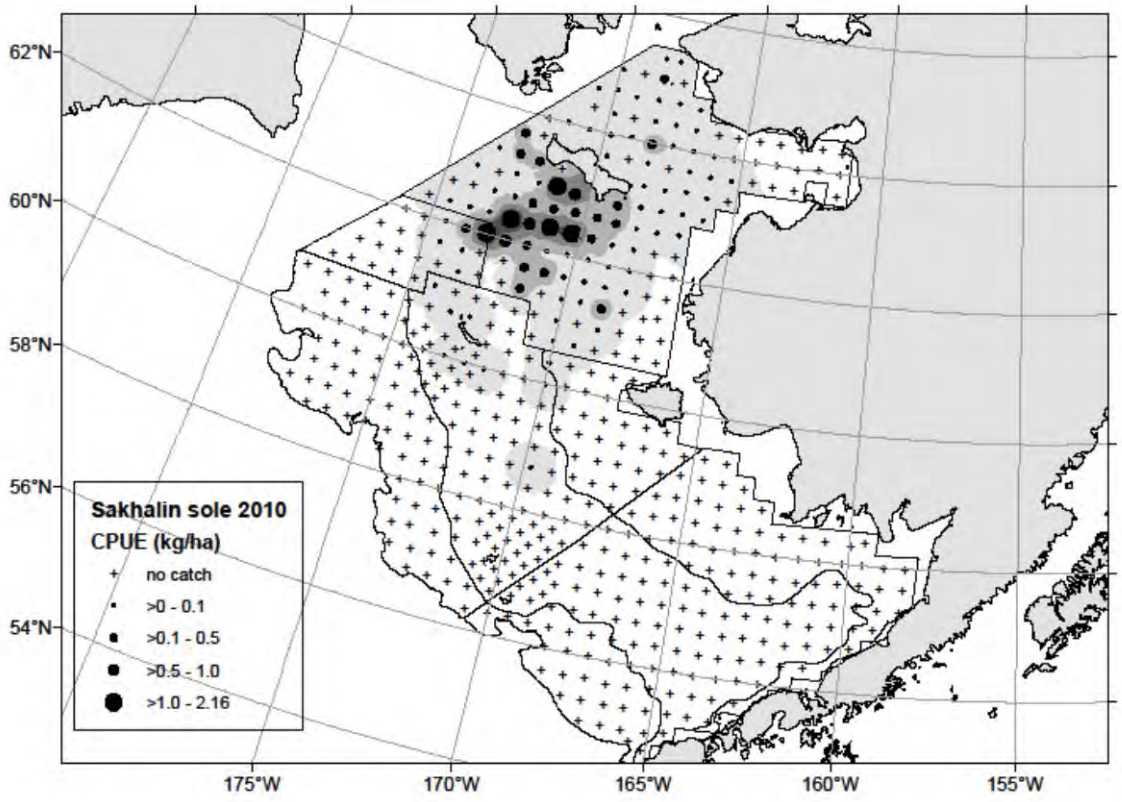

Figure 11-2. Distribution and relative abundance of Sakhalin sole from the AFSC sampling of the Bering Sea in the summer of 2010.

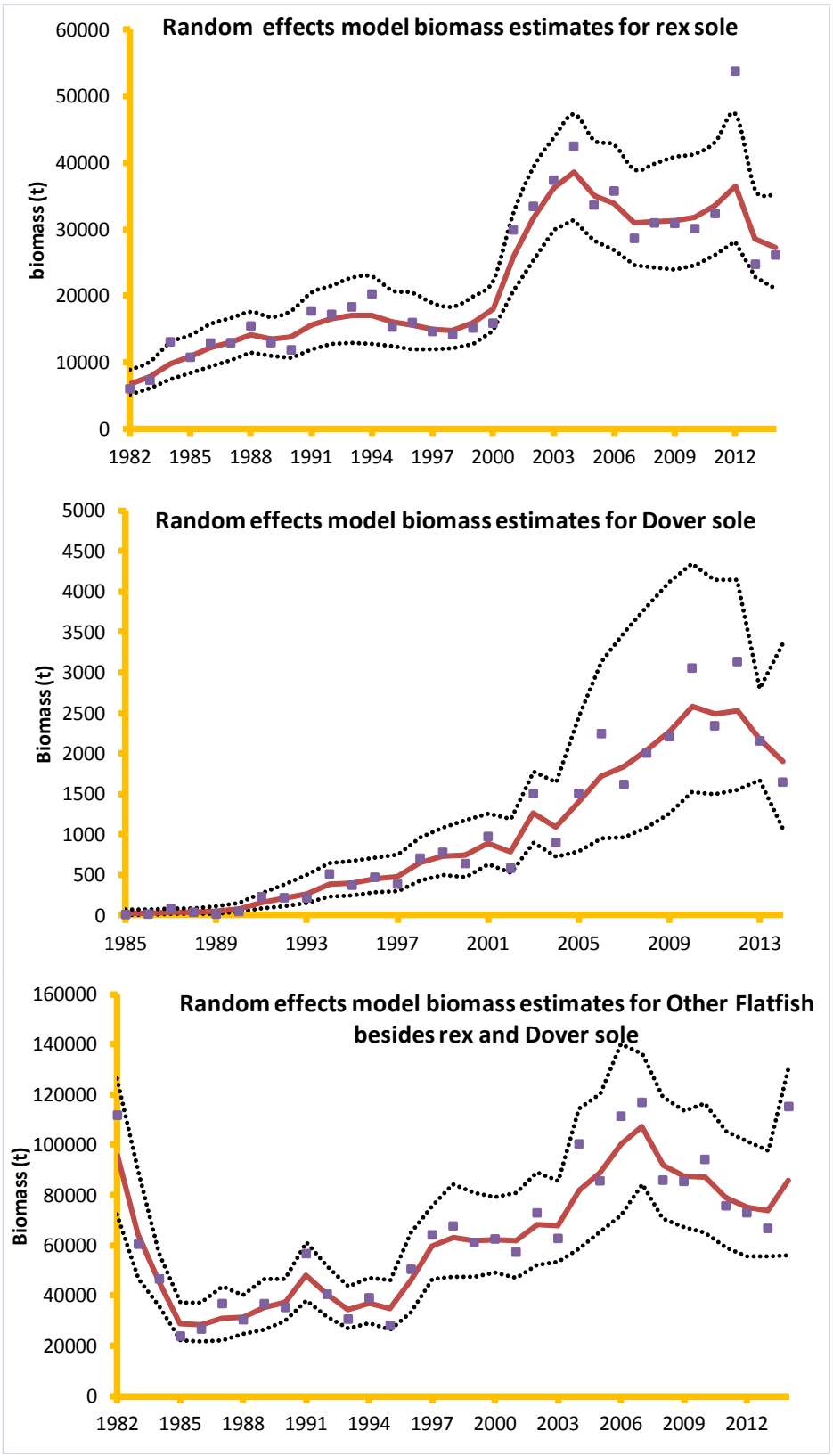

Figure 11.3. Random effects model results for BSAI Other Flatfish. Purple squares are the sum of survey biomasses.

12. Assessment of the Pacific ocean perch stock in the Bering Sea/Aleutian Islands

by

Paul D. Spencer and James N. Ianelli

Executive Summary

The last full assessment for Pacific ocean perch (POP) was presented to the Plan Team in 2012. The following changes were made to POP assessment relative to the November 2012 SAFE:

Summary of Changes in Assessment Inputs

Changes in the Input Data

1) The harvest time series were updated through October 11, 2014.
2) The survey biomass estimates and age composition data from the U.S.-Japan cooperative survey in 1980,1983, and 1986 were removed from the assessment.
3) The 2014 AI survey biomass estimate and length composition was included in the assessment.
4) The 2012 AI survey age compositon was included in the assessment.
5) The 2013 fishery age composition were included in the assessment.
6) The 2012 fishery length composition was included in the assessment

Changes in the Assessment Methodology

1) Several fishery selectivity models were evaluated, with the recommended model using a bicubic spline to model to estimate fishery selectivity as a function of year and age.
2) The multinomial input sample sizes for the age and length composition data were obtained by an iterative reweighting procedure that ensures that the standard deviation of the normalized residuals for each composition data type is 1.
3) The length-at-age, weights-at-age, and age-to-length conversion matrix were updated based on data from the NMFS AI trawl survey beginning in 1991.

Summary of Results

A summary of the 2014 assessment recommended ABC's relative to the 2013 recommendations is shown below. BSAI Pacific ocean perch are not overfished or approaching an overfished condition. The recommended 2015 ABC and OFL are 34,988 t and 42,588 t, which are 11%and 13% increases, respectively, from the maximum ABC and OFL specified last year for 2015 of 31,641 t and 37,817 t. The 2014 AI survey biomass is large and consistent with the survey biomass estimates in 2010 and 2012, and the size composition data continue to show relatively strong cohorts from 1994 to 2000. A summary of the recommended ABCs and OFLs from this assessment relative the ABC and OFL specified last year is shown below:

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Quantity	As estimated or specified last year for: 2014	2015	As estimated or recommended this year for: 2015	2016
M (natural mortality rate)	0.062	0.062	0.062	0.062
Tier	3a	3a	3a	3a
Projected total (age 3+) biomass (t)	639,505	620,270	577,967	561,090
Female spawning biomass (t)				
Projected	257,878	243,400	234,426	223,744
$B_{100\%}$	459,436	459,436	423,008	423,008
$B_{40\%}$	183,774	183,774	169,203	169,203
$B_{35\%}$	160,803	160,803	148,053	148,053
F_{OFL}	0.076	0.076	0.109	0.109
$maxF_{ABC}$	0.063	0.063	0.089	0.089
F_{ABC}	0.063	0.063	0.089	0.089
OFL (t)	39,585	37,817	42,558	40,809
maxABC (t)	33,122	31,641	34,988	33,550
ABC (t)	33,122	31,641	34,988	33,550
Status	As determined last year for: 2012	2013	As determined this year for: 2013	2014
Overfishing	No	n/a	No	n/a
Overfished	n/a		n/a	No
Approaching overfished	n/a		n/a	No

Summaries for the Plan Team

The ABC for BSAI Pacific ocean perch is currently apportioned among four areas: the western, central, and eastern Aleutian Islands, and eastern Bering Sea. The current method of determining area apportionments uses a weighted average of the three most recent trawl survey biomass estimates in each of these areas is used to apportion the ABC. Weights of 4, 6, and 9 are used, with higher weights being applied to the more recent surveys. It is also of interest to estimate the area proportions using the random effects model. The survey averaging workgroup is evaluating the use of the random effects model to smooth survey time series for computing area apportionments, and its use for computing area proportion might logically be delayed until after the workgroup has completed their evaluations. However, a comparison between the two methods may be useful. The following table gives the projected OFLs and apportioned ABCs for 2015 and 2016 from the two methods, and the recent OFLs, ABCs, TACs, and catches.

	BSAI	Western AI	Central AI	Eastern AI	EBS	Total
Apportionment (weighted average)		28.5%	23.6%	24.6%	23.3%	100%
Apportionment (RE model)		29.1%	22.1%	23.8%	25.1%	100%
OFL (2013)	41,900					
ABC (2013)		10,200	6,980	9,790	8,130	35,100
TAC (2013)		10,200	6,980	9,790	8,130	35,100
Catch (2013)		10,065	6,747	9,530	5,050	31,393
OFL (2014)	39,585					
ABC (2014)		9,598	6,594	9,246	7,684	33,122
TAC (2014)		9,598	6,594	9,246	7,684	33,122
Catch (2014)[1]		9,485	6,438	8,124	1,842	25,889
OFL (2015)	42,558					
ABC (2015, weighted average)		9,981	8,240	8,623	8,143	34,988
ABC (2015, RE model)		10,182	7,723	8,312	8,771	34,988
OFL (2016)	40,809					
ABC (2016, weighted average)		9,571	7,902	8,269	7,809	33,550
ABC (2016, RE model)		9,763	7,406	7,970	8,411	33,550

Catch through October 11, 2014

Responses to SSC and Plan Team Comments in General

The SSC requests that all assessment authors of AI species evaluate AI survey information to ensure that the same standardized survey time series is used. (SSC, December 2012)

Model runs in this assessment exclude the cooperative surveys conducted in the 1980s.

"The Teams recommended that each stock assessment model incorporate the best possible estimate of the current year's removals. The Teams plan to inventory how their respective authors address and calculate total current year removals. Following analysis of this inventory, the Teams will provide advice to authors on the appropriate methodology for calculating current year removals to ensure consistency across assessments and FMPs." (Plan Team, September 2013)

The estimates of current year catch are inferred by expanding the catch through September, 2014, by the recent pattern of the proportion of the remaining ABC that is caught by the end of the year.

"For assessments involving age-structured models, this year's CIE review of BSAI and GOA rockfish assessments included three main recommendations for future research: Authors should consider: (1) development of alternative survey estimators, (2) evaluating selectivity and fits to the plus group, and (3) re-evaluating natural mortality rates. The SSC recommends that authors address the CIE review during full assessment updates scheduled in 2014." (SSC, December 2013)

Selectivity curves and natural mortality rates are evaluated in this assessment. The development of alternative survey estimators (i.e., model-based standardization of survey catch data) affects all NPFMC assessments that use survey data. Potential methodologies have been discussed in a limited number of meetings in 2014 among AFSC scientists, and between AFSC scientists and NWFSC scientists, who are in the process of developing more refined standardization methods. Continuation of these meetings will hopefully result in progress on this task.

"During public testimony, it was proposed that assessment authors should consider projecting the reference points for the future two years (e.g., 2014 and 2015) on the phase diagrams. It was suggested that this forecast would be useful to the public. The SSC agrees. The SSC appreciated this suggestion and asks the assessment authors to do so in the next assessment." (SSC December 2013)

These projections were added to the phase-plane plots.

Responses to SSC and Plan Team Comments Specific to this Assessment

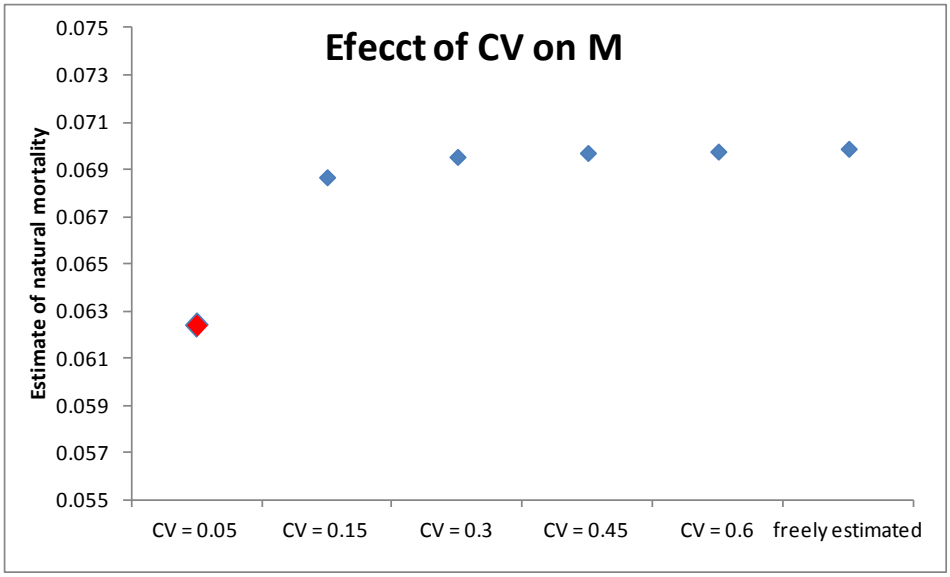
The SSC offers the following advice to assessment authors:
- *Explore alternative selectivity patterns*
- *Evaluate alternative selectivity time periods*
- *Provide model sensitivity to Q and M*
- *Explore lack of fit to the plus age group*
- *Fit to the maturity data should be evaluated for potential bias from excess data consisting of 100% and 0% maturity because the logistic model cannot predict 0 and 1.* (SSC, December 2012)

Several methods for modeling fishery selectivity over age and year were considered in this assessment, with a bicubic spline (used in the preferred model) providing improved fits to the survey and fishery age composition plus group.

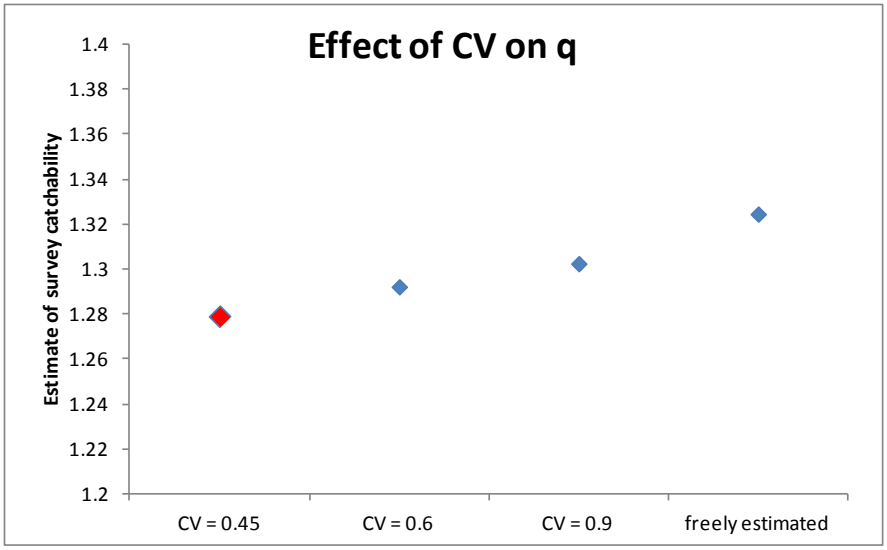
Although predicted proportion mature obtained from the logistic model asymptotically approaches 1 as

age increases, the difference between the asymptote of 1 and the predicted value for older ages is sufficiently small such that any effect on the model fit is not a concern. For example, the predicted proportion mature at age 25 is 0.99999905.

A series of models runs were conducted to address how sensitive the model estimates of natural mortality (*M*) and survey catchability (*q*) are to the prior distributions. Because *M* and *q* are inversely correlated, the runs for *M* were conducted by holding *q* fixed at the value estimated in the preferred model (and vice versa). The current model uses a prior distribution for *M* with a mean and CV each set to 0.05, and produces and estimate of 0.062 (shown in red in the graph below). Increasing the CV, or allowing *M* to be freely estimated, produces estimates ranging between 0.069 and 0.070. This value of *M* is consistent with a recent meta-analysis relating natural mortality estimates to maximum age (Then et al. 2014). Future assessments will consider increasing expected value of the prior distribution for *M* from 0.05 to 0.07.



The prior for *q* has a mean of 1 and a CV of 0.45, and a similar plot showing the effect of increasing the CV of the prior is shown below. The estimates of *q* ranges from 1.28 estimated in the current model to 1.32 when *q* is freely estimated (while holding *M* fixed at 0.0062). For this stock, estimates of *q* are more sensitive to the addition of age and length composition data and survey biomass estimates, which motivate obtaining information on *q* outside the assessment model in order to develop more informative priors.


Effect of CV on q
Estimate of survey catchability
1.4
1.38
1.36
1.34
1.32
1.3
1.28
1.26
1.24
1.22
1.2
CV = 0.45
CV = 0.6
CV = 0.9
freely estimated

Introduction

Pacific ocean perch (*Sebastes alutus*) inhabit the outer continental shelf and upper slope regions of the North Pacific Ocean and Bering Sea. Pacific ocean perch, and four other associated species of rockfish (northern rockfish, *S. polyspinis*; rougheye rockfish, *S. aleutianus*; shortraker rockfish, *S. borealis*; and sharpchin rockfish, *S. zacentrus*) were managed as a complex in the two distinct areas from 1979 to 1990. Known as the POP complex, these five species were managed as a single entity with a single TAC (total allowable catch). In 1991, the North Pacific Fishery Management Council separated POP from the other red rockfish in order to provide protection from possible overfishing. Of the five species in the former POP complex, *S. alutus* has historically been the most abundant rockfish in this region and has contributed most to the commercial rockfish catch.

Information on Stock Structure

A variety of types of research can be used to infer stock structure of POP, including age and length compositions, growth patterns and other life-history information, and genetic studies. Spatial differences in age or length compositions can be used to infer differences in recruitment patterns that may correspond to population structure. In Queen Charlotte Sound, British Columbia, Gunderson (1972) found substantial differences in the mean lengths of POP in fishery hauls taken at similar depths which were related to differences in growth rates and concluded that POP likely form aggregations with distinct biological characteristics. In a subsequent study, Gunderson (1977) found differences in size and age composition between Moresby Gully and two other gullies in Queen Charlotte Sound. Westrheim (1970, 1973) recognized "British Columbia" and "Gulf of Alaska" POP stocks off the western coast of Canada based upon spatial differences in length frequencies, age frequencies, and growth patterns observed from a trawl survey. In a study that has influenced management off Alaska, Chikuni (1975) recognized distinct POP stocks in four areas – eastern Pacific (British Columbia), Gulf of Alaska, Aleutian Islands, and Bering Sea. However, Chikuni (1975) states that the eastern Bering Sea (EBS) stock likely receives larvae from both the Gulf of Alaska (GOA) and Aleutian Islands (AI) stock, and the AI stock likely receives larvae from the GOA stock.

An alternative approach to evaluating stock structure involves examination of rockfish life-history stages directly. Stock differentiation occurs from separation at key life-history stages. Because many rockfish species are not thought to exhibit large-scale movements as adults, movement to new areas and boundaries of discrete stocks may depend largely upon the pelagic larval and juvenile life-history stages. Simulation modeling of ocean currents in the Alaska region suggest that larval dispersal may occur over very broad areas, and may be dependent on month of parturition (Stockhausen and Herman 2007).

Analysis of field samples of rockfish larvae are hindered by difficulties in indentifying species. Analyses of archived *Sebastes* larvae was undertaken by Dr. Art Kendall revealed that species identification based on morphological characteristics is difficult because of overlapping characteristics among species, as few rockfish species in the north Pacific have published descriptions of the complete larval developmental series. However, all of the larvae examined could be assigned to four morphs identified by Kendall (1991), where each morph is associated with one or more species. Rockfish identification can be aided by studies that combine genetic and morphometric techniques and information has been developed to identify individual species based on allozymes (Seeb and Kendall 1991) and mitochondrial DNA (Gharrett et al. 2001, Rocha-Olivares 1998). The Ocean Carrying Capacity (OCC) field program, conducted by the Auke Bay laboratory, uses surface trawls to collect juvenile salmon and incidentally collects juvenile rockfish. These juvenile rockfish are large enough (approximately 25 mm and larger) to allow extraction of a tissue sample for genetic analysis without impeding morphometric studies. In 2002, species identifications were made for an initial sample of 55 juveniles with both morphometric and genetic techniques. The two techniques showed initial agreement on 39 of the 55 specimens, and the

genetic results motivated re-evaluation of some of the morphological species identifications. Forty of the specimens were identified as POP, and showed considerably more morphological variation for this species than previously documented.

Because stocks are, by definition, reproductively isolated population units, it is expected that different stocks would show differences in genetic material due to random drift or natural selection. Thus, analysis of genetic material from North Pacific rockfish is currently an active area of research.

Seeb and Gunderson (1988) used protein electrophoresis to infer genetic differences based upon differences in allozymes from POP collected from Washington to the Aleutian Islands. Discrete genetic stock groups were not observed, but instead gradual genetic variation occurred that was consistent with the isolation by distance model. The study included several samples in Queen Charlotte Sound where Gunderson (1972, 1977) found differences in size compositions and growth characteristics. Seeb and Gunderson (1988) concluded that the gene flow with Queen Charlotte Sound is sufficient to prevent genetic differentiation, but adult migrations were insufficient to prevent localized differences in length and age compositions. More recent studies of POP using microsatellite DNA revealed population structure at small spatial scales, consistent with the work of Gunderson (1972, 1977). These findings suggest that adult POP do not migrate far from their natal grounds and larvae are entrained by currents in localized retention areas (Withler et al. 2001).

Interpretations of stock structure are influenced by the technique used to assess genetic analysis differentiation, as illustrated by the differing conclusions produced from the POP allozyme work of Seeb and Gunderson (1988) and the microsatellite work of Withler et al. (2001). Note that these two techniques assess components of the genome that diverge on very different time scales and that, in this case, microsatellites are much more sensitive to genetic isolation. Protein electrophoresis examines DNA variation only indirectly via allozyme frequencies, and does not recognize situations where differences in DNA may result in identical allozymes (Park and Moran 1994). In addition, many microsatellite loci may be selectively neutral or near-neutral, whereas allozymes are central metabolic pathway enzymes and do not have quite the latitude to produce viable mutations. The mutation rate of microsatellite alleles can be orders of magnitude higher than allozyme locus mutation rates. Most current studies on rockfish genetic population structure involve direct examination of either mitochondrial DNA (mtDNA) or microsatellite DNA.

Dr. Anthony Gharrett of the Juneau Center of Fisheries and Ocean Sciences has examined the mtDNA and microsatellite variation for POP samples collected in the GOA and BSAI. The POP mtDNA analysis was performed on 124 fish collected from six regions ranging from southeast Alaska to the Bering Sea slope and central Aleutian Islands. No population structure was observed, as most fish (102) were characterized by a common haplotype. Preliminary results from an analysis of 10 microsatellite loci from the six regions resulted in 7 loci with significant heterogeneity in the distribution of allele frequencies. Additionally, the sample in each region was statistically distinct from those in adjacent regions, suggesting population structure on a relatively fine spatial scale consistent with the results on Gunderson (1972, 1977) and Wither et al. (2001). Ongoing genetic research with POP is focusing on increasing the sample sizes and collection sites for the microsatellite analysis in order to further refine our perception of stock structure.

Fishery

POP were highly sought by Japanese and Soviet fisheries and supported a major trawl fishery throughout the 1960s. Catches in the eastern Bering Sea peaked at 47,000 (metric tons, t) in 1961; the peak catch in the Aleutian Islands region occurred in 1965 at 109,100 t. These stocks were not productive enough to support such large removals. Catches continued to decline throughout the 1960s and 1970s, reaching

their lowest levels in the mid 1980s. With the gradual phase-out of the foreign fishery in the 200-mile U.S. Exclusive Economic Zone (EEZ), a small joint-venture fishery developed but was soon replaced by a domestic fishery by 1990. In 1990 the domestic fishery recorded the highest POP removals since 1977. The OFLs, ABCs, TACs, and catches by management complex from 1977 to 2000 (when POP were managed as separate stocks in the EBS and AI) are shown in Table 1. Note that in some years, POP were managed in the "POP complex" management group, which also included rougheye rockfish, shortraker rockfish, northern rockfish, and sharpchin rockfish. In 2002 POP were managed as a single stock across the BSAI (with the ABC subdivided between the EBS and AI subareas, and the BSAI OFLs, ABCs, TACs, and catches for this period is shown in Table 2. The ABCs, TACs, and catches from 1988 to 2012 are shown in Table 2. The catches of POP from 1977 by fishery type (i.e., foreign, joint venture, or domestic) is shown in Table 3.

Estimates of retained and discarded POP from the fishery have been available since 1990 (Table 4). From 1990-2009, the eastern Bering Sea region generally showed a higher discard rate than in the Aleutian Islands region, with the average rates 33% and 14%, respectively. From 2010-2013, the eastern Bering Sea discard rate was less than 7% but increased to 41% in 2014, although this may be an artifact of only including the catches through Oct 11, 2014. In contrast, the Aleutian Islands discard rates from 2010-2014 were less than 3%.

Initial age-structured assessments for BSAI POP modeled separate selectivity curves for the foreign and domestic fisheries (Ianelli and Ito 1992), although examination of the distribution of observer catch reveals interannual changes in the depth and areas in which POP are observed to be caught within the foreign and domestic periods. For example, POP are predominately taken in depths between 200 m and 300 m, although during the late 1970s-early-1980s a relatively large portion of POP were observed to be captured at depths greater than 300 m (Table 5, Figure 1). Additionally, from 1999 through the early 2000s the proportion caught between 100 m and 200 m increased from ~ 20% in the early to mid 1990s to ~ 30%,and since the mid 2000s the proportion caught between 200 m and 300 m has increased. The area of capture has changed as well; during the late 1970s POP were predominately captured in the western Aleutians, whereas from the early 1980s to the mid-1990s POP were captured predominately in the eastern Aleutians. Establishment of area-specific TACs in the mid-1990s redistributed the POP catch such that about 50% of the current catch is now taken in the western Aleutians (Table 6, Figure 1). Note that the extent to which the patterns of observed catch can be used as a proxy for patterns in total catch is dependent upon the degree to which the observer sampling represents the true fishery. In particular, the proportions of total POP caught that were actually sampled by observers were very low in the foreign fishery, due to low sampling ratio prior to 1984 (Megrey and Wespestad 1990).

Non-commercial catches are shown in Appendix A.

Data

Fishery Data

Catch per unit effort (CPUE) data from Japanese trawl fisheries indicate that POP stock abundance has declined to very low levels in the Aleutian Islands region (Ito 1986). By 1977, CPUE values had dropped by more than 90-95% from those of the early 1960s. Japanese CPUE data after 1977, however, is not a good index of stock abundance because most of the fishing effort has been directed to species other than POP. Standardizing and partitioning total groundfish effort into effort directed solely toward POP is difficult. Increased quota restrictions, effort shifts to different target species, and rapid improvements in fishing technology undoubtedly affect our estimates of effective fishing effort. Consequently, we included CPUE data primarily to evaluate its consistency with other sources of information. We used nominal CPUE data for class 8 trawlers in the eastern Bering Sea and Aleutian Islands regions from 1968-

1979. During this time period these vessels were known to target on POP (Ito 1982).

Length measurements and otoliths read from the EBS and AI management areas (Tables 7 and 8) were combined to create fishery age/size composition matrices. Years that were not selected for age or length composition were rejected due to low samples sizes of fish measured (years 1973-1976, 1985-1986), and/or otoliths read (years 1984-86). In 1982, the method for aging otoliths at the Alaska Fisheries Science Center changed from surface reading to the break and burn method (Betty Goetz, Alaska Fisheries Science Center, pers. comm.), as the latter method is considered more accurate for older fish (Tagart 1984). The time at which the otoliths collected from 1977 to 1982 were read is not known for many vessels and cruises. However, the information available suggests that otoliths from 1977 to 1980 were read prior to 1981, whereas otoliths from 1981 and 1982 were read after 1982. Thus, fishery otoliths from 1977 to 1980 were not used because they were believed to be read by surface ageing and thought to be biased.

Beginning in 1998, samples of otoliths from the fishery catch have been read almost annually or biennially, and show relatively strong year classes from 1984-1988. Fishery age compositions from 2005-2013 indicate several strong recent year classes from 1995-2000 (Figure 2).

Survey Data

Cooperative U.S. – Japan trawl surveys were conducted in the AI 1980, 1983, and 1986, and have been used in previous BSAI POP assessments. However, differences exist in gear design and vessels used between these surveys and the NMFS surveys beginning in 1991 (Skip Zenger, National Marine Fisheries Service, personal communication). For example, the Japanese nets used in the cooperative surveys varied between years and included large roller gear, in contrast to the poly-nor'eastern nets used in the current surveys (Ronholt et al 1994). Given the difficulty of documenting the methodologies for these surveys, and standardizing these surveys with the NMFS surveys, this assessment model is conducted with only the NMFS surveys.

The Aleutian Islands survey biomass estimates were used as an index of abundance for the BSAI POP stock. Since 2000 the survey has occurred biennially, although the 2008 survey was canceled due to a lack of funding. Note that there is wide variability among survey estimates from the portion of the southern Bering Sea portion of the survey (from 165 ^{o} W to 170 ^{o} W), as the post-1991 coefficients of variation (CVs) range from 0.41 to 0.63 (Table 9). The biomass estimates in this region increased from 1,501 t in 1991 to 18,217 t in 1994, and have since ranged between 12,099 t (1997) and 87,794 t (2010). The estimated biomass of Pacific ocean perch in the Aleutian Islands management area region (170^{o} W to 170^{o} E) appears to be less variable, with CVs ranging from 0.12 to 0.24. The biomass estimates for the AI area have ranged between a low of 342,785 t in 1991 and 887,559 t in 2014, with the estimates from the 2010, 2012, and 2014 survey ranging between 864,000 t (2012) and 888,000 t (2014).

From 1991-2010, the Aleutian Island surveys have indicated higher abundances in the western Aleutian Islands than in other subareas. However, in the 2012 survey the biomass estimate for the western AI was 263,661 t, a decrease from the 2010 estimate of 395,933 t, whereas the estimates for the eastern AI increased from 266,607 in the 2010 survey to 366,413 in the 2012 survey (Table 10). The estimated biomass from the 2014 survey for the western AI and eastern AI are 338,000 t and 234,000 t, respectively, which are more similar to the 2010 survey than the 2012 survey. The 2014 estimate for the central AI is 316,000 t, a 35% increase from the 2012 estimate. The total AI 2014 survey biomass estimate was 970,968 t with a CV of 0.19, which is a 8% increase from the 2012 estimate of 902,398 t (CV=0.17). Maps of survey CPUE are shown in Figure 3, and indicate relatively high abundance throughout much of the Aleutian Islands.

Age composition data exists for each Aleutian Islands survey, and the length measurements and otoliths

read are shown in Table 11. The survey age compositions from 1991-2000 indicate relatively strong year classes in 1977, 1984, and 1988. Recent age composition data from 2004 -2012 indicate relatively strong year classes from 1996 to 2000 (Figure 4).

The biennial EBS slope survey was initiated in 2002. The most recent slope survey prior to 2002, excluding some preliminary tows in 2000 intended for evaluating survey gear, was in 1991. Previous slope survey results have not been used in the BSAI model due to high CVs, relatively small population sizes compared to the AI biomass estimates, and lack of recent surveys. However, the biomass estimates in the EBS slope survey have been increasing, ranging from 76,665 t in 2002 to 231,383 in the 2012 survey, with CVs ranging from 0.33 in 2012 to 0.53 in 2002 (Table 9). The slope survey was canceled in 2008 and 2014 due to lack of funding. The slope survey results are not used in this assessment, but the feasibility of incorporating this time series will be evaluated in future years given the increased length of the time series and increased levels of biomass.

Comparison of Fishery and Survey Catches by Depth and Age

A comparison of fishery and survey catches can indicate whether fishery selectivity is suspected of being time-varying and/or dome-shaped. For example, some of the variation in depths and areas fished mentioned above could be related to changes in the stock distribution, which would suggest that availability to the stock is more constant than implied by examining only the catch data. This issue was examined by comparing the catch-weighted mean depth in the fishery (from 1991 – 2013) to that in tows from the Aleutian Islands trawl survey from 1991 to 2014. The survey tows show a relatively constant mean depth of capture across years, whereas the fishery depth of capture show higher of interannual variation (Figure 5).

The plus group for the POP assessment model is 40 years, and of interest is the relative age composition of the old fish within the plus group. Fishery and survey data were binned across years in each of five periods from 1990 to 2011, the age composition of ages 40 to 70+ are shown in Figure 6. Overall, survey age composition generally exceeds the fishery age composition, and this pattern seems to be more pronounced in the earlier time periods. For example, in the 1990-1991 period, the survey age composition exceeded the fishery age composition for each age from 41 – 52 (except age 53); a similar pattern is seen in the 1997-1998 period for ages greater than 58. The pattern can be seen more clearly in the histogram of differences between survey and fishery age proportions (Figure 7); positive differences indicate that the survey proportion exceeded the fishery proportion for a given age. Of the ages with a non-zero difference, the proportion of ages with a positive difference ranged between 0.78 and 0.82 for the four earliest periods, and decreased to 0.6 in the 2009-2011 period. Overall, these data suggest that the some dome-shaped fishery selectivity has likely occurred since 1991, and that it may be diminishing in recent years.

Biological data

A large number of samples are collected from the surveys for age determination, length-weight relationships, sex ratio information, and for estimating the length distribution of the population. The age compositions were determined by constructing age-length keys for each year and using them to convert the observed length frequencies from each year. Because the survey age data were based on the break and burn method of ageing POP, they were treated as unbiased but measured with error. Kimura and Lyons (1991) reported that the percent agreement between readers varies from 60% for age 3 fish to 13% for age 25 fish data. The information on percent agreement was used to derive the variability of observed age around the "true" age, assuming a normal distribution. The mean number of fish at age available to the survey or fishery is multiplied by the aging error matrix to produce the observed survey or fishery age compositions.

Aging methods have improved since the start of the time series. Historically, POP age determinations were done using scales and surface readings from otoliths. These gave estimates of natural mortality of about 0.15 and longevity of about 30 years (Gunderson 1977). Based on the now accepted break and burn method of age determination using otoliths, Chilton and Beamish (1982) determined the maximum age of *S. alutus* to be 90 years. Using similar information, Archibald et al. (1981) concluded that natural mortality for POP should be on the order of 0.05.

Aleutian Islands survey data from 1991 through 2012 were used to estimate growth curves. The resulting von Bertalannfy growth parameters were L_{inf} = 41.53 cm, k = 0.14, and t_0 = -1.202. Growth information from the Aleutian Islands was used to convert estimated numbers-at-age within the model to estimated numbers-at-length.

A conversion matrix was created to convert modeled number at ages to modeled number at length bin, and consists of the proportion of each age that is expected in each length bin. This matrix was created by fitting a power relationship to the observed standard deviation in length at each age (obtained from the aged fish from the 1991-2012 surveys), and the predicted relationship was used to produce variation around the predicted size at age from the von Bertalanffy relationship. The resulting CVs of length at age of the transition matrix decrease from 0.13 at age 3 to 0.07 at age 40.

The estimated length(cm)-weight(g) relationship for Aleutian Islands POP was estimated with survey information from the same years, with the length-weight parameters estimated as $a = 9.56 \times 10^{-6}$ and b = 3.11, where weight = a*(length)^b. The Aleutian Islands length-weight relationship was used to produce estimated weights at age.

The following table summarizes the data available for the BSAI POP model:

Component	BSAI
Fishery catch	1960-2014
Fishery age composition	1981-82, 1990, 1998, 2000-2009, 2011, 2013
Fishery size composition	1964-72, 1983-1984, 1987-1989, 1991-1997, 1999, 2010, 2012
Fishery CPUE	1968-79
Survey age composition	1991, 1994, 1997, 2000, 2002, 2004, 2006,2010,2012
Survey length composition	2014
Survey biomass estimates	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014

Analytic Approach

Model Structure

An age-structured population dynamics model, implemented in the software program AD Model Builder, was used to obtain estimates of recruitment, numbers at age, and catch at age. Population size in numbers at age a in year t was modeled as

$$N_{t,a} = N_{t-1,a-1} e^{-Z_{t-1,a-1}} \qquad 3 < a < A, \quad 1960 < t \leq T$$

where Z is the sum of the instantaneous fishing mortality rate ($F_{t,a}$) and the natural mortality rate (M), A is the maximum number of age groups modeled in the population, and T is the terminal year of the analysis (defined as 2014).

The numbers at age A are a "pooled" group consisting of fish of age A and older, and are estimated as

$$N_{t,A} = N_{t-1,A-1}e^{-Z_{t-1,A-1}} + N_{t-1,A}e^{-Z_{t-1,A}}$$

The plus group was set to 40+, following a sensitivity analysis conducted in the 2012 stock assessment (Spencer and Ianelli 2012)

The numbers at age in the first year of the model are estimated as

$$N_a = R_0 e^{-M(a-3)}$$

where R_0 is the number of age 3 recruits for an unfished population, thus producing an age structure in equilibrium with an unfished stock. Previous assessments have estimated non-equilibrium numbers at age in the first year of the model (as a function of cohort-dependent deviations from average recruitment), although this formulation tended to put most of abundance in the first year in a single cohort. It is generally thought that little fishing for rockfish occurred prior to 1960, so an equilibrium unfished age-structure seems reasonable.

The total numbers of age 3 fish from 1960 to 2011 are estimated as parameters in the model, and are modeled with a lognormal distribution

$$N_{t,3} = e^{\mu_R + \nu_t}$$

where ν_t is a time-variant deviation with a log-scale recruitment standard deviation of σ_r. Little information exists to determine the year-class strength for the three most recent cohorts (2012-2014), which were set to the estimated mean recruitment (based upon the log-scale mean, and the value of σ_r).

The fishing mortality rate for a specific age and time ($F_{t,a}$) is modeled as the product of a $s^f_{a,t}$ and a year-specific fully-selected fishing mortality rate f. The fully selected mortality rate is modeled as the product of a mean (μ_f) and a year-specific deviation (ε_t), thus $F_{t,a}$ is

$$F_{t,a} = s^f_{a,t} f_t = s^f_{a,t} e^{(\mu_f + \varepsilon_t)}$$

The mean number-at-age for each year was computed as

$$\overline{N}_{t,a} = N_{t,a}(1 - e^{-Z_{t,a}}) / Z_{t,a}$$

Catch biomass-at-age was computed as the product of mean numbers at age, instantaneous fishing mortality, and weight at age. The predicted trawl survey biomass $\hat{B}^{twl}_t$ was computed as

$$\hat{B}^{twl}_t = q^{twl} \sum_a (\overline{N}_{t,a} s^{twl}_a W_a)$$

where W_a is the population weight-at-age, s^{twl}_a is the survey selectivity, and q^{twl} is the trawl survey catchability. A CPUE index from 1968 to 1979 is also included in the assessment and is computed as

$$\hat{I}^{cpue}_t = q^{cpue} \sum_a (\overline{N}_{t,a} s^f_{a,t} W_a)$$

where q^{cpue} is the scaling factor for the CPUE index.

To facilitate parameter estimation, prior distributions were used for the survey catchability and the natural mortality rate *M*. A lognormal distribution was also used for the natural mortality rate *M*, with the mean set to 0.05 and the CV set to 0.05. The standard deviation of log recruits, σ_r, was fixed at 0.75, a value consistent with the root mean squared error (RMSE; defined below) of recruitment deviations. Similar, the prior distribution for *qsurv* followed a lognormal distribution with a mean of 1.0 and a coefficient of variation (CV) of 0.05.

Several quantities were computed in order to compare the variance of the residuals to the assumed input variances. The RMSE should be comparable to the assumed coefficient of variation of a data series. This quantity was computed for the AI trawl survey and the estimated recruitments, and for lognormal distribution is defined as

$$RMSE = \sqrt{\frac{\sum_n (\ln(y) - \ln(\hat{y}))^2}{n}}$$

where y and $\hat{y}$ are the observed and estimated values, respectively, of a series length n. The standardized deviation of normalized residuals (SDNR) are closely related to the RMSE. Values of SDNR approximately 1 indicate that the model is fitting a data component as well as would be expected for a given specified input variance. The normalized residuals for a given year i of the AI trawl survey data was computed as

$$\delta_i = \frac{\ln(B_i) - \ln(\hat{B}_i)}{\sigma_i}$$

where σ_i is the input sampling standard deviation of the estimated survey biomass. For age or length composition data assumed to follow a multinomial distribution, the normalized residuals for age/length group a in year i were computed as

$$\delta_{i,a} = \frac{(p_{i,a} - \hat{p}_{i,a})}{\sqrt{\hat{p}_{i,a}(1 - \hat{p}_{i,a})/n_i}}$$

where p and $\hat{p}$ are the observed and estimated proportion, respectively, and n is the input assumed sample size for the multinomial distribution. The effective sample size was also computed for the age and length compositions modeled with a multinomial distribution, and for a given year i was computed as

$$E_i = \frac{\sum_a \hat{p}_a(1 - \hat{p}_a)}{\sum_a (\hat{p}_a - p_a)}.$$

An effective sample size that is nearly equal to the input sample size can be interpreted as having a model fit that is consistent with the input sample size.

Parameterization of fishery selectivity

Three models were evaluated that differed in the parameterization for fishery selectivity at age ($s^f_{a,t}$).

Model 1) *Logistic curve varying between 4-year blocks* (used in previous assessments):

A time-varying fishery selectivity curve is used to account for the interannual changes in terms of depth

and management area fished (Tables 5 and 6). Fishery selectivity is modeled with a logistic equation in which deviations are allowed in the parameters specifying the age (a_{50}) and slope (slp) at 50% selection such that the fishing selectivity $s^f_{a,t}$ for age a and year t is modeled as

$$s^f_a = \frac{1}{1+e^{-(\phi_{asc}+\gamma_t)(a-(a_{50\%}+\eta_t)}}$$

where η_t and γ_t are time-varying deviations that sum to zero and are constrained by adding a lognormal prior to the likelihood function with mean of zero and a CV of 0.1. Deviations in ϕ_{asc} and $a_{50\%}$ allowed between 4-year blocks (i.e., 1964-67, 1968-71, etc.). Little information exists to estimate the selectivity for the 1960-1963 period, so years were combined with those from 1964-1967.

Model 2) *Time-invariant double logistic*

$$s^f_a = \frac{1}{1+e^{-\phi_{asc}(a-a_{50\%})}} \frac{1}{1+e^{-\phi_{des}(a-d_{50\%})}}$$

where fishing selectivity is the product of two logistic curve, and allows for dome-shaped selectivity when the descending slope parameter (ϕ_{des}) is negative.

Model 3) Bicubic spline

A mathematical definition of a spline is a smooth function that is used for either interpolating between fixed points (referred to as "knots" or "nodes") or smoothing a dataset. Splines are of interest when the underlying process for which the spline represents is a smooth, nonlinear function. Splines are constructed from separate piecewise functions that are joined at the knots, and smoothness is ensured by requiring that at each knot, the two functions joined have equal function values, first derivatives, and second derivatives. These conditions can only be met by using polynomial splines of order 3 or higher, and cubic splines are often used because they limit unnecessary bending between the knots. Splines are implemented in non-parametric modeling such as generalized additive models, and been examined in ecological modeling as an approach for modeling time-varying parameters (Thorson et al. 2013). In stock assessment modeling, non-parameteric selectivity curves (a category that includes splines) performed well in an evaluation of various approaches for modeling fishery selectivity (Thorson and Taylor 2013).

The bicubic splines was implemented with the "vcubic_spline_function" function in AD Modelbuilder and models selectivity varying across time and age, and was developed from code provided in Press et al. (1992). Four year knots and 5 age knots were used, for a total of 20 selectivity parameters.

Briefly, the bicubic spline function requires the user to specify a number of age and year nodes that form a grid in the year-age matrix of time-varying selectivity (with equal grid spacing), and values at these nodes are the log-scale fishery selectivity and estimated as parameters. Fishery selectivity at ages and years between the nodes are interpolated with a bicubic spline. The smoothness of the surface is controlled by the number of nodes, and also by a series of penalties estimated within the model. The bicubic spline function was original developed by Dr. Steve Martell for the Integrated Statistical Catch at Age (iSCAM) model, which included penalties for: 1) smoothness across the ages (modeled with the sum of second differences); 2) the slope of the

rate of decline when selectivity decreases with age (modeled with the sum of first differences); and 3) the smoothness across years (modeled with the sum of second differences). In addition to these penalties, an additional penalty on the interannual variability across years (modeled with the first difference) was used in this assessment to address situations in which the selectivity across years was relatively smooth but also non-constant (as would occur with a trend).

Sample sizes for age and length composition data

In previous assessments, the sample sizes for the age and length composition data were set to the square root of the number of fish lengthed or otoliths read. This procedure has resulted in the SDNR for the age and length compositions differing substantially from 1, indicating a mismatch between the precision of the model fit and the assumed input variance.

In this assessment, the sample sizes for the composition data are obtained from an iteratively reweighted procedure using the SDNR (method TA1.2 in Francis 2011). An initial model run in which the sample sizes are specified as in the 2012 assessment is conducted, and a weight that is the inverse of the variance of the normalized residuals for each composition dataset is obtained. The sample sizes for the next model run are the original sample sizes multiplied by the estimated weights, which then produced a new set of weights, and process is iterated until the weights converge. The reweighting was applied to Model 3, and the final sample sizes were applied to Models 1 and 2.

Parameters Estimated Outside the Assessment Model

The parameters estimated independently include the age error matrix, the age-length conversion matrix, and individual weight at age. The calculations for these quantities are described above.

Parameters Estimated Inside the Assessment Model

Parameter estimation is facilitated by comparing the model output to several observed quantities, such as the age and length composition of the survey and fishery catch, the survey biomass, and the catch biomass. The general approach is to assume that deviations between model estimates and observed quantities are attributable to observation error and can be described with statistical distributions. Each data component provides a contribution to a total log-likelihood function, and parameter values that minimize the negative log-likelihood are selected.

The likelihood of the initial recruitments were modeled with a lognormal distribution, yielding the following negative log-likelihood (excluding some constant terms)

$$\lambda_1 \left[\sum_{t=1}^{n} \frac{\left(\nu_t + {\sigma_r}^2/2\right)^2}{2{\sigma_r}^2} + n \ln(\sigma_r) \right]$$

where n is the number of year where recruitment is estimated. The adjustment of adding $\sigma^2/2$ to the deviation was made in order to produce deviations from the mean, rather than the median, recruitment. If σ_r is fixed, the term $n \ln(\sigma_r)$ adds a constant value to the negative log-likelihood. .

The likelihoods of the fishery and survey age and length compositions were modeled with a multinomial distribution. The negative log of the multinomial function (excluding constant terms) for the fishery length composition data, with the addition of a term that scales the likelihood, is

$$-n_{f,t,l} \sum_{s,t,l} (p_{f,t,l} \ln(\hat{p}_{f,t,l}) - p_{f,t,l} \ln(p_{f,t,l}))$$

where n is the reweighted sample size, and $p_{f,t,l,}$ and $\hat{p}_{f,t,l}$ are the observed and estimated proportion at length in the fishery by year and length. The likelihood for the age and length proportions in the survey, $p_{surv,t,a}$ and $p_{surv,t,l}$, respectively, follow similar equations.

The negative log-likelihood of the survey biomass was modeled with a lognormal distribution:

$$\lambda_2 \sum_t (\ln(obs_biom_t) - \ln(pred_biom_t))^2 / 2cv_t^2$$

where obs_biom_t is the observed survey biomass at time t, cv_t is the coefficient of variation of the survey biomass in year t, and λ_2 is a weighting factor. The negative log-likelihood of the CPUE index is computed in a similar manner, and is weighted by λ_3. The negative log-likelihood of the catch biomass was modeled with a lognormal distribution:

$$\lambda_4 \sum_t (\ln(obs_cat_t) - \ln(pred_cat_t))^2$$

where obs_cat_t and $pred_cat_t$ are the observed and predicted catch. Because the catch biomass is generally thought to be observed with higher precision that other variables, λ_4 is given a very high weight so as to fit the catch biomass nearly exactly. This can be accomplished by varying the F levels, and the deviations in F are not included in the overall likelihood function.

A maturity ogive was fit within the assessment model to samples collected in 2010 from fishery and survey vessels (n=280; TenBrink and Spencer 2013) and in 2004 by fishery observers (n=165). The samples were analyzed using histological methods. Parameters of the logistic equation were estimated by maximizing the bionomial likelihood within the assessment model. The number of fish sampled and number of mature fish by age for each collection were the input data, thus weighting the two collections by sample size. Due to the low number of young fish, high weights were applied to age 3 and 4 fish in order to preclude the logistic equation from predicting a high proportion of mature fish at age 0. The estimated age at 50% maturity is 9.1 years.

The overall negative log-likelihood function, excluding the priors on M and survey catchability, the penalties on time-varying fishery selectivity parameters, and the maturity ogive parameters, is

$$\lambda_1\left[\sum_{t=1}^{n}\frac{\left(v_t+{\sigma_r}^2/2\right)^2}{2{\sigma_r}^2}+n\ln(\sigma_r)\right]+$$
$$\lambda_2\sum_t\left(\ln(obs_biom_t)-\ln(pred_biom_t)\right)^2/2cv_t^2+$$
$$\lambda_3\sum_t\left(\ln(obs_cpue_t)-\ln(pred_cpue_t)\right)^2/2cv_{CPUE}^2+$$
$$-n_{f,t,l}\sum_{s,t,l}(p_{f,t,l}\ln(\hat{p}_{f,t,l})-p_{f,t,l}\ln(p_{f,t,l}))+$$
$$-n_{f,t,a}\sum_{s,t,l}(p_{f,t,a}\ln(\hat{p}_{f,t,a})-p_{f,t,a}\ln(p_{f,t,a}))+$$
$$-n_{surv,t,a}\sum_{s,t,a}(p_{surv,t,a}\ln(\hat{p}_{surv,t,a})-p_{surv,t,a}\ln(p_{surv,t,a}))+$$
$$-n_{surv,t,l}\sum_{s,t,a}(p_{surv,t,l}\ln(\hat{p}_{surv,t,l})-p_{surv,t,l}\ln(p_{surv,t,l}))+$$
$$\lambda_4\sum_t\left(\ln(obs_cat_t)-\ln(pred_cat_t)\right)^2$$

For the model run in this analysis, λ_1, λ_2, λ_3, and λ_4 were assigned weights of 1,1, 0.5, and 500, reflecting a strong emphasis on fitting the catch data and a de-emphasis of the CPUE index. The negative log-likelihood function was minimized by varying the following parameters (using the bicubic fishery selectivity):

Parameter type	Number
1) Fishing mortality mean	1
2) Fishing mortality deviations	55
3) Recruitment mean	1
4) Recruitment deviations	52
5) Unfished recruitment	1
6) Biomass survey catchability	1
7) CPUE index catchability	1
8) Fishery selectivity parameters	20
10) Survey selectivity parameters	2
11) Natural mortality rate	1
12) Maturity parameters	2
Total parameters	137

Finally, a Monte Carlo Markov Chain (MCMC) algorithm was used to obtain estimates of parameter uncertainty (Gelman et al. 1995). One million MCMC simulations were conducted, with every 1,000th sample saved for the sample from the posterior distribution after excluding the first 50,000 simulations. Ninety-five percent confidence intervals were produced as the values corresponding to the 5th and 95th percentiles of the MCMC evaluation. For this assessment, confidence intervals on total biomass, spawning biomass, and recruitment strength are presented.

Results

Model Evaluation

Several attributes of the model fits are shown in Table 12. Models 0 and 0.1 are presented for to demonstrate intermediate steps between the 2012 model and the recommended 2014 model (i.e., a "bridging" analysis). Model 0 has the updated data through 2014, Model 0.1 excludes the cooperative survey biomass estimates and age/size composition data, and each uses the age and length composition sample weights as produced for the 2012 assessment. The sample sizes for the composition are identical in Models 1-3, and were produced by applying iterative reweighting to Model 3 (bicubic spline selectivity). Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) were used to evaluate model selection. Each of these metrics penalize the negative log-likelihood by multiple of the number of parameters; in AIC, this multiple is 2 whereas in BIC is the natural log of the number of data points.

For all the models, the number of parameters is "nominal" number of parameters, which overestimates the number of independent parameters because of the use of penalties and prior distributions in the models. Deviance Information Criterion (DIC) could be used, but will often select the models with higher number of parameters (Martell and Stewart 2014). For these reasons, model selection considered additional information such as the root mean squared errors and negative log-likelihoods in the fits to the data, and the residual patterns in fitting the composition data.

Model 3 (bicubic spline selectivity) had the lowest AIC and BIC, and produced better fits to the fishery length composition and survey age composition data than Models 1 and 2 (as revealed by both the negative log-likelihoods and the RMSE). Model 2 has the lowest number of parameters, and was considered to evaluate whether the lack of fit to the age-plus group in the fishery and survey data is more related to the selectivity shape its variation over time. Both appear to be important, as the improvement in Model 3 is achieved by allowing the dome-shaped selectivity curves to vary over time. Additionally, Model 3 achieves to the best fit the time series of survey biomass estimates, which show a strong trend that is informative on the dynamics of the stock.

The estimated spawning biomass for the models is shown in Figure 8, with the bridging Models 0 and 0.1 shown in blue. Relative to the bridging models, Model 3 estimates higher biomass in the early 1980s (resulting from the dome-shaped selectivity in the 1960s and 1970s), and relative similar levels of biomass in the recent years (resulting from the shift from dome-shaped to near asymptotic selectivity).

Model 3 was selected as the preferred model, and the results below were obtained from this model.

Time series results

In this assessment, spawning biomass is defined as the biomass estimate of mature females age 3 and older. Total biomass is defined as the biomass estimate of POP age 3 and older. Recruitment is defined as the number of age 3 POP.

A retrospective analysis was conducted to evaluate the effect of recent data on estimated spawning stock biomass. For the current assessment model, a series of model runs were conducted in which the end year of the model was varied from 2012 to 2002, and this was accomplished by sequentially dropping age and length composition data, survey biomass estimates, and catch estimates from the input data files.

The plot of retrospective estimates of spawning biomass is shown in Figure 9. The largest changes in estimated survey biomass occurred with end years 2004, 2006, 2010, and 2012, when survey biomass estimates and survey age composition data are added to the model. The 2014 survey contains similar

information as in the 2012 survey and thus has relatively little effect on the retrospective pattern.

The change in estimated spawning biomass from the 2009 to 2010 end years was particularly large, as the 2010 survey biomass estimate was substantially increased from the 2006 estimate. A series of exploratory models runs conducted in the 2010 assessment revealed that a combination of the high survey biomass and new observations of strong 1994-2000 year classes observed in both the fishery and survey age and length composition data lowered the estimates of survey catchability and increased estimated biomass.

Mohn's rho can be used to evaluate the severity of any retrospective pattern, and compares an estimated quantity (in this case, spawning stock biomass) in the terminal year of each retrospective model run with the estimated quantity in the same year of the model using the full data set . The absence of any retrospective pattern would result in a Mohn's rho of 0, and would result from either identical estimates in the model runs, or from positive deviations from the reference model being offset by negative deviations. The Mohn's rho for this retrospective runs was -3.43.

The practice of estimating survey catchability within the model likely contributes to the retrospective pattern. The increasing trend in survey biomass cannot be explained by simply increasing the estimates of recruitments in recent years, but instead require an increase in the recruitment estimates for many year classes. This increases the scale of the biomass estimates, and thus lowers the survey catchability. The estimates of survey catchability is greater than 2 for the retrospective runs with 2004 and 2005 end years, and gradually decrease to the estimate of 1.28 obtained with data through 2014. The sensitivity of estimated survey catchability to the sequential addition of survey biomass estimates and age/length composition data motivates the estimation of survey catchability outside the model.

Prior and Posterior Distributions

Posterior distributions for M, q, total 2014 biomass, and median recruitment, based upon the MCMC integrations, are shown in Figure 10. The posterior distribution for M shows little overlap with the prior distribution. However, a sensitivity analysis on the estimation on M (presented in the Executive Summary) indicates that the estimate of M obtained without a prior would be 0.07 (with fixing survey catchabilitity at its current value), and this value of M is also supported by a recent meta-analysis relating estimates of natural mortality to maximum age (Then at al. 2014). In future assessment, increasing the expected value of the prior distribution for M from 0.05 to 0.07 will be considered.

Biomass Trends

The estimated survey biomass index begins with 1,304,450 t in 1960, declines to 238,512 t in 1981, and increases to 751,086 t in 2010, and declines to 671,125 t in 2012 (Figure 11). The survey point estimates are used in a relative sense rather than in an absolute sense, with a survey catchability (q) estimated at 1.28 rather than fixed at 1.0, which is to 16% increase from the value of 1.10 in the 2012 assessment. The model estimate of survey biomass still does not match the high 2010 - 2014 survey biomass estimates very well. Because the AI survey biomass estimates are taken as an index for the entire BSAI area, one might expect that q would be below 1.0 to the extent that the total BSAI biomass is higher than the Aleutian Islands biomass. One factor that may cause an increase in survey catchability is the expansion of survey trawl estimates to untrawlable areas (Kreiger and Sigler 1996). The fit to the CPUE index is shown in Figure 12.

The total biomass showed a similar trend as the survey biomass, with the 2014 total biomass estimated as 597,506 t. The estimated time series of total biomass and spawning biomass, with 95% credibility bounds obtained from MCMC integration, are shown in Figure 13. Total biomass, spawning biomass, and recruitment are given in Table 13.

Age/size compositions

The fits to the fishery age and length composition is shown in Figures 14-15. The observed proportion in the binned age 25+ group for years 1981 and 1982 is higher than the estimated proportion, although the fits improve for the remainder of the fishery age compositions. The observed proportion in the binned length group of 39+ cm for 1964 and 1965 was lower than the estimated proportion, reflecting the modeling of the initial numbers at age as an equilibrium population. However, by 1966 reasonable fits were observed for the binned length group in the fishery length composition (Figure 15). Some of the lack of fit in the mid- to late-1980s is attributable to the low sample size of lengths observed from a reduced fishery. Good fits are obtained for most age groups in the 1991-2012 surveys (Figure 16). The model provides a reasonable fit to the 2014 survey length composition (Figure 17).

Fishing and Survey Selectivity

The estimated age at 50% selection for the survey is 6.02 (Figure 18). The estimated fishery selectivity by age and year is shown in Figure 19, and shows pattern consistent with the empirical data in fishery catch examined above. Strong dome-shaped selectivity is estimated in the early 1960s to allow fish of age 20 older from this period to survive the large fully-selected fishing rates in the 1960s and early 1970s and be available for capture in the fishery and survey in the early 1980s (by which time they have entered the 40+ group). The model estimates that dome-shaped selectivity has decreased over time (with the exception of dome-shaped selectivity for ages 35 and above since 2010).

Fishing Mortality

The estimates of instantaneous fishing mortality for POP range from highs during the 1970's to low levels in the 1980's (Figure 20). Fishing mortality rates since the early 1980's, however, have moderated considerably due to the phase out of the foreign fleets and quota limitations imposed by the North Pacific Fishery Management Council. Note that because of the change in the fishery selectivity over time, the fully-selected rates are not completely comparable over time with respect to the degree to which the stock has been harvested. Nonetheless, the average fully-selected fishing mortality from 1965 to 1980 was 0.57, whereas the average from 1981 to 2011 was 0.04.

The plot of estimated fishing mortality rates and spawning stock biomass relative to the harvest control rules (Figure 21) indicate that BSAI POP would be considered overfished (using current definitions) during much of the period from the mid-1960s to the mid-1980s, although it should be noted the current definitions of $B_{35\%}$ are based on the estimated recruitment of the post-1977 year classes and the average fishery selectivity from the most recent 5 years.

Recruitment

Year-class strength varies widely for BSAI POP (Figure 22; Table 12). The relationship between spawning stock and recruitment also displays a high degree of variability (Figure 23). The 1957 and 1962 year classes are particularly large and sustained the heavy fishing in the 1960s. The rebuilding of the stock in the 1980s and 1990s was based upon recruitments for the 1981, 1984, 1986, and 1988 year classes. Recruitment appears to be lower in early 1990s, but cohorts from 1994 to 2000 generally show relatively strong recruitment (with the exception the 1997 and 1999 year classes), which is consistent with the increasing trend of biomass and the fishery and survey age compositions shown in Figures 14 and 16.

Harvest recommendations

Amendment 56 reference points

The reference fishing mortality rate for Pacific ocean perch is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish

fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{0.40}$, $F_{0.35}$, and $SPR_{0.40}$ were obtained from a spawner-per-recruit analysis. Assuming that the average recruitment from the 1977-2011 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{0.40}$ is calculated as the product of $SPR_{0.40}$ * equilibrium recruits, and this quantity is 169,203 t. The year 2015 estimated spawning stock biomass is 234,426 t.

Specification of OFL and maximum permissible ABC

Since reliable estimates of the 2015 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B>B_{0.40}$ (234,426 t > 169,203 t), POP reference fishing mortality have been classified in tier 3a. For this tier, F_{ABC} maximum permissible F_{ABC} is $F_{0.40}$, and F_{OFL} is equal to $F_{0.35}$. The values of $F_{0.40}$ and $F_{0.35}$ are 0.089 and 0.109, respectively.

The 2015 ABC associated with the $F_{0.40}$ level of 0.089 is 34,988 t.

The estimated catch level for year 2015 associated with the overfishing level of F = 0.074 is 42,558 t. A summary of these values is below.

2015 SSB estimate (B)	**=**	**234,426 t**
$B_{0.40}$	=	169,203 t
$F_{ABC} = F_{0.40}$	=	0.089
$F_{OFL} = F_{0.35}$	=	0.109
MaxPermABC	=	34,988 t
OFL	=	42,558 t

ABC recommendation

We recommend the maximum permissible ABC 34,988 t.

Projections

A standard set of projections is conducted for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2014 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2015 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2014. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2011, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2015 recommended in the assessment to the *max* F_{ABC} for 2015. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 2009-2013 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the Pacific ocean perch stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above 1) above its MSY level in 2014 or 2) above ½ of its MSY level in 2014 and above its MSY level in 2014 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, F is set equal to *max* F_{ABC}, and in all subsequent years F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2027 under this scenario, then the stock is not approaching an overfished condition.)

The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, and projections of the mean harvest and spawning stock biomass for the remaining six scenarios are shown in Table 14.

Status Determination

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2015, it does not provide the best estimate of OFL for 2016, because the mean 2015 catch under Scenario 6 is predicated on the 2015 catch being equal to the 2015 OFL, whereas the actual 2015 catch will likely be less than the 2015 OFL. The executive summary contains the appropriate one- and two-year ahead projections for both ABC and OFL.

Under the MSFCMA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing. This report involves the answers to three questions: 1) Is the stock being subjected to overfishing? 2) Is the stock currently overfished? 3) Is the stock approaching an overfished condition?

Is the stock being subjected to overfishing? The official BSAI catch estimate for the most recent complete year (2013) is 31,393 t. This is less than the 2013 BSAI OFL of 41,900 t. Therefore, the stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest Scenarios #6 and #7 are used in these determinations as follows:

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2014:

a. If spawning biomass for 2014 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b. If spawning biomass for 2014 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c. If spawning biomass for 2014 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 14). If the mean spawning biomass for 2024 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario #7:

a. If the mean spawning biomass for 2017 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.
b. If the mean spawning biomass for 2017 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c. If the mean spawning biomass for 2017 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2027. If the mean spawning biomass for 2027 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

The results of these two scenarios indicate that the BSAI POP stock is neither overfished nor approaching an overfished condition. With regard whether the stock is currently overfished, the expected stock size in the year 2014 of Scenario 6 is 1.66 times its $B_{35\%}$ value of 148,053 t. With regard to whether the BSAI POP stock is likely to be overfished in the future, the expected stock size in 2017 of Scenario 7 is 1.41 times the $B_{35\%}$ value.

Area Allocation of Harvests

The ABC of BSAI POP is currently partitioned into subarea ABCs based on the relative biomass from research surveys. The current method of obtaining the subarea is a weighted average was applied to the AI trawl surveys in order to compute the average biomass from each of the four subareas, and applies weights of 4, 6, and 9 to the 2010, 2012, and 2014 surveys. A weighted average was also applied to EBS slope survey estimates, with weights of 4, 6, and 9 applied to 2008, 2010, and 2012 surveys.

It is also of interest to estimate the area proportions using the random effects model. The survey averaging workgroup is evaluating the use of the random effects model to smooth survey time series for computing area apportionments, and its use for computing area proportion might logically be delayed until after the workgroup has completed their evaluations. However, a comparison between the two methods may be useful. A comparison between the biomass estimates and proportions is shown below, with the average biomass in the EBS area being the sum of the estimate from the AI SBWS area and the EBS slope area.

	WAI	CAI	EAI	EBS
Weighted average biomass	326,939	269,931	282,471	266,753
Proportion of biomass	28.5%	23.6%	24.6%	23.3%
Estimated 2014 biomass (from random effects model)	311,678	236,416	254,448	268,506
Proportion of biomass	29.1%	22.1%	23.8%	25.1%

The apportionments for the 2015 and 2016 ABC are shown below:

	BSAI	WAI	CAI	EAI	EBS	Total
OFL (2015)	42,558					
ABC (2015, weighted average)		9,981	8,240	8,623	8,143	34,988
ABC (2015, RE model)		10,182	7,723	8,312	8,771	34,988
OFL (2016)	40,809					
ABC (2016, weighted average)		9,571	7,902	8,269	7,809	33,550
ABC (2016, RE model)		9,763	7,406	7,970	8,411	33,550

Ecosystem Considerations

Ecosystem Effects on the stock

1) Prey availability/abundance trends

POP feed upon calanoid copepods, euphausids, myctophids, and other miscellaneous prey (Yang 2003). From a sample of 292 Aleutian Island specimens collected in 1997, calanoid copepods, euphausids, and myctophids contributed 70% of the total diet by weight. The diet of small POP was composed primarily of calanoid copepods (89% by weight), with euphausids and myctophids contributing approximately 35% and 10% of the diet, respectively, of larger POP. The availability and abundance trends of these prey species are unknown.

2) Predator population trends

POP are not commonly observed in field samples of stomach contents, although previous studies have identified sablefish, Pacific halibut, and sperm whales as predators (Major and Shippen 1970). The population trends of these predators can be found in separate chapters within this SAFE document.

3) Changes in habitat quality

POP appear to exhibit ontogenetic shifts in habitat use. Carlson and Straty (1981) used a submersible off southeast Alaska to observe juvenile red rockfish they believed to be POP at approximately 90-100 m in rugged habitat including boulder fields and rocky pinnacles. Kreiger (1993) also used a submersible to observe that the highest densities of small red rockfish in untrawlable rough habitat. As POP mature, they move into deeper and less rough habitats. Length frequencies of the Aleutian Islands survey data indicate that large POP (> 25 cm) are generally found at depths greater than 150 m. Brodeur (2001) also found that POP was associated with epibenthic sea pens and sea whips along the Bering Sea slope. There has been little information identifying how rockfish habitat quality has changed over time.

Fishery Effects on the ecosystem

Catch of prohibited species from 2003-2008 by fishery are available from the NMFS Regional Office. The rockfish fishery in the BSAI area, which consists only of the AI POP target fishery, contributed approximately 2% of the gold/brown king crab catch and approximately 1% of the halibut bycatch. For other prohibited species, the BSAI rockfish fisheries contributed much lower that 1% of the bycatch.

Estimates of non-target catches in the rockfish fishery are also available from the Catch Accounting System database maintained by the NMFS Regional Office. BSAI rockfish fisheries contribute mostly to the bycatch of coral, sponge, and polychaetes. From 2003 to 2008, the BSAI rockfish fisheries contributed 31% of the coral and bryozoan bycatch,18% of the sponge bycatch, 8% of the red tree coral bycatch, and 7% of the polychaete bycatch. The relative contribution was variable between years; for example, the annual relative contribution corals and bryozoans ranged from 5% in 2004 to 53% in 2003, and the other groups listed above show similar levels of variability.

The POP fishery is not likely to diminish the amount of POP available as prey due to its low selectivity for fish less than 27 cm. Additionally, the fishery is not suspected of affecting the size-structure of the population due to the relatively light fishing mortality, averaging 0.04 over the last 5 years. It is not known what effects the fishery may have on the maturity-at-age of POP.

Data Gaps and Research Priorities

Although Pacific ocean perch may be considered a "data-rich" species relative to other rockfish, little information is known regarding most aspects of their biology, including reproductive biology and the distribution, duration, and habitat requirements of various life-history stages. Given the relatively unusual reproductive biology of rockfish and its importance in establishing management reference points, data on reproductive capacity should be collected on a periodic basis.

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Table 1. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of the species groups used to manage Pacific ocean perch from 1977 to 2001 in the Aleutian Islands and the eastern Bering Sea. The "POP complex" includes the other red rockfish species (shortraker rockfish, rougheye rockfish, northern rockfish, and sharpchin rockfish) plus POP.

	Aleutian Islands					Eastern Bering Sea				
Year	Management Group	OFL (t)	ABC (t)	TAC (t)	Catch (t)	Management Group	OFL (t)	ABC (t)	TAC (t)	Catch (t)
1977	POP				7927	POP				2406
1978	POP				5286	POP				2230
1979	POP				5486	POP				1722
1980	POP				4010	POP				959
1981	POP				3668	POP				1186
1982	POP complex				979	POP complex				205
1983	POP complex				471	POP complex				192
1984	POP complex				564	POP complex				315
1985	POP complex				216	POP complex				61
1986	POP			6800	302	POP			825	670
1987	POP			8175	1055	POP			2850	1178
1988	POP		16600	6000	2024	POP		6000	5000	1326
1989	POP complex		16600	6000	2963	POP complex		6000	5000	2533
1990	POP complex		16600	6000	11826	POP complex		6300	6300	6499
1991	POP		10775	10775	2785	POP		4570	4570	5099
1992	POP	11700	11700	11700	10280	POP	3540	3540	3540	3255
1993	POP	16800	13900	13900	13376	POP	3750	3330	3330	3764
1994	POP	16600	10900	10900	10866	POP	2920	1910	1910	1688
1995	POP	15900	10500	10500	10304	POP	2910	1850	1850	1208
1996	POP	25200	12100	12100	12827	POP	2860	1800	1800	2855
1997	POP	25300	12800	12800	12648	POP	5400	2800	2800	681
1998	POP	20700	12100	12100	9299	POP	3300	1400	1400	1022
1999	POP	19100	13500	13500	12484	POP	3600	1900	1400	421
2000	POP	14400	12300	12300	9328	POP	3100	2600	2600	451
2001	POP	11800	10200	10200	8557	POP	2040	1730	1730	896

Table 2. Total allowable catch (TAC), acceptable biological catch (ABC), and catch for BSAI POP from 2002 to present. Catch data is through October 11, 2014, from NMFS Alaska Regional Office.

		Bering Sea/Aleutian Islands			
Year	Management Group	OFL (t)	ABC (t)	TAC (t)	Catch (t)
2002	POP	17500	14800	14800	11215
2003	POP	18000	15100	14100	14744
2004	POP	15800	13300	12580	11896
2005	POP	17300	14600	12600	10427
2006	POP	17600	14800	12600	12867
2007	POP	26100	21900	19900	18451
2008	POP	25700	21700	21700	17436
2009	POP	22300	18800	18800	15347
2010	POP	22400	18860	18860	17852
2011	POP	36300	24700	24700	24004
2012	POP	35000	24700	24700	24143
2013	POP	41900	35100	35100	31393
2014	POP	39585	33122	33122	25889

Table 3. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of POP by area and management group from 1977 to 2014.

	Eastern Bering Sea			Aleutian Islands			BSAI
Year	Foreign	JVP	DAP	Foreign	JVP	DAP	Total catch
1977	2,406	0		7,927	0		10,333
1978	2,230	0		5,286	0		7,516
1979	1,722	0		5,486	0		7,208
1980	907	52		4,010	0		4,969
1981	1,185	1		3,668	0		4,854
1982	186	19		977	2		1,183
1983	99	93		463	8		663
1984	172	142		324	241		879
1985	30	31		0	216		277
1986	18	103	549	0	163	139	972
1987	5	49	1,123	0	502	554	2,233
1988	0	46	1,280	0	1,512	512	3,350
1989	0	26	2,507	0	0	2,963	5,496
1990			6,499			11,826	18,324
1991			5,099			2,785	7,884
1992			3,255			10,280	13,534
1993			3,764			13,376	17,139
1994			1,688			10,866	12,554
1995			1,208			10,304	11,511
1996			2,855			12,827	15,681
1997			681			12,648	13,329
1998			1,022			9,299	10,320
1999			421			12,484	12,905
2000			451			9,328	9,780
2001			896			8,557	9,453
2002			639			10,575	11,215
2003			1,145			13,600	14,744
2004			731			11,165	11,896
2005			879			9,548	10,427
2006			1,041			11,826	12,867
2007			870			17,581	18,451
2008			513			16,923	17,436
2009			623			14,725	15,347
2010			3,547			14,304	17,852
2011			5,601			18,403	24,004
2012			5,589			18,554	24,143
2013			5,050			26,342	31,393
2014*			1,842			24,047	25,889

*Estimated removals through October 11, 2014.

Table 4. Estimated retained and discarded catch (t), and percent discarded, of Pacific ocean perch from the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions.

	EBS			AI			BSAI		
Year	Retained	Discarded	Percent Discarded	Retained	Discarded	Percent Discarded	Retained	Discard	Percent Discarded
1990	5,069	1,275	20.1	10,288	1,551	13.1	15,357	2,826	15.54
1991	4,126	972	19.07	1,815	970	34.82	5,941	1,942	24.63
1992	5,464	1044	16.05	17,332	3,227	15.7	22,797	4,271	15.78
1993	2,601	1163	30.9	11,479	1,896	14.18	14,080	3,059	17.85
1994	1,187	501	29.69	9,491	1,374	12.65	10,678	1,876	14.94
1995	839	368	30.49	8,603	1,701	16.51	9,442	2,069	17.97
1996	2,522	333	11.66	9,831	2,995	23.35	12,353	3,328	21.22
1997	420	261	38.35	10,854	1,794	14.18	11,274	2,055	15.42
1998	821	200	19.62	8,282	1,017	10.93	9,103	1,217	11.79
1999	277	144	34.28	10,985	1,499	12.01	11,261	1,643	12.73
2000	230	221	49.01	8,586	743	7.96	8,816	964	9.85
2001	399	497	55.45	7,195	1,362	15.92	7,594	1,859	19.66
2002	286	355	55.44	9,315	1,260	11.91	9,601	1,615	14.4
2003	549	627	53.31	10,720	2,042	16	11,269	2,668	19.14
2004	536	196	26.75	9,286	1,879	16.83	9,822	2,074	17.44
2005	627	253	28.74	8,100	1,448	15.16	8,727	1,700	16.31
2006	751	290	27.83	9,869	1,957	16.55	10,620	2,246	17.46
2007	508	363	41.68	15,051	2,530	14.39	15,558	2,893	15.68
2008	318	195	37.94	16,640	283	1.67	16,959	477	2.74
2009	463	160	25.67	14,011	713	4.84	14,474	873	5.69
2010	3347	200	5.64	13,988	316	2.21	17,335	516	2.89
2011	5249	353	6.30	18,021	382	2.08	23,269	735	3.06
2012	5181	409	7.32	18,162	392	2.12	23,343	801	3.32
2013	4746	304	6.03	26,094	249	0.94	30,840	553	1.76
2014*	1096	747	40.53	23,873	174	0.72	24,969	920	3.56

*Estimated removals through October 11, 2014.
Source: NMFS Alaska Regional Office

Table 5. Percentage catch (by weight) of Aleutians Islands POP in the foreign/joint venture fisheries and the domestic fishery by depth.

	Depth Zone (m)									
Year	0	100	200	300	400	500	501	Observed catch (t)	Estimated total catch	Percent sampled
1977	25	23	39	11	2	1	0	173	7,927	2
1978	0	40	36	19	3	1	1	145	5,286	3
1979	0	13	60	23	4	0	0	311	5,486	6
1980	0	7	45	49	0	0	0	108	4,010	3
1981	0	9	67	23	0	0	0	138	3,668	4
1982	0	34	56	5	2	1	2	115	979	12
1983	0	11	85	0	1	1	1	54	471	11
1984	0	53	42	5	0	1	0	85	565	15
1985	0	87	13	0	0	0	0	109	216	50
1986	0	74	25	2	0	0	0	66	163	40
1987	0	39	61	0	0	0	0	258	502	51
1988	0	78	21	1	0	0	0	76	1,512	5
1989										
1990	2	23	58	14	2	1	0	7,726	11,826	65
1991	0	23	70	5	1	1	0	1,588	2,785	57
1992	0	21	71	8	0	0	0	6,785	10,280	66
1993	0	20	77	3	0	0	0	8,867	13,375	66
1994	0	20	69	11	0	0	0	7,562	10,866	70
1995	0	15	68	14	2	0	0	6,154	10,303	60
1996	0	17	54	26	2	1	0	8,547	12,827	67
1997	0	13	66	21	0	0	0	9,320	12,648	74
1998	0	21	72	7	0	0	0	7,380	9,299	79
1999	0	30	63	7	0	0	0	10,369	12,483	83
2000	0	21	63	15	0	0	0	7,456	9,328	80
2001	0	29	61	10	0	0	0	5,679	8,557	66
2002	2	36	57	5	1	0	0	8,124	10,575	77
2003	0	26	70	3	0	0	0	11,266	13,600	83
2004	1	26	65	7	1	0	0	10,083	11,165	90
2005	2	36	55	6	1	0	0	7,403	9,548	78
2006	1	33	61	5	0	0	0	9,895	11,826	84
2007	0	23	68	7	1	0	0	15,551	17,581	88
2008	1	20	74	5	0	0	0	16,682	16,923	99
2009	1	26	65	8	1	0	1	14,495	14,724	98
2010	1	21	71	7	1	0	0	14,299	14,304	100
2011	0	13	78	7	1	0	0	18,391	18,403	100
2012	0	21	67	11	1	0	0	18,553	18,554	100
2013	0	12	76	11	1	0	0	26,297	26,342	100

Table 6. Proportional catch (by weight) of Aleutians Islands POP in the foreign and joint venture fisheries and the domestic fishery by management area.

	Area					
	541	542	543	Observed catch (t)	Estimated total catch	Percent sampled
1977	17	22	61	173	7,927	2
1978	30	36	35	145	5,286	3
1979	21	25	55	311	5,486	6
1980	11	42	47	108	4,010	3
1981	42	40	17	138	3,668	4
1982	42	38	20	115	979	12
1983	85	8	7	54	471	11
1984	84	8	7	85	565	15
1985	66	34	0	109	216	50
1986	99	1	0	66	163	40
1987	94	6	0	258	502	51
1988	6	94	0	76	1,512	5
1989						
1990	63	16	21	7,726	11,826	65
1991	27	57	16	1,588	2,785	57
1992	81	15	3	6,785	10,280	66
1993	67	22	11	8,867	13,375	66
1994	64	31	5	7,562	10,866	70
1995	70	25	5	6,154	10,303	60
1996	27	20	54	8,547	12,827	67
1997	20	23	57	9,320	12,648	74
1998	21	27	52	7,380	9,299	79
1999	22	23	56	10,369	12,483	83
2000	22	24	54	7,456	9,328	80
2001	27	25	48	5,679	8,557	66
2002	24	28	48	8,124	10,575	77
2003	30	22	48	11,266	13,600	83
2004	24	27	49	10,083	11,165	90
2005	23	24	52	7,403	9,548	78
2006	24	28	48	9,895	11,826	84
2007	30	26	45	15,551	17,581	88
2008	28	28	44	16,682	16,923	99
2009	27	28	44	14,495	14,724	98
2010	28	28	44	14,299	14,304	100
2011	30	26	44	18,391	18,403	100
2012	30	26	44	18,553	18,554	100
2013	36	26	38	26,297	26,342	100

Table 7. Length measurements from the EBS and AI POP fisheries during 1964-1972, from Chikuni (1975)

Year	EBS	AI	Total
1964	24,150	55,599	79,749
1965	14,935	66,120	81,055
1966	26,458	25,502	51,960
1967	48,027	59,576	107,603
1968	38,370	36,734	75,104
1969	28,774	27,206	55,980
1970	11,299	27,508	38,807
1971	14,045	18,926	32,971
1972	10,996	18,926	29,922

Table 8. Length measurements and otoliths read from the EBS and AI POP fisheries, from the NORPAC Observer database.

	Fish lengths			Otoliths read		
Year	EBS	AI	Total	EBS	AI	Total
1973	1		1**			
1974	84		84**	84		84**
1975	271		271**	125		125**
1976	633		633**	114	19	133**
1977	1,059	9,318	10,377*	139	404	543
1978	7,926	7,283	15,209*	583	641	1,224
1979	1,045	10,921	11,966*	248	353	601
1980		3,995	3,995*		398	398
1981	1,502	7,167	8,669*	78	432	510
1982		4,902	4,902*		222	222
1983	232	441	673			
1984	1,194	1,210	2,404	72		72**
1985	300		300**	160		160**
1986		100	100**		99	99**
1987	11	384	395			
1988	306	1,366	1,672			
1989	957	91	1,048			
1990	22,228	47,198	69,426	144	184	328
1991	8,247	8,221	16,468			
1992	13,077	24,932	38,009			
1993	8,379	26,433	34,812			
1994	2,654	11,546	14,200			
1995	272	11,452	11,724			
1996	2,967	13,146	16,113			
1997	143	10,402	10,545			
1998	989	11,106	12,095		823	823
1999	289	3,839	4,128			
2000	284	3,382	3,666*		487	487
2001	327	2,388	2,715*		524	524
2002	78	3,671	3,749*	11	455	466
2003	247	4,681	4,928*	11	386	397
2004	135	3,270	3,405*	30	754	784
2005	237	2,243	2,480*	42	539	581
2006	274	3,757	4,031*	25	424	449
2007	74	5,629	5,703*	11	664	675
2008	250	7,001	7,251*	17	555	572
2009	460	5,593	6,053*	49	670	719
2010	2,584	5,384	7,968			
2011	4,144	7,965	12,109*	316	616	932
2012	5,686	7,896	13,582			
2013	3,897	13,082	16,979*	233	810	1043
2014	754	7,910	8,664			

*Used to create age composition. **Not used.

Table 9. Pacific ocean perch estimated biomass (t) from the eastern Bering Sea slope and Aleutian Islands trawl surveys (by management area).

	Southern Bering Sea			Aleutian Islands			Total Aleutian Islands Survey			EBS Slope survey		
Year	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1979												
1980	5,833	5,658	97%	76,545	45,686	60%	82,378	46,035	56%			
1981												
1982												
1983	90,622	72,317	80%	141,261	37,075	26%	231,883	81,267	35%			
1984												
1985												
1986	26,784	13,031	49%	197,656	42,463	21%	224,440	44,418	20%			
1987												
1988												
1989												
1990												
1991	1,501	758	51%	342,785	70,773	21%	344,286	70,777	21%			
1992												
1993												
1994	18,217	11,685	64%	369,699	88,327	24%	387,916	89,096	23%			
1995												
1996												
1997	12,099	7,008	58%	565,885	84,524	15%	577,984	84,814	15%			
1998												
1999												
2000	18,870	10,150	54%	500,118	91,099	18%	518,988	91,662	18%			
2001												
2002	16,311	6,637	41%	446,860	77,841	17%	463,171	78,123	17%	72,665	38,586	53%
2003												
2004	74,208	33,397	45%	503,228	64,592	13%	577,436	72,715	13%	112,273	42,681	38%
2005												
2006	23,701	11,194	47%	623,549	90,482	15%	647,250	91,172	14%			
2007												
2008										107,886	43,711	41%
2009												
2010	87,794	47,952	55%	884,241	104,840	12%	972,035	115,286	12%	203,421	78,235	38%
2011												
2012	38,658	24,190	63%	863,741	153,111	18%	902,398	155,010	17%	231,383	75,235	33%
2013												
2014	83,409	41,568	50%	887,559	180,704	20%	970,968	185,423	19%			

Table 10. Pacific ocean perch biomass estimates (t) from the 1991-2014 triennial trawl surveys for the three management sub-areas in the Aleutian Islands region.

	Aleutian Islands Management Sub-Areas		
Year	Western	Central	Eastern
1991	208,465	78,776	55,545
1994	184,703	84,411	100,585
1997	178,437	166,816	220,633
2000	229,850	129,740	140,528
2002	196,704	140,361	109,795
2004	212,639	153,477	137,112
2006	281,946	150,851	190,752
2010	395,944	221,700	266,607
2012	263,661	233,666	366,413
2014	338,455	315,544	233,560
Weighted Average (2010-2014)	326,939	269,931	282,471
Percentage	37.18%	30.70%	32.12%

Table 11. Length measurements and otoliths read from the Aleutian Islands surveys.

Year	Length measurements	Otoliths read
1980	20,796	890
1983	22,873	2,495
1986	14,804	1,860
1991	14,262	1,015
1994	18,922	849
1997	22,823	1,224
2000	21,972	1,238
2002	20,284	337
2004	24,949	1,031
2006	19,737	462
2010	22,725	951
2012	31,450	1,140
2014	30,206	

Table 12. Negative log likelihoods, and several measures of model fits, for the evaluated models for BSAI POP.

	Model 0	Model 0.1	Model 1	Model 2	Model 3
Negative log-likelihood					
Data components					
AI survey biomass	9.97	7.67	9.49	20.92	8.52
CPUE	23.74	24.89	33.59	22.16	26.28
Catch biomass	0.00	0.00	0.00	0.00	0.00
Fishery age comp	41.38	43.80	209.27	225.20	226.03
Fishery length comp	326.17	313.63	416.90	467.54	358.98
AI survey age comp	120.78	52.96	261.75	177.14	150.23
AI survey lengths comp	6.74	6.48	13.32	23.27	10.54
Maturity	2.71	2.71	2.71	2.71	2.71
Priors and penalties					
Recruitment	8.29	6.98	10.48	13.40	11.95
Prior on survey q	14.69	14.38	16.46	0.00	9.89
Prior on M	0.19	0.21	0.01	1.30	0.30
Fishery selectivity	14.32	13.51	23.48	67.66	142.86
Total negative log-likelihood	565.00	483.02	988.71	1018.15	942.41
Parameters	121	145	145	121	137
Number of data points			1024	1024	1024
BIC			2982.49	2875.01	2834.43
AIC			2267.43	2278.30	2158.81
Effective sample size					
Fishery age comp	266	266	324	269	199
Fishery length comp	189	215	144	138	164
AI survey age comp	101	120	158	173	210
AI survey lengths comp	88	93	41	24	52
Sample weights					
Fishery age comp	24	24	153	153	153
Fishery length comp	147	147	168	168	168
AI survey age comp	33	30	224	224	224
AI survey lengths comp	174	174	175	175	175
Root mean square error					
AI survey biomass	0.245	0.198	0.227	0.351	0.222
CPUE	0.778	0.790	0.875	0.761	0.804
Recruitment	0.763	0.744	0.793	0.832	0.813
Fishery age comp	0.013	0.013	0.012	0.013	0.014
Fishery length comp	0.025	0.025	0.027	0.027	0.023
AI survey age comp	0.020	0.016	0.014	0.013	0.011
AI survey lengths comp	0.020	0.019	0.029	0.037	0.026
Standard Deviation of Normalized Residuals					
AI survey biomass	1.24	1.24	1.38	2.04	1.30
CPUE	2.59	2.63	2.92	2.54	2.68
Fishery age comp	0.47	0.53	0.88	1.05	1.00
Fishery length comp	1.05	1.03	1.16	1.20	1.00
AI survey age comp	1.42	1.16	1.77	1.07	1.00
AI survey lengths comp	0.80	0.78	1.14	1.51	1.00

Table 13. Estimated time series of POP total biomass (t), spawning biomass (t), and recruitment (thousands) for each region.

	Total Biomass (ages 3+) Assessment Year		Spawning Biomass (ages 3+) Assessment Year		Recruitment (age 3) Assessment Year	
Year	2014	2012	2014	2012	2014	2012
1977	238,630	124,658	99,038	40,191	25,581	26,044
1978	226,774	122,886	93,438	39,443	23,814	35,844
1979	221,931	128,670	89,477	39,942	65,542	84,341
1980	218,921	137,002	86,494	41,018	57,894	85,676
1981	218,423	152,553	84,678	42,955	38,725	113,845
1982	221,874	165,729	83,672	45,547	72,287	52,563
1983	231,810	185,825	84,372	49,941	78,598	80,592
1984	250,389	216,581	86,102	55,711	145,384	176,053
1985	267,617	241,708	89,001	63,190	76,490	67,223
1986	285,047	267,573	93,376	72,676	51,875	67,491
1987	324,368	316,811	98,946	83,575	311,366	329,776
1988	349,846	356,870	105,631	95,212	45,770	140,299
1989	381,769	396,998	113,713	107,429	140,206	131,150
1990	406,537	431,007	121,809	118,965	59,069	84,057
1991	427,526	464,005	128,713	128,974	192,205	236,082
1992	454,119	500,992	139,920	143,481	92,298	123,119
1993	470,393	525,969	150,480	157,834	52,015	68,419
1994	477,652	541,359	160,910	172,697	26,405	46,977
1995	486,685	557,206	172,343	188,861	43,833	51,764
1996	492,300	569,967	182,568	203,668	33,146	56,337
1997	498,090	581,483	190,338	215,652	127,572	133,733
1998	503,929	594,244	197,447	226,765	92,073	125,087
1999	522,414	617,922	202,870	235,761	201,659	209,310
2000	529,217	630,674	205,025	240,999	48,880	84,719
2001	549,735	654,299	206,720	245,314	188,650	181,061
2002	563,361	673,980	208,269	248,953	59,844	113,471
2003	597,042	702,078	210,198	252,743	331,236	228,612
2004	611,396	713,418	213,591	257,607	38,212	48,243
2005	629,571	723,660	220,422	265,526	81,642	43,243
2006	643,005	730,659	229,350	274,802	29,979	40,220
2007	654,833	731,429	238,001	282,981	94,791	48,897
2008	657,981	722,295	245,839	288,902	78,861	46,016
2009	656,210	710,471	254,326	293,817	36,897	43,792
2010	653,665	702,831	261,815	296,276	45,917	
2011	646,482	692,564	264,704	293,527	59,397	
2012	633,007	676,409	262,190	285,289		
2013	618,851	661,440	256,200	273,683		
2014	597,506		246,104			
2015	577,967					

Table 14. Projections of BSAI spawning biomass (t), catch (t), and fishing mortality rate for each of the several scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 169,203 t and 148,053 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2014	31,162	31,162	31,162	31,162	31,162	31,162	31,162
2015	34,988	34,988	17,819	12,337	0	42,558	34,988
2016	33,194	33,194	17,534	12,280	0	39,716	33,194
2017	31,413	31,413	17,187	12,170	0	36,996	38,210
2018	29,768	29,768	16,838	12,049	0	34,544	35,625
2019	28,299	28,299	16,507	11,929	0	32,398	33,354
2020	27,088	27,088	16,247	11,848	0	30,554	31,484
2021	26,131	26,131	16,064	11,810	0	28,391	29,574
2022	25,348	25,348	15,976	11,832	0	26,840	27,831
2023	24,634	24,634	15,966	11,903	0	25,850	26,640
2024	24,133	24,133	16,020	12,012	0	25,262	25,887
2025	23,837	23,837	16,123	12,152	0	24,946	25,442
2026	23,676	23,676	16,247	12,303	0	24,792	25,184
2027	23,605	23,605	16,381	12,458	0	24,741	25,054
Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2014	246,105	246,105	246,105	246,105	246,105	246,105	246,105
2015	234,426	234,426	236,594	237,273	238,782	233,451	234,426
2016	221,197	221,197	231,347	234,610	241,995	216,756	221,197
2017	208,987	208,987	226,189	231,857	244,930	201,666	208,118
2018	198,647	198,647	222,008	229,894	248,429	188,971	194,699
2019	190,249	190,249	218,933	228,845	252,576	178,678	183,739
2020	183,936	183,936	217,242	229,013	257,706	170,851	175,298
2021	179,344	179,344	216,654	230,127	263,543	165,173	168,988
2022	176,272	176,272	217,096	232,144	270,096	161,558	164,690
2023	174,328	174,328	218,199	234,709	277,021	159,394	161,943
2024	173,230	173,230	219,732	237,614	284,150	158,192	160,261
2025	172,627	172,627	221,405	240,573	291,195	157,533	159,205
2026	172,341	172,341	223,123	243,505	298,094	157,207	158,553
2027	172,283	172,283	224,857	246,386	304,831	157,113	158,192
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2014	0.076	0.076	0.076	0.076	0.076	0.076	0.076
2015	0.089	0.089	0.045	0.031	0	0.109	0.089
2016	0.089	0.089	0.045	0.031	0	0.109	0.089
2017	0.089	0.089	0.045	0.031	0	0.109	0.109
2018	0.089	0.089	0.045	0.031	0	0.109	0.109
2019	0.089	0.089	0.045	0.031	0	0.109	0.109
2020	0.089	0.089	0.045	0.031	0	0.109	0.109
2021	0.089	0.089	0.045	0.031	0	0.106	0.108
2022	0.089	0.089	0.045	0.031	0	0.103	0.105
2023	0.088	0.088	0.045	0.031	0	0.102	0.103
2024	0.087	0.087	0.045	0.031	0	0.100	0.102
2025	0.086	0.086	0.045	0.031	0	0.100	0.101
2026	0.086	0.086	0.045	0.031	0	0.099	0.100
2027	0.086	0.086	0.045	0.031	0	0.099	0.100

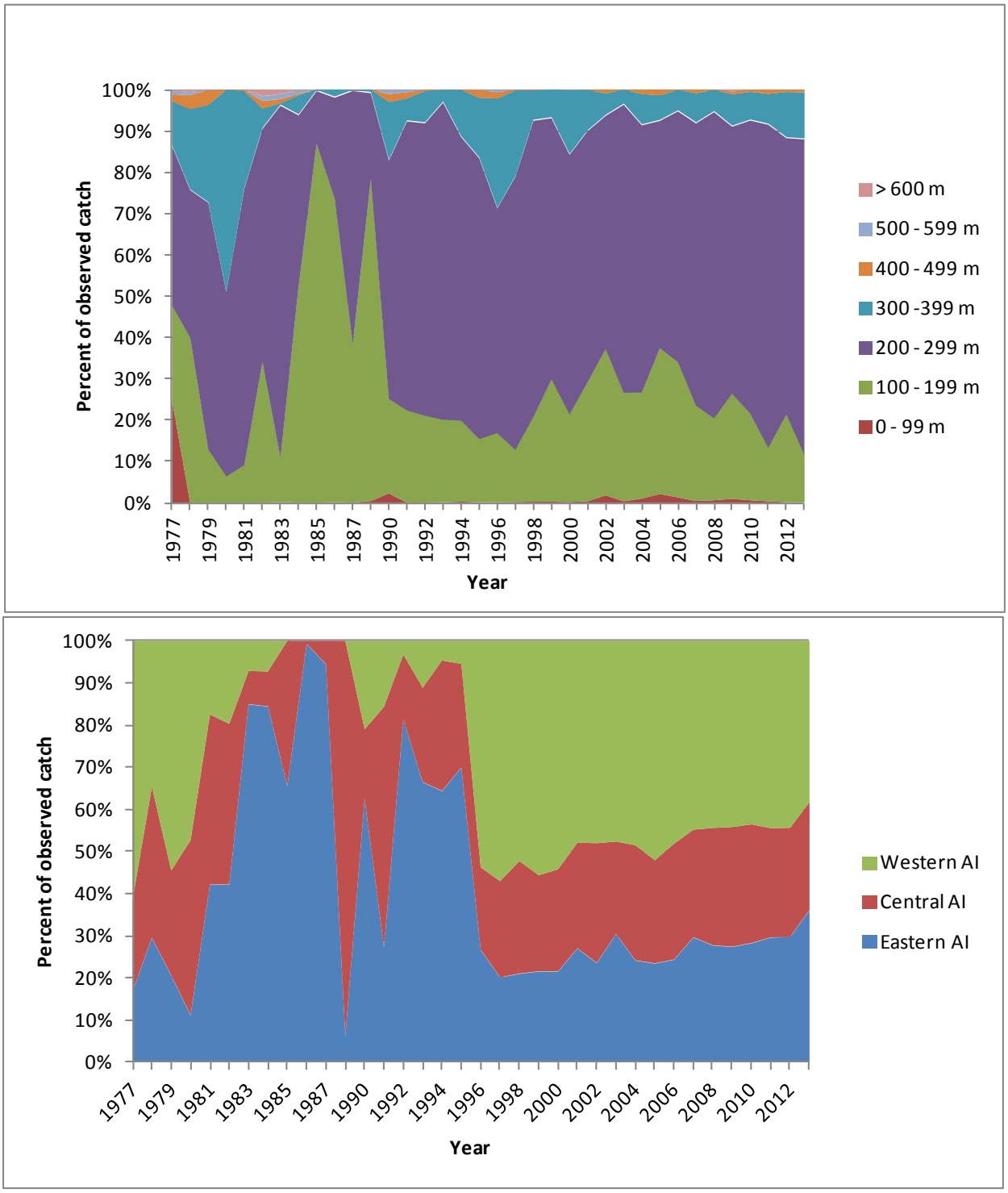

Figure 1. Distribution of observed Aleutian Islands Pacific ocean perch catch (from North Pacific Groundfish Observer Program) by depth zone (top panel) and AI subarea (bottom panel) from 1977 to 2013.

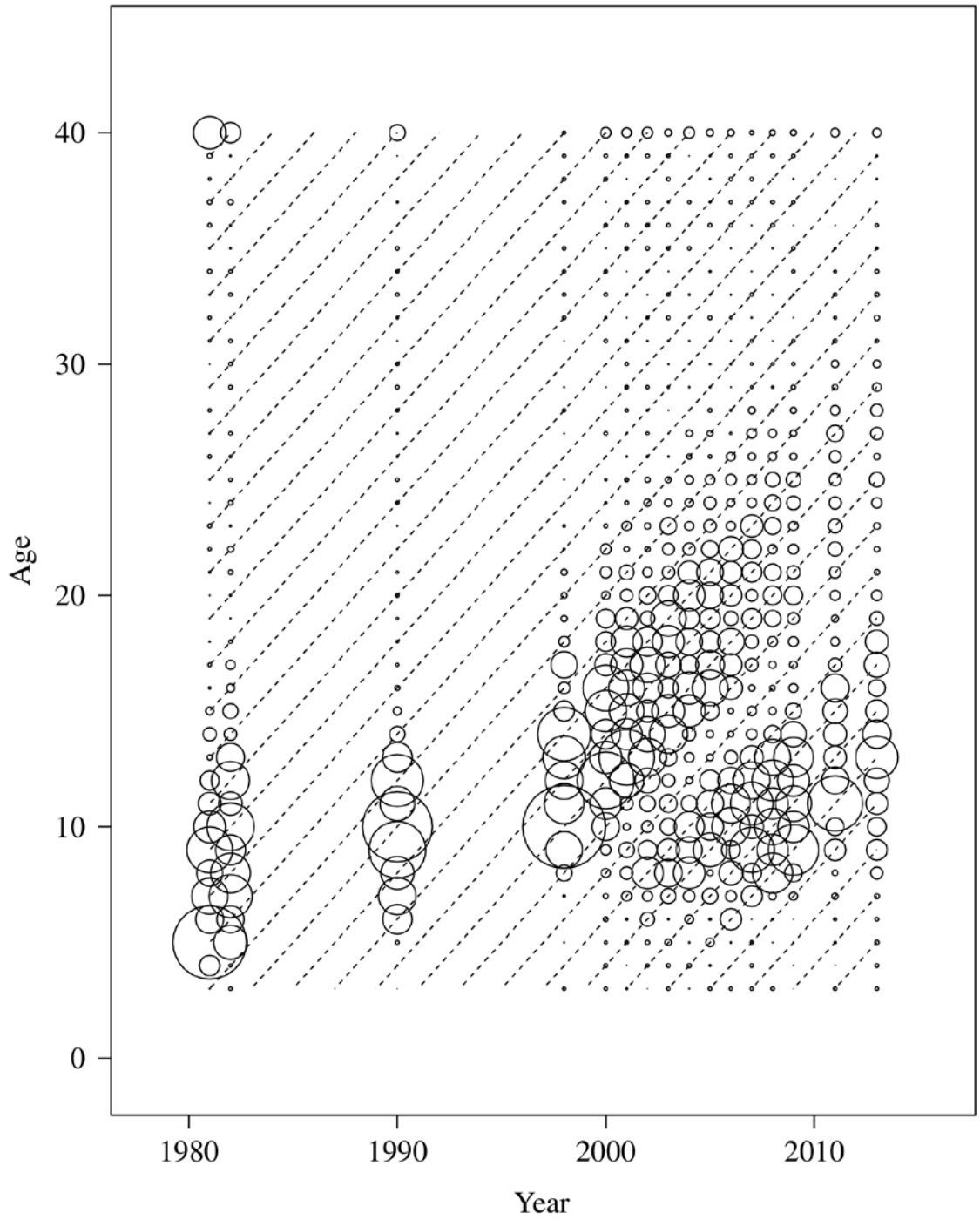

Figure 2. Fishery age composition data for the BSAI POP; The diameter of the circles are scaled within each year of samples, and dashed lines denote cohorts.

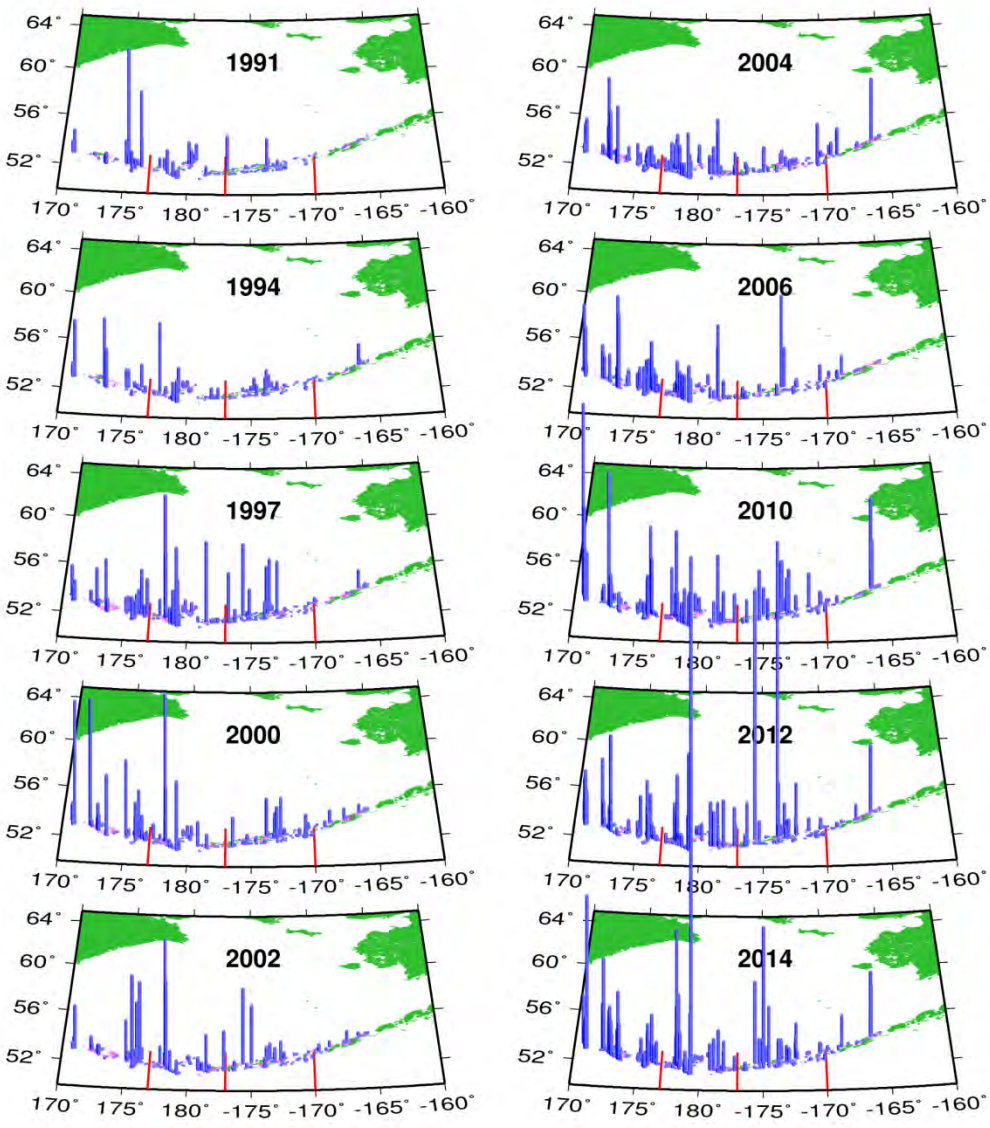

Figure 3. AI survey POP CPUE (kg/km^2) from 1991-2014; the symbol × denotes tows with no catch. The red lines indicate boundaries between the WAI, CAI, EAI, and EBS areas.

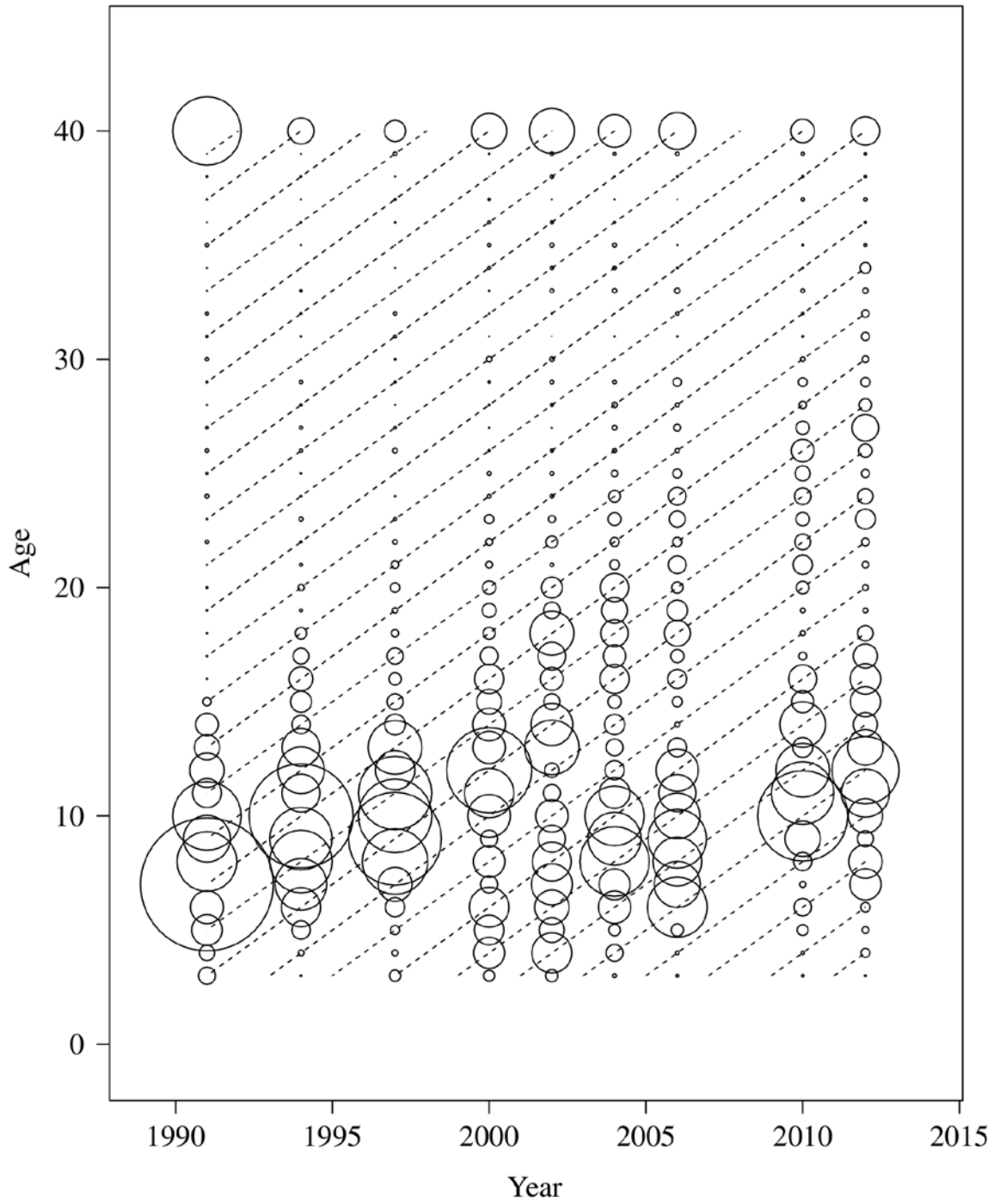

Figure 4. Age composition data from the Aleutian Islands trawl survey; bubbles are scaled within each year of samples; and dashed lines denote cohorts.

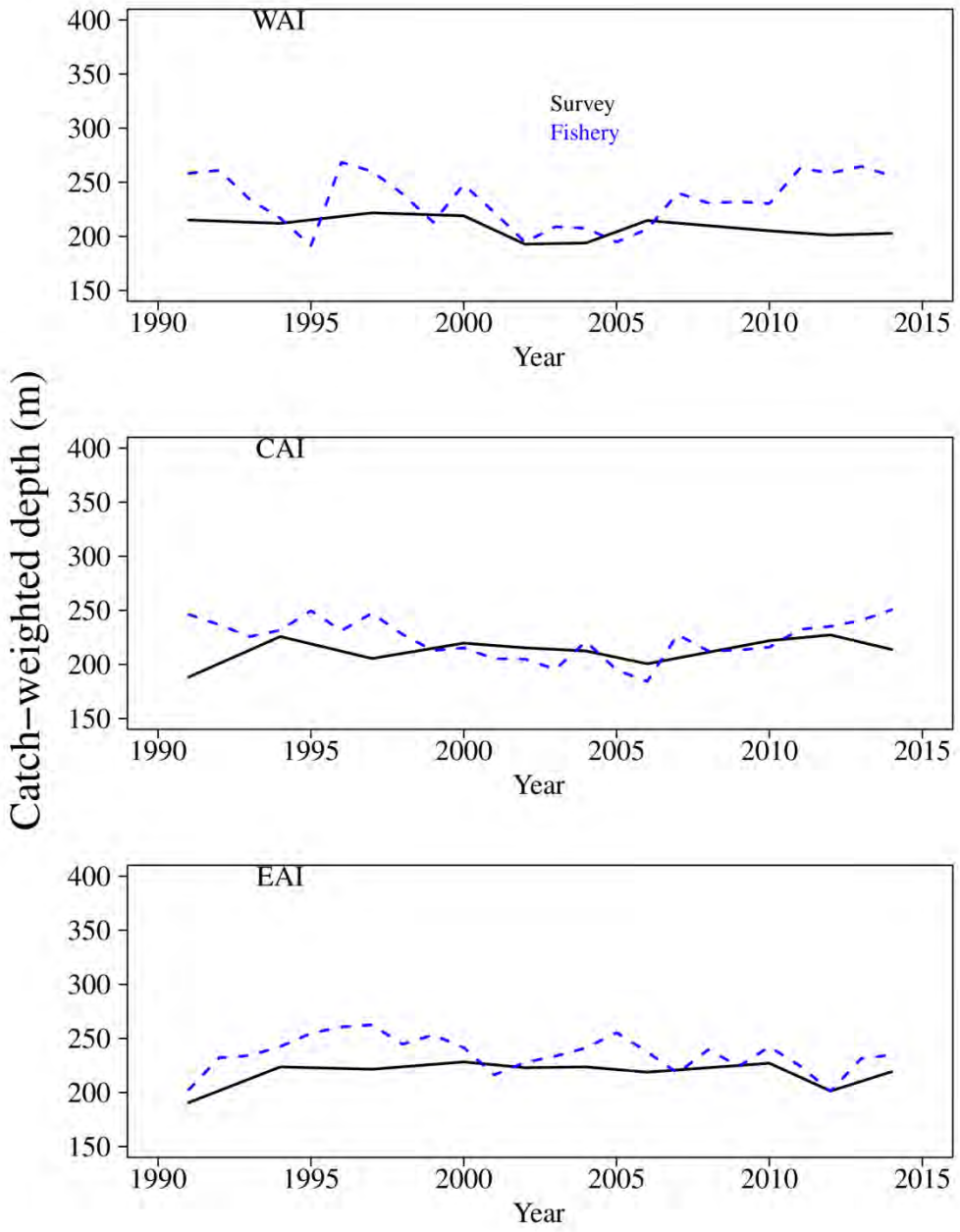

Figure 5. Catch-weighted (by numbers) depth of capture for Pacific ocean perch in the fishery and AI survey by AI subarea from 1991 to 2014.

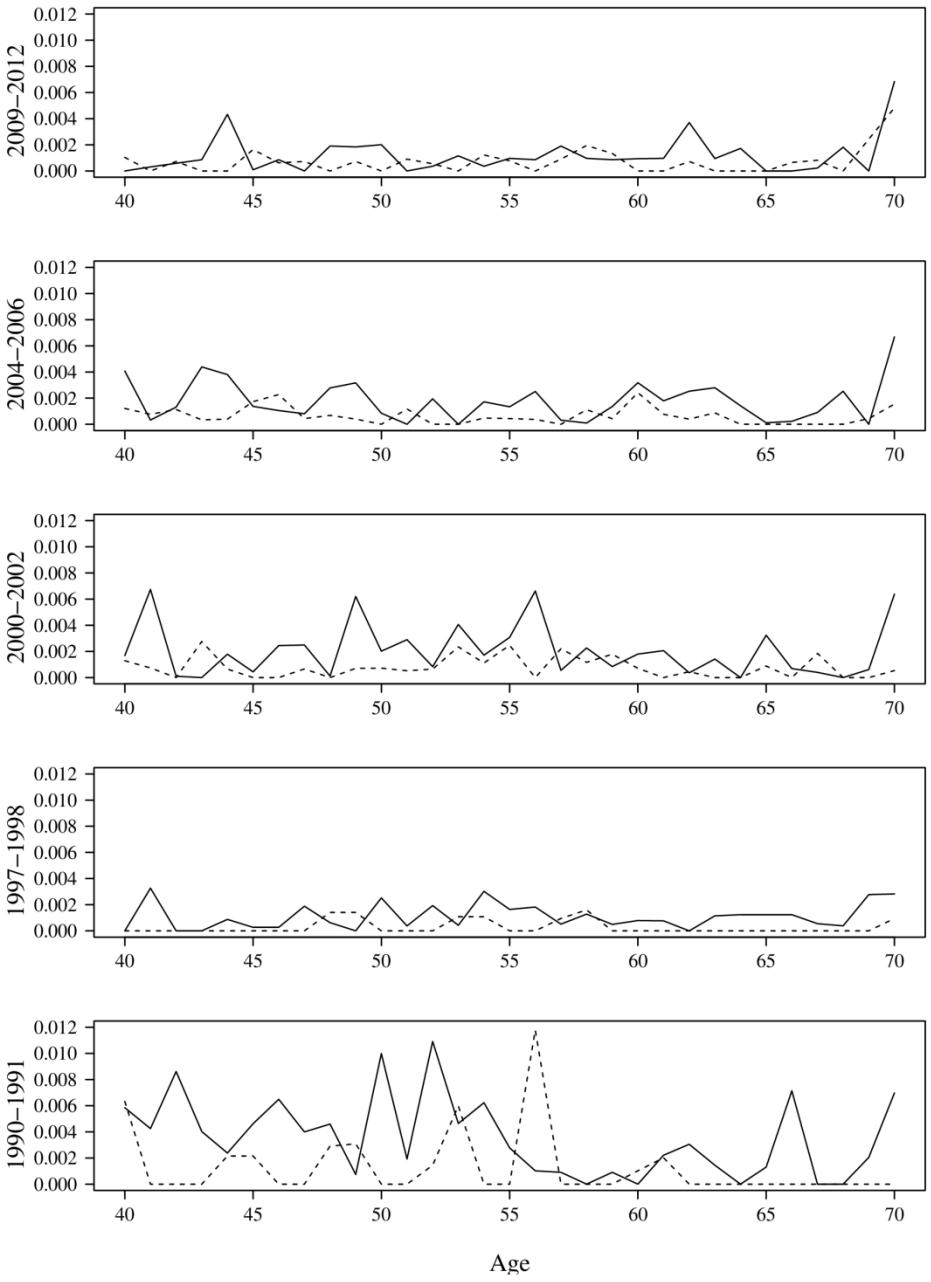

Figure 6. Age compositions in the Aleutian Islands survey (solid line) and fishery (dashed line) for ages 40 to 70+ for five time periods.

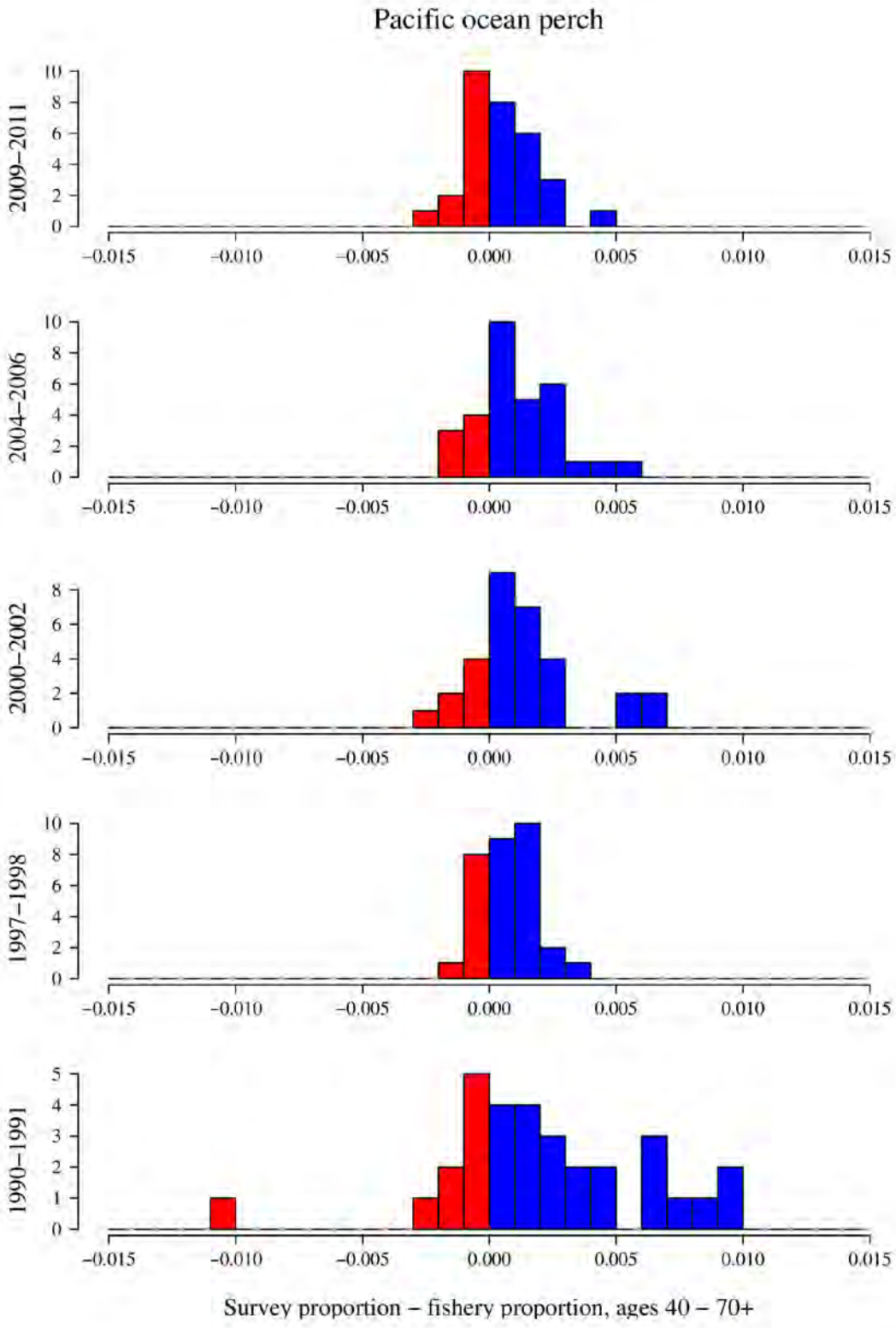

Figure 7. Histograms of the difference (survey proportion – fishery proportion) for ages 40 to 70+ for five time periods.

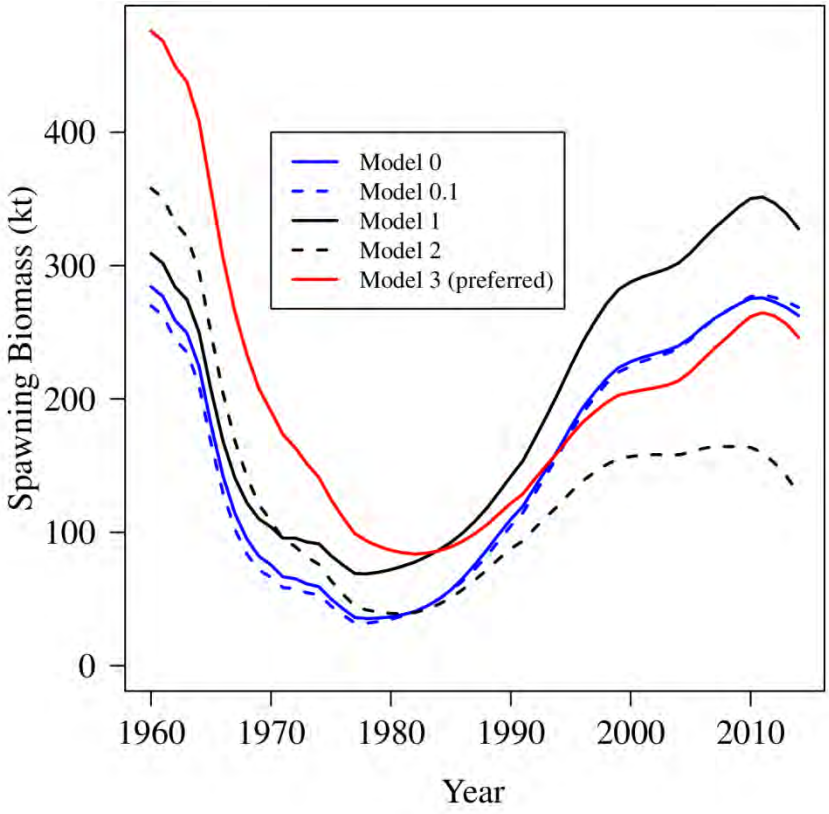

Figure 8. Estimated time series of spawning stock biomass across the models.

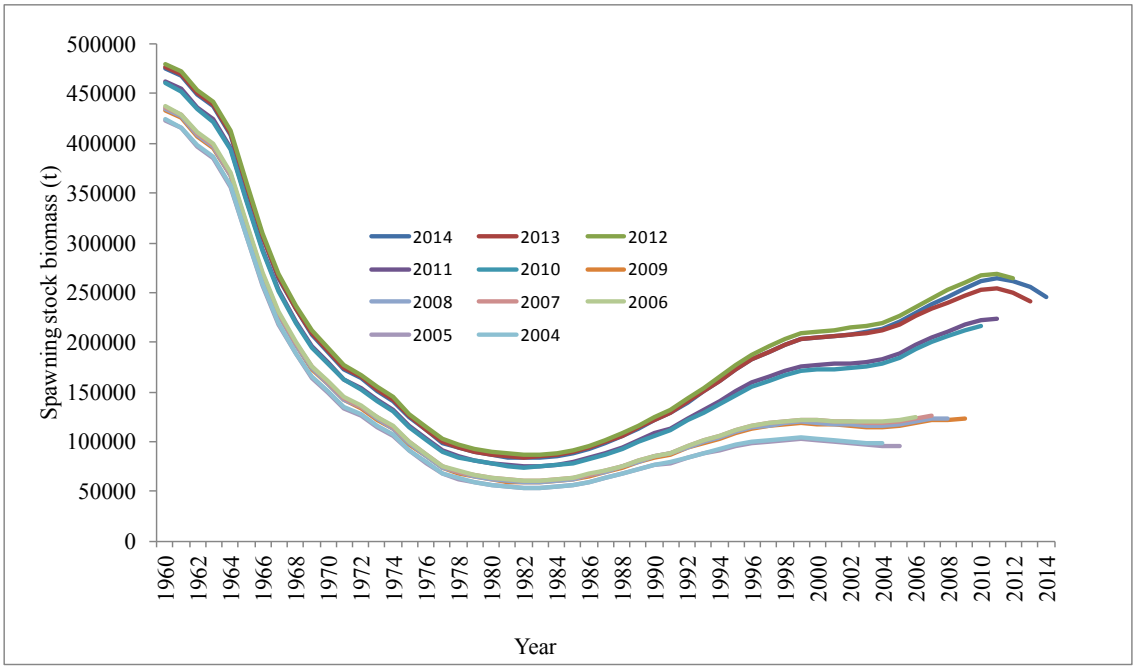

Figure 9. Retrospective estimates of spawning stock biomass for model runs with end years of 2004 to 2014.

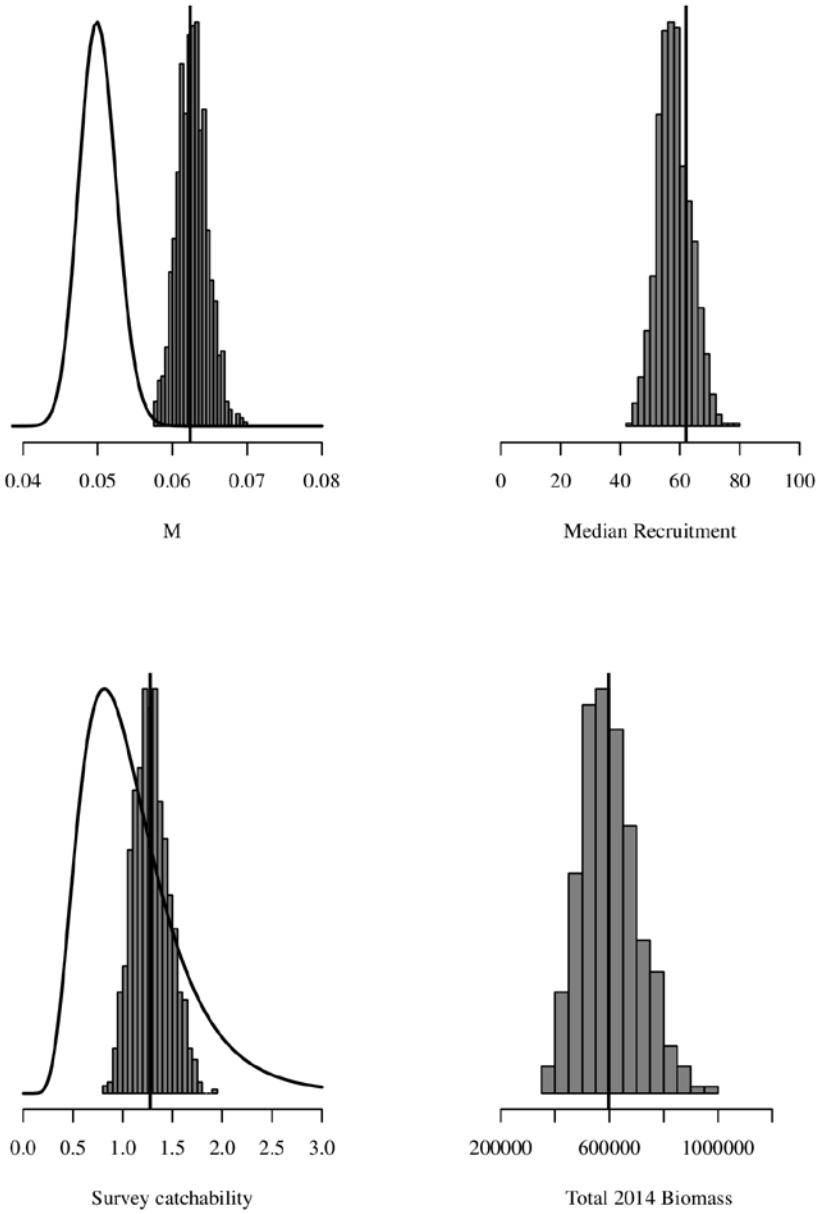

Figure 10. Posterior distributions for key model quantities *M*, survey catchability, median recruitment, and 2014 total biomass. For *M* and survey catchability, the prior distributions are also shown in the solid lines. The MLE estimates are indicated by the vertical lines.

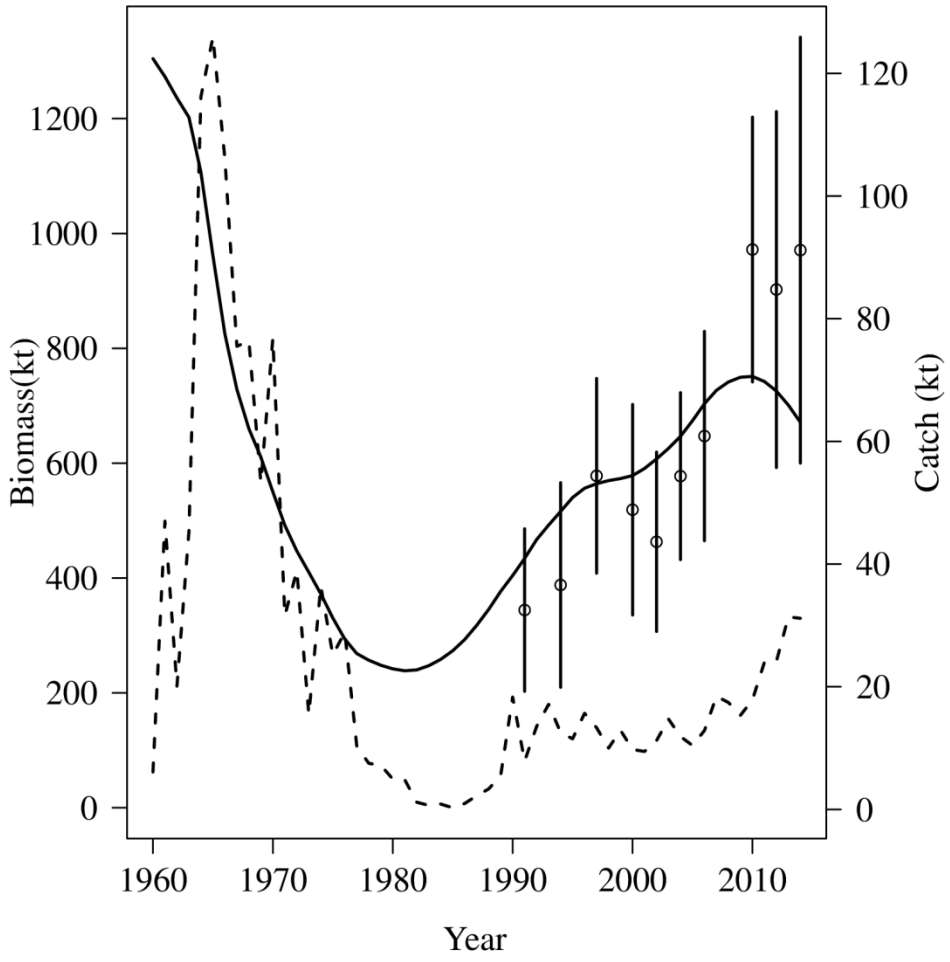

Figure 11. Observed AI survey biomass (data points, +/- 2 standard deviations), predicted survey biomass(solid line), and BSAI harvest (dashed line).

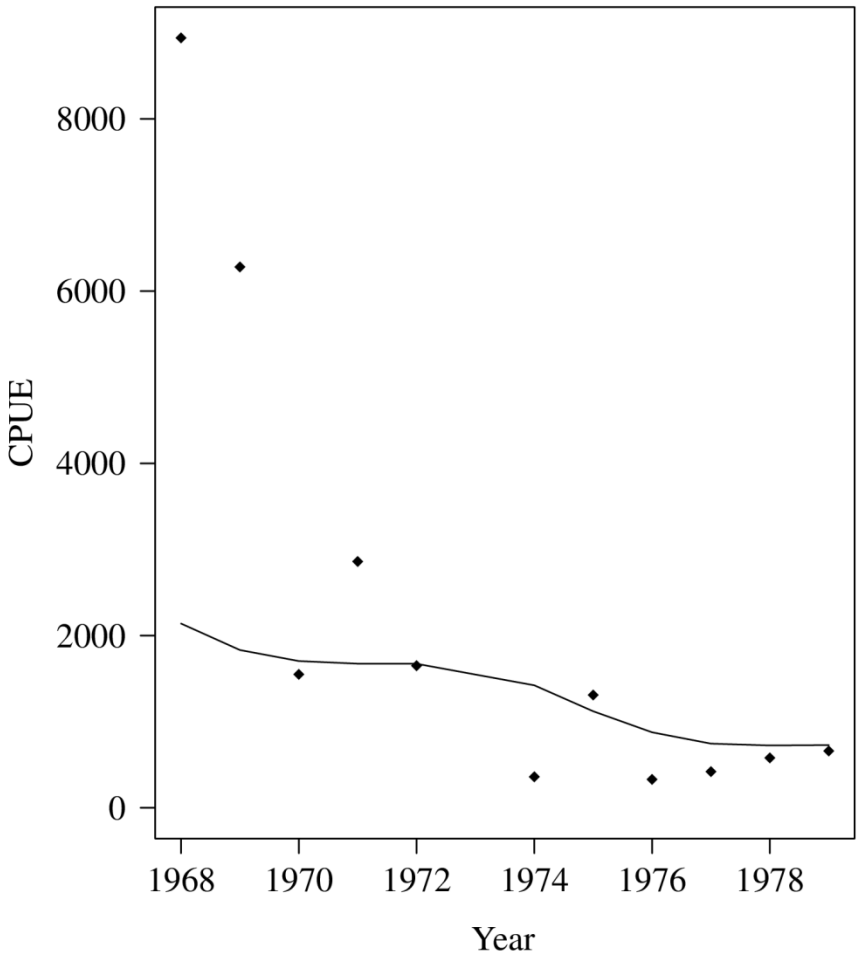

Figure 12. Observed AI CPUE (data points) and predicted CPUE (solid line) for BSAI POP.

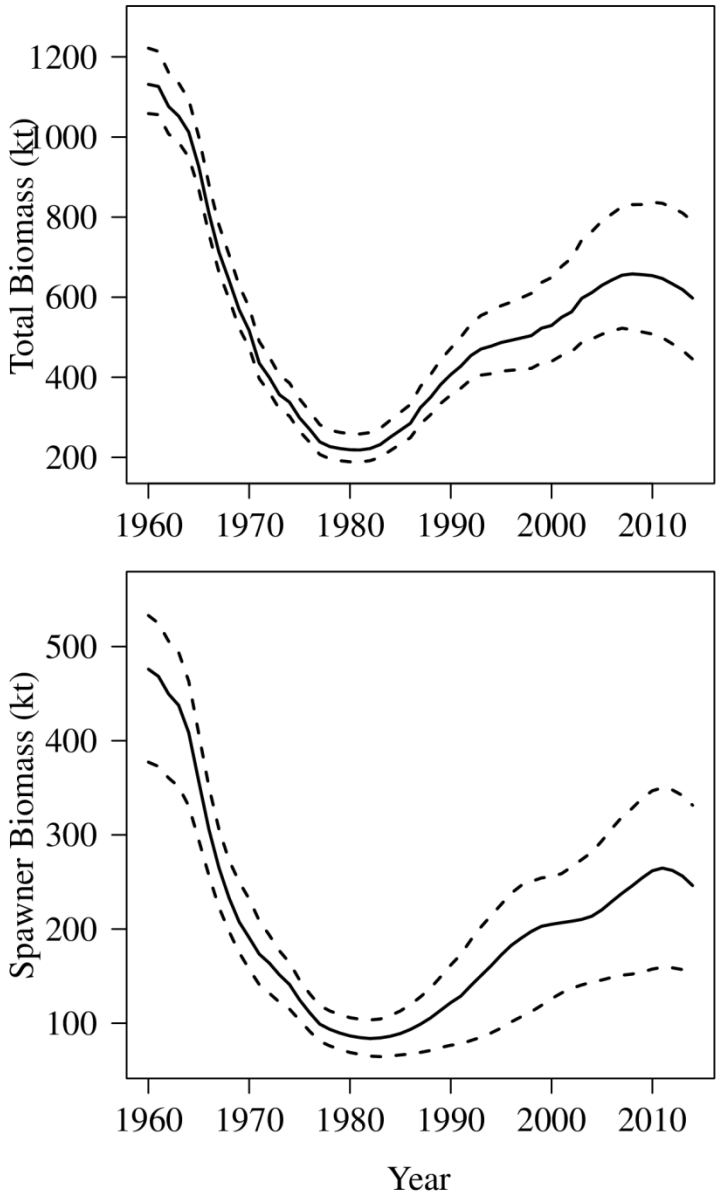

Figure 13. Total and spawner biomass for BSAI Pacific ocean perch, with 95% confidence intervals from MCMC integration.

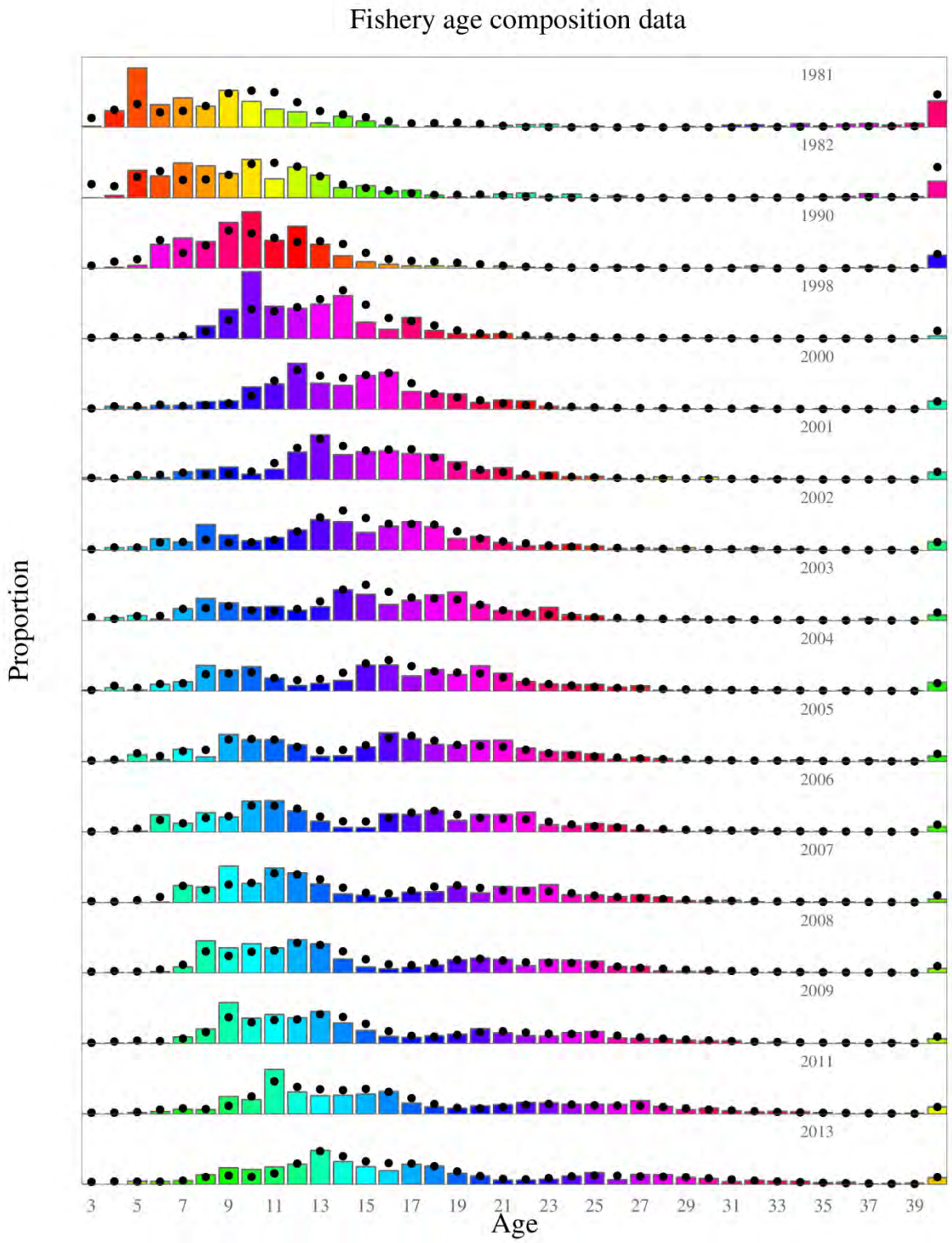

Figure 14. Model fits (dots) to fishery age composition data (columns) for Aleutian Islands Pacific ocean perch, 1981-2013. Colors correspond to cohorts (except for the 40+ group).

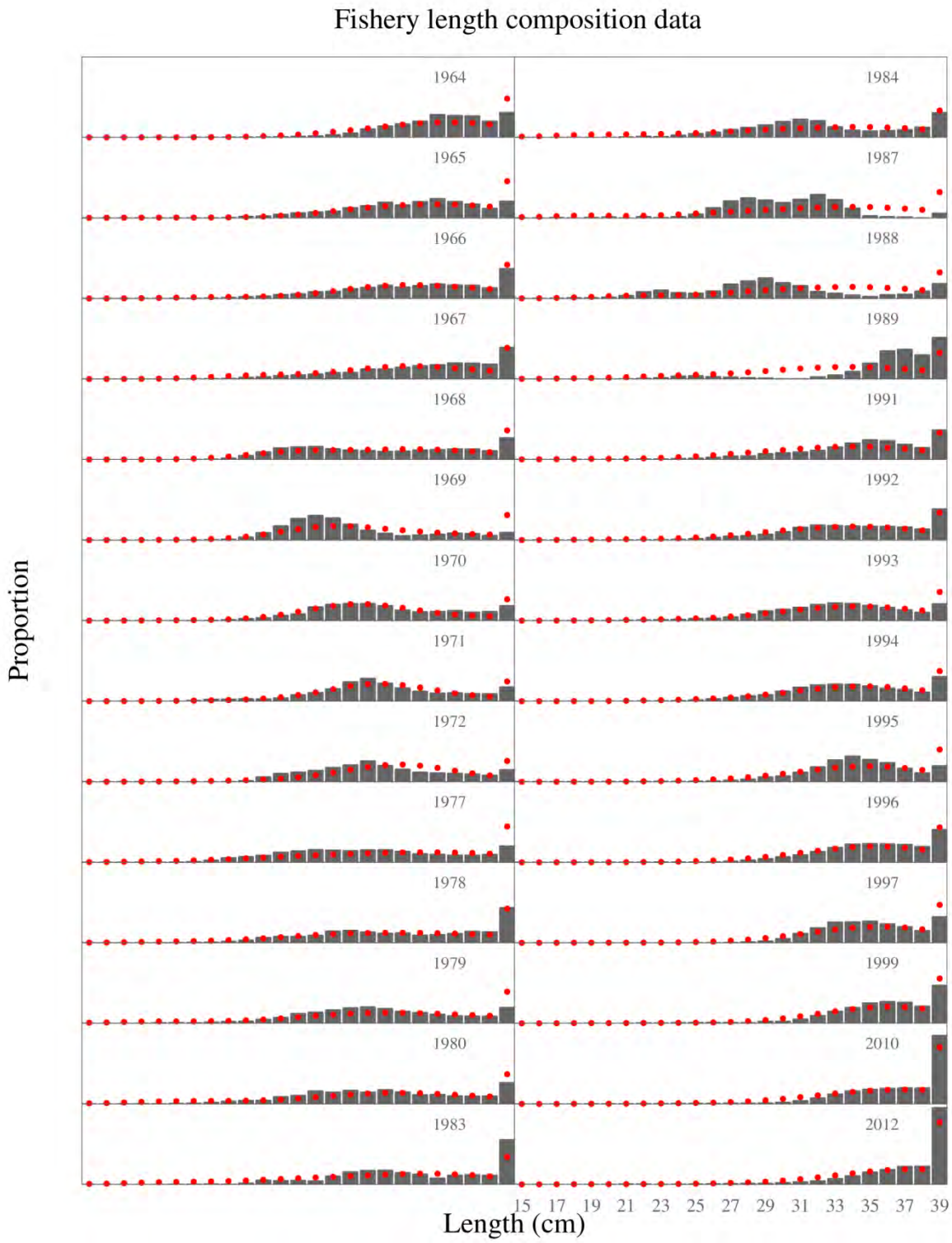

Figure 15. Model fits (dots) to fishery length composition data (columns) for Aleutian Islands Pacific ocean perch, 1964-2012.

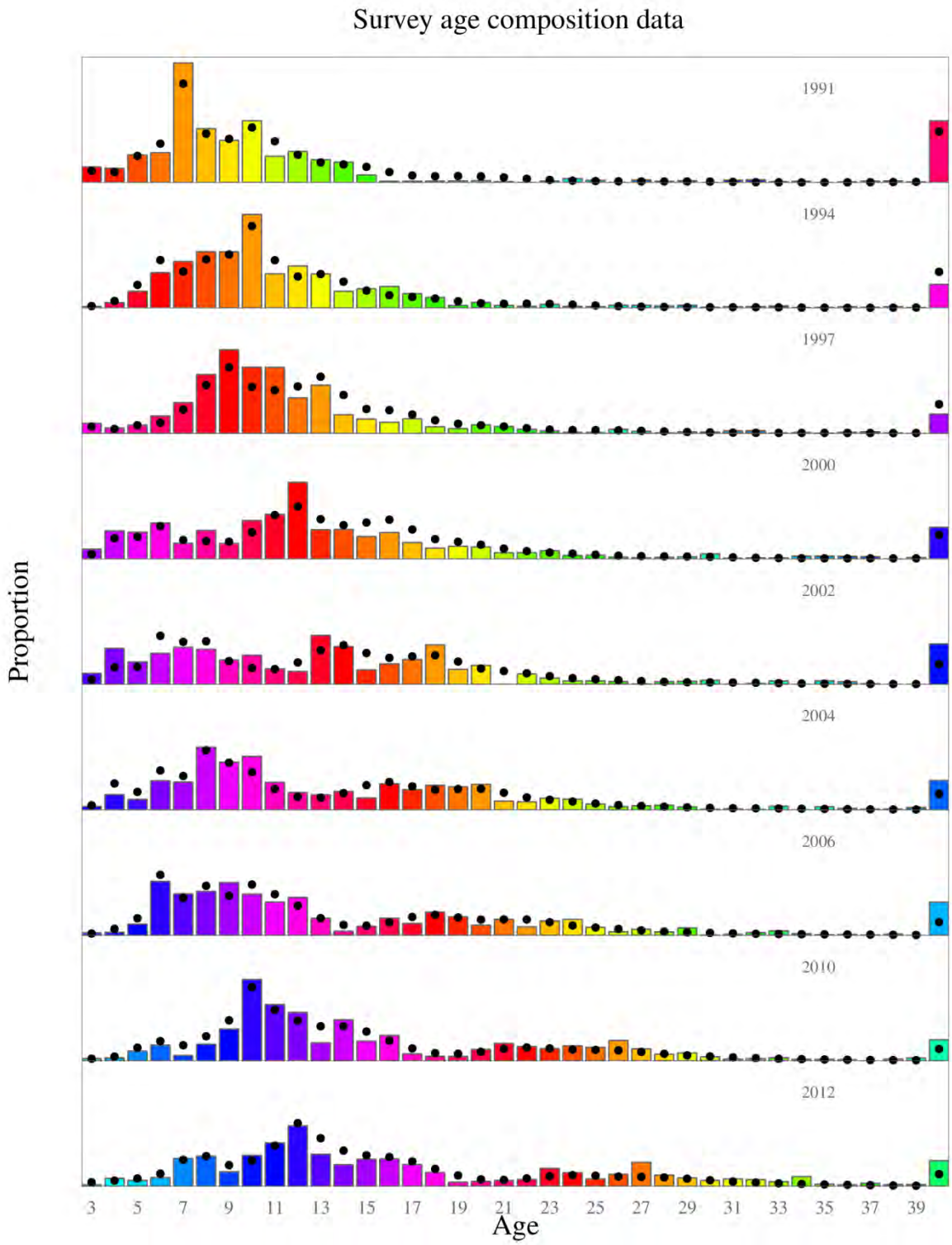

Figure 16. Model fits (dots) to survey age composition data (columns) for Aleutian Islands Pacific ocean perch, 1991-2012. Colors correspond to cohorts (except for the 40+ group).

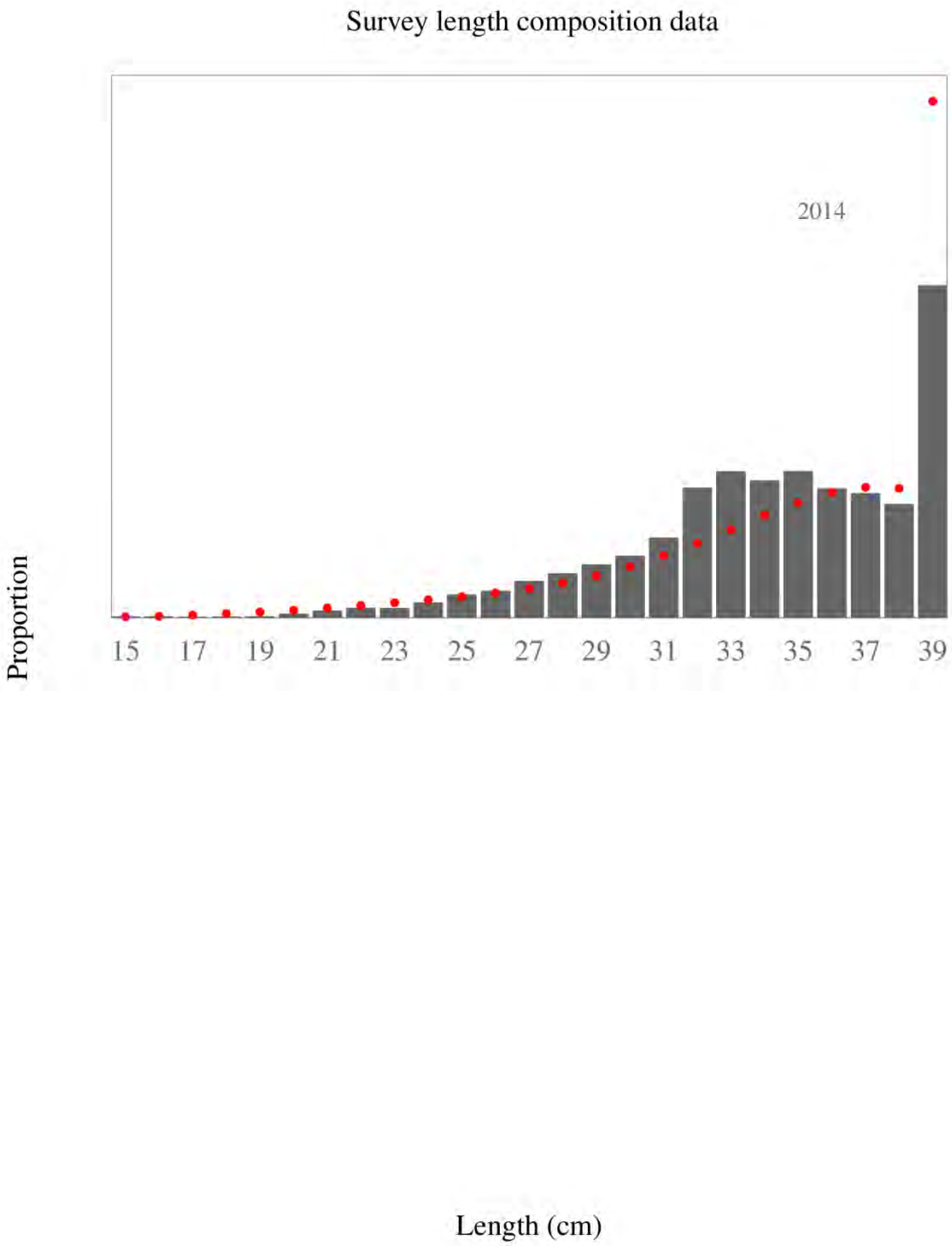

Figure 17. Model fits (dots) to 2014 survey length composition data (columns) for Aleutian Islands Pacific ocean perch.

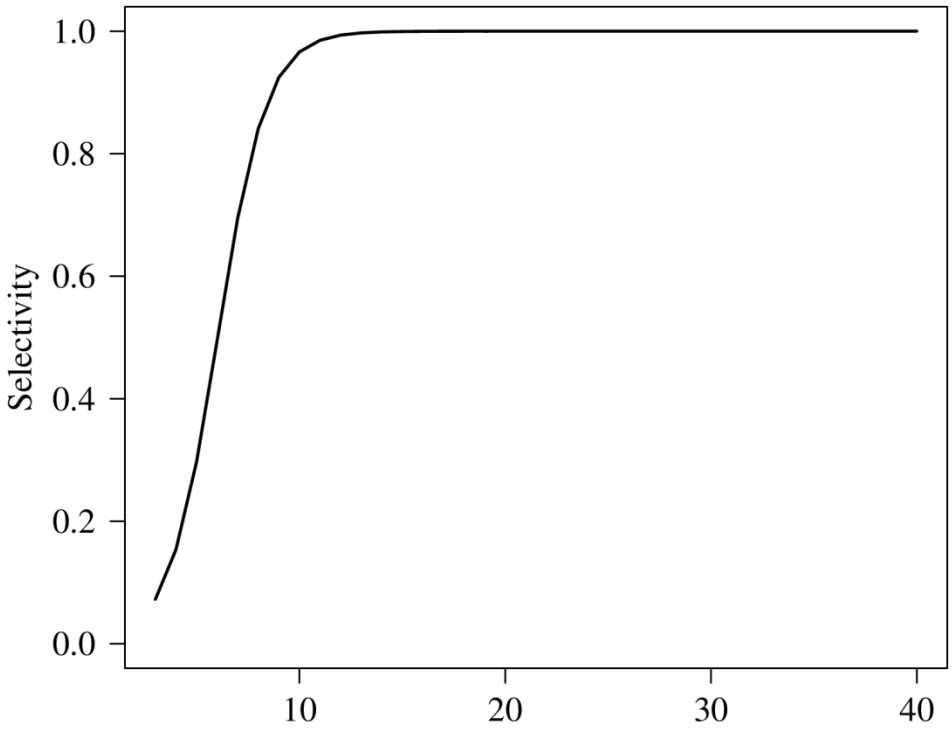

Figure 18. Estimated survey selectivity curve for BSAI POP

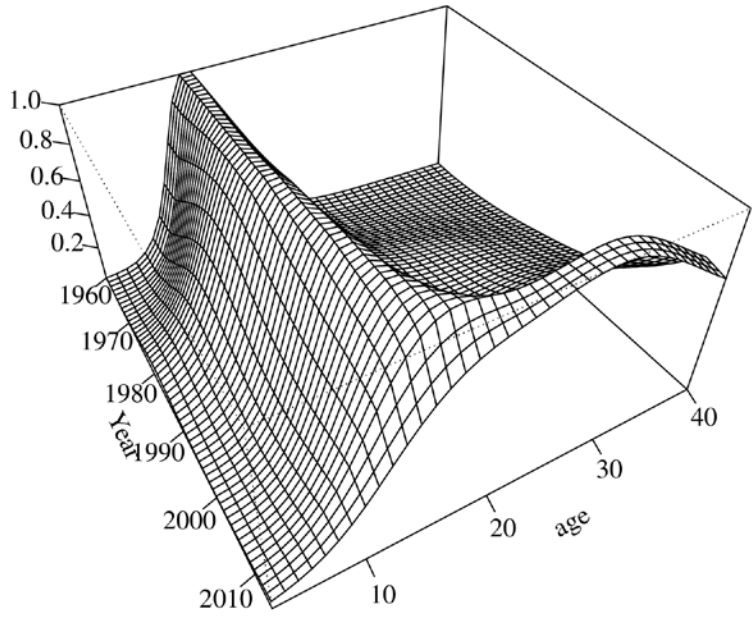

Figure 19. Estimated fishery selectivity from 1960-2014.

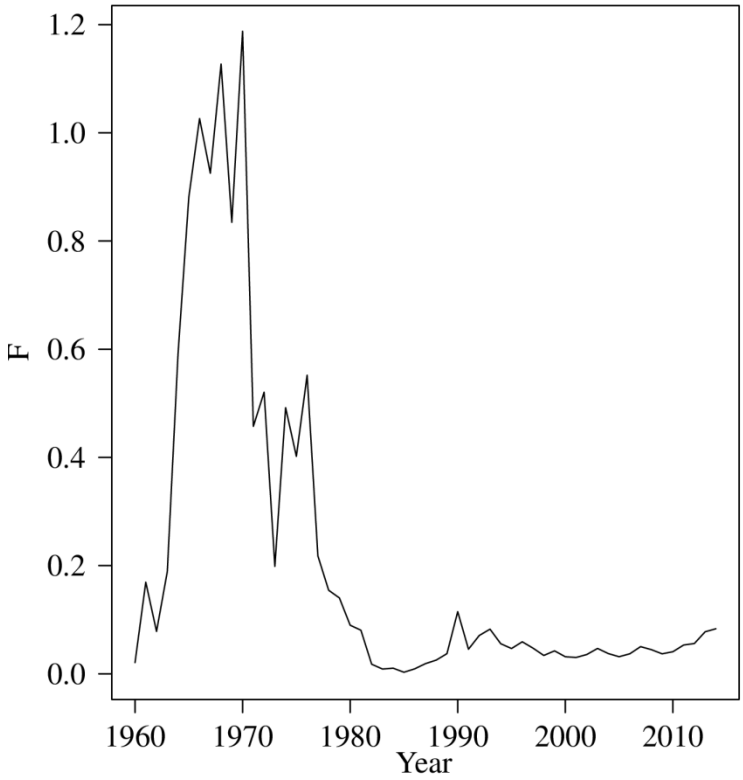

Figure 20. Estimated fully selected fishing mortality for BSAI POP.

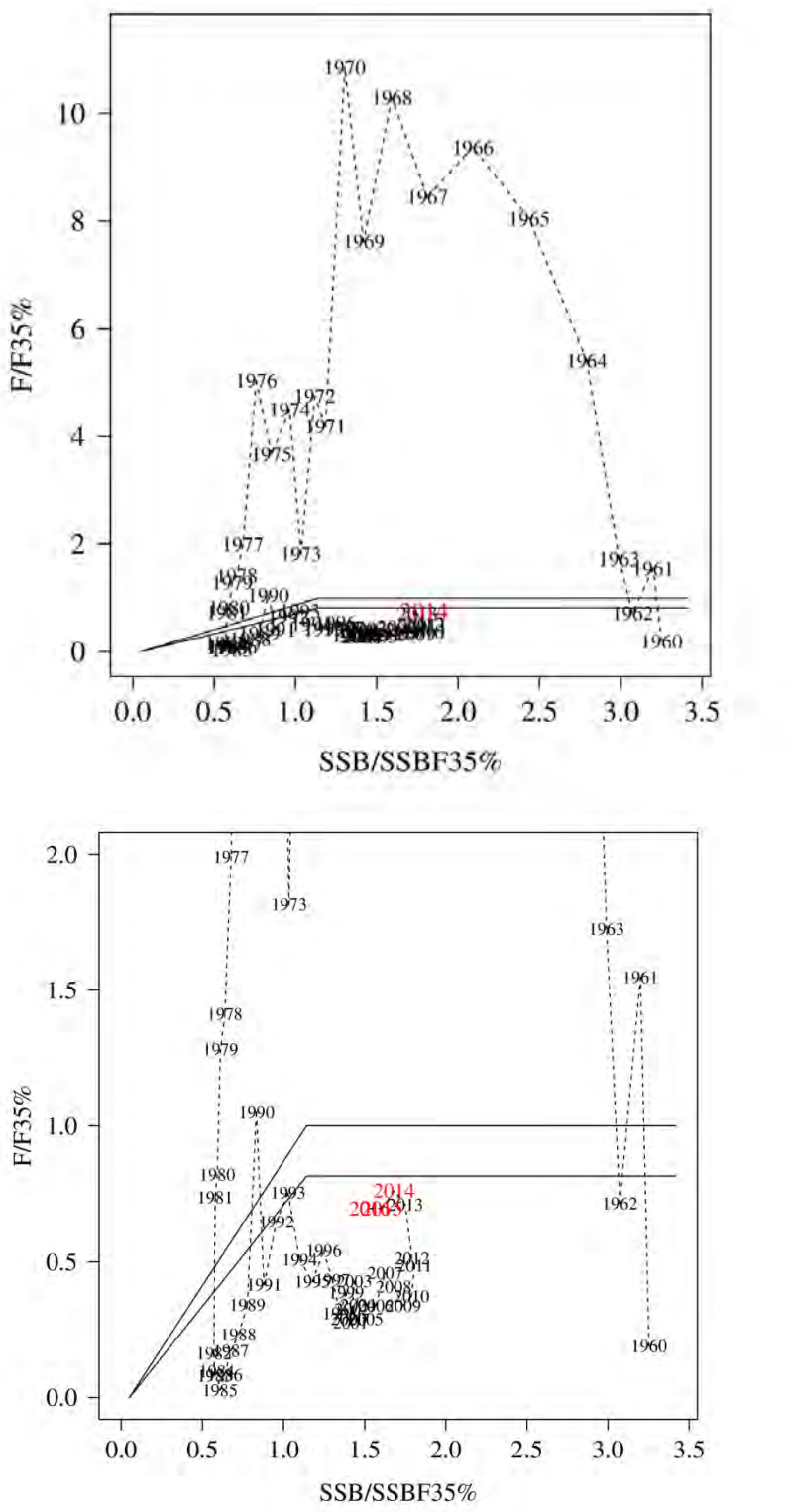

Figure 21. (Top panel) Estimated fishing mortality and SSB in reference to OFL (upper line) and ABC (lower line) harvest control rules, with 2014 shown in red. The bottom panel shows a reduced vertical scale, and the projected F and stock size for 2015 and 2016.

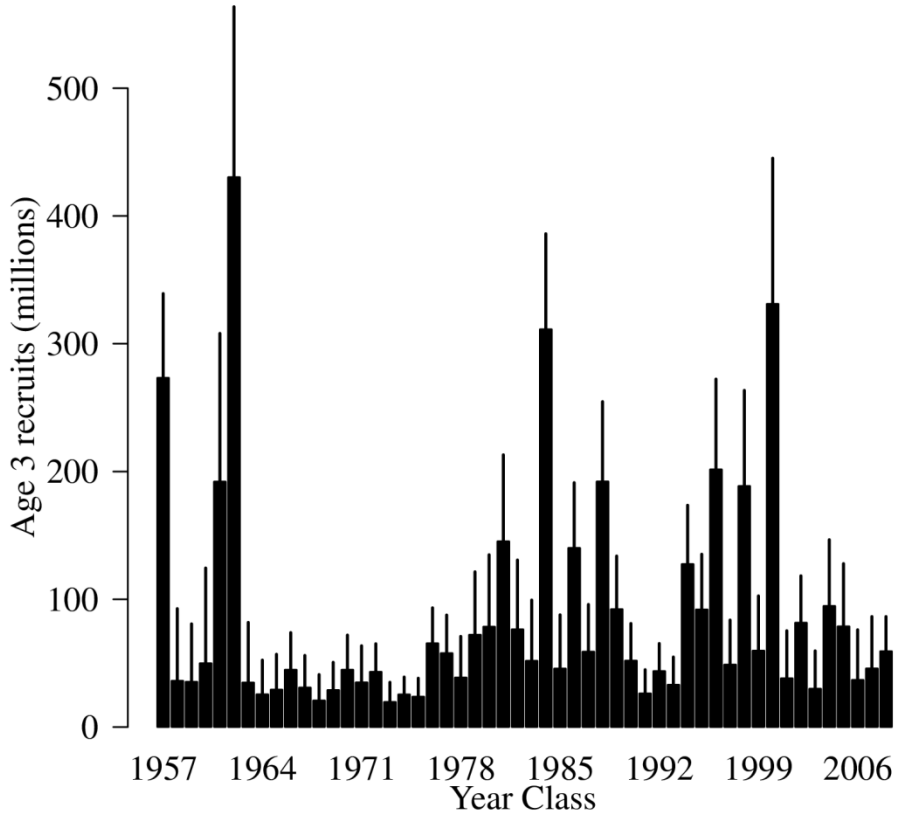

Figure 22. Estimated recruitment (age 3) of BSAI POP, with 95% CI limits obtained from MCMC

integration.

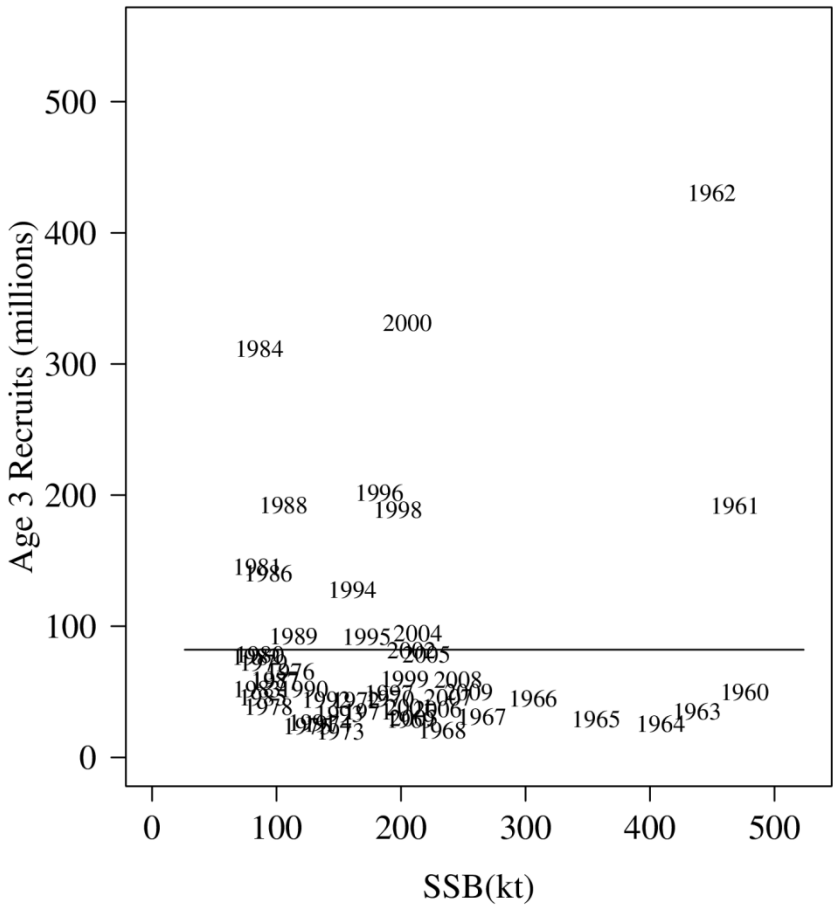

Figure 23. Scatterplot of BSAI POP spawner-recruit data; label is year class.

Appendix A. Supplemental Catch Data

In order to comply with the Annual Catch Limit (ACL) requirements, non-commercial removals that do not occur during directed groundfish fishing activities are reported (Table A1). This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System estimates. For BSAI POP, these estimates can be compared to the trawl research removals reported in previous assessments. POP research removals are small relative to the fishery catch. The majority of removals are taken by the Alaska Fisheries Science Center's (AFSC) biennial bottom trawl survey which is the primary research survey used for assessing the population status of BSAI POP. The amount of POP captured in research longline gear has typically been less than 0.1 t. There was no recorded recreational harvest or harvest that was non-research related in 2010 and 2011. Total removals of POP ranged between 8 and 267 t between 2010 and 2014, which was were 267 t in 2010 and 3 t in 2011, and did not exceed 1.4 of the ABC for these years.

Appendix Table A1. Removals of BSAI POP from activities other than groundfish fishing (t). Trawl and longline include research survey and occasional short-term projects. "Other" is recreational, personal use, and subsistence harvest.

Year	Source	Trawl	Longline	Other
1977	NMFS-AFSC survey databases	0.008		
1978		0.144		
1979		3.083		
1980		71.474		
1981		13.982		
1982		14.250		
1983		133.461		
1984		0.000		
1985		98.567		
1986		164.541		
1987		0.014		
1988		10.428		
1989		0.003		
1990		0.031		
1991		76.327		
1992		0.383		
1993		0.011		
1994		112.815		
1995		0.023		
1996		1.179	0.015	
1997		178.820		
1998		0.006	0.003	
1999		0.192	0.014	
2000		164.166	0.019	
2001		0.114	0.015	
2002		143.795	0.026	
2003		7.595	0.012	
2004		180.928	0.029	
2005		10.682	0.019	
2006		168.609	0.043	
2007		0.063	0.036	
2008		21.087	0.037	
2009		1.436	0.139	
2010	AKFIN database	266.674	0.097	
2011		104.409	0.011	
2012		285.773	0.046	
2013		8.496	0.057	
2014		247.860	0.000	

13. Assessment of the Northern Rockfish stock in the Bering Sea/Aleutian Islands

by

Paul D. Spencer and James N. Ianelli

Executive Summary

The last full assessment for northern rockfish was presented to the Plan Team in 2012. The following changes were made to northern rockfish assessment relative to the November 2012 SAFE:

Summary of Changes in Assessment Inputs

Changes in the input data:

1) Catch updated through October 11, 2014.
2) The survey biomass estimates and age composition data from the U.S.-Japan cooperative surveys in 1980, 1983, and 1986 were removed from the assessment.
3) The 2014 AI survey biomass estimate and length composition was included in the assessment.
4) The 2012 AI survey age composition was included in the assessment.
5) The 2012 fishery length composition was included in the assessment

Changes in the Assessment Methodology

1) The multinomial input sample sizes for the age and length composition data were obtained by an iterative reweighting procedure that ensures that the standard deviation of the normalized residuals for each composition data type is 1.
2) The length-at-age, weights-at-age, and age-to-length conversion matrix were updated based on data from the NMFS AI trawl survey beginning in 1991.

Summary of Results

BSAI northern rockfish are not overfished or approaching an overfished condition. The recommended 2015 ABC and OFL are 12,488 t and 15,337 t, which are 28% and 29% increases from the values specified last year for 2015 of 9,652 t and 12,488 t. The 1980s cooperative surveys had low biomass estimates relative to the remainder of the time series, and removal of these data increased the estimated population size. A summary of the recommended ABCs and OFLs from this assessment relative the ABC and OFL specified last year is shown below:

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Quantity	As estimated or specified last year for: 2014	2015	As estimated or recommended this year for: 2015	2016
M (natural mortality rate)	0.0413	0.0413	0.049	0.049
Tier	3a	3a	3a	3a
Projected total (age 3+) biomass (t)	196,519	197,541	218,901	218,898
Female spawning biomass (t)				
Projected	84,237	83,698	94,873	93,540
$B_{100\%}$	147,918	147,918	144,420	144,420
$B_{40\%}$	59,167	59,167	57,768	57,768
$B_{35\%}$	51,771	51,771	50,547	50,547
F_{OFL}	0.079	0.079	0.088	0.088
$maxF_{ABC}$	0.063	0.063	0.070	0.070
F_{ABC}	0.063	0.063	0.070	0.070
OFL (t)	12,077	11,943	15,337	15,100
maxABC (t)	9,761	9,652	12,488	12,295
ABC (t)	9,761	9,652	12,488	12,295
Status	As determined last year for: for: 2012	2013	As determined this year for: 2013	2014
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Summaries for the Plan Team

The following table gives the recent biomass estimates, catch, and harvest specifications, and projected biomass, OFL and ABC for 2015-2016.

Year	Biomass[1]	OFL	ABC	TAC	Catch
2013	195,446	12,200	9,850	3000	2038
2014	197,541	12,077	9,761	2594	2282
2015	218,901	15,337	12,488		
2016	218,898	15,100	12,295		

[1] Total biomass from age-structured projection model.
[2] Catch as of October 11, 2014.

Responses to SSC and Plan Team Comments on Assessments in General

The SSC requests that all assessment authors of AI species evaluate AI survey information to ensure that the same standardized survey time series is used. (SSC, December 2012)

Model runs in this assessment exclude the cooperative surveys conducted in the 1980s.

"The Teams recommended that each stock assessment model incorporate the best possible estimate of the current year's removals. The Teams plan to inventory how their respective authors address and calculate total current year removals. Following analysis of this inventory, the Teams will provide advice to authors on the appropriate methodology for calculating current year removals to ensure consistency across assessments and FMPs." (Plan Team, September 2013)

The estimates of current year catch are inferred by expanding the catch through September, 2014, by the recent pattern of the proportion of the remaining ABC that is caught by the end of the year.

"For assessments involving age-structured models, this year's CIE review of BSAI and GOA rockfish assessments included three main recommendations for future research: Authors should consider: (1) development of alternative survey estimators, (2) evaluating selectivity and fits to the plus group, and (3) re-evaluating natural mortality rates. The SSC recommends that authors address the CIE review during full assessment updates scheduled in 2014." (SSC, December 2013)

Selectivity curves and natural mortality rates are evaluated in this assessment. The development of alternative survey estimators (i.e., model-based standardization of survey catch data) affects all NPFMC assessments that use survey data. Potential methodologies have been discussed in a limited number of meetings in 2014 among AFSC scientists, and between AFSC scientists and NWFSC scientists, who are in the process of developing more refined standardization methods. Continuation of these meetings will hopefully result in progress on this task.

"During public testimony, it was proposed that assessment authors should consider projecting the reference points for the future two years (e.g., 2014 and 2015) on the phase diagrams. It was suggested that this forecast would be useful to the public. The SSC agrees. The SSC appreciated this suggestion and asks the assessment authors to do so in the next assessment." (SSC December 2013)

These projections were added to the phase-plane plots.

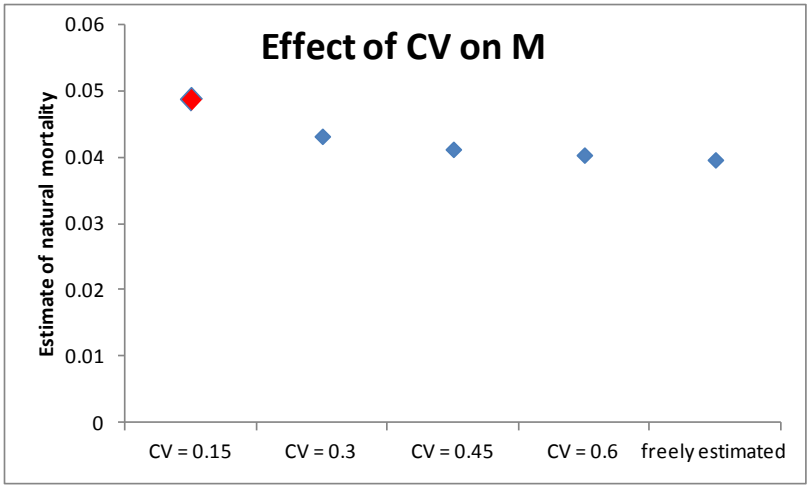
Responses to SSC and Plan Team Comments Specific to this Assessment

The SSC offers the following advice to assessment authors:
- *Evaluate priors on survey catchability and natural mortality.*
- *Explore alternative selectivity patterns*
- *Evaluate alternative selectivity time periods*
- *Evaluate/compare mean vs. median recruitment and which time period should be used for estimating fishery bench marks and provide rationale* (SSC, Dec 2012)

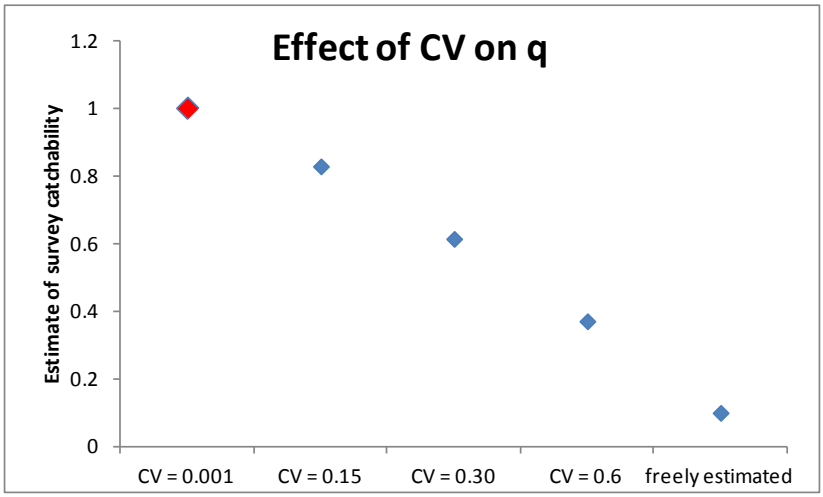
Alternative selectivity functional forms, including time-varying selectivity, are included in this assessment. The preferred model used a time-invariant double logistic equation to model fishery selectivity.

Previous attempts to estimate natural mortality (M) and survey catchability (q) within the assessment model have produced estimates that are implausible, which necessitated prior distributions with tight CVs. A series of models runs were conducted to address how sensitive the model estimates of M and q are to the prior distributions. Because M and q are inversely correlated, the runs for M were conducted by

holding *q* fixed at the value estimated in the preferred model (and vice versa). The current model uses a prior distribution for *M* with a mean set to 0.06 (based on the method of Alverson and Carney (1975)) and CV set to 0.15, and produces and estimate of 0.049 (shown in red in the graph below). The estimate obtained when *M* is freely estimated declines to 0.04. These estimates are lower those obtained from a recent analysis of empirical estimators of natural mortality, in which an estimator based on a power function of maximum age was developed (Then et al. 2014) and yields an estimate of 0.08 for northern rockfish. Additionally, Then at al. (2014) found that estimators that rely on maximum age had less prediction error than the Alverson-Carney method. In future assessments, the effect of increasing the mean and/or lowering the CV for the prior on *M* will be considered.



The prior for *q* has a mean of 1 and a CV of 0.001, and a similar plot showing the effect of increasing the CV of the prior is shown below. The estimates of *q* range from 1.0 fixed in the current model to 0.1 when estimated freely (while holding *M* fixed at 0.049). The inability to estimate *q* within the model is not surprising given that there is little contrast in the survey time series regarding how the stock has responded to exploitation, and motivates obtaining information on *q* outside the assessment model in order to develop more informative priors.



Introduction

Northern rockfish (*Sebastes polyspinus*) inhabit the outer continental shelf and upper slope regions of the North Pacific Ocean and Bering Sea. Northern rockfish (*Sebastes polyspinus*) in the Bering Sea/Aleutians Islands (BSAI) region were assessed under Tier 5 of Amendment 56 of the NPFMC BSAI Groundfish FMP until 2004. The reading of archived otoliths from the Aleutian Islands (AI) surveys allowed the development of an age-structured model for northern rockfish beginning in 2003. Since 2004, BSAI northern rockfish have been assessed as a Tier 3 species in the BSAI Groundfish FMP.

Information on Stock Structure

A stock structure evaluation was included as an appendix to the 2012 stock assessment (Spencer and Ianelli 2012). A variety of types of data were considered, including genetic data, potential barriers to movement, growth differences, and spatial differences in growth and age and size structure.

Several genetic tests were conducted on northern rockfish samples obtained in the 2004 Aleutian Islands and EBS trawl surveys (Gharrett et al. 2012). A total of 499 samples were collected at six locations ranging from the EBS slope to the western Aleutian Islands, and analyses were applied to 11 microsatellite loci. Information on the spatial population structure was obtained from the spatial analysis of molecular variance (SAMOVA; Dupanloup et al. 2002), which identified sets of collections that showed maximum differentiation. Three groups were identified: 1) the eastern Bering Sea; 2) two collections west of Amchitka Pass; and 3) three collections between Amchitka Pass and Unimak Pass. The genetic data also show a statistically significant pattern of isolation by distance, indicating genetic structure being produced from the dispersal of individuals being smaller than the spatial extent of the sampling locations. A range of expected lifetime dispersal distance were estimated, reflecting different assumptions regarding effective population size and migration rates of spawners, and the estimated lifetime dispersal distances did not exceed 250 km. This estimated dispersal distance is comparable to other *Sebastes* species in the north Pacific, which have ranged from 4 to 40 for near shore species such as grass rockfish (Buonaccorsi et al. 2004), brown rockfish ((Buonaccorsi et al. 2005), and vermilion rockfish (Hyde and Vetter 2009), and up to 111 km for deeper species such as POP (Palof et al. 2011) and darkblotched rockfish (Gomez-Uchida and Banks 2005). The demographic implication is that movement of fish from birth to reproduction is at a much smaller scale than the geographic scale of the BSAI area. Finally, it is important to recall that the time unit for the estimated dispersal is not years, but generations, and the generation time for northern rockfish is more than 36 years.

Aleutian Island trawl survey data was used to estimate von Bertalannfy growth curves by areas, and show increasing size at age from the western AI to the eastern AI. The largest difference in the growth curves was in the rate parameter *K*, which was smallest in the western Aleutians, indicating that fish in this area approached their asymptotic size more slowly than fish in the EAI and SBS.

Spatial differences in age compositions, obtained from the AI trawl surveys from 2002, 2004, and 2006, were evaluated by testing for significant differences in mean age between areas. Significant differences were observed in the mean age between subareas for individual years, but a consistent pattern did not emerge across the years.

Finally, any potential physical limitations to movement were considered. Physical barriers are rare in marine environments, but the Aleutian Islands are unique due to the occurrence of deep passes, typically exceeding 500 m, that may limit the movement of marine biota. For example, Logerwell et al. (2005) identify a “biophysical transition zone” occurs at Samaga Pass. Northern rockfish are a demersal species captured during the AI trawl survey at depths between 100 m and 200 m, so adult rockfish traversing the much deeper AI passes would require greater utilization of pelagic habitats or deeper depths than currently observed in the AI trawl surveys. Movement of larvae between areas is likely a function of ocean currents. On the north side of archipelago, the connection between the east and west Aleutians is

limited due to the break associated with Petral Bank and Bowers Ridge, which results in water flowing away from the Aleutian Islands archipelago. On the south side of the Aleutian Islands, the Alaska Stream provides much of the source of the Alaska North Slope Current (ANSC) via flow through Amutka Pass and Amchitka Pass. However, The Alaska Stream separates from the slope west of the Amchitka Pass and forms meanders and eddies, perhaps limiting the connection between the east and west Aleutians.

Fishery

BSAI foreign and joint venture rockfish catch records from 1977 to 1989 are available from foreign "blend" estimates of total catch by management group, and observed catches from the North Pacific Observer Program database. The foreign catch of BSAI rockfish during this time was largely taken by Japanese trawlers, whereas the joint-venture fisheries involved partnerships with the Republic of Korea. Because northern rockfish are taken as bycatch in the BSAI area, historical foreign catch records have not identified northern rockfish catch by species. Instead, northern rockfish catch has been reported in a variety of categories such as "other species" (1977, 1978), "POP complex" (1979-1985, 1989), and "rockfish without POP" (1986-1988).

Rockfish management categories in the domestic fishery since 1991 have also included multiple species. In 1991, the "other red rockfish" species group was used in both the EBS and AI, but beginning in 1992 northern rockfish in the AI were managed in the "northern/sharpchin" species group. Prior to 2001, northern rockfish were managed with separate ABCs and TACs for the AI and EBS, and in 2001 the two areas were combined into a single management unit under the "sharpchin/northern" species complex. In 2002, sharpchin rockfish were dropped from the complex because of their sparse catches, leaving single-species management category of northern rockfish. The OFLs, ABCs, TACS, and catches by management complex from 1977-2000 are shown in Table 1, and those from 2001 to present are shown in Table 2.

Since 2002, the blend and catch accounting system (CAS) databases has reported catch of northern rockfish within the EBS and AI subareas. From 1991-2001, species catches were reconstructed by computing the harvest proportions within management groups from the North Pacific Foreign Observer Program database, and applying these proportions to the estimated total catch obtained from the NOAA Fisheries Alaska Regional Office "blend" database. This reconstruction was conducted by estimating the northern rockfish catch for each area (i.e., the EBS and each of the three AI areas) and gear type from 1994-2001. For 1991-1993, the Regional Office blend catch data for the Aleutian Islands was not reported by AI subarea, and the AI catch was obtained using the observer harvest proportions by gear type for the entire AI area. Similar procedures were used to reconstruct the estimates of catch by species from the 1977-1989 foreign and joint venture fisheries. Estimated domestic catches in 1990 were obtained from Guttormsen et al. 1992. Catches from the domestic fishery prior to the domestic observer program were obtained from PACFIN records.

Catches of northern rockfish since 1977 by area are shown in Table 3. Northern rockfish catch prior to 1990 was small relative to more recent years (with the exception of 1977 and 1978). Harvest data from 2004 -2010 indicates that approximately 88% of the BSAI northern rockfish are harvested in the Atka mackerel fishery. Prior to 2011, much of the northern rockfish catch occurred in the western and central Aleutian Islands, reflecting the high proportion of Atka mackerel fishing in these areas (Table 4). However, restrictions on Atka mackerel fishing in the western Aleutians beginning in 2011 have restricted the current northern rockfish harvest in this area, and from 2011-2014 the proportion of northern rockfish harvested in the Atka mackerel fishery has declined to 55%. Northern rockfish are patchily distributed and are harvested in relatively few areas within the broad management subareas of the Aleutian Islands, with important fishing grounds being Petral Bank, Sturdevant Rock, south of Amchitka I., and Seguam Pass (Dave Clausen, NMFS-AFSC, personal communication).

Temporal variability has occurred in AI subareas in which northern rockfish are captured, and to a lesser extent in the depth of capture (Figure 1). The domestic fishery observer data indicates that the eastern AI accounted for 49% and 63% of the AI harvest in 1990 and 1991, respectively, decreasing to less than 15% of the observed catch from 1997 to 2006 (except 1999 and 2000). In contrast, the proportion of observed catch in the western AI increased from less than 20% from 1991 to 1993 to greater than 40% in most years from 1996-2005, and has decreased to less than 20% from 2011 – 2014 with the closure of the western AI to Atka mackerel fishing since 2010. The observed catch of northern rockfish is predominately captured at depths between 100 m and 200 m, although percentage obtained at depths between 200 m and 300 m has been variable, ranging from less than 5% during 2000 – 2007 to between 5% and 13% from 2008 – 2013.

Information on proportion discarded is generally not available for northern rockfish in years where the management categories consist of multi-species complexes. However, because the catches of sharpchin rockfish are generally rare in both the fishery and survey, the discard information available for the "sharpchin/northern" complex can interpreted as northern rockfish discards. This management category was used in 2001 in the EBS, and from 1993-2001 in the AI. Prior to 2003 the discard rates were generally above 80%, with the exception of the mid-1990s when some targeting occurred in the Aleutians Islands (Table 4). Discard rates in the AI have declined from 96% in 2003 to < 10% in 2013 and 2014. In the Aleutian Islands, discard rates have declined from 80% in 2003 to < 10% in 2010, and increased in year to 50% in 2012 and 46% in 2014.

Non-commercial catch data are shown in Appendix A.

Data

Fishery Data

The fishery data is characterized by inconsistent sampling of lengths and ages (Table 6). In some years, such as 1984 and 1987 over 700 fish lengths were obtained but these data samples came from a limited number of hauls. Additionally, the length data from the foreign fishery tended to originate from predominately one location in each year, and was not consistent between years. For example, the 1977 and 1978 fishery length data were collected from Tahoma Bank in the western Aleutians, whereas samples in 1984 were obtained from Seguam Pass and samples in 1987 were obtained from Petral Bank. In the domestic fishery, changes in observer sampling protocol since 1999 have improved the distribution of hauls from which northern rockfish age and length data are collected.

The selection of fishery length frequency data for the age-structured assessment model was based on the consistency in sampling location and the number of samples collected. Foreign fishery length data from 1977 and 1978 were used, in part, because of the consistency in their sampling location with other sampling years, the increased numbers of hauls from which they were obtained, and the absence of other length composition data during this portion of the time series. Domestic fishery length data from 1996, 1998-1999, 2010, and 2012-2013 were used, and the length and age data from 2000-2009 and 2011 were used to estimate the age-frequency of the fishery catch.

The fishery age composition data indicates the relatively strong cohorts in 1984-1985 and 1995, as each of these cohorts was observed as relatively abundant in multiple years of fishery age composition data (Figure 2).

Survey data

Biomass estimates for other red rockfish were produced from cooperative U.S.-Japan trawl survey from 1979-1985 on the eastern Bering Sea slope, and from 1980-1986 in the Aleutian Islands. U.S trawl surveys on the eastern Bering Sea slope were conducted by the National Marine Fisheries Service

(NMFS) in 1988, 1991, and biennially beginning in 2002 (except 2006 and 2014, when the survey was canceled due to lack of funding). NMFS trawl survey in the Aleutian Islands were conducted in 1991, 1994, 1997, and biennially beginning in 2000. The EBS slope surveys in 2008 and 2014, and the AI trawl survey in 2008, were canceled to due lack of funding. Differences exist between the 1980-1986 cooperative surveys and the 1991-2012 from the U.S. domestic surveys with regard to the vessels and gear design used (Skip Zenger, National Marine Fisheries Service, personal communication). For example, the Japanese nets used in the 1980, 1983, and 1986 cooperative surveys varied between years and included large roller gear, in contrast to the poly-nor'eastern nets used in the current surveys (Ronholt et al 1994), and similar variations in gear between surveys occurred in the cooperative EBS surveys. In previous assessments, these surveys were included in the assessment as to provide some indication of biomass during the 1980s. Given the difficulty of documenting the methodologies for these surveys, and standardizing these surveys with the NMFS surveys, this assessment model is conducted with only the NMFS surveys.

Survey abundance in the western and central Aleutians from 1991-2012 was larger than abundance in the eastern Aleutians and eastern Bering Sea (Table 7, Figure 3). In 2014, the survey abundance in the eastern AI increased sharply to 77,000 t (from an average of 20,000 t from 2006-2012) and has a large coefficient of variation of 0.79. Areas of particularly high survey abundance are Amchitka Island, Kiska Island, Buldir Island, and Tahoma Bank. An average of 70% of the estimated biomass from the 1991-2014 NMFS AI trawl surveys occurs in the western Aleutian Islands. The coefficients of variation (CV) of these biomass estimates by region are generally high, but especially so in the southern Bering Sea portion of the surveyed area (165 W to 170 W), where the CV was less than 0.50 only in the 2000 survey. The 2014 Aleutian Island survey biomass was 472,895 t, which represents an increase of 36% from the 2012 estimate of 285,164 t. Much of this increase occurred in the eastern AI (mentioned above) and the western AI, where the estimates biomass increased from 216,325 t in 2012 to 346,392 in 2014. The coefficient of variation (CV) for the 2014 estimate is 0.31, approximately equal to the average CV from the 1991-2012 surveys of 0.30. In the western AI in 2012, and in the eastern AI in 2012 and 2014, a single large tow accounted for the high CVs of the survey biomass estimate (Figure 3).

In the 1991-1996 surveys, a large portion of the age composition was less than 15 year old, reflecting relative abundant 1984, 1989, and 1994 cohorts (Figure 4).

The AFSC biennial EBS slope survey was initiated in 2002. The most recent slope survey prior to 2002, excluding some preliminary tows in 2000 intended for evaluating survey gear, was in 1991, and previous slope survey results have not been used in the BSAI model due to high CVs, relatively small population sizes compared to the AI biomass estimates, and lack of recent surveys. The EBS slope survey biomass estimates of northern rockfish from the 2002-2012 surveys ranged between 3 t (2008 and 2012) and 42 t (2010), with CVs between 0.38 (2002) and 1.0 (2008 and 2012). Given these low levels of biomass, the slope survey results are not used in this assessment.

Comparison of Fishery and Survey Catches by Depth and Age

A comparison of fishery and survey catches can indicate whether fishery selectivity is suspected of being time-varying and/or dome-shaped. The catch-weighted mean depth in the fishery (from 1991 – 2013) similar to the catch-weighted depth in the AI trawl survey (Figure 5), with the exceptions being the early 1990s in the central AI, and the western AI since 2010 (when a relatively higher proportion of the northern rockfish catch was obtained in rockfish fisheries).

Dome-shaped fishery selectivity indicates a decrease in the proportion of the population captured by the fishery for older-aged fish. Assuming that old fish in the survey are fully selected, a comparison of fishery and survey age compositions can reveal the potential presence of dome-shaped selectivity. The plus group for the northern rockfish assessment model is 40 years, and of interest is the relative age composition of the old fish within the plus group. Fishery and survey data were binned across years in each of three

periods from 2000 to 2011 (2000-2002, 2004-2006, and 2009-2011), the age composition of ages 40 to 70+ are shown in Figure 6. Overall, survey age composition is similar to fishery age composition for the ages in the plus group. For example, in the 2000 - 2002 period, the survey age composition exceeded the fishery age composition for 14 of 31 ages, whereas the fishery age composition exceeded the survey age composition in 8 of the 31 ages (8 ages were captured by neither the fishery or the survey). The pattern can be seen more clearly in the histogram of differences between survey and fishery age proportions (Figure 7); positive differences indicate that the survey proportion exceeded the fishery proportion for a given age. Overall, these data do not suggest that the fishery is selecting older northern rockfish in different proportions than the survey since 2000. Fishery age data are not available to conduct a similar analysis for years prior to 2000.

Biological Data

The AI survey provides data on age and length composition of the population, growth rates, and length-weight relationships. The number of otoliths collected and lengths measured are shown in Table 8, along with the number of hauls producing these data. The number of otoliths read by area is shown in Table 9. The survey data produce reasonable sample sizes of lengths and otoliths from throughout the survey area. The maximum age observed in the survey samples was 72 years.

The survey otoliths were read with the break and burn method, and were thus considered unbiased (Chilton and Beamish 1982); however, the potential for aging error exists. Information on aging error was obtained from Courtney et al. 1999, based on two independent readings of otoliths from the Gulf of Alaska trawl survey from 1984-1993. The raw data in Courtney et al. (1999) was used to estimate the standard deviation for each age. The standard deviations were regressed against age to provide a predicted estimate of standard deviation of observed ages for a given true age, and this linear relationship was used to produce the aging error matrix. Use of the aging error matrix from GOA northern rockfish for the BSAI stock is considered appropriate because longevity is similar between the areas.

The expected length at age was estimated by fitting a von Bertalanffy curve to estimates of mean size at age obtained from the AI surveys from 1991-2012. Within each survey year, mean size at age was obtained by multiplying the estimated population length composition by the age-length key. The estimated von Bertalanffy parameters are as follows, and were used to create a conversion matrix and a weight-at-age vector:

L_{inf}	K	t_0
33.77	0.19	-0.30

A conversion matrix was created to convert modeled number at ages to modeled number at length bin, and consists of the proportion of each age that is expected in each length bin. This matrix was created by fitting a power relationship to the observed standard deviation in length at each age (obtained from the aged fish from the 1991-2012 surveys), and the predicted relationship was used to produce variation around the predicted size at age from the von Bertalanffy relationship. The resulting CVs of length at age of the transition matrix decrease from 0.13 at age 3 to 0.10 at age 40.

A length-weight relationship of the form $W = aL^b$ was fit from the survey data from 1991-2012, and produced estimates of $a = 1.32 \times 10^{-5}$ and $b = 3.02$. This relationship was used in combination with the von Bertalanffy growth curve to obtain the estimated weight at age vector of the population (Table 10).

The following table summarizes the data available for the BSAI northern rockfish model:

Component	BSAI
Fishery catch	1977-2014
Fishery age composition	2000-2009, 2011
Fishery size composition	1977-1978, 1996, 1998-1999, 2010, 2012-2013
Survey age composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012
Survey length composition	2014
Survey biomass estimates	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014

Analytic Approach

Model structure

An age-structured population model, implemented in the software program AD Model Builder, was used to obtain estimates of recruitment, numbers at age, and catch at age. The assessment model for northern rockfish is very similar to that currently used for BSAI Pacific ocean perch, which was used as a template for the current model. Population size in numbers at age a in year t was modeled as

$$N_{t,a} = N_{t-1,a-1}e^{-Z_{t-1,a-1}} \quad 3 < a < A, \quad 1977 < t \leq T$$

where Z is the sum of the instantaneous fishing mortality rate ($F_{t,a}$) and the natural mortality rate (M), A is the maximum number of age groups modeled in the population, and T is the terminal year of the analysis (defined as 2012).

The numbers at age A are a "plus" group consisting of fish of age A and older, and are estimated as

$$N_{t,A} = N_{t-1,A-1}e^{-Z_{t-1,A-1}} + N_{t-1,A}e^{-Z_{t-1,A}}$$

The plus group was set to 40+, following a sensitivity analysis conducted in the 2012 stock assessment (Spencer and Ianelli 2012).

The numbers at age in the first year are estimated as

$$N_a = R_{init}e^{-M(a-3)+\gamma_a}$$

where R_{init} is the mean number of age 3 recruits prior to the start year if the model, and γ is an age-dependant deviation assumed to be normally distributed with mean of zero and a standard deviation equal to σ_r, the recruitment standard deviation. Estimation of the vector of age-dependant deviations from average recruitment allows estimation of year class strength.

The total numbers of age 3 fish from 1977 to 2011 are estimated as parameters in the model, and are modeled with a lognormal distribution

$$N_{t,3} = e^{(\mu_R + \nu_t)}$$

where μ_R is the log-scale mean and v_t is a time-variant deviation. The number of age 3 from 2012-2014 are set the expected mean recruitment (based upon the log-scale mean, and the value of σ_r).

The fishing mortality rate for a specific age and time ($F_{t,a}$) is modeled as the product of a fishery age-specific selectivity (*fishsel*) and a year-specific fully-selected fishing mortality rate *f*. The fully selected mortality rate is modeled as the product of a mean (μ_f) and a year-specific deviation (ε_t), thus $F_{t,a}$ is

$$F_{t,a} = S_{f,a} f_t \equiv S_{f,a} e^{(\mu_f + \varepsilon_t)}$$

The mean numbers at age for each year was computed as

$$\overline{N}_{t,a} = N_{t,a} * (1 - e^{-Z_{t,a}}) / Z_{t,a}$$

The predicted length composition data were calculated by multiplying the mean numbers at age by a transition matrix, which gives the proportion of each age (rows) in each length group (columns); the sum across each age is equal to one. The mean number of fish at age available to the survey or fishery is multiplied by the aging error matrix to produce the observed survey or fishery age compositions.

Catch biomass at age was computed as the product of mean numbers at age, instantaneous fishing mortality, and weight at age. The predicted trawl survey biomass (*pred_biom*) was computed as

$$pred_biom_t = qsurv \sum_a \left(\overline{N}_{t,a} * survsel_a * W_a \right)$$

where W_a is the population weight at age, $survsel_a$ is the survey selectivity, and *qsurv* is the trawl survey catchability.

To facilitate parameter estimation, prior distributions were used for the survey catchability and the natural mortality rate *M*. A lognormal distribution was also used for the natural mortality rate *M*, with the mean set to 0.06 (the value used in previous assessments, based upon expected relationships between *M*, longevity, and the von Bertalanffy growth parameter *K* (Alverson and Carney 1975)) and the CV set to 0.15. The standard deviation of log recruits, σ_r, was fixed at 0.75, a value consistent with the root mean squared error (RMSE; defined below) of recruitment deviations. Similar, the prior distribution for *qsurv* followed a lognormal distribution with a mean of 1.0 and a coefficient of variation (CV) of 0.001, essentially fixing *qsurv* at 1.0.

Several quantities were computed in order to compare the variance of the residuals to the assumed input variances. The RSME should be comparable to the assumed coefficient of variation of a data series. This quantity was computed for the AI trawl survey and the estimated recruitments, and for lognormal distribution is defined as

$$RMSE = \sqrt{\frac{\sum_n (\ln(y) - \ln(\hat{y}))^2}{n}}$$

where y and $\hat{y}$ are the observed and estimated values, respectively, of a series length n. The standardized deviation of normalized residuals (SDNR) are closely related to the RMSE; values of SDNR greater approximately 1 indicate that the model is fitting a data component as well as would be expected for a given specified input variance. The normalized residuals for a given year i of the AI trawl survey data was computed as

$$\delta_i = \frac{\ln(B_i) - \ln(\hat{B}_i)}{\sigma_i}$$

where σ_i is the input sampling standard deviation of the estimated survey biomass. For age or length composition data assumed to follow a multinomial distribution, the normalized residuals for age/length group *a* in year *i* were computed as

$$\delta_{i,a} = \frac{(p_{i,a} - \hat{p}_{i,a})}{\sqrt{\hat{p}_{i,a}(1-\hat{p}_{i,a})/n_i}}$$

where *p* and $\hat{p}$ are the observed and estimated proportion, respectively, and *n* is the input assumed sample size for the multinomial distribution. The effective sample size was also computed for the age and length compositions modeled with a multinomial distribution, and for a given year *i* was computed as

$$E_i = \frac{\sum_a \hat{p}_a(1-\hat{p}_a)}{\sum_a (\hat{p}_a - p_a)^2}.$$

An effective sample size that is nearly equal to the input sample size can be interpreted as having a model fit that is consistent with the input sample size.

Parameterization of fishery selectivity

Four models were evaluated that differed in the parameterization for fishery selectivity at age ($S_{f,a}$).

Model 1) *Logistic curve* (used in previous assessments):

$$S_{f,a} = \frac{1}{1+e^{-\phi(a-a_{50\%})}}$$

where the $a_{50\%}$ and ϕ parameters control the age at 50% maturity and the slope of the curve at this point, respectively.

Model 2) *Double logistic curve*:

$$S_{f,a} = \frac{1}{1+e^{-\phi_{asc}(a-a_{50\%})}} \frac{1}{1+e^{-\phi_{des}(a-d_{50\%})}}$$

where fishing selectivity is the product of two logistic curve, and allows for dome-shaped selectivity when the descending slope parameter (ϕ_{des}) is negative.

Model 3) Cubic spline

Model 4) Bicubic spline

A mathematical definition of a spline is a smooth function that is used for either interpolating between fixed points (referred to as "knots" or "nodes") or smoothing a dataset. Splines are of interest when the underlying process for which the spline represents is a smooth, nonlinear function. Splines are constructed from separate piecewise functions that are joined at the knots, and smoothness is ensured by requiring that at each knot, the two functions joined have equal function values, first derivatives, and second derivatives. These conditions can only be met by

using polynomial splines of order 3 or higher, and cubic splines are often used because they limit unnecessary bending between the knots. Splines are implemented in non-parametric modeling such as generalized additive models, and been examined in ecological modeling as an approach for modeling time-varying parameters (Thorson et al. 2013). In stock assessment modeling, non-parameteric selectivity curves (a category that includes splines) performed well in an evaluation of various approaches for modeling fishery selectivity (Thorson and Taylor 2013).

Cubic and bicubic splines were implemented with the "vcubic_spline_function" and "bicubic_spline" functions in AD Modelbuilder. The cubic spline models time-invariant selectivity, whereas the bicubic spline model selectivity varying across time and age; each function was developed from code provided in Press et al. (1992).

Briefly, the bicubic spline function requires the user to specify a number of age and year nodes that form a grid in the year-age matrix of time-varying selectivity (with equal grid spacing), and values at these nodes are the log-scale fishery selectivity and estimated as parameters. Fishery selectivity at ages and years between the nodes are interpolated with a bicubic spline. The smoothness of the surface is controlled by the number of nodes, and also by a series of penalties estimated within the model. The bicubic spline function was original developed by Dr. Steve Martell for the Integrated Statistical Catch at Age (iSCAM) model, which included penalties for: 1) smoothness across the ages (modeled with the sum of second differences); 2) the slope of the rate of decline when selectivity decreases with age (modeled with the sum of first differences); and 3) the smoothness across years (modeled with the sum of second differences). In addition to these penalties, an additional penalty on the interannual variability across years (modeled with the first difference) was used in this assessment to address situations in which the selectivity across years was relatively smooth but also non-constant (as would occur with a trend).

Sample sizes for age and length composition data

In previous assessments, the sample sizes were set to the number of hauls, and multiplied by 2/3 for the fishery data and 4/3 for the survey data based upon the notion that the fishery data are less reliable. This procedure has resulted in the SDNR for the age and length compositions differing substantially from 1, indicating a mismatch between the precision of the model fit and the assumed input variance. Additionally, the reliability of the fishery composition data is largely reflected in the reduced number of sample for some years, thus application of reduced weight to these data may be redundant.

In this assessment, the sample sizes for the composition data are obtained from an iteratively reweighted procedure using the SDNR (method TA1.2 in Francis 2011). An initial model run in which the sample sizes are specified as in the 2012 assessment is conducted, and a weight that is the inverse of the variance of the normalized residuals for each composition dataset is obtained. The sample sizes for the next model run are the original sample sizes multiplied by the estimated weights, which then produced a new set of weights, and process is iterated until the weights converge.

Parameters Estimated Outside the Assessment Model

The parameters estimated independently include the age error matrix, the age-length conversion matrix, individual weight at age, and proportion mature females at age. The derivation of the age error matrix, the age-length transition matrix, and the weight at age vector are described above.

Parameters Estimated Inside the Assessment Model

Parameter estimation is facilitated by comparing the model output to several observed quantities, such as the age and length composition of the survey and fishery catch, the survey biomass, and the catch biomass. The general approach is to assume that deviations between model estimates and observed quantities are attributable to observation error and can be described with statistical distributions. Each data component provides a contribution to a total log-likelihood function, and parameter values that minimize the negative log-likelihood are selected.

The negative log-likelihood of the initial recruitments were modeled with a lognormal distribution

$$\lambda_1 \left[\sum_{t=1}^{n} \frac{\left(\nu_t + {\sigma_r}^2/2\right)^2}{2{\sigma_r}^2} + n \ln(\sigma_r) \right]$$

where n is the number of year where recruitment is estimated. The adjustment of adding $\sigma_r^2/2$ to the deviation was made in order to produce deviations from the mean recruitment, rather than the median. If σ_r is fixed, the term n ln (σ_r) adds a constant value to the negative log-likelihood. The negative log-likelihood of the recruitment of cohorts represented in the first year (excluding age 3, which is included in the recruitment negative log-likelihood) of the model treated in a similar manner:

$$\lambda_1 \left[\sum_{a=4}^{A} \frac{\left(\gamma_a + {\sigma_r}^2/2\right)^2}{2{\sigma_r}^2} + (A-3) \ln(\sigma_r) \right]$$

The negative log-likelihoods of the fishery and survey age and length compositions were modeled with a multinomial distribution. The negative log likelihood of the multinomial function (excluding constant terms) for the fishery length composition data, with the addition of a term that scales the likelihood, is

$$-n_{f,t,l} \sum_{s,t,l} (p_{f,t,l} \ln(\hat{p}_{f,t,l}) + p_{f,t,l} \ln(p_{f,t,l}))$$

where n is the reweighted sample size, and $p_{f,t,l,}$ and $\hat{p}_{f,t,l}$ are the observed and estimated proportion at length in the fishery by year and length. The negative log likelihood for the age and length proportions in the survey, $p_{surv,t,a}$ and $p_{surv,t,l}$, respectively, follow similar equations.

The negative log-likelihood of the survey biomass was modeled with a lognormal distribution:

$$\lambda_2 \sum_t (\ln(obs_biom_t) - \ln(pred_biom_t))^2 / 2{cv_t}^2$$

where obs_biom_t is the observed survey biomass at time t, cv_t is the coefficient of variation of the survey biomass in year t, and λ_2 is a weighting factor. The negative log-likelihood of the catch biomass was modeled with a lognormal distribution:

$$\lambda_3 \sum_t (\ln(obs_cat_t) - \ln(pred_cat_t))^2$$

where obs_cat_t and $pred_cat_t$ are the observed and predicted catch. Because the catch biomass is generally thought to be observed with higher precision that other variables, λ_3 is given a very high weight

so as to fit the catch biomass nearly exactly. This can be accomplished by varying the *F* levels, and a large λ is used to constrain the predicted catches to closely match the input catches.

A maturity ogive was fit in the assessment model to samples collected in 2010 (*n*=322; TenBrink and Spencer 2013) and in 2004 by fishery observers (*n*=256). Parameters of the logistic equation were estimated by maximizing the bionomial likelihood within the assessment model. The number of fish sampled and number of mature fish by age for each collection were the input data, thus weighting the two collection by sample size. Due to the low number of young fish, high weights were applied to age 3 and 4 fish in order to preclude the logistic equation from predicting a high proportion of mature fish at age 0. The estimated age at 50% maturity is 8.2 years.

The overall negative log-likelihood function (excluding the catch component, and the maturity likelihood) is

$$\lambda_1\left[\sum_{t=1}^{n}\frac{\left(\nu_t+{\sigma_r}^2/2\right)^2}{2{\sigma_r}^2}+n\ln(\sigma_r)\right]+$$

$$\lambda_1\left[\sum_{a=4}^{A}\frac{\left(\gamma_a+{\sigma_r}^2/2\right)^2}{2{\sigma_r}^2}+(A-3)\ln(\sigma_r)\right]+$$

$$\lambda_2\sum_t\left(\ln(obs_biom_t)-\ln(pred_biom_t)\right)^2/2cv_t^2+$$

$$-n_{f,t,l}\sum_{s,t,l}(p_{f,t,l}\ln(\hat{p}_{f,t,l})+p_{f,t,l}\ln(p_{f,t,l}))+$$

$$-n_{f,t,a}\sum_{s,t,l}(p_{f,t,a}\ln(\hat{p}_{f,t,a})+p_{f,t,a}\ln(p_{f,t,a}))+$$

$$-n_{surv,t,a}\sum_{s,t,a}(p_{surv,t,a}\ln(\hat{p}_{surv,t,a})+p_{surv,t,a}\ln(p_{surv,t,a}))+$$

$$-n_{surv,t,l}\sum_{s,t,a}(p_{surv,t,l}\ln(\hat{p}_{surv,t,l})+p_{surv,t,l}\ln(p_{surv,t,l}))+$$

$$\lambda_3\sum_t\left(\ln(obs_cat_t)-\ln(pred_cat_t)\right)^2$$

For the model run in this analysis, λ_1, λ_2, and λ_3 were assigned weights of 1,1, and 200, reflecting the strong emphasis on fitting the catch data.

The negative log-likelihood function was minimized by varying the following parameters (for an age-plus group of 40 years, and with the time-invariant logistic fishery selectivity) :

Parameter type	Number
1) fishing mortality mean	1
2) fishing mortality deviations	38
3) recruitment mean	1
4) recruitment deviations	35
5) Initial recruitment	1
6) first year recruitment deviations	37
7) biomass survey catchability	1
8) natural mortality rate	1
9) survey selectivity parameters	2
10) fishery selectivity parameters	2
11) maturity parameters	2
Total number of parameters	121

Results

Model Evaluation

Several attributes of the model fits are shown in Table 11, including AIC and BIC values. Models 0 and 0.1 are presented for to demonstrate intermediate steps between the 2012 model and the recommended 2014 model (i.e., a "bridging" analysis). Model 0 has the updated data through 2014, Model 0.1 excludes the cooperative survey biomass estimates and age/size composition data, and each uses the age and length composition sample weights as produced for the 2012 assessment. The sample sizes for the composition are identical in Models 1-4, and were produced by applying iterative reweighting to Model 1 (time-invariant logistic selectivity). Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) were used to evaluate model selection. Each of these metrics penalize the negative log-likelihood by a multiple of the number of parameters; in AIC, this multiple is 2 whereas in BIC is the natural log of the number of data points.

For all the models, the number of parameters is "nominal" number of parameters, which overestimates the number of independent parameters because of the use of penalties and prior distributions in the models. Deviance Information Criterion (DIC) could be used, but will often select the models with higher number of parameters (Martell and Stewart 2014). For these reasons, model selection considered additional information such as the root mean squared errors and negative log-likelihoods in the fits to the data, and the residual patterns in fitting the composition data.

Model 1 (time-invariant logistic selectivity) had the lowest AIC and BIC, with the negative log-likelihood being very similar to Model 2 (time-invariant double logistic selectivity). Although the double logistic curve has the flexibility to fit dome-shaped patterns, in this case the double logistic selectivity curve was an asymptotic curve similar to that estimated in Model 1. The RMSEs and negative log-likelihoods for the components of the composition data were generally similar for all four models, with the exception of some degradation on the fit to the fishery age composition data with the time-invariant cubic spline (Model 4). Both the non-parameteric cubic spline and bicubic spline model estimated selectivity that was largely asymptotic, and the temporal variation in selectivity obtained with the bicubic spline was relatively small. Information on the composition of the fishery catches is sparse prior to the mid-1990s, and as indicated above, the recent fishery and survey data do not suggest a strong dome-shaped selectivity pattern.

The estimated spawning biomass for the models is shown in Figure 8, with the bridging Models 0 and 0.1 shown in blue. Removing the cooperative survey data increases the scale of the spawning stock for all models prior to 2010, as the cooperative survey biomass estimates were lower than those initiated by AFSC beginning in 2000.

Relative to the bridging models, Model 3 estimates higher biomass in the early 1980s (resulting from the dome-shaped selectivity in the 1960s and 1970s), and relative similar levels of biomass in the recent years (resulting from the shift from dome-shaped to near asymptotic selectivity). Each of models 1-4 estimate similar time series of spawning stock biomass, with the spawning stock biomass estimate for 2014 in model 1 being very close to that from bridging model 0.

Model 1 was selected as the preferred model, and the results below were obtained from this model.

Time series results

In this assessment, spawning biomass is defined as the biomass estimate of mature females age 3 and older. Total biomass is defined as the biomass estimate of northern rockfish age 3 and older. Recruitment is defined as the number of age northern rockfish.

A retrospective analysis was conducted to evaluate the effect of recent data on estimated spawning stock biomass. For the current assessment model, a series of model runs were conducted in which the end year of the model was varied from 2014 to 2004, and this was accomplished by sequentially dropping age and length composition data, survey biomass estimates, and catch from the input data files.

The plot of retrospective estimates of spawning biomass is shown in Figure 9. The largest changes in estimated survey biomass occurred in the runs with end years of years 2012 and 2014, when high survey biomass estimate are added to the model. The model is limited in its capacity to increase recruitment to match the high survey estimates because the survey catchability is essentially fixed at 1. Mohn's rho can be used to evaluate the severity of any retrospective pattern, and compares an estimated quantity (in this case, spawning stock biomass) in the terminal year of each retrospective model run with the estimated quantity in the same year of the model using the full data set . The absence of any retrospective pattern would result in a Mohn's rho of 0, and would result from either identical estimates in the model runs, or from positive deviations from the reference model being offset by negative deviations. The Mohn's rho for these retrospective runs was -1.50.

Biomass trends

The estimated survey biomass shows an increasing trend, starting at 113,792 t in 1977 and increasing to a peak of 233,818 t in 2004 (Figure 10). The estimated total biomass shows a similar trend, increasing to peak values of 250,000 t from 2001-2003, whereas the estimated spawner biomass increases from 48,463 in 1977 to its highest value of 108,216 in 2007 (Table 11, Figure 11).

Age/size compositions

The model fits to the fishery age and size compositions are shown in Figures 12-13, and the model fit to the survey age and length composition are shown in Figures 14-15. The model fit the fishery and survey age composition data reasonably well (notwithstanding years with low sample sizes). The plus group in the fishery length composition data (38 cm+) is consistently underestimated by the model, whereas the fishery age plus group (40+ years) is overestimated, reflecting a trade-off in the model.

Fishing and survey selectivity

The estimated survey selectivity curve had an age of 50% selection of 5.5, whereas this parameter was 9.6 for the fishery selectivity curve (Figure 16). These values are decreases from the estimates of 5.8 and 10.6, respectively, in the 2012 assessment.

Fishing mortality

The estimates of instantaneous fishing mortality rate are shown in Figure 17. A relatively high rate in 1977 is required to account for the relatively high catch in this year, followed by very low levels of fishing mortality during the 1980s when catch was small. Fishing mortality rates began to increase during the early 1990s, and the 2013 estimate is 0.011. A plot of fishing mortality rates and spawning stock biomass in reference to the ABC and OFL harvest control rules indicates that the stock is currently below $F_{35\%}$ and above $B_{40\%}$ (Figure 18).

Recruitment

Recruitment strengths by year class are shown in Figure 19. Relatively strong year classes are observed in 1978, 1981, 1984-1985, 1989, and 1993-1998, reflecting several of the strong year classes observed in the age composition input data (Figures 12 and 14). The scatterplot of recruitment against spawning stock biomass is shown in Figure 20, indicating substantial variability in the pattern between recruitment and spawning stock size.

Harvest recommendations

Amendment 56 reference points

The reference fishing mortality rate for northern rockfish is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{0.40}$, $F_{0.35}$, and $SPR_{0.40}$ were obtained from a spawner-per-recruit analysis. Assuming that the average recruitment from the 1977-2011 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{0.40}$ is calculated as the product of $SPR_{0.40}$ * equilibrium recruits, and this quantity is 57,768 t. The year 2015 spawning stock biomass is estimated as 94,873 t.

Specification of OFL and maximum permissible ABC

Since reliable estimates of the 2015 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B>B_{0.40}$ (94,873 t > 57,768 t), northern rockfish reference fishing mortality is defined in tier 3a. For this tier, F_{ABC} is defined as $F_{0.40}$ and F_{OFL} is defined as $F_{0.35}$. The values of $F_{0.40}$ and $F_{0.35}$ are 0.070 and 0.087, respectively.

The ABC associated with the $F_{0.40}$ level of 0.070 is 12,488 t.

The estimated catch level for year 2015 associated with the overfishing level of F = 0.087 is 15,337 t. A summary of these values is below.

2015 SSB estimate (B)	**=**	**94,873 t**
$B_{0.40}$	=	57,768 t
$F_{ABC} = F_{0.40}$	=	0.070
$F_{OFL} = F_{0.35}$	=	0.087
MaxPermABC	=	12,488 t
OFL	=	15,337 t

ABC recommendation

We recommend the maximum permissible ABC 12,488 t.

Projections

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2014 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2015 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2014. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2015, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2013 recommended in the assessment to the *max* F_{ABC} for 2015. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 2009-2013 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above 1) above its MSY level in 2014 or 2) above ½ of its MSY level in 2014 and above its MSY level in 2015 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, F is set equal to *max* F_{ABC}, and in all subsequent years F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2027 under this scenario, then the stock is not approaching an overfished condition.)

The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, and projections of the mean harvest and spawning stock biomass for the remaining six scenarios are shown in Table 12.

Status Determination

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2015, it does not provide the best estimate of OFL for 2016, because the mean 2015 catch under Scenario 6 is predicated on the 2015 catch being equal to the 2015 OFL, whereas the actual 2015 catch will likely be less than the 2015 OFL. The executive summary contains the appropriate one- and two-year ahead projections for both ABC and OFL.

Under the MSFCMA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing. This report involves the answers to three questions: 1) Is the stock being subjected to overfishing? 2) Is the stock currently overfished? 3) Is the stock approaching an overfished condition?

Is the stock being subjected to overfishing? The official BSAI catch estimate for the most recent complete year (2013) is 2,038 t. This is less than the 2013 BSAI OFL of 12,200 t. Therefore, the stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest Scenarios #6 and #7 are used in these determinations as follows:

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2014:

a. If spawning biomass for 2014 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b. If spawning biomass for 2014 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c. If spawning biomass for 2014 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 12). If the mean spawning biomass for 2024 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario #7:

a. If the mean spawning biomass for 2017 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.
b. If the mean spawning biomass for 2017 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2017 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2027. If the mean spawning biomass for 2027 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

The results of these two scenarios indicate that the BSAI northern rockfish stock is neither overfished nor approaching an overfished condition. With regard whether the stock is currently overfished, the estimated 2014 stock size is 1.9 its $B_{35\%}$ value of 50,547 t. With regard to whether BSAI northern rockfish is likely to be overfished in the future, the expected stock size in 2015 of Scenario 7 is 1.9 times the $B_{35\%}$ value.

Ecosystem Considerations

Ecosystem Effects on the stock

1) Prey availability/abundance trends

Northern rockfish feed primarily upon zooplankton, including calanoid copepods, euphausids, and chaetonaths. From a sample of 118 Aleutian Island specimens collected in 1994, calanoid copepods, euphausids, and chaetognaths contributed 84% of the total diet by weight. Small northern rockfish (<30 cm FL) consumed a higher proportion of calanoid copepods than larger northern rockfish, whereas euphausids were consumed primarily by fish larger than 25 cm. Myctophids and cephalopods were consumed mainly by the largest size group, contributing 11% and 16%, respectively, of the diet for fish > 35 cm. The availability and abundance trends of these prey species are unknown.

2) Predator population trends

Northern rockfish are not commonly observed in field samples of stomach contents. Pacific ocean perch, a rockfish with similar life-history characteristics as northern rockfish, has been found in the stomachs of Pacific halibut and sablefish (Major and Shippen 1970), and it is likely that these also prey upon northern rockfish as well. The population trends of these predators can be found in separate chapters within this SAFE document.

3) Changes in habitat quality

Little information exists on the habitat use of northern rockfish. Carlson and Straty (1981) and Kreiger (1993) used submersibles to observe that other species of rockfish appear to use rugged, shallower habitats during their juvenile stage and move deeper with age. Although these studies did not specifically observe northern rockfish, it is reasonable to suspect a similar ontogenetic shift in habitat. Length frequencies of the Aleutian Islands survey data indicate that small northern rockfish (< 25 cm) are generally found at depths less than 100 m. The mean depths of northern rockfish from recent AI trawl surveys have ranged between 100 and 150 m. There has been little information identifying how rockfish habitat quality has changed over time.

Fishery Effects on the ecosystem

A northern rockfish target fishery does not currently exist in the BSAI management area. As previously discussed, most northern rockfish catch in the BSAI management area occurs in the Atka mackerel fishery. The ecosystem effects of the Atka mackerel fishery can be found in the Atka mackerel assessment in this SAFE document.

Harvesting of northern rockfish is not likely to diminish the amount of northern rockfish available as prey due to the low fishery selectivity for fish less than 20 cm. Although the recent fishing mortality rates have been relatively light, averaging 0.03 over the last five years, it is not know what the effect of harvesting is on the size structure of the population or the maturity at age.

Data Gaps and Research Priorities

Little information is known regarding most aspects of the biology of northern rockfish, particularly in the Aleutian Islands. Recent genetic data suggests that the spatial movement of northern rockfish, per generation, may be much smaller that the currently-used BSAI management area. The evaluation of spatial management units can be conducted with a template developed by the Plan Team-SSC working group on stock structure. More generally, little is known regarding the reproductive biology and the distribution, duration, and habitat requirements of various life-history stages. Given the relatively unusual reproductive biology of rockfish and its importance in establishing management reference points, data on reproductive capacity should be collected on a periodic basis.

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Table 1. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of the species groups used to manage northern rockfish from 1977 to 2000 in the Aleutian Islands and the eastern Bering Sea. The "other red rockfish" group includes, shortraker rockfish, rougheye rockfish, northern rockfish, and sharpchin rockfish. The "POP complex" includes the other red rockfish species plus POP.

	Aleutian Islands					Eastern Bering Sea				
Year	Management Group	OFL (t)	ABC (t)	TAC (t)	Catch (t)	Management Group	OFL (t)	ABC (t)	TAC (t)	Catch (t)
1977	Other species				3264	Other species				5
1978	Other species				3655	Other species				32
1979	POP complex				601	POP complex				46
1980	POP complex				549	POP complex				89
1981	POP complex				111	POP complex				35
1982	POP complex				177	POP complex				71
1983	POP complex				47	POP complex				42
1984	POP complex				196	POP complex				32
1985	POP complex				189	POP complex				6
1986	Other rockfish	n/a	UN	5800	208	Other rockfish	n/a	UN	825	61
1987	Other rockfish	n/a	UN	1430	308	Other rockfish	n/a	UN	450	77
1988	Other rockfish	n/a	1100	1100	493	Other rockfish	n/a	400	400	40
1989	POP complex	n/a	16600	6000	306	POP complex	n/a	6000	5000	78
1990	POP complex	n/a	16600	6000	1235	POP complex	n/a	6300	6300	247
1991	Other red rockfish	0	4685	4685	233	Other red rockfish	0	1670	1670	626
1992	Sharpchin/northern	5670	5670	5670	1548	Other red rockfish	1400	1400	1400	309
1993	Sharpchin/northern	5670	5670	5100	4530	Other red rockfish	1400	1400	1200	859
1994	Sharpchin/northern	5670	5670	5670	4666	Other red rockfish	1400	1400	1400	61
1995	Sharpchin/northern	5670	5670	5103	3858	Other red rockfish	1400	1400	1260	266
1996	Sharpchin/northern	5810	5810	5229	6637	Other red rockfish	1400	1400	1260	87
1997	Sharpchin/northern	5810	4360	4360	1996	Other red rockfish	1400	1050	1050	164
1998	Sharpchin/northern	5640	4230	4230	3746	Other red rockfish	356	267	267	45
1999	Sharpchin/northern	5640	4230	4230	5492	Other red rockfish	356	267	267	157
2000	Sharpchin/northern	6870	5150	5150	5066	Other red rockfish	259	194	194	97

Table 2. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of the species groups used to manage northern rockfish from 2001 to present to 2000 in the eastern Bering Sea and Aleutian Islands.

		Bering Sea and Aleutian Islands			
Year	Management Group	OFL (t)	ABC (t)	TAC (t)	Catch (t)
2001	Sharpchin/northern	9020	6764	6764	6488
2002	Northern rockfish	9020	6760	6760	4057
2003	Northern rockfish	9468	7101	6000	4929
2004	Northern rockfish	8140	6880	5000	4684
2005	Northern rockfish	9810	8260	5000	3964
2006	Northern rockfish	10100	8530	4500	3828
2007	Northern rockfish	9750	8190	9190	4016
2008	Northern rockfish	9740	8180	8180	3287
2009	Northern rockfish	8540	7160	7160	3111
2010	Northern rockfish	8640	7240	7240	4332
2011	Northern rockfish	10600	8670	4000	2764
2012	Northern rockfish	10500	8610	4700	2479
2013	Northern rockfish	12200	9850	3000	2038
2014*	Northern rockfish	12077	9761	2594	2282

*Catch data through October 11, 2014, from NMFS Alaska Regional Office.

Table 3. Catch of northern rockfish (t) in the BSAI area.

	Eastern Bering Sea			Aleutian Islands			
Year	Foreign	Joint Venture	Domestic	Foreign	Joint Venture	Domestic	Total
1977	5	0		3,264	0		3,270
1978	32	0		3,655	0		3,687
1979	46	0		601	0		647
1980	84	5		549	0		638
1981	35	0		111	0		145
1982	63	8		177	0		248
1983	10	32		47	0		89
1984	26	6		11	185		229
1985	5	1		0	189		195
1986	5	41	15	0	193	15	270
1987	1	45	31	0	248	60	385
1988	0	4	36	0	438	55	534
1989	0	12	66	0	0	306	384
1990			247			1,235	1,481
1991			626			233	859
1992			309			1,548	1,857
1993			859			4,530	5,389
1994			61			4,666	4,727
1995			266			3,858	4,124
1996			87			6,637	6,724
1997			164			1,996	2,161
1998			45			3,746	3,791
1999			157			5,492	5,650
2000			97			5,066	5,162
2001			180			6,309	6,488
2002			114			3,943	4,057
2003			67			4,862	4,929
2004			116			4,567	4,684
2005			112			3,852	3,964
2006			246			3,582	3,828
2007			70			3,946	4,016
2008			22			3,265	3,287
2009			48			3,064	3,111
2010			299			4,033	4,332
2011			198			2,566	2,764
2012			91			2,388	2,479
2013			137			1,900	2,038
2014*			125			2,156	2,282

*Catch data through October 11, 2014, from NMFS Alaska Regional Office.

Table 4. Area-specific catches of northern rockfish (t) in the BSAI area, obtained from the North Pacific Groundfish Observer Program, NMFS Alaska Regional Office.

Year	WAI	CAI	EAI	EBS	Total
1994	1,572	2,534	560	61	4,727
1995	1,421	1,641	796	266	4,124
1996	3,146	1,978	1,514	87	6,724
1997	1,287	490	219	164	2,161
1998	2,392	916	438	45	3,791
1999	3,185	1,104	1,203	157	5,650
2000	1,516	2,347	1,202	97	5,162
2001	3,725	1,840	743	180	6,488
2002	2,328	1,318	298	114	4,057
2003	2,506	1,994	361	67	4,929
2004	1,947	2,410	211	116	4,684
2005	1,885	1,697	271	112	3,964
2006	1,139	2,138	306	246	3,828
2007	1,013	1,782	1,151	70	4,016
2008	1,314	1,344	608	22	3,287
2009	1,191	1,315	558	48	3,111
2010	1,988	1,266	778	299	4,332
2011	311	1,351	905	198	2,764
2012	140	1,651	597	91	2,479
2013	115	1,308	478	137	2,038
2014*	83	1,110	963	125	2,282

* Estimated removals through October 11, 2014.

Table 5. Estimated retained, discarded, and percent discarded sharpchin/northern (SC/NO), and northern rockfish catch in the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions. The catches of the SC/NO group consist nearly entirely of northern rockfish.

	Aleutian Islands					Eastern Bering Sea				
Year	Species Group	Retained	Discarded	Total	Percent Discarded	Species Group	Retained	Discarded	Total	Percent Discarded
1993	SC/NO	317	4218	4535	93.00%	Other red rockfish	367	97	464	20.92%
1994	SC/NO	797	3870	4667	82.92%	Other red rockfish	29	100	129	77.59%
1995	SC/NO	1208	2665	3873	68.82%	Other red rockfish	274	70	344	20.42%
1996	SC/NO	2269	4384	6653	65.89%	Other red rockfish	58	149	207	71.92%
1997	SC/NO	145	1852	1997	92.74%	Other red rockfish	44	174	218	80.02%
1998	SC/NO	458	3288	3747	87.76%	Other red rockfish	38	59	97	61.06%
1999	SC/NO	735	4759	5493	86.63%	Other red rockfish	75	163	238	68.33%
2000	SC/NO	592	4492	5084	88.37%	Other red rockfish	111	140	155	90.22%
2001	SC/NO	403	5906	6309	93.62%	SC/NO	15	164	180	91.11%
2002	Northerns	347	3595	3943	91.19%	Northerns	9	105	113	92.42%
2003	Northerns	188	4397	4585	95.89%	Northerns	14	59	73	80.36%
2004	Northerns	686	3881	4567	84.97%	Northerns	35	82	116	70.23%
2005	Northerns	912	2940	3852	76.32%	Northerns	45	67	112	59.56%
2006	Northerns	965	2617	3582	73.06%	Northerns	109	137	246	55.56%
2007	Northerns	850	3096	3946	78.45%	Northerns	23	46	69	66.40%
2008	Northerns	1523	1742	3265	53.34%	Northerns	8	14	22	64.28%
2009	Northerns	1941	1122	3064	36.63%	Northerns	40	8	48	15.92%
2010	Northerns	3070	963	4033	23.88%	Northerns	284	15	299	4.91%
2011	Northerns	2442	124	2566	4.85%	Northerns	166	32	198	16.06%
2012	Northerns	2009	379	2388	15.87%	Northerns	45	46	91	50.38%
2013	Northerns	1720	181	1900	9.51%	Northerns	97	40	137	29.26%
2014*	Northerns	2078	78	2156	3.61%	Northerns	68	57	125	45.73%

* Estimated removals through October 11, 2014.

Table 6. Samples sizes of otoliths and lengths from fishery sampling, with the number of hauls from which these data were collected, from 1977-2013.

Year	Lengths	Hauls	Otoliths collected	Otoliths read	Hauls (read otoliths)
1977	1202	16	230	224**	11
1978	759	11	148	148**	16
1979					
1980					
1981					
1982	334**	5			
1982					
1984	703**	4			
1985	12**	9	12	0	0
1986	100**	2	100	0	0
1987	976**	9	79	0	0
1988					
1989	80**	1	80	0	0
1990	403**	11			
1991	145**	8			
1992					
1993	1809**	16			
1994	767**	8			
1995	833**	14			
1996	4554	68			
1997	1**	1			
1998	543	14	30	29**	5
1999	917	42	50	0	0
2000	995*	69	170	169*	49
2001	661*	70	136	135*	58
2002	889*	68	200	195*	60
2003	1362*	124	318	317*	110
2004	842*	78	198	196*	69
2005	466*	47	120	118*	44
2006	895*	73	231	230*	71
2007	843*	98	230	228*	90
2008	897*	127	271	270	125
2009	834*	108	247	247	103
2010	1281	148	346		
2011	1596*	210	469	462	200
2012	1785	219	507		
2013	2081	268	609		

*Used to create age composition

Table 7. Northern rockfish biomass estimates (t) from Aleutian Islands trawl survey, with coefficients of variation shown in parentheses.

	Aleutian Islands Management Sub-Areas			EBS estimates	
Year	Western	Central	Eastern	southern BS	Total
1980					37,593 (0.90)
1983					56,368 (0.15)
1986					140,405 (0.34)
1991	144,043 (0.21)	64,119 (0.18)	4,068 (0.52)	582 (0.63)	212,813 (0.15)
1994	65,843 (0.65)	15,832 (0.58)	5,933 (0.54)	855 (0.60)	88,463 (0.50)
1997	65,493 (0.38)	18,363 (0.55)	3,331 (0.58)	204 (0.68)	87,391 (0.31)
2000	143,348 (0.39)	37,949 (0.44)	24,982 (0.70)	49 (0.40)	205,369 (0.30)
2002	136,440 (0.33)	38,819 (0.43)	3,242 (0.42)	290 (0.67)	178,791 (0.27)
2004	146,179 (0.27)	26,913 (0.39)	10,375 (0.37)	5,980 (0.93)	189,446 (0.22)
2006	101,276 (0.29)	72,961 (0.52)	22,982 (0.45)	22,883 (1.00)	220,102 (0.25)
2010	143,953 (0.29)	51,331 (0.40)	21,847 (0.50)	189 (0.52)	217,319 (0.22)
2012	216,325 (0.65)	52,674 (0.40)	15,615 (0.60)	550 (0.73)	285,164 (0.50)
2014	346,392 (0.38)	48,049 (0.44)	76,787 (0.79)	1,668 (0.80)	472,895 (0.31)
1991-2014 mean	150,929	42,701	18,916	3,325	215,871
Percentage	69.92%	19.78%	8.76%	1.54%	

Table 8. Sample sizes of otoliths and length measurement from the AI trawl survey, 1991-2014, with the number of hauls from which these data were collected.

Year	Lengths	Hauls	Otoliths read	Hauls
1980	3351	31	473	4
1983	6535	71	625	11
1986	5881	41	565	18
1991	4853	47	456	14
1994	6252	118	409	19
1997	7554	153	652	68
2000	7779	135	725	92
2002	9459	153	259	69
2004	12176	201	515	65
2006	8404	160	535	57
2010	11796	198	538	72
2012	10523	188	576	67
2014	14760	208		

Table 9. Sample sizes of read otoliths by area and year in the Aleutian Islands surveys.

Year	Western AI	Central AI	Eastern AI	Southern Bering Sea	Total
1980	201	92	180		473
1983	268	225	93	39	625
1986	132	293	25	115	565
1991		243	159	54	456
1994	180	61	127	41	409
1997	234	219	199		652
2000	229	275	200	21	725
2002	88	74	66	31	259
2004	193	156	120	46	515
2006	197	148	113	77	535
2010	195	186	139	18	538
2012	206	156	160	54	576

Table 10. Predicted weight and proportion mature at age for BSAI northern rockfish.

Age	Predicted weight (g)	Proportion mature
3	68	0.026
4	107	0.050
5	149	0.096
6	192	0.176
7	235	0.301
8	274	0.464
9	311	0.636
10	344	0.779
11	374	0.876
12	401	0.934
13	424	0.966
14	444	0.983
15	461	0.991
16	476	0.996
17	488	0.998
18	499	0.999
19	508	0.999
20	516	1
21	523	1
22	529	1
23	533	1
24	537	1
25	541	1
26	544	1
27	546	1
28	548	1
29	550	1
30	551	1
31	552	1
32	553	1
33	554	1
34	555	1
35	556	1
36	556	1
37	557	1
38	557	1
39	557	1
40	558	1

Table 11. Negative log likelihood of model components, average effective and input sample sizes, root mean squared errors and standard deviation of normalized residuals for the two models considered in this assessment.

	Model 0	Model 0.1	Model 1	Model 2	Model 3	Model 4
Negative log-likelihood						
Data components						
AI survey biomass	19.65	10.67	11.10	11.01	10.71	10.80
Catch biomass	0.00	0.00	0.00	0.00	0.00	0.00
Fishery age comp	77.75	78.80	198.40	198.57	227.59	208.27
Fishery length comp	137.42	136.29	66.33	65.70	65.80	64.86
AI survey age comp	90.29	78.88	160.26	160.49	163.38	162.25
AI survey lengths comp	25.81	26.90	14.74	14.70	13.61	14.06
Maturity	7.21	7.21	7.21	7.21	7.21	7.21
Priors and penalties						
Recruitment	-1.01	-2.19	1.92	1.64	2.45	1.62
Prior on survey q	0.00	0.00	0.00	0.00	0.00	0.00
Prior on M	4.56	1.35	0.89	0.81	0.86	0.74
Fishery selectivity	0.00	0.00	0.00	0.00	4.97	4.57
Total negative log-likelihood	365.78	342.34	465.28	464.54	500.95	478.73
Parameters	121	121	121	123	124	134
Number of data points			1024	1024	1024	1024
BIC			1769.26	1781.65	1861.40	1886.27
AIC			1172.56	1175.08	1249.89	1225.45
Effective sample size						
Fishery age comp	144	139	174	172	144	156
Fishery length comp	28	29	28	29	29	28
AI survey age comp	118	140	140	138	130	132
AI survey lengths comp	95	94	87	87	92	90
Sample weights						
Fishery age comp	59	59	167	167	167	167
Fishery length comp	66	66	30	30	30	30
AI survey age comp	62	78	157	157	157	157
AI survey lengths comp	277	277	132	132	132	132
Root mean square error						
AI survey biomass	0.502	0.497	0.511	0.508	0.498	0.500
Recruitment	0.622	0.642	0.699	0.695	0.717	0.701
Fishery age comp	0.015	0.015	0.014	0.014	0.014	0.014
Fishery length comp	0.047	0.047	0.047	0.047	0.047	0.047
AI survey age comp	0.022	0.016	0.016	0.016	0.016	0.016
AI survey lengths comp	0.020	0.020	0.021	0.021	0.021	0.021
Standard Deviation of Normalized Residuals						
AI survey biomass	1.71	1.42	1.45	1.44	1.42	1.42
Fishery age comp	0.63	0.64	1.00	1.00	1.03	0.99
Fishery length comp	1.43	1.42	1.00	0.99	0.98	0.98
AI survey age comp	0.66	0.70	1.00	1.00	1.01	1.01
AI survey lengths comp	1.34	1.36	1.00	1.00	0.96	0.98

Table 12. Estimated time series of northern rockfish total biomass (t), spawner biomass (t), and recruitment (thousands) for each region.

	Total Biomass (ages 3+) Assessment Year		Spawner Biomass (ages 3+) Assessment Year		Recruitment (age 3) Assessment Year	
Year	2014	2012	2014	2012	2014	2012
1977	129,004	98,338	48,863	38,155	38,346	27,256
1978	132,501	100,084	50,241	38,719	40,140	29,365
1979	135,330	101,233	52,158	39,715	31,119	21,848
1980	140,643	105,438	55,188	41,822	21,970	21,633
1981	147,186	110,591	58,175	43,963	52,577	35,921
1982	153,777	115,927	61,199	46,255	35,902	25,535
1983	159,187	120,675	64,144	48,557	17,266	18,679
1984	166,657	126,763	67,084	50,967	64,087	40,048
1985	172,448	131,692	69,903	53,376	22,698	18,658
1986	177,175	135,963	72,693	55,820	13,649	13,492
1987	186,891	144,325	75,459	58,284	120,272	82,887
1988	196,793	152,477	78,201	60,726	75,467	53,943
1989	205,810	159,683	80,982	63,189	38,798	30,272
1990	215,055	166,993	83,927	65,751	42,171	30,108
1991	222,496	173,030	87,005	68,312	36,447	30,058
1992	231,578	181,018	90,863	71,432	66,356	54,837
1993	237,564	186,276	94,468	74,143	24,682	21,804
1994	239,305	187,562	96,990	75,786	32,104	24,906
1995	239,610	188,059	99,441	77,571	9,311	10,873
1996	241,577	190,575	101,191	79,002	58,545	45,744
1997	239,532	189,608	102,010	79,754	29,604	30,425
1998	244,822	195,847	103,748	81,672	87,768	71,525
1999	248,386	200,409	104,157	82,478	59,051	53,351
2000	250,266	203,176	103,645	82,536	51,504	44,272
2001	252,523	206,016	103,208	82,712	44,089	34,834
2002	251,638	206,040	103,045	83,109	13,480	14,081
2003	252,437	207,683	104,224	84,747	22,841	16,249
2004	250,573	207,188	105,497	86,415	10,222	10,971
2005	248,379	206,322	106,888	88,213	25,434	17,324
2006	245,614	205,118	107,974	89,812	16,830	13,227
2007	242,560	203,544	108,216	90,694	25,097	17,303
2008	239,459	201,281	107,541	90,761	35,429	18,584
2009	236,034	198,981	106,402	90,410	14,606	12,296
2010	231,995	197,816	104,654	89,445	10,986	
2011	226,224	195,771	102,437	87,925	12,338	
2012	223,088	195,712	100,753	86,792		
2013	220,860	195,446	99,230			
2014	219,801		97,785			
2015	218,901					

Table 13. Projections of BSAI northern rockfish catch (t), spawning biomass (t), and fishing mortality rate for each of the several scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 59,167 t and 51,771 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2014	2,468	2,468	2,468	2,468	2,468	2,468	2,468
2015	12,488	12,488	6,348	2,744	0	15,337	12,488
2016	11,640	11,640	6,116	2,694	0	14,074	11,640
2017	10,879	10,879	5,901	2,647	0	12,956	13,362
2018	10,235	10,235	5,723	2,612	0	12,017	12,379
2019	9,722	9,722	5,589	2,593	0	11,268	11,590
2020	9,332	9,332	5,502	2,591	0	10,693	10,979
2021	9,035	9,035	5,448	2,601	0	10,248	10,501
2022	8,802	8,802	5,416	2,619	0	9,896	10,119
2023	8,611	8,611	5,397	2,640	0	9,581	9,796
2024	8,449	8,449	5,385	2,663	0	9,255	9,468
2025	8,299	8,299	5,376	2,686	0	8,954	9,150
2026	8,156	8,156	5,368	2,708	0	8,698	8,869
2027	8,023	8,023	5,363	2,729	0	8,486	8,634
Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2014	97,785	97,785	97,785	97,785	97,785	97,785	97,785
2015	94,873	94,873	95,662	96,116	96,457	94,500	94,873
2016	88,665	88,665	92,333	94,502	96,160	86,974	88,665
2017	83,372	83,372	89,536	93,277	96,186	80,601	83,050
2018	79,148	79,148	87,464	92,643	96,738	75,500	77,682
2019	75,885	75,885	86,058	92,556	97,777	71,528	73,466
2020	73,377	73,377	85,169	92,888	99,189	68,443	70,158
2021	71,379	71,379	84,597	93,455	100,796	65,970	67,485
2022	69,743	69,743	84,230	94,160	102,512	63,940	65,276
2023	68,360	68,360	83,981	94,923	104,259	62,232	63,404
2024	67,156	67,156	83,795	95,694	105,988	60,778	61,796
2025	66,099	66,099	83,646	96,448	107,673	59,556	60,428
2026	65,179	65,179	83,534	97,187	109,317	58,546	59,286
2027	64,390	64,390	83,454	97,910	110,916	57,720	58,345
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2014	0.013	0.013	0.013	0.013	0.013	0.013	0.013
2015	0.070	0.070	0.035	0.015	0.000	0.087	0.070
2016	0.070	0.070	0.035	0.015	0.000	0.087	0.070
2017	0.070	0.070	0.035	0.015	0.000	0.087	0.087
2018	0.070	0.070	0.035	0.015	0.000	0.087	0.087
2019	0.070	0.070	0.035	0.015	0.000	0.087	0.087
2020	0.070	0.070	0.035	0.015	0.000	0.087	0.087
2021	0.070	0.070	0.035	0.015	0.000	0.087	0.087
2022	0.070	0.070	0.035	0.015	0.000	0.087	0.087
2023	0.070	0.070	0.035	0.015	0.000	0.086	0.087
2024	0.070	0.070	0.035	0.015	0.000	0.086	0.086
2025	0.070	0.070	0.035	0.015	0.000	0.084	0.085
2026	0.070	0.070	0.035	0.015	0.000	0.083	0.084
2027	0.070	0.070	0.035	0.015	0.000	0.083	0.083

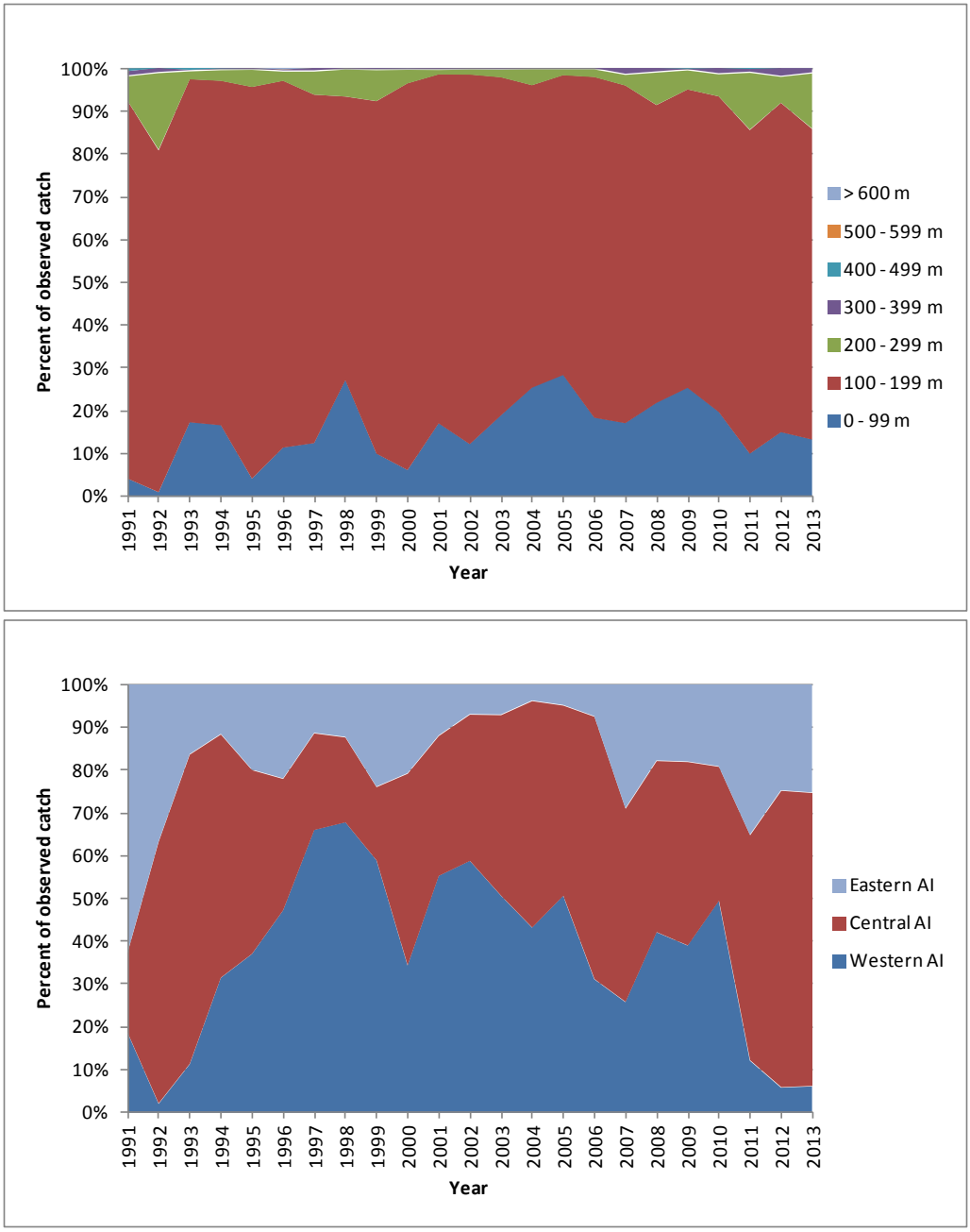

Figure 1. Distribution of observed Aleutian Islands northern rockfish catch (from North Pacific Groundfish Observer Program) by depth zone (top panel) and AI subarea (bottom panel) from 1991 to 2013.

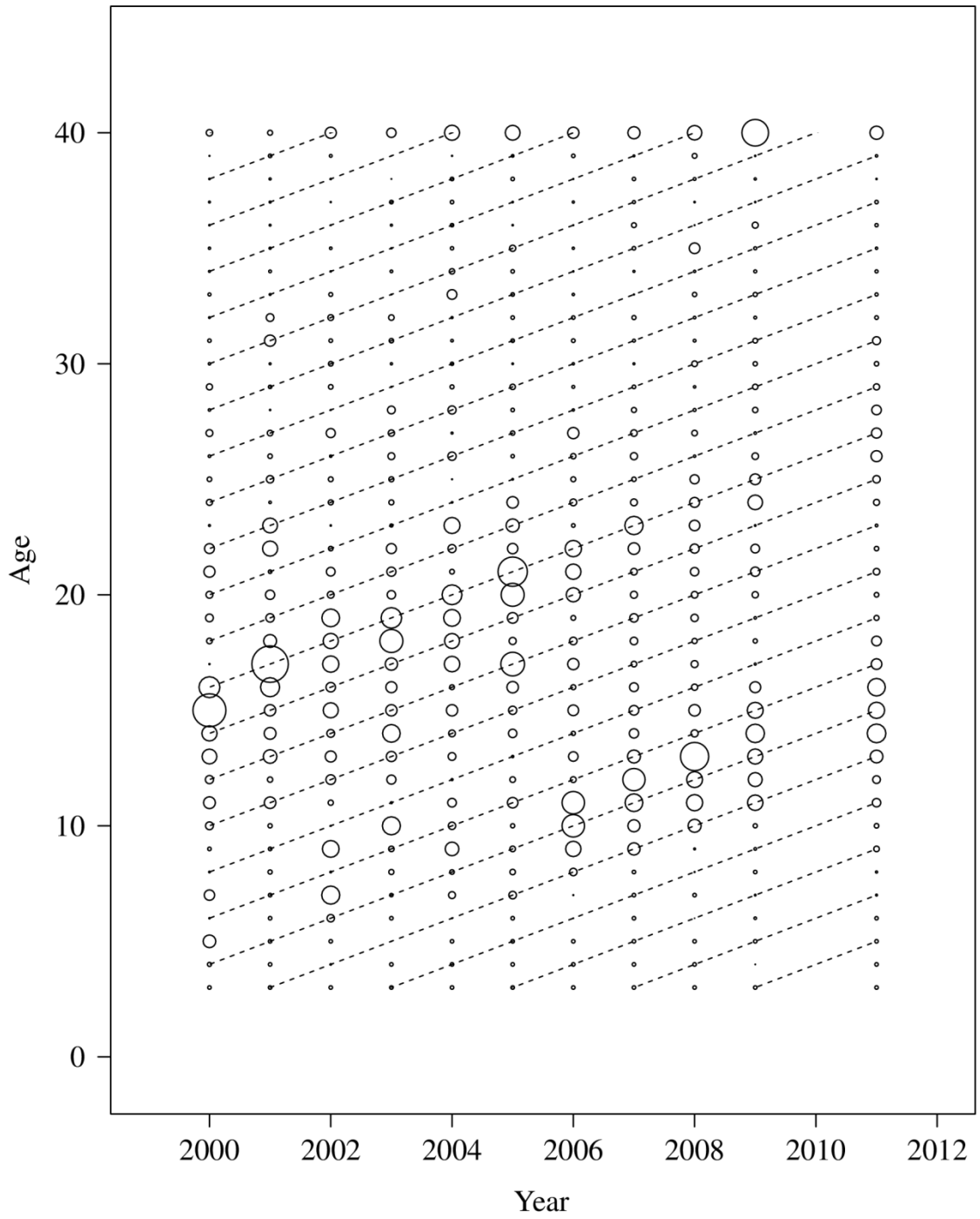

Figure 2. Fishery age composition data for the Aleutian Islands; bubbles are scaled within each year of samples; and dashed lines denote cohorts.

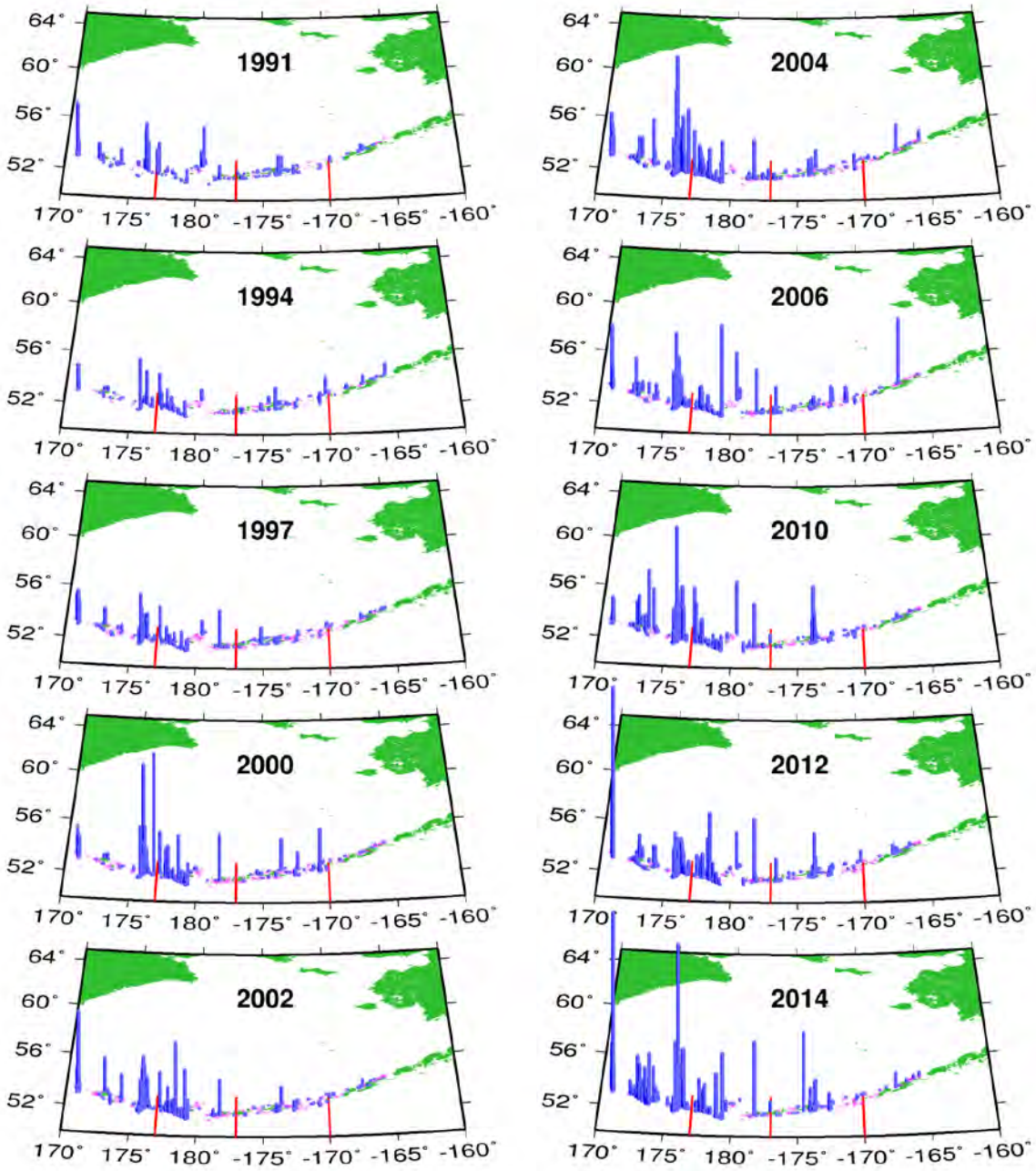

Figure 3. Scaled AI survey northern rockfish CPUE from (square root of kg/km^2) from 1991-2014; the red lines indicate boundaries between the WAI, CAI, EAI, and EBS areas.

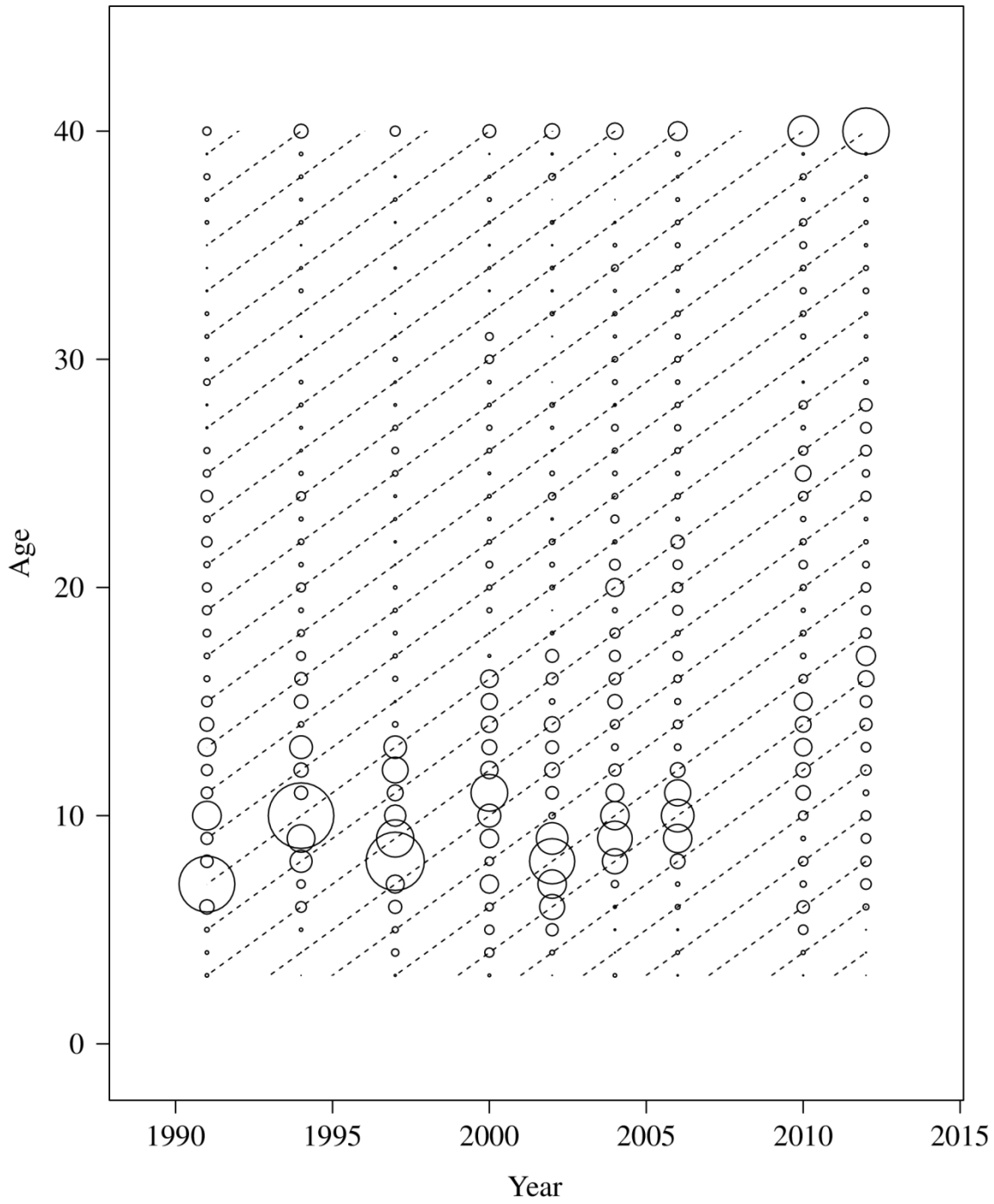

Figure 4. Age composition data from the Aleutian Islands trawl survey; bubbles are scaled within each year of samples; and dashed lines denote cohorts.

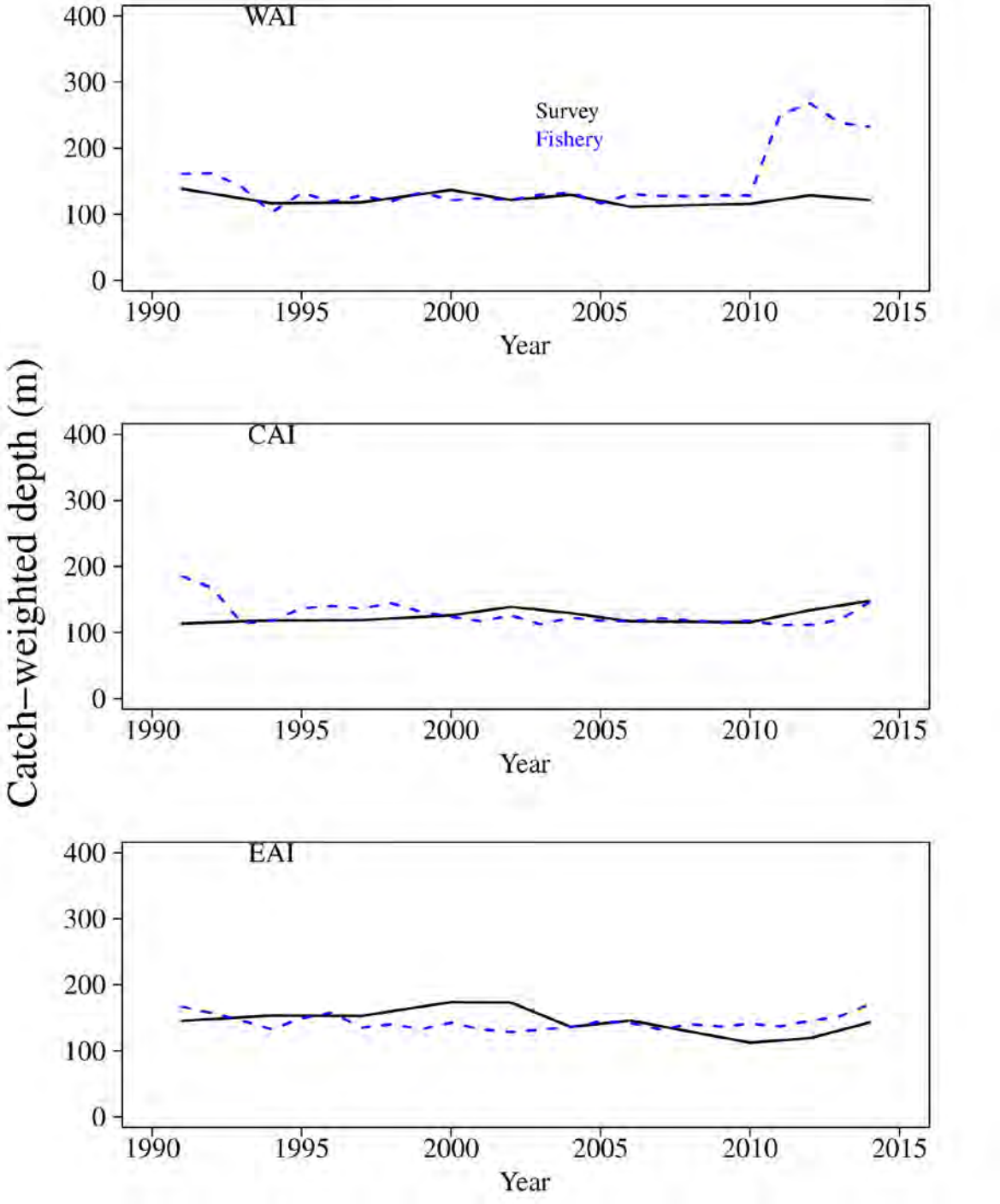

Figure 5. Catch-weighted (by numbers) depth of capture for northern rockfish in the fishery and AI survey by AI subarea from 1991 to 2014.

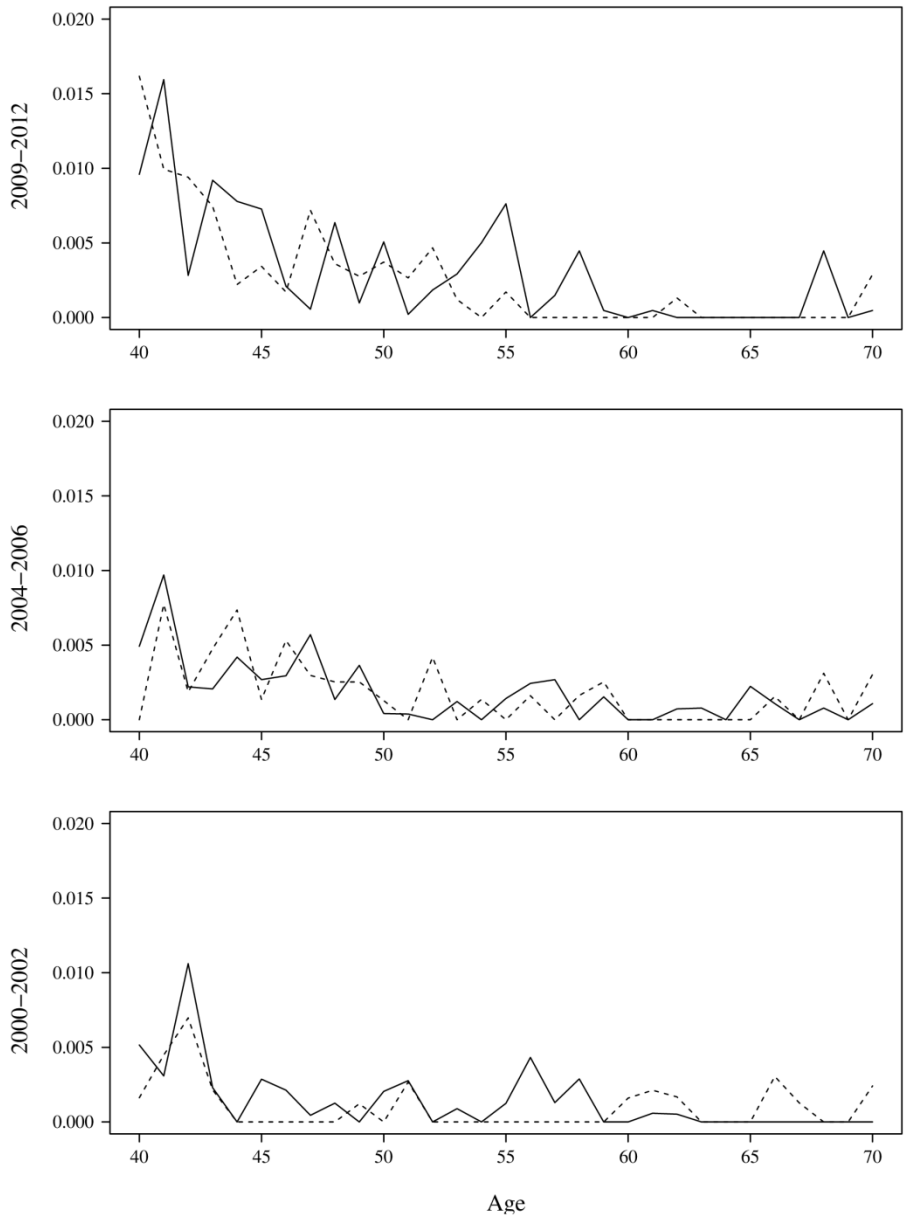

Figure 6. Age compositions in the Aleutian Islands survey (solid line) and fishery (dashed line) for ages 40 to 70+ for three time periods.

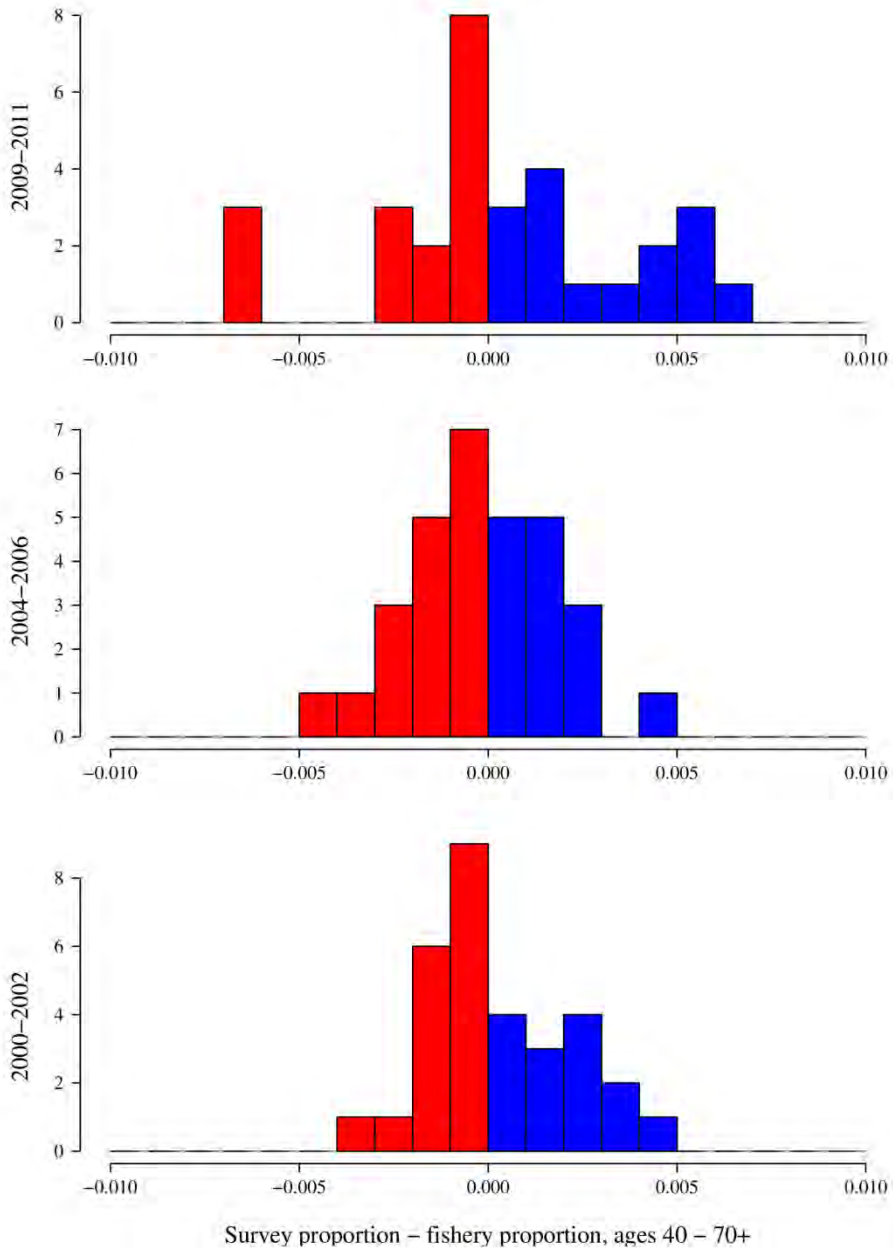

Figure 7. Histograms of the difference (survey proportion – fishery proportion) for ages 40 to 70+ for three time periods.

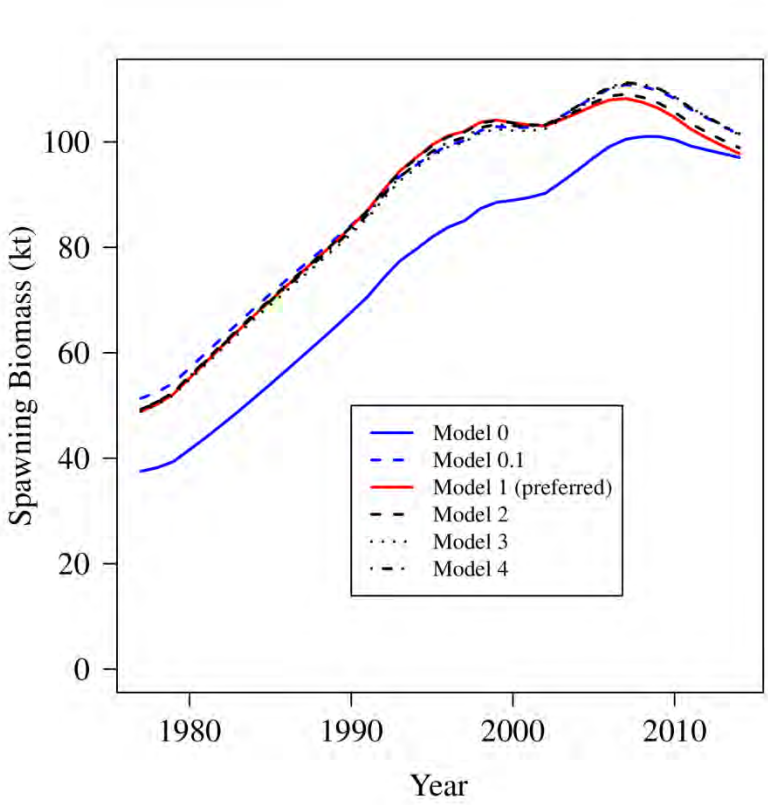

Figure 8. Estimated time series of spawning stock biomass across the models.

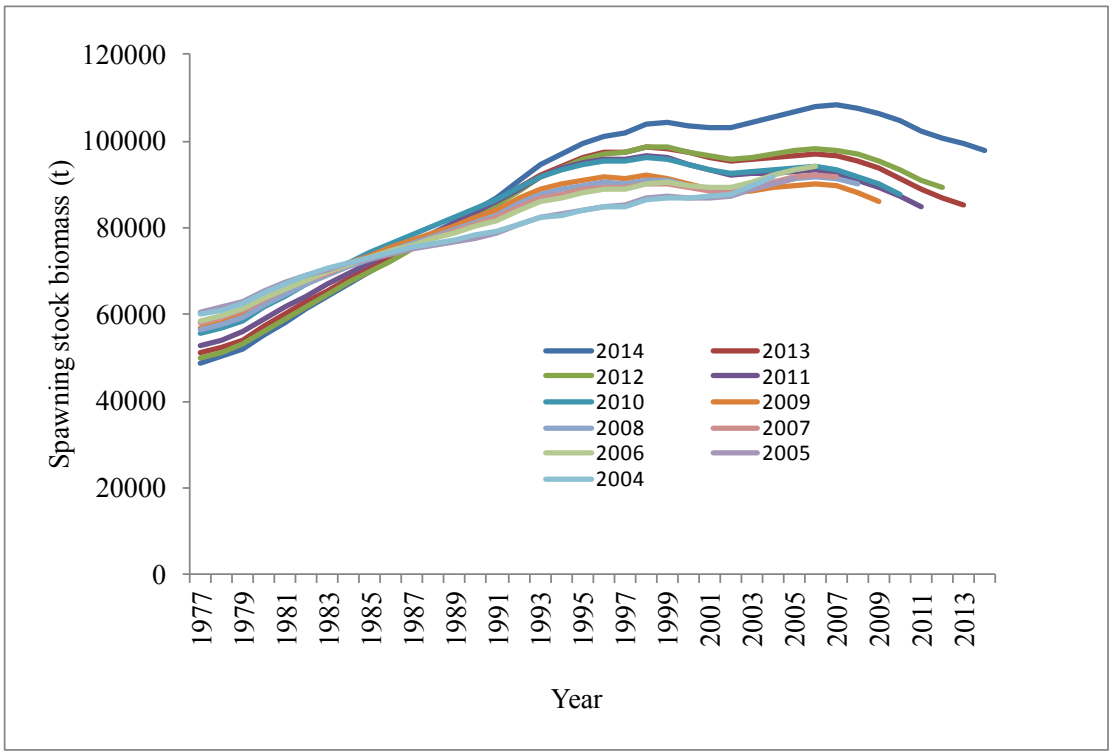

Figure 9. Retrospective estimates of spawning stock biomass for model runs with end years of 2004 to 2014.

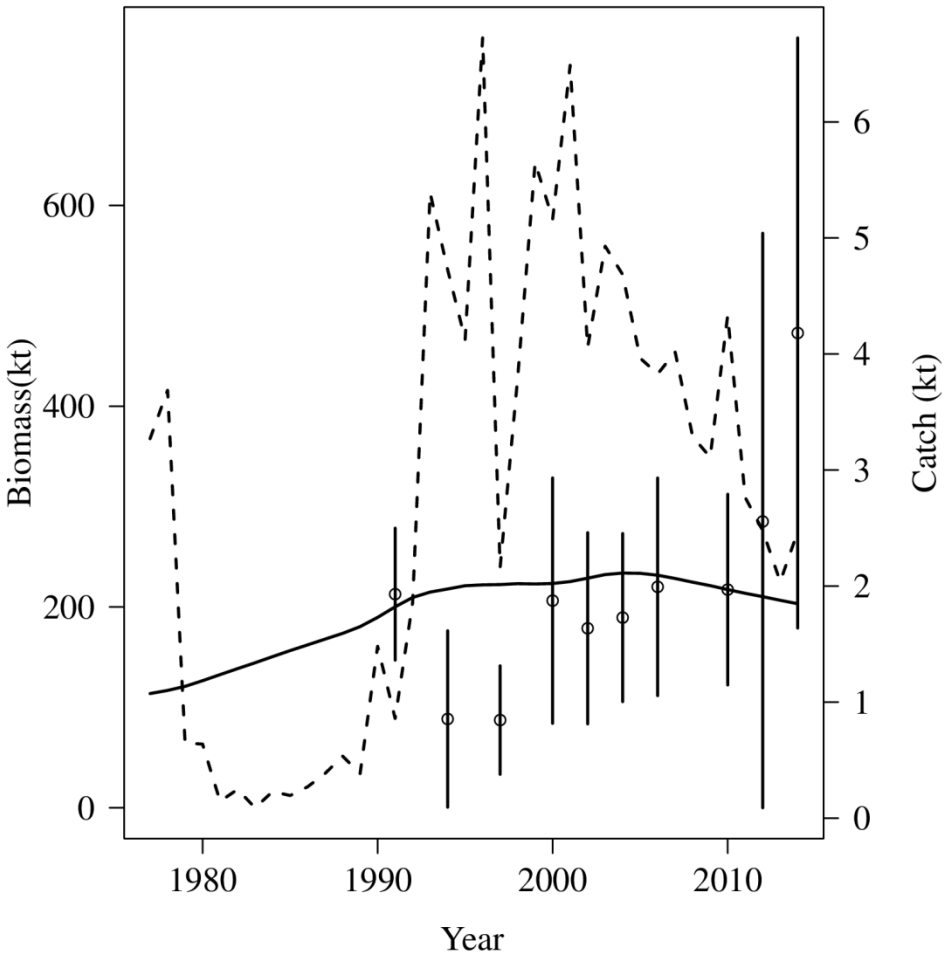

Figure 10. Observed Aleutian Islands survey biomass (data points, ± 2 standard deviations), predicted survey biomass (solid line) and BSAI harvest (dashed line).

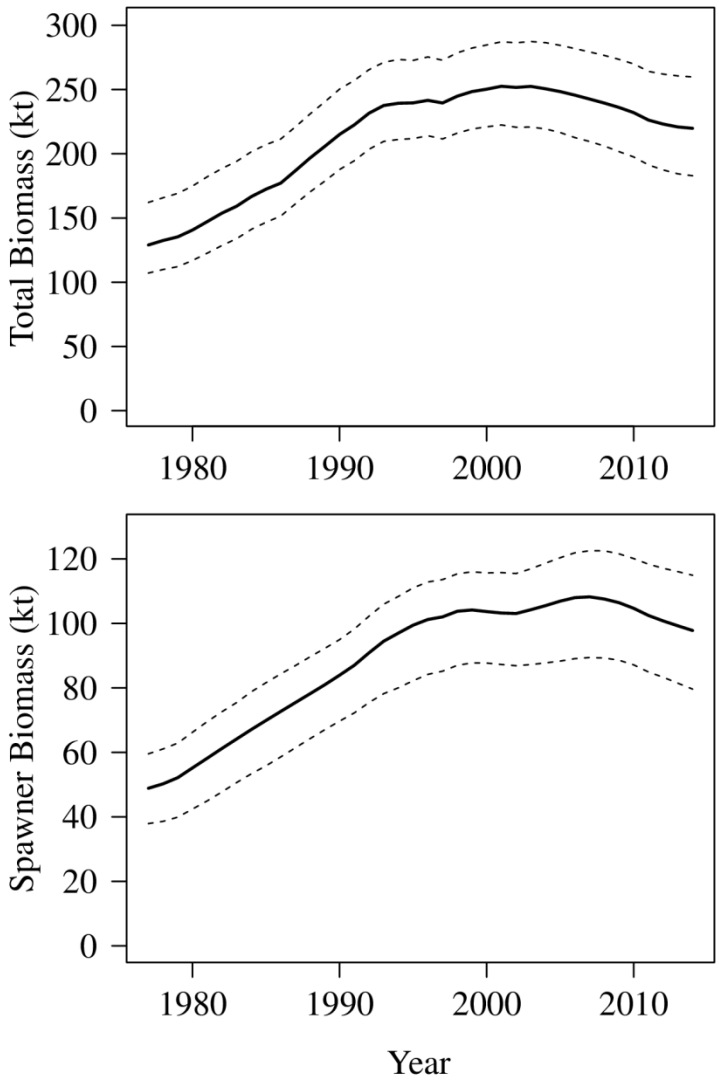

Figure 11. Total and spawner biomass for BSAI northern rockfish with 95% confidence intervals from MCMC integration.

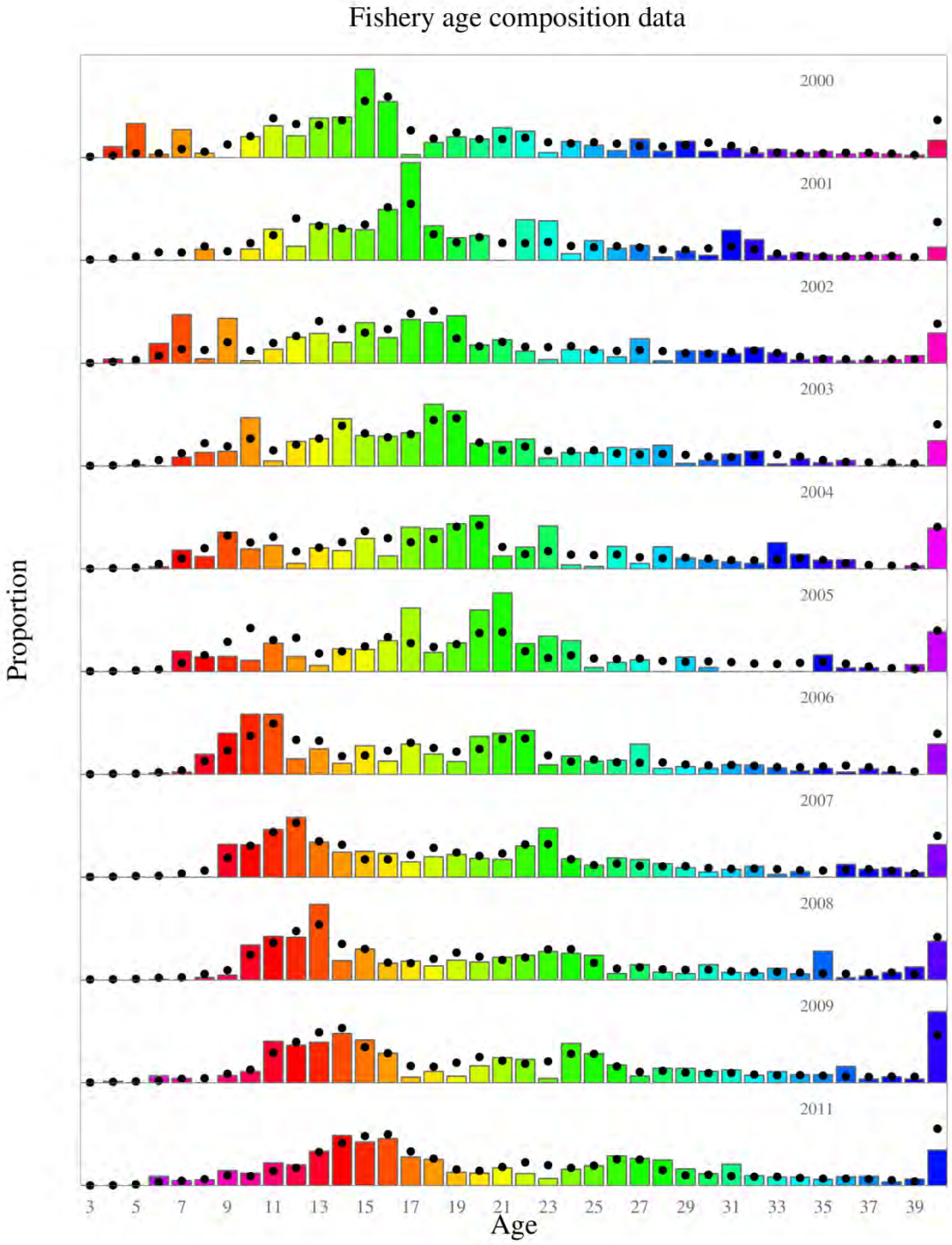

Figure 12. Model fits (dots) to the fishery age composition data (columns) for BSAI northern rockfish. Colors of the bars correspond to cohorts (except for the 40+ group).

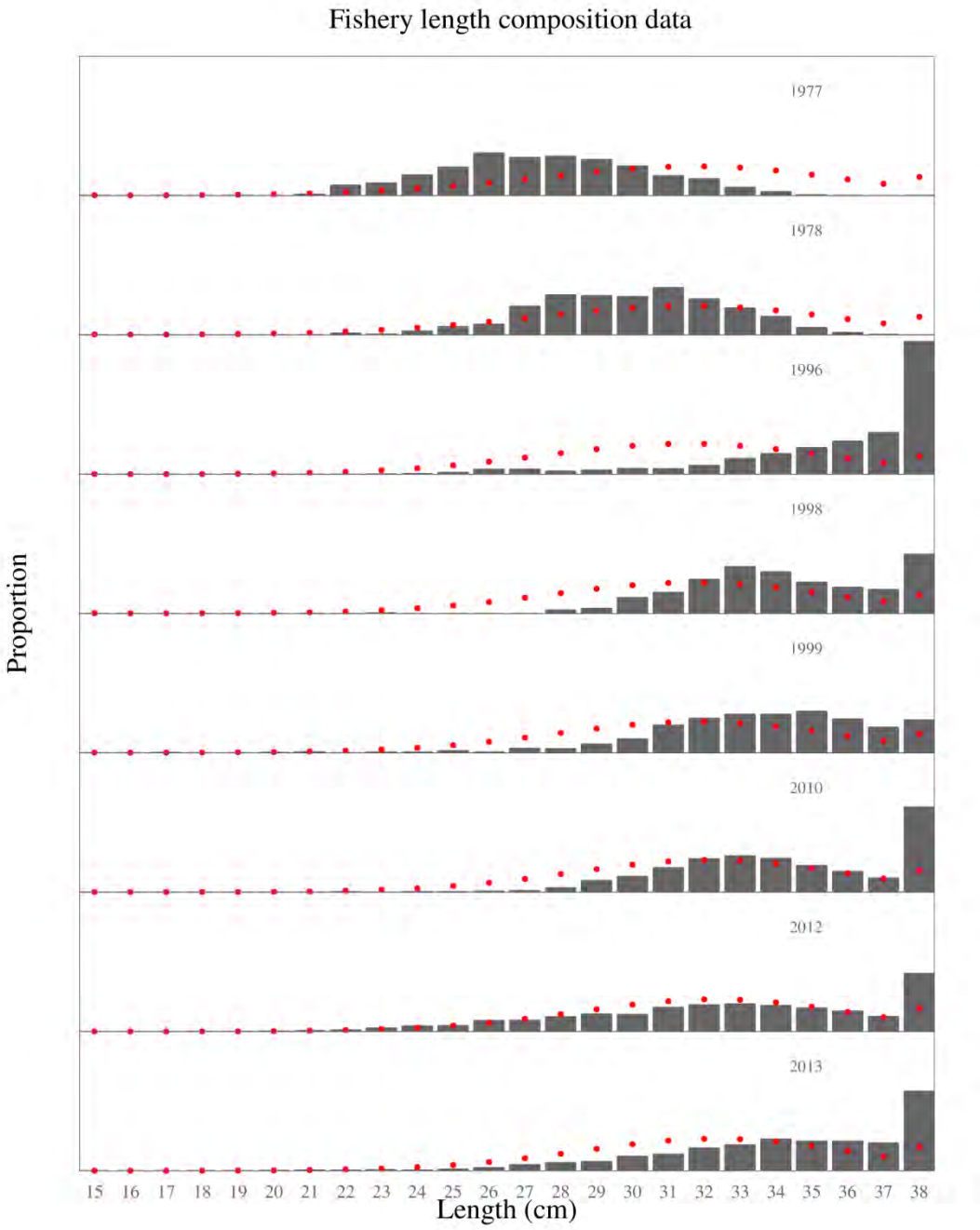

Figure 13. Model fits (dots) to the fishery length composition data (columns) for BSAI northern rockfish.

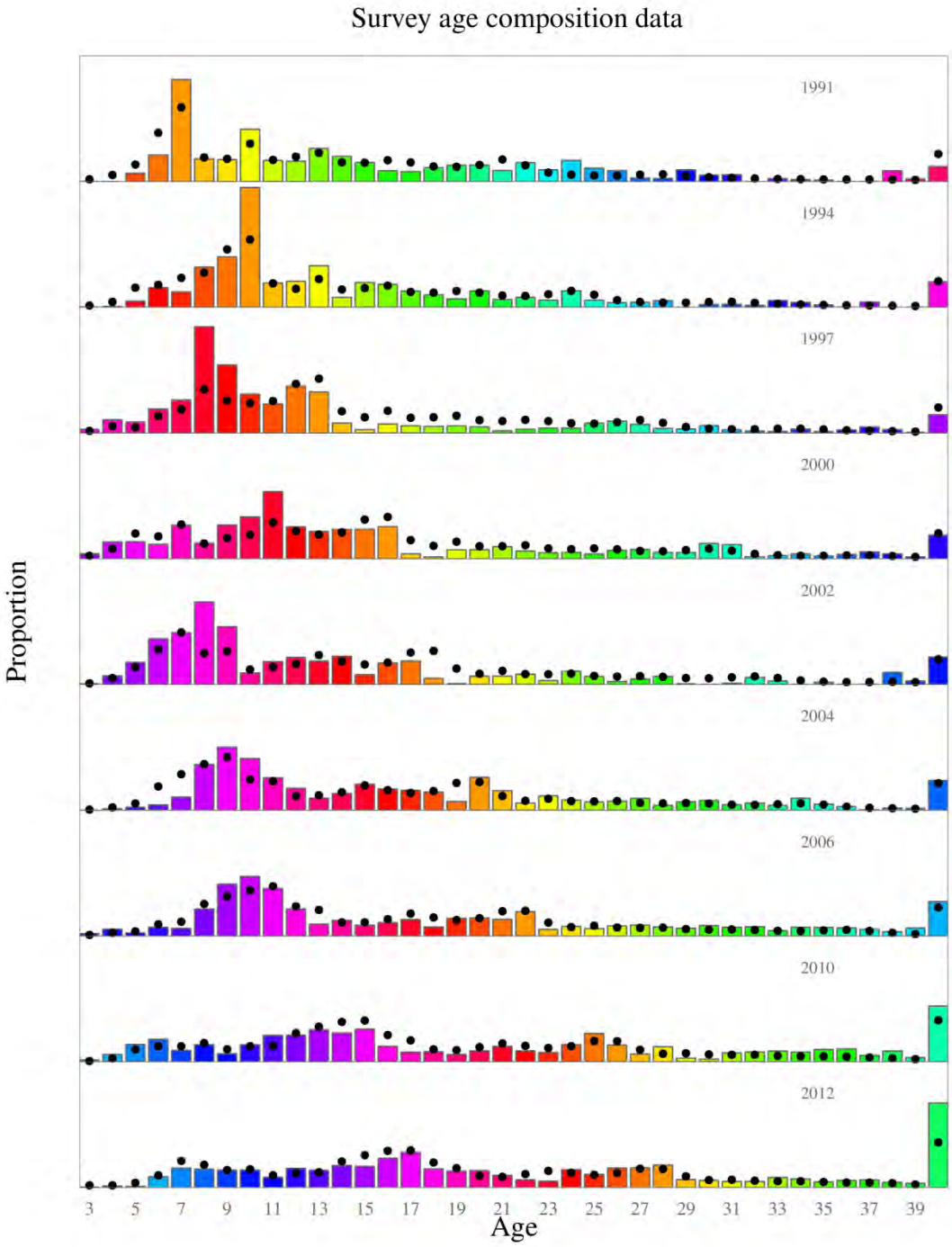

Figure 14. Model fits (dots) to the survey age composition data (columns) for BSAI northern rockfish. Colors of the bars correspond to cohorts (except for the 40+ group).

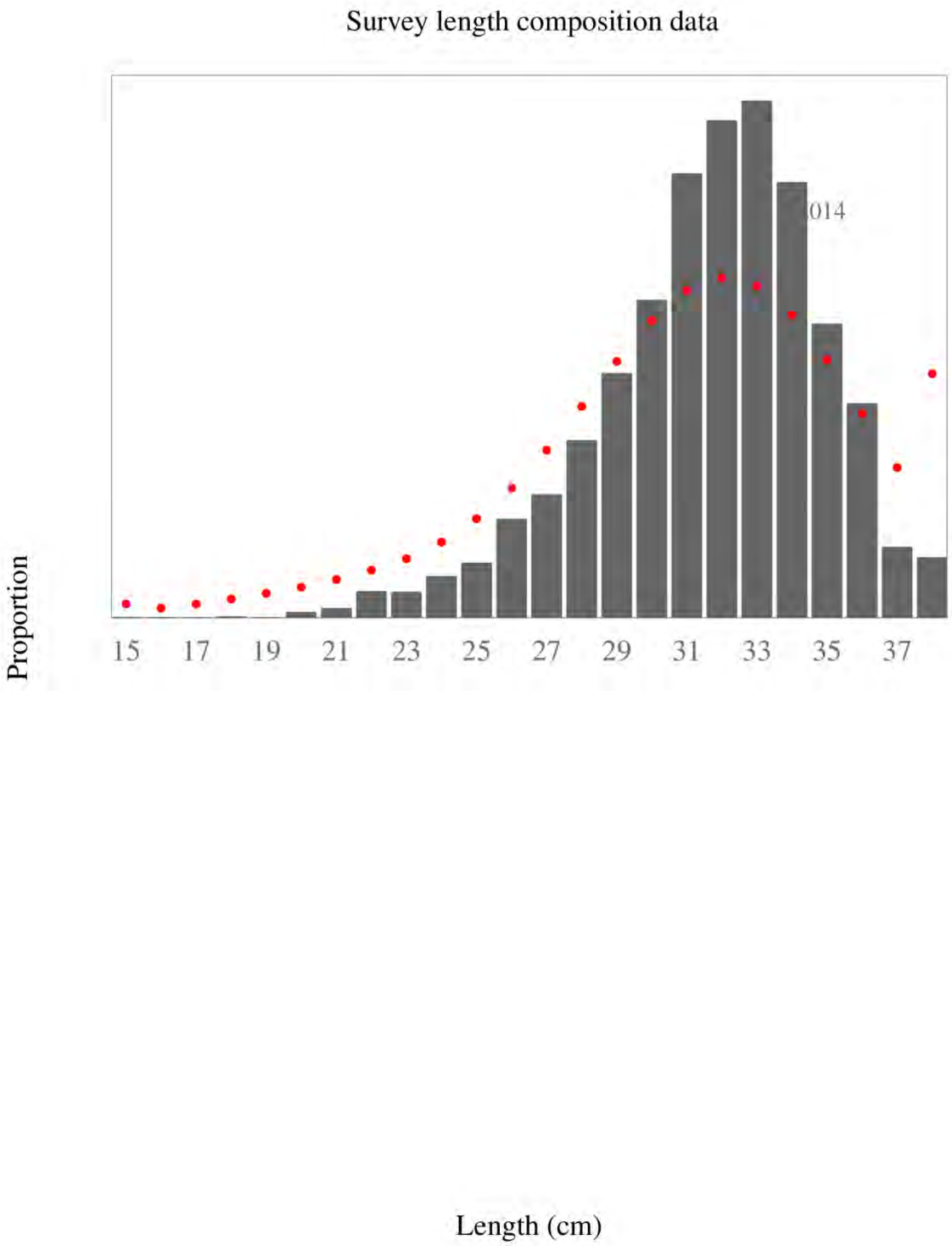

Figure 15. Model fits (dots) to the 2014 survey length composition data (columns) for BSAI northern rockfish.

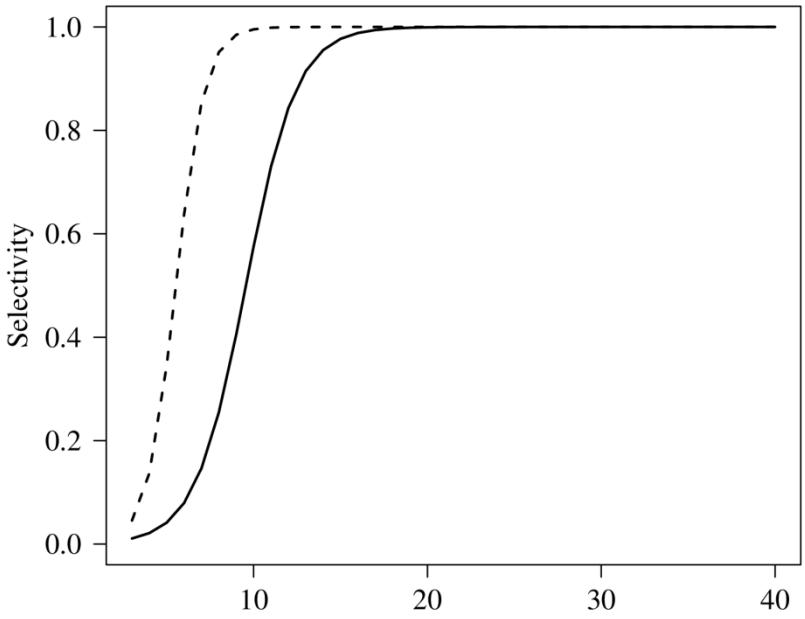

Figure 16. Estimated fishery (solid line) and survey (dashed line) selectivity at age for BSAI northern rockfish.

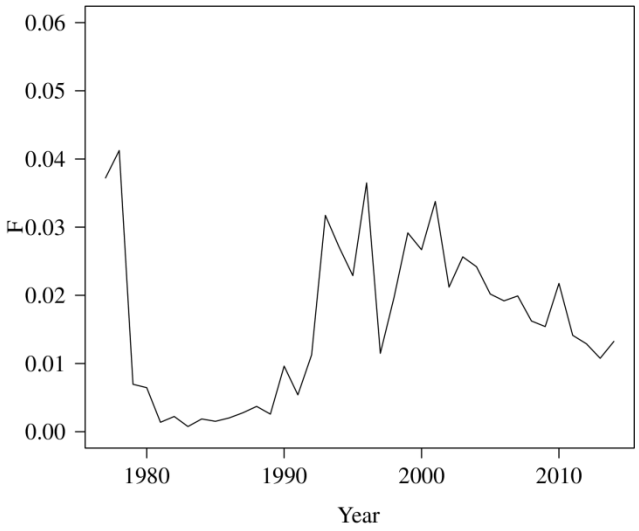

Figure 17. Estimated fully-selected fishing mortality rate for BSAI northern rockfish.

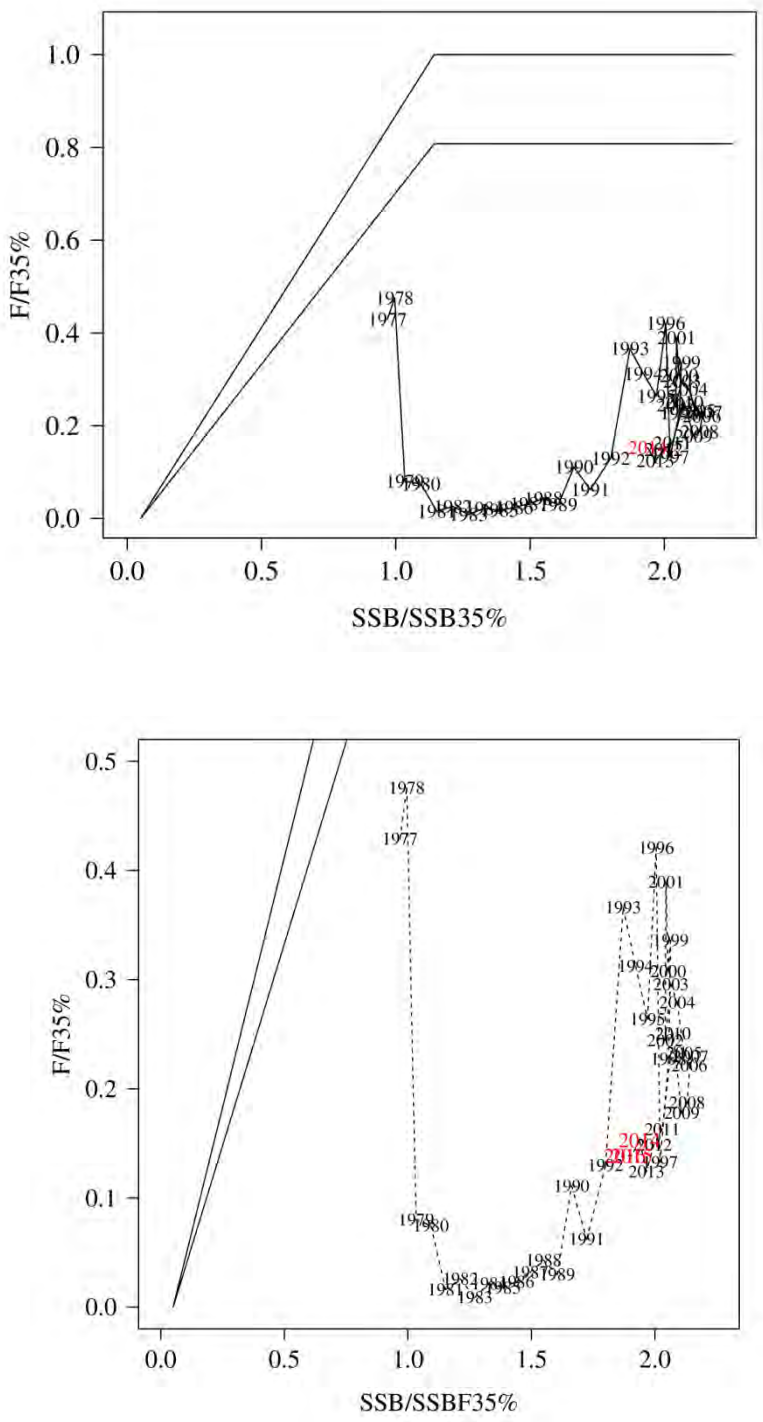

Figure 18. (Top panel) Estimated fishing mortality and SSB from 1977-2014 (with 2014 in red) in reference to OFL (upper line) and ABC (lower line) harvest control rules. The bottom panel shows a reduced vertical scale, and the projected F and stock size for 2015 and 2016.

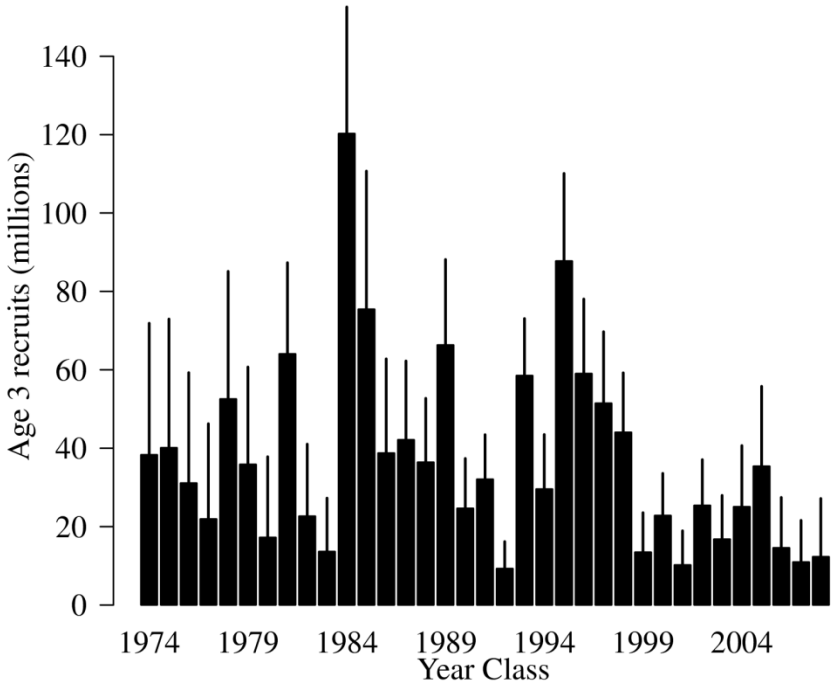

Figure 19. Estimated recruitment (age 3) of BSAI northern rockfish, with 95% CI limits obtained from MCMC integration.

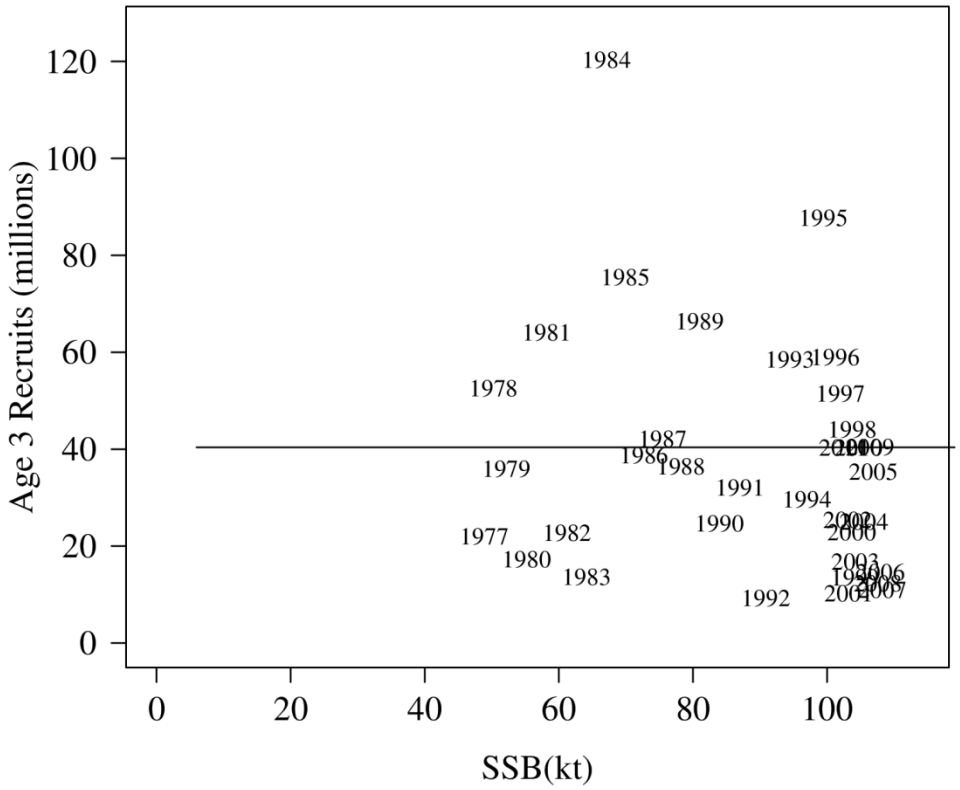

Figure 20. Scatterplot of BSAI northern rockfish spawner-recruit data; label is year class.

Appendix A. Supplemental Catch Data.

In order to comply with the Annual Catch Limit (ACL) requirements, non-commercial removals that do not occur during directed groundfish fishing activities are reported (Table A1). This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System estimates. For BSAI northern rockfish, these estimates can be compared to the trawl research removals reported in previous assessments. BSAI northern rockfish research removals are small relative to the fishery catch. The majority of removals are taken by the Alaska Fisheries Science Center's (AFSC) biennial bottom trawl survey which is the primary research survey used for assessing the population status of BSAI northern rockfish. The annual amount of northern rockfish captured in research longline gear not exceeded 0.06 t. Total removals ranged between 0.05 t and 140 t between 2010 and 2014, which were less than 1.6% of the ABC in these years.

Appendix Table A1. Removals of BSAI northern rockfish from activities other than groundfish fishing. Trawl and longline include research survey and occasional short-term projects. "Other" is recreational, personal use, and subsistence harvest.

Year	Source	Trawl	Longline	Other
1977				
1978		0.000		
1979		0.012		
1980		3.576		
1981		0.059		
1982		0.898		
1983		29.285		
1984		0.095		
1985		0.021		
1986		56.895		
1987		0.168		
1988		0.130		
1989		0.062		
1990		0.740		
1991		15.470		
1992	NMFS-AFSC survey databases	0.077		
1993		0.001		
1994		13.155		
1995		0.015		
1996		0.001	0.034	
1997		17.728		
1998		0.252	0.004	
1999		0.089		
2000		39.883	0.002	
2001		0.038	0.006	
2002		36.657	0.011	
2003		0.124	0.002	
2004		56.763	0.005	
2005		0.002	0.002	
2006		41.112	0.059	
2007		0.172	0.008	
2008		0.026	0.008	
2009		0.005	0.023	
2010		50.354	0.025	
2011		140.163	0.022	
2012	AKFIN database	89.765	0.021	
2013		0.014	0.039	
2014		69.148	0.000	

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14. Assessment of Blackspotted and Rougheye Rockfish stock complex in the Bering Sea/Aleutian Islands

by

Paul D. Spencer and Chris N. Rooper

Executive Summary

Fish previously referred to as rougheye rockfish are now recognized as consisting of two species, the rougheye rockfish (*Sebastes aleutianus*) and blackspotted rockfish (*Sebastes melanostictus*) (Orr and Hawkins 2007). The current information on these two species is not sufficient to support species-specific assessments, so they are combined as a complex in one assessment. Since 2008, an age-structured model has been applied to the Aleutian Islands (AI) portion of the population whereas the eastern Bering Sea (EBS) portion of the population are assessed with Tier 5 methods applied to survey biomass estimates. The last full assessment for blackspotted and rougheye rockfish was presented to the Plan Team in 2012. The following changes were made relative to the November 2014 SAFE:

Summary of Changes in Assessment Inputs

Changes in the input data

1) Catch updated through October 11, 2014.
2) The survey biomass estimates and age composition data from the U.S.-Japan cooperative survey in 1980, 1983, and 1986 were removed from the assessment.
3) The 2014 AI survey biomass estimate and length composition was included in the assessment.
4) The 2012 AI survey age composition was included in the assessment.
5) The 2012 and 2013 fishery length compositions were included in the assessment

Changes in the Assessment Methodology

1) Several fishery selectivity models were evaluated, with the recommended model using a double logistic model to estimate fishery selectivity as a function of year and age.
2) The multinomial input sample sizes for the age and length composition data were obtained by an iterative reweighting procedure that ensures that the standard deviation of the normalized residuals for each composition data type is 1.
3) The length-at-age, weights-at-age, and age-to-length conversion matrices were updated based on data from the NMFS AI trawl survey beginning in 1991.

This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Marine Fisheries Service and should not be construed to represent any agency determination or policy.

Summary of Results

The 2010 and 2012 assessments estimated large year class strength for the 1998 year class, and this is also the case in this assessment. This and other relatively recent year classes contribute to an estimated increase from 12,000 t in 1998 to 38,000 t in 2014.

The stock status relative to $B_{35\%}$ is a function of the years that are used to compute the mean recruitment. In 2010, the Plan Team concluded that $B_{35\%}$ should be based on a mean recruitment that excluded recent cohorts. However, in 2012 the SSC concluded that $B_{35\%}$ should be based on all the estimated recruitments. In this assessment, we recommend basing mean recruitment on those cohorts that have reached the age of 10% survey selection (which is 16 for the preferred model). Very recent cohorts are based on relatively few observations and are often imprecisely estimated. Additionally, even for cohorts that appear to be relatively well-estimated, there is a time lag between the estimation of year class strength and the contribution of the cohort to the exploitable stock and the survey biomass estimate. This problem is exacerbated for this stock because the fishery and survey select fish at relatively old ages. This results in a counter-intuitive case where our harvest control rule (when using mean recruitment from all estimated cohorts) would lower fishing mortality on stocks that are increasing.

As mentioned above, an age-structure population model was used to estimate the population size and harvest levels for the AI portion of the population. A summary of the 2014 recommended ABC's for the AI portion of the population relative to the 2013 recommendations is shown below.

	As estimated or *specified* last year for:		As estimated or *recommended* this year for:	
Quantity	2014	2015	2015	2016
M (natural mortality rate)	0.033	0.033	0.033	0.033
Tier	3b	3b	3b	3b
Projected total (age 3+) biomass (t)	29,087	30,062	40,391	42,445
Female spawning biomass (t)				
Projected	7,328	7,902	7,932	9,002
$B_{100\%}$	26,255	26,255	28,507	28,507
$B_{40\%}$	10,502	10,502	11,403	11,403
$B_{35\%}$	9,189	9,189	9,977	9,977
F_{OFL}	0.029	0.031	0.039	0.045
$maxF_{ABC}$	0.024	0.026	0.032	0.036
F_{ABC}	0.024	0.026	0.032	0.036
OFL (t)	459	534	516	642
maxABC (t)	382	444	420	522
ABC (t)	382	444	420	522
	As determined *last* year for:		As determined *this* year for:	
Status	2013	2014	2014	2015
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

The population size and harvest levels for the EBS portion of the population were obtained by applying Tier 5 methods to recent survey biomass estimates. A random effects model was used to fit a random walk smoother to the survey biomass data from the EBS portion of the stock. A summary of the 2014 recommended ABC's for the EBS portion of the population relative to the 2013 recommendations is shown below.

	As estimated or *recommended* last year for:		As estimated or *recommended* this year for:	
Quantity	2014	2015	2015	2016
M (natural mortality rate)	0.033	0.033	0.033	0.033
Tier	5	5	5	5
Biomass (t)	1389	1389	1,339	1,339
F_{OFL}	0.033	0.033	0.033	0.033
$maxF_{ABC}$	0.0248	0.0248	0.0248	0.0248
F_{ABC}	0.0248	0.0248	0.0248	0.0248
OFL (t)	46	46	44	44
maxABC (t)	34	34	33	33
ABC (t)	34	34	33	33
	As determined *last* year for:		As determined *this* year for:	
Status	2013	2014	2014	2015
Overfishing	No	n/a	No	n/a

The overall BSAI ABC and OFL are shown below.

	As estimated or *specified* last year for:		As estimated or *recommended* this year for:	
Quantity/Status	2014	2015	2015	2016
OFL (t)	505	580	560	686
ABC (t)	416	478	453	555

The BSAI blackspotted/rougheye stock complex was not subjected to overfishing in 2014. Based upon the age-structured model for the AI portion of the stock, BSAI blackspotted/rougheye rockfish is not overfished nor approaching an overfished condition.

Area Apportionment

The ABC for BSAI blackspotted/rougheye is currently apportioned among two areas: the western and central Aleutian Islands, and eastern Aleutian Islands and eastern Bering Sea. In previous assessments, a weighted average of the three most recent trawl survey biomass estimates is used to apportion the AI ABC. Weights of 4, 6, and 9 are used, with higher weights applied to the more recent surveys. Additionally, apportionments were also obtained from the random effects model to provide a comparison to the status quo method of survey averaging. Although the survey averaging work group is still evaluating the use of the random effects model for determining area apportionments, a comparison between the weighted average and the random effects model may be useful. The AI apportionment from the two methods are:

	Area			
	WAI	CAI	WAI+CAI	EAI
Weighted average biomass (t)	722	4,446	5,167	2,643
Proportion of biomass	9.2%	56.9%	66.2%	33.8%
Estimated 2014 biomass (from random effects model)	566	3,152	3,718	1,425
Proportion of biomass	11.0%	61.3%	72.3%	27.7%

The following table gives the current apportionments used in this assessment, the projected OFLs and apportioned ABCs for 2015 and 2016 and the recent OFLs, ABCs, TACs, and catches.

	BSAI	WAI+CAI	EAI+EBS	Total
OFL (2013)	462			462
ABC (2013)		209	169	378
TAC (2013)		209	169	378
Catch (2013)		146	178	324
OFL (2014)	505			576
ABC (2014)		239	177	416
TAC (2014)		239	177	416
Catch (2014)[1]		98	96	194
OFL (2015)	560			560
ABC (2015, weighted average)		278	175	453
ABC (2015, RE model)		304	149	453
OFL (2016)	686			686
ABC (2016, weighted average)		345	210	555
ABC (2016, RE model)		377	178	555

[1] BSAI catch as of October 11, 2014.

Apportionment within the WAI/CAI area

In December, 2013, the SSC requested information *"for consideration of separating the WAI ABC from the other sub-areas."* In October, 2014, the SSC recommended "*that the current stock structure policy be clarified to include a requirement for a recommended area specific catch level when a stock or stock complex is elevated to the level of 'concern'".* Given the concern over exploitation rates in the WAI, separate ABC for the WAI and CAI from the two methods of determining apportionments are shown below:

	WAI	CAI	WAI-CAI
ABC (2015, weighted average)	39	239	278
ABC (2015, RE model)	46	257	304
ABC (2016, weighted average)	48	297	345
ABC (2016, RE model)	57	320	377

Summaries for the Plan Team

Year	Biomass[1]	OFL	ABC	TAC	Catch
2013	29,810	462	378	378	324
2014	30,476	505	475	475	194[2]
2015	41,780	560	453		
2016	43,834	686	555		

[1] Total biomass from AI age-structured projection model, and survey biomass estimates from EBS.
[2] BSAI catch as of October 11, 2014.

Responses to SSC and Plan Team Comments on Assessments in General

The SSC requests that all assessment authors of AI species evaluate AI survey information to ensure that the same standardized survey time series is used. (SSC, December 2012)

Model runs in this assessment exclude the cooperative surveys conducted in the 1980s.

"The Teams recommended that each stock assessment model incorporate the best possible estimate of the current year's removals. The Teams plan to inventory how their respective authors address and calculate total current year removals. Following analysis of this inventory, the Teams will provide advice to authors on the appropriate methodology for calculating current year removals to ensure consistency across assessments and FMPs." (Plan Team, September 2013)

The estimates of current year catch are inferred by expanding the catch through September, 2014, by the recent pattern of the proportion of the remaining ABC that is caught by the end of the year.

"For assessments involving age-structured models, this year's CIE review of BSAI and GOA rockfish assessments included three main recommendations for future research: Authors should consider: (1) development of alternative survey estimators, (2) evaluating selectivity and fits to the plus group, and (3) re-evaluating natural mortality rates. The SSC recommends that authors address the CIE review during full assessment updates scheduled in 2014." (SSC, December 2013)

Selectivity curves and natural mortality rates are evaluated in this assessment. The development of alternative survey estimators (i.e., model-based standardization of survey catch data) affects all NPFMC assessments that use survey data. Potential methodologies have been discussed in a limited number of meetings in 2014 among AFSC scientists, and between AFSC scientists and NWFSC scientists, who are

in the process of developing more refined standardization methods. Continuation of these meetings will hopefully result in progress on this task.

"During public testimony, it was proposed that assessment authors should consider projecting the reference points for the future two years (e.g., 2014 and 2015) on the phase diagrams. It was suggested that this forecast would be useful to the public. The SSC agrees. The SSC appreciated this suggestion and asks the assessment authors to do so in the next assessment." (SSC December 2013)

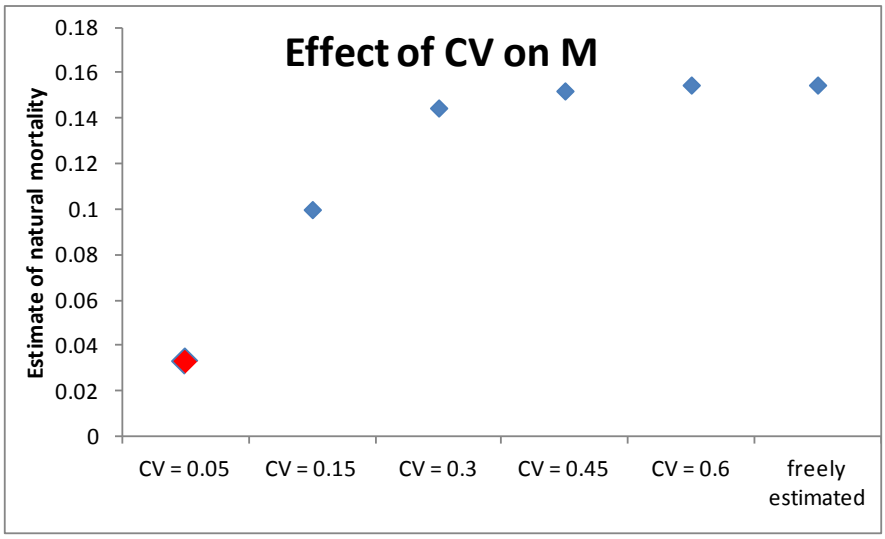
These projections were added to the phase-plane plots.

Responses to SSC and Plan Team Comments Specific to this Assessment

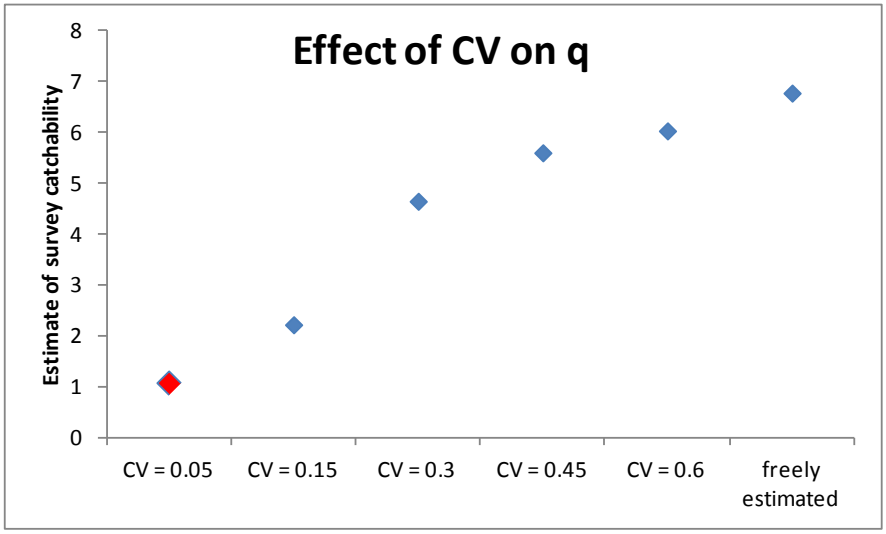
The SSC offers the following advice to assessment authors:
- *Evaluate priors on survey catchability and natural mortality.*
- *Explore alternative selectivity patterns*
- *Evaluate alternative selectivity time periods*
- *Evaluate/compare mean vs. median recruitment and which time period should be used for estimating fishery bench marks and provide rationale* (SSC, Dec 2012)

Alternative selectivity functional forms, including time-varying selectivity, are included in this assessment. The preferred model used a time-invariant double logistic equation to model fishery selectivity.

Previous attempts to estimate natural mortality (M) and survey catchability (q) within the assessment model have produced estimates that are implausible, which necessitated prior distributions with tight CVs. A series of models runs were conducted to address how sensitive the model estimates of M and q are to the prior distributions. Because M and q are inversely correlated, the runs for M were conducted by holding q fixed at the value estimated in the preferred model (and vice versa). The current model uses a prior distribution for M with a mean set to 0.03 (McDermott 1994, based on the a relation between M and the gonadosomatic index) and CV set to 0.05, and produces and estimate of 0.033 (shown in red in the graph below). The estimate obtained when M is freely estimated increases to 0.15.



The prior for q has a mean of 1 and a CV of 0.05, and a similar plot showing the effect of increasing the CV of the prior is shown below. The estimates of q range from 1.08 in the current model to 6.78 when estimated freely (while holding M fixed at 0.033). The inability to estimate q within the model is not surprising given that there is little contrast in the survey time series regarding how the stock has responded to exploitation, and motivates obtaining information on q outside the assessment model in order to develop more informative priors.



The choice of using mean or median recruitment has been evaluated by the Plan Team Stock-Recruitment Working Group. Median recruitment provides improved short-term management performance, whereas mean recruitment provides improved long-term management performance. The group recommended using mean recruitment.

In this assessment, we consider two time periods for computing mean recruitment (which is then used to compute the biomass reference points $B_{40\%}$ and $B_{35\%}$). One option is to use all of the estimated recruitment (i.e., the 1977-2011 year classes), which was used by the SSC in 2012 to set reference points. A second option is to use only those year classes which have reach the age at which they are estimated to be 10% selected in the AI trawl survey (which is age 16 for the preferred model). This is a modification of one of the options considered by the Plan Team Stock-Recruitment Working Group, and is motivated by the consideration that year classes that not reached the age of 10% survey selection may be considered incompletely observed. Using all the estimated recruitments results in a stock status of $B_{16\%}$, and the stock would thus be considered overfished. This designation results not from a declining stock (in fact, the assessment shows an increasing stock), but rather high estimates of recently observed year classes which increases the mean recruitment. Using only the year classes which are 10% selected in the survey results in a stock status of $B_{24\%}$, similar to the stock estimated in the 2012 ($B_{25\%}$).

The authors presented seven reasons for concern about fishing pressure on the Western Aleutian Island (WAI) component of the population. The Plan Team also expressed "strong concern" about the WAI component of the stock. The SSC shares this concern and agrees with the Plan Team recommendation to have the authors update the seven reasons for concern and bring this forward in 2014 for consideration of separating the WAI ABC from the other sub-areas. The SSC requests that authors include an update on species identification issues, and if possible, species composition among areas. The SSC also recommends that the authors present spatial distribution trends on catch, length frequencies, trawl survey

biomass and any other pertinent information as if the authors'/ Plan Team recommended ABC and/or OFL changes were made. The SSC recommends that the authors comment on data and research requirements that would be required to better inform stock structure and comment on any potential correlation to other species declines in the Aleutians such as Steller sea lions. The Blackspotted/Rougheye stock in the western AI stands out among other BSAI rockfish stocks as a potential conservation concern. (SSC, Dec 2013)

The 7 attributes for BSAI blackspotted/rougheye are updated in an appendix of this assessment. The original list of attributes included a statistically significant isolation by distance relationship based on genetic samples available in 2010. An updated analysis with additional samples does not support a strongly significant relationship ($P = 0.11$). Updates of several of the attributes were presented at the September, 2014 Plan Team meeting, which reiterated its concern regarding stock structure. This conclusion was based upon disproportionate harvest rates, the observed decline in the western Aleutians, and recognition that demographic independence between spatial areas can often be difficult to infer from genetic data. The 2014 survey biomass estimate for the western Aleutians (589 t) was increased slightly from the 2012 estimate (335 t). The level of depletion can be obtained by comparing the estimated current biomass to the estimated 1991 biomass (both obtained by applying a random effects smoother the western AI trawl survey data). The estimated levels of depletion with and without the 2014 survey estimate are 81% and 85%, respectively.

The non-genetic attributes updated in the appendix present spatial patterns in catch, trawl survey biomass, and length composition.

While species identification between blackspotted and rougheye rockfish remains problematic in area where each species is relatively abundant, the species distribution of rougheye rockfish does not extend east of the eastern/central Aleutians Islands. In the western AI, the area of most concern, the complex is composed nearly entirely of blackspotted rockfish, and this is supported by the identifications in the trawl survey and several morphological and genetic analyses (as reviewed in the initial stock structure document, which is included as an appendix to the 2010 SAFE chapter (Spencer and Rooper 2010).

Additional information regarding stock structure would ideally focus on the spatial scale of dispersal at various life stages. Acquisition of this data would be challenging, given the logistical issues of field work in remote areas such as the western Aleutians, the inability to identify rockfish larvae to species without genetic techniques, and the difficulty in tagging deep-water species subject to barotrauma. It may be possible that otolith microchemistry can used to identify movement from natal areas, although this would depend on the degree to which distinct signatures in the water chemistry occur in the Aleutian Islands.

We are not well-equipped to provide a comparison to Stellar Sea lions, although we do note that the abundances of POP and northern rockfish have been increasing in the western Aleutians. One difference, however, from Stellar Sea lions is that fishing has appeared to play a major role in the decline in western Aleutian Islands blackspotted/rougheye rockfish. As noted by Spencer (2013), the available catch and survey data indicate that high rates of exploitation for western AI blackspotted rockfish have occurred in the 1990s (particularly in 1996 and 1997), and abundance in this area has decreased (beginning in the 2000 survey) and has not been replenished from neighboring areas.

The SSC requests spatial catch information by fishery (SSC, Oct 2014).

This information is presented in the assessment.

The SSC recommends that the current stock structure policy be clarified to include a requirement for a recommended area specific catch level when a stock or stock complex is elevated to the level of

"concern". This would provide a clear guide to industry regarding what reductions in catch would be needed to alleviate the "concern". This area specific catch level would likely be estimated by the assessment author with review and comment by the Plan Teams and SSC. (SSC, Oct 2014).

Given that the concern regarding subarea exploitation pertains to the western AI, a subarea ABC for this area is documented in this assessment.

Introduction

Rougheye rockfish (*Sebastes aleutianus*) have historically been managed within various stock complexes within the Bering Sea/Aleutian Islands (BSAI) region. For example, from 1991 to 2000 rougheye rockfish in the eastern Bering Sea (EBS) area were managed under the "other red rockfish" species complex, which consisted of shortraker (*Sebastes borealis*), rougheye (*S. aleutianus*), sharpchin (*S. zacentrus*), and northern rockfish (*S. polyspinis*), whereas in the Aleutian Islands (AI) area during this time rougheye rockfish were managed within the rougheye/shortraker complex. In 2001, the other red rockfish complex in the EBS was split into two groups, rougheye/shortraker and sharpchin/northern, matching the complexes used in the Aleutian Islands. Additionally, separate TACs were established for the EBS and AI management areas, but the overfishing level (OFL) pertained to the entire BSAI area. By 2004, rougheye, shortraker, and northern rockfish were managed with species-specific OFLs applied to the BSAI management area.

Fish historically referred to as "rougheye" rockfish are now recognized as consisting of two separate species (Orr and Hawkins 2008), with rougheye rockfish retaining the name *Sebastes aleutianus* and resurrection of a new species, blackspotted rockfish (*S. melanostictus*). Both species are distributed widely throughout the north Pacific. *S. aleutianus* is distributed from the eastern AI near Unalaska Island along the continental slope to southern Oregon, where *S. melanostictus* is distributed along the continental slope from Japan to California (Orr and Hawkins 2008). Several studies (Hawkins et al. 2005; Gharrett et al. 2005; Orr and Hawkins 2008) have used genetic and morphometric analyses to document the scarcity of rougheye rockfish west of the eastern AI and the occurrence of blackspotted rockfish throughout the BSAI area, thus establishing differences in species composition between areas in the BSAI. This distribution pattern has also been observed in recent AI trawl surveys, where rougheye rockfish are rarely found in the central and western AI. Some differences in species composition based upon field identification may be due to errors in species identification, particularly in areas where both species are common, as blackspotted and rougheye rockfish are similar in appearance. This issue appears to be particularly problematic in the Gulf of Alaska (GOA), where a field test in the 2009 GOA trawl survey reported high misidentification rates. However, the distribution pattern in the AI survey biomass estimates is consistent with information obtained from the previously cited genetic and morphometric analyses, which did not rely on field identification. The title of this assessment was changed to "blackspotted and rougheye rockfish" in 2008 upon recognition of blackspotted rockfish and its high abundance in the BSAI relative to rougheye rockfish. Data for the two species are combined in the assessment, as species-specific catch records do not exist and identification by species has occurred in the AI trawl survey only since 2006.

Information on stock structure

A stock structure evaluation report was included in the 2010 assessment, and evaluated species distributions within the blackspotted/rougheye complex, genetic data, and size at age data. The patterns of spatial variation in species composition noted above for this two-species complex was considered in this evaluation because differences in species composition could imply different levels of productivity across spatial areas. Tests for genetic homogeneity indicated that genetic differences occurred between samples of blackspotted rockfish grouped into four areas within the BSAI. A significant isolation by distance

(IBD) pattern was also estimated in the 2010 analysis, although this was based upon a relatively small sample size. The BSAI Plan Team concluded in 2010 that spatial structure exists within the BSAI for blackspotted and rougheye rockfish, and recommended the BSAI ABC be partitioned into an ABC for the western and central Aleutian Islands, with a separate ABC for the remainder of the BSAI area.

Additional information was presented to the BSAI Plan Team in 2010, 2012, and 2013 indicating disproportionate harvesting within the three subareas within the AI, and identifying several attributes regarding spatial patterns in abundance, mean size, proportion of survey tows with no blackpotted/rougheye catch, exploitation rates, and distribution of harvest. These attributes are updated with the most recent survey and catch data in Appendix A of this assessment.

The relative small number of samples available for the genetic analysis conducted in 2010 motivated the collection and analysis of additional samples since 2010. The most recent genetic analysis does not indicate a strong significant pattern of isolation by distance (P=0.11). However, stock structure remains a concern due to the limitations of using genetic data to infer spatial structure on temporal scales of interest to fisheries management, and because of the pattern of disproportionately high harvest rates and reduced abundance in the western AI.

Fishery

Historical Background

Catches of rougheye rockfish have been reported in a variety of species groups in the foreign and domestic Alaskan fisheries. Foreign catch records did not identify rougheye rockfish by species, but reported catches in categories such as "other species" (1977, 1978), "POP complex" (1979-1985, 1989), and "rockfish without POP" (1986-1988).

Rougheye rockfish have also been managed in multiple species groups since 1991 in the in the domestic fishery as part of the “other red rockfish” or “shortraker/rougheye” complexes. In 1991, the “other red rockfish” species group was used in both the EBS and AI, but beginning in 1992 rougheye rockfish in the AI were managed in the “rougheye/shortraker” species group. Prior to 2001, rougheye rockfish were managed with separate ABCs and TACs for the AI and EBS, and from 2001-2003 rougheye rockfish were managed as a single stock in the BSAI area with a single OFL and ABC, but separate TACs for the EBS and AI subareas. From 2005-2010, rougheye rockfish were managed with BSAI-wide OFLs, ABCs, and TACs, and beginning in 2011 the BSAI ABC and TAC has been divided between the western and central AI, and the eastern AI and the EBS area. The OFLs, ABCs, TACS, and catches by management complex from 1977-2003 are shown in Table 1, and those from 2004 to present are shown in Table 2.

Since 2003, the catch accounting system (CAS) has reported catch of rougheye by species and area. From 1991-2002, species catches were reconstructed by computing the harvest proportions within management groups from the North Pacific Foreign Observer Program database, and applying these proportions to the estimated total catch obtained from the NOAA Fisheries Alaska Regional Office “blend” database. This reconstruction was conducted by estimating the rougheye catch for each area (i.e., the EBS and each of the three AI areas) and gear type from 1994-2002. For 1991-1993, the Regional Office blend catch data for the AI was not reported by AI subarea, and the AI catch was obtained using the observer harvest proportions by gear type for the entire AI area. Similar procedures were used to reconstruct the estimates of catch by species from the 1977-1989 foreign and joint venture fisheries. Estimated domestic catches in 1990 were obtained from Guttormsen et al. 1992. Catches from the domestic fishery prior to the domestic observer program were obtained from PACFIN records. Catches of rougheye since 1977 by the EBS and AI subareas are shown in Table 3. Catches were relatively high during the late 1970s, declined during the late 1980s as the foreign fishery was reduced, increased in the early 1990s and mid-1990s, and declined in the late-1990s.

The catches by area from 1994-2014 have been relatively evenly distributed throughout the three AI subareas, with 32%, 26%, and 36% in the WAI, CAI, and EAI, respectively, and the remaining 5% in the EBS management area (Table 4). However, biomass estimates from the AI survey indicate that a relatively small portion of the stock (approximately 9%) occurs in WAI. Information on spatial exploitation rates is updated in Appendix A.

Temporal variability has occurred in AI subareas in which blackspotted/rougheye rockfish are captured, and in the depths of capture (Figure 1). The domestic fishery observer data indicates that the eastern AI accounted for more than 50% of the observed catch from 1992 to 1995, with the western AI accounting for less than 10%. However, since the mid-1990s the proportion of the harvest in the western and central Aleutians has increased, and the proportion obtained from western Aleutians ranged between 0.58 and 0.72 from 2004 – 2006. The proportion captured at depths greater than 300 has increased recently, ranging from 3% to 20% during 1998- 2003 to 28% to 46% from 2009 – 2013.

Non-commercial catches are shown in Appendix B.

Discards

Estimates of discarding by species complex are shown in Table 5. Estimates of discarding of the other red rockfish complex in the EBS were generally above 56% from 1993 to 2000, with the exception of 1993 and 1995 when discard rates were less than 26%. The variation in discard rates may reflect different species composition of the other red rockfish catch. Discard rates of the EBS RE/SR complex from 2001 to 2003 were at or below 52%, and discard rates of the AI RE/SR complex from 1993-2003 were below 41%. In general, the discard rates of the EBS RE/SR (2001-2003) are less than the discard rates of the EBS other red rockfish (1993-2000), likely reflecting the relatively higher value of rougheye and shortraker rockfishes over other members of the complex. From 2004 to 2014, discard rates of rougheye in the AI and EBS averaged 19% and 36%, respectively.

Recent Distribution of Catch across Areas and Target Fisheries

Rougheye rockfish in the AI have been caught primarily in the rockfish trawl, Pacific cod longline, and Atka mackerel trawl fisheries in recent years. From 2004-2012, these three fisheries accounted for 86% of the AI rougheye catch. Catches of the AI rougheye rockfish from 2004-2012 were primarily taken in the western and central Aleutians, with 43% and 30% in areas 543 and 542, respectively (Table 6). Approximately 91% of the catches of rougheye rockfish from 2004-2012 in the EBS management area were in the arrowtooth flounder trawl fishery, Pacific cod longline, halibut longline fishery, rockfish trawl fishery, turbot longline fishery, pollock midwater trawl fishery, and "other flatfish" trawl fisheries. Catches of rougheye in the EBS management area were concentrated in areas 517, 518, 519 and 521, which comprise much of the EBS slope and the area north of Unmak and Unalaska Islands (Table 6).

Data

Fishery data

The catch data used in the assessment model are the estimates of single species catch described above and shown in Table 3.

Prior to 1999, the fishery data is characterized by inconsistent sampling of lengths (Table 7) and ages (Table 8), as many fish were measured in some years whereas other years had no data. In 1979, 1990, 1992, and 1993, over 1000 fish were measured in the AI and the size compositions were used in the assessment model. In the domestic fishery, changes in observer sampling protocol went into effect in 1999, increasing the number of fish and hauls from which rougheye rockfish age and length data are collected, increasing the utility for stock assessment modeling. The size compositions in 2003 and 2010, and the age compositions in 2004-2005, 2007-2009, and 2011 were used in the assessment model.

The fishery age composition data indicates relatively moderate cohorts from the early 1970s to early 1980s, but some of the more recent cohorts from the mid-1990s appear inconsistently in the data (Figure 2). For example, the 1997 cohort is appears relatively strong as 12 year olds in the 2009 age composition and 14 year olds in the 2011 age composition, but were not observed in previous samples. Similarly, the 1996 cohort appears strong in the 2008 fishery age composition, is not observed in the 2009 age composition, and appears weak in the 2011 age composition. One exception to this pattern is the 1998 cohort, which appears relatively strong in both the 2009 and 2011 fishery age compositions.

Survey data

Biomass estimates for other red rockfish were produced from the cooperative U.S.-Japan trawl survey from 1979-1985 on the EBS slope, and from 1980-1986 in the AI. U.S trawl surveys on the EBS slope were conducted by the National Marine Fisheries Service (NMFS) in 1988, 1991, and biennially beginning in 2002. NMFS trawl surveys in the AI were conducted in 1991, 1994, 1997, and biennially beginning in 2000. The EBS slope surveys in 2006 and 2014, and the AI trawl survey in 2008, were canceled due to lack of funding. Differences exist between the 1980-1986 cooperative surveys and the 1991-2012 U.S. domestic surveys with regard to the vessels and gear design used (Skip Zenger, NMFS, personal communication). For example, the Japanese nets used in the 1980, 1983, and 1986 cooperative surveys varied between years and included large roller gear, in contrast to the poly-nor'eastern nets used in the current surveys (Ronholt et al 1994), and similar variations in gear between surveys occurred in the cooperative EBS surveys. In previous assessments, these surveys were included in the assessment to provide some indication of biomass during the 1980s. Given the difficulty of documenting the methodologies for these surveys and standardizing these surveys with the NMFS surveys, this year's assessment model is conducted with only the NMFS surveys (Table 9).

The AI surveys from 1991 to 2014 indicated higher abundances in the central (542) and eastern Aleutians than in the western AI (543) or southern Bering Sea area (Figure 3,Table 10). In the western Aleutians, surveys prior to 2012 typically had positive CPUE tows near Attu Island and Tahoma Bank-Buldir Island area. However, the 2012 survey was characterized by generally lower CPUE levels in the WAI, which reduced the biomass estimate for this area to 335 t from an average of 1,075 t in the 2000-2010 surveys. The 2014 survey biomass estimate for the western AI shows the same general spatial pattern of survey CPUE, and the biomass estimate has increased to 589 t. In the central and eastern AI, the survey biomass estimates for 2014 are reduced 65% and 74%, respectively, from the estimates in the 2012 survey. In the central AI, the 2012 survey estimate of 8,268 t was high relative to previous surveys (due primarily to one large tow near Kiska Island), and the 2014 estimate of 2,878 is low relative to the time series. The 2014 estimate of 958 t for the eastern AI is the lowest observed in the time series; the next lowest estimate occurred in 2006 and was 2,803 t. The spatial pattern of the survey CPUE was similar between the 2012 and 2014 surveys, and the magnitude of the survey CPUE was smaller for the 2014 survey in the eastern and central AI.

The biennial EBS slope survey was initiated in 2002. The most recent slope survey prior to 2002 (excluding some experimental tows in 2000 to evaluate survey gear) was in 1991. The 2008 EBS slope survey was completed, but the 2006 survey was canceled due to lack of funding. The survey biomass estimates of blackspotted and rougheye rockfish from the 2002-2012 EBS slope surveys have ranged between 553 t (2002) and 1,613 t (2012), with CVs between 0.16 and 0.50. Given these low levels of biomass, the slope survey results are not used in this year's assessment, and the feasibility of incorporating this time series in the age-structured model will be evaluated as new data becomes available.

Identification to species within the blackspotted/rougheye complex was initiated in the 2006 AI survey and the 2008 EBS slope survey. These data show the complex is composed nearly entirely of blackspotted rockfish in the AI management area (ranging between 95% and 99% by weight in the 2006 –

2012 surveys), with a higher proportion of rougheye rockfish in the southern Bering Sea (SBS) and EBS slope. Field identification of these species can be difficult in areas where both species are abundant, such as the Gulf of Alaska, but blackspotted rockfish in the AI have been observed to have more clearly identifiable characteristics than blackspotted rockfish in other areas (Jay Orr, AFSC, pers. comm.).

Comparison of Fishery and Survey Catches by Depth and Age

A comparison of fishery and survey catches can indicate whether fishery selectivity is suspected of being time-varying and/or dome-shaped. A comparison of the catch-weighted mean depth in the AI fishery and the AI trawl survey is shown in Figure 4, and indicates relatively constant mean depth of capture across years in the AI survey, whereas the fishery depth of capture show higher interannual variation. Additionally, the mean depth in the fishery has been increasing in the eastern and western AI since the mid-2000s, which is consistent with the pattern observed in Figure 1.

The plus group for the rougheye assessment model is 45 years, and of interest is the relative age composition of the old fish within the plus group. Fishery and survey data were binned across years in two periods from 2004 to 2011, and the age composition of ages 45 to 70+ are shown in Figure 5. Overall, survey age composition is similar to fishery age composition for the ages in the plus group. For example, in the 2004 - 2006 time period, the survey age composition exceeded the fishery age composition for 12 of 26 ages, whereas the fishery age composition exceeded the survey age composition in 10 of the 26 ages (4 ages were captured by neither the fishery or the survey). The pattern can be seen more clearly in the histogram of differences between survey and fishery age proportions (Figure 6); positive differences indicate that the survey proportion exceeded the fishery proportion for a given age. Overall, these data do not suggest that the fishery is selecting older rougheye rockfish in different proportions than the survey since 2004. Fishery age data are not available to conduct a similar analysis for years prior to 2004.

Biological Data

The AI survey provides data on age and length composition of the population, growth rates, and length-weight relationships. The number of lengths measured and otoliths sampled are shown in Tables 11 and 12, along with the number of hauls producing these data. The survey data produce reasonable sample sizes of lengths and otoliths throughout the survey area. The maximum age observed in the survey samples was 121 years.

The survey age composition data indicates that in most surveys, blackspotted/rougheye rockfish have a relatively even distribution across a broad range of ages (i.e., ages 20 to 40) (Figure 7). Prior to 2006, fish less than 10 years old have been uncommon in the surveys; however, the 2006 and 2010 surveys indicate potentially strong 1998 and 1999 year classes.

The survey otoliths were read with the break and burn method, and are considered unbiased (Chilton and Beamish 1982); however, the potential for aging error exists. Information on aging error was obtained from multiple independent readings on GOA otoliths collected in 1990, 1999, and 2003 (Shotwell et al. 2007). These data were used to estimate the error in age reading based on the percent agreement between the readers. A fitted relationship describing the standard deviation in age was used to produce the aging error matrix.

The AI survey otolith data from 1991-2012 were used to estimate size at age and von Bertalannfy growth parameters. Unbiased estimates of mean length at age were generated from multiplying the survey length composition by the age-length key in order to produce a matrix of estimated population numbers by age and length, from which an unbiased average length for each age could be determined. Preliminary analyses did not reveal any patterns by year and subarea within the AI survey areas, so the mean length at

age from each survey year from 1986 to 2010 was used to fit the growth curve. The estimated von Bertalannfy parameters are as follows, and were used to create a conversion matrix and a weight-at-age vector:

L_{inf}	K	t_0
50.87	0.06	-3.48

A conversion matrix was created to convert modeled number at age into modeled number at length bin, and consists of the proportion of each age that is expected in each length bin. This matrix was created by fitting a second-order polynomial model to the observed standard deviation in length at each age (obtained from the aged fish from the 1991-2012 surveys), and the predicted relationship was used to produce variation around the predicted size at age from the von Bertalanffy relationship. The resulting CVs of length at age of the conversion matrix decrease from 0.17 at age 3 to 0.10 at age 45.

A length-weight relationship of the form $W = aL^b$ was fit from the survey data, and produced estimates of $a = 6.60 \times 10^{-6}$ and $b = 3.24$. This relationship was used in combination with the von Bertalanffy growth curve to obtain the estimated weight at age vector of the population (Table 13).

The following table summarizes the data available for the both the AI blackspotted/rougheye rockfish assessment models:

Component	BSAI
Fishery catch	1977-2014
Fishery age composition	2004-2005, 2007-2009, 2011
Fishery size composition	1979, 1990, 1992-1993, 2003, 2010, 2012-2013
Survey age composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012
Survey length composition	2014
Survey biomass estimates	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014

Analytic Approach

Model structure

The assessment model for rougheye rockfish is similar to that currently used for other BSAI rockfish, which was used as a template for the current model. Population size in numbers at age a in year t was modeled as

$$N_{t,a} = N_{t-1,a-1} e^{-Z_{t-1,a-1}} \qquad 3 \le a < A, \quad 1977 < t \le T$$

where Z is the sum of the instantaneous fishing mortality rate ($F_{t,a}$) and the natural mortality rate (M), A is the maximum number of age groups modeled in the population (defined as 45), and T is the terminal year of the analysis (defined as 2014). The numbers at age A are a "pooled" group consisting of fish of age A and older, and are estimated as

$$N_{t,A} = N_{t-1,A-1} e^{-Z_{t-1,A-1}} + N_{t-1,A} e^{-Z_{t-1,A}}$$

The numbers at age in the first year are estimated as

$$N_a = R_0 e^{-M(a-3)+\gamma_a}$$

where R_0 is the mean number of age 3 recruits prior to the start year of the model, and γ_a is an age-dependent deviation assumed to be normally distributed with mean of zero and a standard deviation equal to σ_r, the recruitment standard deviation. Estimation of the vector of age-dependant deviations from average recruitment allows estimation of year class strength.

The total numbers of age 3 fish from 1977 to 2011 are estimated as parameters in the model, and are modeled with a lognormal distribution

$$N_{t,3} = e^{(\mu_R + \nu_t)}$$

where ν_t is a time-variant deviation. Little information exists to estimate recruitment in the most recent years due to the relatively late age of recruitment to both the fishery and survey, and recruitment for 2012-2014 are set at the expected mean recruitment (based upon the log-scale mean, and the value of σ_r).

The fishing mortality rate for a specific age and time ($F_{t,a}$) is modeled as the product of a fishery age-specific selectivity ($s^f_{a,t}$) that increases asymptotically with age and a year-specific fully-selected fishing mortality rate f. The fully selected mortality rate is modeled as the product of a mean (μ_f) and a year-specific deviation (ε_t), thus $F_{t,a}$ is

$$F_{t,a} = s^f_{a,t} f_t = s^f_{a,t} e^{(\mu_f + \varepsilon_t)}$$

The mean number at age for each year was computed as

$$\overline{N}_{t,a} = N_{t,a} * (1 - e^{-Z_{t,a}}) / Z_{t,a}$$

The predicted length composition data were calculated by multiplying the mean numbers at age by a conversion matrix, which gives the proportion of each age (rows) in each length group (columns). The age bins range from 3 to 45 and the length bins range from 12 to 50, with the terminal bin being a plus group that includes all older (or larger) fish. The mean number of fish at age available to the survey or fishery is multiplied by the aging error matrix to produce the observed survey or fishery age compositions.

Catch biomass at age was computed as the product of mean numbers at age, instantaneous fishing mortality, and weight at age. The predicted trawl survey biomass (*pred_biom*) was computed as

$$pred_biom_t = qsurv \sum_a \left(\overline{N}_{t,a} * survsel_a * W_a \right)$$

where W_a is the population weight at age, $survsel_a$ is the survey selectivity, and *qsurv* is the trawl survey catchability.

To facilitate parameter estimation, prior distributions were used for the survey catchability and the natural mortality rate M. A lognormal distribution was also used for the natural mortality rate M, with the mean set to 0.03 and with the coefficient of variation (CV) set to 0.05. The prior distribution for *qsurv* followed a lognormal distribution with a mean of 1.0 and a CV of 0.05, essentially fixing *qsurv* at 1.0. In previous assessments, attempts to obtain reasonable estimates of survey catchability have not been successful. The standard deviation of log recruits, σ_r, was fixed at 0.75, a value consistent with the root mean squared error (RMSE; defined below) of recruitment deviations.

Several quantities were computed in order to compare the variance of the residuals to the assumed input variances. The root mean squared error (RMSE) should be comparable to the assumed coefficient of variation of a data series. This quantity was computed for the AI trawl survey and the estimated recruitments, and for lognormal distribution is defined as

$$RMSE = \sqrt{\frac{\sum_{n}(\ln(y) - \ln(\hat{y}))^2}{n}}$$

where y and $\hat{y}$ are the observed and estimated values, respectively, of a series length n. The standardized deviation of normalized residuals (SDNR) is closely related to the RMSE; values of SDNR approximately at 1 indicate that the model is fitting a data component as well as would be expected for a given specified input variance. The normalized residuals for a given year i of the AI trawl survey data were computed as

$$\delta_i = \frac{\ln(B_i) - \ln(\hat{B}_i)}{\sigma_i}$$

where σ_i is the input sampling standard deviation of the estimated survey biomass. For age or length composition data assumed to follow a multinomial distribution, the normalized residuals for age/length group a in year i were computed as

$$\delta_{i,a} = \frac{(y_{i,a} - \hat{y}_{i,a})}{\sqrt{\hat{y}_{i,a}(1 - \hat{y}_{i,a})/n_i}}$$

where y and $\hat{y}$ are the observed and estimated proportion, respectively, and n is the input assumed sample size for the multinomial distribution. The effective sample size was also computed for the age and length compositions modeled with a multinomial distribution, and for a given year i was computed as

$$E_i = \frac{\sum_{a} \hat{y}_a * (1 - \hat{y}_a)}{\sum_{a} (\hat{y}_a - y_a)^2}.$$

An effective sample size that is nearly equal to the input sample size can be interpreted as having a model fit that is consistent with the input sample size.

Parameterization of fishery selectivity

Four models were evaluated that differed in the parameterization for fishery selectivity at age ($s^f_{a,t}$).

Model 1) *Logistic curve* (used in previous assessments):

$$S_{f,a} = \frac{1}{1 + e^{-\phi(a - a_{50\%})}}$$

where the $a_{50\%}$ and ϕ parameters control the age at 50% maturity and the slope of the curve at this point, respectively.

Model 2) *Double logistic curve*:

$$S_{f,a} = \frac{1}{1+e^{-\phi_{asc}(a-a_{50\%})}} \frac{1}{1+e^{-\phi_{des}(a-d_{50\%})}}$$

where fishing selectivity is the product of two logistic curves, and allows for dome-shaped selectivity when the descending slope parameter (ϕ_{des}) is negative.

Model 3) Cubic spline

Model 4) Bicubic spline

A mathematical definition of a spline is a smooth function that is used for either interpolating between fixed points (referred to as "knots" or "nodes") or smoothing a dataset. Splines are of interest when the underlying process for which the spline represents is a smooth, nonlinear function. Splines are constructed from separate piecewise functions that are joined at the knots, and smoothness is ensured by requiring that at each knot, the two functions joined have equal function values, first derivatives, and second derivatives. These conditions can only be met by using polynomial splines of order 3 or higher, and cubic splines are often used because they limit unnecessary bending between the knots. Splines are implemented in non-parametric modeling such as generalized additive models, and have been examined in ecological modeling as an approach for modeling time-varying parameters (Thorson et al. 2013). In stock assessment modeling, non-parameteric selectivity curves (a category that includes splines) performed well in an evaluation of various approaches for modeling fishery selectivity (Thorson and Taylor 2013).

Cubic and bicubic splines were implemented with the "vcubic_spline_function" and "bicubic_spline" functions in AD Modelbuilder. The cubic spline models time-invariant selectivity, whereas the bicubic spline model selectivity varying across time and age; each function was developed from code provided in Press et al. (1992).

Briefly, the bicubic spline function requires the user to specify a number of age and year nodes that form a grid in the year-age matrix of time-varying selectivity (with equal grid spacing), and values at these nodes are the log-scale fishery selectivity and estimated as parameters. Fishery selectivity at ages and years between the nodes are interpolated with a bicubic spline. The smoothness of the surface is controlled by the number of nodes, and also by a series of penalties estimated within the model. The bicubic spline function was originally developed by Dr. Steve Martell for the Integrated Statistical Catch at Age (iSCAM) model, which included penalties for: 1) smoothness across the ages (modeled with the sum of second differences); 2) the slope of the rate of decline when selectivity decreases with age (modeled with the sum of first differences); and 3) the smoothness across years (modeled with the sum of second differences). In addition to these penalties, an additional penalty on the interannual variability across years (modeled with the first difference) was used in this assessment to address situations in which the selectivity across years was relatively smooth but also non-constant (as would occur with a trend).

Sample sizes for age and length composition data

In previous assessments, the sample sizes were set to the number of hauls, and multiplied by 2/3 for the fishery data and 4/3 for the survey data based upon the notion that the fishery data are less reliable. This procedure has resulted in the SDNR for the age and length compositions differing substantially from 1, indicating a mismatch between the precision of the model fit and the assumed input variance. Additionally, the reliability of the fishery composition data is largely reflected in the reduced number of samples for some years, thus application of reduced weight to these data may be redundant.

In this year's assessment, the sample sizes for the composition data were obtained from an iteratively reweighted procedure using the SDNR (method TA1.2 in Francis 2011). An initial model run in which the sample sizes were specified as in the 2012 assessment (Spencer and Rooper 2012) was conducted, and a weight that is the inverse of the variance of the normalized residuals for each composition dataset was obtained. The sample sizes for the next model run were the original sample sizes multiplied by the estimated weights, which then produced a new set of weights, and the process is iterated until the weights converge.

Parameters Estimated Outside the Assessment Model

The parameters estimated independently include the age error matrix, the age-length conversion matrix, individual weight at age, and proportion mature females at age. The derivation of the age error matrix, the age-length conversion matrix, and the weight at age vector are described above. The proportion of females mature at age (Table 13) was obtained from data on Gulf of Alaska rougheye rockfish in McDermott (1994).

Parameters Estimated Inside the Assessment Model

Parameter estimation is facilitated by comparing the model output to several observed quantities, such as the age and length composition of the survey and fishery catch, the survey biomass, and the catch biomass. The general approach is to assume that deviations between model estimates and observed quantities are attributable to observation error and can be described with statistical distributions. Each data component provides a contribution to a total log-likelihood function, and parameter values that minimize the negative log-likelihood are selected.

The negative log-likelihood of the initial recruitments were modeled with a lognormal distribution

$$\lambda_1 \left[\sum_{t=1}^{n} \frac{\left(\nu_t + {\sigma_r}^2/2\right)^2}{2{\sigma_r}^2} + n \ln(\sigma_r) \right]$$

where n is the number of years where recruitment is estimated. The adjustment of adding $\sigma_r^2/2$ to the deviation was made in order to produce deviations from the mean, rather than the median, recruitment. If σ_r is fixed, the term $n \ln(\sigma_r)$ adds a constant value to the negative log-likelihood. The negative log-likelihood of the recruitment of cohorts represented in the first year (excluding age 3, which is included in the recruitment negative log-likelihood) of the model is treated in a similar manner:

$$\lambda_1 \left[\sum_{a=4}^{A} \frac{\left(\gamma_a + {\sigma_r}^2/2\right)^2}{2{\sigma_r}^2} + (A-3) \ln(\sigma_r) \right]$$

The negative log-likelihoods of the fishery and survey age and length compositions were modeled with a multinomial distribution. The log of the multinomial function (excluding constant terms) for the fishery length composition data, with the addition of a term that scales the likelihood, is

$$-n_{f,t,l}\sum_{s,t,l}(p_{f,t,l}\ln(\hat{p}_{f,t,l})+p_{f,t,l}\ln(p_{f,t,l}))$$

where n is the number of hauls that produced the data, and $p_{f,t,l.}$ and $\hat{p}_{f,t,l}$ are the observed and estimated proportion at length in the fishery by year and length. The negative log-likelihood for the age and length proportions in the survey, $p_{surv,t,a}$ and $p_{surv,t,l}$, respectively, follow similar equations.

The negative log-likelihood of the survey biomass was modeled with a lognormal distribution:

$$\lambda_2\sum_t(\ln(obs_biom_t)-\ln(pred_biom_t))^2/2cv_t^2$$

where obs_biom_t is the observed survey biomass at time t, cv_t is the coefficient of variation of the survey biomass in year t, and λ_2 is a weighting factor. The negative log-likelihood of the catch biomass was modeled with a lognormal distribution:

$$\lambda_3\sum_t(\ln(obs_cat_t)-\ln(pred_cat_t))^2$$

where obs_cat_t and $pred_cat_t$ are the observed and predicted catch. Because the catch biomass is generally thought to be observed with higher precision than other variables, λ_3 is given a very high weight so as to fit the catch biomass nearly exactly. The overall negative log-likelihood function (excluding the catch component) is

$$\lambda_1\left[\sum_{t=1}^{n}\frac{\left(\nu_t+\sigma_r^2/2\right)^2}{2\sigma_r^2}+n\ln(\sigma_r)\right]+$$
$$\lambda_1\left[\sum_{a=4}^{A}\frac{\left(\gamma_a+\sigma_r^2/2\right)^2}{2\sigma_r^2}+(A-3)\ln(\sigma_r)\right]+$$
$$\lambda_2\sum_t\left(\ln(obs_biom_t)-\ln(pred_biom_t)\right)^2/2cv_t^2+$$
$$-n_{f,t,l}\sum_{s,t,l}(p_{f,t,l}\ln(\hat{p}_{f,t,l})+p_{f,t,l}\ln(p_{f,t,l}))+$$
$$-n_{f,t,a}\sum_{s,t,l}(p_{f,t,a}\ln(\hat{p}_{f,t,a})+p_{f,t,a}\ln(p_{f,t,a}))+$$
$$-n_{surv,t,a}\sum_{s,t,a}(p_{surv,t,a}\ln(\hat{p}_{surv,t,a})+p_{surv,t,a}\ln(p_{surv,t,a}))+$$
$$-n_{surv,t,l}\sum_{s,t,a}(p_{surv,t,l}\ln(\hat{p}_{surv,t,l})+p_{surv,t,l}\ln(p_{surv,t,l}))+$$
$$\lambda_3\sum_t\left(\ln(obs_cat_t)-\ln(pred_cat_t)\right)^2$$

For the model runs in this year's assessment, λ_1, λ_2, and λ_3 were assigned weights of 1,1, and 50, reflecting the strong emphasis on fitting the catch data.

The negative log-likelihood function was minimized by varying the following parameters (for the model with double logistic selectivity):

Parameter type	***Number***
1) fishing mortality mean	1
2) fishing mortality deviations	38
3) recruitment mean	1
4) recruitment deviations	35
5) historic recruitment	1
6) first year recruitment deviations	42
7) biomass survey catchability	1
8) natural mortality rate	1
9) survey selectivity parameters	2
10) fishery selectivity parameters	4
Total number of parameters	126

Results

Model Evaluation

Several attributes of the model fits are shown in Table 14. Models 0 and 0.1 are presented to demonstrate intermediate steps between the 2012 model and the recommended 2014 model (i.e., a "bridging" analysis). Model 0 has the updated data through 2014, Model 0.1 excludes the cooperative survey biomass estimates and age/size composition data, and each uses the age and length composition sample weights as produced for the 2012 assessment. The sample sizes for the composition are identical in Models 1-4, and were produced by applying iterative reweighting to Model 1 (time-invariant logistic selectivity). Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) were used to evaluate model selection. Each of these metrics penalize the negative log-likelihood by multiple of the number of parameters; in AIC, this multiple is 2 whereas in BIC is the natural log of the number of data points. In addition, the root mean squared errors in the fits to the data, and the residual patterns in fitting the composition data, were considered in model evaluation.

For all the models, the number of parameters is "nominal" number of parameters, which overestimates the number of independent parameters because of the use of penalties and prior distributions in the models. Deviance Information Criterion (DIC) could be used, but will often select the models with higher number of parameters (Martell and Stewart 2014). For these reasons, model selection considered additional information such as the root mean squared errors and negative log-likelihoods in the fits to the data, and the residual patterns in fitting the composition data.

Model 2 (time-invariant double logistic selectivity) had the lowest AIC and BIC. Although the double logistic curve has the flexibility to fit dome-shaped patterns, in this case the fitted double logistic selectivity curve showed nearly no selectivity below age 8, and an approximately linear increase in selectivity between ages 8 and 45+. Very low selectivity at the low ages is also estimated with the logistic model (Model 1), but because of the symmetry of the logistic curve, fitting very low selectivity at the youngest ages affects the overall curve and lowers the value of 50% selection relative to that obtained with the double logistic curve. Model 2 shows better fits to the fishery and survey age composition data (a combined reduction of 31.7 in the negative log likelihood), although a somewhat worse fit to the fishery length composition (an increase of 4.3 in the negative log-likelihood). Model 4 (the bicubic spline) show a similar overall negative log-likelihood to that of Model 2 (510.5 compared to 508.5, respectively) but has an additional 11 parameters (with 3 year nodes and 5 ages nodes). With only 4 years of fishery length composition data and no years of fishery age composition data available prior to 2004, there is relatively little information to estimate time-varying fishery selectivity.

A comparison of the spawning stock biomass from the models is shown in Figure 8. All models, including the bridging models, show an increase in spawning stock biomass in recent years due to the increased proportion of the strong 1998 year class becoming mature as it ages. However, in models the recent increase is stronger, and extends over an increased number of years, relative to the bridging models. The reweighting of the age and length composition input sizes has a similar effect across models 1-4, and puts increased emphasis and provides better fits to the survey age composition data. Between models 1-4, there is little effect on the recent estimates of spawning stock biomass.

Model 2 was selected as the preferred model, and the results below were obtained from this model.

Time series results

In this assessment, spawning biomass is defined as the biomass estimate of mature females age 3 and older. Total biomass is defined as the biomass estimate of all blackspotted/rougheye rockfish age 3 and older. Recruitment is defined as the number of age 3 blackspotted/rougheye rockfish.

A retrospective analysis was conducted to evaluate the effect of recent data on estimated spawning stock biomass. For the current assessment model, a series of model runs were conducted in which the end year of the model was varied from 2014 to 2004, and this was accomplished by sequentially dropping age and length composition data, the survey biomass estimates, and the catch from the input data files.

The plot of retrospective estimates of spawning biomass is shown in Figure 9. The largest changes in estimated survey biomass occurred in years 2004, 2006, and 2010, when both survey biomass estimates and survey age composition data are added to the model. The current estimated time series of spawning biomass is approximately centrally located within the suite of 2004-2014 spawning biomass time series. Mohn's rho can be used to evaluate the severity of any retrospective pattern, and compares an estimated quantity (in this case, spawning stock biomass) in the terminal year of each retrospective model run with the estimated quantity in the same year of the model using the full data set . The absence of any retrospective pattern would result in a Mohn's rho of 0, and would result from either identical estimates from the model runs, or from positive deviations from the reference model being offset by negative deviations. The Mohn's rho for these retrospective runs was 7.85.

Biomass Trends

The estimated survey biomass decreases from 6,842 t in 1977 to 4,180 t in 1980 due to large catches in the late 1970s, increased to 7,381 t in 1991, declined throughout the 1990s and has increased to 11,004 t in 2014 (Figure 10). The total and spawning biomass also show a decline in the late 1970s, increases

throughout the 1980s, and a decline during most of the 1990s. Since 1998, the spawning biomass has increased from 3,701 t to 6,978 t in 2014, and the total biomass has increased from 11,822 t to 38,155 t over this period (Figure 11). The more rapid recent increase of total biomass relative to spawning stock biomass reveals that much of this increase can be attributed to relatively recent year classes that have not fully matured, such as the 1998 year classes. The time series of estimated total biomass, spawner biomass, and recruitment are shown in Table 15.

Age/size compositions

The model fits to the fishery age and size compositions are shown in Figures 12 and 13 and the model fits to the survey age and length compositions are shown in Figures 14 and 15. The 2009 fishery age composition shows strong year class strengths for the 1998 and 1999 year classes, whereas the size of these year classes appears reduced in the 2011 fishery age composition data (particularly for the 1999 year class). The model essentially splits the difference in the fit to these years of fishery age compositions. The 2010 and 2012 fishery length composition data indicate that higher proportions of relatively small rougheye (i.e., 33-36 cm in 2010, 34-40 cm in 2012) are caught by the fishery. These lengths correspond approximately to 14-17 year old fish in 2010 and 15-23 year old fish in 2012, and the 1991-1997 year classes. Because these year classes are not consistently observed in other age and length compositions, the model does not produce a strong fit to the 2010 and 2012 fishery length composition data. The 2013 fishery length composition data showed a broader range of sizes, and had better model fits.

The 2010 survey age composition data also indicates relatively strong 1998 and 1999 year classes, and the 2014 survey age composition data showed a strong 1999 year class but a reduced proportion for the 1998 year class. The 2012 survey age composition data shows relatively high proportions for ages 27 -33, which correspond to lengths between 43 and 45 cm. However, the 2014 survey length composition shows relatively low reduced proportions for lengths between 35 and 45 cm, which is inconsistent with other age and length composition data and accounts for the poor model fit. The absence of fish between 35 and 45 cm in the 2014 survey is likely related to the low survey biomass estimate.

The CVs of 5% for the priors on survey catchability and natural mortality constrained these parameters to values of 1.081 and 0.033, respectively, a slight increase from the prior distribution means of 1.0 and 0.03, respectively.

The estimated age at 50% selection for the AI trawl survey was 23.5, whereas the fishery selectivity reached 50% at age 24 (Figure 16). The change in the fishery selectivity curve from a logistic to a double logistic partially accounts for the increased fishery $a_{50\%}$ from 17.8 years in the 2012 assessment.

The estimates of instantaneous fishing mortality rate are shown in Figure 17. Very high rates of fishing mortality are required in 1978 and 1979 to account for the high catches during these years, followed by rapid decreases in the early 1980s. Fishing mortality rates began to increase during the late 1980s, and were high for several years between the late 1980s and mid 1990s. Fishing mortality rates began to decline in late 1990s, and have been below the $F_{35\%}$ reference rate since 2000 (with the exception if 2001).

Fishing Mortality and Stock Status

A plot of fishing mortality rates and spawning stock biomass in reference to the ABC and OFL harvest control rules (Figure 18) shows stock status relative to $B_{35\%}$ computed from two different time periods of recruitment. The years labeled in black use the estimated recruitments the 1997- 2011 year classes, which

has been the existing practice. Although the abundance of the AI stock is estimated to be increasing, the stock status relative to $B_{35\%}$ is diminished because of the estimation of strong year classes that have been recently observed. Applying this method would result in the 2014 abundance being below ½ of $B_{35\%}$, and thus below its minimum stock size threshold (MSST). Assuming that the intent of the MSST is to identify stocks that have declined to low levels, it appears nonsensical to apply this designation to AI blackspotted/rougheye based not on a stock decline, but rather increased recruitment.

The issue for blackspotted/rougheye is that estimated strong recruitments that are relatively recently observed immediately increase the mean recruitment and $B_{35\%}$ but do not immediately affect the survey biomass estimates, or the portion of the stock that is exploited, because of the relatively high $a_{50\%}$ values for the survey and fishery selectivity. Thus, even if the recent recruitment were well-estimated, this time lag would result in the harvest control rule lowering the harvest rate for a stock that is not only not declining, but expected to increase. Additionally, some of the most recent estimates of recruitment are based on limited observations and would be expected to be imprecisely estimated. The estimated recruitment CVs (from both the Hessian and MCMC iterations) from the 2012 and 2014 assessments are shown in Figure 19. In each assessment, the Hessian and MCMC methods produce results that are similar to each other (notwithstanding the most recent year class), and show that the 1998 year class has one of the lowest estimated CVs. In addition, the CV of the 1998 year has declined from ~ 0.5 in the 2012 model to 0.25 in the 2014 model. Recruitment CVs are generally high for most of the post-1998 year classes in the 2014 assessment model.

The relative stock status for years labeled in red in Figure 18 were obtained from an estimate of mean recruitment that only uses those cohorts which have reached ages that are at least 10% selected by the trawl survey. This corresponds to ages 16 and older, and year classes 1977 – 1998. This includes the 1998 year class, which is estimated as being very large. However, this year class has now been observed for several years in the fishery and survey data, and in previous assessments has a relatively low CV associated with its estimate. Using mean recruitment from the 1977 – 1998 year classes results in a stock status for 2014 of $B_{24\%}$.

Recruitment

Recruitment strengths by year class are shown in Figure 20. There is little information to discern strong recruitments in the early years of the model, although relatively strong year classes were estimated for 1976 and 1981 and were observed in several years of survey sampling. Relative to the 2012 assessment, in which both the 1998 and 1999 year classes were strong, this assessment increases the estimate for the 1998 year class and lowers the estimate for the 1999 year class. It is likely that the ageing error matrix is allowing the model to fit the apparently strong 1999 year class in the composition data. The model estimates strong 2002 and 2006 year classes, although these are based upon relatively limited data.

The plot of recruitment against spawning stock biomass is shown in Figure 21.

Harvest Recommendations

Amendment 56 reference points for AI blackspotted/rougheye rockfish

The reference fishing mortality rate for blackspotted/rougheye rockfish is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{0.40}$, $F_{0.35}$, and $SPR_{0.40}$ were obtained from a spawner-per-recruit analysis. Based on the information presented above, estimated recruitment from post-1998 year classes were not used to estimate equilibrium recruitment for future years. The average recruitment from the 1977-1998 year classes estimated in this assessment is assumed

to represents a reliable estimate of equilibrium recruitment. An estimate of $B_{0.40}$ is calculated as the product of $SPR_{0.40}$ * equilibrium recruits, and this quantity is 11,403 t. The year 2015 spawning stock biomass is estimated as 7,932 t.

Specification of OFL and maximum permissible ABC for AI blackspotted/rougheye rockfish

Since reliable estimates of the 2015 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B<B_{0.40}$ (7,932 t < 11,403 t), blackspotted/rougheye rockfish reference fishing mortality is defined in Tier 3b. For this tier, the maximum permissible and F_{ABC} and F_{OFL} are reduced from $F_{0.40}$ and $F_{0.35}$, respectively. The values of F_{abc} and F_{OFL} are 0.032 and 0.039, respectively. The 2015 ABC and OFL for the AI blackspotted/rougheye resulting from these rates are 420 t and 516 t, respectively. A summary of these values is below.

2015 SSB estimate (B)	=	7,932 t
$B_{0.40}$	=	11,403 t
$F_{0.40}$	=	0.047
F_{ABC}	=	0.033
$F_{0.35}$	=	0.058
F_{OFL}	=	0.039

Amendment 56 reference points for EBS blackspotted/rougheye rockfish

The age-structured model pertains to the AI management area, and management reference points for the EBS management area were obtained from applying Tier 5 methods to the survey data in the EBS management area. Tier 5 reference points specify $F_{abc} = 0.75*M$ and $F_{ofl} = M$, and current estimates of M for blackspotted/rougheye rockfish obtained from the AI age structured model (0.033) were used, resulting in F_{abc} and F_{ofl} levels of 0.248 and 0.033, respectively. The ABC and OFL levels for the EBS blackspotted/rougheye rockfish were obtained by multiplying the F_{abc} and F_{ofl} values by estimated biomass. At the September 2013 Groundfish PlanTeam meeting, the Groundfish Plan Team recommended using a random effects model to estimate current biomass, and it was used in 2013 to estimate the biomass for the EBS blackspotted/rougheye rockfish.

Application of the random effects model results in a biomass estimate of 1,339 t for the EBS subarea, and was obtained by summing the estimates of biomass obtained from the EBS slope and the southern Bering Sea (SBS) area sampled by the AI trawl survey. Application of the F_{abc} and F_{ofl} values above to this biomass estimate yields the EBS OFL and ABC values to 44 t and 33 t, respectively. Summing the EBS ABC and OFL values with those obtained from the age-structured model for the AI portion of the population results in an overall BSAI ABC and OFL of 560 t and 453 t, respectively.

Population Projections for AI blackspotted/rougheye rockfish

Age-structured population projections are not possible for the EBS portion of the blackspotted/rougheye rockfish, and were conducted only for the AI blackspotted/rougheye rockfish. A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2014 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2015 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2014. In each subsequent year, the fishing mortality rate is prescribed on the basis of the

spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2015, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2015 recommended in the assessment to the *max* F_{ABC} for 2013. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 2009-2013 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be; 1) above its MSY level in 2014 or; 2) above ½ of its MSY level in 2014 and above its MSY level in 2024 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, F is set equal to *max* F_{ABC}, and in all subsequent years F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2027 under this scenario, then the stock is not approaching an overfished condition.)

The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, and projections of the mean harvest and spawning stock biomass for the remaining six scenarios are shown in Table 16.

Status Determination

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2015, it does not provide the best estimate of OFL for 2016, because the mean 2016 catch under Scenario 6 is predicated on the 2015 catch being equal to the 2015 OFL, whereas the actual 2015 catch will likely be less than the 2015 OFL. The executive summary contains the appropriate one- and two-year ahead projections for both ABC and OFL.

Under the MSFCMA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing. This report involves the answers to three questions: 1) Is the stock being subjected to overfishing? 2) Is the stock currently overfished? 3) Is the stock approaching an overfished condition?

Is the stock being subjected to overfishing? The official BSAI catch estimate for the most recent complete year (2013) is 324 t. This is less than the 2013 BSAI OFL of 462 t. Therefore, the stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. In this assessment, determination of whether the stock is overfished is complicated in that the age-structured model is applied only to the AI portion of the population; thus an estimate of MSST is only available for this portion of the population. Because current management regulations use a single OFL for the BSAI area, a meaningful measure of MSST and overfished status would need to reflect the entire BSAI population. However, the AI portion of the population composes the majority of the BSAI blackspotted/rougheye rockfish, and evaluation of its population size relative the MSST computed for the AI provides a useful index of stock condition. Harvest Scenarios #6 and #7 are used in these determinations for the AI portion of the population as follows:

Is the AI portion of the population currently below its MSST? This depends on the estimated spawning biomass in 2014:
a. If spawning biomass for 2014 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b. If spawning biomass for 2014 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c. If spawning biomass for 2014 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 16). If the mean spawning biomass for 2024 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the AI portion of the population projected to go below its MSST? This is determined by referring to harvest Scenario #7:
a. If the mean spawning biomass for 2017 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.
b. If the mean spawning biomass for 2017 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c. If the mean spawning biomass for 2017 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2027. If the mean spawning biomass for 2027 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

The results of these two scenarios indicate that the AI portion of the blackspotted/rougheye rockfish stock is neither below its MSST or projected to go below its MSST. With regard whether this portion of the stock is currently below its MSST, the expected stock size in the year 2024 of Scenario 6 is 1.65 times its

$B_{35\%}$ value of 9,978 t. With regard to whether AI portion of the blackspotted/rougheye is to go below its MSST, the expected stock size in 2027 of Scenario 7 is 1.78 times the $B_{35\%}$ value.

Area Allocation of ABC

The BSAI blackspotted/rougheye ABC is currently allocated with a subarea ABC for the western AI-central AI area, and a separate subarea ABC for the eastern AI-eastern Bering Sea area. As described above, the estimated 2015 ABC for the EBS area is 44 t. Within the AI management area, weighted averages of subarea biomass from the 2010, 2012, and 2014 AI surveys were used to compute average biomass. Weights of 4-6-9 were used, with higher weights given to more recent years.

It is also of interest to estimate the area proportions using the random effects model. The survey averaging workgroup is evaluating the use of the random effects model to smooth survey time series for computing area apportionments, and its use for computing area proportion might logically be delayed until after the workgroup has completed their evaluations. However, because the procedure does not differ from that applied to obtain the biomass for the EBS area, it seems reasonable to apply it here to compare it to the current method of using a weighted average.

The proportions obtained from these two methods were applied to the 2015 AI ABC of 420 t. The results of these calculations are shown below:

	WAI	CAI	EAI
Weighted average biomass (t)	722	4,446	2,643
Proportion of biomass	9.2%	56.9%	33.8%
Area ABC	39	239	142
Estimated 2014 biomass (from random effects model)	566	3,152	1,425
Proportion of biomass	11.0%	61.3%	27.7%
Area ABC	46	257	116

The two methods for obtaining the proportions produce similar results. Combining the WAI and CAI , and adding the EBS to the EAI, produces the following subarea ABCs from the two methods for determining the proportions (the OFL are also shown).

	BSAI	WAI+CAI	EAI+EBS	Total
OFL (2015)	560			560
ABC (2015, weighted average)		278	175	453
ABC (2015, RE model)		304	149	453
OFL (2016)	686			686
ABC (2016, weighted average)		345	210	555
ABC (2016, RE model)		377	178	555

Finally, within the last year the SSC has requested that the potential subarea ABCs be computed and presented for the subareas within the AI, particularly for the western AI. These numbers are shown below for 2015 and 2016. As shown above, if an ABC were to be applied to the western AI in 2015, its value from weighted averaging is 39 t, and its value from using a random effects model is 46 t.

	WAI	CAI	WAI-CAI
ABC (2015, weighted average)	39	239	278
ABC (2015, RE model)	46	257	304
ABC (2016, weighted average)	48	297	345
ABC (2016, RE model)	57	320	377

Data Gaps and Research Priorities

Little information is known regarding most aspects of the biology of blackspotted and rougheye rockfish, particularly in the AI. Distinguishing blackspotted rockfish from rougheye rockfish in the field is a pressing issue, particularly along the EBS slope where both species are found. Further studies to examine the distribution and movement of early life-history stages are needed. Given the results of recent genetic work, further information on the population structure associated with distinctive oceanographic features such as AI passes is needed. Finally, given the relatively unusual reproductive biology of rockfish and its importance in establishing management reference points, data on reproductive capacity should be collected on a periodic basis.

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Table 1. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of the species groups used to manage blackspotted and rougheye rockfish in the Aleutian Islands and eastern Bering Sea from 1977 to 2003. The "other red rockfish" group includes shortraker rockfish, rougheye rockfish, northern rockfish, and sharpchin rockfish. The "POP complex" includes the other red rockfish species plus POP.

	BSAI				AI					EBS			
Year	Manageme Group	OFL	ABC (t)	TAC (t)	Catch (t)	Management Group	OFL	ABC	TAC	Catch	Management Group	OFL	ABC	TAC	Catch
1977						Other species				155	Other species				2
1978						Other species				2423	Other species				99
1979						Other species				3077	Other species				477
1980						Other species				660	Other species				160
1981						Other species				595	Other species				283
1982						POP complex				189	POP complex				124
1983						POP complex				58	POP complex				53
1984						POP complex				35	POP complex				79
1985						POP complex				10	POP complex				18
1986						Other rockfish			5800	21	Other rockfish			825	52
1987						Other rockfish			1430	79	Other rockfish			450	99
1988						Other rockfish		1100	1100	75	Other rockfish		400	400	111
1989						POP Complex		16600	6000	381	POP Complex		6000	5000	204
1990						POP Complex		16600	6000	1619	POP Complex		6300	6300	369
1991						Other red		4685	4685	137	Other red		1670	1670	106
1992						RE/SR	1220	1220	1220	1181	ORR	1400	1400	1400	77
1993						RE/SR	1220	1220	1100	924	ORR	1400	1400	1200	146
1994						RE/SR	1220	1220	1220	749	ORR	1400	1400	1400	22
1995						RE/SR	1220	1220	1098	395	ORR	1400	1400	1260	28
1996						RE/SR	1250	1250	1125	816	ORR	1400	1400	1260	34
1997						RE/SR	1250	938	938	954	ORR	1400	1050	1050	15
1998						RE/SR	1290	965	965	526	ORR	356	267	267	16
1999						RE/SR	1290	965	965	385	ORR	356	267	267	9
2000						RE/SR	1180	885	885	280	ORR	259	194	194	26
2001	RE/SR	1369	1028	1028	565	RE/SR			912	550	RE/SR			116	15
2002	RE/SR	1369	1028	1028	284	RE/SR			912	273	RE/SR			116	12
2003	RE/SR	1289	967	967	191	RE/SR			830	174	RE/SR			137	17

Table 2. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of the species groups used to manage blackspotted and rougheye rockfish in the Aleutian Islands and eastern Bering Sea from 2004 to 2014. Catch data is through October 11, 2014, from NMFS Alaska Regional Office. The "rougheye" management group includes both blackspotted rockfish and rougheye rockfish.

	BSAI					WAI/CAI					EAI/EBS			
Year	Manageme Group	OFL	ABC (t)	TAC (t)	Catch (t)	Management Group	OFL	ABC	TAC	Catch	Management Group	OFL	ABC	TAC	Catch
2004	Rougheye	259	195	195	209										
2005	Rougheye	298	223	223	90										
2006	Rougheye	299	224	224	203										
2007	Rougheye	269	202	202	167										
2008	Rougheye	269	202	202	214										
2009	Rougheye	660	539	539	209										
2010	Rougheye	669	547	547	256										
2011	Rougheye	549	454	454	170	Rougheye		220	220	77	Rougheye		234	234	94
2012	Rougheye	576	475	475	201	Rougheye		244	244	131	Rougheye		231	231	70
2013	Rougheye	462	378	378	324	Rougheye		209	209	146	Rougheye		169	169	178
2014	Rougheye	505	416	416	194	Rougheye		239	239	98	Rougheye		177	177	96

Table 3. Catch of blackspotted and rougheye rockfish (t) in the BSAI area.

	Eastern Bering Sea			Aleutian Islands			BSAI
Year	Foreign	JV	Domestic	Foreign	JV	Domestic	Total
1977	2	0		155	0		157
1978	99	0		2,423	0		2,522
1979	477	0		3,077	0		3,553
1980	160	0		660	0		820
1981	283	0		595	0		878
1982	124	0		189	0		312
1983	53	0		56	2		111
1984	79	0		31	4		114
1985	18	0		1	9		27
1986	3	1	48	0	2	19	74
1987	1	2	96	0	3	76	179
1988	0	1	110	0	5	70	185
1989	0	2	202	0	0	381	585
1990			369			1,619	1,988
1991			106			137	243
1992			77			1,181	1,258
1993			146			924	1,070
1994			22			749	770
1995			28			395	423
1996			34			816	850
1997			15			954	969
1998			16			526	542
1999			9			385	394
2000			26			280	307
2001			15			550	565
2002			12			273	284
2003			17			174	191
2004			24			185	209
2005			12			78	90
2006			7			196	203
2007			10			157	167
2008			29			185	214
2009			12			197	209
2010			34			222	256
2011			39			131	170
2012			18			183	201
2013			27			297	324
2014*			21			173	194

*Catch data through October 11, 2014, from NMFS Alaska Regional Office.

Table 4. Area-specific catches (t) of blackspotted and rougheye rockfish (t) in the BSAI area, obtained from the North Pacific Groundfish Observer Program, NMFS Alaska Regional Office. BSAI subareas are the western Aleutians Islands (WAI), central Aleutian Islands (CAI), and eastern Aleutian Islands (EAI), and eastern Bering Sea (EBS).

Year	WAI	CAI	EAI	EBS	Total
1994	49	197	503	22	770
1995	43	100	252	28	423
1996	446	184	186	34	850
1997	513	138	303	15	969
1998	109	232	185	16	542
1999	88	161	136	9	394
2000	103	139	39	26	307
2001	128	133	289	15	565
2002	96	63	114	12	284
2003	66	58	51	17	191
2004	115	58	12	24	209
2005	43	24	11	12	90
2006	109	45	42	7	203
2007	44	42	71	10	167
2008	61	74	50	29	214
2009	74	84	39	12	209
2010	94	52	76	34	256
2011	46	31	54	39	170
2012	65	66	52	18	201
2013	84	62	151	27	324
2014*	56	42	75	21	194

* Estimated removals through October 11, 2014.

Table 5. Estimated retained (t), discarded (t), and percent discarded of other red rockfish (ORR), shortraker/rougheye (SR/RE), and blackspotted/rougheye rockfish from the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions.

	AI					EBS				
	Species				Percent	Species				Percent
Year	Group	Retained	Discarded	Total	Discarded	Group	Retained	Discarded	Total	Discarded
1993	RE/SR	737	403	1139	35%	Other red rockfish	367	97	464	21%
1994	RE/SR	701	224	925	24%	Other red rockfish	29	100	129	78%
1995	RE/SR	456	103	558	18%	Other red rockfish	274	70	344	20%
1996	RE/SR	751	208	959	22%	Other red rockfish	58	149	207	72%
1997	RE/SR	733	310	1043	30%	Other red rockfish	44	174	218	80%
1998	RE/SR	447	238	685	35%	Other red rockfish	38	59	97	61%
1999	RE/SR	319	195	514	38%	Other red rockfish	75	163	238	68%
2000	RE/SR	285	196	480	41%	Other red rockfish	111	141	253	56%
2001	RE/SR	476	246	722	34%	RE/SR	27	16	43	38%
2002	RE/SR	333	146	478	30%	RE/SR	50	54	105	52%
2003	RE/SR	197	84	281	30%	RE/SR	62	54	116	47%
2004	Rougheye	83	102	185	55%	Rougheye	15	9	24	39%
2005	Rougheye	72	6	78	8%	Rougheye	3	9	12	73%
2006	Rougheye	166	30	196	15%	Rougheye	5	2	7	30%
2007	Rougheye	127	30	157	19%	Rougheye	7	3	10	29%
2008	Rougheye	142	43	185	23%	Rougheye	12	17	29	58%
2009	Rougheye	162	35	197	18%	Rougheye	9	3	12	26%
2010	Rougheye	187	34	222	15%	Rougheye	20	14	34	42%
2011	Rougheye	115	16	131	12%	Rougheye	31	9	39	22%
2012	Rougheye	158	24	183	13%	Rougheye	14	5	18	25%
2013	Rougheye	243	54	297	18%	Rougheye	20	7	27	28%
2014*	Rougheye	158	15	173	9%	Rougheye	16	5	21	23%

* Estimated removals through October 11, 2014.

Table 6. Aleutian Islands and eastern Bering Sea cumulative catch (t) of blackspotted and rougheye rockfish from top gear and target combinations by management area and target fishery in 2004-2012, from the NMFS Alaska Regional Office catch accounting system database.

Aleutian Islands

		Management Area			
Target	Gear	541	542	543	Total
Rockfish	Bottom trawl	204.72	180.51	506.59	891.82
Pacific cod	Longline	25.39	123.12	73.72	222.22
Atka mackerel	Bottom trawl	33.58	92.07	66.34	191.99
Arrowtooth	Bottom trawl	73.71			73.71
Kamchatka	Bottom trawl	37.17			37.17
Sablefish	Longline	13.26	19.78		33.04
Halibut	Longline	9.05	15.01	3.80	27.85
Arrowtooth	Longline	0.02	16.31		16.33
Turbot	Longline	0.10	9.84		9.95
Pacific cod	Bottom trawl	2.69	4.36	0.35	7.40
Total (all targets and gears)		403.33	462.03	651.58	1516.94

Eastern Bering Sea

		Management Area									
Target	Gear	509	513	514	517	518	519	521	523	524	Total
Arrowtooth	Bottom trawl				15.99	18.53	8.00	3.40	0.11	0.75	46.77
Pacific cod	Longline	0.02	0.03		3.40	0.07	2.12	27.92	3.42	0.26	37.24
Rockfish	Bottom trawl				19.91	10.53	1.02	2.90	0.80		35.17
Halibut	Longline			0.02	1.73	9.85	1.24	3.75	2.09	3.53	22.20
Turbot	Longline				0.10	0.08	0.05	9.82	3.08	0.10	13.23
pollock pelagic	Pelagic trawl	0.15	0.04		5.25		1.94	1.38	0.01	0.03	8.81
Other flatfish	Bottom trawl				3.09		3.40				6.49
Flathead sole	Bottom trawl		1.07		1.02			0.46	0.48		3.03
Kamchatka	Bottom trawl					2.28	0.13			0.26	2.67
Pacific cod	Bottom trawl	0.10	0.00		0.69		0.62	0.34	0.28		2.02
Pollock bottom	Pelagic trawl	0.02	0.01		0.41		1.03	0.02			1.49
Sablefish	Longline				0.60	0.17	0.49	0.04	0.06		1.36
Atka mackerel	Bottom trawl						1.19				1.19
Total (all targets and gears)		0.27	1.16	0.02	55.45	42.33	21.79	50.28	10.42	4.94	186.66

Table 7. Samples sizes of blackspotted/rougheye lengths from fishery sampling in the eastern Bering Sea (EBS), Aleutian Islands (AI), and the eastern Bering Sea and Aleutian Islands combined (BSAI), with the number of hauls from which these data were collected, from 1977-2013.

	EBS		AI		BSAI	
Year	Lengths	Hauls	Lengths	Hauls	Lengths	Hauls
1977						
1978			54	6	54	6
1979	2340	132	4406	93	6746	225
1980						
1981						
1982						
1983			33	1	33	1
1984						
1985						
1986						
1987						
1988						
1989						
1990	800	29	1161	20	1961	49
1991	95	16	49	1	144	17
1992	61	1	1182	67	1243	68
1993	2	2	1046	39	1048	41
1994			27	1	27	1
1995	42	3			42	3
1996	14	3			14	3
1997						
1998						
1999	4	2	53	4	57	6
2000	4	1	160	21	164	22
2001	10	1	277	42	287	43
2002			336	49	336	49
2003	76	18	832	100	908	118
2004	215	41	1265	242	1480	283
2005	71	39	314	94	385	133
2006	61	16	266	56	327	72
2007	104	40	716	160	820	200
2008	38	20	371	105	409	125
2009	16	10	1002	211	1018	221
2010	103	46	1904	375	2007	421
2011	157	81	692	170	849	251
2012	81	48	923	164	1004	212
2013	208	80	1501	274	1709	354

Table 8. Samples sizes of blackspotted/rougheye otoliths from fishery sampling in the eastern Bering Sea (EBS), Aleutian Islands (AI), and the eastern Bering Sea and Aleutian Islands combined (BSAI), with the number of hauls from which these data were collected, from 1977-2013.

	Otoliths Sampled			Otoliths Read			Hauls (Otoliths Read)		
Year	EBS	AI	BSAI	EBS	AI	BSAI	EBS	AI	BSAI
1977									
1978									
1979	440	383	823	14	38	52	6	4	10
1980									
1981									
1982									
1983									
1984									
1985									
1986									
1987									
1988									
1989									
1990	54	0	54						
1991									
1992		50	50						
1993									
1994									
1995									
1996									
1997									
1998									
1999	4	4	8						
2000	2	24	26						
2001	2	76	78						
2002		67	67						
2003	19	120	139						
2004	14	147	161	14	146	160	11	90	101
2005	37	100	137	35	97	132	23	65	88
2006	5	83	88		82	82		47	47
2007	14	138	152	14	134	148	10	83	93
2008	17	125	142	17	121	138	13	74	87
2009	13	138	151	6	138	144	6	90	96
2010	26	172	198						
2011	22	155	177	19	154	173	12	85	97
2012	26	109	135						
2013	49	254	303						

Table 9. Estimated biomass (t) of blackspotted/rougheye rockfish from the EBS slope survey and AI trawl survey (by management area), with the coefficient of variation (CV) shown in parentheses.

		AI survey		
Year	AI	S. Bering Sea	Total	EBS Slope survey
1979				1053
1980	8,987 (0.07)	6 (1.00)	8,993 (0.07)	
1981				816
1982				605
1983	13,104 (0.19)	2,111 (0.33)	15,215 (0.17)	
1984				
1985				1716
1986	57,351 (0.51)	2,724 (0.49)	60,076 (0.49)	
1987				
1988				876 (0.32)
1989				
1990				
1991	10,638 (0.47)	676 (0.12)	11,314 (0.44)	884 (0.30)
1992				
1993				
1994	13,415 (0.28)	1,208 (0.49)	14,623 (0.26)	
1995				
1996				
1997	10,905 (0.22)	561 (0.66)	11,466 (0.21)	
1998				
1999				
2000	14,240 (0.23)	1,054 (0.26)	15,294 (021)	
2001				
2002	8,423 (0.21)	1,251 (0.48)	9,674 (0.20)	553 (0.20)
2003				
2004	14,386 (0.26)	654 (0.31)	15,039 (0.25)	646 (0.16)
2005				
2006	8,281 (0.25)	1,224 (0.33)	9,505 (0.23)	
2007				
2008				829 (0.24)
2009				
2010	8,541 (0.26)	221 (0.28)	8,762 (0.26)	999 (0.25)
2011				
2012	12,401 (0.38)	405 (0.27)	12,807 (0.37)	1,613 (0.50)
2013				
2014	4,425 (0.19)	311 (0.20)	4,736 (0.18)	

Table 10. Blackspotted/rougheye subarea biomass estimates (t) from the 1991-2014 Aleutian Islands trawl surveys.

	Aleutian Islands Survey Sub-Areas			
Year	Western AI	Central AI	Eastern AI	Southern Bering Sea
1991	3,037	2,380	5,221	676
1994	2,908	3,470	7,037	1,208
1997	3,373	4,607	2,925	561
2000	683	9,333	4,224	1,054
2002	1,390	3,934	3,099	1,251
2004	1,185	7,681	5,520	654
2006	519	4,959	2,803	1,224
2010	1,601	2,238	4,702	221
2012	335	8,268	3,798	405
2014	589	2,878	958	311
Weighted Average (2010-2014)	722	4,445	2,643	322

Table 11. Samples sizes of blackspotted/rougheye lengths from the Aleutian Island trawl survey, with the number of hauls from which these data were collected, from 1991-2014.

	Lengths			Hauls		
Year	SBS	AI	Total	SBS	AI	Total
1991	79	981	1060	5	30	35
1992						
1993						
1994	412	1963	2375	14	90	104
1995						
1996						
1997	90	1727	1817	13	108	121
1998						
1999						
2000	165	1508	1673	18	101	119
2001						
2002	258	1030	1288	19	79	98
2003						
2004	103	1419	1522	13	104	117
2005						
2006	177	1082	1259	20	102	122
2007						
2008						
2009						
2010	27	959	986	10	82	92
2011						
2012	129	1227	1356	25	94	119
2013						
2014	62	973	1035	19	88	107

Table 12. Samples sizes of blackspotted/rougheye otoliths from the Aleutian Island (AI) trawl survey, with the number of hauls from which these data were collected, from 1991-2014. SBS is the southern Bering Sea, which is the portion of Aleutian Islands trawl survey from 165° W to 170 W°.

	Otoliths sampled			Otoliths Read			Hauls (Otoliths Read)		
Year	SBS	AI	Total	SBS	AI	Total	SBS	AI	Total
1991	79	401	480	79	397	476	6	23	29
1992									
1993									
1994	194	535	729	130	356	486	13	55	68
1995									
1996									
1997	76	790	866	52	526	578	9	83	92
1998									
1999									
2000	116	376	492	115	375	490	16	71	87
2001									
2002	114	359	473	114	337	451	15	66	81
2003									
2004	103	372	475	102	370	472	14	83	97
2005									
2006	120	339	459	120	339	459	19	83	102
2007									
2008									
2009									
2010	27	464	491	26	456	482	10	79	89
2011									
2012	92	468	560	77	468	535	13	82	95
2013									
2014	57	338	395						

Table 13. Predicted weight and proportion mature at age for BSAI rougheye rockfish.

Age	Predicted weight (g)	Proportion mature
3	59	0
4	86	0
5	117	0
6	154	0.001
7	195	0.001
8	240	0.003
9	289	0.008
10	340	0.015
11	394	0.03
12	450	0.053
13	507	0.09
14	566	0.141
15	625	0.209
16	684	0.29
17	744	0.378
18	803	0.467
19	861	0.551
20	919	0.625
21	976	0.689
22	1,031	0.742
23	1,085	0.785
24	1,138	0.82
25	1,189	0.847
26	1,239	0.87
27	1,287	0.888
28	1,333	0.902
29	1,378	0.914
30	1,421	0.924
31	1,462	0.932
32	1,502	0.939
33	1,540	0.944
34	1,576	0.949
35	1,611	0.953
36	1,644	0.956
37	1,675	0.959
38	1,706	0.962
39	1,734	0.964
40	1,762	0.966
41	1,788	0.968
42	1,812	0.969
43	1,836	0.97
44	1,858	0.971
45+	2,054	0.977

Table 14. Negative log likelihoods, and several measures of model fits, for the evaluated models for BSAI blackspotted/rougheye rockfish.

	Model 0	Model 0.1	Model 1	Model 2	Model 3	Model 4
Negative log-likelihood						
Data components						
AI survey biomass	26.29	20.78	26.26	29.17	30.64	26.60
Catch biomass	0.01	0.00	0.00	0.01	0.01	0.01
Fishery age comp	111.77	109.82	114.89	101.38	112.27	109.93
Fishery length comp	103.11	101.81	155.11	159.40	162.74	151.75
AI survey age comp	121.15	101.93	189.38	172.14	177.67	171.77
AI survey lengths comp	33.91	29.79	10.29	10.03	11.06	10.16
Priors and penalties						
Recruitment	21.02	23.52	33.38	26.97	26.32	21.97
Prior on survey q	2.33	0.50	0.61	1.27	1.40	1.04
Prior on M	4.97	1.96	2.36	1.87	1.93	1.57
Fishery selectivity	0.00	0.00	0.00	0.00	16.32	9.68
Total negative log-likelihood	430.56	395.87	538.28	508.51	546.57	510.49
Parameters		124	124	126	127	137
Number of data points		1044	1044	1044	1044	1044
BIC		1653.65	1938.46	1892.82	1975.89	1973.23
AIC		1039.75	1324.56	1269.02	1347.14	1294.97
Effective sample size						
Fishery age comp	55	57	55	60	57	57
Fishery length comp	523	433	395	195	225	148
AI survey age comp	104	153	207	244	244	259
AI survey lengths comp	129	78	67	68	67	64
Sample weights						
Fishery age comp	54	54	55	55	55	55
Fishery length comp	94	94	152	152	152	152
AI survey age comp	85	93	202	202	202	202
AI survey lengths comp	115	117	28	28	28	28
Root mean square error						
AI survey biomass	0.601	0.464	0.521	0.556	0.572	0.529
Recruitment	0.911	0.935	0.968	0.966	0.951	0.924
Fishery age comp	0.023	0.023	0.023	0.021	0.023	0.023
Fishery length comp	0.017	0.017	0.016	0.015	0.016	0.015
AI survey age comp	0.018	0.014	0.012	0.011	0.011	0.011
AI survey lengths comp	0.015	0.018	0.019	0.019	0.019	0.019
Standard Deviation of Normalized Residuals						
AI survey biomass	1.90	1.93	2.18	2.22	2.27	2.13
Fishery age comp	0.98	0.96	1.00	0.99	0.96	0.96
Fishery length comp	0.82	0.81	1.00	1.02	1.02	0.99
AI survey age comp	0.77	0.73	1.00	0.95	0.97	0.95
AI survey lengths comp	1.13	1.49	1.00	0.97	1.06	0.96

Table 15. Estimated time series of AI blackspotted/rougheye total biomass (t), spawner biomass (t), and recruitment (thousands).

	Total Biomass (ages 3+) Assessment Year		Spawner Biomass (ages 3+) Assessment Year		Recruitment (age 3) Assessment Year	
Year	2014	2012	2014	2012	2014	2012
1977	15,500	18,520	4,303	5,299	881	1,062
1978	15,992	19,106	4,433	5,474	1,044	1,265
1979	14,083	17,341	3,731	4,833	1,535	1,797
1980	11,441	14,849	3,003	4,132	1,223	1,509
1981	11,335	14,833	3,035	4,193	823	1,079
1982	11,286	14,869	3,100	4,289	838	1,078
1983	11,661	15,332	3,296	4,523	1,110	1,323
1984	12,186	15,948	3,533	4,803	1,408	1,591
1985	12,761	16,580	3,778	5,093	1,755	1,448
1986	13,359	17,221	4,031	5,390	1,416	1,166
1987	13,917	17,820	4,273	5,677	820	833
1988	14,402	18,339	4,493	5,943	670	712
1989	14,886	18,840	4,687	6,181	769	705
1990	15,047	18,998	4,674	6,207	762	616
1991	13,932	17,797	4,335	5,881	557	475
1992	14,288	18,133	4,426	6,009	460	401
1993	13,566	17,344	4,171	5,774	440	380
1994	13,078	16,798	4,016	5,640	458	397
1995	12,746	16,411	3,947	5,592	515	464
1996	12,764	16,374	3,974	5,638	670	600
1997	12,349	15,887	3,846	5,518	927	730
1998	11,822	15,258	3,701	5,372	1,645	1,019
1999	11,771	15,109	3,713	5,382	2,058	1,650
2000	11,851	15,105	3,779	5,439	1,362	1,533
2001	13,334	15,838	3,854	5,501	23,104	10,990
2002	13,902	16,673	3,839	5,466	3,283	13,342
2003	15,136	17,410	3,932	5,538	7,391	2,118
2004	16,378	18,314	4,037	5,612	2,057	2,339
2005	18,356	19,369	4,134	5,674	13,303	3,566
2006	20,256	20,494	4,258	5,756	4,044	1,549
2007	22,198	21,603	4,371	5,837	3,662	1,252
2008	24,205	22,695	4,483	5,889	3,038	1,329
2009	26,782	23,777	4,628	5,951	11,653	1,581
2010	29,042	24,857	4,829	6,048	2,011	
2011	31,281	25,907	5,136	6,208	1,560	
2012	33,663	27,040	5,597	6,488		
2013	35,973	28,079	6,208			
2014	38,155		6,978			
2015	40,391					

Table 16. Projections of Aleutian Island (AI) blackspotted/rougheye rockfish spawning biomass (t), catch (t), and fishing mortality rate for each of the several scenarios resulting from the AI model. The values of $B_{40\%}$ and $B_{35\%}$ are 11,403 t and 9,977 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2014	191	191	191	191	191	191	191
2015	420	420	211	309	0	516	420
2016	516	516	264	336	0	629	516
2017	630	630	328	365	0	761	774
2018	759	759	400	397	0	909	922
2019	828	828	433	429	0	1,001	1,007
2020	882	882	466	462	0	1,060	1,067
2021	937	937	499	496	0	1,121	1,127
2022	991	991	534	530	0	1,181	1,187
2023	1,045	1,045	569	565	0	1,239	1,245
2024	1,097	1,097	603	599	0	1,294	1,301
2025	1,147	1,147	638	634	0	1,347	1,353
2026	1,194	1,194	671	667	0	1,395	1,402
2027	1,238	1,238	703	699	0	1,439	1,445
Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2014	6,978	6,978	6,978	6,978	6,978	6,978	6,978
2015	7,932	7,932	7,944	7,939	7,956	7,927	7,932
2016	8,953	8,953	9,042	9,003	9,132	8,913	8,953
2017	10,053	10,053	10,239	10,175	10,432	9,970	10,045
2018	11,181	11,181	11,489	11,409	11,815	11,045	11,119
2019	12,311	12,311	12,769	12,687	13,263	12,111	12,185
2020	13,411	13,411	14,042	13,958	14,727	13,137	13,212
2021	14,469	14,469	15,291	15,205	16,191	14,113	14,188
2022	15,447	15,447	16,478	16,390	17,616	15,004	15,078
2023	16,316	16,316	17,570	17,482	18,968	15,780	15,854
2024	17,076	17,076	18,568	18,479	20,247	16,443	16,515
2025	17,704	17,704	19,445	19,356	21,425	16,970	17,041
2026	18,202	18,202	20,201	20,113	22,500	17,366	17,435
2027	18,579	18,579	20,843	20,756	23,478	17,640	17,706
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2014	0.016	0.016	0.016	0.016	0.016	0.016	0.016
2015	0.032	0.032	0.016	0.023	0	0.039	0.032
2016	0.036	0.036	0.018	0.023	0	0.044	0.036
2017	0.041	0.041	0.021	0.023	0	0.050	0.050
2018	0.046	0.046	0.023	0.023	0	0.056	0.056
2019	0.047	0.047	0.023	0.023	0	0.058	0.058
2020	0.047	0.047	0.023	0.023	0	0.058	0.058
2021	0.047	0.047	0.023	0.023	0	0.058	0.058
2022	0.047	0.047	0.023	0.023	0	0.058	0.058
2023	0.047	0.047	0.023	0.023	0	0.058	0.058
2024	0.047	0.047	0.023	0.023	0	0.058	0.058
2025	0.047	0.047	0.023	0.023	0	0.058	0.058
2026	0.047	0.047	0.023	0.023	0	0.058	0.058
2027	0.047	0.047	0.023	0.023	0	0.058	0.058

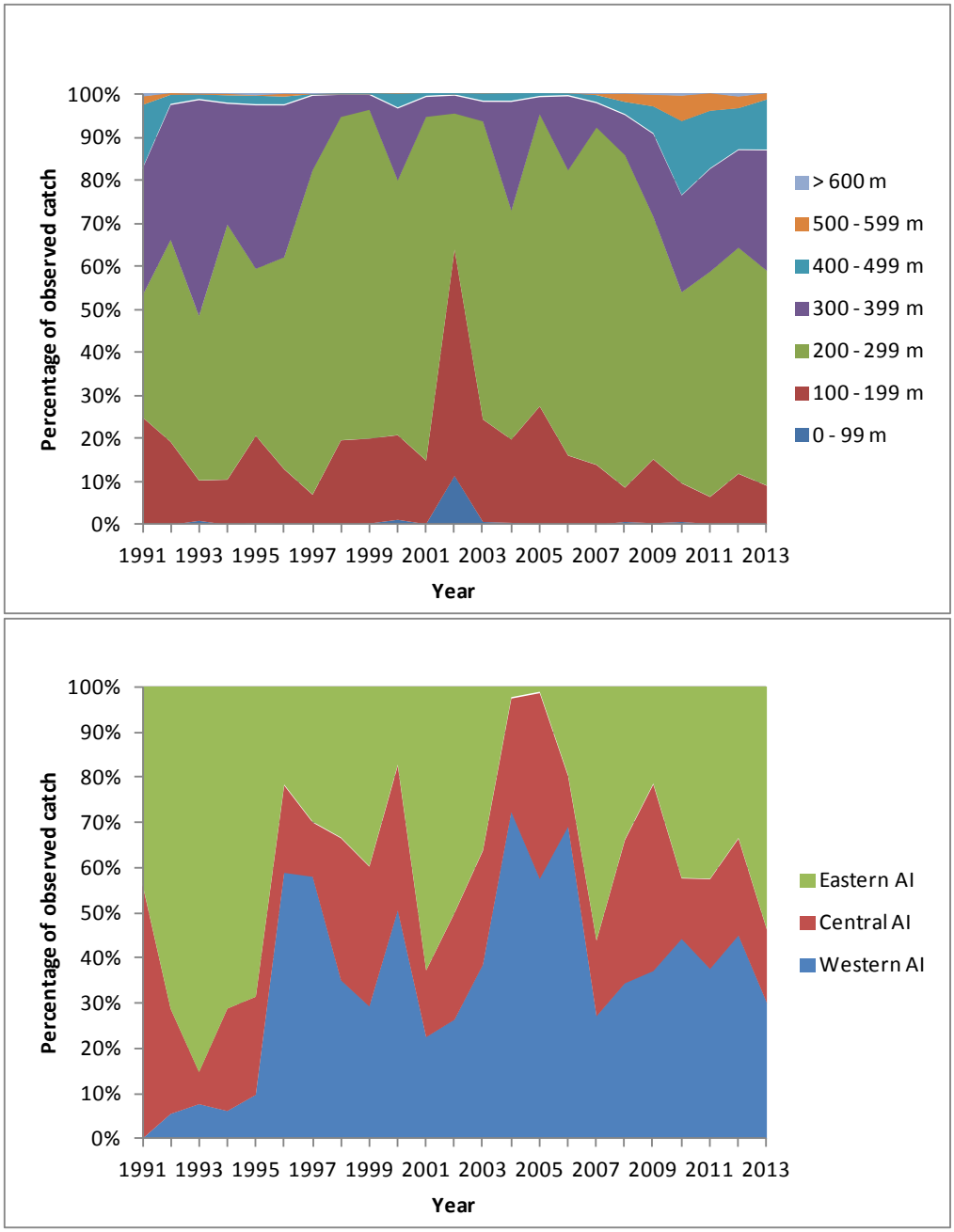

Figure 1. Distribution of observed Aleutian Islands (AI) blackspotted/rougheye rockfish catch (from North Pacific Groundfish Observer Program) by depth zone (top panel) and AI subarea (bottom panel) from 1991 to 2013.

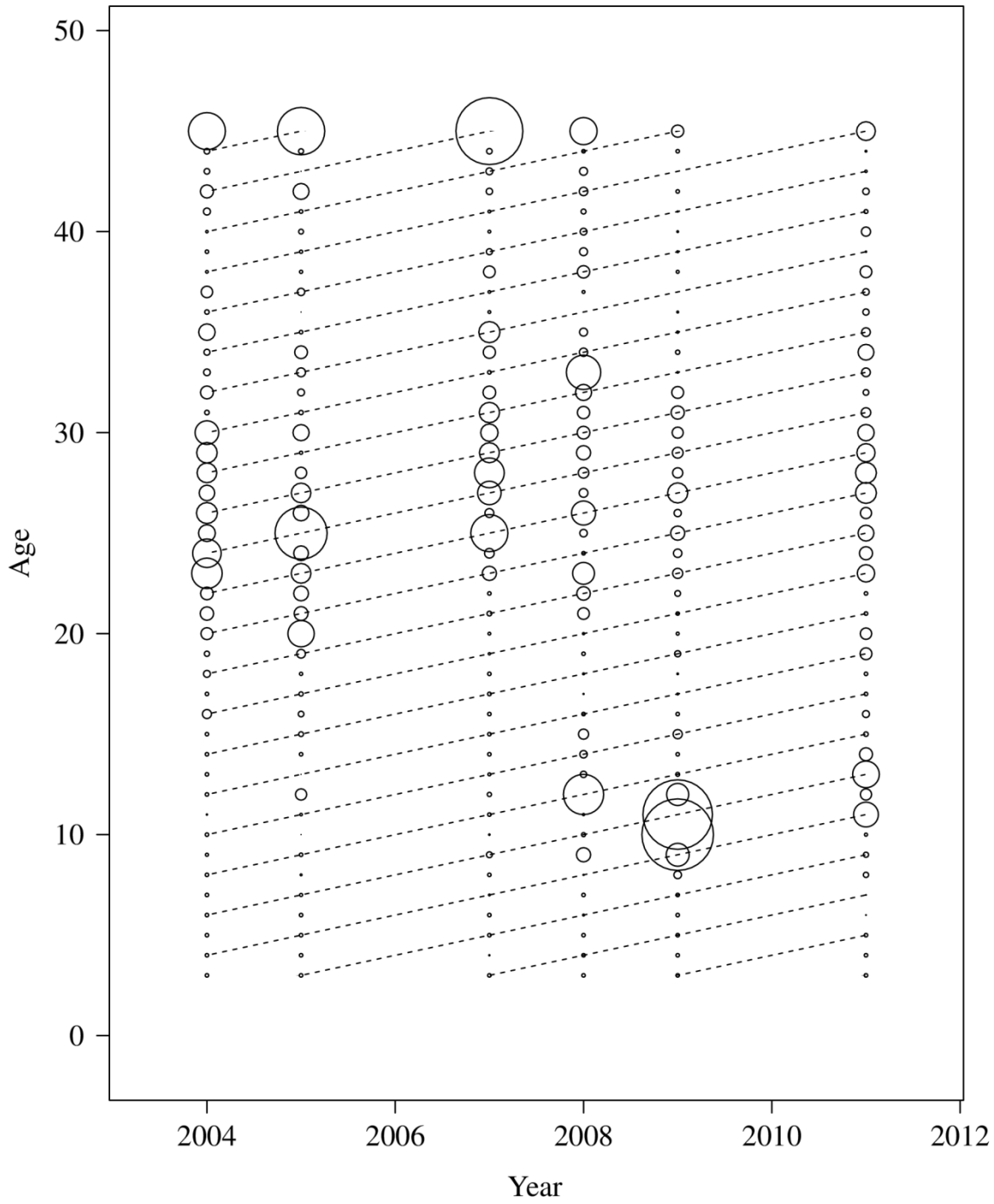

Figure 2. Fishery age composition data for the Aleutian Islands; bubbles are scaled within each year of samples and dashed lines denote cohorts.

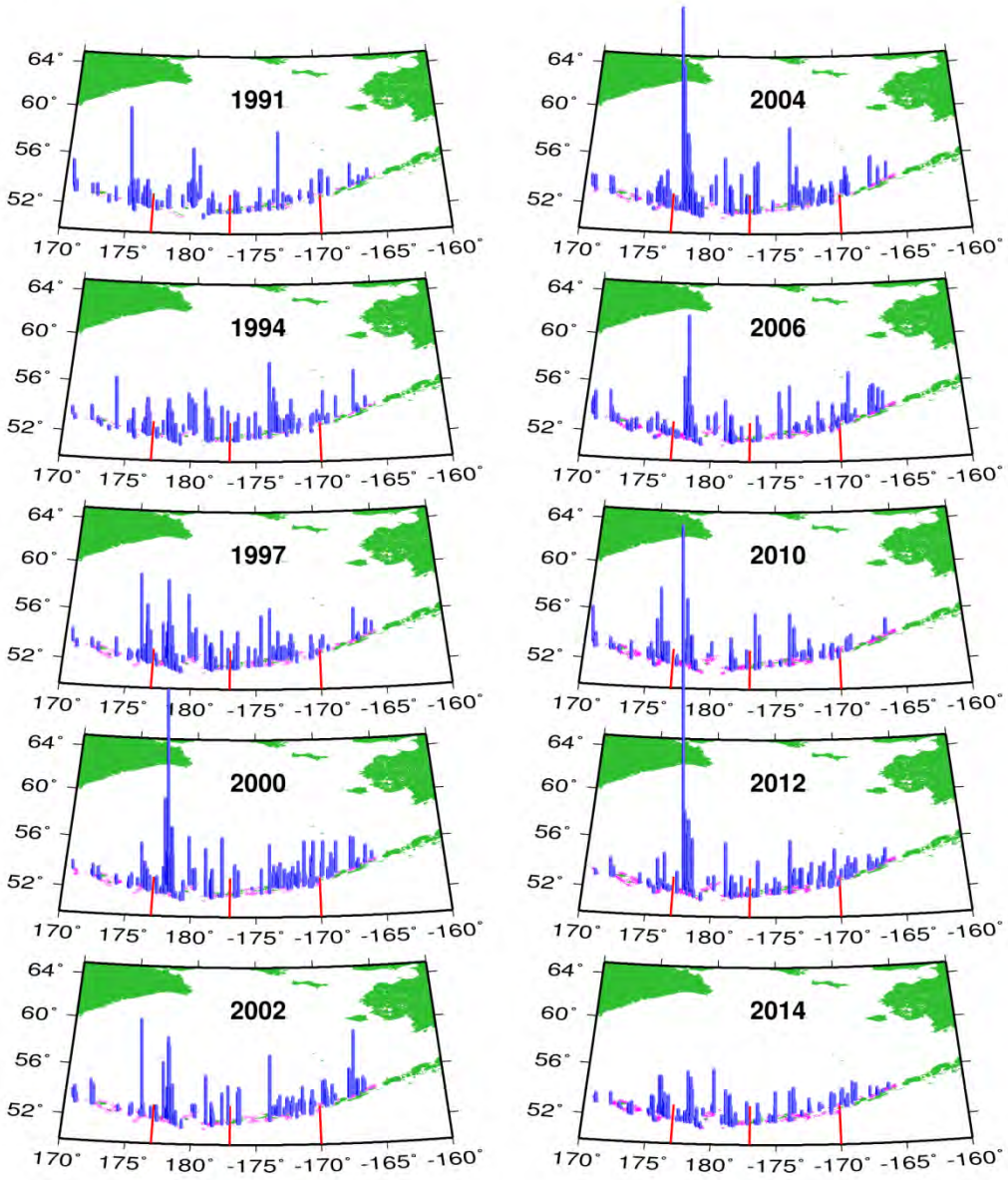

Figure 3. Scaled Aleutian Islands (AI) survey combined blackspotted and rougheye rockfish CPUE (square root of kg/km^2) from 1991-2014; the symbol × denotes tows with no catch. The red lines indicate boundaries between the western Aleutian Islands (WAI), central Aleutian Islands (CAI), eastern Aleutian Islands (EAI), and eastern Bering Sea (EBS) areas.

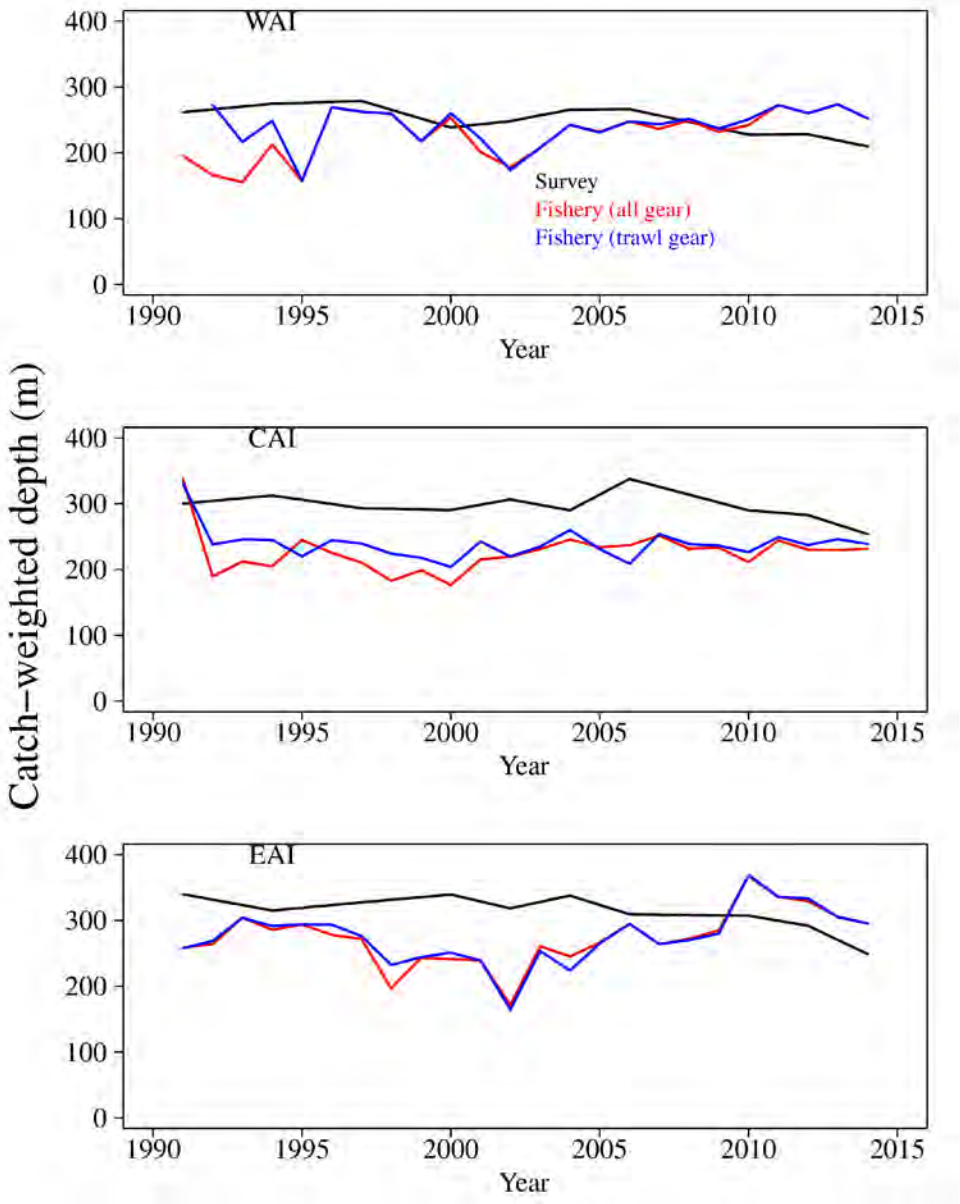

Figure 4. Catch-weighted (by numbers) depth of capture for blackspotted/rougheye rockfish in the fishery and AI survey by AI subarea from 1991 to 2014: WAI = western Aleutian Islands (top panel), CAI = central Aleutian Islands (middle panel), and EAI = eastern Aleutian Islands (bottom panel).

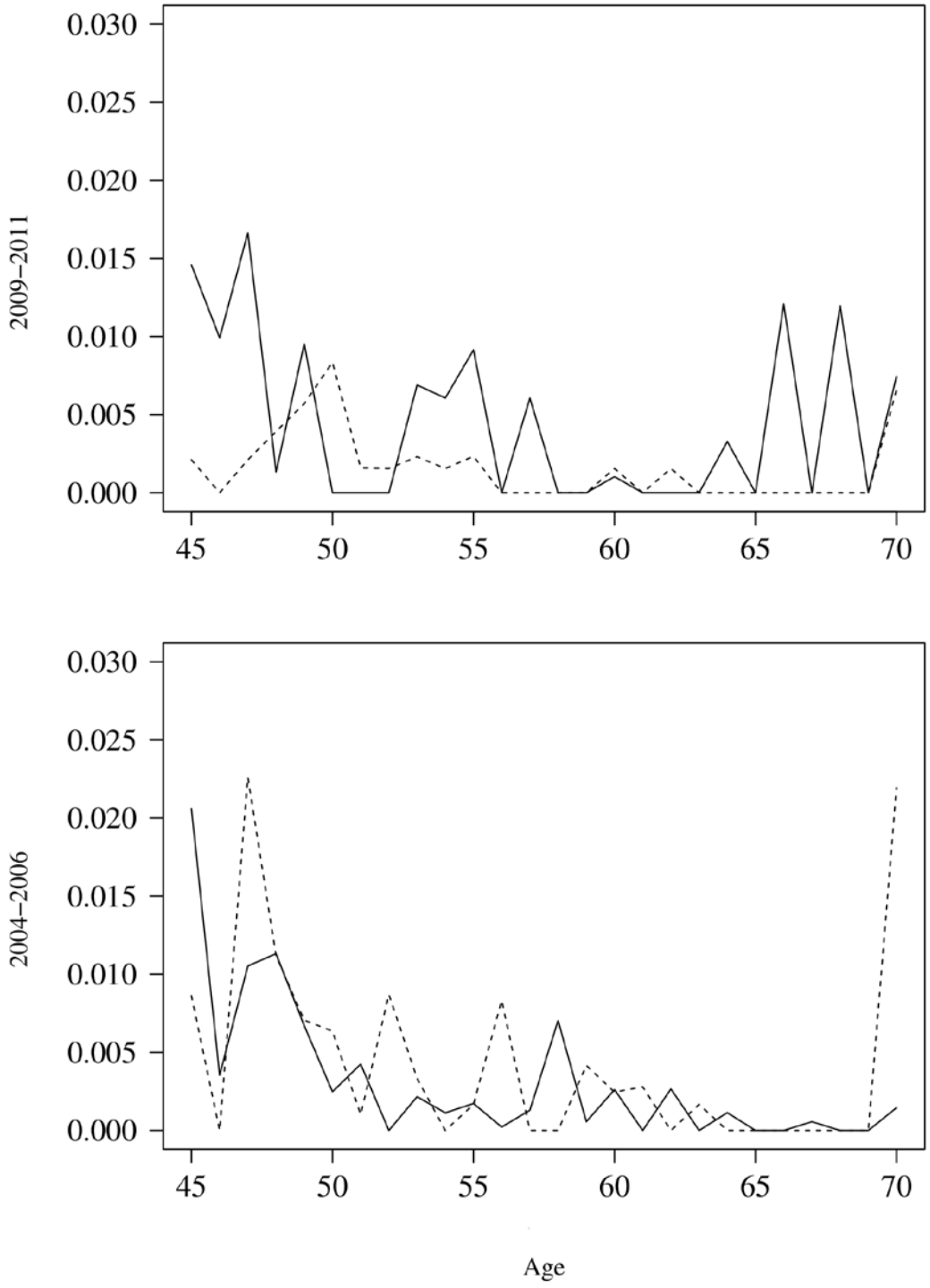

Figure 5. Age compositions in the Aleutian Islands survey (solid line) and fishery (dashed line) for ages 45 to 70+ for two time periods: 2004-2006 (bottom panel) and 2009 – 2011 (top panel).

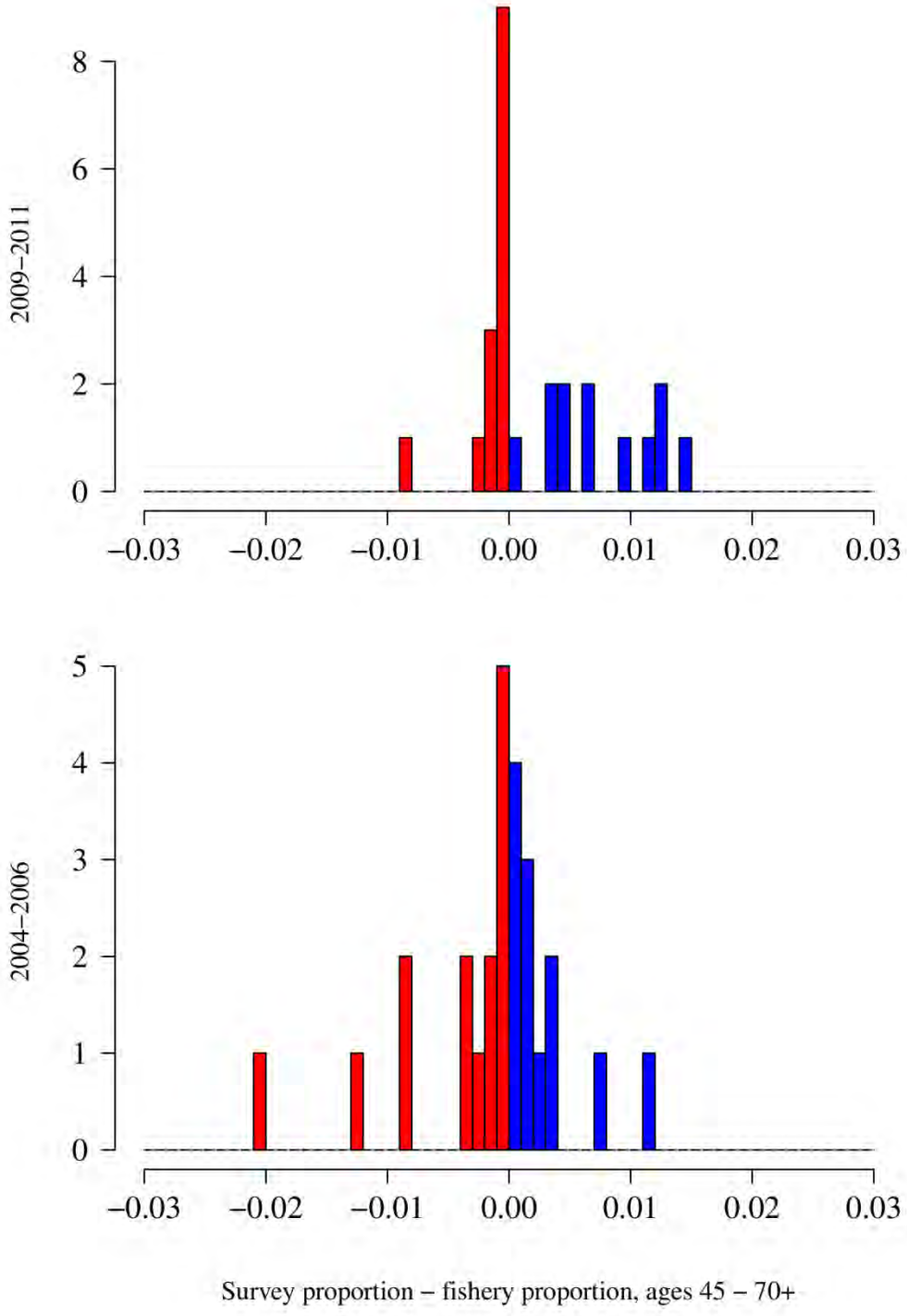

Figure 6. Histograms of the difference (survey proportion – fishery proportion) for ages 45 to 70+ for two time periods: 2004-2006 (bottom panel) and 2009 – 2011 (top panel).

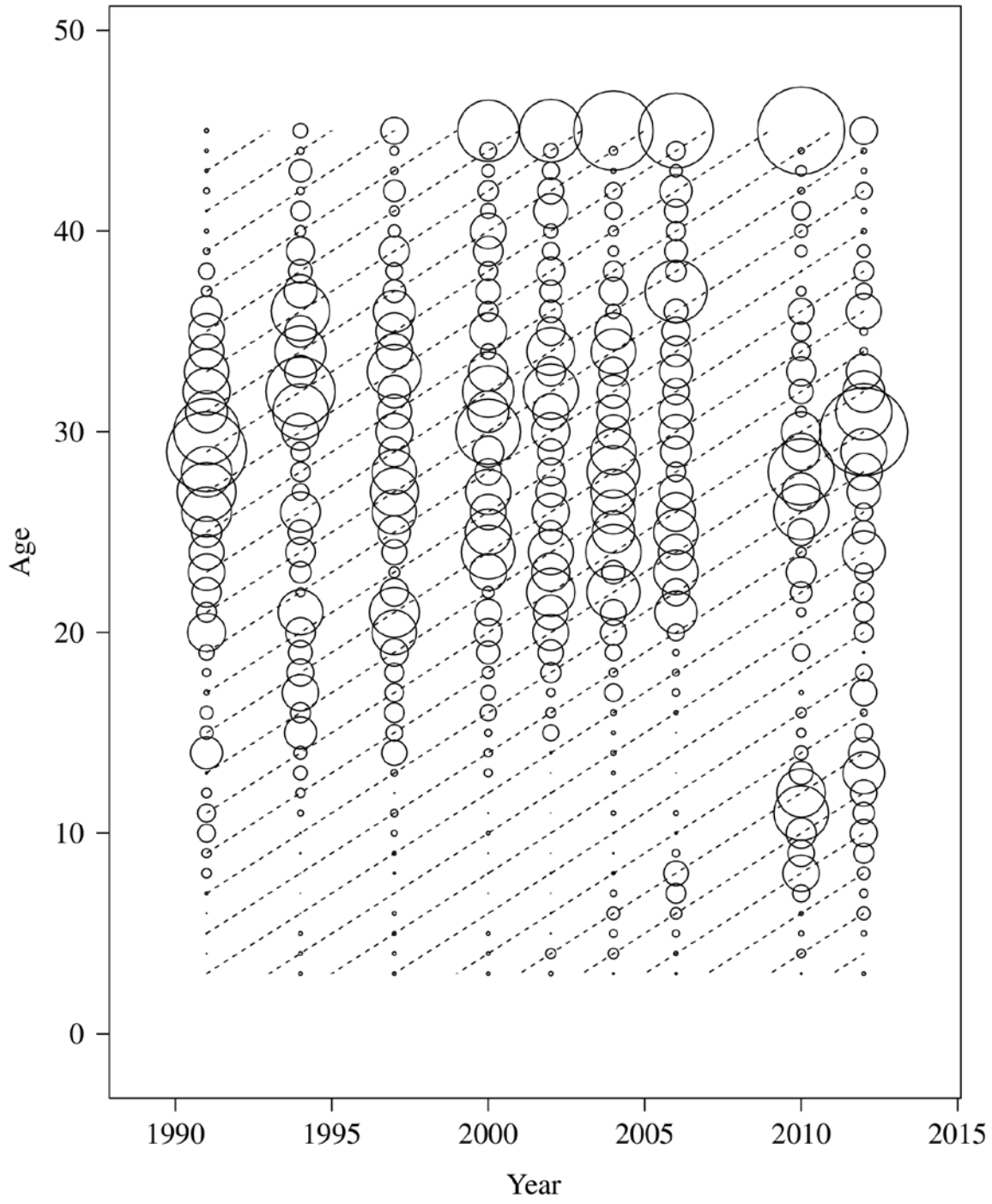

Figure 7. Age composition data from the Aleutian Islands trawl survey; bubbles are scaled within each year of samples and dashed lines denote cohorts.

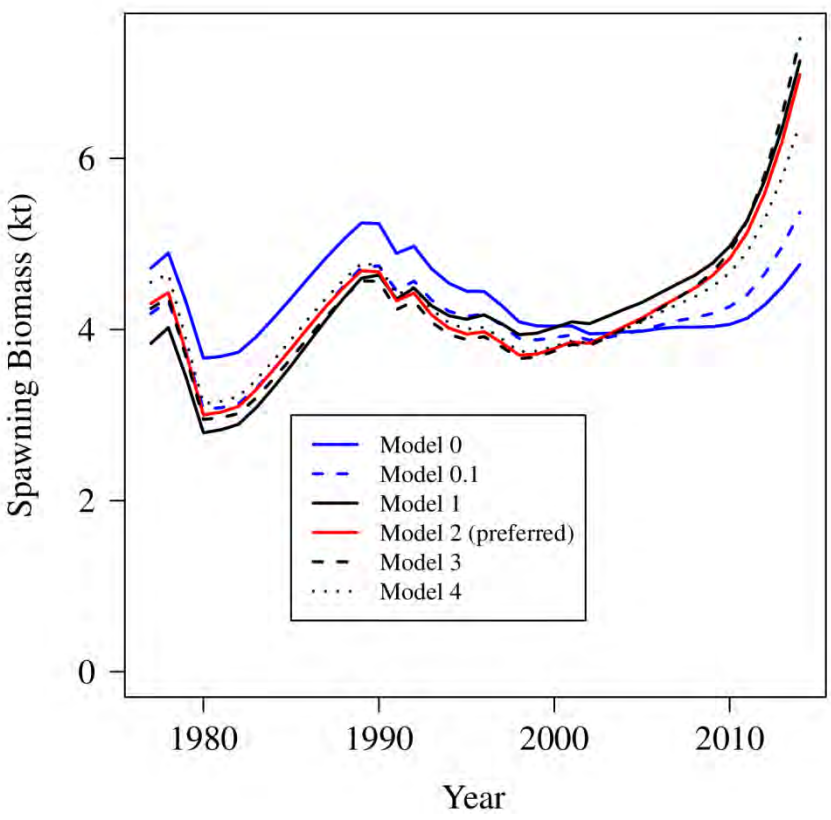

Figure 8. Estimated timer series of spawning stock biomass across the model runs

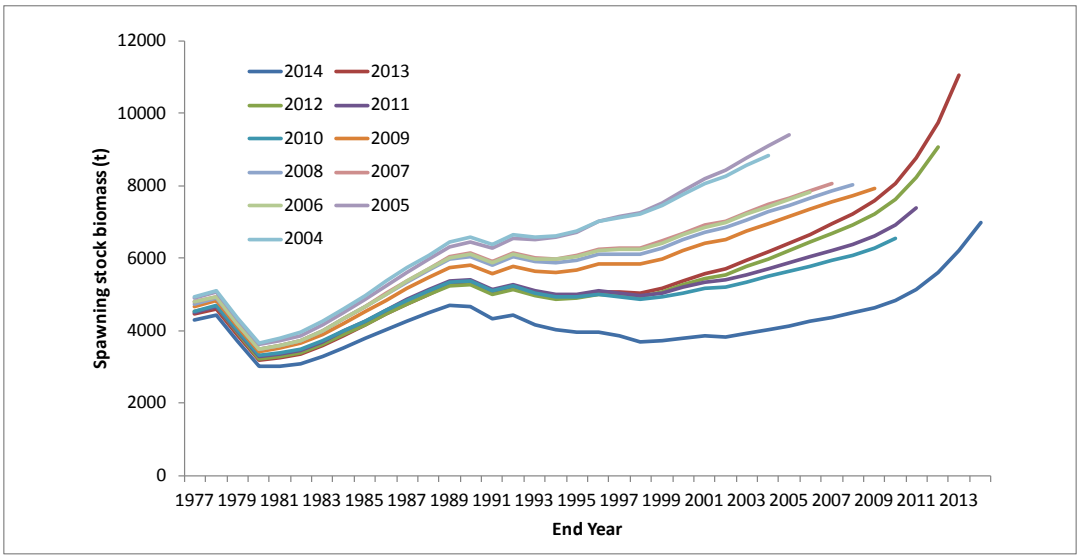

Figure 9. Retrospective estimates of spawning stock biomass for model runs with end years of 2004 to 2014.

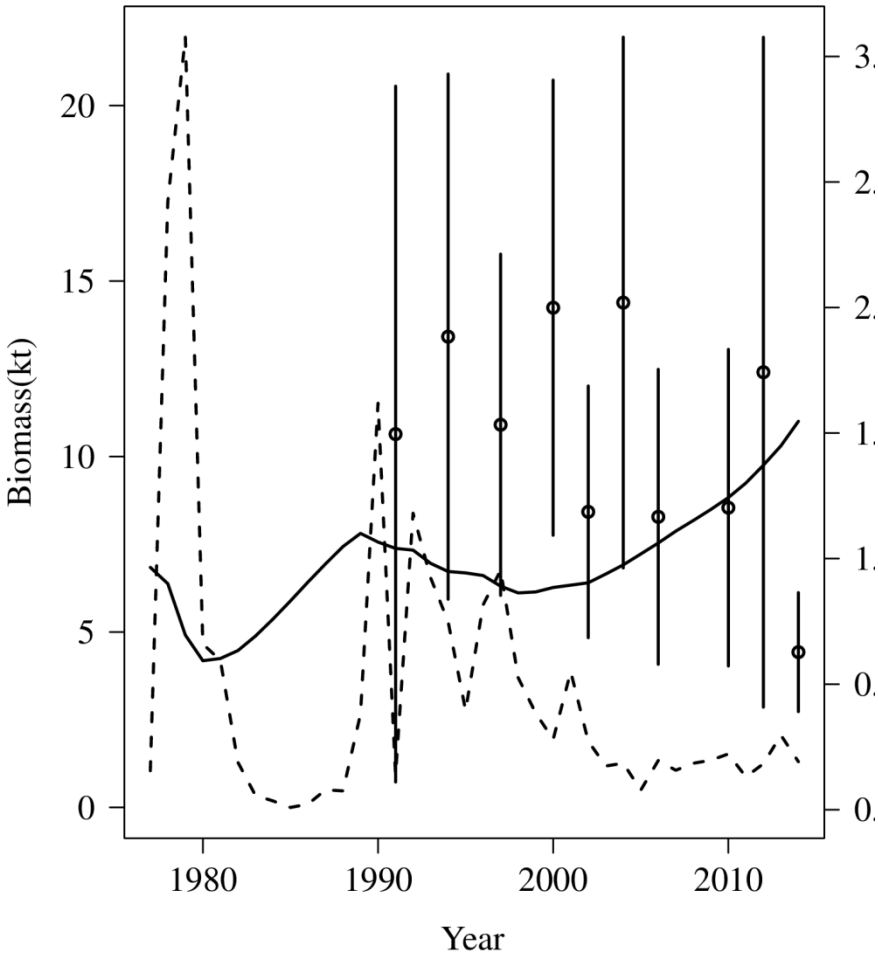

Figure 10. Observed Aleutian Islands (AI) survey biomass for blackspotted/rougheye rockfish (data points, +/- 2 standard deviations), predicted survey biomass (solid line), and AI harvest (dashed line).

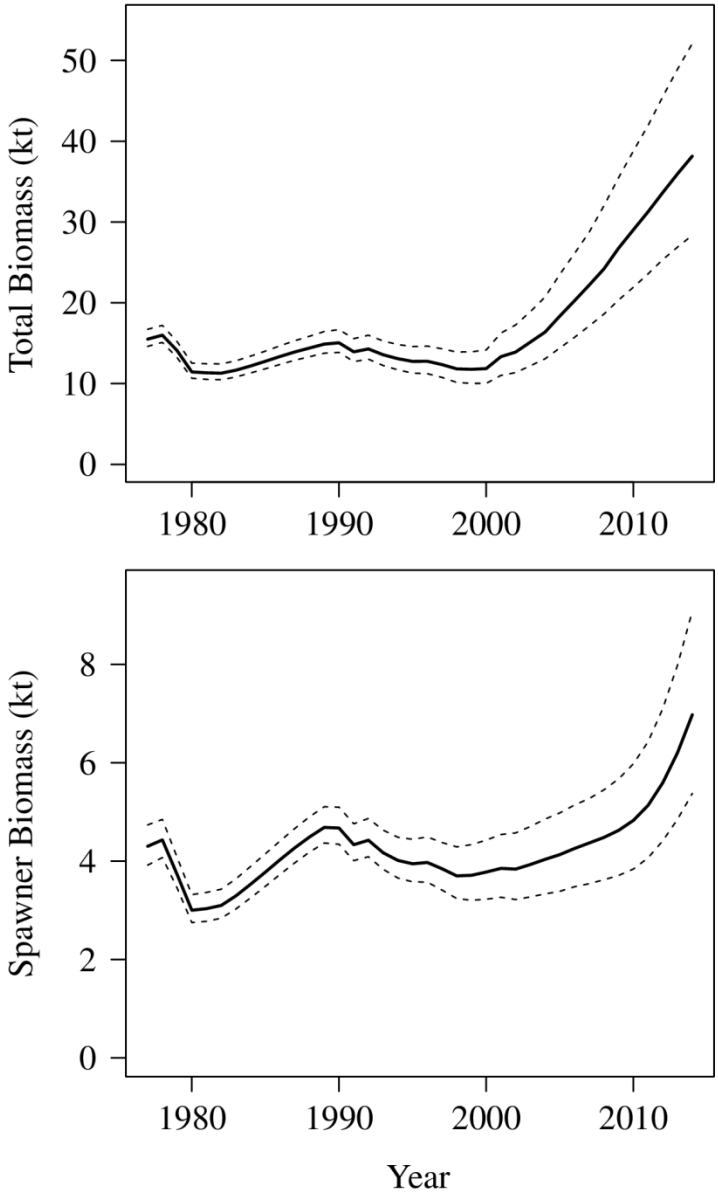

Figure 11. Total (top panel) and spawner (bottom panel) biomass for Aleutian Islands (AI) blackspotted/rougheye rockfish, with 95% confidence intervals from MCMC integration.

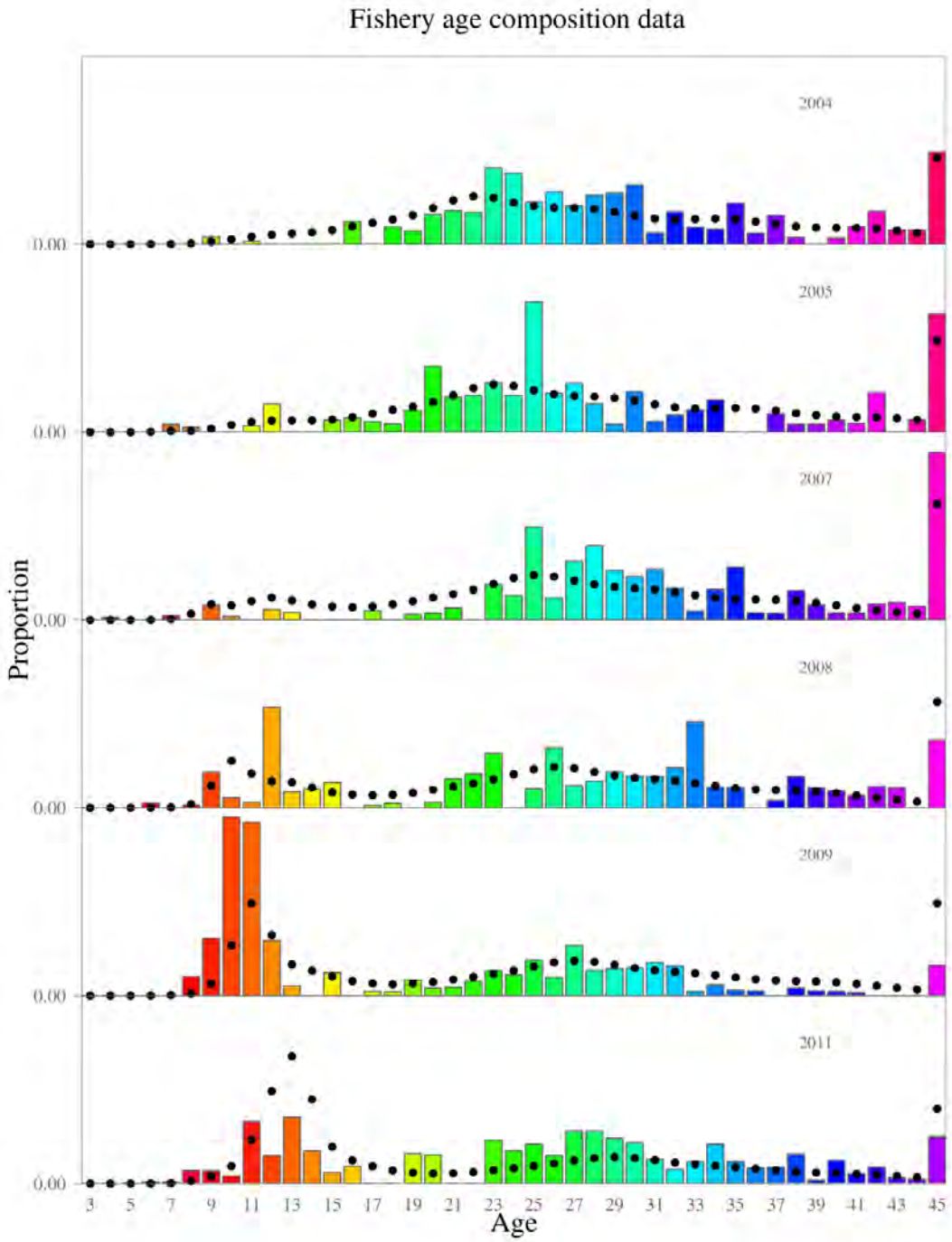

Figure 12. Model fits (dots) to the fishery age composition data (columns) for Aleutian Islands (AI) blackspotted/rougheye rockfish, 2004-2011. Colors of the bars correspond to cohorts (except for the 45+ group).

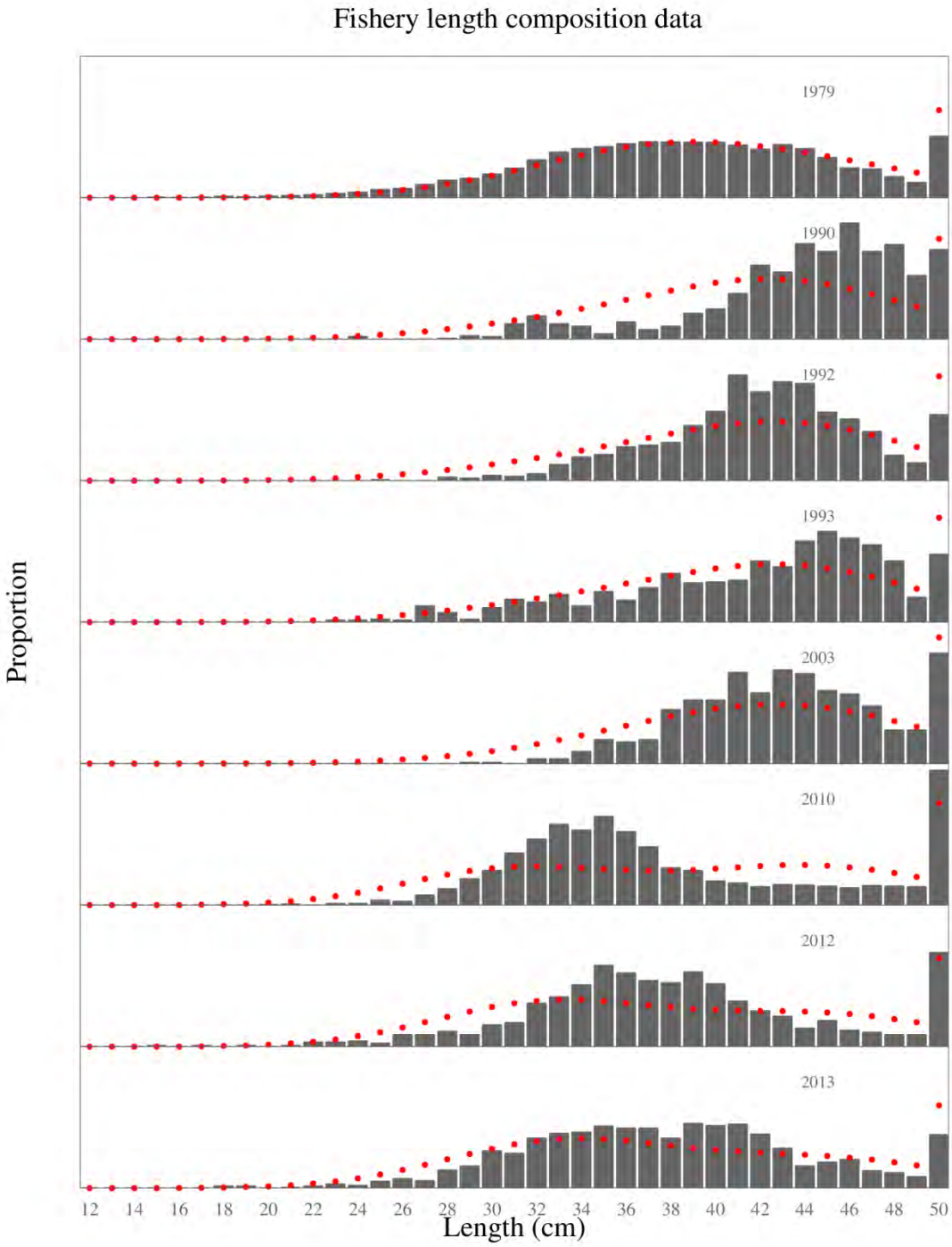

Figure 13. Model fits (dots) to the fishery length composition data (columns) for Aleutian Islands (AI) blackspotted/rougheye rockfish, 1979-2013.

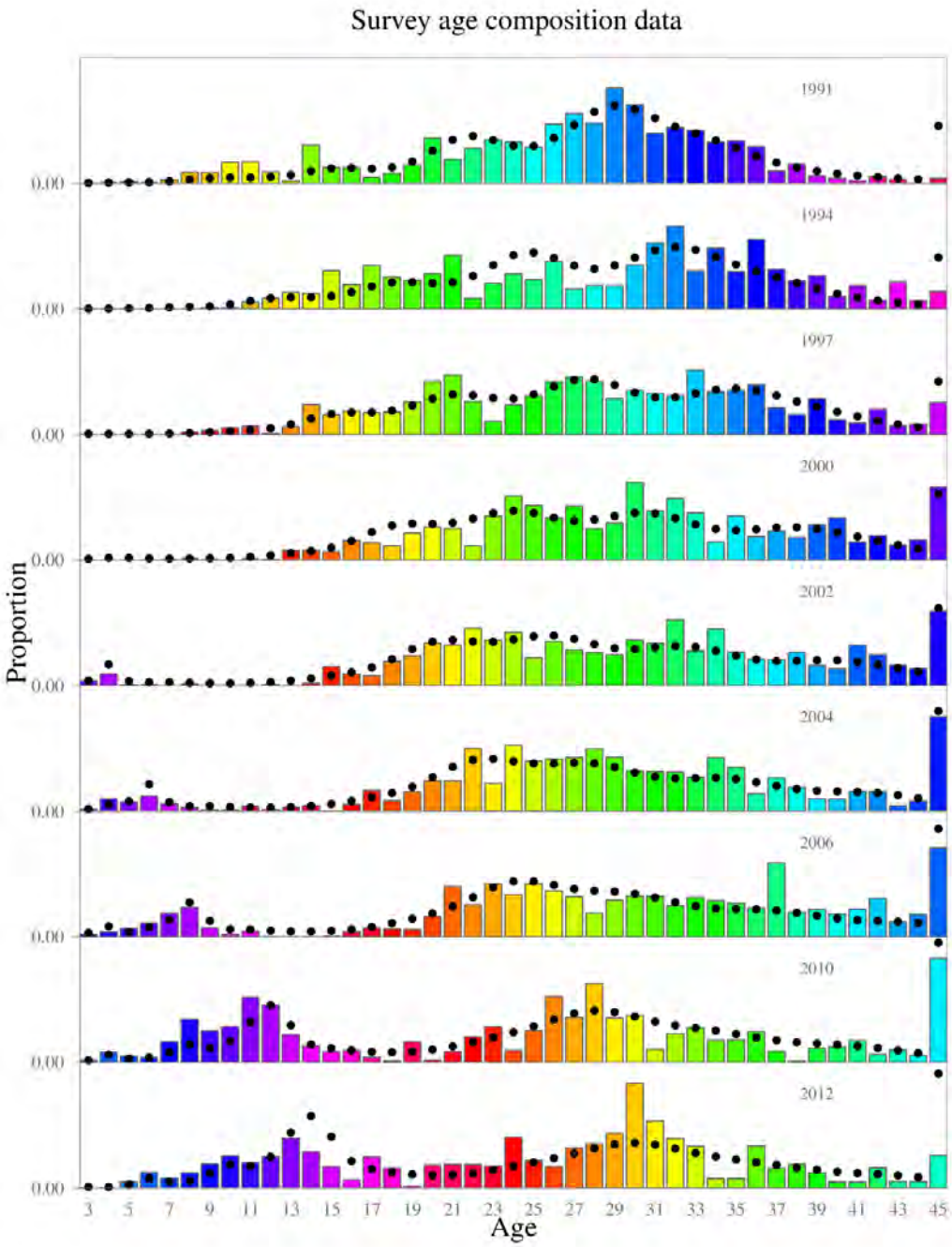

Figure 14. Model fits (dots) to the survey age composition data (columns) for Aleutian Islands (AI) blackspotted/rougheye rockfish, 1991-2012. Colors of the bars correspond to cohorts (except for the 45+ group).

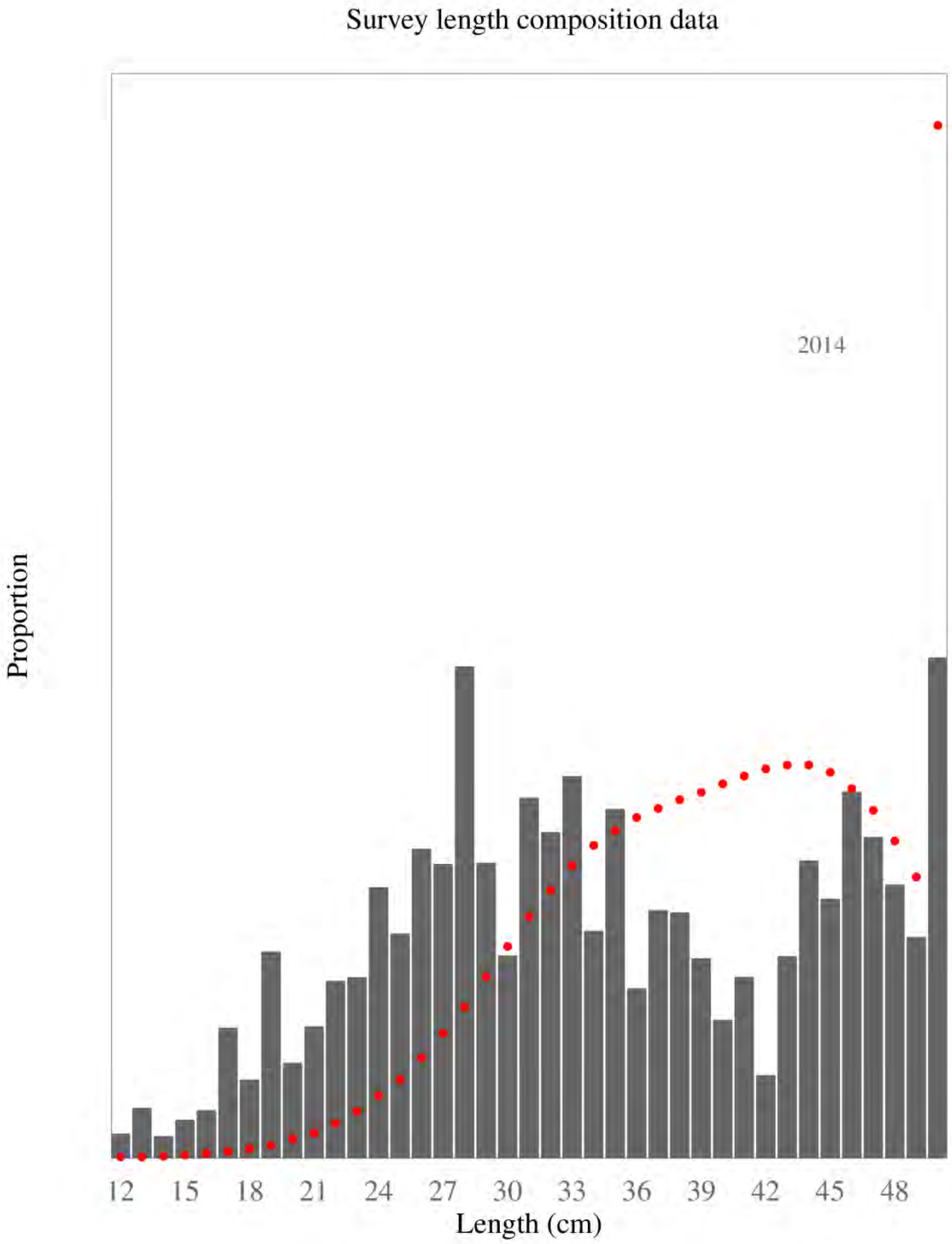

Figure 15. Model fits (dots) to the 2014 Aleutian Islands (AI) survey length composition data (columns) for the AI blackspotted/rougheye rockfish.

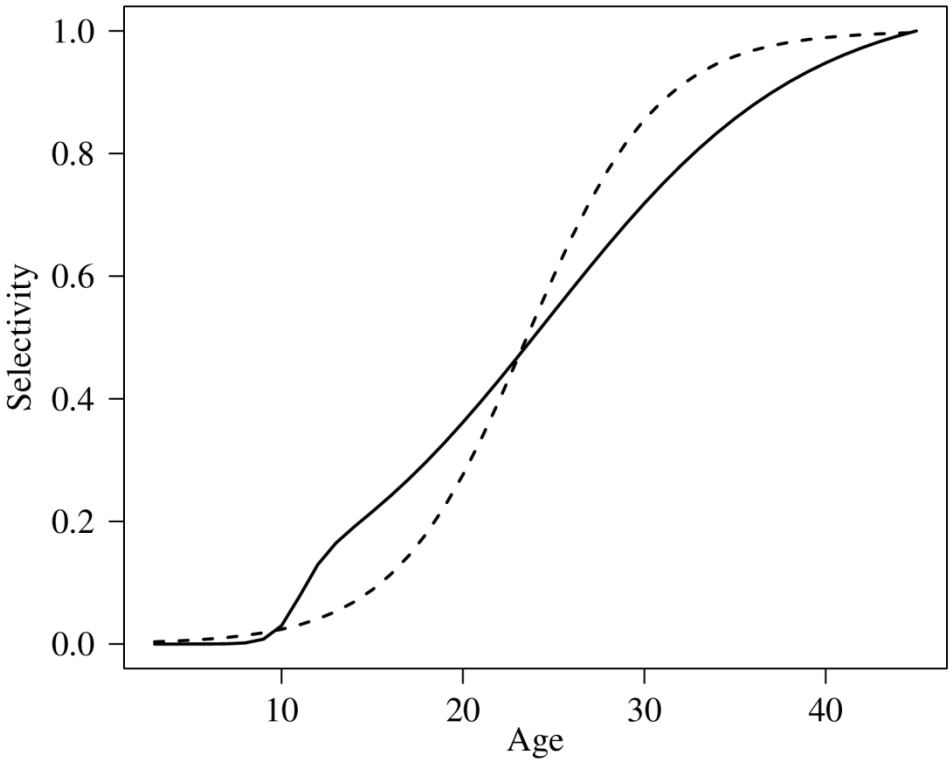

Figure 16. Estimated fishery (solid line) and survey (dashed line) selectivity curve by age for Aleutian Island (AI) blackspotted/rougheye rockfish.

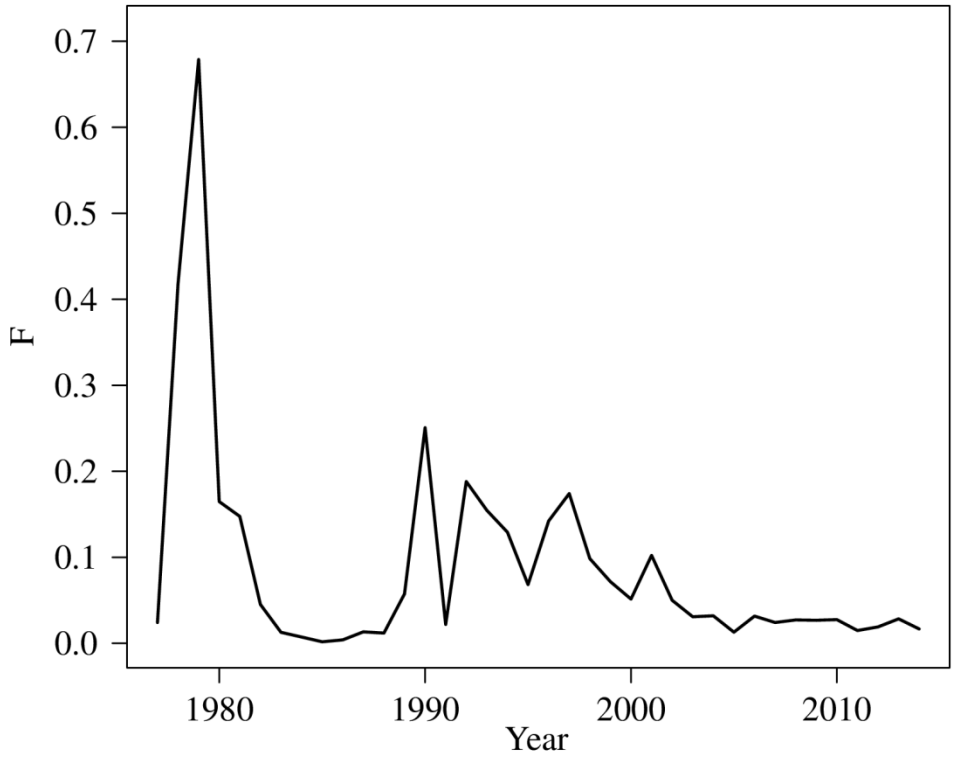

Figure 17. Estimated fully selected fishing mortality for Aleutian Islands (AI) blackspotted/rougheye rockfish.

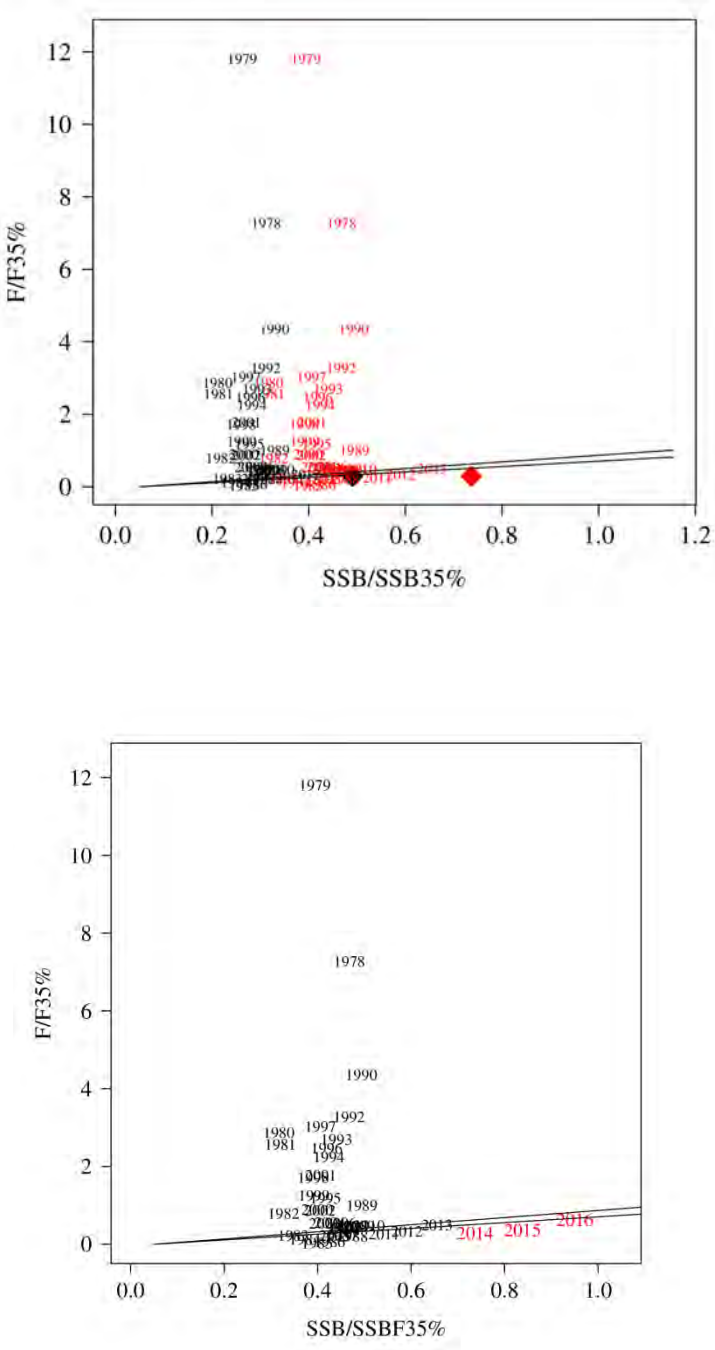

Figure 18. (Top panel) Estimated fishing mortality and SSB in reference to OFL (upper line) and ABC (lower line) harvest control rules, with the effect of including and excluding the post-1998 year classes shown in red and black, respectively. For each case, 2014 is shown with the diamond symbol. The bottom panel shows the projected stock status and *F* for 2015 and 2016 for the case of excluding the post-1998 year classes.

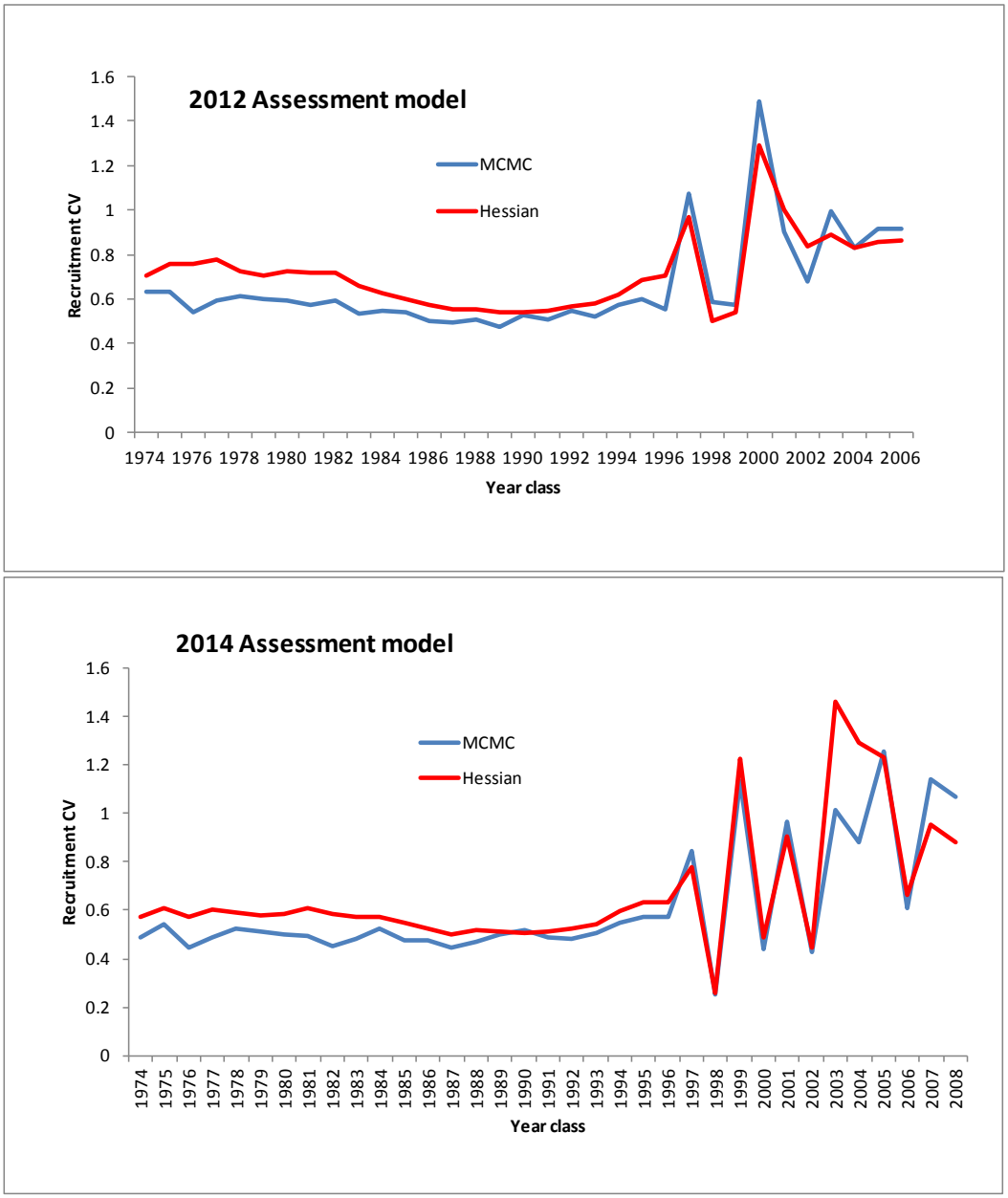

Figure 19. Recruitment CVs for BSAI blackspotted/rougheye rockfish for the 2012 and 2014 stock assessmements.

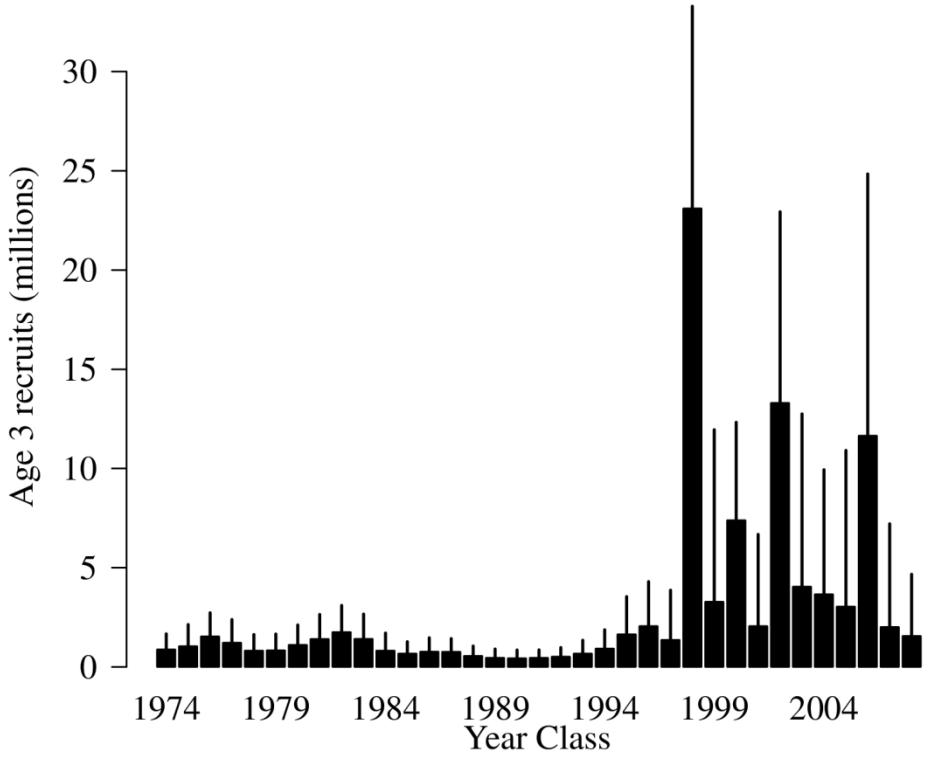

Figure 20. Estimated recruitment (age 3) of Aleutian Islands (AI) blackspotted/rougheye rockfish, with 95% CI limits obtained from MCMC integration.

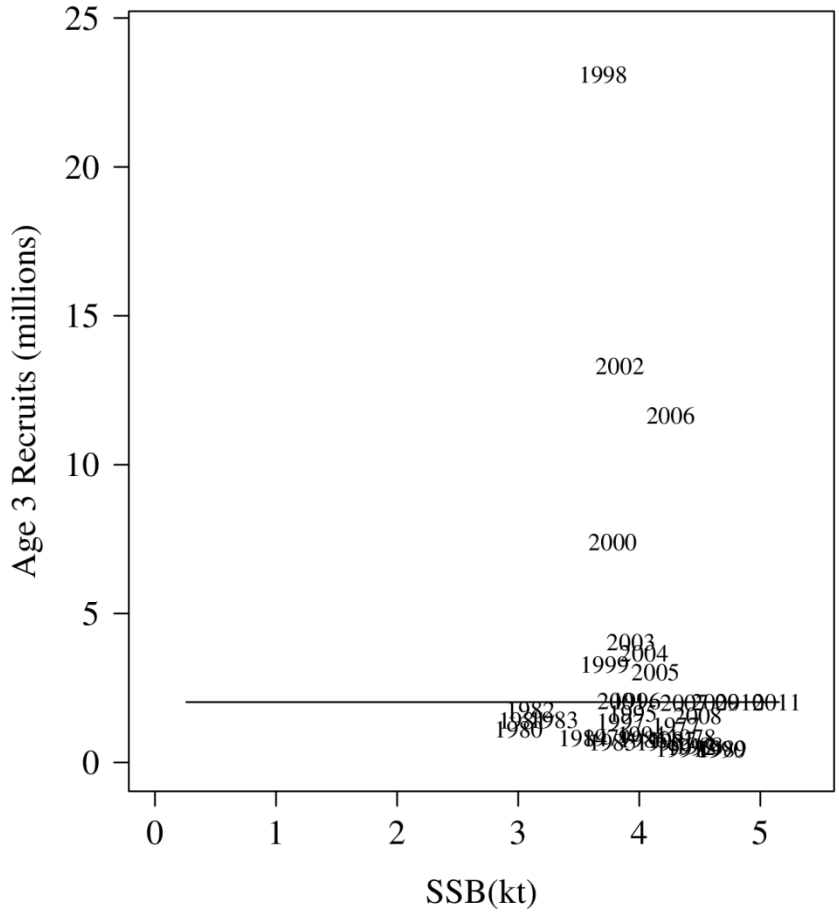

Figure 21. Scatterplot of Aleutian Islands (AI) blackspotted/rougheye rockfish spawner-recruit data; label is year class. Horizontal line is median recruitment.

Appendix A. Updated spatial analysis of BSAI blackspotted/rougheye rockfish catch in fishery and trawl survey tows

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[2]UAF-Fairbanks, Juneau Center for Fisheries and Aquatic Sciences

Executive summary

In 2013, a report was presented to the BSAI Plan Team that identified 1 genetic and 6 non-genetic attributes for BSAI blackspotted rockfish (Spencer 2013). The 6 non-genetic attributes pertained to spatial analyses of catch and survey data, which the BSAI Plan Team found "compelling" and formed the basis for their "strong concern" over the harvest rates and abundance in the western Aleutian Islands. The BSAI Plan team requested an update of the 7 attributes for 2014. This report provides updates for those attributes which have updated data since 2013, which include genetic data ,catch data, the 2014 AI survey trawl data, and revised estimates of AI biomass from the 2014 stock assessment model.

New genetic samples were collected in the 2010 and 2012 Aleutian Islands trawl survey, and substantially increased the sample size and number of loci examined from the original blackspotted rockfish genetic study in 2010 (Spencer and Rooper, 2010). The previous conclusion of a strongly significant isolation by distance relationship is not supported with the updated dataset, which show a *P*-value of 0.11. A sensitivity analysis indicates that the both the change in sample size and number of loci examined contribute to the difference between the two studies, with additional loci contributing more to that difference.

The BSAI Plan Team concluded in September, 2014, that stock structure for BSAI blackspotted/rougheye rockfish is still a "concern", based upon disproportionate harvest rates, the observed decline in the western Aleutians, and recognition that demographic independence between spatial areas can often be difficult to infer from genetic data.

The update of the catch and survey data do not indicate that the non-genetic attributes have substantially changed from the analysis in 2013. The 2014 AI trawl survey do not indicate a substantial increase in abundance in the WAI, but rather decreased abundance (particularly of larger fish) in the CAI and EAI. The updated catch data indicates that the 2013 harvest of blackspotted rockfish in the western AI resulted in the second highest exploitation rate since 2006. The exploitation rate for 2014 is decreased due to industry efforts to limit bycatch, but is still exceeds the $U_{F40\%}$ rate. As noted by Spencer (2013), the available catch and survey data indicate that high rates of exploitation for western AI blackspotted rockfish have occurred in the 1990s, and abundance in this area has decreased and has not been replenished from neighboring areas. This suggests some population structure on the "ecological" scale that should be of interest to fisheries management. In cases such as blackspotted rockfish that have spatially disproportionate harvest, spatial management of fishery harvest would be expected to prevent subarea depletions and maintain stock sizes that maximize yield.

Introduction

In 2013, a report on spatial analysis of survey and fishery catch data for blackspotted rockfish was presented to the BSAI Plan Team (Spencer 2013). The report noted that BSAI blackspotted rockfish show the following attributes:

1) Genetic information showing spatial structure at scales < 500 km (Spencer and Rooper 2010)
2) High catch levels in the 1990s in the WAI that have been followed with a sharp decline in WAI survey biomass estimates beginning in 2000.
3) High estimated exploitation in the WAI, where they have exceeded $U_{F40\%}$ reference exploitation rate every year from 2004-2012 except 2011.
4) An overall decline in survey biomass estimates in the WAI from 1991-2012, as estimated by a random effects time series model.
5) An increase in the proportion of survey tows which have not caught blackspotted/rougheye over all survey strata in the WAI.
6) A large percentage of the total harvest occurring in the WAI.
7) A decline in mean size in the WAI but not other BSAI subareas.

The BSAI Plan Team concurred with these conclusions, found the quality and quantity of information to be "compelling", and expressed "more concern over the local exploitation of this assemblage than other stocks that have been subjected to the stock structure template" (BSAI Plan Team minutes, September, 2013). The BSAI Plan Team reiterated its "strong concern" in its November, 2013 meeting, and noted that it anticipates a management response in 2014 if the SSC concurs with this level of concern. The BSAI Plan Team recommended that the 7 metrics shown above be updated and presented for the September meeting (BSAI Plan Team minutes, November, 2013). The SSC also "shares this concern" regarding the western Aleutian Islands portion of the stock, and agrees with the recommendation to update the seven metrics above (SSC minutes, December, 2013).

The purpose of this report is to present updates of the seven metrics above. Information on blackspotted rockfish genetics was originally presented in 2010 and mentioned only in passing in 2013, and new genetic samples have been subsequently analyzed and are summarized here. The new information for metrics 2-7 is the finalized 2013 catch data and estimated 2014 catch, and the 2014 AI survey biomass estimates and length composition.

Update on genetic analyses for Aleutian Islands blackspotted rockfish

Information on the genetics of blackspotted rockfish was presented to the BSAI Plan Team in 2010. The available genetic data consisted of genetic samples from 173 individuals from which 7 microsatellite loci were analyzed. The analysis was presented as one of the case studies in the 2010 report from the Stock Structure Working Group (Spencer et al. 2010), which found a significant isolation by distance (IBD) pattern, and estimated a range of lifetime dispersal distance less than 200 km. The SSWG also noted several caveats to the data: 1) the sample size is small for the large geographic scale of interest; 2) the number of loci is also small; 3) the samples may be too concentrated to prove a good estimate of the IBD relationship. However, the samples represented the best available genetic data at the time, and the finding of an IBD relation was consistent with several other rockfish species in the north Pacific. The SSWG report recommended collection of more extensive data for genetic analysis.

The genetic analysis was also presented in 2010 in the stock structure evaluation report for BSAI blackspotted rougheye (Spencer and Rooper 2010), along with additional analyses of spatial growth patterns and age composition.

Since the genetic analysis presented in 2010, blackspotted rockfish genetic samples were collected in the 2010 and 2012 Aleutian Islands trawl survey, increasing the total sample size to 942 and the number of loci analyzed to 12. A map of the sampling locations is shown in Figure A1. Additionally, the samples were obtained from many locations along the Aleutian Islands and eastern Bering Sea slope, thus addressing the concern regarding the spatial concentration of samples. With the updated dataset, a statistically significant relationship between genetic distance and geographic distance is no longer observed ($P = 0.113$).

The two studies differed not only in the number of loci analyzed and sample size, but also the location of samples. The Aleutian Islands samples in the initial study were to the east of Bowers Ridge, whereas the updated study had samples throughout the entire AI chain west to Stalemate Bank. Additionally, the EBS slope samples in the updated dataset showed a relatively large number of sampling locations along the EBS just northwest of Unimak Pass, whereas in the original study the EBS slope samples generally occurred farther to the northwest. Additional tests were conducted to determine whether the difference in results between the two studies is driven by having a larger and more representative sample size in the 2014 analysis, or rather by the inclusion of areas sampled in 2014 study that were not sampled in the 2010 study.

The original samples from the 2010 study were "rescored", in which the initial reading of the gel images were verified by running PCR amplification and reading the new gel images. The rescored data from the original samples yielded a significant IBD relationship for six of the original loci examined ($P = 0.0074$; one loci was dropped because it was viewed as relatively uninformative). Next, samples from a subset of the updated dataset in the locations sampled in the original study (n=692) yielded a marginally significant IBD relationship for six of the original loci ($P = 0.0637$) and an insignificant relationship for all 12 loci ($P = 0.1035$). These results suggest that both the change in sample size and number of loci examined contribute to the difference between the two studies, with additional loci contributing more to that difference. A final sensitivity test was performed which used the original samples but only the new loci, and yielded $P = 0.1645$. A summary of the tests are shown below:

Description	Sample size	Number of loci	*P*-value for IBD relationship
Original samples from 2010 study, rescored data	168	6	0.0074
Updated dataset, same loci and areas sampled in 2010 study	692	6	0.0637
Updated dataset and loci, same areas sampled in 2010 study	692	12	0.1035
Original samples from 2010 study, rescored data, only new loci	168	6	0.1645
Updated dataset and loci	942	12	0.1126

Area-specific exploitation rates

Area-specific exploitation rates are defined here as the yearly catch within a subarea divided by an estimate of the subarea biomass at the beginning of the year. Area-specific exploitation rates are generated to assess whether subarea harvest is disproportionate to biomass, which could result in reductions of subarea biomass for stocks with spatial structure. A map of the BSAI subareas is shown in Figure A2.

For each year from 2004 through 2014, the subarea biomass was obtained by partitioning the estimated total biomass (ages 3+) at the beginning of the year (obtained from 2014 BSAI blackspotted/rougheye stock assessment) into the Aleutian Islands subareas. The biomass estimates from the 2014 stock assessment are assumed to be the best available information on the time series of total biomass, and this method can be considered a "retrospective" look at past exploitation rates. For each year, a weighted average of the subarea biomass from the three most recent surveys Aleutian Islands and eastern Bering Sea slope trawl survey (weights of 4, 6, and 9, with more recent surveys receiving higher weights) was computed, and the proportions from these averages were used to partition the biomass into subareas. Catches through October 11, 2014, were obtained from the Catch Accounting System database. To evaluate the potential impact upon the population, exploitation rates were compared to two measures of stock productivity: 1) 0.75 times the estimate rate of natural mortality (M), which is the fishing mortality F_{abc} that produces the allowable catch for Tier 5 stocks; and 2) the exploitation rate for each year that would result from applying a fishing rate of $F_{40\%}$ to the estimated beginning-year numbers, and this rate is defined as $U_{F40\%.}$ The $U_{F40\%}$ rate takes into account maturity, fishing selectivity, size at age, and time-varying numbers at age, and thus may be seen as more appropriate for Tier 3 stocks because harvest recommendations are based upon this age-structured information. BSAI blackspotted/rougheye rockfish were managed as a Tier 5 stock prior to 2009, and as a Tier 3 stock since 2009.

Exploitation rates for the WAI blackspotted/rougheye rockfish have been at or above 0.75M for from 2004-2006, 2008-2010, and 2013. The exploitation rates have exceeded $U_{F40\%}$ in all years from 2004 -2013 except 2011 (Figure A3a). These results differ slightly from those presented in 2013 due to the revised time series of biomass from the 2014 assessment model, and revised estimates of numbers at age and fishery selectivity (which affect the calculation of $U_{F40\%}$). The catch of WAI blackspotted for 2013 was 84 t, which increased the 2013 WAI exploitation rate to 2.05 times $U_{F40\%.}$ The preliminary exploitation rate for 2014 is 1.27 times $U_{F40\%.}$ The values of $U_{F40\%}$ are similar to 0.75*M for 2004, and have decreased slightly from 2004-2009 because a large portion of the catch weight is derived from relatively young fish where the fishery selectivity (and thus fishing mortality) is relatively low; since 2009, the values of $U_{F40\%}$ have increased slightly. The exploitation rates for the other subareas do not exceed $U_{F40\%}$ with the exception of the EBS in 2008, 2010, and 2011.

The calculation of exploitation rates and the $U_{F40\%}$ values back to 1994 reveal high rates of exploitation for the western AI in the mid-1990s (Figure A4). In 1996 and 1997, the exploitation rates were 6.5 and 8.1 times the value of $U_{F40\%}$, respectively. A random effects model was used to obtain the area proportions, as taking an average of three most recent survey is not possible in the early 1990s because the NMFS survey time series was initiated in 1991. A comparison of the exploitation rates since 2004 produced from using either the random effects model or the weighted average of the surveys indicates that both methods produce similar results (Figure A4).

Application of the random effects model to the updated survey biomass time series

The 2014 survey biomass for the WAI area was 589 t, an increase from the estimate of 335 t from the 2012 survey. Of the 10 points in the WAI survey estimate time series since 1991, the lowest 3 estimates have been obtained since 2006. The ratio of the 2014 estimate of biomass from the random effects model to the 1991 estimate indicates an 81% decline since 1991; this is increased from the previous estimate of 85% based upon the 1991-2012 surveys (Figure A5).

The 2014 biomass estimates in the other AI subareas are reduced from their 2012 estimates. The decline in the EAI was particularly sharp, with the 2014 estimate of 958 t being a 75% decline from the 2012 estimate of 3,798 t. This decline was large enough to result in the random effects model fitting an overall decline to the EAI biomass time series, as without the 2014 data point the model fits only a mean biomass with no trend.

Survey length composition and mean size

The size composition from the 2014 AI trawl survey continues to indicate relatively small fish in the WAI (Figure A6). The percentage of the WAI survey size composition less than 35 cm was 57%, and this value has ranged between 26% and 73% in surveys from 2014 to 2012. As in the 2012 survey, few fish over 40 cm were observed in the WAI. In the CAI and EAI, fish 40 cm and larger comprised a large portion of the population in each survey from 1991 to 2012, but lower abundance of this size group was observed in the 2014 survey (particularly in the EAI).

The mean size in the WAI was 356 cm in the 2014 survey, which is an increase from the 2012 survey and similar to values in 2006 (352 cm) and 2010 (357 cm) survey (Figure A7). However, the WAI mean sizes from 2006-2014 are low than those observed in the 1991-2002 surveys, which ranged from 390 cm to 448 cm. The low numbers of large fish observed in 2014 for the CAI and EAI resulted in the 2014 mean size for these areas being substantially smaller than those observed in previous surveys.

Proportion of tows without catch of blackspotted/rougheye rockfish

The spatial pattern in the percentage of survey tows which did not catch blackspotted/rougheye rockfish in the 2014 survey is similar to that observed in the 2012 survey (Figure 8). In 2014, the WAI and EAI had the highest proportion of tows without blackspotted/rougheye rockfish (each at 88%). The percentages appear to have increased since the early 1990s in the WAI, CAI, and EAI, but the rate of increase in the percentage appears to be higher and less variable for the WAI. In the 1991-1994 surveys, the WAI had the lowest percentage of tows without blackspotted/rougheye rockfish among the subareas, whereas beginning in 2000 the WAI had the highest percentage (or tied of the highest percentage) of tows without blackspotted/rougheye rockfish.

Spatial distribution of harvest

The high exploitation rates in the WAI reflect that a large portion of the harvest occurs in this area, relative to a small portion of the survey biomass. From 2004-2014, 40% of the harvest in the AI management area occurred in the WAI but only 9% of the survey abundance for the AI management area. In 2013, the catch in the western, central, and eastern AI were 84 t, 62 t, and 151 t, respectively; despite the relatively large catch in the western AI (second largest since 2006), the proportion was reduced to 28% due to the large catch in the eastern AI.

Within the western AI, most of the blackspotted rockfish catch occurs in the eastern portion of the western AI between 174° E and 177° E (Figure A9). The portion of the catch between 174° E and 175° E has increased since 2008. As noted in Spencer (2013), this is an area with low trawl survey catches because the fishing grounds are not sampled in the trawl survey.

Conclusions

The main difference between this updated analysis and the analysis presented in 2013 is the reanalysis of genetic data that included a much larger sample size and additional microsatellite loci. The new analysis failed to detect a strongly significant IBD relationship. In September, 2014, the BSAI Plan Team considered how to interpret both the genetic information and the spatial survey and catch data showing high exploitation rates in the western AI. The Team concluded that stock structure for BSAI blackspotted/rougheye is still a “concern”, based upon disproportionate harvest rates, the observed decline in the western Aleutians, and recognition that demographic independence between spatial areas can often be difficult to infer from genetic data.

The update of the catch and survey data do not indicate that the non-genetic attributes listed above (i.e., attributes 2-7) have substantially changed. The 2014 AI trawl survey does not indicate a substantial increase in the abundance for WAI blackspotted/rougheye, but rather decreased abundance (particularly of larger fish) in the CAI and EAI blackspotted/rougheye rockfish. The updated catch data indicates that the 2013 harvest of blackspotted rockfish in the western AI resulted in the highest exploitation rate since 2006. As noted by Spencer (2013), the available catch and survey data indicate that high rates of exploitation for western AI blackspotted rockfish have occurred in the 1990s, and abundance in this area has decreased and has not been replenished from neighboring areas. This suggests some population structure on the "ecological" scale that should be of interest to fisheries management. In cases such as blackspotted rockfish that have spatially disproportionate harvest, spatial management of fishery harvest would be expected to prevent subarea depletions and maintain stock sizes that maximize yield.

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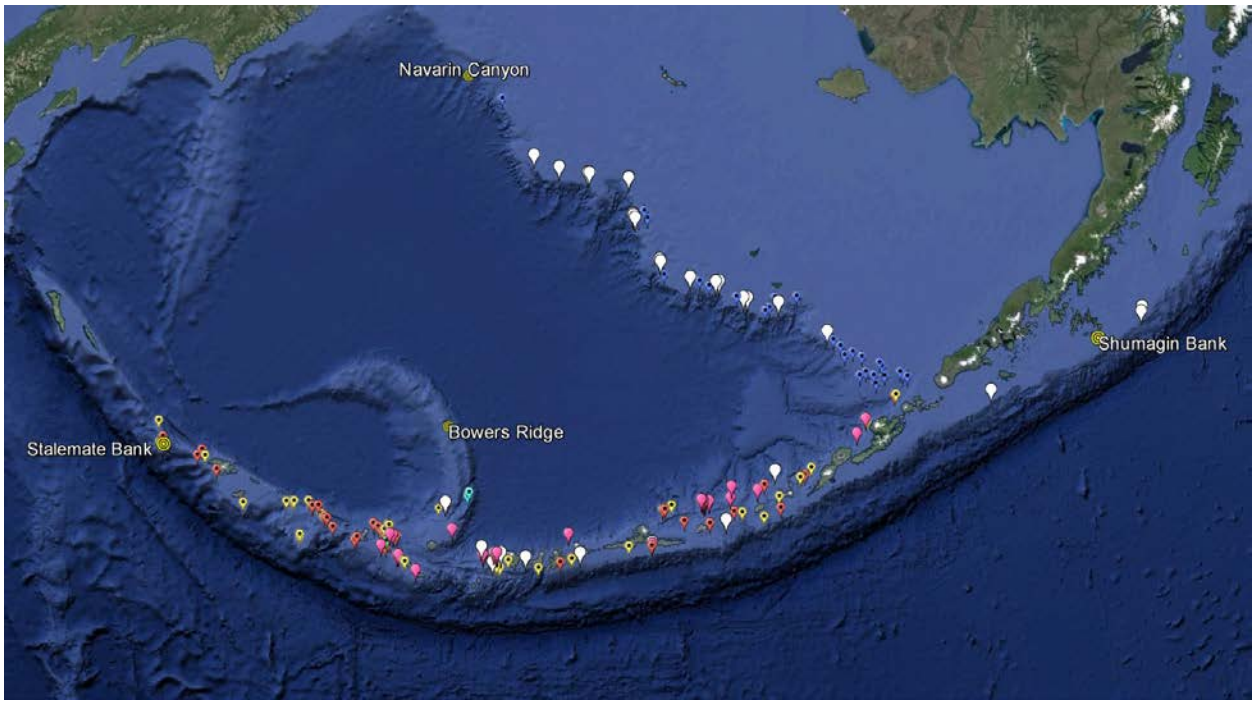

Figure A1. Map locations of genetic samples for blackspotted rockfish in the BSAI area. Symbol colors are as follows: 1) white – samples in original genetic study; 2) yellow and red – samples from two vessel in 2010 AI survey; 3) pink – samples from 2012 AI survey; 4) light blue and light green – samples from the 2010 fishery; 4) dark blue – samples from 2010 EBS slope survey.

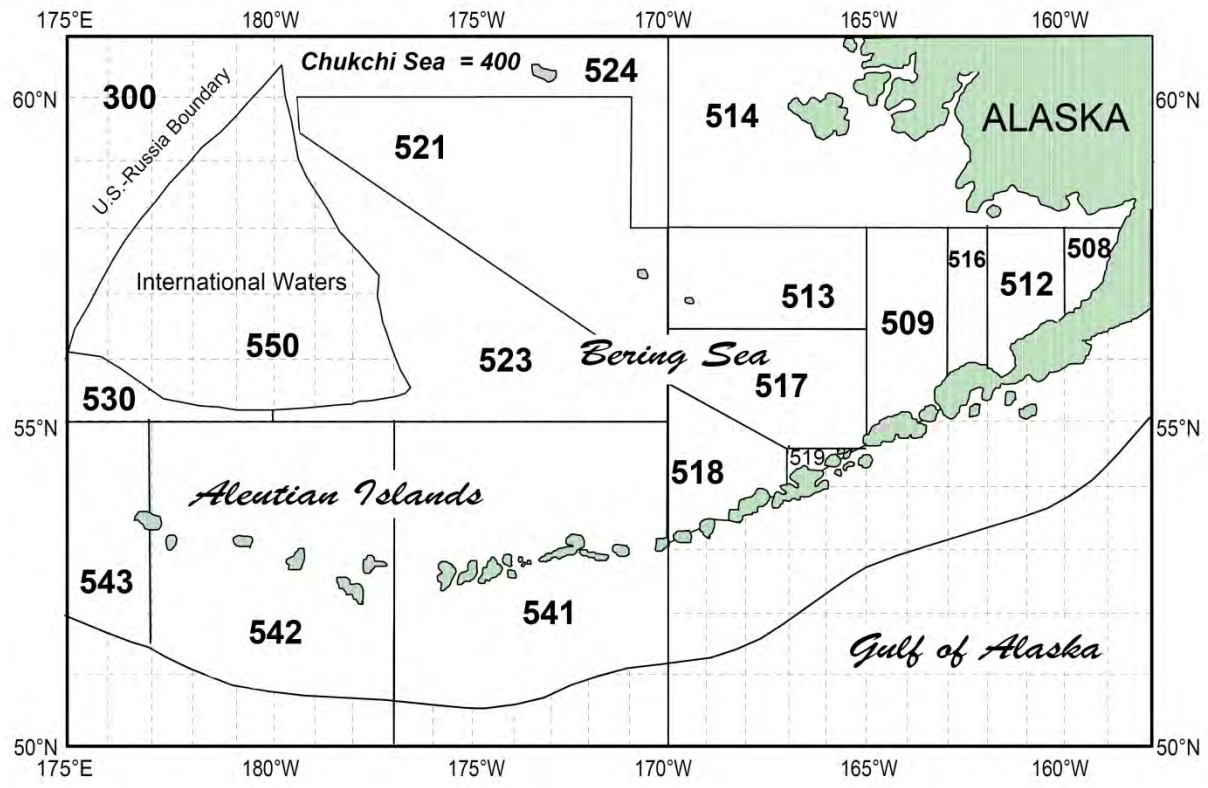

Figure A2. Map of statistical reporting zones in the BSAI management area. The western Aleutian area is zone 543 (which extends west to 170°E), the southern Bering Sea (SBS) zone comprises zones 518 and 519, and the central Aleutian Islands (CAI) and eastern Aleutian Islands (EAI) zones are 542 and 541, respectively. Figure obtained from the NOAA-Alaska Regional Management Office.

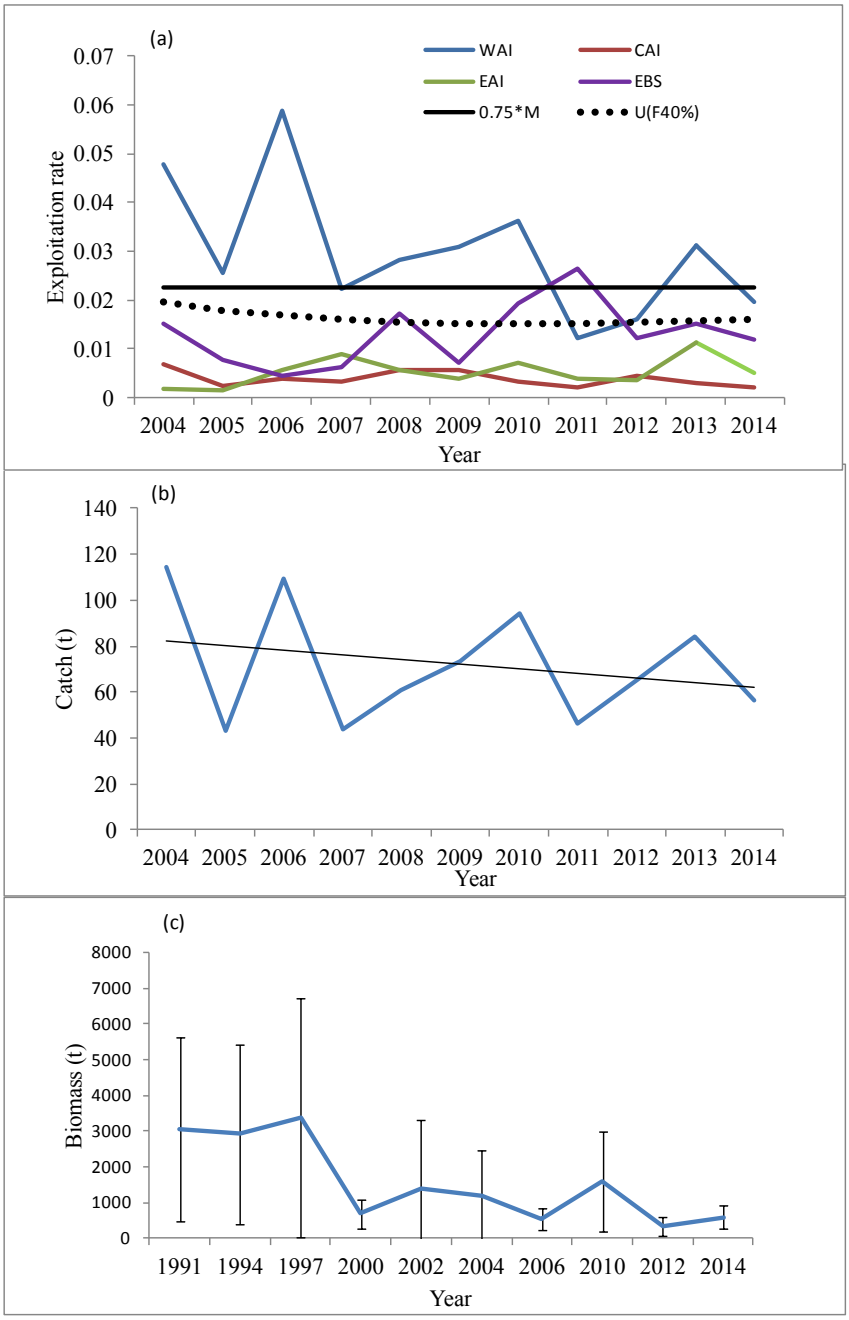

Figure A3. BSAI blackspotted/rougheye subarea exploitation rates (a), and catch (b) and trawl survey biomass estimates (c, with 95% confidence intervals) for the western Aleutian Islands. Exploitation rates and catch for 2014 are based on catches through October 11, 2014.

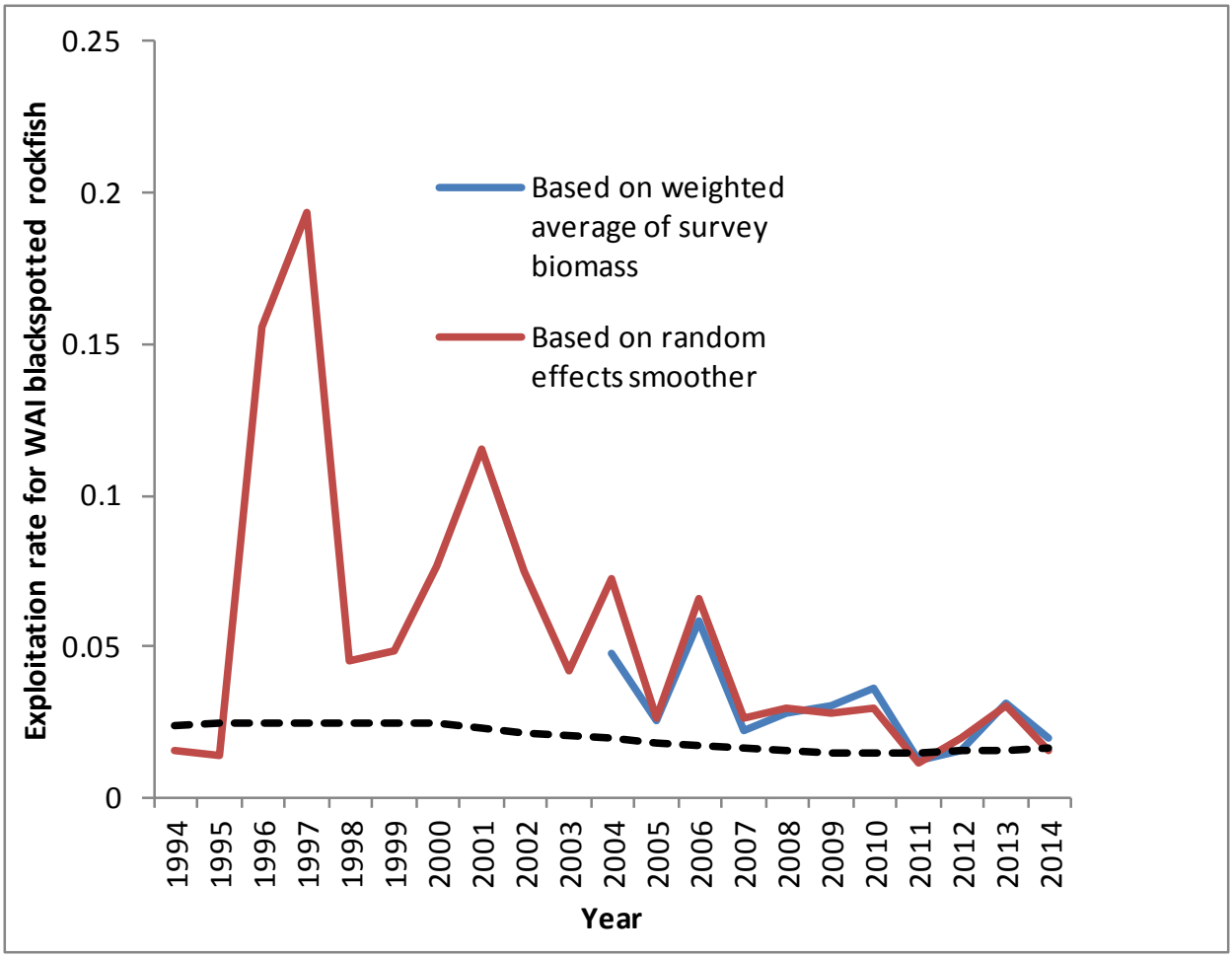

Figure A4. Estimated exploitation rates in the WAI from 1994 – 2014, with the proportion of biomass in the WAI based upon a random effects model to smooth survey biomass time series. For comparison, the exploitation rates from 2004-2014 that use a weighted average of recent surveys to obtain subarea proportions are also shown.

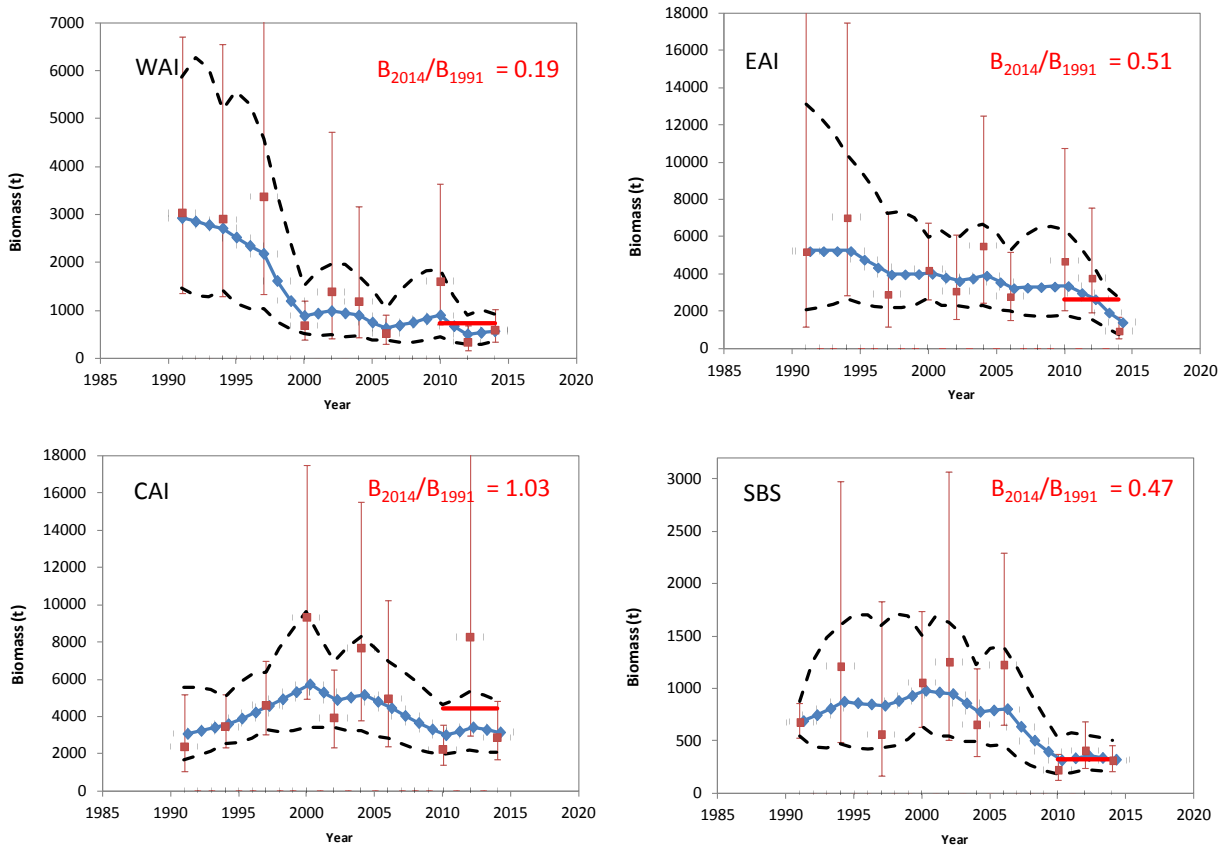

Figure A5. Time series of AI trawl survey biomass by subarea, with the fits from a random effects model to smooth the time series. The ratio of the biomass estimate in 2014 to that in 1991 indicates the estimated level of depletion over this time period. The horizontal red lines show the estimate from a weighted average of the three most recent surveys.

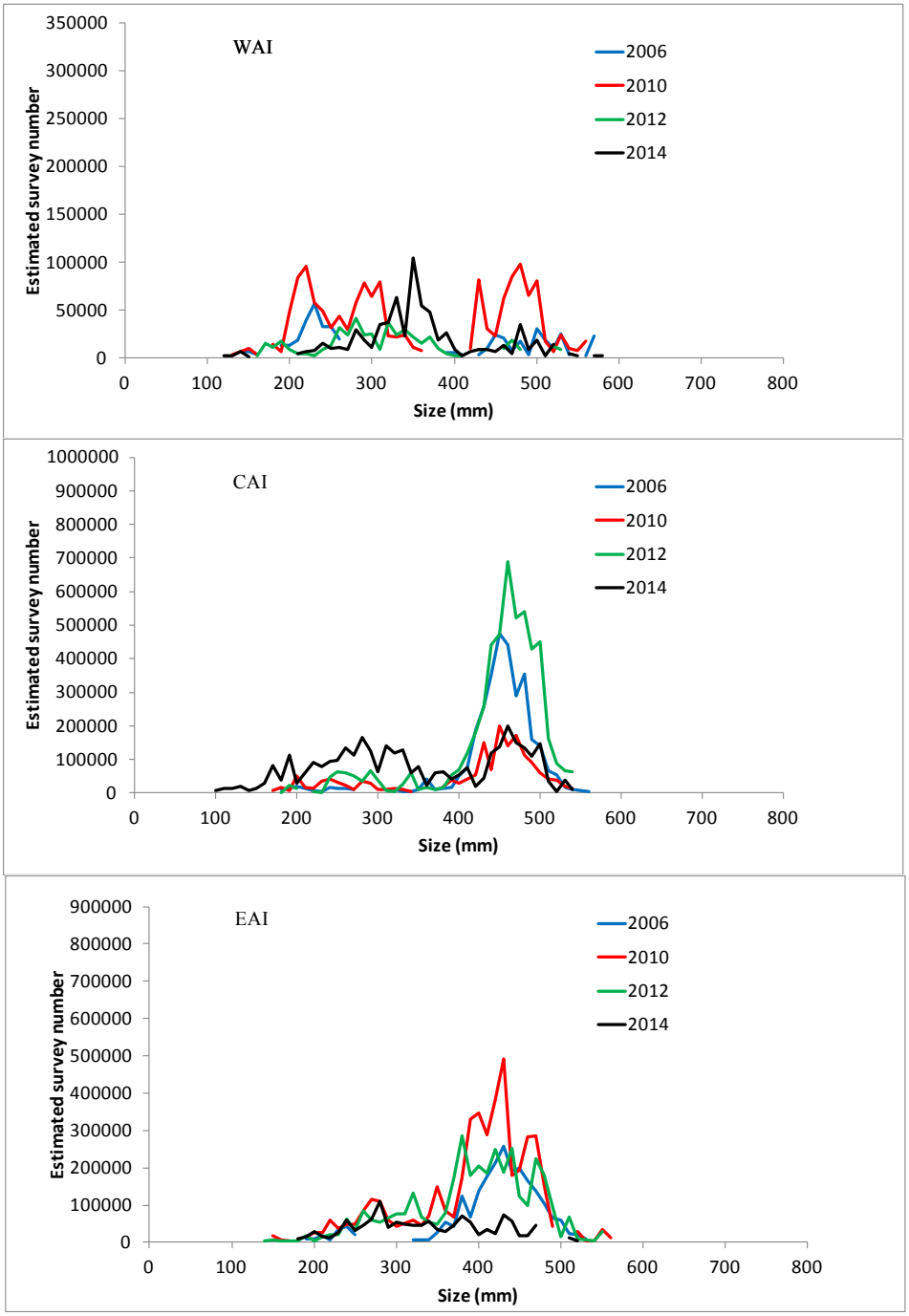

Figure A6. Size compositions of blackspotted/rougheye rockfish from the 2006-2-14 AI surveys by AI subarea.

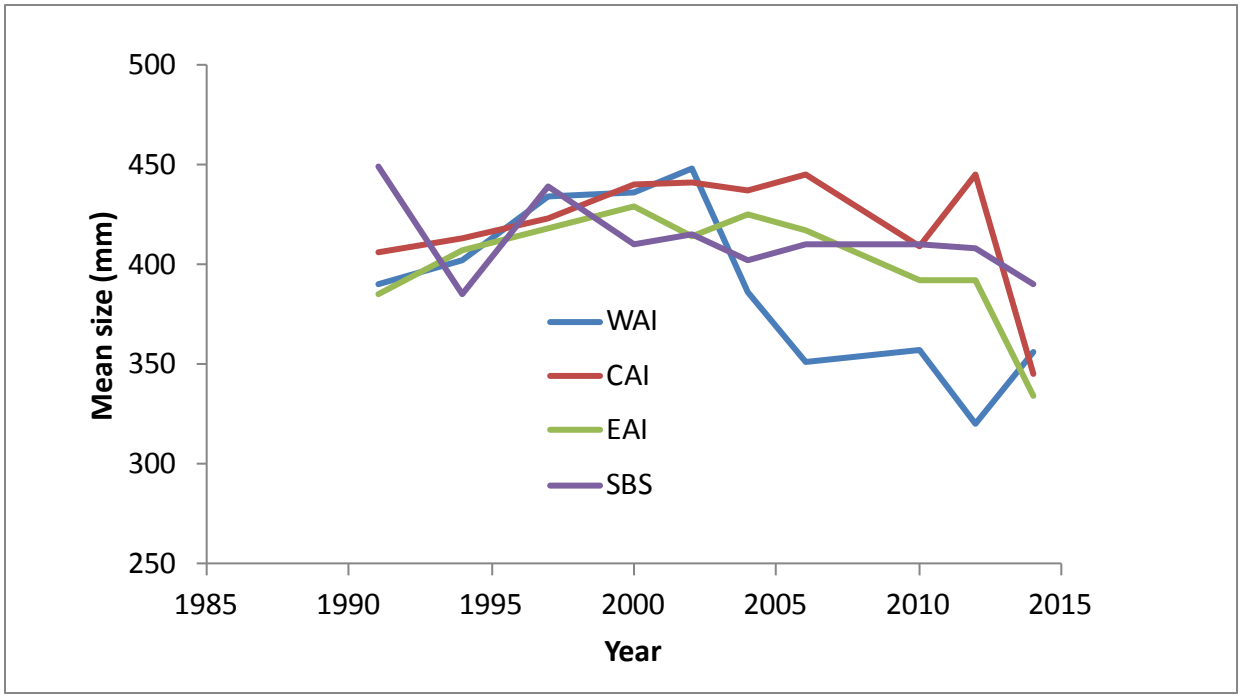

Figure A7. Mean size of blackspotted/rougheye rockfish from the 1991-2014 AI trawl surveys by subarea.

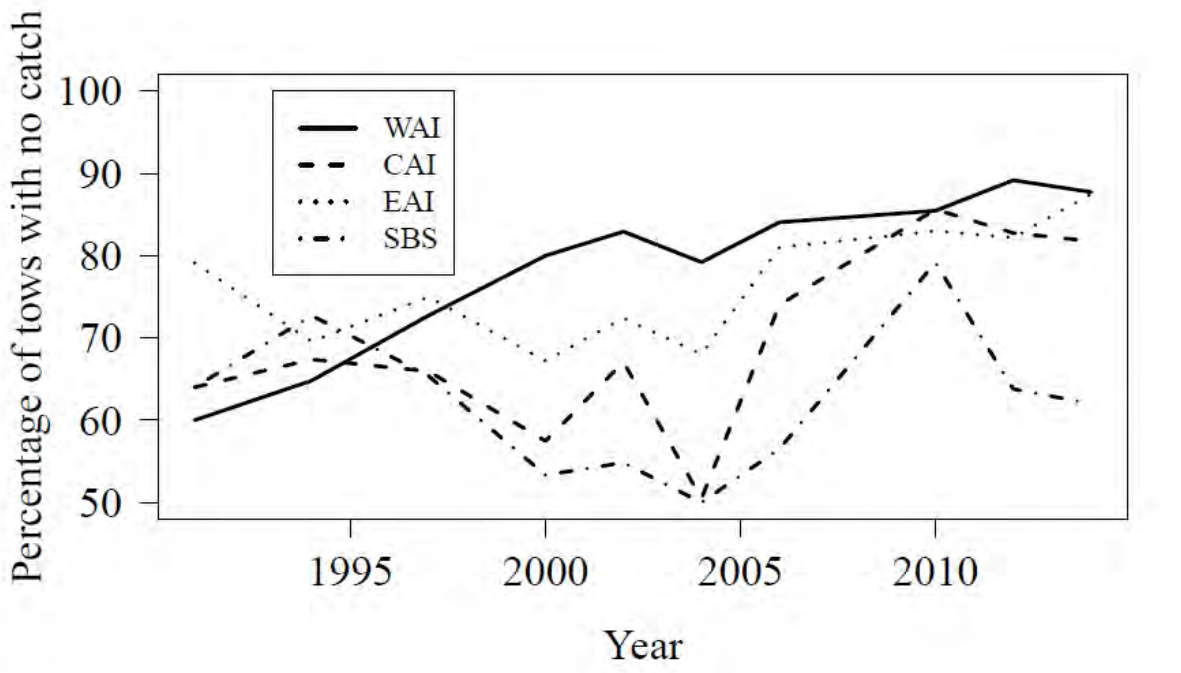

Figure A8. Percentage of survey tows with no catch of blackspotted/rougheye rockfish from the 1991-2014 AI trawl surveys by subarea.

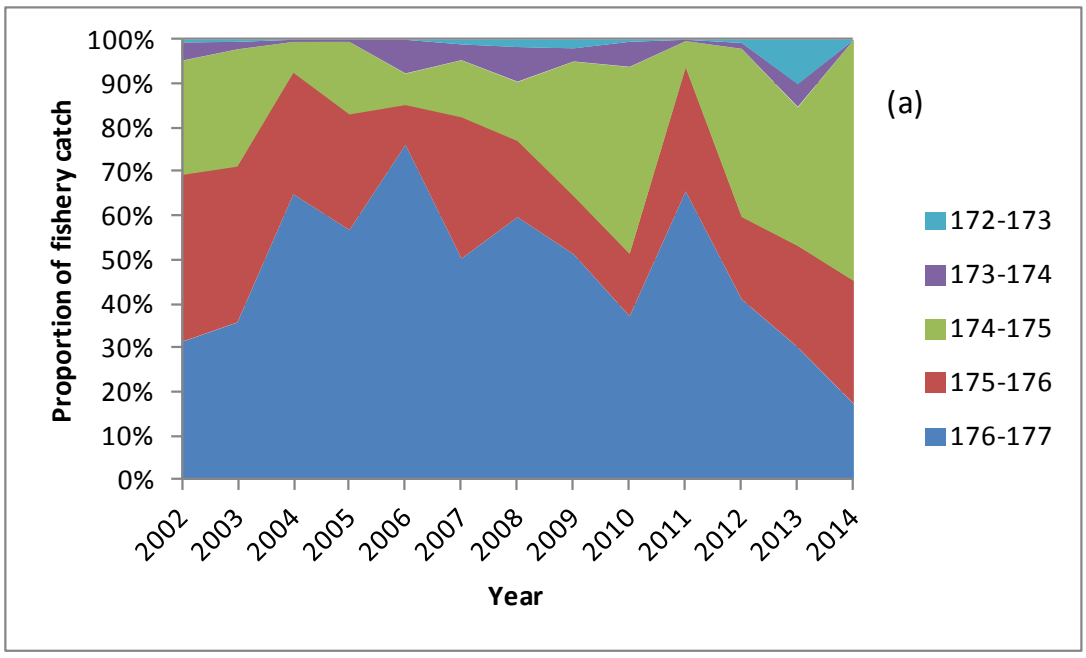

Figure A9. The proportion of fishery catch from 2002-2014 by 1° longitude bins in the WAI; the easternmost bin within the WAI occurs between 176°E and 177°E.

Appendix B. Supplemental Catch Data.

In order to comply with the Annual Catch Limit (ACL) requirements, non-commercial removals that do not occur during directed groundfish fishing activities are reported (Table A1). In these datasets, blackspotted /rougheye rockfish are often reported as rougheye rockfish. This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System estimates. For BSAI blackspotted/rougheye rockfish, these estimates can be compared to the trawl research removals reported in previous assessments. BSAI blackspotted/rougheye rockfish research removals are small relative to the fishery catch. The majority of removals are taken by the Alaska Fisheries Science Center's (AFSC) biennial bottom trawl survey which is the primary research survey used for assessing the population status of BSAI blackspotted/rougheye rockfish. The annual amount of blackspotted/rougheye rockfish captured in research longline gear not exceeded 0.5 t. Total removals ranged between 0.03 t and 0.6 t between 2010 and 2014, which were less than 1.0% of the ABC in these years.

Appendix Table B1. Removals of BSAI blackspotted/rougheye rockfish from activities other than groundfish fishing. Trawl and longline include research survey and occasional short-term projects. "Other" is recreational, personal use, and subsistence harvest.

Year	Source	Trawl	Longline
1977	NMFS-AFSC survey databases	0.000	
1978		0.002	
1979		0.468	
1980		6.844	
1981		1.086	
1982		0.963	
1983		9.780	
1984		0.000	
1985		3.719	
1986		24.241	
1987		0.006	
1988		0.200	
1989		0.001	
1990		0.018	
1991		1.994	
1992		0.014	
1993		0.000	
1994		2.769	
1995		0.003	
1996		0.001	
1997		2.596	
1998		0.000	
1999		0.010	
2000		3.343	
2001		0.001	
2002		2.276	
2003		0.011	
2004		3.499	
2005		0.001	
2006		1.976	
2007		0.001	
2008		0.205	
2009		0.006	
2010	AKFIN database	0.133	0.424
2011		0.005	0.154
2012		0.132	0.3
2013		0.000	0.299
2014		0.032	0

15. Assessment of the shortraker rockfish stock in the Bering Sea and Aleutian Islands

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Executive Summary

Summary of Changes in Assessment Inputs

Changes in the input data:

1) The catch data have been revised and updated through October 31, 2014.
2) The biomass estimate from the 2014 Aleutian Islands (AI) trawl survey was added to the model input data.

Changes in the assessment methodology:

The assessment methodology has changed since the last full assessment in 2012. The previous method used the Gompertz-Fox surplus production model to estimate the shortraker rockfish population, and the Kalman filter to statistically estimate the parameter values. In 2014 biomass is estimated using the random effects model. This is the authors' preferred model used in setting ABC and OFL.

Summary of Results

The recommended 2015 ABC and OFL for BSAI shortraker rockfish are 518 t and 690 t, respectively. This is an increase of 40% from the 2014. A summary of the recommend ABCs and OFLs for 2015 relative the ABC and OFL specified last year is shown below.

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2014	2015	2015	2016
M (natural mortality rate)	0.03	0.03	0.03	0.03
Tier	5	5	5	5
Biomass (t)	16,447	16,447	23,009	23,009
F_{OFL}	0.03	0.03	0.03	0.03
$maxF_{ABC}$	0.0225	0.0225	0.0225	0.0225
F_{ABC}	0.0225	0.0225	0.0225	0.0225
OFL (t)	493	493	690	690
maxABC (t)	370	370	518	518
ABC (t)	370	370	518	518
	As determined *last* year for:		As determined *this* year for:	
Status	2012	2013	2013	2014
Overfishing		n/a		n/a

This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Marine Fisheries Service and should not be construed to represent any agency determination or policy.

Summaries for the Plan Team

The following table gives the recent biomass estimates, catch, harvest specifications, and projected biomass, OFL and ABC for 2015-2016.

Year	Biomass	OFL	ABC	TAC	Catch
2013	16,447	493	370	370	372
2014	16,447	493	370	370	187[1]
2015	23,009	690	518		
2016	23,009	690	518		

[1] Catch as of November 3, 2014.

Responses to SSC and Plan Team Comments on Assessments in General

None pertaining to this assessment.

Responses to SSC and Plan Team Comments Specific to this Assessment

October 2014 SSC meeting: The Plan Team recommended and the SSC agrees that the random effects model be included in the November assessment anticipating that this will be the Team's preferred model for use in setting ABC and OFL.

Authors' response: The 2014 assessment is based on the random effects model. Results using the surplus production model, last year's approved model, are presented in an appendix.

Introduction

Shortraker rockfish (*Sebastes borealis*) are distributed along the continental slope in the north Pacific from Point Conception in southern California to Japan, and are commonly found between eastern Kamchatka and British Columbia (Love et al. 2002). Shortraker rockfish are among the longest lived animal species in the world, reaching ages > 150 years. The species is viviparous with spawning believed to occur throughout the spring and summer (Westerheim 1975, McDermott 2004). Little is known of shortraker rockfish early life history and habitat preferences, as immature fish are rarely observed. Love et al. (2002) indicates the species is found at shallower depths during early life history. As adults the species occurs in a narrow range of depths on the continental slope centered at ~350 m (Rooper 2008) often in areas of steep slope (Rooper and Martin 2012). In bottom trawl survey data, the species is most common through the Aleutian Islands(AI) and northern Gulf of Alaska (GOA). Studies of habitat preferences in the GOA indicate shortraker rockfish may be more abundant in boulder patches with associated *Primnoa* coral (Krieger and Ito 1999, Krieger and Wing 2002). Shortraker rockfish consume large benthic or near-bottom prey, including myctophids, shrimp and squid (Yang et al. 2006).

Several types of research can be used to infer stock structure of shortraker rockfish, including larval distribution patterns and genetic studies. In 2002, an analysis of archived *Sebastes* larvae was undertaken by Dr. Art Kendall; using data collected in 1990 off southeast Alaska (650 larvae) and the AFSC ichthyoplankton database (16,895 *Sebastes* larvae, collected on 58 cruises from 1972 to 1999, primarily in the GOA). The southeast Alaska larvae all showed the same morph, and were too small to have characteristics that would allow species identification. A preliminary examination of the AFSC ichthyoplankton database indicated that most larvae were collected in the spring, the larvae were widespread in the areas sampled, and most were small (5-7 mm). The larvae were organized into three size classes for analysis: <7.9 mm, 8.0-13.9 mm, and >14.0 mm. A subset of the abundant small larvae

was examined, as were all larvae in the medium and large groups. Species identification based on morphological characteristics is difficult because of overlapping characteristics among species, as few rockfish species in the north Pacific have published descriptions of the complete larval developmental series. However, all of the larvae examined could be assigned to four morphs identified by Kendall (1991), where each morph is associated with one or more species. Most of the small larvae examined belong to a single morph, which contains the species *S. alutus* (Pacific ocean perch), *S. polyspinus* (northern rockfish), and *S. ciliatus* (dusky rockfish). Some larvae (18) belonged to a second morph which has been identified as *S. borealis* (shortraker rockfish) in the Bering Sea. The locations of these larvae were near Kodiak Island, the Semidi Islands, Chirkof Island, the Shumagin Islands, and near the eastern end of the AI.

Population structure for shortraker rockfish has been observed in microsatellite data (Matala et al. 2004), with the geographic scale consistent with current management regions (i.e., GOA, AI, and EBS). The most efficient partitioning of the genetic variation into non-overlapping sets of populations identified three groups: a southeast Alaska group, a group extending from southeast Alaska to Kodiak Island, and a group extending from Kodiak Island to the central AI (the western limit of the samples). The available data are consistent with a neighborhood genetic model, suggesting that the expected dispersal of a particular specimen is much smaller than the species range. A parallel study with mtDNA revealed weaker stock structure than that observed with the microsatellite data. It is not known how shortraker in the EBS or western AI relate to the large population groups identified by Matala et al. (2004) due to a lack of samples in these areas.

Spatial differences in life-history characteristics, such as growth rates and age at maturity, could also provide information on stock structure. However, little data is available on these processes, in part because of the difficulty of aging shortraker rockfish. Production aging of shortraker rockfish is currently impeded by the lack of consistent age criteria. Recent, ^{14}C age validation studies appeared promising, but additional testing regarding the accuracy of ages may be needed before initiating production aging.

Fishery

Catches of shortraker rockfish have been reported in a variety of species groups in the foreign and domestic Alaskan fisheries. Foreign catch records did not report shortraker rockfish by species, but in categories such as "other species" (1977, 1978), "POP complex" (1979-1985, 1989), and "rockfish without POP" (1986-1988). Shortraker rockfish were managed in the domestic fishery as part of the “other red rockfish” from 1991-2000 and the “shortraker/rougheye” complex from 2001-2003. The ABCs, TACS, and catches by management complex from 1988-2014 are shown in Table 1. Since 2003, the catch accounting system (CAS) has reported catch of shortraker rockfish by species and area. From 1991-2002, shortraker rockfish catch was reconstructed by computing the harvest proportions within management groups from the North Pacific Foreign Observer Program database, and applying these proportions to the estimated total catch obtained from the NOAA Fisheries Alaska Regional Office “blend” database. This reconstruction was conducted by estimating the shortraker catch for each area (i.e., the EBS and each of the three Aleutian Island areas, the central (CAI), Western (WAI), and Eastern Aleutian Islands (EAI)) and gear type from 1994-2002. For 1991-1993, the Regional Office blend catch data for the AI was not reported by AI subarea, and the AI catch was obtained using the observer harvest proportions by gear type for the entire AI area. Similar procedures were used to reconstruct the estimates of catch from the 1977-1989 foreign and joint venture fisheries. Estimated domestic catches in 1990 were obtained from Guttormsen et al. 1992. Catches from the domestic fishery prior to the domestic observer program were obtained from PACFIN records. Catches of shortraker rockfish since 1977 are shown in Table 2. Catches were relatively high during the late 1970s, declined during the late 1980s as the foreign fishery was reduced, increased in the early 1990s, and declined in the mid-1990s.

The catches by area from 1994-2014 have been variable, with the largest catches often occurring in the EBS (Table 3). From 2003 to 2014, 35% of the shortraker catch occurred in the EBS, with 24%, 23%, and 13% in the central, western, and eastern AI areas respectively. Catches in the western AI increased in 2011-2013 to an average of 164 t, as compared to an average of 34 t from 2003-2010, which resulted in the proportion of catch in the western AI in 2011-2013 increasing to an average of 47% of the total eastern Bering Sea/Aleutian Islands (BSAI) catch for those years. Catch as of November 3, 2014 was only 26 t in the Western AI.

Estimates of discarding by species complex are shown in Table 4. Estimates of discarding of the other red rockfish complex in the EBS were generally above 55% from 1993 to 2000, with the exception of 1993 and 1995 when discarding rates were less than 26%. The variation in discard rates may reflect different species compositions of the other red rockfish catch. Discard rates of EBS shortraker/rougheye (SR/RE) complex from 2001 to 2003 were below 52%, and discard rates of AI SR/RE complex from 1993-2003 were below 41%. In general, the discard rates of EBS SR/RE are less than the discard rates of EBS other red rockfish in most years, likely reflecting the relatively higher value of rougheye and shortraker rockfishes over other members of the complex. Discard rates of BSAI shortraker rockfish from 2004-2014 have ranged from 23% to 50%, and were 30% in 2013 and 45% for 2014 (through November 3).

Shortraker rockfish in the AI have been primarily taken in the rockfish trawl fishery, the turbot, sablefish, arrowtooth flounder, halibut, and Pacific cod longline fisheries, and the Atka mackerel, Pacific cod, arrowtooth flounder, and Kamchatka flounder trawl fisheries (Table 5). From 2004-2014, these fisheries accounted for 98% of the AI catch of shortraker. Catches of shortraker rockfish from 2004-2014 in the AI management area were caught primarily in the rockfish bottom trawl fishery (58%), followed by sablefish longline (10%) and Atka mackerel bottom trawl fisheries (9%). Catches of shortraker rockfish from 2004-2014 in the EBS were caught largely in the midwater pollock trawl fishery (22%), Pacific cod (20%), Greenland turbot (9%), and halibut (10%) longline fisheries, and arrowtooth flounder (15%), other flatfish (1%), and rockfish trawl fisheries (19%); these fisheries contributed 95% of the total EBS catch (Table 6). Catches of shortraker rockfish in the EBS management area were concentrated in areas 517 and 521, the areas occupying much of the EBS slope (Table 6).

Shortraker rockfish and four other species of rockfish (Pacific ocean perch, northern rockfish, rougheye rockfish, *S. aleutianus*; and sharpchin rockfish, *S. zacentrus*) were managed as a complex in the EBS and AI management areas from 1979 to 1990. Known as the POP complex, these five species were managed as a single entity with a single TAC (total allowable catch) within each management area. In 1991, the North Pacific Fishery Management Council enacted new regulations that changed the species composition of the POP complex. For the eastern Bering Sea slope region, the POP complex was divided into two subgroups: 1) Pacific ocean perch, and 2) shortraker, rougheye, sharpchin, and northern rockfishes combined, also known as "other red rockfish" (ORR). For the AI region, the POP complex was divided into three subgroups: 1) Pacific ocean perch, 2) shortraker/rougheye rockfishes, and 3) sharpchin/northern rockfishes. In 2001, the other red rockfish complex in the EBS was split into two groups, shortraker/rougheye and sharpchin/northern, matching the complexes used in the AI. These subgroups were established to protect Pacific ocean perch, shortraker rockfish, and rougheye rockfish (the three most valuable commercial species in the assemblage) from possible overfishing. Additionally, separate TACs were established for the EBS and AI management areas, but the overfishing level (OFL) pertained to the entire BSAI area. In 2002, sharpchin rockfish were assigned to the "other rockfish" category, leaving only northern rockfish and the shortraker/rougheye complex as members of other red rockfish. In 2004, rougheye and shortraker rockfishes were managed by species in the BSAI area. Shortraker rockfish has been assessed separately since 2008.

Data

Fishery

The length composition from observer sampling of the domestic fishery (Figure 1), indicate relatively consistent length distributions with the bulk of the sampled fish generally between 30 and 70 cm. There are no apparent trends in the size distribution. The number of length observations taken by fishery observers in the BSAI is shown in the following table.

Year	Number of fishery length observations	Year	Number of fishery length observations
1991	1,230	2003	5,608
1992	1,144	2004	4,315
1993	1,153	2005	3,904
1994	125	2006	3,409
1995	88	2007	3,727
1996	55	2008	2,362
1997	50	2009	3,100
1998	107	2010	3,685
1999	627	2011	2,174
2000	330	2012	2,121
2001	302	2013	2,017
2002	440	2014	1,847

The catch data are the estimates of single species catch described above and shown in Table 2. However, given the history of previously managing EBS rockfish as separate stock complexes, and recent information on genetic population structure for other BSAI rockfish species, it is prudent to examine how area-specific exploitation rates compare to F_{ABC} and F_{OFL} reference points. Area-specific exploitation rates for a given year were obtained by dividing the yearly catch by the estimate of biomass for the subarea. The subareas considered here are the 3 AI subareas, the southern Bering Sea (i.e., areas 518 and 519) and the EBS (i.e., the remainder of the EBS managemnent area minus the southern Bering Sea). The subarea biomass for each year was obtained by applying the proportional biomass in each region, based on a 3 year (4,6,9) weighted average, to the total biomass, estimated by the random effects model.

Exploitation rates in the CAI and EAI have been below M and generally low from 2004-2014 (Figure 2a). Increases in the catch in the western AI in 2011-2013 resulted in the exploitation rates in this area exceeding F_{ABC} in these years, but not F_{OFL} (Table 3, Figure 2a). The 2014 catch in the WAI is lower than previous years, as of November 3, 2014. Catch of shortraker rockfish in the SBS is variable, ranging from 2-40 t from 2003-2014 (Table 3). Biomass in that region appears to be decreasing, and the current year estimate of 28 t is the second lowest on record (Table 7, Figures 3 and 4). Exploitation rates in the SBS was higher than F_{OFL} (0.03), in 2012 (Figure 2a). The exploitation rate for the entire BSAI has remained below F_{ABC} and F_{OFL} since 2002 (Figure 2b).

Removals from sources other than those that are included in the Alaska Region's official estimate of catch are presented in Appendix 1.

Survey

Biomass estimates for other red rockfish were produced from cooperative U.S.-Japan trawl surveys from 1979-1985 on the EBS Bering Sea slope, and from 1980-1986 in the AI. U.S domestic trawl surveys were conducted in 1988, 1991, 2002, 2004, 2008, 2010, and 2012 on the EBS slope, and in 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, and 2014 in the AI (Table 7). The 2008 AI survey and 2006 and 2010 EBS slope survey were canceled. The 2002 EBS slope survey represents the initiation of a new

survey time series distinct from the previous surveys in 1988 and 1991. EBS slope and the AI surveys were used to compute biomass estimates in this assessment. The EBS slope survey was initiated in 2002; therefore, biomass estimates are available from 2002-2014.

In contrast to the fishery length compositions, the survey length compositions reveal fewer large fish (Figure 5). In surveys from 1994 to 2014, fish lengths from survey samples generally occurred between 30 cm and 65 cm.

The AI surveys from 1980 to 2014 indicated higher abundances in the Western (543) and Central (542) than in the eastern AI (541), with the SBS area having the lowest abundance (Figure 4). Biomass in the SBS has shown a consistent decline in biomass estimated by the survey since 1983.

The biennial EBS slope survey was initiated in 2002. The most recent slope survey prior to 2002, excluding some preliminary tows in 2000 intended for evaluating survey gear, was in 1991. The survey biomass estimates of shortraker rockfish from the 2002-2012 EBS slope surveys have ranged between 2570 t (2004) and 9,299 t (2012), with CVs between 0.22 and 0.57.

Analytic Approach

The random effects model was used to estimate biomass of shortraker rockfish in the BSAI. The random effects (RE) model is an approximation to the Kalman Filter approach. The process errors (step changes) from one year to the next are the random effects to be integrated over and the process error variance is a free parameter. The observations can be irregularly spaced; therefore this model can be applied to datasets with missing data. Large observation errors increase errors predicted by the model, which can provide a way to weight predicted estimates of biomass (http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/2012/Sept/survey_average_wg.pdf).

Estimates were made using the 1980-2014 AI and 2002-2012 EBS slope survey time series for biomass and estimates of uncertainty. The most recent slope survey was conducted in 2012; therefore the best estimate of the past 2 years of slope biomass is the 2012 estimate. This method produces estimates of BSAI shortraker biomass from 2002-2014.

Shortraker rockish in the BSAI are managed under Tier 5, where OFL = M * average survey biomass, where M represents natural mortality, and F_{ABC} is estimated by 0.75 * M. The acceptable biological catch (ABC) is obtained by multiplying F_{ABC} by the estimated biomass, ABC $\leq$ 0.75 * M * biomass.

Parameter Estimates

Shortraker rockfish are assumed to have a natural mortality rate (M) of 0.03. This estimate of natural mortality is consistent with estimates for north Pacific shortraker rockfish using the gonad somatic index, which ranged from 0.027 to 0.042 (McDermott 1994).

Results

Estimated shortraker rockfish biomass in the BSAI has been relatively stable since 2002. Biomass has decreased slightly from 23,938 t in 2002 to 20,896 t in 2006, and has increased to 23,009 t in 2014 (Figure 6, Table 8). Biomass estimates using last year's approved method, the surplus production model, are shown in Appendix 2 Table 1. The random effect model results are higher than the 2012 model results due to the inclusion of Bering Sea slope biomass estimates from the Bering Sea slope survey. The random effects model estimates of Aleutian Island and Eastern Bering Sea slope shortraker rockfish biomass from 2002- 2014, as well as the total biomass estimate, are shown in Table 9.

Harvest Recommendations

Shortraker rockfish are currently managed under Tier 5 of Amendment 56 of the NPFMC BSAI Groundfish FMP, which requires a reliable estimate of stock biomass and natural mortality rate. The estimate of *M* for shortraker rockfish was obtained from Heifetz and Clausen (1991), and for Tier 5 stocks, F_{OFL} and F_{ABC} are defined as *M* and 0.75*M,* respectively:

Shortraker rockfish	2014 biomass	*M*	ABC	OFL
	23,009 t	0.03	518 t	690 t

Data Gaps and Research Priorities

Validating aging techniques of shortraker rockfish, and obtaining ages from archived samples, remains research priorities and are required for age-structured population modeling. More information on the genetic population structure within the BSAI area is needed. Little is known regarding most aspects of the biology of shortraker rockfish, including the reproductive biology and distribution, duration, and habitat requirements of various life-history stages. Given the relatively unusual reproductive biology of rockfish and its importance in establishing management reference points, data on reproductive capacity should be collected on a periodic basis.

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Tables

Table 1. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of the species groups used to manage shortraker rockfish from 1988 to 2014. The "other red rockfish" group includes, shortraker rockfish, rougheye rockfish, northern rockfish, and sharpchin rockfish. The "POP complex" includes the other red rockfish species plus POP. *Estimated removals through November 3, 2014.

Year	Area	Management Group	ABC (t)	TAC (t)	Catch (t)
1988	BS	POP Complex	6,000		1,509
	AI	POP Complex	16,600		2,629
1989	BS	POP Complex	6,000		2,873
	AI	POP Complex	16,600		3,780
1990	BS	POP Complex	6,300		7,231
	AI	POP Complex	16,600		15,224
1991	BS	Other Red Rockfish	1,670	1,670	942
	AI	Shortraker/rougheye	1,245	1,245	388
1992	BS	Other Red Rockfish	1,400	1,400	467
	AI	Shortraker/rougheye	1,220	1,220	1,470
1993	BS	Other Red Rockfish	1,400	1,200	1,226
	AI	Shortraker/rougheye	1,220	1,100	1,139
1994	BS	Other Red Rockfish	1,400	1,400	129
	AI	Shortraker/rougheye	1,220	1,220	925
1995	BS	Other Red Rockfish	1,400	1,260	344
	AI	Shortraker/rougheye	1,220	1,098	559
1996	BS	Other Red Rockfish	1,400	1,260	207
	AI	Shortraker/rougheye	1,250	1,125	959
1997	BS	Other Red Rockfish	1,050	1,050	218
	AI	Shortraker/rougheye	938	938	1,043
1998	BS	Other Red Rockfish	267	267	112
	AI	Shortraker/rougheye	965	965	685
1999	BS	Other Red Rockfish	356	267	238
	AI	Shortraker/rougheye	1,290	965	514
2000	BS	Other Red Rockfish	259	194	253
	AI	Shortraker/rougheye	1,180	885	480
2001	BSAI	Shortraker/rougheye	1,028		
	BS	Shortraker/rougheye		116	72
	AI	Shortraker/rougheye		912	722
2002	BSAI	Shortraker/rougheye	1,028		
	BS	Shortraker/rougheye		116	105
	AI	Shortraker/rougheye		912	478
2003	BSAI	Shortraker/rougheye	967		
	BS	Shortraker/rougheye		137	124
	AI	Shortraker/rougheye		830	306
2004	BSAI	Shortraker	526	526	242
2005	BSAI	Shortraker	596	596	170
2006	BSAI	Shortraker	580	580	213
2007	BSAI	Shortraker	424	424	323
2008	BSAI	Shortraker	424	424	133
2009	BSAI	Shortraker	387	387	184
2010	BSAI	Shortraker	387	387	300
2011	BSAI	Shortraker	393	393	333
2012	BSAI	Shortraker	393	393	344
2013	BSAI	Shortraker	370	370	372
2014*	BSAI	Shortraker	370	370	187

Table 2. Catches of shortraker rockfish (t) in the BSAI area, obtained from the North Pacific Groundfish Observer Program, NMFS Alaska Regional Office, and PACFIN.

	Eastern Bering Sea			Aleutian Islands			
Year	Foreign	Joint Venture	Domestic	Foreign	Joint Venture	Domestic	Total
1977	0	0		27	0		27
1978	1,069	0		874	0		1,943
1979	279	0		3,008	0		3,286
1980	649	0		185	0		833
1981	441	0		381	0		821
1982	242	0		379	0		621
1983	145	0		89	1		235
1984	54	0		28	0		83
1985	19	0		1	0		21
1986	2	2	14	0	0	12	30
1987	0	0	28	0	0	36	64
1988	0	0	31	0	0	37	69
1989	0	0	58	0	0	130	188
1990			116			546	662
1991			205			251	456
1992			79			289	368
1993			221			216	437
1994			46			176	223
1995			49			164	213
1996			87			143	230
1997			36			90	126
1998			52			159	211
1999			66			129	195
2000			130			200	330
2001			57			172	229
2002			93			206	299
2003			107			131	239
2004			119			123	242
2005			108			62	170
2006			47			165	212
2007			114			210	323
2008			41			91	133
2009			69			116	184
2010			161			139	300
2011			106			227	333
2012			117			227	344
2013			105			268	372
2014*			88			99	187

* Estimated removals through November 3, 2014.

Table 3. Area-specific catches of shortraker rockfish (t) in the BSAI area from 1994-2014, obtained from the North Pacific Groundfish Observer Program, NMFS Alaska Regional Office. Abbreviations are: Western Aleutian Islands (WAI), Central Aleutian Islands (CAI), Eastern Aleutian Islands (EAI), Southern Bering Sea (SBS), Eastern Bering Sea (EBS), and Bering Sea (BS).

Year	WAI	CAI	EAI	SBS	BS	Total
1994	2	84	91		46	223
1995	7	44	113		49	213
1996	33	48	63		87	230
1997	47	14	29		36	126
1998	27	100	32		52	211
1999	23	63	43		66	195
2000	20	85	95		130	330
2001	58	87	27		57	229
2002	78	62	66		93	299
Year	WAI	CAI	EAI	SBS	EBS	Total
2003	30	65	37	0	107	239
2004	32	76	15	5	114	242
2005	27	17	18	5	103	170
2006	39	103	23	2	45	212
2007	23	145	43	6	108	323
2008	40	35	17	12	29	133
2009	34	41	41	15	54	184
2010	48	40	51	7	154	300
2011	162	37	28	21	85	333
2012	168	32	27	40	77	344
2013	163	68	37	12	93	372
2014*	26	32	41	8	80	187

* Estimated removals through November 4, 2014.

Table 4. Estimated retained (t), discarded (t), and percent discarded of other red rockfish (ORR) and shortraker/rougheye (SR/RE) from the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions. Prior to 2001, ORR in the eastern Bering Sea was managed as a single complex.

Area	Species Group	Year	Catch (t) Retained	Discard	Total	Percentage
EBS	ORR	1993	916	308	1226	25.2%
		1994	29	100	129	77.6%
		1995	273	70	343	20.4%
		1996	58	149	207	71.9%
		1997	43	174	217	80.0%
		1998	42	70	112	62.4%
		1999	75	162	238	68.4%
		2000	111	141	252	55.9%
EBS.	SR/RE	2001	27	16	43	34.7%
		2002	50	54	104	51.9%
		2003	66	58	124	46.8%
AI	SR/RE	1993	737	403	1,139	35.3%
		1994	701	224	925	24.2%
		1995	456	103	559	18.4%
		1996	751	208	959	21.7%
		1997	733	310	1,043	29.7%
		1998	447	238	685	34.8%
		1999	319	195	514	38.0%
		2000	285	196	480	40.8%
		2001	476	246	722	34.1%
		2002	333	146	478	30.4%
		2003	214	92	306	29.9%
BSAI	SR	2004	143	99	242	41.1%
		2005	129	40	170	23.9%
		2006	130	82	212	38.7%
		2007	163	161	323	49.7%
		2008	102	31	133	23.3%
		2009	136	48	184	26.2%
		2010	230	70	300	23.4%
		2011	299	34	333	10.2%
		2012	290	54	344	15.8%
		2013	262	111	372	29.8%
		2014*	103	84	187	44.8%

* Estimated removals through November 3, 2014.

Table 5. Aleutian Islands catch (t) of shortraker rockfish by management area and target fishery from 2004-2014, from the NMFS Alaska Regional Office catch accounting system database.

		Management area			
Target Fishery	Gear	541	542	543	Percentage
Pacific cod	Longline	43.06	34.39	10.76	5.16%
Halibut	Longline	32.26	16.67	7.79	3.32%
Rockfish	Longline	0.02	4.01	0.51	0.27%
Other species	Longline		6.18		0.36%
Sablefish	Longline	67.44	77.92	19.19	9.62%
Turbot	Longline	0.91	117.93		6.95%
Arrowtooth flounder	Longline	1.60	59.76		3.59%
Atka mackerel	Bottom Trawl	28.60	90.73	29.16	8.68%
Pacific cod	Bottom Trawl	0.90	6.49	0.02	0.43%
Rockfish	Bottom Trawl	77.57	217.23	694.43	57.83%
Turbot	Bottom Trawl	2.35			0.14%
Arrowtooth flounder	Bottom Trawl	55.46			3.24%
Pacific cod	Pot		0.67		0.04%
Sablefish	Pot	4.94	1.73		0.39%
Sum (all targets and gears)		315.11	633.70	761.85	1,710.66

Table 6. Eastern Bering Sea catch (t) of shortraker rockfish by management area and target fishery from 2004-2014, from the NMFS Alaska Regional Office catch accounting system database.

		Management area										
Target Fishery	Gear	508	509	513	514	517	518	519	521	523	524	Percentage
Atka mackerel	Bottom trawl							6.59				0.6%
Bottom pollock	Bottom trawl					0.32	1.00	0.30	0.65			0.2%
Pacific cod	Pot					0.05		0.05				0.0%
Pacific cod	Longline		0.01	0.04		15.21	0.12	12.95	142.94	38.30	0.04	19.5%
Pacific cod	Bottom trawl					0.18		0.94	0.87			0.2%
Other flatfish	Bottom trawl					9.20		3.48				1.2%
Halibut	Longline			0.37	0.49	2.68	10.89	3.37	69.09	8.59	7.05	9.5%
Rockfish	Longline					0.59	0.01		5.22	2.96		0.8%
Rockfish	Bottom trawl					84.49	6.28	39.84	55.04	15.95		18.7%
Flathead sole	Bottom trawl					3.35		0.65	1.27	3.27		0.8%
Other species	Longline								0.36	4.20		0.4%
Other species	Bottom trawl					1.30						0.1%
Sablefish	Pot					0.19	1.27	0.99				0.2%
Sablefish	Longline					6.82	1.43	0.87	0.98	0.48		1.0%
Turbot	Longline					1.33	1.29	0.17	69.67	21.64	1.22	8.8%
Turbot	Bottom trawl					5.00	0.16		0.57			0.5%
Arrowtooth flounder	Longline					0.70	0.63	0.01	1.15	2.65		0.5%
Arrowtooth flounder	Bottom trawl			0.25		70.62	17.39	15.40	55.43	0.23	1.26	14.9%
Midwaterpollock	Pelagic trawl		0.25	2.27		206.47		4.02	23.91	0.29		22.0%
Sum (all targets and gears)			0.26	2.92	0.49	408.50	40.47	89.62	427.15	98.53	9.57	1,077.51

Table 7. Estimated biomass (t) of shortraker rockfish from the NMFS bottom trawl surveys, with the coefficient of variation (CV) shown in parentheses. The Aleutian Island survey data includes the Southern Bering Sea.

Year	WAI	CAI	EAI	SBS	AI survey (total)	EBS Slope survey
1979						1,391
1980	0	2,665	4,165	45	6,874 (0.55)	
1981						3,571
1982						5,176
1983	7,249	7,239	11,787	9,477	35,753 (0.19)	
1984						
1985						4,010
1986	1,821	4,291	5,554	6,485	18,153 (0.28)	
1987						
1988						1,260 (0.43)
1989						
1990						
1991	17,558	3,225	1,053	1,925	23,761 (0.64)	2,758 (0.38)
1992						
1993						
1994	6,493	8,164	11,627	1,959	28,244 (0.21)	
1995						
1996						
1997	6,658	21,560	7,840	2,428	38,487 (0.26)	
1998						
1999						
2000	17,746	13,543	5,863	645	37,797 (0.44)	
2001						
2002	3,906	8,639	2,797	1,463	16,805 (0.19)	4,851 (0.44)
2003						
2004	16,333	8,779	7,499	630	33,242 (0.37)	2,570 (0.22)
2005						
2006	2,471	5,335	3,975	1,180	12,961 (0.23)	
2007						
2008						7,308 (0.31)
2009						
2010	6,729	7,424	4,071	15	18,239 (0.23)	4,365 (0.28)
2011						
2012	4,455	7,182	4,031	562	16,230 (0.26)	9,299 (0.57)
2013						
2014	1,579	12,678	2,144	28	16,429 (0.38)	

Table 8. Estimated fishing mortality rates and beginning year biomass for shortraker rockfish from the 2010, 2012, and 2014 assessments. The 2010 and 2012 assessments were based on the surplus production model, and the 2014 biomass estimate was based on the random effects model, which includes the Bering Sea slope and Aleutian Islands survey data. The Bering Sea slope survey was initiated in 2002; therefore, the 2014 assessment estimates biomass from 2002 through 2014.

	Biomass (t)				
Year	2010 Assessment	2012 Assessment	2014 Assessment (95% confidence intervals)		
1980	29,722	29,776			
1981	28,313	28,350			
1982	27,537	27,561			
1983	27,091	27,101			
1984	28,580	28,564			
1985	28,125	28,102			
1986	27,684	27,655			
1987	25,722	25,690			
1988	25,614	25,574			
1989	25,550	25,503			
1990	25,373	25,320			
1991	25,599	25,560			
1992	25,528	25,493			
1993	25,388	25,350			
1994	25,378	25,341			
1995	25,645	25,609			
1996	25,458	25,419			
1997	25,269	25,220			
1998	26,305	26,249			
1999	25,226	25,165			
2000	24,201	24,139			
2001	23,301	23,251			
2002	22,316	22,223	23,938	(16,262,	31,613)
2003	20,584	20,519	23,402	(15,385,	31,418)
2004	20,129	20,055	22,906	(14,977,	30,836)
2005	20,192	20,113	21,792	(13,801,	29,783)
2006	19,599	19,512	20,896	(12,276,	29,515)
2007	18,033	17,953	21,709	(12,528,	30,891)
2008	17,758	17,662	22,641	(13,511,	31,770)
2009	17,647	17,530	22,492	(14,077,	30,907)
2010	17,503	17,369	22,356	(15,454,	29,259)
2011		17,216	22,693	(14,215,	31,171)
2012		16,858	23,093	(13,278,	32,909)
2013			23,051	(12,248,	33,855)
2014			23,009	(11,554,	34,464)

Table 9. Random effect estimates of biomass for shortraker rockfish from 2002-2014, for the Aleutian Islands (AI, including the Southern Bering Sea portion of the survey) and theh Eastern Bering Sea slope survey.

Year	Bering Sea slope	Aleutian Islands	Total
2002	3,763	20,175	23,938
2003	3,376	20,025	23,402
2004	3,029	19,877	22,906
2005	3,538	18,254	21,792
2006	4,132	16,763	20,896
2007	4,826	16,883	21,709
2008	5,637	17,004	22,641
2009	5,366	17,125	22,492
2010	5,109	17,248	22,356
2011	5,669	17,024	22,693
2012	6,290	16,804	23,093
2013	6,290	16,761	23,051
2014	6,290	16,719	23,009

Figures

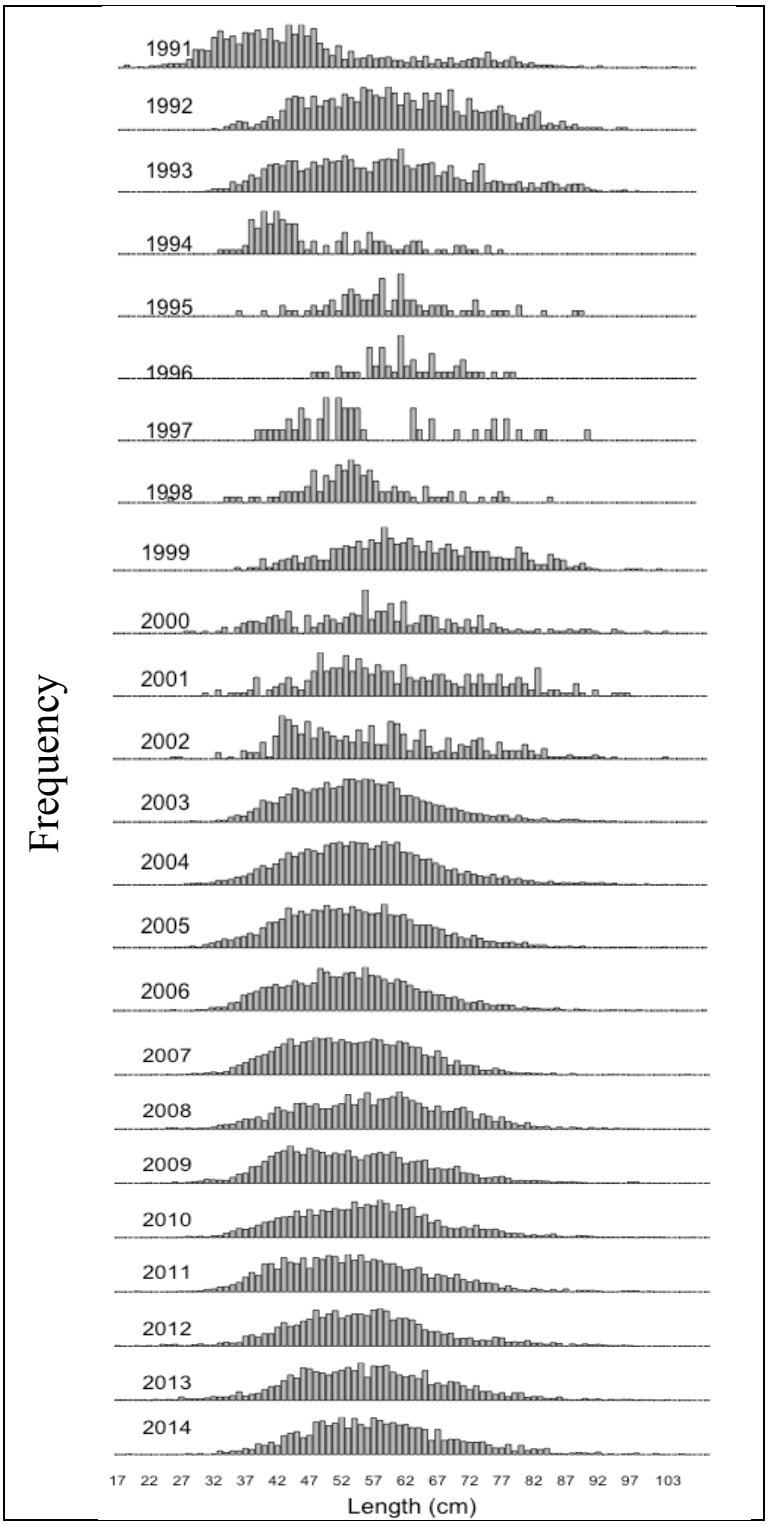

Figure 1. Length compositions from the US domestic fishery, 1991-2014.

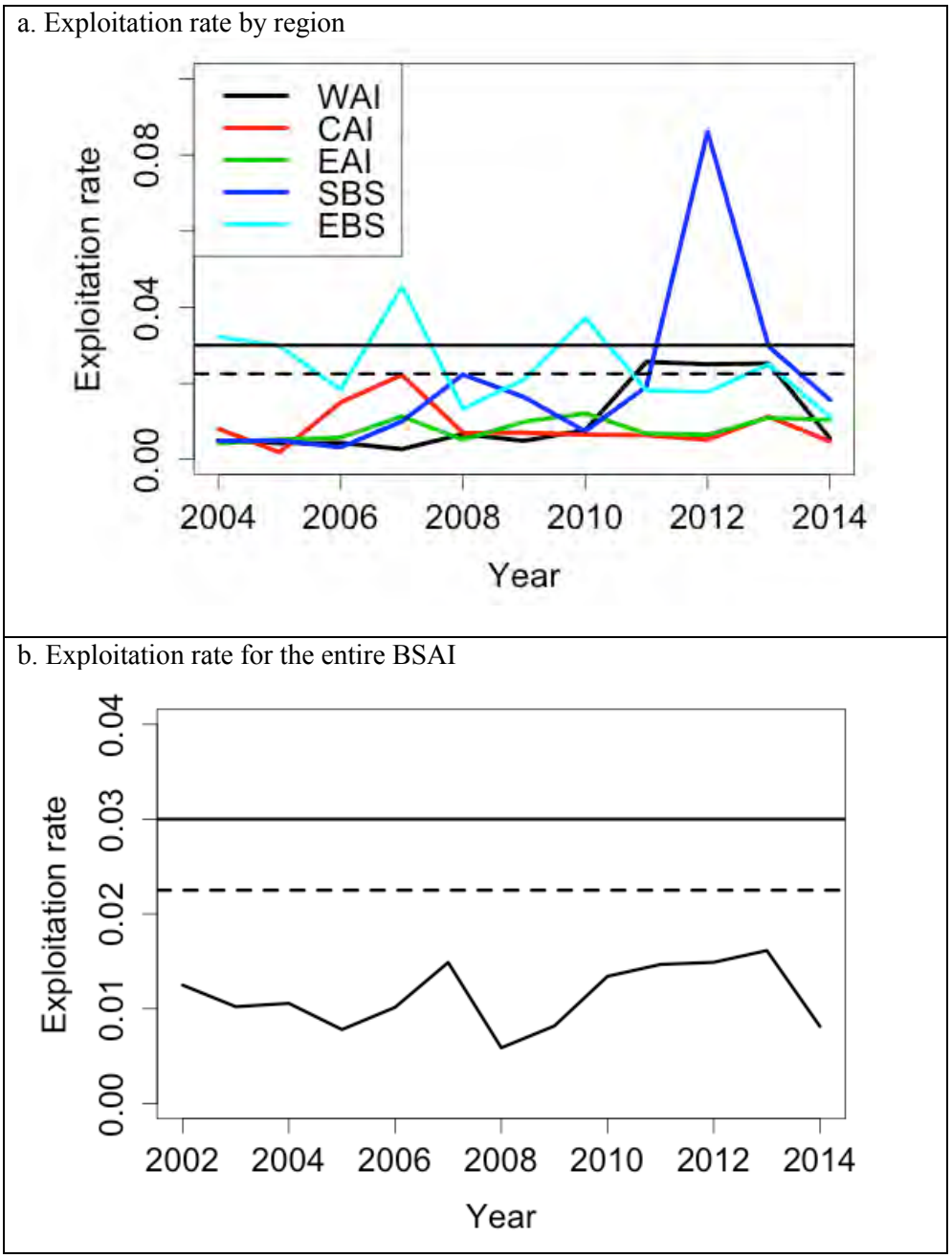

Figure 2. Area-specific exploitation rates for BSAI shortraker rockfish from 2003-2014 (panel a.), and for the entire BSAI (panel b). Abbreviations are: Western Aleutian Islands (WAI), Central Aleutian Islands (CAI), Eastern Aleutian Islands (EAI), Southern Bering Sea (SBS), Eastern Bering Sea (EBS), and Bering Sea (BS).

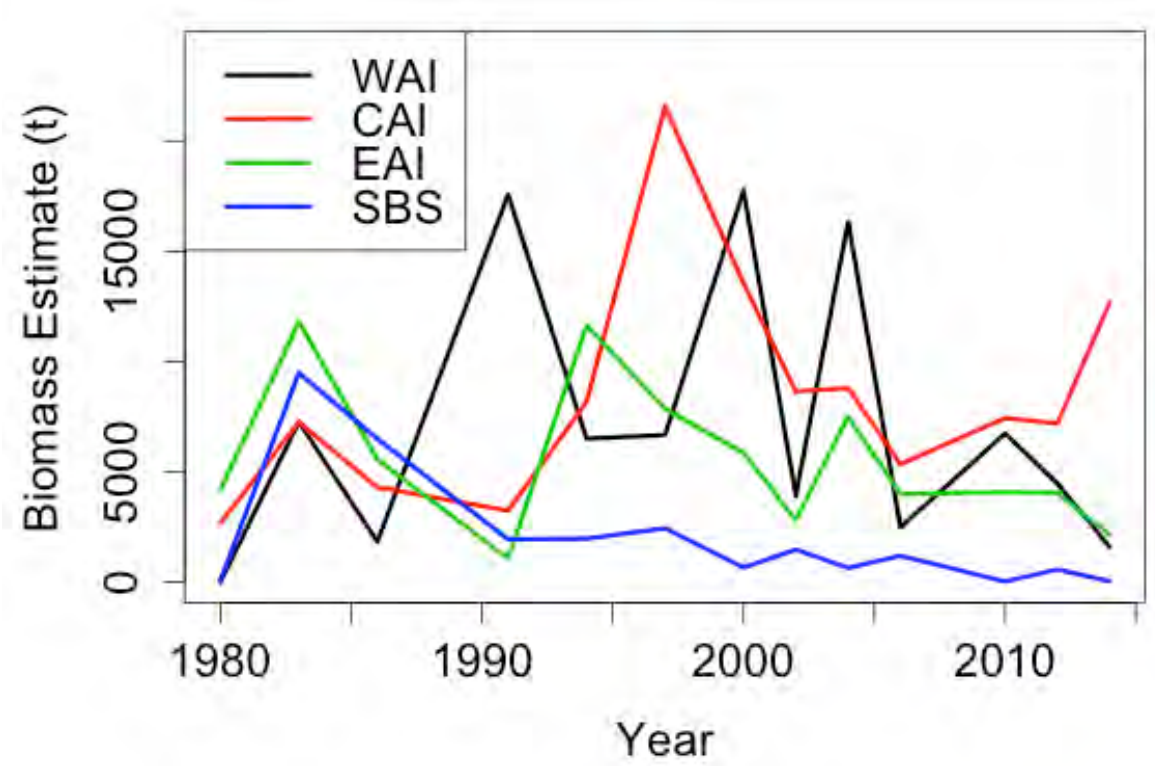

Figure 3. Survey estimates of biomass in the Western Aleutian Islands (WAI), Central Aleutian Islands (CAI), Eastern Aleutian Islands (EAI), Southern Bering Sea (SBS), Eastern Bering Sea (EBS), and Bering Sea (BS).

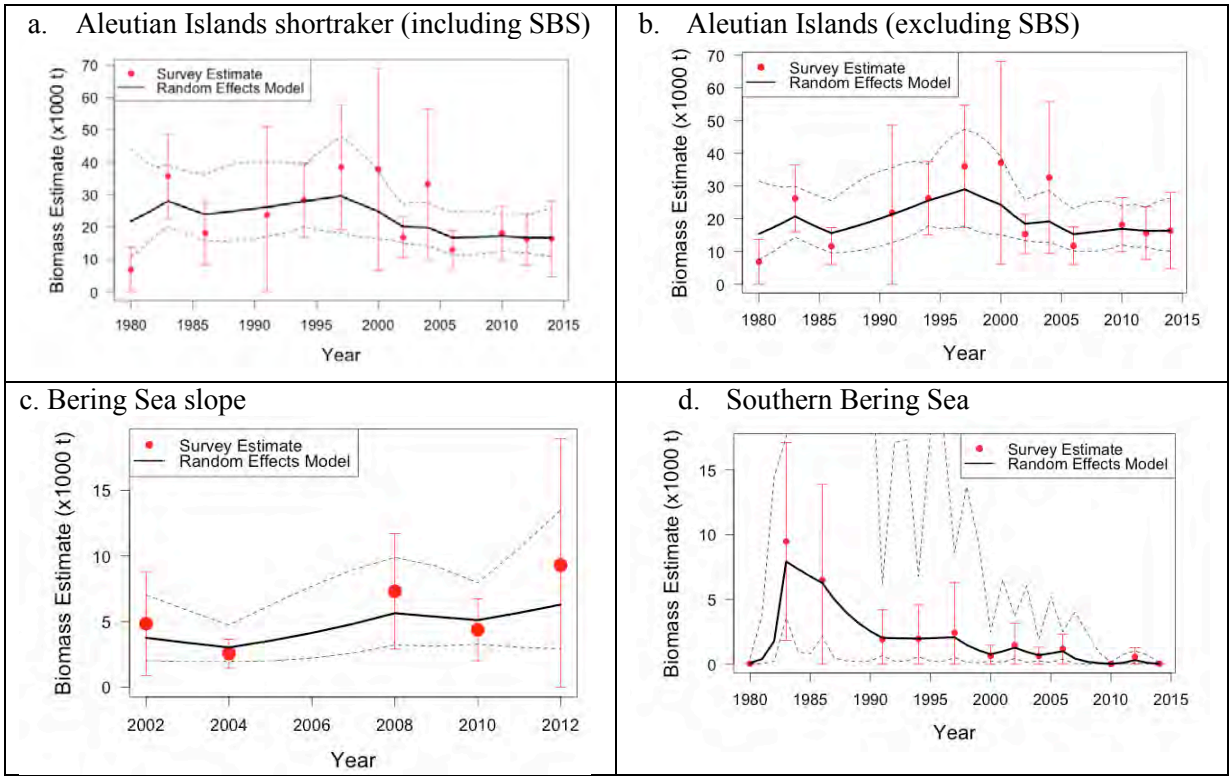

Figure 4. Observed survey biomass (red data points +/- 2 standard deviations), and predicted survey biomass estimates using the random effects model (black lines with 95% confidence intervals shown as dotted lines). Panel (a.) Aleutian Islands (AI), including the Southern Bering Sea (SBS), (b.) AI, excluding the SBS, (c.) Bering Sea slope, and (d.) the SBS.

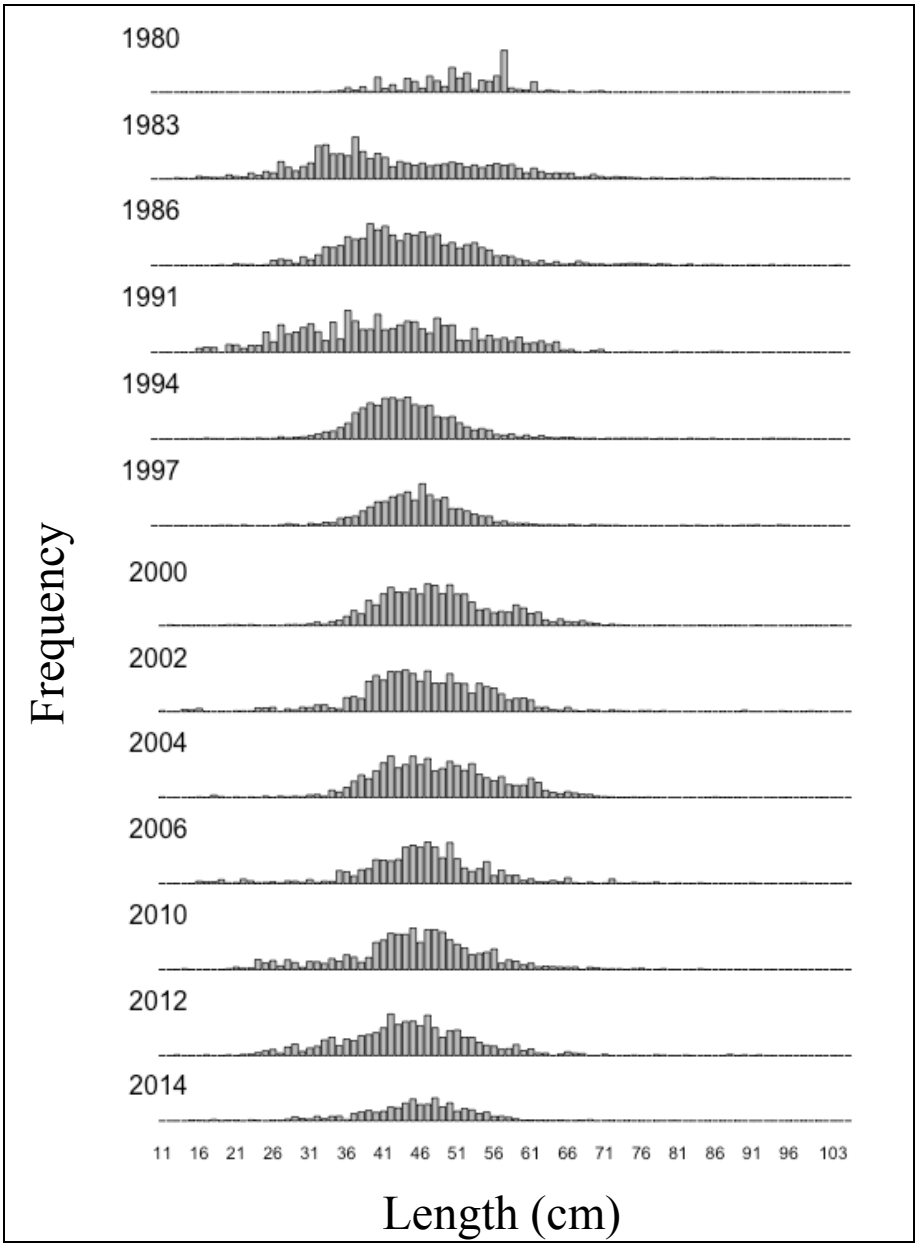

Figure 5. Length compositions from the Aleutian Islands trawl surveys, 1980-2014.

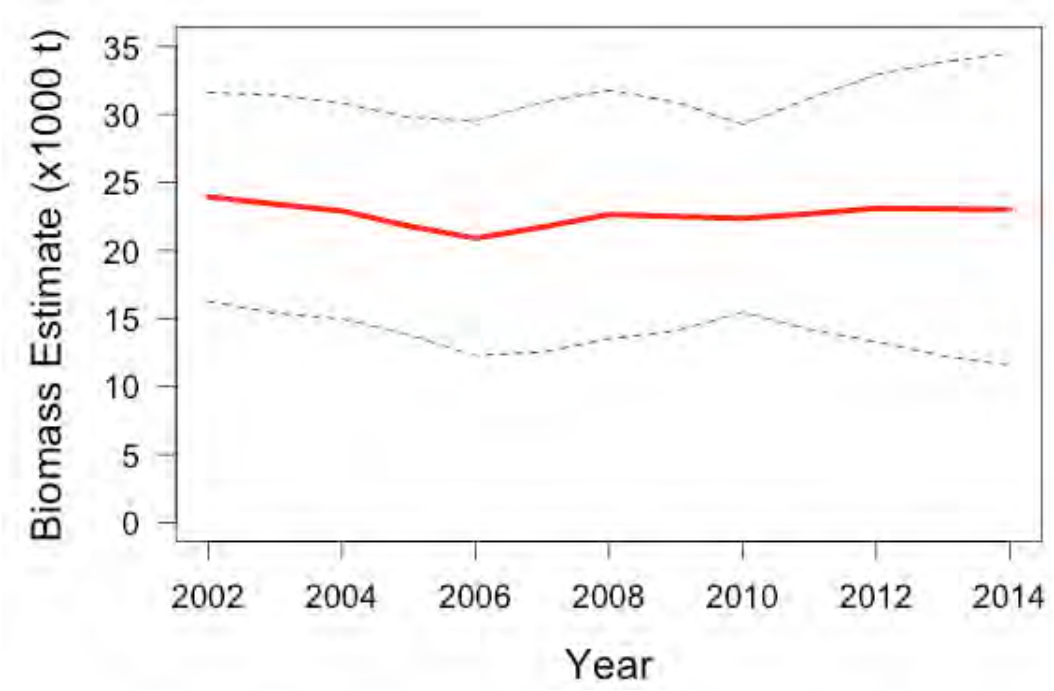

Figure 6. Estimated Bering Sea/Aleutian Islands (BSAI) Shortraker biomass (t) time series, from 2002-2014.

Appendix 1. Supplemental Catch Data

In order to comply with the Annual Catch Limit (ACL) requirements, two new datasets have been generated to help estimate total catch and removals from NMFS stocks in Alaska. The first dataset, non-commercial removals, estimates total removals that do not occur during directed groundfish fishing activities (Appendix 1 Table 1). This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System estimates. For Bering Sea/Aleutian Islands (BSAI) shortraker rockfish, these estimates can be compared to the trawl research removals reported in previous assessments. Shortraker rockfish research removals are small relative to the fishery catch. The majority of removals are taken by the Alaska Fisheries Science Center's (AFSC) biennial bottom trawl survey which is the primary research survey used for assessing the population status of BSAI shortraker rockfish. Other research activities that harvest shortraker rockfish include other trawl research activities and minor catches occur in longline surveys conducted by the International Pacific Halibut Commission and the AFSC. Some catches in the AFSC longline survey are reported as shortraker/rougheye. There was no recorded recreational harvest or harvest that was non-research related in 2010 and 2011. Total removals of shortraker and "shortraker/rougheye" rockfish were less than 7 t and 3 t in 2010 and 2011, respectively, which represent less than 2% of the ABC in these years. Research harvests in even years beginning in 2000 (excluding 2008, when the Aleutian Islands (AI) trawl survey was canceled) are higher due to the biennial cycle of the AFSC bottom trawl survey in the AI. These catches have varied between 2 and 6 t.

The second dataset, Halibut Fishery Incidental Catch Estimation (HFICE), is an estimate of the incidental catch of groundfish in the halibut IFQ fishery in Alaska, which is currently unobserved. To estimate removals in the halibut fishery, methods were developed by the HFICE working group and approved by the Gulf of Alaska (GOA) and BSAI Plan Teams and the Scientific and Statistical Committee of the North Pacific Fishery Management Council. A detailed description of the methods is available in Tribuzio et al. (2011).

These estimates are for total catch of groundfish species in the halibut IFQ fishery and do not distinguish between "retained" or "discarded" catch. These estimates should be considered a separate time series from the current CAS estimates of total catch. Because of potential overlaps HFICE removals should not be added to the CAS produced catch estimates. The overlap will apply when groundfish are retained or discarded during an IFQ halibut trip. IFQ halibut landings that also include landed groundfish are recorded as retained in eLandings and a discard amount for all groundfish is estimated for such landings in CAS. Discard amounts for groundfish are not currently estimated for IFQ halibut landings that do not also include landed groundfish. For example, catch information for a trip that includes both landed IFQ halibut and sablefish would contain the total amount of sablefish landed (reported in eLandings) and an estimate of discard based on at-sea observer information. Further, because a groundfish species was landed during the trip, catch accounting would also estimate discard for all groundfish species based on available observer information and following methods described in Cahalan et al. (2010). The HFICE method estimates all groundfish caught during a halibut IFQ trip and thus is an estimate of groundfish caught whether landed or discarded. This prevents simply adding the CAS total with the HFICE estimate because it would be analogous to counting both retained and discarded groundfish species twice. Further, there are situations where the HFICE estimate includes groundfish caught in State waters and this would need to be considered with respect to ACLs (e.g. Chatham Strait sablefish fisheries). Therefore, the HFICE estimates should be considered preliminary estimates for what is caught in the IFQ halibut fishery. Improved estimates of groundfish catch in the halibut fishery will become available following restructuring of the Observer Program in 2013, when all vessels >25 ft will be monitored for groundfish catch.

The HFICE estimates of BSAI shortraker rockfish catches are variable, ranging between 2 and 18 t from 2001 -2014. Years with relatively high catches are caused by increased catches in the eastern and central AI.

Appendix 1 Table 1. Removals (t) of BSAI shortraker rockfish from activities other than groundfish fishing. Trawl and longline include research survey and occasional short-term projects. "Other" is recreational, personal use, and subsistence harvest.

		Shortraker			Shortraker/Rougheye	
Year	Source	Trawl	Longline	Other	Trawl	Longline
1977						
1978						
1979		0.933				
1980		5.707				
1981		4.972				
1982		7.646				
1983		15.496				
1984						
1985		9.246				
1986		9.151				
1987						
1988		0.336				
1989						
1990						
1991		3.437				
1992						
1993	NMFS-AFSC survey databases	0.008				
1994		4.604				
1995						
1996						
1997		5.824				
1998			0.830			2.174
1999		0.017	1.198			0.494
2000		6.348	0.973			2.066
2001		0.010	1.258			0.422
2002		3.875	0.785			1.649
2003			2.138			0.376
2004		5.367	0.691			1.680
2005		0.011	1.299			0.347
2006		2.176	1.186			3.367
2007			1.307			0.429
2008		2.321	0.650			1.544
2009			1.706			0.571
2010	NMFS-Alaska	2.764	2.556		0.018	1.546
2011	Regional Office	1.424	2.544			0.411
2012		3.874				
2013		1.205				
2014		1.571				

Appendix 1 Table 2. Estimates of the BSAI shortraker rockfish catch (t) from the Halibut Fishery Incidental Catch Estimation (HFICE) working group. The 2014 values are incomplete.

Year	Eastern AI	Central AI	Western AI	Central/Western AI	Total
2001	0.85	2.68	2.88	0.00	6.40
2002	1.65	1.50	0.17	0.00	3.32
2003	0.00	4.52	0.00	0.00	4.52
2004	1.31	0.00	1.09	0.00	2.40
2005	14.05	1.27	0.15	0.00	15.47
2006	10.69	4.95	0.00	0.00	15.65
2007	1.98	4.10	0.44	0.00	6.52
2008	1.95	2.65	0.00	0.00	4.60
2009	3.36			0.11	3.47
2010	7.52	8.74	1.32	0.00	17.58
2011					1.12
2012					0.56
2013					0.51
2014					
Average	4.33	3.38	0.67	0.01	7.99

Literature Cited

Cahalan J., J. Mondragon., and J. Gasper. 2010. Catch Sampling and Estimation in the Federal Groundfish Fisheries off Alaska. NOAA Technical Memorandum NMFS-AFSC-205. 42 p.

Heifetz, J., D. Hanselman, J. N. Ianelli, S. K. Shotwell, and C. Tribuzio. 2009. Gulf of Alaska northern rockfish. In Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 2010. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501. pp. 817-874.

Tribuzio, C.A., S. Gaichas, J. Gasper, H. Gilroy, T. Kong, O. Ormseth, J. Cahalan, J. DiCosimo, M. Furuness, H. Shen, K. Green. 2011. Methods for the estimation of non-target species catch in the unobserved halibut IFQ fleet. August Plan Team document. Presented to the Joint Plan Teams ofthe North Pacific Fishery Management Council.

Appendix 2.
Assessment of shortraker rockfish in the Bering Sea and Aleutian Islands using last year's approved method, the surplus production model.

Executive Summary

Summary of Changes in Assessment Inputs

1) The catch data have been revised and updated through October 31, 2014.
2) The biomass estimate from the 2014 AI survey was added to the model input data.

The assessment methodology has not changed since the last full assessment in 2012. The Gompertz-Fox surplus production model is used to estimate the shortraker rockfish population, and the Kalman filter to statistically estimate the parameter values.

Summary of Results

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2014	2015	2015	2016
M (natural mortality rate)	0.03	0.03	0.03	0.03
Tier	5	5	5	5
Biomass (t)	16,447	16,447	16,073	16,073
F_{OFL}	0.03	0.03	0.03	0.03
$maxF_{ABC}$	0.0225	0.0225	0.0225	0.0225
F_{ABC}	0.0225	0.0225	0.0225	0.0225
OFL (t)	493	493	482	482
maxABC (t)	370	370	362	362
ABC (t)	370	370	362	362
	As determined *last* year for:		As determined *this* year for:	
Status	2012	2013	2013	2014
Overfishing		n/a		n/a

Introduction

This document presents the 2014 shortraker rockfish assessment with biomass estimated using last year's approved methodology, the surplus production model.

Responses to SSC and Plan Team Comments Specific to this Assessment

October 2014 SSC meeting: The Plan Team recommended and the SSC agrees that the random effects model be included in the November assessment anticipating that this will be the Team's preferred model for use in setting ABC and OFL.

Authors' response: The 2014 assessment is based on the random effects model. Results using the surplus production model, last year's approved model, are presented in Appendix 2.

Fishery

Please refer to the main document for this section.

Analytic Approach

Model Structure

A simple surplus production model, the Gompertz-Fox model, was used to model the shortraker rockfish population, and the Kalman filter provided a method of statistically estimating the parameter values. The model was implemented in the software program AD Model Builder. The Gompertz-Fox model (Fox 1970) describes the rate of change of stock size as

$$\frac{dx}{dt} = ax(\ln(k) - \ln(x)) - fx \quad (1)$$

where x is stock size, k is carrying capacity, and f is fishing mortality. The model is mathematically equivalent to a model of individual growth developed by Gompertz, and describes a situation where stocks at low sizes would show a sigmoidal increase in stock size to an asymptote. The Gompertz-Fox model can be derived from the Pella-Tomlinson model (Pella and Tomlinson 1969) by taking the limit as n (the parameter controlling the location of the peak of the production curve) approaches 1. The peak of the production curve occurs at approximately 37% of the carrying capacity, in contrast to the logistic model where the peak occurs at 50% of the carrying capacity. The Gompertz-Fox model was chosen for this analysis because it is a simple model that offers some information on growth rate and carrying capacity, and it is easily transformed into a linear form suitable for the Kalman filter (Thompson 1996). Under the Gompertz-Fox model, the rate of change of yield is modeled as $y = fx$, and the f level corresponding to the maximum sustainable yield (MSY) is equivalent to the growth parameter a. Equilibrium biomass (b) is

$$b = ke^{-f/a} \quad (2)$$

and the equilibrium stock size corresponding to MSY, B_{msy}, is k/e.

The Kalman filter

A brief review of the Kalman filter is provided here, as more thorough presentations are provided in Meinhold and Singpurwalla (1983), Harvey (1990), and Pella (1993). The Kalman filter separates the system into a model of the state variable, which describes the true (but unobserved) state of nature, and a model of the observation variables, which describes how the observed data relate to the state variable. The state variable is modeled as

$$X_t = T_t X_{t-1} + c_t + R_t \eta_t \quad (3)$$

where X_t is a vector of state variables at time t, T_t is a matrix containing the parameter that define state dynamics , c_t is a $m \times 1$ vector of constants (in, general, this could be set to zero), R_t is a $m \times g$ matrix and η_t is a $g \times 1$ vector of random process errors with a mean of zero and a covariance matrix of Q_t. The

inclusion of the R_t vector is useful when a particular state variable is affected by more than one type of random disturbance. For the shortraker rockfish application there is a single state variable at each time step (the log biomass) and the problem simplifies considerably and all terms become scalars. Finally, the state variable is described by a distribution with an estimated mean α_t and variance P_t.

The observation equation is

$$Y_t = Z_t X_t + d_t + \varepsilon_t \tag{4}$$

where Y_t is a vector of observed variables, Z_t is a matrix containing parameters that define how observations are generated, d_t is a $n \times 1$ vector (in general, this could be set to zero) and ε_t is a $n \times 1$ vector of random observation errors with mean zero and covariance matrix H_t.

A distinct advantage of the Kalman filter is that both the process errors and observation errors are incorporated into the parameter estimation procedure. The method by which this occurs can be understood by invoking the Bayesian concepts of "prior" and "posterior" estimates of the state variable (Meinhold and Singpurwalla 1983). Denote α_{t-1} as the posterior estimate of X_{t-1} using all the data up to and including time *t-1*. At time step *t*, a prior estimate of the state variable is made from the state equation (Eq. 3) and the posterior estimate from the previous step α_{t-1}. Because this prior estimate of X_t uses all the data up to time *t-1*, it is denoted as $\alpha_{t|t-1}$. The prior estimate can be used with Eq. 4 to predict the observation variables at time *t*. Upon observation of Y_t there are now two estimates of the observed variables; the observed data Y_t and the prediction from the prior estimate $\alpha_{t|t-1}$. The Kalman filter updates the prior and produces a posterior estimate, $\alpha_{t|t}$, that results in a value of Y_t between these two points, and the extent to which the posterior estimate differs from the prior estimate is a function of the magnitude of prediction error and the observation error variance relative to the process error variance. The posterior estimates are then used as prior estimates in the next time step to continue the recursive procedure.

Parameter estimation can be obtained by minimizing the log likelihood of the data, and the log likelihood (without constant terms) is

$$\ln L = -\frac{1}{2}\sum_{t=1}^{T} \ln\left|F_t\right| - \frac{1}{2}\sum_{t=1}^{T} \nu_t' F_t^{-1} \nu_t \tag{5}$$

where F_t is $Z_t P_{t|t-1} Z_t' + H_t$, $P_{t|t-1}$ (the prior estimate of the variance of the state variable) is $T_t P_{t-1} T_t' + R_t Q_t R_t'$, and ν_t (the one step ahead prediction error) is $y_t - Z_t \alpha_{t|t-1} - d_t$.

Application of the Gompertz-Fox model to the Kalman filter can be obtained by defining the state variable as log biomass, and using catch and survey biomass as observation variables. The log transformation of Eq. 1 is

$$\frac{dX}{dt} = a(B - X) \tag{6}$$

where $X = \ln(x)$ and $B = \ln(b) = \ln(ke^{-f/a})$. The solution to this differential equation is

$$X_t = e^{-at} X_0 + (1 - e^{-at}) B_t \tag{7}$$

where annual changes in f_t result in $B_t = \ln(ke^{-f_t/a})$. This solution can be also expressed in a recursive form as

$$X_{t+\Delta t} = e^{-a\Delta t} X_t + (1 - e^{-a\Delta t}) B_t \tag{8}$$

where Δt is a discrete time period. For a single species case, defining $T_t = e^{-a\Delta t}$ and $c_t = (1\text{-}T_t)B_t$ produces the deterministic portion of the state equation (Eq. 3).

For shortraker rockfish, we typically have annual estimates of catch but triennial or biennial estimates of survey biomass, and this missing data complicates the observation equation. For years in which both data types are available,

$$Y_t = \begin{bmatrix} \ln(s_t) \\ \ln(c_t) \end{bmatrix}, \quad Z_t = \begin{bmatrix} 1 \\ 1 \end{bmatrix}, \text{ and } d_t = \begin{bmatrix} \ln(q) \\ \ln(f_t) \end{bmatrix}$$

where s_t is the survey biomass estimates of shortraker rockfish in year t, c_t is the aggregated catch of shortraker rockfish during year t, q is the survey catchability coefficient, and f_t is the rate of removal from fishing. Note that this model formulation assumes the non-logged survey biomasses are proportional to the true biomass. Additionally, the aggregated catch during the year is used as an estimate of the rate of catch at the time of the survey, a reasonable approximation for BSAI rockfish because the survey occurs at the midpoint of the year. The observation equation simplifies when only catch data are available:

$$Y_t = \left[\ln(c_t)\right], \quad Z_t = \left[1\right], \text{ and } d_t = \left[\ln(f_t)\right]$$

Although the observed data reflect the system at the midpoint of a year, it is expected that the instantaneous fishing mortality rate would change between calendar years; thus, a time-step of one-half year was chosen for the discretized model. At the beginning of the calendar year neither data type is available, and updating the prior estimates with observed data is not possible. In these cases, the posterior estimate is set equal to the prior estimate for the next time step (Kimura et al. 1996).

An initial estimate of the mean and variance of the state variable (α_0 and P_0, respectively) is required to begin the recursive calculations, and can be obtained in several ways. These terms could also be estimated freely along with the other model parameters, or a diffuse prior may be placed upon them (Pella 1993). However, freely estimating these parameters increases the complexity of the estimation procedure and is not recommended (Pella 1993). For this analysis, a concentrated likelihood function was used to obtain maximum likelihood estimates of the initial state variables, which were then used in a standard Kalman filter (Rosenberg 1973).

Catch estimation error

As mentioned above, species-specific catches of shortraker rockfish are often made from application of an observed proportion of the catch (from observer sampling) to the estimated aggregated catch for the species complex. For example, in years where shortraker and rougheye catches are reported as a two species complex, the shortraker rockfish catch would be obtained by

$$C_{SR} = p_{SR} * C_{RE/SR}$$

where p_{SR} is the proportion of shortraker observed in observer sampling and $C_{re/sr}$ is the aggregated catch. This estimation procedure produces quantities that can be viewed as the product of two random variables. While overall catch data are often viewed as relatively precisely observed as compared to other fisheries information, the proportions from observer sampling adds additional error. For this assessment, it was assumed that the aggregated species complex catch were lognormally distributed, the species proportions from observer sampling followed a multinomial distribution, and these two random variables were independent. The variances of the log of estimated catch can be obtained from the Delta method (Seber 1982) and is

$$V(\ln(C_{SR})) = \sigma^2 + \frac{p_{RE}}{Np_{SR}}$$

where N is the assumed sample size for the multinomial distribution, σ is approximately the coefficient of variation of the aggregated complex catch, and the levels of p_{RE} and p_{SR} are taken at their expected values. In addition, two species-specific estimates of catch are likely to be correlated because they are functions with some variables in common, but this covariance is not utilized in the single species model.
An additional complication arises when the species-specific catch estimation procedure is applied across several areas and/or fisheries, and the total catch for each species is a sum of several random variables. In this case, define S_{RE} and S_{SR} as

$$S_{SR} = \sum_i p_{SR,i} * C_{RE/SR,i}$$

where i indexes the total number terms in the summation, and the means and variances of each of the terms within this summation are additive.

Parameter estimates

The survey catchability coefficient for each species was fixed at 1.0. Attempts to obtain reasonable estimate of survey catchability were not successful, reflecting a catch history that does not provide information regarding the scale of population biomass. The parameters relating to the estimation error on catches were fixed such that $N = 100$ and $\sigma = 0.15$. Because of the longevity and perceived low population growth rate of shortraker rockfish, the process error CV was set to the relatively low value of 0.05.

The parameters estimated conditionally in the model include a, k, and f_t. The estimation of a proved problematic with this dataset, and lognormal priors were utilized to stabilize parameter values. The mean of the lognormal prior was equal to the assumed natural mortality rate M of 0.03, and a large CV of 1.0 was used for the variance. This estimate of natural mortality is consistent with estimates for north Pacific shortraker rockfish using the gonad somatic index, which ranged from 0.027 to 0.042 (McDermott 1994). The rationale for expecting a to approximate M is because the a parameter in the Gompertz-Fox model is equivalent to F_{msy}, and M is often used as an approximation of F_{msy} (Gulland 1970).

Results

Estimated shortraker rockfish biomass decreased slightly from 28,856 t in 1980 to 26,430 t in 1997, and have since declined to 16,073 t in 2014 (Figure 1, Table 1). The time series of estimated fishing mortality

shows the largest values of approximately 0.025 to 0.029 in the early 1980s and early 1990s, which are comparable to assumed natural mortality estimate of 0.03 (Table 1, Figure 2).

Considerable uncertainty in the parameter estimates of *a* in the Gompertz-Fox model exists for shortraker rockfish. The lack of data regarding this parameter can be seen in plots of annual surplus production (ASP), which is the change in biomass over a period plus the catch during that period, expressed on an annual basis. Plots of ASP as a function of mean biomass are shown in Figure 3new, and indicate little information on the *a* parameter for shortraker rockfish. The *a* parameter is related to the slope of the production curve at low stock sizes, and one could imagine alternate production curves with high levels of *a* providing suitable fits to ASP data. Given the longevity of shortraker rockfish, one would not expect observed surplus production to deviate far from zero, and this was the motivation for constraining *a* by information on the natural morality rate. The observation of some levels of surplus production substantially different from zero reflects large fluctuations in estimated survey biomass that are generally inconsistent with perceived shortraker rockfish life-history characteristics.

Harvest Recommendations

Shortraker rockfish are currently managed under Tier 5 of Amendment 56 of the NPFMC BSAI Groundfish FMP, which requires a reliable estimate of stock biomass and natural mortality rate. The estimate of *M* for shortraker rockfish was obtained from Heifetz and Clausen (1991), and for Tier 5 stocks, F_{OFL} and F_{ABC} are defined as *M* and 0.75*M,* respectively. The acceptable biological catch (ABC) is obtained by multiplying F_{ABC} by the estimated biomass. This procedure results in the following BSAI ABCs and OFLs:

Shortraker rockfish	2014 biomass	M	ABC	OFL
	16,073 t	0.03	361 t	482 t

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Tables

Appendix 2 Table 1. Estimated fishing mortality rates and beginning year biomass for shortraker rockfish from the 2010 and 2012 assessments.

	Biomass (t)			Fishing Mortality Rate	
Year	2012 Assessment	2010 Assessment	2014 Preferred model	2012 Assessment	2014 Assessment
1980	29,776	28,856		0.028	0.029
1981	28,350	28,048		0.028	0.028
1982	27,561	27,487		0.022	0.022
1983	27,101	28,793		0.008	0.008
1984	28,564	28,251		0.003	0.003
1985	28,102	27,771		0.001	0.001
1986	27,655	25,792		0.001	0.001
1987	25,690	25,695		0.002	0.002
1988	25,574	25,629		0.003	0.003
1989	25,503	25,502		0.007	0.007
1990	25,320	25,971		0.025	0.025
1991	25,560	25,806		0.017	0.017
1992	25,493	25,621		0.014	0.014
1993	25,350	25,648		0.017	0.017
1994	25,341	25,818		0.009	0.009
1995	25,609	25,624		0.008	0.008
1996	25,419	25,434		0.009	0.009
1997	25,220	26,430		0.005	0.005
1998	26,249	25,377		0.009	0.009
1999	25,165	24,332		0.008	0.008
2000	24,139	23,505		0.014	0.014
2001	23,251	22,416		0.011	0.011
2002	22,223	20,727	23,938	0.015	0.015
2003	20,519	20,231	23,402	0.012	0.012
2004	20,055	20,298	22,906	0.012	0.012
2005	20,113	19,658	21,792	0.009	0.009
2006	19,512	18,099	20,896	0.012	0.012
2007	17,953	17,866	21,709	0.018	0.018
2008	17,662	17,664	22,641	0.010	0.010
2009	17,530	17,525	22,492	0.012	0.012
2010	17,369	17,429	22,356	0.019	0.019
2011	17,216	17,085	22,693	0.020	0.020
2012	16,858	16,678	23,093	0.021	0.021
2013		16,348	23,051		0.023
2014		16,073	23,009		0.018

Figures

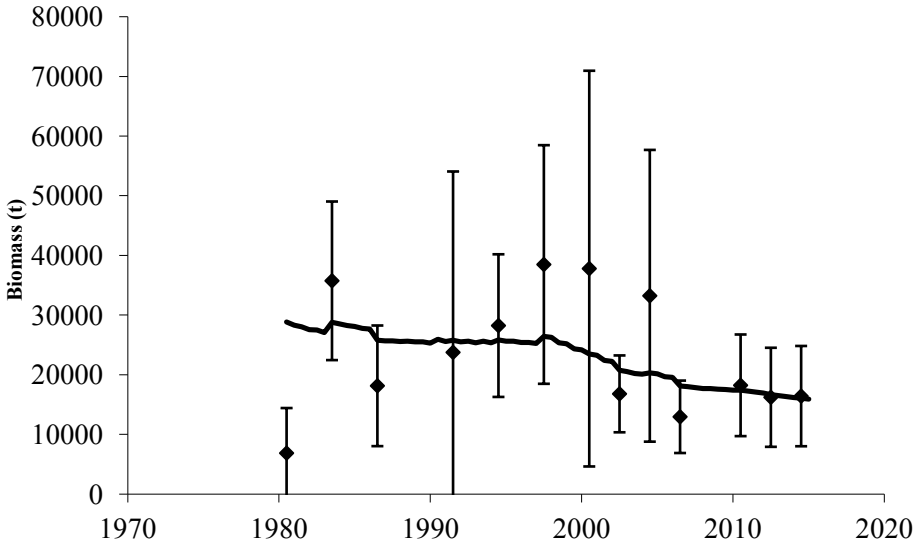

Figure 1. Observed AI survey biomass (data points +/- 2 standard deviations) and predicted survey biomass estimates from the Kalman filter model.

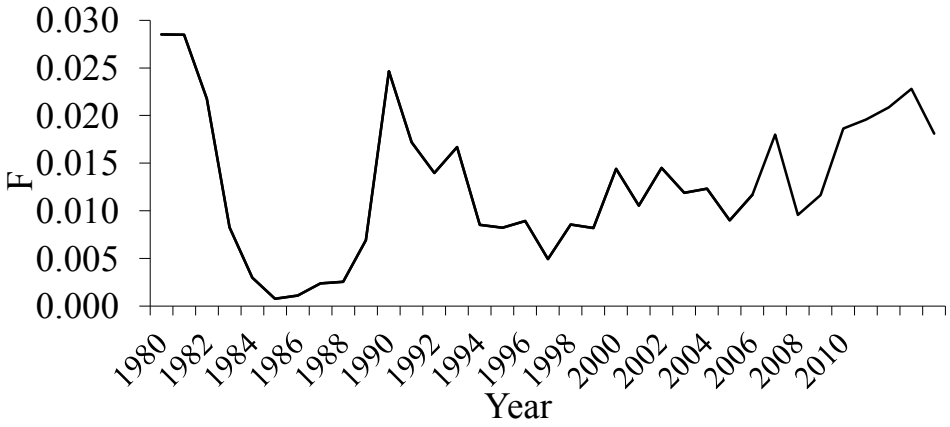

Figure 2. Estimated fishing mortality rate of BSAI shortraker rockfish, 1980-2014.

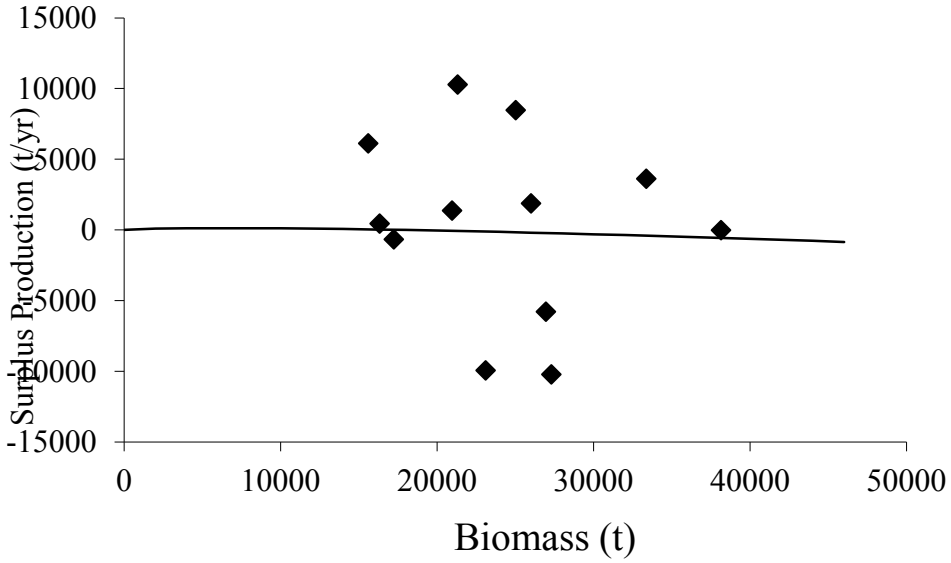

Figure 3. Estimated annual surplus production (data points, estimated as the harvest plus the change in biomass over a time interval), and production model fits of BSAI shortraker rockfish.

16. Assessment of the Other Rockfish stock complex in the Bering Sea/Aleutian Islands

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Executive Summary

Summary of Changes in Assessment Inputs

Changes in the input data

1) Catch and fishery lengths updated through October 25, 2014.
2) Biomass estimates, catch per unit effort (CPUE), and length frequency compositions were included from the 2014 AI trawl survey, the 2013 and 2014 EBS shelf surveys.

Changes in the assessment methodology

1) There were no changes in the assessment methodology.

Summary of Results

Summary for SST portion of the Other Rockfish complex.

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2015
M (natural mortality rate)	0.03	0.03	0.03	0.03
Tier	5	5	5	5
Biomass (t)	45,820	45,820	47,042	47,042
F_{OFL}	0.03	0.03	0.03	0.03
$maxF_{ABC}$	0.03	0.03	0.03	0.03
F_{ABC}	0.0225	0.0225	0.0225	0.0225
OFL (t)	1,375	1,375	1,411	1,411
maxABC (t)	1,031	1,031	1,058	1,058
ABC (t)	1,031	1,031	1,058	1,058
AI ABC (t)	367	367	376	376
EBS ABC (t)	664	664	682	682
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing		n/a		n/a

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Summary for non-SST portion of the Other Rockfish complex.

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2016
M (natural mortality rate)	0.09	0.09	0.09	0.09
Tier	5	5	5	5
Biomass (t)	1,885	1,885	3,165	3,165
F_{OFL}	0.09	0.09	0.09	0.09
$maxF_{ABC}$	0.0675	0.0675	0.0675	0.0675
F_{ABC}	0.0675	0.0675	0.0675	0.0675
OFL (t)	170	170	285	285
maxABC (t)	128	128	214	214
ABC (t)	128	128	214	214
AI ABC (t)	106	106	194	194
EBS ABC (t)	22	22	20	20
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing		n/a		n/a

Summary for the entire Other Rockfish complex (SST and non-SST combined).

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2015
M (natural mortality rate)	0.03	0.03	0.03	0.03
Tier	5	5	5	5
Biomass (t)	47,705	47,705	50,050	50,050
F_{OFL}*	-	-	-	-
$maxF_{ABC}$	-	-	-	-
F_{ABC}	-	-	-	-
OFL (t)	1,550	1,550	1,696	1,696
maxABC (t)	1,163	1,163	1,272	1,272
ABC (t)	1,163	1,163	1,272	1,272
AI ABC (t)	473	473	570	570
EBS ABC (t)	690	690	702	702
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing		n/a		n/a

*****Fishing mortality rates are specified separately for the SST and non-SST portions of the Other Rockfish complex.

Summaries for Plan Team

The following table gives the recent biomass estimates, catch, and harvest specifications, and projected biomass, OFL and ABC for 2015-2016.

Species	Year	Biomass[1]	OFL	ABC	TAC	Catch[2]
Other rockfish	2013	47,705	1,540	1,159	873	814
	2014	47,705	1,540	1,159	1,159	905
	2015	50,050	1,696	1,272		
	2106	50,050	1,696	1,272		

[1]Total biomass from trawl survey estimates.

[2] Current as of October 25, 2014. Source: NMFS AKRO BLEND/Catch Accounting System.

Responses to SSC and Plan Team Comments on Assessments in General

None pertaining to this assessment.

Responses to SSC and Plan Team Comments Specific to this Assessment

In December 2013 the SSC noted that the Other Rockfish authors presented some evidence for high harvest of the non-shortspine thornyhead portion of the stock in the November 2013 stock assessment. The SSC agreed with Plan Team to recommend the stock structure template be completed for this assessment by September 2014.

Authors' response: The stock structure template was completed for the BSAI Other Rockfish complex in September 2014. The main findings were that: 1) the Aleutian Island ABCs and TACs were exceeded in 2012, 2013, and 2014 (Table 1); and 2) Aleutian Islands exploitation rates are higher than target values (F_{ABC}) for non-SST species. Non-SST species consist primarily of dusky rockfish (*Sebastes variabilis*). Although uncertainty is high in biomass estimates for this species, catch has likely exceeded F_{OFL} since 2007 in the Aleutian Islands (Figure 1).

In September 2014, the authors presented the stock structure template for the Other Rockfish complex to the Plan Team. The Plan Team recommended that the authors monitor the spatial location of dusky rockfish catches.

Authors' response: This information will be presented to the September 2015 Plan Team meeting.

Introduction

The Bering Sea/Aleutian Islands (BSAI) Other Rockfish complex is defined by what it excludes rather than by what it includes. The Other Rockfish complex includes all species of *Sebastes* and *Sebastolobus*, other than Pacific ocean perch (POP, *Sebastes alutus*), northern rockfish (*Sebatses. polyspinis)* rougheye rockfish (*S. aleutianus*), and shortraker rockfish (*S. borealis*). Current definitions of the complex do not specifically exclude blackspotted rockfish (S. *melanostictus)*, a recently recognized species (Orr and Hawkins 2008) that had historically been identified as rougheye rockfish in research surveys. However, blackspotted is currently not distinguished from rougheye rockfish in the fishery catches, and is thus currently managed under the BSAI blackspotted/rougheye complex.

Rockfish are long-lived species which do not attain reproductive maturity until 5-20 years of age. They are viviparious; they mate and fertilize the eggs internally. Embryos develop within the female, and thousands or millions of tiny larvae are released after several months. Juveniles settle in kelp, eelgrass, or rocky habitat and move to deeper water as they mature.

An analysis was conducted in the 2001 Other Rockfish SAFE report to distinguish species expected to occur in the BSAI Other Rockfish complex from rarely observed and potentially misidentified species (Reuter and Spencer 2001, http://www.afsc.noaa.gov/REFM/docs/2010/BSAIshortraker.pdf). The criteria used for the analysis was occurrence in at least one haul of the BSAI surveys and/or occurrence in at least 1% of observed fishery hauls. Using data from 1999-2001, 7 species (shortspine thornyhead; *Sebastolobus alascanus*, dusky rockfish; *Sebastes variabilis*, redbanded rockfish; *Sebastes babcocki*, redstripe rockfish; *Sebastes proriger*, yelloweye rockfish; *Sebastes ruberrimus*, harlequin rockfish; *Sebastes variegatus*, and sharpchin rockfish; *Sebastes zacentrus*) were identified as meeting these criteria (Table 2). Dark rockfish also met the criteria, but have since been removed from the Other Rockfish complex and is now managed by the State of Alaska.

The two most abundant species for Other Rockfish complex are dusky rockfish and shortspine thornyheads (SST). In the Aleutian Islands (AI) and eastern Bering Sea (EBS) slope, shortspine thornyheads occur between 200 m and 500 m (Reuter and Spencer 2001). In contrast, dusky rockfish are typically captured between 125-200 m in the AI, and are rarely encountered on the EBS slope in either survey or fishery catches.

Fishery

In 2001, separate TACs were established for EBS and AI management areas, but the overfishing level pertained to the entire BSAI area. In 2005, the BSAI Other Rockfish complex was moved to a biennial assessment schedule to coincide with the frequency of trawl surveys in the AI and the EBS slope. These surveys occur in even years, and for these years a full assessment of the Other Rockfish complex in the BSAI area is conducted.

There is no directed fishery for the species included the Other Rockfish complex; however, between 2004 and 2014, approximately 15% of the "Other Rockfish" was caught in the directed rockfish fishery. The highest proportion (37%) has been caught in the Atka mackerel fishery, followed by the flatfish fishery (22%). Other less significant fisheries (under 6%) are, in order of

significance: sablefish (12%), Pacific cod (10%), and pollock (3%). Since 2004 they have been primarily caught by bottom trawl (66%) and hook and line (31%).

Foreign catch records did not identify the various Other Rockfish by species, but reported catches in categories such as "other species" (1977-1979), and "Other Rockfish" (1980-1990), with the definitions of these groups changing between years. In the domestic fishery, the NOAA Fisheries Alaska Regional Office “Blend” catch database often reported the catches of Other Rockfish species in a single “Other Rockfish” category, although species-specific catch records have been available with the Catch Accounting System (CAS) database beginning in 2003. Reported ABCs, TACs, and catches of Other Rockfish from 1988-2014 are shown in Table 3. From 1991-2002, species catches were reconstructed by computing the harvest proportions within management groups from the North Pacific Foreign Observer Program database, and applying these proportions to the estimated total catch obtained from the NOAA Fisheries Alaska Regional Office “Blend” database. An identical procedure was used to reconstruct the estimates of catch by species from the 1977-1989 foreign and joint venture fisheries. Estimated domestic catches in 1990 were obtained from Guttormsen et al. 1992. Catches from the domestic fishery prior to the domestic observer program were obtained from PACFIN records. Catches of Other Rockfish since 1977 by area are shown in Table 4. Some relatively high catches occurred in the late 1970s – early 1980s; total catch has only exceeded 1,000 t in 1978, 1979, 1980, 1982, and 1990. Tables 3 and 4 report only the catches of seven most common species identified above (dusky, yelloweye, sharpchin, redbanded, redstripe, and harlequin rockfish, and shortspine thornyhead).

The catches of Other Rockfish are composed primarily of dusky rockfish and shortspine thornyhead; from 2004 -2014, these two species composed 91% of the catch identified to species in the AI and in the 98% in the EBS (Tables 5 and 6). In the AI, the catches of dusky rockfish and SST average 243 t and 141 t, respectively, from 2004-2014. The proportion of SST in the EBS Other Rockfish catch was higher, as the catches of dusky rockfish and SST averaged 32 t and 166 t, respectively from 2004-2014. Discrepancy between total catch and individual catch (e.g. Tables 4 and 5) is due to the catch weight of less common species and to catch assigned to the “Other Rockfish“ group without being identified to species.

There is no directed fishing for any of the Other Rockfish species; however, incidental catch occurs in multiple fisheries and gear types. The catch of dusky rockfish and SST in various target fisheries and gear types from 2004-2014 are shown in Tables 7-10. In the EBS, dusky rockfish are primarily caught in the Pacific cod longline fishery (44%), followed by trawl fisheries for pollock (22%), rockfish (13%), Pacific cod (9%), flatfish (5%), and Atka mackerel (4%) (Table 7). Shortspine thornyhead catches in the EBS are obtained in the flatfish bottom trawl fishery (36%), followed by flatfish longline fisheries (19%), and the rockfish trawl fishery (15%) (Table 8). Dusky rockfish in the AI are caught in the atka mackerel trawl fishery (84%) followed by the rockfish trawl fishery (9%) and the Pacific cod longline gear (4%) (Table 9). Shortspine thornyhead in the AI are caught primarily in the sablefish longline fishery (48%) followed by the rockfish trawl fishery (27%), and the flatfish longline fishery (8%) (Table 10). Both species are caught primarily in NMFS reporting areas 517, 519, and 521 along the EBS slope (Tables 7 and 8). In the AI, the highest catch of dusky rockfish in in the eastern Aleutians (541; Table 9), and shortspine thornyhead catch is relatively evenly dispersed throughout the Aleutians (Table 10).

A summary of the Other Rockfish catch retained and discarded from 2004-2014 are shown in Table 11. From 2004-2014 the percent of Other Rockfish retained has ranged from 51% to almost 90%, and has generally increased over time. Low discard rates are observed for SST, particularly if they are caught using fixed-gear, which yields a higher quality product than trawl gear (Hiatt et al. 2002).

Data

Fishery:

Fishery length samples have been collected for both SST and dusky rockfish since 2002. Sample sizes are shown below by year.

Year	dusky rockfish	SST
2002	576	764
2003	251	881
2004	534	617
2005	383	809
2006	493	780
2007	749	929
2008	1,089	976
2009	543	609
2010	404	1,910
2011	1,079	1,650
2012	1,521	966
2013	1,077	1,714
2014	898	1,031

The fishery length frequencies for each species since 2002 show little change, with the bulk of the dusky rockfish between approximately 36 and 50 cm (Figure 2), and the bulk of the SST lengths between 30 and 60 cm (Figure 3).

Removals of the Other Rockfish complex from non-commercial sources (i.e. those not included in the Alaska Regional Office's Catch Accounting System) are shown in Appendix Table 1. Non-commercial removals ranged from 1-23 metric tons (t) between 1996-2014.

Survey:

Several bottom trawl surveys provide biomass estimates for the EBS and AI regions. The 1979-85 cooperative U.S.-Japan trawl surveys in the EBS were conducted both on the continental shelf and slope, and cooperative surveys were also conducted in the AI from 1980-1986. U.S domestic trawl surveys were conducted in 1988, 1991, 2002, 2004, 2008, 2010, and 2012 on the EBS slope, and in 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, and 2014 in the AI (Tables 12, 13, and 14). The 2002 EBS slope survey represents the initiation of a new survey time series distinct from the previous surveys in 1988 and 1991. The EBS slope survey samples depths from 200 to ~1200 m, whereas the AI survey samples depths to 500 m. Thus, survey biomass estimates of deep-water species such as shortspine thornyhead are likely underestimated in the AI survey. The cooperative U.S. – Japan AI trawl survey were conducted with different vessels, survey gear, and sampling design relative to the U.S. domestic trawls surveys that began in 1991. The NMFS

EBS shelf survey has been conducted every year since 1982, but few rockfish are found there, primarily dusky and harlequin rockfish (Table 12).

From 1979-2004, the biomass estimates for Other Rockfish increased in both the AI and southern Bering Sea (SBS, the area from 165° W to 170° W) portions of the area covered by the AI trawl survey, and have remained fairly stable (Table 12). The 2012 Other Rockfish biomass estimate in the Aleutian Islands decreased by approximately 25% from the 2010 survey but increased by 60% in 2014 (Table 12). Biomass estimates for dusky rockfish and shortspine thornyhead in the Aleutian Islands increased in 2014, with a particularly large increase of over an order of magnitude in dusky rockfish, 5,773 t, CV = 0.82 (Tables 12 and 13). Such large fluctuations would not be expected in such a long-lived species, and are likely due to high uncertainty in the biomass estimates. Between 1997 and 2014, the dusky rockfish biomass estimate in the AI area has fluctuated between 236 t (2012) and 5,957 t (2006), although the large 2006 estimate was driven by a small number of very large tows, leading to a large coefficient of variation (CV) of 0.89 (Table 13). The biomass estimate of SST in the AI area increased from 6,153 t in 1991 to a high of 20,178 t in 2014, the highest on record in the AI (Table 14). The estimates of SST for the Southern Bering Sea between 1991 and 2012 have been lower and more variable, ranging between 187 t to 1,545 t with CVs between 0.41 and 0.73.

The Other Rockfish species captured in the EBS slope survey from 2002-2014 were primarily SST, but also included broadfin thornyhead, longspine thornyhead, dusky, silvergray, yellowmouth, and redbanded rockfish, although the estimated biomass for redbanded rockfish did not exceed 7 t for any year. The total for these species increased from 16,975 t in 2002 to 29,619 t in 2012 (Tables 12, 14).

The lengths of dusky rockfish obtained in the 1997-2014 AI surveys (dusky was not identified by species prior to 1997) were generally between 35 and 45 cm, corresponding closely to the length distribution in the BSAI fishery (Figure 4). Shortspine thornyhead lengths from the survey are smaller than those for the fishery, falling primarily between 20 and 44 cm (Figure 5). Assuming that larger SST in the AI inhabit deeper water, this difference is likely related to the 500 m depth limit of the AI survey. Length frequencies were generally consistent between years (Figure 5).

The spatial distribution of dusky rockfish biomass in the AI surveys shows concentrations near Amchitka Island and the Delarof Islands (Figure 6). The spatial distribution of SST shows high densities primarily west of the Petral Bank (Figure 7).

Very little age information exists for species in the Other Rockfish complex. The only available age data for dusky rockfish are from the 2002 AI survey (n = 108). Growth analysis of these data using a von Bertalanffy growth equation result in an L_{inf} of 41.6 cm, k=0.32 and a t_o=2.5 (Reuter and Spencer 2003). These results show that dusky rockfish in the AI grow to a smaller maximum length than dusky rockfish in the GOA (Clausen and Heifetz 2001). No age data exists for SST because an ageing technique has yet to be satisfactorily determined.

Analytic Approach

Model Structure

Other Rockfish are currently assessed with the Tier 5 methodology, which requires estimates of natural mortality (M) and population size. For Tier 5 stocks, F_{OFL} and F_{ABC} are defined as M and 0.75M, respectively. The acceptable biological catch (ABC) is obtained by multiplying F_{ABC} by

the estimated biomass and the overfishing level (OFL) is obtained by multiplying F_{OFL} by the estimated biomass. The estimated natural mortality differs between shortspine thornyhead (SST) and the remaining stocks in the Other Rockfish complex; therefore, ABC and OFL (and F_{OFL} and F_{ABC}) are calculated separately for SST and non-SST Other Rockfish. Biomass estimates for Other Rockfish were obtained by taking a weighted (4-6-9) biomass estimate of the most recent three surveys by area, with higher weights applied to more recent surveys (Bering Sea slope, Bering Sea shelf, and Aleutian Islands surveys). The EBS estimated biomass was obtained from summing the weighted average from the EBS slope survey with the weighted average from the SBS portion of the AI survey, and the AI biomass estimate was obtained using the AI portions of the AI surveys.

Biomass is also estimated using the Random Effects model for comparison, although this value is not used to set ABCs and OFLs (Figure 8). The random effects (RE) model is an approximation to the Kalman Filter approach. The process errors (step changes) from one year to the next are the random effects to be integrated over and the process error variance is a free parameter. The observations can be irregularly spaced; therefore this model can be applied to datasets with missing data. Large observation errors increase errors predicted by the model, which can provide a way to weight predicted estimates of biomass (http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/2012/Sept/survey_average_wg.pdf), and an exploitation rate is then applied to estimate of current biomass to obtain the ABC and OFL.

Biomass estimates used for ABCs and OFLs are based on the 4-6-9 weighted average of the past 3 most recent surveys. Apportionments between the AI and the EBS are based on survey estimates in those regions.

Parameter Estimates

Estimates of natural mortality of SST have been variable due to the difficulty of ageing this species. In the GOA shortspine thornyhead assessment, Gaichas and Ianelli (2003) presented natural mortality estimates from several studies. Studies have calculated natural mortality differently due to the age of their oldest sample. Miller (1985) estimated natural mortality to be 0.07 from a sample of SST in Southeast Alaska whose oldest age was 62 years old. A study using west coast SST estimated a natural mortality between 0.05-0.07 with the oldest age in the sample being 80 (Kline 1996). Pearson and Gunderson (2003) suggest that SST from Alaska have an M = 0.013, based on a study using the gonadosomatic index to estimate natural mortality. A natural mortality rate that low suggests that these fish reach maximum ages from 250-350 years, which would be very old even among rockfish species. One source of variability in these estimates is the variation in otolith age reading techniques. Miller (1985) used surface ageing and the break and burn technique, and found that precision and comparability was low. Kline (1996) used a thin section technique that had better inter-reader ageing agreement, and radiometric verification supported this technique. Subsequent radiometric work by Kastelle et al. (2000) corroborated Kline's results. Thus, Kline's methodology and results are presumed to be the most accurate given the uncertainty of ageing SST. Work is currently being done at the Alaska Fisheries Science Center to determine the best ageing technique to use for SST (personal communication Betty Goetz, Age and Growth group, REFM, AFSC).

Historically, the value of M of 0.07 has been used to assess the Other Rockfish stock, which represents an approximation based on knowledge of rockfish life histories from other areas. This value is based on the estimate for SST from Ianelli and Ito (1994), as this species comprises well over 90% of the Other Rockfish biomass (as calculated by survey data). In the 2003 GOA SST

assessment a value of M of 0.038 was used, which was obtained as an alternate value given in Pearson and Gunderson (2003). Because this value has been reviewed by the Plan Team and SSC, we use a value of 0.03 for the SST portion of the BSAI Other Rockfish biomass in order to maintain consistency with GOA SST. The majority of the non-SST Other Rockfish biomass is composed of dusky rockfish. The parameter estimate for natural mortality for dusky rockfish in the GOA is 0.09, and thus is currently the best estimate of *M* (Clausen and Heifetz 2001) For the 2014 assessment, we use an *M* of 0.09 for the remaining group of Other Rockfish.

Results

Harvest Recommendations

The 2014 weighted average biomass estimate of all species in the Other Rockfish complex is 50,050 t, 47,041 t for the SST component, and 3,165 t for the non-SST component. The random effect model estimates are similar, but provide uncertainty estimates. The 95% confidence intervals are higher for the non-SST component of the stock complex, reflecting uncertainty in those estimates. The total BSAI estimate for the Other Rockfish based on the random effects model is 49,630 t (42,528 - 56,731 t, 95% CI), with 46,647 t (39,849 - 53,444 t) for the SST and 2,983 t (927 - 5,039 t) for the non-SST components of the complex. These biomass estimates are used to estimate OFL and ABC in Appendix 1.

In recent years, BSAI Other Rockfish have been managed with a BSAI-wide OFL level and separate ABCs for the AI and EBS subareas. For the 2015 fishery, we recommend the maximum allowable ABC of 702 t for the Other Rockfish complex in the EBS and 570 t in the AI. We also recommend an OFL of 1,696 t for the entire complex. Further breakdowns of reference values for SST and the remaining stocks in the Other Rockfish complex are summarized in the following table.

Area	Species	M	2014 Weighted Survey Average Biomass	2014 Random Effects biomass estimate (95% confidence interval)	ABC	OFL
BSAI	SST	0.03	47,041	46,647 (39,849, 53,444)		1,411
BSAI	Non-SST	0.09	3,165	2,983 (927, 5,039)		285
BSAI	Total Other Rockfish		50,050	49,630 (42,528, 56,731)		1,696
EBS	SST	0.03	30,333	30,321 (25,370, 35,271)	682	
EBS	Non-SST	0.09	289	300 (165, 436)	20	
EBS	Total Other Rockfish		30,466	30,621 (25,668, 35,574)	702	
AI	SST	0.03	16,708	16,326 (11,668, 20,984)	376	
AI	Non-SST	0.09	2,876	2,682 (631, 4,733)	194	
AI	Total Other Rockfish		19,584	19,008 (13,919, 24,098)	570	

Ecosystem Considerations

Ecosystem Effects on Stock

Little to no information is available to determine the diet of Other Rockfish species, important predators, or their trends over time.

Fishery Effects on the Ecosystem

The Other Rockfish complex is not a targeted fishery, therefore reference on the effects of the fishery on the ecosystem will be described in the SAFE chapters of the fisheries in which Other Rockfish is taken as bycatch.

Data gaps and research priorities

Validating aging techniques of shortspine thornyheads, and obtaining ages from archived samples, remains research priorities and are required for age-structured population modeling. Little is known regarding most aspects of the biology of the species in the Other Rockfish complex, including the reproductive biology and distribution, duration, and habitat requirements of various life-history stages. Given the relatively unusual reproductive biology of rockfish and its importance in establishing management reference points, data on reproductive capacity should be collected on a periodic basis.

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Tables

Table 1. Catch, TAC, ABC, and OFL for the Other Rockfish complex are summarized in the following table.

[1]Updated October 25, 2014.

	BSAI	AI	EBS	Total
OFL (2012)	1,700			1,700
ABC (2012)		570	710	1,280
TAC (2012)		570	500	1,070
Catch (2012)		736	210	947
OFL (2013)	1,540			1,540
ABC (2013)		473	686	1,159
TAC (2013)		473	400	873
Catch (2013)		623	191	814
OFL (2014)	1,550			1,550
ABC (2014)		473	690	1,163
Catch (2014)[1]		601	304	905
TAC (2014)				686
OFL (2015)	1,550			1,550
ABC (2015)		473	690	1,163
OFL (2016)	1,550			1,550
ABC (2016)		473	690	1,163

Table 2. The percentage catch of "Other Rockfish" in AFSC research bottom trawl surveys (where at least one fish was observed) and in observed fisheries hauls (where fish were observed in >1% of hauls) from 1991-2001. Cases were no fish were observed are denoted with "~".

		EBS		**AI**	
Common name	Scientific name	**Survey**	**Fishery**	**Survey**	**Fishery**
Redbanded rockfish	*Sebastes babcocki*	~	~	1%	<1%
Dusky rockfish	*Sebastes variabilis*	18%	39%	22%	45%
Redstripe rockfish	*Sebastes proriger*	~	1%	~	1%
Yelloweye rockfish	*Sebastes ruberrimus*	~	1%	<1%	1%
Harlequin rockfish	*Sebastes variegatus*	~	1%	9%	5%
Sharpchin rockfish	*Sebastes zacentrus*	~	<1%	<1%	<1%
Shortspine thornyhead	*Sebastolobus alascanus*	62%	43%	61%	34%

Table 3. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of seven Other Rockfish species (SST, dusky, redbanded, redstripe, yelloweye, harlequin, and sharpchin rockfish) from 1988 to 2014 in the Aleutian Islands (AI) and Eastern Bering Sea (BS). Source: 2004-2014 data is from the NMFS Alaska Regional Office Catch Accounting System, accessed October 25, 2014. Data previous to 2004 was obtained using several different sources that are described in the text.

Year	Area	ABC (t)	TAC (t)	Catch (t)
1988	BS	400	340	254
	AI	1,100	935	237
1989	BS	400	340	180
	AI	1,100	935	352
1990	BS	500	425	395
	AI	1,100	935	822
1991	BS	500	340	239
	AI	1,100	786	313
1992	BS	400	400	201
	AI	925	925	470
1993	BS	400	400	142
	AI	925	925	443
1994	BS	365	365	123
	AI	770	770	272
1995	BS	365	329	257
	AI	770	693	223
1996	BS	497	497	164
	AI	952	857	272
1997	BS	373	373	114
	AI	714	714	274
1998	BS	369	369	155
	AI	685	685	327
1999	BS	369	369	145
	AI	685	685	372
2000	BS	369	369	239
	AI	685	685	558
2001	BS	361	361	295
	AI	676	676	524
2002	BS	361	361	370
	AI	676	676	502
2003	BS	960	960	316
	AI	634	634	408
2004	BS	960	460	247
	AI	634	634	266
2005	BS	810	460	130
	AI	590	590	242
2006	BS	810	460	127
	AI	590	590	324
2007	BS	414	414	205
	AI	585	585	397
2008	BS	414	414	194
	AI	585	585	330
2009	BS	485	485	184
	AI	555	555	303

Table 3. Continued.

Year	Area	ABC (t)	TAC (t)	Catch (t)
2010	BS	485	485	224
	AI	555	555	432
2011	BS	485	485	298
	AI	555	555	594
2012	BS	710	500	168
	AI	570	500	648
2013	BS	686	400	165
	AI	473	473	593
2014	BS	686	686	276
	AI	473	473	517

Table 4. Catch (t) of seven Other Rockfish species (SST, dusky, redbanded, redstripe, yelloweye, harlequin, and sharpchin rockfish) from 1977 to 2014 in foreign, joint venture (JV), and domestic fisheries. Source: 2004-2014 data is from the NMFS Alaska Regional Office Catch Accounting System, accessed October 25, 2014. Data previous to 2004 was obtained using several different sources that are described in the text. Data prior to 1990 are on file at the Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115.

	Eastern Bering Sea				Aleutian Islands				BSAI
Year	Foreign	JV	Domestic	Total	Foreign	JV	Domestic	Total	Total
1977	52	0		52	537	0		537	589
1978	304	0		304	795	0		795	1,099
1979	281	0		281	2,053	0		2,053	2,334
1980	566	1		567	484	0		484	1,051
1981	337	0		337	236	0		236	574
1982	365	0		365	2,057	0		2,057	2,422
1983	208	1		210	717	4		721	931
1984	112	7		119	57	25		81	200
1985	35	1		36	1	14		15	51
1986	4	14	81	99	0	10	147	157	256
1987	3	4	535	542	0	5	138	143	684
1988	0	3	252	254	0	68	168	237	491
1989	0	9	171	180	0	0	352	352	533
1990			395	395			822	822	1,217
1991			239	239			313	313	552
1992			201	201			470	470	671
1993			142	142			443	443	584
1994			123	123			272	272	395
1995			257	257			223	223	479
1996			164	164			272	272	437
1997			114	114			274	274	388
1998			155	155			327	327	482
1999			145	145			372	372	517
2000			239	239			558	558	797
2001			295	295			524	524	819
2002			370	370			502	502	872
2003			316	316			408	408	724
2004			247	247			266	266	514
2005			130	130			242	242	372
2006			127	127			324	324	451
2007			205	205			397	397	602
2008			194	194			330	330	524
2009			184	184			303	303	487

Table 4. Continued.

	Eastern Bering Sea				Aleutian Islands				BSAI
Year	Foreign	JV	Domestic	Total	Foreign	JV	Domestic	Total	Total
2010			224	224			432	432	657
2011			298	298			594	594	892
2012			168	168			648	648	816
2013			165	165			593	593	758
2014			276	276			517	517	794

Table 5. Catch (t) of Other Rockfish species in the Aleutian Islands from 2004-2014. Source: NMFS AKRO BLEND/Catch Accounting System, accessed October 25, 2014.

Year	dusky rockfish	SST	harlequin rockfish	sharpchin rockfish	yelloweye rockfish
2004	129.45	81.75	36.87	14.05	0.90
2005	134.16	87.94	14.35	0.01	5.57
2006	161.43	132.92	25.22	2.00	0.38
2007	231.28	123.32	39.93		0.57
2008	179.80	109.78	34.33	0.01	4.48
2009	141.96	137.80	22.76		0.22
2010	224.75	159.89	42.60	0.08	0.54
2011	380.51	153.10	59.26		0.26
2012	429.79	164.17	49.85		0.15
2013	331.43	234.62	25.94		0.53
2014	331.15	165.46	19.99		0.33
Average	243.25	140.98	33.74	1.47	1.27

Year	redbanded rockfish	redstripe rockfish	black rockfish	silvergray rockfish	darkblotched rockfish	Total catch (t)
2004	0.17	3.15	1.35		0.21	267.90
2005	0.17					242.19
2006	0.13	1.72	0.15		0.75	324.68
2007	1.42	0.53	0.09	3.01		400.15
2008	1.03	0.65	3.18	0.02	0.06	333.34
2009	0.39	0.05	1.24		0.01	304.43
2010	3.61	0.93	0.37			432.76
2011	0.40		0.12			593.64
2012	3.70	0.04	0.18			647.88
2013	0.96		0.01		0.03	593.52
2014*	0.42	0.05	0.22			517.63
Average	1.13	0.65	0.63	0.28	0.10	423.47

Table 6. Catch (t) of Other Rockfish species in the eastern Bering Sea from 2004- October 25, 2014. Species with catches less than 1 ton of catch from 2004-2014 are not shown. Source: NMFS AKRO BLEND/Catch Accounting System.

Year	dusky rockfish	SST	harlequin rockfish	yelloweye rockfish
2004	31.86	203.12	0.37	1.42
2005	36.22	92.33	0.19	0.74
2006	46.60	78.22	0.04	1.41
2007	44.95	158.05	0.03	1.72
2008	15.39	177.59	0.03	1.04
2009	10.25	172.58	0.07	1.07
2010	32.32	189.46	0.35	1.39
2011	43.72	248.26	4.58	1.38
2012	27.05	137.90	0.05	0.47
2013	27.81	136.05	0.63	0.21
2014*	36.06	233.41	1.25	0.91
Average	32.02	166.09	0.69	1.07

Year	redbanded rockfish	redstripe rockfish	black rockfish	Total catch (t)
2004	10.44	0.02	0.86	248.17
2005	0.31		7.20	137.26
2006	0.40	0.06	0.18	126.90
2007	0.05	0.04	0.29	205.17
2008	0.04	0.06	2.23	196.63
2009	0.22	0.05	0.18	184.54
2010	0.48		0.03	224.25
2011	0.42	0.03	2.16	300.66
2012	2.59	0.08	1.20	169.37
2013	0.09	0.04	0.17	165.02
2014*		4.74	0.35	276.71
Average	1.37	0.47	1.35	203.15

Table 7. Total catch (t) of EBS dusky rockfish from 2004-2014 by target fishery and gear type. Areas 508-524 refer to NMFS areas within the BSAI. Source: NMFS AKRO BLEND/Catch Accounting System, accessed October 25, 2014.

Gear	Target	508	509	513	514	516	517	518	519	521	523	524	Percentage
Atka Mackerel	Bottom Trawl								13.12				0.04
Atka Mackerel	Pelagic Trawl						0.01		0.03				0.00
Flatfish	Longline									1.87	0.05		0.01
Flatfish	Bottom Trawl		2.13	1.36		0.03	3.08	0.03	3.66	8.53		0.28	0.05
Halibut	Longline							0.10				0.04	0.00
Kamchatka Flounder	Bottom Trawl								0.04				0.00
Pacific Cod	Longline		0.15	3.32			12.75	0.02	4.28	135.33	0.21	0.01	0.44
Pacific Cod	Jig							0.07	0.04				0.00
Pacific Cod	Bottom Trawl		3.47				4.29		16.55	8.63	0.12	0.07	0.09
Pacific Cod	Pot		0.18				0.34		2.08				0.01
Pacific Cod	Pelagic Trawl						0.21						0.00
Pollock	Bottom Trawl		0.15				0.34		0.10	0.03			0.00
Pollock	Pelagic Trawl		6.94	0.53	0.06	0.03	43.53		15.49	9.75	0.90	0.27	0.22
Rockfish	Longline												0.00
Rockfish	Jig				0.58				0.09				0.00
Rockfish	Bottom Trawl	0.16					36.57	2.54	6.52	0.60	0.46		0.13
Sablefish	Longline							0.04					0.00
Sablefish	Bottom Trawl								0.08				0.00
Sum		0.16	13.02	5.21	0.63	0.06	101.12	2.80	62.07	164.75	1.74	0.66	352.22

Table 8. Total catch (t) of EBS shortspine thornyhead from 2004-2014 by target fishery and gear type. Areas 508-524 refer to NMFS areas within the BSAI. Source: NMFS AKRO BLEND/Catch Accounting System. NOTE: Thornyheads are identified to genus but not to species in commercial catches; therefore, the weight of shortspine thornyhead is extrapolated by multiplying the proportion of shortspine thornyhead by year in the total catch of thornyhead rockfish based on observer catch data from the NORPAC database.

Gear	Target	508	509	513	514	517	518	519	521	523	524	530	Percentage
Bottom Trawl	Atka					3.03		21.46					0.01
Bottom Trawl	Flatfish		0.04	2.72	0.06	468.97	6.05	150.13	33.21	0.74	1.18		0.36
Bottom Trawl	Kamchatka Flounder					86.68	1.44	38.71			0.15		0.07
Bottom Trawl	Pacific Cod					32.58		6.26	0.01				0.02
Bottom Trawl	Pollock		0.05			4.67	0.13	5.88	0.60				0.01
Bottom Trawl	Rockfish					121.27	0.83	118.50	35.39	3.72			0.15
Bottom Trawl	Sablefish					2.57		5.71					0.00
Longline	Flatfish					20.88	4.53	1.03	237.13	84.22	3.86		0.19
Longline	Halibut			0.25		7.52	35.17	4.71	6.18	3.81	0.04		0.03
Longline	Kamchatka Flounder									0.03			0.00
Longline	Other								0.52	0.11			0.00
Longline	Pacific Cod					5.88	0.37	1.43	22.46	1.55	0.15		0.02
Longline	Pollock												0.00
Longline	Rockfish					0.55	1.37	1.23	0.45	1.69			0.00
Longline	Sablefish	0.07			0.17	33.10	52.31	17.92	4.19	4.18		0.15	0.06
Pot	Flatfish												0.00
Pot	Sablefish					0.13	1.99	0.95					0.00
Pelagic Trawl	Pollock		0.40	0.19		74.87		35.67	0.20	0.01			0.06
Jig	Halibut												0.00
Trawl	Flatfish					0.23							0.00
Grand Total		0.07	0.48	3.16	0.23	862.95	104.20	409.58	340.35	100.07	5.37	0.15	1827

Table 9. Total catch (t) of AI dusky rockfish from 2004-2014 by target fishery and gear type. Areas 541, 542, and 543 refer to NMFS areas within the AI. Source: NMFS AKRO BLEND/Catch Accounting System, accessed October 25, 2014.

Gear	Target	541	542	543	Percentage of total
Bottom Trawl	Atka Mackerel	1804.38	387.78	60.48	0.84
Bottom Trawl	Flatfish	23.97			0.01
Longline	Flatfish		0.48		0.00
Longline	Halibut	0.03	0.31	0.01	0.00
Bottom Trawl	Kamchatka Flounder	7.83			0.00
Longline	Other		0.02	0.15	0.00
Bottom Trawl	Pacific Cod	31.47	5.59	2.96	0.01
Pot	Pacific Cod	0.03	0.41		0.00
Longline	Pacific Cod	46.80	37.16	16.99	0.04
Pelagic Trawl	Pollock	0.06			0.00
Bottom Trawl	Rockfish	165.68	59.65	23.32	0.09
Longline	Sablefish	0.08	0.07		0.00
Sum		2,080.33	491.47	103.91	2,675.71

Table 10. Total catches (t) of Aleutian Island (AI) shortspine thornyhead from 2004-2014 by target fishery and gear type. Areas 541, 542, and 543 refer to NMFS areas within the AI. Source: NMFS AKRO BLEND/Catch Accounting System. NOTE: Thornyheads are identified to genus but not to species in commercial catches; therefore, the weight of shortspine thornyhead is extrapolated by multiplying the proportion of shortspine thornyhead by year in the total catch of thornyhead rockfish based on observer catch data from the NORPAC database.

Gear	Target	541	542	543	Percentage of total
Bottom Trawl	Atka	4.70	33.71	35.36	0.05
Bottom Trawl	Flatfish	6.22			0.00
Bottom Trawl	Kamchatka Flounder	2.33			0.00
Bottom Trawl	Pacific Cod	0.18		0.41	0.00
Bottom Trawl	Pollock	0.02			0.00
Bottom Trawl	Rockfish	10.79	91.93	313.07	0.27
Longline	Flatfish	10.90	113.37		0.08
Longline	Halibut	34.81	52.67	19.34	0.07
Longline	Other	0.31	1.82		0.00
Longline	Pacific Cod	27.26	12.28	14.70	0.03
Longline	Rockfish	0.60	4.03	7.90	0.01
Longline	Sablefish	335.80	268.80	145.06	0.48
Pot	Pacific Cod		0.01		0.00
Pot	Rockfish	0.02			0.00
Pot	Sablefish	2.08	0.08		0.00
Jig	Pacific Cod	0.02			0.00
Sum		436	579	536	1,551

Table 11. Retained and discarded catch of seven Other Rockfish species (shortspine thornyhead, dusky rockfish, redbanded rockfish, redstripe rockfish, yelloweye rockfish, harlequin rockfish, and sharpchin rockfish) from 2004 to 2014 in the Aleutian Islands and Eastern Bering Sea. Accessed October 25, 2014 from the NMFS AKRO BLEND/Catch Accounting System.

Area	Year	Retained (t)	Discarded (t)	Total catch (t)	Percent Discarded
Aleutian Islands	2004	162	120	282	57.34%
	2005	185	82	267	68.99%
	2006	228	121	349	65.32%
	2007	208	197	405	51.36%
	2008	266	70	336	79.35%
	2009	253	55	308	82.14%
	2010	379	63	442	85.75%
	2011	472	126	598	78.86%
	2012	574	80	654	87.65%
	2013	461	137	598	77.09%
	2014	461	57	518	88.88%
Eastern Bering Sea	2004	221	65	286	77.42%
	2005	137	19	156	87.29%
	2006	119	23	142	84.02%
	2007	143	72	215	66.70%
	2008	140	63	203	68.72%
	2009	169	21	190	88.90%
	2010	199	37	236	84.25%
	2011	267	39	306	87.37%
	2012	146	28	174	84.03%
	2013	143	24	167	85.57%
	2014	237	41	278	85.24%

Table 12. Survey biomass estimates (t) and CVs (in parentheses) for Other Rockfish (including shortspine thornyhead) from 1979 - 2014. Southern Bering Sea refers to NMFS reporting area 799.

	AI survey			EBS Shelf survey	EBS Slope survey
Year	AI	S. Bering Sea	Total		
1979					3,251
1980	930 (0.18)	36 (0.73)	966 (0.18)		
1981					4,975
1982					4,381
1983	3,971 (0.17)	802 (0.23)	4,774 (0.15)		
1984				18 (1.0)	
1985				0	5,127
1986	6,550 (0.19)	3,253 (0.86)	9,803 (0.31)	0	
1987				0	
1988				0	8,759
1989				0	
1990				0	
1991	6,643 (0.22)	248 (0.48)	6,891 (0.22)	0	4,529
1992				0	
1993				0	
1994	6,452 (0.16)	1,172 (0.48)	7,624 (0.15)	0	
1995				0	
1996				36 (1.0)	
1997	9,539 (0.17)	1,683 (0.63)	11,223 (0.18)	0	
1998				538 (0.68)	
1999				398 (0.75)	
2000	11,924 (0.17)	1,107 (0.45)	13,031 (0.16)	0	
2001				0	
2002	14,781 (0.20)	1,111 (37)	15,892 (0.18)	0	16,975 (0.12)
2003				55 (0.70)	
2004	18,566 (0.18)	6,473 (67)	25,039 (0.22)	0	18,807 (0.09)
2005				36 (1.0)	
2006	23,879 (0.24)	1,706 (0.52)	25,585 (0.23)	357 (0.85)	
2007				0	
2008				0	26,072 (0.12)
2009				122 (0.58)	
2010	18,663 (0.15)	1,172 (0.66)	19,835 (0.15)	57 (0.92)	29,453 (0.12)
2011				56 (1.0)	
2012	14,694 (0.15)	586 (0.61)	15,280 (0.15)	37 (1.0)	29,619 (0.11)
2013				40 (1.0)	
2014	23,254 (0.27)	2799 (0.62)	26,053 (0.31)	28 (1.0)	

Table 13. Survey biomass estimates (t) and CVs (in parentheses) for Dusky rockfish from 1997 - 2014. Southern Bering Sea refers to NMFS reporting area 799.

	AI survey			EBS Slope survey
Year	AI	S. Bering Sea	Total	
1997	574 (0.76)	138 (0.46)	712 (0.62)	
1998				
1999				
2000	1,250 (0.34)	55 (0.36)	1,306 (0.33)	
2001				
2002	515 (0.32)	97 (0.36)	612 (0.27)	25 (0.57)
2003				
2004	730 (0.44)	1,359 (0.91)	2,089 (0.61)	13(0.57)
2005				
2006	5,956 (0.89)	731 (0.96)	6,687 (0.80)	
2007				
2008				10 (1.00)
2009				
2010	560 (0.34)	120 (0.44)	680 (0.29)	117 (0.87)
2011				
2012	236 (0.32)	135 (0.57)	371 (0.29)	41 (0.61)
2013				
2014	5542 (0.83)	231 (0.50)	5773 (0.82)	

Table 14. Survey biomass estimates (t) and CVs (in parentheses) for shortspine thornyhead from 1991- 2014. Southern Bering Sea refers to NMFS reporting area 799.

	AI survey			EBS Slope survey
Year	AI	S. Bering Sea	Total	
1991	6,153 (0.24)	187 (0.58)	6,341 (0.23)	
1992				
1993				
1994	6,240 (0.16)	1,071 (0.52)	7,311 (0.16)	
1995				
1996				
1997	8,896 (0.18)	1,545 (0.69)	10,441 (0.18)	
1998				
1999				
2000	10,649 (0.19)	1,051 (0.48)	11,700 (0.17)	
2001				
2002	14,243 (0.20)	1,012 (0.41)	15,255 (0.19)	16,950 (0.12)
2003				
2004	17,335 (0.19)	945 (0.56)	18,280 (0.18)	18,793 (0.09)
2005				
2006	17,876 (0.12)	968 (0.55)	18,844 (0.12)	
2007				
2008				26,055 (0.12)
2009				
2010	18,075 (0.16)	1,052 (0.73)	19,127 (0.16)	29,334 (0.12)
2011				
2012	14,443 (0.15)	452 (0.77)	14,895 (0.15)	29,574 (0.11)
2013				
2014	17,611 (0.24)	2,567 (0.67)	20,178 (0.23)	

Figures

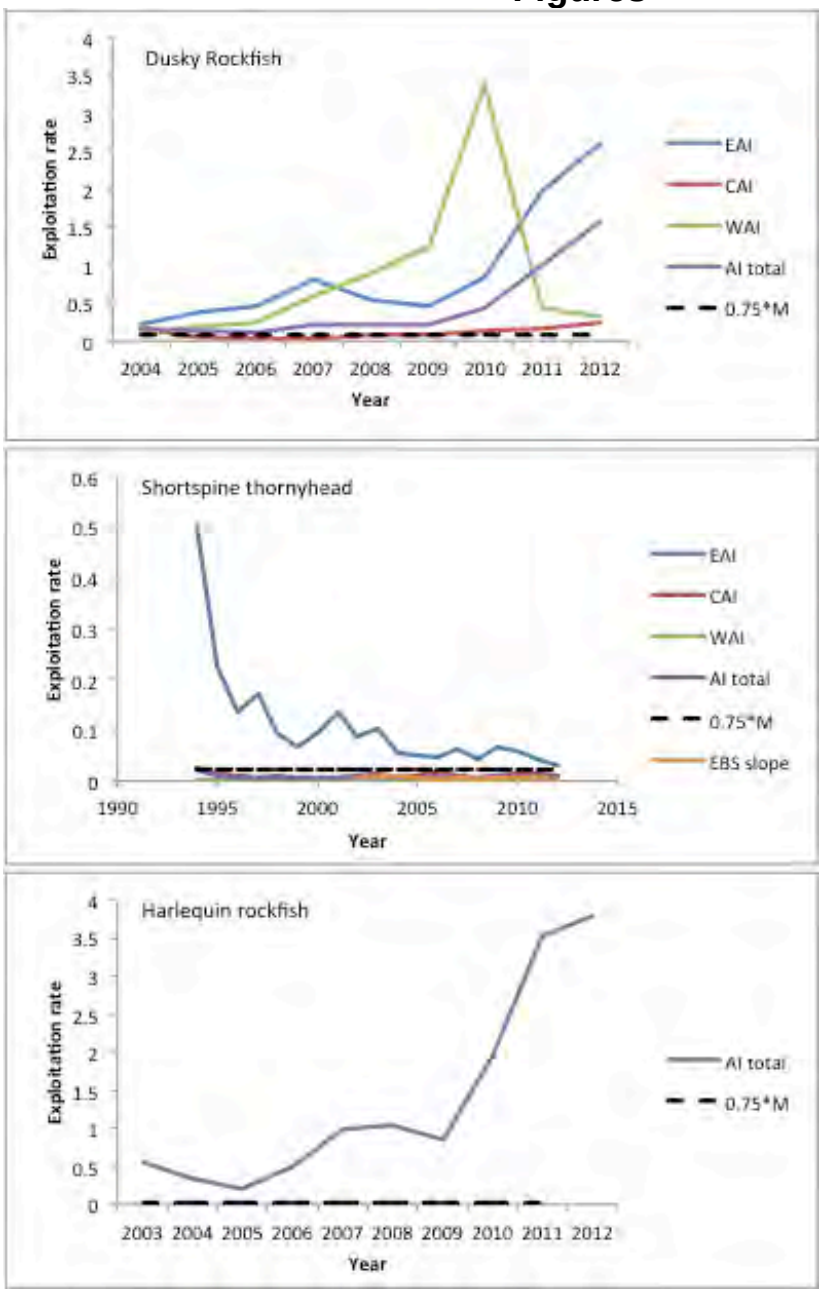


Figure 1. Exploitation rates for dusky rockfish in the western, central, and eastern Aleutian Islands (WAI, CAI, and EAI; 2004-2012), shortspine thornyhead from the three Aleutian Islands regions (1990-2012), and harlequin rockfish from the AI combined (2003-2012).

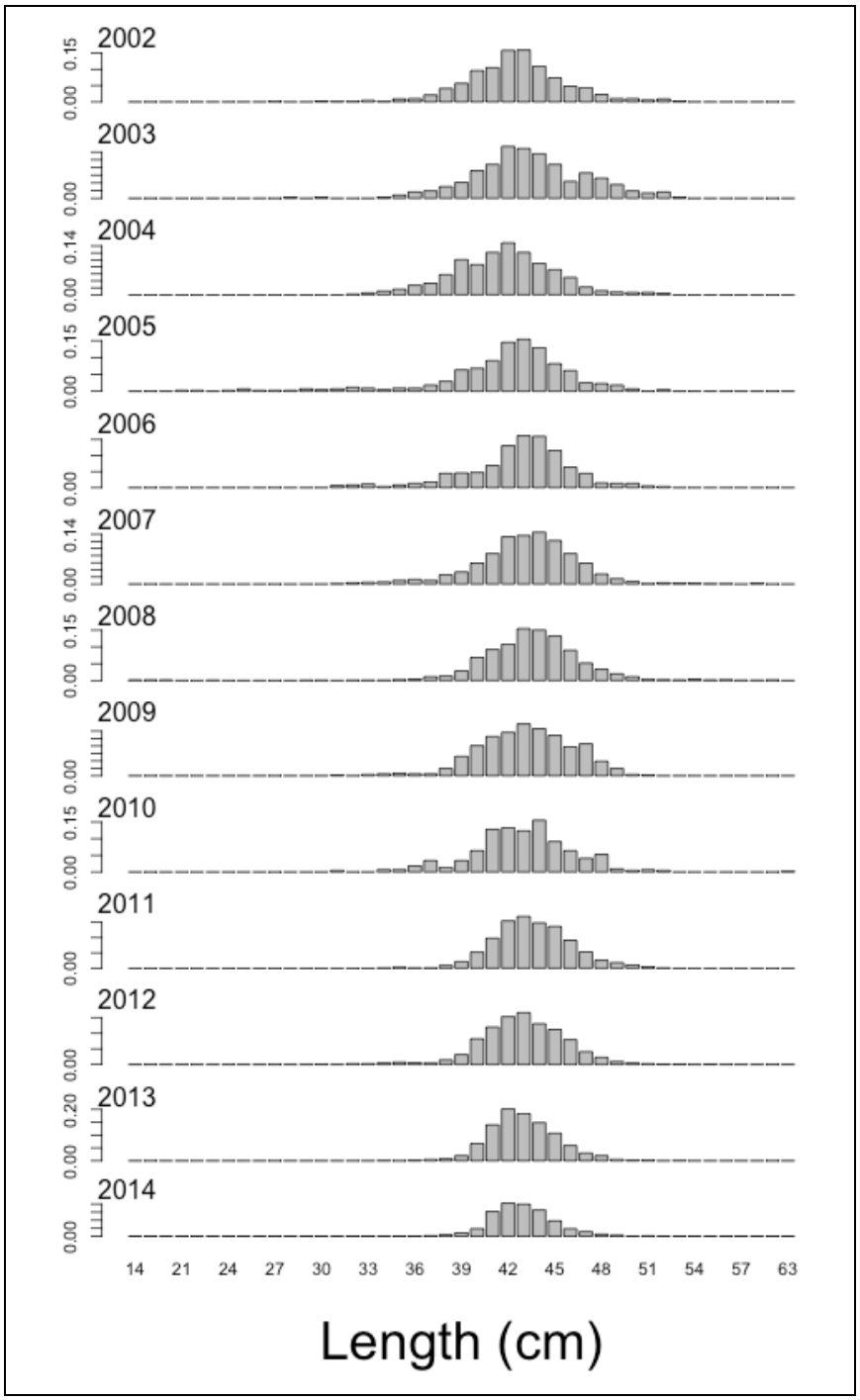


Figure 2. Dusky rockfish length frequency data from fishery observers. Source: NMFS AFSC FMA Observer Debriefed Haul and Length tables.

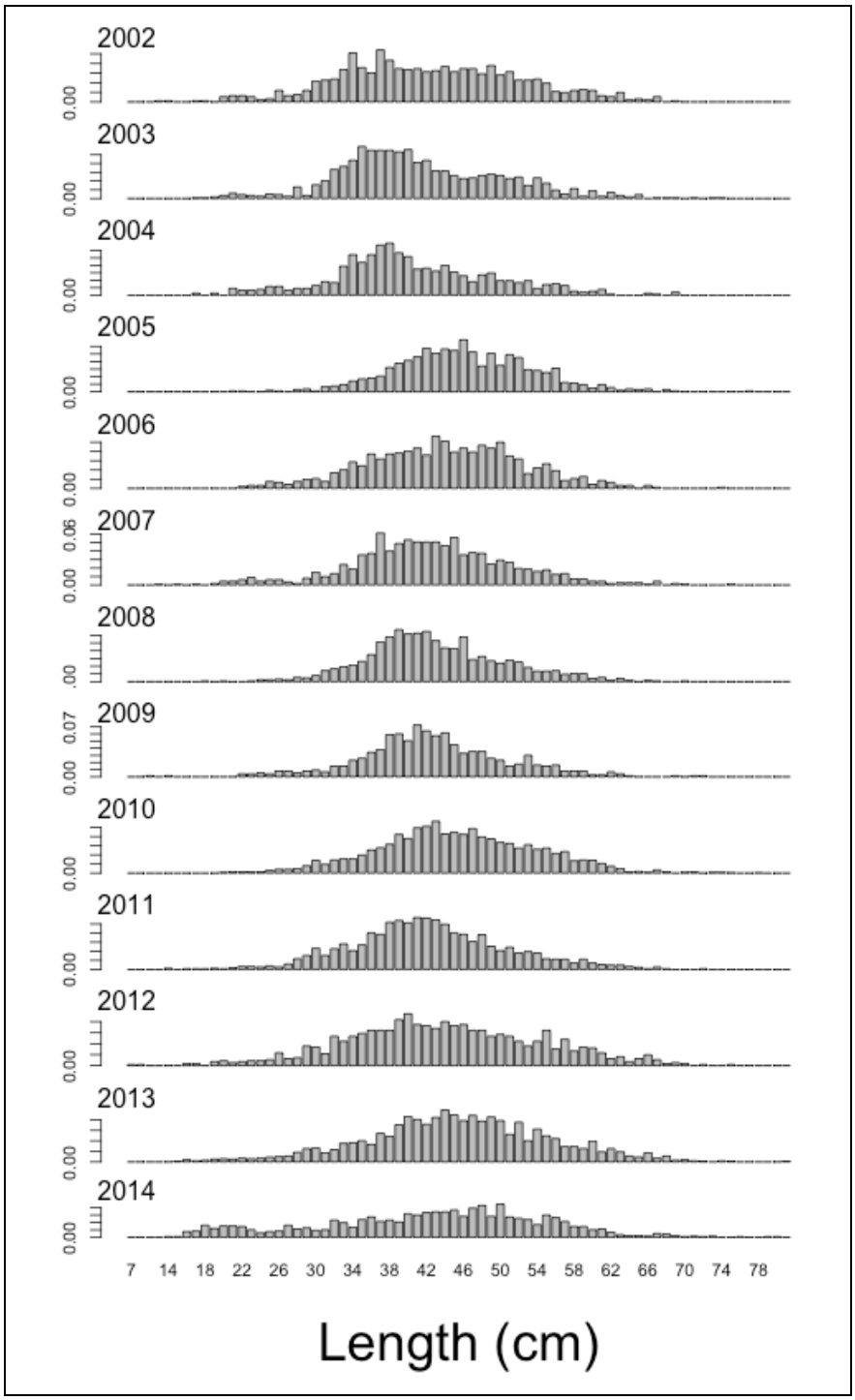


Figure 3. Shortspine thornyhead length frequency data from fisheries observers. Source: NMFS AFSC FMA Observer Debriefed Haul and Length tables.

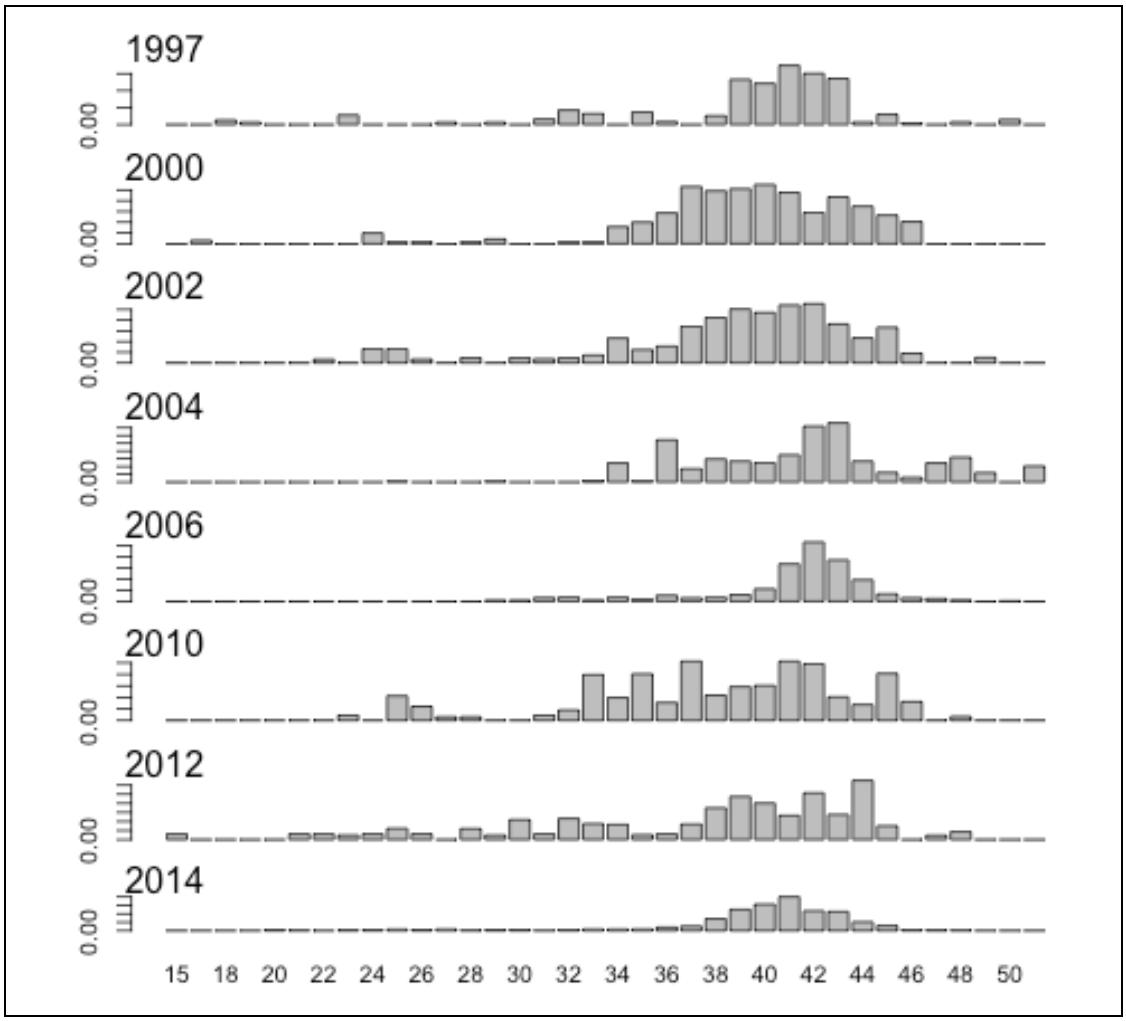


Figure 4. Dusky rockfish lengths (cm) from Aleutian Islands survey data 1997-2014. Source: NMFS AFSC FMA Observer Debriefed Haul and Length tables.

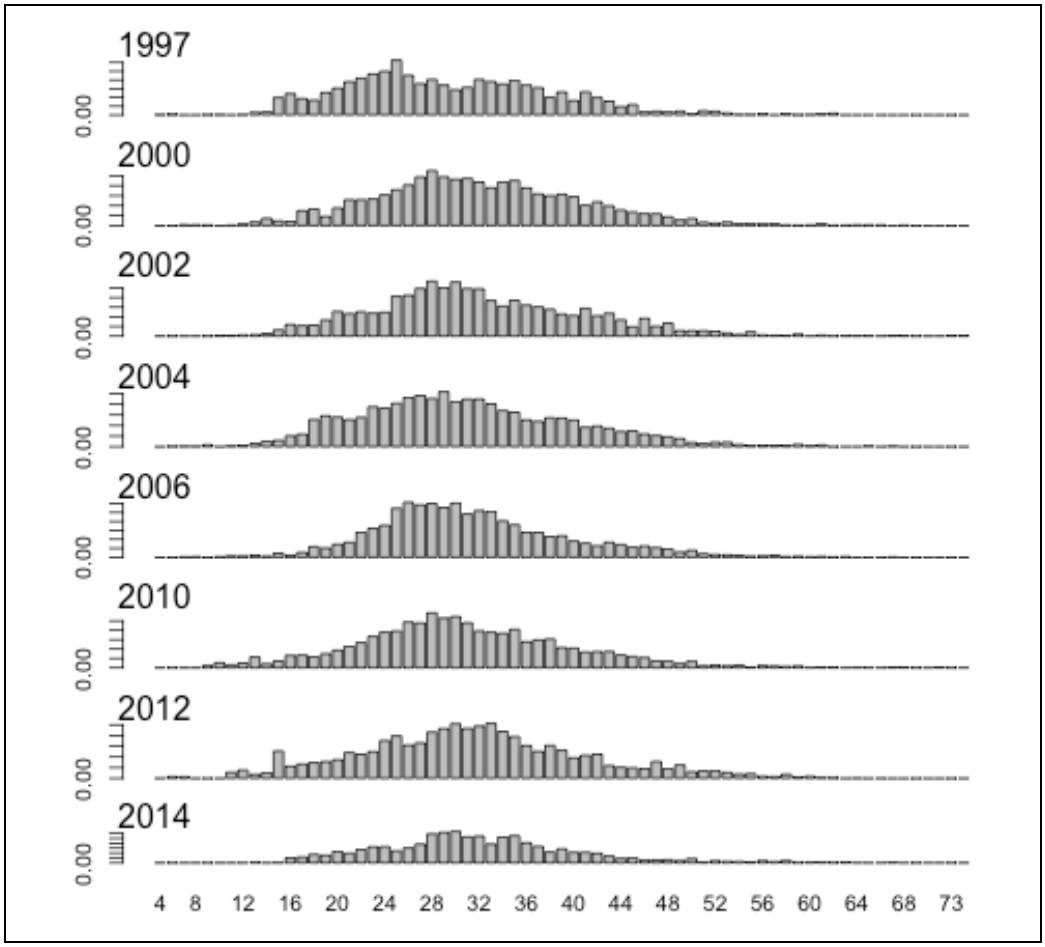


Figure 5. Shortspine thornyhead rockfish length frequencies from Aleutian Islands survey data, 2002-2014.

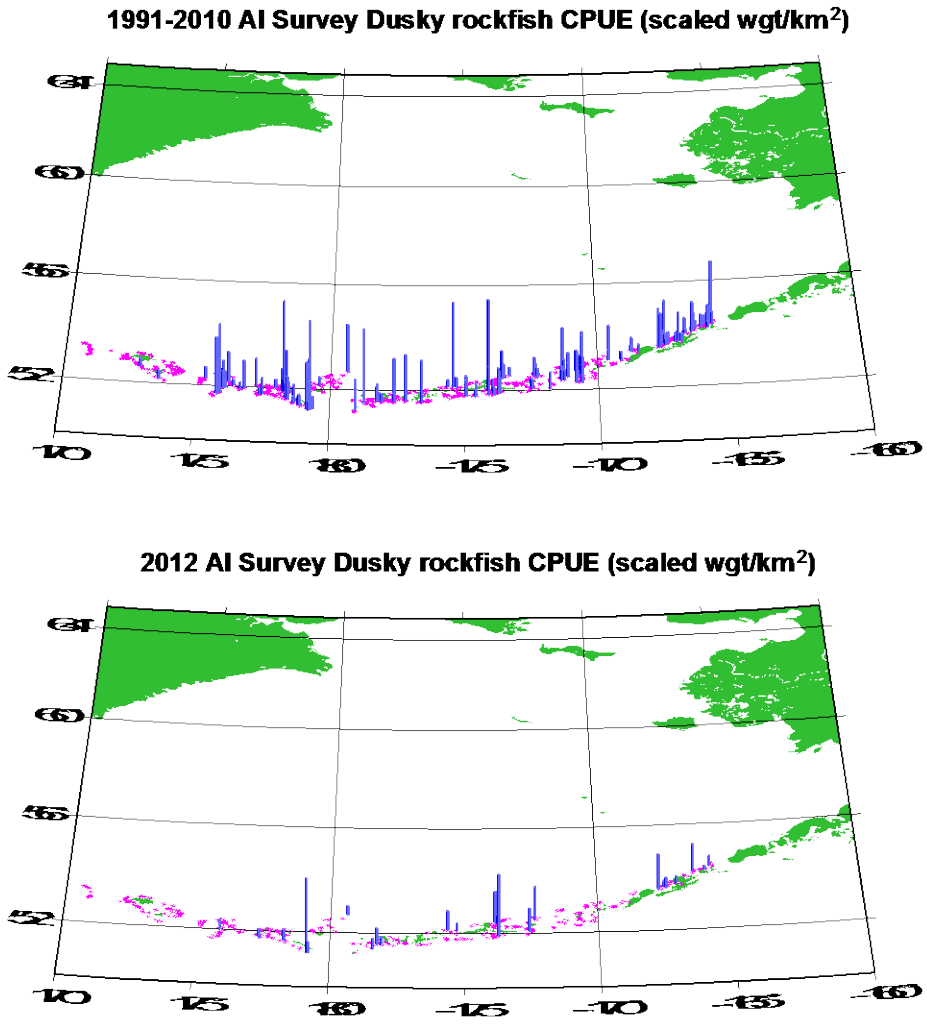


Figure 6. AI survey CPUE (scaled kg/km^2) of dusky rockfish from 1997 to 2012.

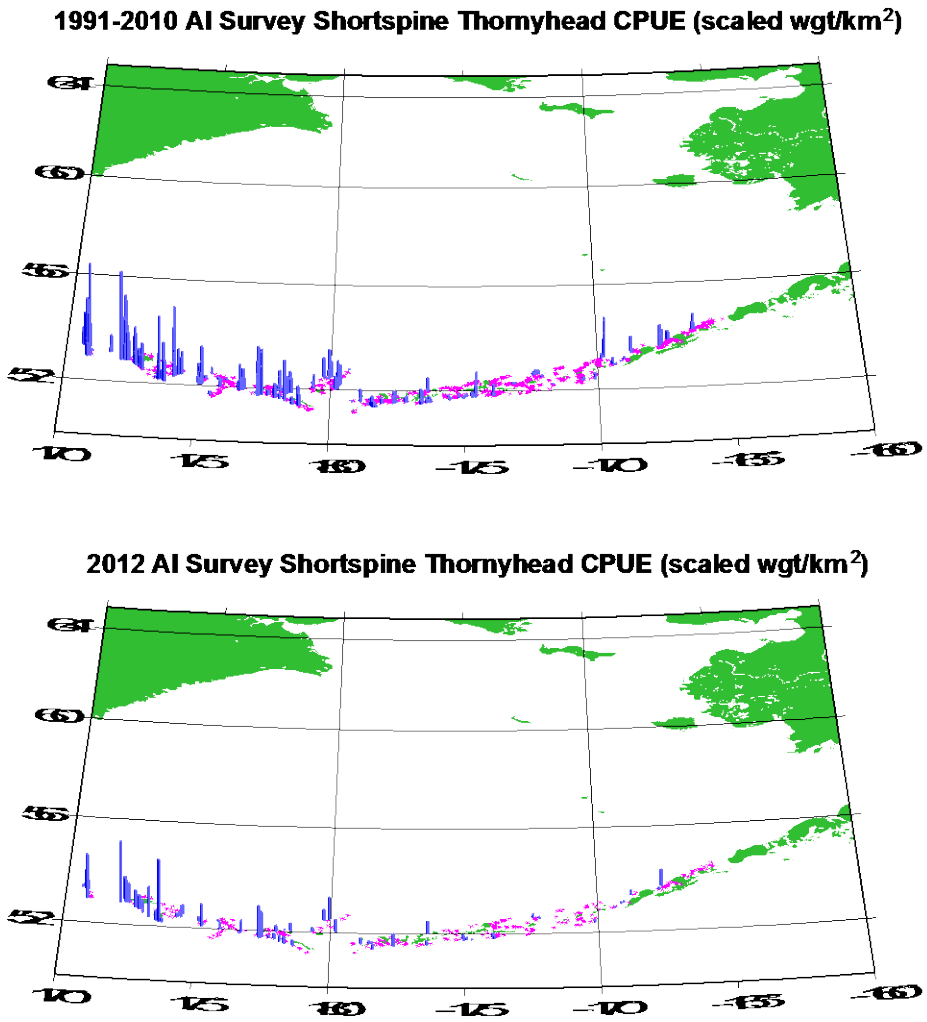
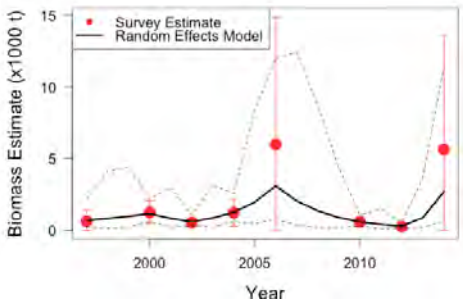
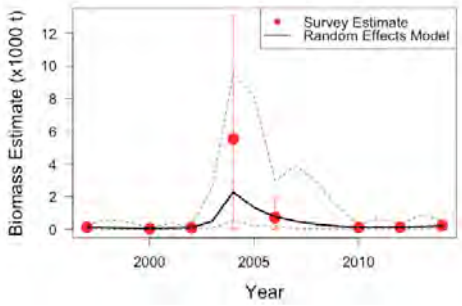


Figure 7. AI survey CPUE (scaled kg/km^2) of shortspine thornyhead from 1980 to 2012.

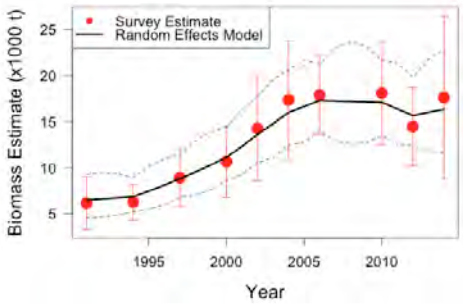
Aleutian Islands non-SST Other Rockfish



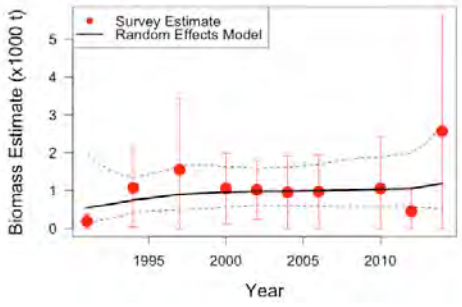
Southern Bering Sea non-SST Other Rockfish



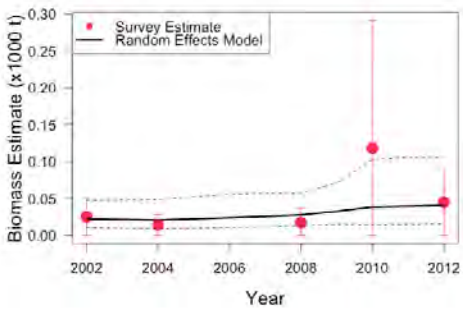
Aleutian Islands SST



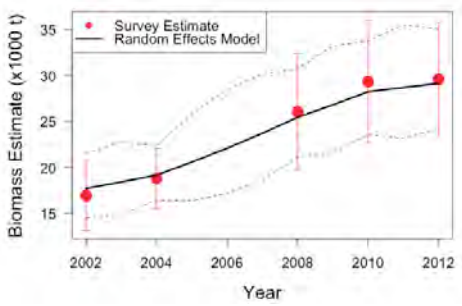
Southern Bering Sea SST



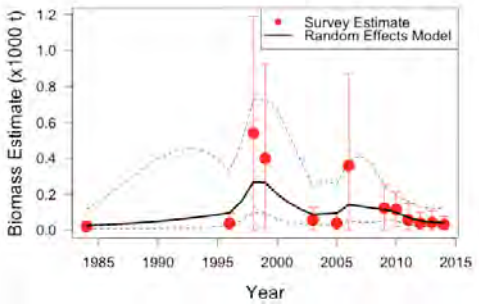
Bering Sea slope non-SST Other Rockfish



Bering Sea slope SST



Bering Sea shelf non-SST Other Rockfish



Random effect estimate of Other Rockfish biomass (BSAI)

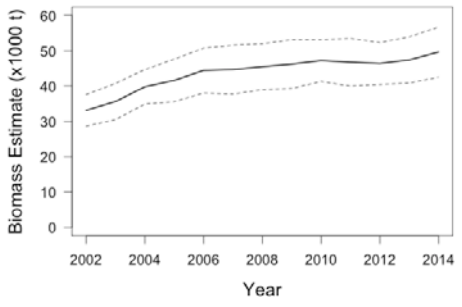


Figure 8. Random effect model biomass estimates of Other Rockfish in the Aleutian Islands, Southern Bering Sea, Bering Sea shelf and slope.

Appendix Table 1. Removals from sources other than those included in the Alaska Region's official estimate of catch (e.g., removals due to scientific surveys, subsistence fishing, recreational fishing, fisheries managed under other FMPs). Source: AKR.V_NONCOMMERCIAL_FISHERY_CATCH table.

Year	Catch (t)
1996	3.18
1997	2.48
1998	3.32
1999	0.62
2000	1.59
2001	1.02
2002	1.55
2003	1.36
2004	1.46
2005	1.36
2006	1.68
2007	1.78
2008	1.49
2009	2.00
2010	13.54
2011	23.39
2012	10.22
2013	3.86
2014	3.00

Appendix 1. Assessment of the other rockfish complex in the Bering Sea and Aleutian Islands, using alternative methodology

Introduction

Here we explore alternative methodology for calculating the estimate of BSAI other rockfish complex biomass. In the past, and in the main assessment presented here, a 4-6-9 weighted average of three most recent surveys for each region (Aleutian Islands, Bering Sea shelf, and Bering Sea slope) has been used, with the highest weights given to the most recent surveys. This appendix calculates the BSAI estimate of biomass using the random effects model. The model was applied separately to survey biomass estimates from the Aleutian Islands, Bering Sea shelf, and Bering Sea slope surveys. The 2014 random effects model estimate of other rockfish biomass in the BSAI is the sum of the random effects biomass estimate for the Bering Sea slope, Shelf, and Aleutian Islands. The variance is summed to obtain 95% confidence intervals. The total BSAI estimate for the Other Rockfish based on the random effects model is 49,630 t (42,528 - 56,731 t, 95% CI), with 46,647 t (39,849 - 53,444 t) for the SST and 2,983 t (927 - 5,039 t) for the non-SST components of the complex.

Results using the random effects estimates of biomass are shown in the following summary tables.

Summary of Results

Summary for SST portion of the Other Rockfish complex.

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2014	2015	2015	2015
M (natural mortality rate)	0.03	0.03	0.03	0.03
Tier	5	5	5	5
Biomass (t)	45,820	45,820	46,647	46,647
F_{OFL}	0.03	0.03	0.03	0.03
$maxF_{ABC}$	0.03	0.03	0.03	0.03
F_{ABC}	0.0225	0.0225	0.0225	0.0225
OFL (t)	1,375	1,375	1,399	1,399
maxABC (t)	1,031	1,031	1,050	1,050
ABC (t)	1,031	1,031	1,050	1,050
AI ABC (t)	367	367	373	373
EBS ABC (t)	664	664	676	676
	As determined *last* year for:		As determined *this* year for:	
Status	2012	2013	2013	2014
Overfishing		n/a		n/a

Summary for non-SST portion of the Other Rockfish complex.

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2016
M (natural mortality rate)	0.09	0.09	0.09	0.09
Tier	5	5	5	5
Biomass (t)	1,885	1,885	2,983	2,983
F_{OFL}	0.09	0.09	0.09	0.09
$maxF_{ABC}$	0.0675	0.0675	0.0675	0.0675
F_{ABC}	0.0675	0.0675	0.0675	0.0675
OFL (t)	170	170	268	268
maxABC (t)	128	128	201	201
ABC (t)	128	128	201	201
AI ABC (t)	106	106	182	182
EBS ABC (t)	22	22	19	19
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing		n/a		n/a

Summary for the entire Other Rockfish complex (SST and non-SST combined).

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2015
M (natural mortality rate)	0.03	0.03	0.03	0.03
Tier	5	5	5	5
Biomass (t)	47,705	47,705	49,630	49,630
F_{OFL}*	-	-	-	-
$maxF_{ABC}$	-	-	-	-
F_{ABC}	-	-	-	-
OFL (t)	1,550	1,550	1,667	1,667
maxABC (t)	1,163	1,163	1,251	1,251
ABC (t)	1,163	1,163	1,251	1,251
AI ABC (t)	473	473	555	555
EBS ABC (t)	690	690	695	695
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing		n/a		n/a

*****Fishing mortality rates are specified separately for the SST and non-SST portions of the Other Rockfish complex.

17. Assessment of the Atka mackerel stock in the Bering Sea/Aleutian Islands

Sandra Lowe, James Ianelli, and Wayne Palsson

Executive Summary

Relative to the November 2013 SAFE report, the following substantive changes have been made in the assessment of Atka mackerel.

Summary of Changes in Assessment Inputs

1. Fishery catch data were updated.
2. The 2013 fishery age composition data were added.
3. Total 2014 year end catch was estimated at 31,670 t based on the observation that an average of 25% of the catch has occurred after Oct. 1 in recent years.
4. The 2014 survey biomass estimates were included.
5. The estimated average selectivity for 2010-2014 was used for projections.
6. We assume that 80% of the BSAI-wide ABC is likely to be taken under the revised Steller Sea Lion Reasonable and Prudent Alternatives (SSL RPAs) to be implemented in 2015. This percentage was applied to the 2015 maximum permissible ABC, and that amount was assumed to be caught in order to estimate the 2016 ABCs and OFL values.

Summary of Changes in the Assessment Methodology

There were no changes to the assessment methodology.

Summary of Results

1. The addition of the 2013 fishery age composition and the 2014 survey biomass information impacted the estimated magnitude of the 1999-2001 year classes which increased 12-15%, and the magnitude of the 2006 year class which increased 17%, relative to last year's assessment.
2. Estimated values of $B_{100\%}$, $B_{40\%}$, $B_{35\%}$ are 15% higher relative to last year's assessment.
3. Projected 2015 female spawning biomass (167,136 t) is up 43% relative to last year's estimate of 2014 female spawning biomass.
4. Projected 2015 female spawning biomass is above $B_{40\%}$, thereby placing BSAI Atka mackerel in Tier 3a.
5. The projected 2015 yield at $F_{ABC} = F_{40\%} = 0.403$ is 106,000 t, which is 65% higher relative to last year's estimate for 2014.
6. The projected 2015 overfishing level at $F_{35\%}$ ($F = 0.489$) is 125,297 t, which is 68% higher than last year's estimate for 2014.

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Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015*	2016
M (natural mortality rate)	0.30	0.30	0.30	0.30
Tier	3a	3b	3a	3a
Projected total (age 1+) biomass (t)	482,147	510,584	694,421	673,327
Female spawning biomass (t)				
Projected	117,171	115,640	167,136	146,682
$B_{100\%}$	291,028	291,028	333,237	333,237
$B_{40\%}$	116,411	116,411	133,295	133,295
$B_{35\%}$	101,860	101,860	116,633	116,633
F_{OFL}	0.514	0.514	0.489	0.489
$maxF_{ABC}$	0.421	0.421	0.403	0.403
F_{ABC}	0.421	0.421	0.403	0.403
OFL (t)	74,492	74,898[1]	125,297	115,908[1]
maxABC (t)	64,131	64,477[1]	106,000	98,137[1]
ABC (t)	64,131	64,477[1]	106,000	98,137[1]
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

*Projections are based on estimated total 2014 catch of 31,670 t.
[1]These values were calculated assuming reduced catch levels under SSL RPAs.

Area apportionment of ABC

The apportionments of the 2015 and 2016 recommended ABCs based on the most recent 4-survey weighted average are:

	2015 (t)	2016 (t)
Eastern (541+S.BSea)	38,492	35,637
Central (542)	33,108	30,652
Western (543)	34,400	31,848
Total	106,000	98,137

Responses to SSC and Plan Team Comments on Assessments in General

From the December 2012 SSC minutes*: The SSC recommends that the authors consider whether it is possible to estimate M with at least two significant digits in all future stock assessments to increase validity of the estimated OFL. The SSC encourages assessment authors of stocks managed in Tier 5 to consider the recommendations found in the draft survey averaging workgroup report.*
Atka mackerel are a Tier 3 species, and in the current assessment *M* is not estimated in the base model. We do report estimated *M* to two significant digits for Model 4 in the Model Evaluation section.

From the December 2013 SSC minutes: *The SSC asks assessment authors project the reference points for the future two years (e.g., 2014 and 2015) on the phase diagrams.* The reference points for 2015 and 2016 are plotted on the phase diagram figure (Fig. 17.22).

From the September 2013 Joint Plan Team minutes:
Accounting for total catch removals: The Teams recommended that SAFE chapter authors continue to include "other" removals as an appendix. Optionally, authors could also calculate the impact of these removals on reference points and specifications, but are not required to include such calculations in final recommendations for OFL and ABC.
Other removals are reported in Appendix 17B. Supplemental Catch data.

Retrospective analyses: In conformity with the main recommendations of the Retrospective Working Group, the Team recommended the following:

1. *Assessment authors should routinely do retrospective analyses extending back 10 years, plot spawning biomass estimates and error bars, plot relative differences, and report Mohn's rho (revised).*
2. *If a model exhibits a retrospective pattern, try to investigate possible causes.*
3. *Communicate the uncertainty implied by retrospective variability in biomass estimates.*
4. *For the time being, do not disqualify a model on the grounds of poor retrospective performance alone.*
5. *Do consider retrospective performance as one factor in model selection.*

A retrospective analysis was conducted going back 15 years with error bars (Fig. 17.20), and is discussed in the Results section. In general, the pattern is consistent with the variability of survey observations in scaling the stock.

Total Current Year Removals: The Teams recommended that each stock assessment model incorporate the best possible estimate of the current year's removals.

The Atka mackerel assessment assumes a total 2014 year end catch of 31,670 t based on the assumption that an average of 25% of the catch has occurred after Oct. 1 in recent years.

Responses to SSC and Plan Team Comments Specific to the Atka Mackerel Assessment

From the December 2012 and 2013 SSC minutes: *SSC recommends that the authors:*
i) estimate M and q directly in the model and report the correlation between these two estimates from the variance-covariance matrix of the final model, or
ii) conduct a sensitivity analysis between various input Ms around 0.20-0.40 and estimated q's.

We present Model 4 in the Model Evaluation section, which estimates *M* and *q* as an initial step to addressing these recommendations. A full evaluation of model configurations which estimate *M* and *q* will be done in conjunction with addressing the 2014 CIE review comments for the 2015 assessment.

From the November 2013 BSAI Plan Team minutes: *The Team recommended plotting the average 2009-2013 fishery selectivity vector in Figure 17.13 for comparison purposes, along with selectivity from the terminal year.* The average 2010-2014 fishery selectivity vector (used for projections) is plotted in Fig. 17.14 for comparison purposes, along with selectivity from the terminal year.

Introduction

Native Names: In the Aleut languages, Atka mackerel are known as *tmadgi-{* among the Eastern and Atkan Aleuts and Atkan of Bering Island. They are also known as *tavyi-{* among the Attuan Aleuts (Sepez *et al.* 2003).

Distribution

Atka mackerel (*Pleurogrammus monopterygius*) are widely distributed along the continental shelf across the North Pacific Ocean and Bering Sea from Asia to North America. On the Asian side they extend from the Kuril Islands to Provideniya Bay (Rutenburg 1962); moving eastward, they are distributed throughout the Komandorskiye and Aleutian Islands (AI), north along the eastern Bering Sea (EBS) shelf, and through the Gulf of Alaska (GOA) to southeast Alaska.

Early life history

Atka mackerel are a substrate-spawning fish with male parental care. Single or multiple clumps of adhesive eggs are laid on rocky substrates in individual male territories within nesting colonies where males brood eggs for a protracted period. Nesting colonies are widespread across the continental shelf of the Aleutian Islands and western GOA down to bottom depths of 144 m (Lauth *et al*. 2007b). Historical data from ichthyoplankton tows done on the outer shelf and slope off Kodiak Island in the 1970's and 1980's (Kendall and Dunn 1985) suggest that nesting colonies may have existed at one time in the central GOA. Possible factors limiting the upper and lower depth limit of Atka mackerel nesting habitat include insufficient light penetration and the deleterious effects of unsuitable water temperatures, wave surge, or high densities of kelp and green sea urchins (Gorbunova 1962, Lauth *et al.* 2007b, Zolotov 1993).

In the eastern and central AI, larvae hatch from October to January with maximum hatching in late November (Lauth *et al.* 2007a). After hatching, larvae are neustonic and about 10 mm in length (Kendall and Dunn 1985). Along the outer shelf and slope of Kodiak Island, larvae caught in the fall were about 10.3 mm compared to larvae caught the following spring which were about 17.6 mm (Kendall and Dunn 1985). Larvae and fry have been observed in coastal areas and at great distances offshore (>500 km) in the Bering Sea and North Pacific Ocean (Gorbunova 1962, Materese *et al*. 2003, Mel'nikow and Efimkin 2003).

The Bering-Aleutian Salmon International Survey (BASIS) project studies salmon during their time at the high seas, and has conducted standardized surveys of the upper pelagic layer in the EBS shelf using a surface trawl. In addition to collecting data pertaining to salmon species, BASIS also collected and recorded information for many other Alaskan fish species, including juvenile Atka mackerel. The EBS shelf was sampled during the mid-August through September from 2004 to 2006 and juvenile Atka mackerel with lengths ranging from 150-200 mm were distributed along the outer shelf in the southern EBS shelf and along the outer middle shelf between St. George and St. Matthew Islands (Appendix B in Lowe *et al*. 2007). The fate or ecological role of these juveniles is unknown since adult Atka mackerel are much less common or absent in annual standardized bottom trawl surveys in the EBS shelf (Lauth and Acuna 2009).

Reproductive ecology

The reproductive cycle consists of three phases: 1) establishing territories, 2) spawning, and 3) brooding (Lauth *et al*. 2007a). In early June, a fraction of the adult males end schooling and diurnal behavior and begin aggregating and establishing territories on rocky substrate in nesting colonies (Lauth *et al*. 2007a). The widespread distribution and broad depth range of nesting colonies suggests that previous conjecture of a concerted nearshore spawning migration by males in the AI is not accurate (Lauth *et al.* 2007b). Geologic, oceanographic, and biotic features vary considerably among nesting colonies, however, nesting

habitat is invariably rocky and perfused with moderate or strong currents (Lauth *et al.* 2007b). Many nesting sites in the AI are inside fishery trawl exclusion zones which may serve as *de facto* marine reserves for protecting Atka mackerel (Cooper *et al*. 2010).

The spawning phase begins in late July, peaks in early September, and ends in mid-October (Lauth *et al*. 2007a). Mature females spawn an average of 4.6 separate batches of eggs during the 12-week spawning period or about one egg batch every 2.5 weeks (McDermott *et al*. 2007). After spawning ends, territorial males with nests continue to brood egg masses until hatching. Incubation times for developing eggs decrease logarithmically with an increase in water temperature and range from 39 days at a water temperature of 12.2° C to 169 days at 1.6 °C, however, an incubation water temperature of 15 °C was lethal to developing embryos *in situ* (Guthridge and Hillgruber 2008). Higher water temperatures in the range of water temperatures observed in nesting colonies, 3.9 °C to 10.5 °C (Gorbunova 1962, Lauth *et al*. 2007b), can result in long incubation times extending the male brooding phase into January or February (Lauth *et al*. 2007a).

Prey and predators

Adult Atka mackerel in the Aleutians consume a variety of prey, but principally calanoid copepods and euphausiids (Yang 1999), and are consumed by a variety of piscivores, including groundfish (e.g., Pacific cod and arrowtooth flounder, Livingston *et al.* unpubl. manuscr.), marine mammals (e.g., northern fur seals and Steller sea lions, Kajimura 1984, NMFS 1995, Sinclair and Zeppelin 2002, Sinclair *et al*. 2013), and seabirds (e.g., thick-billed murres, tufted puffins, and short-tailed shearwaters, Springer *et al.* 1999).

Predation on Atka mackerel eggs by cottids and other hexagrammids is prevalent during the spawning season as is cannibalism by other Atka mackerel of both sexes (heterocannibalism) and by males from their own nest (filial cannibalism; Canino *et al*. 2008, Yang 1999, Zolotov 1993). Filial egg cannibalism is a common phenomenon in species with extended paternal care.

Nichol and Somerton (2002) examined the diurnal vertical migrations of Atka mackerel using archival tags and related these movements to light intensity and current velocity. Atka mackerel displayed strong diel behavior, with vertical movements away from the bottom occurring almost exclusively during daylight hours, presumably for feeding, and little to no movement at night (where they were closely associated with the bottom).

Stock structure

A morphological and meristic study suggests there may be separate populations in the GOA and the AI (Levada 1979). This study was based on comparisons of samples collected off Kodiak Island in the central Gulf, and the Rat Islands in the Aleutians. Lee (1985) also conducted a morphological study of Atka mackerel from the Bering Sea, AI, and GOA. The data showed some differences (although not consistent by area for each characteristic analyzed), suggesting a certain degree of reproductive isolation. Results from an allozyme genetics study comparing Atka mackerel samples from the western GOA with samples from the eastern, central, and western AI showed no evidence of discrete stocks (Lowe *et al.* 1998). A survey of genetic variation in Atka mackerel using microsatellite DNA markers provided little evidence of genetic structuring over the species range, although slight regional heterogeneity was evident in comparisons between some areas (Canino *et al*. 2010). Samples collected from the AI, Japan, and the GOA did not exhibit genetic isolation by distance or a consistent pattern of differentiation. Examination of these results over time (2004, 2006) showed temporal stability in Stalemate Bank, but not at Seguam Pass. These results indicate a lack of structuring in Atka mackerel over a large portion of the species range, perhaps reflecting high dispersal, a recent population expansion and large effective population size, or some combination of all these factors (Canino *et al*. 2010).

The question remains as to whether the Aleutian Island and Gulf of Alaska populations of Atka mackerel should be managed as a unit stock or separate populations given that there is a lack of consistent genetic stock structure over the species range. There are significant differences in population size, distribution, recruitment patterns, and resilience to fishing, suggesting that management as separate stocks is appropriate. Bottom trawl surveys and fishery data suggest that the Atka mackerel population in the GOA is smaller and much more patchily distributed than that in the AI, and composed almost entirely of fish >30 cm in length. There are also more areas of moderate Atka mackerel density in the AI than in the GOA. The lack of small fish in the GOA suggests that Atka mackerel recruit to that region differently than in the AI. Nesting sites have been located in the GOA in the Shumagin Islands (Lauth *et al.* 2007a), and historical ichthyoplankton data from the 1970's around Kodiak Island indicate there was a spawning and nesting population even further to the east (Kendall and Dunn 1985), but the source of these spawning populations is unknown. They may be migrant fish from strong year classes in the AI or a self-perpetuating population in the GOA, or some combination of the two. The idea that the western GOA is the eastern extent of their geographic range might also explain the greater sensitivity to fishing depletion in the GOA as reflected by the history of the GOA fishery since the early 1970s. Catches of Atka mackerel from the GOA peaked in 1975 at about 27,000 t. Recruitment to the AI population was low from 1980-1985, and catches in the GOA declined to 0 in 1986. Only after a series of large year classes recruited to the AI region in the late 1980s, did the population and fishery reestablish in the GOA beginning in the early 1990s. After passage of these year classes through the population, the GOA population, as sampled in the 1996 and 1999 GOA bottom trawl surveys, has declined and is very patchy in its distribution. More recently, the strong 1999 and 2006 year classes documented in the AI showed up in the GOA. Leslie depletion analyses using historical AI and GOA fishery data suggest that catchability increased from one year to the next in the GOA fished areas, but remained the same in the AI areas (Lowe and Fritz 1996; 1997). These differences in population resilience, size, distribution, and recruitment support separate assessments and management of the GOA and AI stocks and a conservative approach to management of the GOA portion of the population.

Management units

Amendment 28 to the Bering Sea/Aleutian Islands (BSAI) Fishery Management Plan became effective in mid-1993, and divided the Aleutian subarea into three districts at 177°W and 177°E for the purposes of spatially apportioning Total Allowable Catches (TAC). Since 1994, the BSAI Atka mackerel TAC has been allocated to the three regions (541 Eastern Aleutians, 542 Central Aleutians, 543 Western Aleutians) based on the average distribution of biomass estimated from the AI bottom trawl surveys.

Fishery

Catch History

Annual catches of Atka mackerel in the EBS and AI regions increased during the 1970s reaching an initial peak of over 24,000 t in 1978 (see BSAI SAFE Introduction Table 3). Atka mackerel became a reported species group in the BSAI Fishery Management Plan in 1978. Catches (including discards and community development quota [CDQ] catches), corresponding Acceptable Biological Catches (ABC), TAC, and Overfishing Levels (OFL) set by the North Pacific Fishery Management Council (NPFMC or Council) from 1978 to the present are given in Table 17.1.

From 1970-1979, Atka mackerel were landed off Alaska exclusively by the distant water fleets of the U.S.S.R., Japan and the Republic of Korea. U.S. joint venture fisheries began in 1980 and dominated the landings of Atka mackerel from 1982 through 1988. Total landings declined from 1980-1983 primarily due to changes in target species and allocations to various nations rather than changes in stock abundance. Catches increased quickly thereafter, and from 1985-1987 Atka mackerel catches averaged 34,000 t annually, dropping to a low of 18,000 t in 1989. The last joint venture allocation of Atka mackerel off

Alaska was in 1989, and since 1990, all Atka mackerel landings have been made by U.S. fishermen. Beginning in 1992, TACs increased steadily in response to evidence of a large exploitable biomass, particularly in the central and western AI.

Description of the Directed Fishery

The patterns of the Atka mackerel fishery generally reflect the behavior of the species: (1) the fishery is highly localized and usually occurs in the same few locations each year; (2) the schooling semi-pelagic nature of the species makes it particularly susceptible to trawl gear fished on the bottom; and (3) trawling occurs almost exclusively at depths less than 200 m. In the early 1970s, most Atka mackerel catches were in the western AI (west of 180°W longitude). In the late 1970s and through the 1980s, fishing effort moved eastward, with the majority of landings occurring near Seguam and Amlia Islands. In 1984 and 1985 the majority of landings came from a single 0.5° latitude by 1° longitude block bounded by 52° 30' N, 53° N, 172° W, and 173° W in Seguam Pass (73% in 1984, 52% in 1985). Areas fished by the Atka mackerel fishery from 1977 to 1992 are displayed in Fritz (1993). Areas of 2013 and 2014 fishery operations are shown in Fig. 17.1.

Management History

Prior to 1992, ABCs were allocated to the entire Aleutian management district with no additional spatial management. However, because of increases in the ABC beginning in 1992, the Council recognized the need to disperse fishing effort throughout the range of the stock to minimize the likelihood of localized depletions. In 1993, an initial Atka mackerel TAC of 32,000 t was caught by March 11, almost entirely south of Seguam Island. This initial TAC release represented the amount of Atka mackerel that the Council thought could be appropriately harvested in the eastern portion of the AI subarea (based on the assessment for the 1993 fishery; Lowe 1992). In mid-1993, however, Amendment 28 to the BSAI Fishery Management Plan became effective, dividing the Aleutian subarea into three districts at 177°W and 177°E for the purposes of spatially apportioning TACs (Fig. 17.1). On August 11, 1993, an additional 32,000 t of Atka mackerel TAC was released to the Central (27,000 t) and Western (5,000 t) districts. Since 1994, the BSAI Atka mackerel TAC has been allocated to the three regions based on the average distribution of biomass estimated from the AI bottom trawl surveys. Table 17.2 gives the time series of BSAI Atka mackerel catches, corresponding ABC, OFL, and TAC by region.

In June 1998, the Council passed a fishery regulatory amendment that proposed a four-year timetable to temporally and spatially disperse and reduce the level of Atka mackerel fishing within Steller sea lion critical habitat (CH) in the BSAI Islands. Temporal dispersion was accomplished by dividing the BSAI Atka mackerel TAC into two equal seasonal allowances, an A-season beginning January 1 and ending April 15, and a B-season from September 1 to November 1. Spatial dispersion was accomplished through a planned 4-year reduction in the maximum percentage of each seasonal allowance that could be caught within CH in the Central and Western AI. This was in addition to bans on trawling within 10 nm of all sea lion rookeries in the Aleutian district and within 20 nm of the rookeries on Seguam and Agligadak Islands (in area 541), which were instituted in 1992. The goal of spatial dispersion was to reduce the proportion of each seasonal allowance caught within CH to no more than 40% by the year 2002. No CH allowance was established in the Eastern subarea because of the year-round 20 nm trawl exclusion zone around the sea lion rookeries on Seguam and Agligadak Islands that minimized effort within CH. The regulations implementing this four-year phased-in change to Atka mackerel fishery management became effective on January 22, 1999 and lasted only 3 years (through 2001). In 2002, new regulations affecting management of the Atka mackerel, pollock, and Pacific cod fisheries went into effect. Furthermore, all trawling was prohibited in CH from August 8, 2000 through November 30, 2000 by the Western District of the Federal Court because of violations of the Endangered Species Act (ESA).

As part of the plan to respond to the Court and comply with the ESA, NMFS and the NPFMC formulated new regulations for the management of Steller sea lion and groundfish fishery interactions that went into effect in 2002. The objectives of temporal and spatial fishery dispersion, cornerstones of the 1999 regulations, were retained. Season dates and allocations remained the same (A season: 50% of annual TAC from 20 January to 15 April; B season: 50% from 1 September to 1 November). However, the maximum seasonal catch percentage from CH was raised from the goal of 40% in the 1999 regulations to 60%. To compensate, effort within CH in the Central (542) and Western (543) Aleutian fisheries was limited by allowing access to each subarea to half the fleet at a time. Vessels fishing for Atka mackerel were randomly assigned to one of two teams, which started fishing in either area 542 or 543. Vessels were not permitted to switch areas until the other team had caught the CH allocation assigned to that area. In the 2002 regulations, trawling for Atka mackerel was prohibited within 10 nm of all rookeries in areas 542 and 543; this was extended to 15 nm around Buldir Island and 3 nm around all major sea lion haulouts. Steller sea lion CH east of 178° W in the Aleutian district, including all CH in subarea 541 and a 1° longitude-wide portion of subarea 542, is closed to directed Atka mackerel fishing.

The 2010 NMFS BiOp found that the fisheries for Alaska groundfish in the Bering Sea and AI and GOA, and the cumulative effects of these fisheries, are likely to jeopardize the continued existence of the western distinct population segment (DPS) of Steller sea lions, and also likely to adversely modify the designated critical habitat of the western DPS of Steller sea lions. Because this BiOp found jeopardy and adverse modification of critical habitat, the agency was required to implement reasonable and prudent alternatives (RPAs) to the proposed actions (the fisheries). The 2010 BiOp included RPAs which required changes in groundfish fishery management in Management Sub-areas 543, 542, and 541 in the AI Management Area. NOAA Fisheries implemented the RPAs via an interim final rule before the start of the 2011 fishery in January.

Subsequently, the U.S. District Court ordered NMFS to prepare an Environmental Impact Statement (EIS) on the interim final rule. The NPFMC preferred alternative in the draft EIS for the final EIS differed from the interim final rule, and a reinitiation of consultation was requested for the proposed action under the preferred alternative. The NMFS Section 7 Consultation BiOp determined that the proposed action is not likely to jeopardize the continued existence of the western DPS of Steller sea lions and is not likely to destroy or adversely modify designated critical habitat (NMFS 2014a). The final EIS was issued May, 2014 (NMFS 2014b). The proposed modifications to the RPAs are due to go in to effect for the 2015 fishing year.

The RPAs from the 2010 BiOp and the proposed action from the 2014 Section 7 Consultation Biological Opinion specific to Atka mackerel are listed below.

RPAs from the 2010 Biological Opinion

In Area 543:

- Prohibit retention by all federally permitted vessels of Atka mackerel and Pacific cod.
- Establish a TAC for Atka mackerel sufficient to support the incidental discarded catch that may occur in other targeted groundfish fisheries (e.g., Pacific ocean perch).
- Eliminate the Atka mackerel platoon management system in the HLA.

In Area 542:

- Close waters from 0–3 nm around Kanaga Island/Ship Rock to directed fishing for groundfish by federally permitted vessels.
- Set TAC for Area 542 to no more than 47 percent of the Area 543 ABC.
- Between 177° E to 179° W longitude and 178° W to 177° W longitude, close critical habitat from 0–20 nm to directed fishing for Atka mackerel by federally permitted vessels year round.
- Between 179° W to 178° W longitude, close critical habitat from 0-10 nm to directed fishing for Atka

mackerel by federally permitted vessels year round. Between 179° W and 178° W longitude, close critical habitat from 10-20 nm to directed fishing for Atka mackerel by federally permitted vessels not participating in a harvest cooperative or fishing a CDQ allocation.
• Add a 50:50 seasonal apportionment to the CDQ allocation to mirror seasonal apportionments for Atka mackerel harvest cooperatives.
• Limit the amount of Atka mackerel harvest allowed inside critical habitat to no more than 10 percent of the annual allocation for each harvest cooperative or CDQ group. Evenly divide the annual critical habitat harvest limit between the A and B seasons.
• Change the Atka mackerel seasons to January 20, 12:00 noon to June 10, 12:00 noon for the A season and June 10, 12:00 noon to November 1, 12:00 noon for the B season.
• Eliminate the Atka mackerel platoon management system in the HLA.

In Area 541:
• Change the Bering Sea Area 541 Atka mackerel seasons to January 20, 12:00 noon to June 10, 12:00 noon for the A season and June 10,12:00 noon to November 1, 12:00 noon for the B season.

In Bering Sea Subarea:
- Close the Bering Sea subarea year round to directed fishing for Atka mackerel.
- Prohibit trawling for Atka mackerel from 0 to 20 nm around all Steller sea lion rookeries and haulouts and in the Bogoslof Foraging Area.

RPAs as modified in the proposed action from the 2014 Biological Opinion

The proposed action would modify the season dates for the AI Atka mackerel trawl fishery relative to the action analyzed in the 2010 Biological Opinion. The season dates from the action in the 2010 BiOp, the interim final rule, and the proposed action are shown in the table below. The interim final rule changed the Atka mackerel trawl season dates to align the Atka mackerel seasons with the AI pollock and Pacific cod trawl fisheries and to temporally disperse catch. The Atka mackerel trawl fishery season dates would be extended even further under the proposed action.

Atka mackerel trawl fishery season dates in 2010 Biological Opinion (BiOp), 2011–2014 Interim Final Rule, and as proposed:

	A Season		B Season	
	Start	End	Start	End
Action in 2010 BiOp	20-Jan	15-Apr	1-Sep	1-Nov
Interim Final Rule	20-Jan	10-Jun	10-Jun	1-Nov
Proposed Action	20-Jan	10-Jun	10-Jun	31-Dec

In Area 543:
- Modify the closure around Buldir Island from a 0 to 15 nm closure to trawl fishing for Atka mackerel to a 0 to 10 nm closure.
- Limit the Area 543 Atka mackerel TAC to less than or equal to 65 percent of the ABC.

The action analyzed in the 2010 BiOp did not include an Area 543-specific Atka mackerel harvest limit and prohibited directed fishing for Atka mackerel and Pacific cod.

In Area 542:
- Close Stellar sea lion CH to Atka mackerel fishing between 178°E and 180° longitude.
- Increase 0 to 10 nm closures to 0 to 20 nm closures year-round at five rookeries (Ayugadak Point, Amchitka/Column Rocks, Amchitka Island/East Cape, Semisopochnoi/Petrel, and Semisopochnoi/Pochnoi)

- Increase 0 to 3 nm closures to 0 to 20 nm at six haulouts (Unalga and Dinkum Rocks, Amatignak Island/Nitrof Point, Amchitka Island/Cape Ivakin, Hawadax Island (formerly Rat Island), Little Sitkin Island, and Segula Island).

The action analyzed in the 2010 BiOp included an Area 542-specific Atka mackerel harvest limit which set TAC for Area 542 to no more than 47 percent of the Area 542 ABC. The proposed action does not include an Area 542-specific Atka mackerel harvest limit.

In Area 541:

- Open a portion of CH in Area 541 from 12 to 20 nm southeast of Seguam Island.
- Beyond the 50 percent seasonal apportionments there would be no limit on the amount of the Atka mackerel TAC that could be harvested inside this open area of CH.

All of CH in Area 541 was closed to Atka mackerel fishing under the action analyzed in the 2010 BiOp. Fishing for Atka mackerel has been prohibited in Steller sea lion CH in Area 541 since 2001.

In Bering Sea Subarea:
Management of the Atka mackerel TAC in the AI Area 541 is combined with the Bering Sea subarea. In general, the harvest of Atka mackerel in the Bering Sea is incidental to harvest of other groundfish target species, and occurs in relatively small quantities in critical habitat areas closed to directed fishing for Atka mackerel

- Modify maximum retainable amount (MRA) regulations for Amendment 80 vessels and Western Alaska Community Development Quota (CDQ) entities operating in the Bering Sea subarea to revise the method for calculating the MRA.

The effect of the modifications in the Bering Sea subarea would provide for more of the combined Bering Sea/541 Atka mackerel TAC to be harvested in the Bering Sea subarea rather than the AI.

Amendment 78 to the BSAI Groundfish FMP closed a large portion of the AI subarea to nonpelagic trawling. The Amendment 78 closures to nonpelagic trawling include the AI Habitat Conservation Area (AIHCA), the AI Coral Habitat Protection Areas, and the Bowers Ridge Habitat Conservation Zone, located in the northern portion of Area 542 and 543. These closures were implemented on July 28, 2006. These closures are in addition to the Steller sea lion protection measures and, in combination, substantially limit the locations available for nonpelagic trawling in the AI subarea

Amendment 80 to the BSAI Groundfish FMP was adopted by the Council in June 2006 and implemented for the 2008 fishing year. This action allocated several BSAI non-pollock trawl groundfish species (including Atka mackerel) among trawl fishery sectors, facilitated the formation of harvesting cooperatives in the non-American Fisheries Act (non-AFA) trawl catcher/processor sector, and established a limited access privilege program (also referred to as a catch share program). BSAI Atka mackerel is one of the groundfish species directly affected by Amendment 80. Participation in the Atka mackerel fishery is now limited as a result of Amendment 80. In addition, the Alaska Seafood Cooperative (AKSC) formerly the Best Use Cooperative was formed under Amendment 80 which includes most of the participants in the BSAI Atka mackerel fishery.

Bycatch and Discards

Atka mackerel are not commonly caught as bycatch in other directed Aleutian Islands fisheries. The largest amounts of discards of Atka mackerel, which are likely under-size fish, occur in the directed Atka mackerel trawl fishery. Atka mackerel are also caught as bycatch in the trawl Pacific cod and rockfish

fisheries. Discard data have been available for the groundfish fishery since 1990. Discards of Atka mackerel for 1990-1999 and 2000-2005 have been presented in previous assessments (Lowe *et al.* 2003 and Lowe *et al*. 2011, respectively).

Bering Sea/Aleutian Islands Atka mackerel discard data from 2006 to the present are given below:

Year	Fishery	Discarded (t)	Retained (t)	Total (t)	Discard Rate (%)
2006	Atka mackerel	1,793	57,815	59,608	3.0
	All others	1,252	1,035	2,287	
	All	3,045	58,850	61,895	
2007	Atka mackerel	1,730	55,563	57,293	3.0
	All others	324	1,130	1,454	
	All	2,054	56,693	58,747	
2008	Atka mackerel	1,091	54,024	55,114	2.0
	All others	158	2,810	2,968	
	All	1,249	56,834	58,082	
2009	Atka mackerel	2,620	67,271	69,891	3.7
	All others	326	2,590	2,916	
	All	2,946	69,861	72,807	
2010	Atka mackerel	3,880	63,191	67,071	5.8
	All others	95	1,480	1,575	
	All	3,975	64,671	68,646	
2011	Atka mackerel	1,191	47,377	48,568	2.5
	All others	575	2,667	3,242	
	All	1,766	50,044	51,810	
2012	Atka mackerel	929	44,097	45,026	2.1
	All others	415	2,384	2,799	
	All	1,344	46,481	47,825	
2013	Atka mackerel	448	19,387	19,835	2.3
	All others	254	3,092	3,346	
	All	702	22,479	23,181	

Discard rates have been 2-3% until 2009 when the discard rate increased to nearly 4%. The increases in 2009 and 2010 may have been due to large numbers of small fish from the 2006 and 2007 year classes. In 2011, Steller sea lion protection measures were implemented which resulted in closures of the Western and Central Aleutian sub-areas (543, 542) to the Atka mackerel fishery and a reduction in the Atka mackerel TAC in the Central Aleutian sub-area (542). The large decrease in the 2011 discard rate likely reflects regulatory changes to the operation of the Atka mackerel fishery.

Until 1998, discard rates of Atka mackerel by all fisheries have generally been greatest in the western AI (543) and lowest in the east (541, Lowe *et al.* 2003). In the 2004 fishery, the discard rates decreased in both the central and western Aleutians (542 & 543) while the eastern rate increased (Lowe *et al*. 2011). Subsequently, the 2005 discard rates dropped significantly in all three areas, contributing to the large overall drop in the 2005 discard rate (Lowe *et al*. 2011). Discard rates have continued to decrease in eastern AI (541) since 2005, and the discard rates in the central AI (542) have increased, reflecting a shift in effort of the Atka mackerel fishery. The 2011-2013 data from the Western AI (543) are minimal Atka mackerel catches from the rockfish fisheries; directed fishing for Atka mackerel in 543 is prohibited under Steller sea lion protection measures.

Year		Aleutian Islands Subarea 541	542	543
2006	Retained (t)	4,013	38,447	14,374
	Discarded (t)	232	1,389	263
	Rate	***5%***	***4%***	***2%***
2007	Retained (t)	19,752	25,475	8,847
	Discarded (t)	169	1,248	251
	Rate	***1%***	***5%***	***3%***
2008	Retained (t)	18,701	22,180	15,650
	Discarded (t)	18	746	395
	Rate	***0.1%***	***3%***	***2%***
2009	Retained (t)	25,734	28,415	15,512
	Discarded (t)	439	1,722	740
	Rate	***2%***	***6%***	***5%***
2010	Retained (t)	23,073	24,035	17,460
	Discarded (t)	384	2,354	1,190
	Rate	***2%***	***9%***	***6%***
2011	Retained (t)	39,214	9,828	0.3
	Discarded (t)	467	886	205
	Rate	***2%***	***8%***	***100%***
2012	Retained (t)	36,034	9,599	0.2
	Discarded (t)	308	723	195
	Rate	***1%***	***7%***	***100%***
2013	Retained (t)	15,481	416	1.3
	Discarded (t)	149	6,867	119
	Rate	***1%***	***6%***	***99%***

Steller Sea Lions and Atka Mackerel Fishery Interactions

Since 1979, the Atka mackerel fishery has occurred largely within areas designated in 1993 as Steller sea lion critical habitat (20 nm around rookeries and major haulouts). While total removals from critical habitat may be small in relation to estimates of total Atka mackerel biomass in the Aleutian region, fishery harvest rates in localized areas may have been high enough to affect prey availability of Steller sea lions (Section 12.2.2 of Lowe and Fritz 1997). The localized pattern of fishing for Atka mackerel apparently does not affect fishing success from one year to the next since local populations in the Aleutian Islands appear to be replenished by immigration and recruitment. However, this pattern could have created temporary reductions in the size and density of localized Atka mackerel populations which may have affected Steller sea lion foraging success during the time the fishery was operating and for a period of unknown duration after the fishery closed. As a consequence, the NPFMC passed regulations in 1998 and 2001 (described above) to disperse fishing effort temporally and spatially as well as reduce effort within Steller sea lion critical habitat.

NMFS has ongoing investigations to determine the efficacy of trawl exclusion zones as a fishery-Steller sea lion management tool, and to determine the local movement rates of Atka mackerel through tagging studies. In August 1999, the AFSC conducted a pilot survey to explore the variance in survey catches of Atka mackerel and the feasibility of tagging as methods to determine small-scale changes in abundance and distribution. The tagging work was very successful and tagging surveys were conducted near Seguam Pass (in area 541) in August 2000, 2001 and 2002 (McDermott *et al.* 2005). Results indicated that the 20 nm trawl exclusion zone around the rookeries on Seguam and Agligadak Islands is effective in minimizing disturbance to prey fields within them. The boundary of the 20 nm trawl exclusion zone at

Seguam appears to occur at the approximate boundary of two naturally occurring assemblages. The movement rate between the two assemblages is small. Therefore, the results obtained in area 541 at Seguam regarding the efficacy of the trawl exclusion zone may not generally apply to other, smaller zones to the west. The tagging work has been expanded and tagging studies were conducted inside and outside the 10 nm trawl exclusion zones in Tanaga Pass (in 2002), near Amchitka Island (in 2003) and off Kiska Island (in 2006). Movement rates at Tanaga pass and Kiska Island appear similar to those at Seguam with the trawl exclusion zones overlaying apparent natural boundaries to local aggregations. Movement rates at Amchitka appear to be higher relative to Seguam (pers. comm. Elizabeth Logerwell and Susanne McDermott, AFSC). The boundaries at Amchitka bisect Atka mackerel habitat unlike Seguam and Tanaga.

After the release of the 2010 BiOp and implementation of the closure of area 543 to the Atka mackerel and Pacific cod fisheries, another tagging study was conducted with the primary objective of examining Atka mackerel populations near rookeries in all areas open to directed Atka mackerel fishing in the Aleutian Islands. Since 2006, NMFS has been working cooperatively with the North Pacific Fisheries Foundation (NPFF) to conduct field work under a Memorandum of Agreement. In May to June 2011 NMFS, in collaboration with NPFF released 8,500 tagged fish in the Eastern Aleutian Islands subarea (Seguam pass, area 541) and 19,000 fish in the Central Aleutian Islands subarea (Tanaga pass and Petrel bank, area 542). A tag recovery survey was conducted by a chartered fishing vessel and augmented with recoveries from the fishery in the open areas outside the trawl exclusion zones. Even though tags were released both inside and outside the closed areas during the recent release cruises in 2011 and 2012, recoveries were not conducted inside the trawl exclusion zones in order to minimize potential negative impacts of Atka mackerel removals to the Steller sea lion prey fields inside the closed areas. In addition to the data collected from the tag and release experiment, biological data including stomachs, gonad samples, age structures, sexed length frequencies, genetic tissue samples, and catch composition were also collected from each haul during the tag recovery charter. The second objective of this study was to use catch composition data to estimate relative abundance indexes (CPUEs) for all major fish and invertebrate species present in the study areas. The third objective of this study was to characterize Atka mackerel habitat by conducting underwater camera tows at each area where fish were recaptured. In 2011 and 2012 underwater camera tows were conducted in the areas of tag releases and recoveries to define bottom characteristics of areas with high abundance of Atka mackerel, and to develop methods for estimating indices of abundance of Atka mackerel and other Steller sea lion prey species with non-extractive methods such as camera tows.

Additionally, during the 2012 survey there was an opportunity to study the prey distribution of a Steller sea lion adult female that was tagged in November 2011 by the AFSC National Marine Mammal Laboratory. A hydroacoustic transect was conducted, species composition data collected, and camera tows were conducted in the area where the sea lion was feeding (South Petrel Bank). This provided a unique opportunity to investigate possible prey species availability during the same time and in the same location where the tagged female sea lion was diving. Tag recoveries from this study are ongoing, and the analyses of the tagging data are currently being conducted. Further details and preliminary results can be found at: http://www.afsc.noaa.gov/REFM/Stocks/fit/FITcruiserpts.htm.

Data

Fishery Data

Fishery Length Frequencies

From 1977 to 1988, commercial catches were sampled for length and age structures by the NMFS foreign fisheries observer program. There was no JV allocation of Atka mackerel in 1989, when the fishery became fully domestic. Since the domestic observer program was not in full operation until 1990, there

was little opportunity to collect age and length data in 1989. Also, the 1980 and 1981 foreign observer samples were small, so these data were supplemented with length samples taken by R.O.K. fisheries personnel from their commercial landings. Data from the foreign fisheries are presented in Lowe and Fritz (1996).

Atka mackerel length distributions from the 2013 and 2014 fisheries by management area are shown in Figures 17.2 and 17.3, respectively. The modes at about 29-35 cm and 30-36 cm in the 2013 and 2014 542 fishery length distributions represent the 2006 and 2007 year classes. The available 2014 fishery data are presented and should be considered preliminary, but are similar to the 2013 distributions. A significant difference in 2014 is the bimodal distribution of area 541 fish with modes at 32 and 39 cm. The 2014 area 541 mode at 32 cm may include 2 and 3 year olds from the 2011 and 2010 year classes. The 39-40 cm modes from area 541 in 2013 and 2014 are likely comprised of fish from the 2009 year class.

Fishery Age Data

Fishery data consist of total catch biomass from 1977 to 2013 and projected end of year 2014 catch data (Table 17.1). Also, length measurements collected by observers and otoliths read by the AFSC Age and Growth Lab (Table 17.3) were used to create age-length keys to determine the age composition of the catch from 1977-2011 (Table 17.4). In previous assessments (prior to 2008), the catch-at-age in numbers was compiled using total annual BSAI catches and global (Aleutian-wide) year-specific age-length keys. The formulas used are described by Kimura (1989). As with the length frequencies, the age data for 1980-1981 and 1989 presented problems. The commercial catches in 1980 and 1981 were not sampled for age structures, and there were too few age structures collected in 1989 to construct a reasonable age-length key. Kimura and Ronholt (1988) used the 1980 survey age-length key to estimate the 1980 commercial catch age distribution, and these data were further used to estimate the 1981 commercial catch age distribution with a mixture model (Kimura and Chikuni 1987). However, this method did not provide satisfactory results for the 1989 catch data and that year has been excluded from the analyses (Lowe *et al*. 2007).

An alternative approach to compiling the catch-at-age data was adopted in the 2008 assessment in response to issues raised during the 2008 Center for Independent Experts (CIE) review of the Aleutian Islands Atka mackerel and pollock assessments. This method uses stratified catch by region (Table 17.2) and compiles (to the extent possible) region-specific age-length keys stratified by sex. This method also accounts for the relative weights of the catch taken within strata in different years. This approach was applied to catch-at-age data after 1989 (the period when consistent observer data were available) and follows the methods described by Kimura (1989) and modified by Dorn (1992; Table 17.4). Briefly, length-stratified age data are used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates are then weighted by the catch within each stratum to arrive at an overall age composition for each year. In summary, estimates of the proportion of catch-at-age are derived from the mean of the bootstrap sampling of the revised catch-at-age estimates. The bootstrap method also allows evaluation of sample-size scaling that better reflect inter-annual differences in sampling and observer coverage. Since body mass is applied in this estimation, stratum-weighted mean weights-at-age are available with the estimates of catch-at-age. The three strata for the Atka mackerel coincide with the three management areas (eastern, central, and western regions of the Aleutian Islands). This method was used to derive the age compositions for 1990-2013 (the period for which all the necessary information is readily available). Prior to 1990, the catch-age composition estimates remain the same as in previous assessments.

The most notable features of the estimated catch-at-age data (Table 17.4) are the strong 1975, 1977, 1999, 2000, and 2001 year classes, and large numbers of the 2006 year class which showed up in the 2009 and 2010 fisheries. The 1975 year class appeared strong as 3 and 4-year-olds in 1978 and 1979. It is unclear

why this year class did not continue to show up strongly after age 4. The 1977 year class appeared strong through 1987, after entering the fishery as 3-year-olds in 1980. The 2002 fishery age data showed the first appearance in the fishery of the exceptionally strong 1999 year class, and the 2003 and 2004 fishery data showed the first appearance of large numbers from the 2000 and 2001 year classes, respectively. The 2012 fishery data are dominated by 5 and 6-year-olds of the 2007 and 2006 year classes, respectively, and continue to show the presence of the 2001 year class. There are significant numbers of 4 year olds of the 2009 year class that were observed in the 2013 catches (Table 17.4).

Atka mackerel are a summer-fall spawning fish that do not appear to lay down an otolith annulus in the first year (Anderl *et al.*, 1996). For stock assessment purposes, one year is added to the number of otolith hyaline zones determined by the Alaska Fisheries Science Center Age and Growth Unit. All age data presented in this report have been corrected in this way.

Survey Data

Atka mackerel are a difficult species to survey because: (1) they do not have a swim bladder, making them poor targets for hydroacoustic surveys; (2) they prefer hard, rough and rocky bottom which makes sampling with survey bottom trawl gear difficult; (3) their schooling behavior and patchy distribution result in survey estimates associated with large variances; and 4) Atka mackerel are thought to be very responsive to tide cycles. During extremes in the tidal cycle, Atka mackerel may not be accessible which could affect their availability to the survey. Despite these shortcomings, the U.S.-Japan cooperative trawl surveys conducted in 1980, 1983, 1986, and the 1991- 2014 domestic trawl surveys, provide the only direct estimates of population biomass from throughout the Aleutian Islands region. Furthermore, the biomass estimates from the early U.S-Japan cooperative surveys are not directly comparable with the biomass estimates obtained from the U.S. trawl surveys because of differences in the net, fishing power of the vessels and sampling design (Barbeaux *et al.* 2004).

Aleutian Islands trawl survey biomass estimates of Atka mackerel varied from 63,215 t in 1980 to 1,121,148 t in 1986 and 1,157,084 t in 2004 (Tables 17.5 and 17.6). However, the high value for 1986 is not directly comparable to previous estimates. During the 1980 survey, no successful sampling occurred in shallow waters (<100 m) around Kiska and Amchitka Islands. However, during the 1986 survey, several stations were successfully trawled in waters less than 100 m, and some produced extremely large catches of Atka mackerel. In 1986, the biomass estimate from this one depth interval alone totaled 1,011,991 t in the Central Aleutians (Table 17.5), or 90% of the total biomass of Atka mackerel in the Aleutian Islands. This was a 908,403 t increase over the 1983 biomass estimate for the same stratum-depth interval. The 1986 biomass estimate is associated with a large coefficient of variation (0.80). Due to differences in area and depth coverage of the surveys, it is not clear how this biomass estimate compares to earlier years.

The most recent Aleutian Islands biomass estimate from the 2014 Aleutian Islands bottom trawl survey is 723,928 t, up 161% relative to the 2012 survey estimate (Table 17.6). The breakdown of the Aleutian biomass estimates by area corresponds to the management sub-districts (541-Eastern, 542-Central, and 543-Western). The increase in biomass in the 2014 survey is largely a result of the huge increase in biomass found in the Eastern Aleutian area (up 812%), but all areas showed large increases (Table 17.6). Relative to the 2012 survey, the 2014 biomass estimates are up 61% in the Western area, 88% in the Central area, and 789% in the combined Southern Bering Sea/Eastern area (Fig. 17.4). The 95% confidence interval about the mean total 2014 Bering Sea/Aleutian Islands biomass estimate is 120,479-1,338,622t. The coefficient of variation (*CV*) of the 2014 mean BSAI biomass is 24% (Table 17.6).

The distribution of biomass in the Western, Central, and Eastern Aleutians and the southern Bering Sea shifted between each of the surveys, most dramatically in area 541 in the 2000 survey, and recently in the 2012 survey (Fig. 17.4). The 2000 Eastern Aleutian area biomass estimate (900 t) was the lowest of all

surveys, contributing only 0.2% of the total 2000 Aleutian biomass and represented a 98% decline relative to the 1997 survey. The 2012 Eastern Aleutian biomass estimate of 33,149 t was down 91% relative the 2010 survey, and represented 12% of the total 2012 Aleutian biomass. The extremely low 2000 biomass estimate for the Eastern area has not been reconciled, but there are several factors that may have had a significant impact on the distribution of Atka mackerel that were discussed in Lowe *et al.* (2001).

The area specific variances for area 541 have always been high relative to 542 and 543; the distribution of Atka mackerel in 541 is patchier with episodic large catches often resulting from trawl samples in the major passes. During 2012, large catches of Atka mackerel were not observed in area 541 as they were during 2006, 2010, and most recently in 2014. During the 2006, 2010, and 2014 surveys, the biomass from area 541 comprised 40 to 47% of the Aleutian Island biomass, but during 2012, only comprised 12% of the Atka mackerel biomass (Table 17.6).

This variation in survey biomass and low estimates for 2012 may be affected by colder than average temperatures in the region and their effects on fish behavior. Gear temperature near the bottom during the 2012 survey in area 541 was 0.25 °C colder than average for the 100 to 200 m depth stratum where 99% of the Atka mackerel are caught in the surveys, and both 2012 and 2000 were years with colder than average temperatures and low abundances of Atka mackerel (Fig. 17.5). Temperatures from the 2014 survey were some of the warmest in the time series over all depth strata (Fig. 17.5). Previous studies suggest that temperature affects the incubation period and potentially the occupation of nesting habitats by males (Lauth *et al*. 2007a). The effect of temperature on survey catchability and fish behavior should be examined more fully in the future to examine whether temperature affects the vertical or broad scale distribution of Atka mackerel to make them less available to the trawl during cold years.

Other factors could also affect survey catches. Sampling in area 541 includes passes with high currents that may affect towing success and catchability during daily tidal cycles and bi-weekly spring and neap tides. Atka mackerel are thought to be very responsive to tide cycles and current patterns, and the catchability of Atka mackerel may be influenced by currents. However, there were not any changes in survey protocols during 2012 that affected trawling operations with respect to tidal cycles and tows at stations were attempted with some failures through different current strengths. Three stations were resampled at the end of the cruise in area 541 in 2012 without any affect on the catch per unit effort of Atka mackerel. There is no evidence to suggest that the survey vessels were not sampling properly in 2012. Appendix 1 in Lowe *et al*. (2001) examined the distribution of historical Atka mackerel survey data. Simulation results showed that it is very possible to underestimate the true biomass when the target organism has a very patchy distribution (E. Conners, Appendix 1 in Lowe *et al*. 2001).

In 1994 for the first time since the initiation of the Aleutian triennial surveys, a significant concentration of biomass was detected in the southern Bering Sea area (66,603 t). This occurred again in 1997 (95,680 t), 2002 (59,883 t), 2004, (267,556 t), and in the 2010 survey (103,529 t, Table 17.6). These biomass estimates are a result of large catches from a single haul encountered north of Akun Island in all five surveys. In addition, large catches of Atka mackerel in the 2004 survey were also encountered north of Unalaska Island, with a particularly large haul in the northwest corner of Unalaska Island. The 2004 southern Bering Sea strata biomass estimate of 267,556 t is the largest biomass encountered in this area in the survey time series. The *CV* of the 2004 southern Bering Sea estimate is 43%, much lower than previous years as several hauls contributed to the 2004 estimate. Most recently, the 2014 survey estimated only 1,443 t of biomass in the southern Bering Sea (*CV*=73%). Very little biomass was observed in the southern Bering Sea in 2012 and 2014, and no large hauls were encountered north of Akun Island similar to the 2006 and 2010 surveys (Fig. 17.6).

Areas with large catches of Atka mackerel in the 2010 survey included north of Akun Island, northwest of the Islands of Four Mountains, Seguam Pass, Kiska Island, Buldir Island, and Stalemate Bank (Fig. 17.6). In the 2012 survey there were no extremely large catches observed as in previous surveys, and moderate catches were only observed south of Amchitka Island, Kiska Island, and Stalemate Bank (Fig. 17.6) In the most recent 2014 survey, several large catches were observed at Seguam Pass, Atka Island, Tanaga Island, Kiska Island, and Stalemate Bank. In the 2002, 2004, 2006, and 2010 surveys Atka mackerel were much less patchily distributed relative to previous surveys and were encountered in 55, 58, 52, and 56% of the hauls respectively, which are the highest rates of encounters in the survey time series. Although no extremely large catches of Atka mackerel were encountered in the 2012 survey, low to moderate catches were observed in areas consistent with previous surveys, and the percent occurrence of Atka mackerel in the 2012 survey was 48%. In the most recent 2014 survey, Atka mackerel were encountered in 55% of the survey hauls, similar to surveys before 2012.

The average bottom temperatures measured in the 2000 and 2012 surveys were the lowest of any of the Aleutian surveys, particularly in depths less than 200 m where 99% of the Atka mackerel are caught in the surveys (Fig. 17.5). The average bottom temperatures measured in the 2014 survey were the second highest of the Aleutian surveys, significantly higher than the 2000 and 2012 surveys and very similar to the 1991 and 1997 surveys (Fig. 17.5).

Survey length frequencies

The bottom trawl surveys have consistently revealed a strong east-west gradient in Atka mackerel size, with the smallest fish in the west and progressively larger fish to the east along the Aleutian Islands chain. This was evident in the 2010 and 2012 surveys (Figure 17.7 in Lowe *et al.* 2011 and Lowe *et al*. 2012). The 2014 survey length frequency distributions also show a strong east-west gradient in Atka mackerel size (Fig. 17.7). The 2014 survey length frequency distributions from each area showed bimodal distributions. The Eastern Aleutians showed modes at 35 and 43-45 cm, larger than the Central and Western fish, both with modes at 24-25 and 37-38 cm. The smaller modes in the distributions may be 2 and 3-year olds of the 2012 and 2011 year classes.

Survey age frequencies

The 2010 survey age composition was dominated by 3 and 4-year olds of the 2007 and 2006 year classes (Fig. 17.8 in Lowe *et al*. 2011). The 2009-2013 fishery data confirm the strong presence of the 2006 and 2007 year classes in fishery catches. The most recent available 2012 survey age composition is dominated by 3 and 5-year olds of the 2009 and 2007 year classes, respectively (Fig. 17.8). Six year olds of the 2006 year class are still numerous. The mean age in the 2012 survey age composition is 5.6 years. Table 17.7 gives estimated survey numbers at age of Atka mackerel from the Bering Sea/Aleutian Islands trawl surveys and numbers of Atka mackerel otoliths aged.

Survey abundance indices

A partial time series of relative indices from the 1980, 1983, 1986 and 1991 Aleutian Islands surveys had been used in the previous stock synthesis assessments (Lowe *et al.* 2001). The relative indices of abundance excluded biomass from the 1-100 m depth strata of the Southwest Aleutian Islands region (west of 180°) due to the lack of sampling in this stratum in some years. Because the excluded area and depth stratum have consistently been found to be locations of high Atka mackerel biomass in later surveys, it was determined that the indices did not provide useful additional information to the model and have been omitted from the assessment since 2001. Analyses to determine the impact of omitting the relative time series showed that results without the relative index are more conservative (Lowe *et al*. 2002).

Analytic Approach

The 2002 BSAI Atka mackerel stock assessment introduced a new modeling approach implemented through the "Stock Assessment Toolbox" (an initiative by the NOAA Fisheries Office of Science and Technology) that evaluated favorably with previous assessments (Lowe *et al.* 2002). This approach used the Assessment Model for Alaska (AMAK)[1] from the Toolbox, which is similar to the stock synthesis application (Methot 1989, 1990; Fournier and Archibald 1982, Fournier 1998) used for Aleutian Islands Atka mackerel from 1991–2001, but allows for increased flexibility in specifying models with uncertainty in changes in fishery selectivity and other parameters such as natural mortality and survey catchability (Lowe *et al.* 2002). This approach (AMAK) has also been adopted for the Aleutian Islands pollock stock assessment (Barbeaux *et al.* 2004).

Model Structure

The AMAK models catch-at-age with the standard Baranov catch equation. The population dynamics follows numbers-at-age over the period of catch history (here 1977-2013) with natural and age-specific fishing mortality occurring throughout the 11-age-groups that are modeled (1-11+). Age 1 recruitment in each year is estimated as deviations from a mean value expected from an underlying stock-recruitment curve. Deviations between the observations and the expected values are quantified with a specified error model and cast in terms of a penalized log-likelihood. The overall log-likelihood (L) is the weighted sum of the calculated log-likelihoods for each data component and model penalties. The component weights are inversely proportional to the specified (or in some cases, estimated) variances. The model structure has not changed since the previous assessment. Appendix Tables A-1 – A-3 provide a description of the variables used, and the basic equations describing the population dynamics of Atka mackerel as they relate to the available data. The quasi[2] likelihood components and the distribution assumption of the error structure are given below:

Data component	Years of data	Likelihood form	*CV* or sample size (*N*)
Catch biomass	1977-2014	Lognormal	*CV*=5%
Fishery catch age composition	1977-2013	Multinomial	Year specific *N*=25-234
Survey biomass	1991, 1994, 1997, 2000, 2002 2004, 2006, 2010, 2012, 2014	Lognormal	Average *CV*=25%
Survey age composition	1986, 1991, 1994, 1997, 2000 2002, 2004, 2006, 2010, 2012	Multinomial	*N*=50
Recruitment deviations		Lognormal	
Stock recruitment curve		Lognormal	
Selectivity smoothness (in age-coefficients, survey and fishery)		Lognormal	
Selectivity change over time (fishery and survey)		Lognormal	
Priors (where applicable)		Lognormal	

[1] AMAK. 2011. A statistical catch at age model for Alaska, version 2.0. NOAA version available on request to authors.

[2] Quasi likelihood is used here because model penalties (not strictly relating to data) are included.

The age-composition components are heavily influenced by the sample size assumptions specified for the multinomial likelihood. Since sample variances of our catch-at-age estimates are available (Dorn 1992), "effective sample sizes" ($\dot{N}_{i,j}$) can be derived as follows (where *i* indexes year, and *j* indexes age):

$$\dot{N}_{i,j} = \frac{p_{i,j}\left(1 - p_{i,j}\right)}{\mathrm{var}\left(p_{i,j}\right)}$$

where $p_{i,j}$ is the proportion of Atka mackerel in age group *j* in year *i* plus an added constant of 0.01 to provide some robustness. The variance of $p_{i,j}$ was obtained from the estimates of variance in catch-at-age. Thompson and Dorn (2003, p. 137) and Thompson (AFSC pers. comm.) note that the above is a random variable that has its own distribution. Thompson and Dorn (2003) show that the harmonic mean of this distribution is equal to the true sample size in the multinomial distribution. This property was used to obtain sample size estimates for the (post 1989) fishery numbers-at-age estimates (scaled to have a mean of 100; earlier years were set to constant values):

1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
25	25	25	25	50	50	50	50	50	50	50	50
1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
47	35	10	10	65	59	116	16	82	218	233	103
2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
135	132	132	88	116	88	143	149	128	83	100	100

An ageing error conversion matrix is used in the assessment model to translate model population numbers at age to expected fishery catch at age. We estimated this matrix using an ageing error model fit to the observed percent agreement at ages 2 through 10. Mean percent agreement is close to 100% at age 2 and declines to 54% at age 10. Annual estimates of percent agreement are variable, but show no obvious trend, hence a single conversion matrix for all years in the assessment model was adopted. The model is based on a linear increase in the standard deviation of ageing error and the assumption that ageing error is normally distributed. The model predicts percent agreement by taking into account the probability that both readers are correct, both readers are off by one year in the same direction, and both readers are off by two years in the same direction. The probability that both readers agree and were off by more than two years was considered negligible.

Parameters Estimated Outside the Assessment Model

The following parameters were estimated independently of other parameters outside of the assessment model: natural mortality (*M*), length and weight at age parameters, and maturity at age and length parameters. A description of these parameters and how they were estimated follows.

Natural mortality

Natural mortality (*M*) is a difficult parameter to estimate reliably. One approach we took was to use the regression model of Hoenig (1983) which relates total mortality as a function of maximum age. His equation is:

$\ln(Z) = 1.46 - 1.01(\ln(Tmax))$.

Where *Z* is total instantaneous mortality (the sum of natural and fishing mortality, $Z=M+F$), and *Tmax* is the maximum age. The instantaneous total mortality rate can be considered an upper bound for the natural mortality rate if the fishing mortality rate is minimal. The catch-at-age data showed a 14-year-old

fish in the 1990 fishery, and a 15-year-old in the 1994 fishery. Assuming a maximum age of 14 years and Hoenig's regression equation, Z was estimated to be 0.30 (Lowe 1992). Because fishing mortality was relatively low in 1990, natural mortality has been reasonably approximated by a value of 0.30 in past assessments.

An analysis was undertaken to explore alternative methods to estimate natural mortality for Atka mackerel (Lowe and Fritz, 1997). Several methods were employed based on correlations of M with life history parameters including growth parameters (Alverson and Carney 1975, Pauly 1980, Charnov 1993), longevity (Hoenig 1983), and reproductive potential (Roff 1986, Rikhter and Efanov 1976). Atka mackerel appear to be segregated by size along the Aleutian chain. Thus, natural mortality estimates based on growth parameters would be sensitive to any sampling biases that could result in under- or over-estimation of the von Bertalanffy growth parameters. Fishery data collections are more likely to be biased as the fishery can be more size selective and concentrates harvests in specific areas as opposed to the surveys. Natural mortality estimates derived from fishery data ranged from 0.05 to 1.13 with a mean of 0.53. Natural mortality estimates, excluding those based on fishery data, ranged from 0.12 to 0.74 with a mean value of 0.34. The current assumed value of 0.3 is consistent with these values. Also, a value of 0.3 is consistent with values of M derived by the methods of Hoenig (1983) and Rikhter and Efanov (1976) which do not rely on growth parameters (Lowe and Fritz, 1997).

The 2003 assessment explored the use of priors on M, resulting in drastically inflated biomass levels (Fig. 17.11 in Lowe *et al.* 2003). In the current assessment, a natural mortality value of 0.3 was used in the assessment model.

Length and weight at age

Atka mackerel exhibit large annual and geographic variability in length at age. Because survey data provide the most uniform sampling of the Aleutian Islands region, data from these surveys were used to evaluate variability in growth (Kimura and Ronholt 1988, Lowe *et al.* 1998). Kimura and Ronholt (1988) conducted an analysis of variance on length-at-age data from the 1980, 1983, and 1986 U.S.-Japan surveys, and the U.S.-U.S.S.R. surveys in 1982 and 1985, stratified by six areas. Results showed that length at age did not differ significantly by sex, and was smallest in the west and largest in the east. More recent analyses by Lowe *et al.* (1998) corroborated differential growth in three sub-areas of the Aleutian Islands and the Western GOA. Based on the work of Kimura and Ronholt (1988), and annual examination of length and age data by sex which has found no differences, growth parameters are presented for combined sexes. Parameters of the von Bertalanffy length-age equation and a weight-length equation have been calculated for (1) the combined 1986, 1991, and 1994 survey data for the entire Aleutians region, and for the Eastern (541) and combined Central and Western (542 and 543) subareas, and (2) the combined 1990-96 fishery data for the same areas:

Data source	L_∞(cm)	K	t_0
86, 91& 94 surveys			
Areas combined	41.4	0.439	-0.13
541	42.1	0.652	0.70
542 & 543	40.3	0.425	-0.38
1990-96 fishery			
Areas combined	41.3	0.670	0.79
541	44.1	0.518	0.35
542 & 543	40.7	0.562	0.37

Length-age equation: Length (cm) = $L_\infty\{1\text{-exp}[-K(\text{age}-t_0)]\}$

Both the survey and fishery data show a clear east to west size cline in length at age with the largest fish found in the eastern Aleutians.

The weight-length relationship determined from the same data sets are as follows:

$$\text{weight (kg)} = 9.08\text{E-}06 \times \text{length (cm)}^{3.0913} \quad (86, 91 \text{ \& } 94 \text{ surveys; N} = 1{,}052)$$
$$\text{weight (kg)} = 3.72\text{E-}05 \times \text{length (cm)}^{2.6949} \quad (1990\text{-}1996 \text{ fisheries; N} = 4{,}041).$$

The observed differences in the weight-length relationships from the survey and fishery data, particularly in the exponent of length, probably reflect the differences in the timing of sample collection. The survey data were all collected in summer, the spawning period of Atka mackerel when gonad weight would contribute the most to total weight. The fishery data were collected primarily in winter, when gonad weight would be a smaller percentage of total weight than in summer.

Year-specific weight-at-age estimates are used in the model to scale fishery and survey catch-at-age (and the modeled numbers-at-age) to total catch biomass and are intended to represent the average weight-at-age of the catch. Separate annual survey weights-at-age are complied for expanding modeled numbers into –age-selected- survey biomass levels (Table 17.8). Specifically, survey estimates of length-at-age were obtained using year-specific age-length keys. Weights-at-age were estimated by multiplying the length distribution at age from the age-length key, by the mean weight-at-length from each year-specific data set (De Robertis and Williams 2008). In addition, a single vector of weight-at-age values based on the 2006, 2010, and 2012 surveys is used to derive population biomass from the modeled numbers-at-age in order to allow for better estimation of current biomass (Table 17.8).

The fishery weight-at-age data presented in previous assessments (prior to 2008) were compiled based on unweighted, unstratified (Aleutian-wide) fishery catch-age samples to construct the year-specific age-length keys (see Table 17.8 in Lowe *et al*. 2007). Beginning with the 2008 assessment, the weights-at-age for the post 1989 fishery reflect stratum-weighted values based on the relative catches. The fishery weight-at-age data presented in Table 17.8 for 1990 to 2014 were compiled using the two-stage catch-estimation scheme described above in the Fishery Data section. Prior to 1990, the fishery weight-at-age estimates are as in previous assessments and given in Table 17.8.

Maturity at age and length

Female maturity at length and age were determined for Aleutian Islands Atka mackerel (McDermott and Lowe, 1997). The age at 50% maturity is 3.6 years. Length at 50% maturity differs by area as the length at age differs by Aleutian Islands sub-areas:

	Length at 50% maturity (cm)
Eastern Aleutians (541)	35.91
Central Aleutians (542)	33.55
Western Aleutians (543)	33.64

The maturity schedules are given in Table 17.9. Cooper *et al*. (2010) examined spatial and temporal variation in Atka mackerel female maturity at length and age. Maturity at length data varied significantly between different geographic areas and years, while maturity at age data failed to indicate differences and corroborated the age at 50% maturity determined by McDermott and Lowe (1997).

Parameters Estimated Inside the Assessment Model

Deviations between the observations and the expected values are quantified with a specified error structure. Lognormal error is assumed for survey biomass estimates and fishery catch, and a multinomial error structure is assumed for survey and fishery age compositions. These error structures are used to estimate the following parameters conditionally within the model (fishing mortality, survey selectivity,

survey catchability, age 1 recruitment). A description of these parameters and how they were estimated follows.

Fishing mortality

Fishing mortality is parameterized to be separable with a year component and an age (selectivity) component in all models. The selectivity relationship is modeled with a smoothed non-parametric relationship that can take on any shape (with penalties controlling the degree of change over time, degree of declining selectivity at age (dome-shape, σ_d), and curvature as specified by the user; Table A-2). Selectivity is conditioned so that the mean value over all ages will be equal to one. To provide regularity in the age component, a moderate penalty was imposed on sharp shifts in selectivity between ages (curvature) using the sum of squared second differences (log-scale). In addition, the age component parameters are assumed constant for ages 10 and older. Asymptotic growth is reached at about age 9 to 10 years. Thus, it seemed reasonable to assume that selectivity of fish older than age 10 would be the same. A moderate penalty was imposed to allow the model limited flexibility on degree of declining selectivity at age. In the 2012 assessment we evaluated a range of alternative values for the prior penalty of the parameter determining the degree of dome-shape (σ_d) for fishery selectivity and assumed a value of 0.3 for σ_d for the recommended Model 2 which was accepted (Lowe *et al*. 2012). This assumption is carried forward in the current assessment.

Prior to the 2008 assessment, selectivity had been allowed to vary annually with a low constraint as described in the 2002 assessment (Lowe *et al*. 2002). As suggested by the 2008 CIE reviewers, we adopted a new model configuration with blocks of years with constant selectivity which correspond approximately to the foreign fishery, the joint venture fishery, the domestic fishery prior to Steller sea lion regulations, and the domestic fishery post Steller sea lion regulations. This model configuration was used in the 2008-2012 assessments. In the 2013 assessment, a method to allow fishery selectivity to vary without having to subjectively specify an arbitrary degree of penalty was implemented based on analysis developed and presented at the CAPAM workshop on selectivity. This method was accepted by the SSC and follows the procedure outlined in Annex 2.1.1 of the 2012 BSAI Pacific cod assessment (Thompson and Lauth 2012, p. 442-445) and implements the following procedure:

1) Estimate time-varying selectivity with negligible constraint, and compute the resulting standard deviation of the coefficient residuals (relative to their mean)
2) Iterate models with alternative trial values for time-varying selectivity penalties until the input value equals the output value (of residuals)
3) Compute a final value which weights the two variances, i.e., $\sigma_{sel} = \sqrt{\sigma_1^2 - \sigma_2\left(\sigma_1 - \sigma_2\right)}$ where σ_1, σ_2 are the standard deviations from steps 1 and 2 above.

The current assessment estimates time-varying selectivity according to the method described above.

Survey selectivity and catchability

For the bottom trawl survey, selectivity-at-age follows a parameterization similar to the fishery selectivity-at-age presented above (except with except with no allowance for time-varying selectivity). In response to the December 2010 SSC minutes which noted a lack of model fit to survey biomass estimates after 1999, the 2011 assessment explored the implementation of a random walk for a transition set of years in survey catchability and time periods for survey selectivity, as one approach to help resolve the poor residual pattern identified (Lowe *et al*. 2011). Results were unsatisfactory and little improvement of model fit to survey biomass was noted. The random walk for catchability was not carried forward. Based on recommendations from the 2014 CIE review, we will explore options for implementing time-varying selectivity for the survey in the 2015 assessment. As in the past, we also specified that the average

selectivity-at-age for the survey is equal to 1 over ages 4-10. This was done to standardize the ages over which selectivity most reasonably applies.

The 2002 assessment explored the estimation of M and survey catchability (q) simultaneously with various combinations of priors (Lowe *et al*. 2002). Preliminary results were unsatisfactory and difficult to interpret biologically. The 2003 assessment explored a range of priors on M or q, while the other parameter was fixed with mixed results that were also difficult to interpret and did not seem biologically reasonable (Lowe *et al.* 2003). In the 2004 assessment we presented a model (Model 4, Lowe *et al.* 2004), with a moderate prior on q (mean = 1.0, $\sigma^2 = 0.2^2$) which was accepted and used as the basis for the ABC and OFL specifications since 2004.

The 2015 assessment will include a more comprehensive analysis of fishery and survey time-varying selectivity, and also explore the estimation of M and q directly in the model as requested in the 2013 December SSC minutes. These analyses were not conducted for the 2014 assessment, so that they could be coordinated with responses to the 2014 CIE review in the 2015 assessment.

Recruitment

The Beverton-Holt form of stock recruitment relationship based on Francis (1992) was used (Table A-2). Values for the stock recruitment function parameters α and β are calculated from the values of R_0 (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the "steepness" of the stock-recruit relationship (h, Table A-2). The "steepness" parameter is the fraction of R_0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992). Past assessments have assumed a value of 0.8. A value of $h = 0.8$ implies that at 20% of the unfished spawning stock size, an expected value of 80% of the unfished recruitment level will result. Model runs exploring other values of h and the use of a prior on h were explored in previous assessments (Lowe *et al.* 2002), but were found to have little or no bearing on the stock assessment results and were not carried forward for further evaluation at the time. As in past years, we assumed $h = 0.8$ for all model runs since previous work showed that assessment results were insensitive to this assumption (and given the Tier 3 status does not affect future projections). Prior to the 2012 assessment, the recruitment variance (σ_R^2) was fixed at a value of 0.6. In the 2012-2013 and the current assessment, we estimate σ_R^2.

Results

Model Evaluation

The current assessment begins with the model configuration from 2013 but continues on the theme of evaluating fits to the survey biomass estimates and the estimation of M and q consistent with previous explorations and SSC recommendations.

The explorations of natural mortality and survey catchability (M , q) in the 2003 and 2004 assessments indicated inconsistencies between the fishery and survey age compositions and the survey biomass estimates (Lowe *et al*. 2003, 2004). The models evaluated in those assessments could only reconcile the observed variability in survey biomass estimates by an unrealistic re-scaling of incoming year classes, or alternatively, substantial changes in the numbers of older-age fish (Lowe *et al*. 2004). Improved model fits to the survey were achieved by having survey catchability increase, resulting in lower overall biomass and better fits to the survey trends (Lowe *et al*. 2004). The 2012 assessment model was configured to constrain the degree of dome-shape for fishery selectivity,which resulted in more plausible values of q and better reflected the fishery age composition data. The 2013 assessment model was the same, but allowed a greater degree of time-varying fishery selectivity with the degree of smoothness over age and

time estimated. This configuration was accepted and used for 2013 recommendations and is carried forward here with three preliminary sensitivity runs based on feedback from the 2014 CIE review and SSC comments:

Model 1 2013 model updated with 2013 fishery and 2014 survey data (baseline model)

Model 2 as in Model 1, but with down-weighted survey indices (survey *CV*s inflated by a factor of 10)

Model 3 as in Model 2, but with down-weighted survey ages (survey age sample sizes reduced by a factor of 10, from 50 to 5)

Model 4 as in Model 1, but with moderate priors on both M (mean = 0.3, $\sigma^2 = 0.06^2$), and q (mean = 1.0, $\sigma^2 = 0.2^2$)

A summary of key results from Models 1-4 are presented in Table 17.10. Estimated survey catchability increases slightly from 1.04 for Model 1 to 1.07 for Model 3; q is estimated at 0.90 in Model 4. Natural mortality is fixed at 0.30 in Models 1-3 and estimated at 0.45 in Model 4. The estimated 2014 biomass ranges from about 400,000 t for Models 2 and 3, to 1,307,000 t for Model 4. The estimated magnitude of the 2001 year class ranges from about 1.1 billion age 1 recruits for Models 2 and 3, to over 5.4 billion for Model 4. Estimates of the most recent strong year class (2006) range from about 700 million age 1 recruits for Models 2 and 3, to 3 billion for Model 4. Overall estimated recruitment variability was similar for all models and ranged from 0.54 to 0.57. Figure 17.9 shows the estimated spawning biomass trends with approximate 90% confidence bands for Model 1 compared to the sensitivity runs (Models 2-4). Models 2-3 provide similar and more conservative estimates of spawning biomass relative Model 1. As expected, estimates of spawning biomass from Model 4 are highly inflated relative to Model 1.

Down-weighting the survey (Models 2 and 3) and the survey age compositions (Model 3) results in improved fits to the fishery age compositions as expected (Table 17.10). Model 4 however, had the best fit for the fishery age composition because those data favor a higher natural mortality rate than was assumed in the other models.

The role of the survey data, specifically the biomass index, was one of the important topics covered in the 2014 CIE review. Results of simulations conducted during the CIE review confirmed that most of the abundance trend signal is coming from the fishery (and survey) age compositions rather than from the biomass index. This was consistent with sensitivity results from Models 2 and 3 that resulted in lower biomass estimates and consequently higher Fs to account for changes in the relative abundance of cohorts observed in the age composition data.

The estimation of M influences stock abundance estimates as in Model 4. Exploratory runs were also conducted during the CIE review that estimated an age-varying M (constant over time) within the model. Results were similar to those of Model 4 (higher estimates of M, large changes in the perceived magnitude of recruitment and spawning biomass). The CIE reviewers suggested an alternative formulation for M could be to consider an age-dependent M selected outside the assessment model and recommended exploring the Lorenzen model which is based on the relationship between size and natural mortality (Lorenzen 1996). Further evaluations will be conducted in 2015 in response to the CIE comments.

Based on the 2014 CIE review, the Model 1 configuration was deemed reasonable and consistent with the best available science without serious gaps or inconsistencies in the population dynamics modeling or logic. No immediate, high-priority changes to the model configuration were identified. Results of Model

1 fall within the range of results from sensitivity runs provided by Models 2, 3, and 4. We therefore selected last year's model configuration for harvest recommendations based on the quality of fits to the age composition data, and that the variance specified for the survey index is reasonably large which moderates the extent that the model estimates are unduly affected by interannual variability in the survey estimates.

Model Fit

A summary of key results from Model 1 are presented in Table 17.10. The coefficient of variation or *CV* (reflecting uncertainty) about the 2014 biomass estimate is 22% and the *CV*s on the strength of the 2001 and 2006 year classes at age 1 are 17 and 18%, respectively (Table 17.10). Recruitment variability was moderate and estimated to be 0.554. Sample size values were calculated for the fishery data and fixed at 50 for the bottom trawl survey data. The model estimated an average fishery effective sample size (*N*) of 231 and average survey effective *N* of 117, which are higher than the input values but reasonable given the level of sampling that occurs in the fishery and survey. The overall residual mean square error (RMSE) for the survey is estimated at 0.247, which is in line with estimates of sampling-error *CV*s for the survey which range from 14-35% and average 25% over the time series (Table 17.6).

Figure 17.10 compares the observed and estimated survey biomass abundance values for the BSAI. The decreases in biomass indicated by the 1994 and 1997 surveys followed by the large increases in biomass from the 2000, 2002 and 2004 surveys appear to be consistent with recruitment patterns. However, the large increase observed in the 2004 survey is fit poorly by the model. In the 2004 survey, an unusually high biomass (268,000 t) was estimated for the southern Bering Sea area. This value represented 23% of the entire 2004 BSAI survey biomass estimate. The 2006 survey indicates a downward trend which is consistent with the population age composition at the time. The 2010 survey biomass estimate indicated a large increase that was not predicted by the assessment model. The 2010 survey biomass estimate for the southern Bering Sea was also unusually high (103,500 t) and represented a 741% increase over the 2006 southern Bering Sea estimate. The 2012 survey is associated with the lowest variance in the time series but is not fit by the model (Figure 17.10). However, the declining trend in biomass indicated by the 2012 survey is consistent with the population age composition. Population biomass would be expected to decline as the most recent strong year class (2006 year class) is aging and past peak cohort biomass. The large increase in survey biomass indicated by the most recent 2014 is also not fit well by the model. A moderate increase in the predicted survey biomass is estimated for 2014, consistent with continued strong presence of the 2006 and 2007 year classes and good recruitment from the 2009 year class. We note that the model's predicted survey biomass trend is very conservative relative to the recent (2004, 2010, and 2014) observed bottom trawl survey biomass values, but fits the other survey years quite well (survey catchability is approximately equal to 1).

The fits to the survey and fishery age compositions for Model 1 are depicted in Figures 17.11 and 17.12, respectively. The model fits the fishery age composition data well particularly after 1997, and the survey age composition data less so. This reflects the fact that the sample sizes for age and length composition data are higher for the fishery in some years than the survey. These figures also highlight the patterns in changing age compositions over time. Note that the older age groups in the fishery age data are largely absent until around 1985 when the 1977 year class appears. Fits to the recent fishery age composition data in Lowe *et al*. (2012) indicated a need for greater flexibility in selectivity. The 2013 assessment allowed for more flexibility to estimate time-varying fishery selectivity, which improved fits to the fishery age compositions.

The results discussed below are based on the recommended Model 1 with updated 2013 fishery catch- and weight-at-age values, and 2014 Aleutian Islands survey biomass data.

Time Series Results

Selectivity

For Atka mackerel, the estimated selectivity patterns are particularly important in describing their dynamics. Previous assessments focused on the transitions between ages and time-varying selectivity (Lowe *et al.* 2002, 2008, 2013). The current assessment allows for flexibility (over time and age) and pre and post 1999 selectivity patterns for the survey (Figures 17.13, 17.14, and 17.15 and Table 17.11). The current assessment's terminal year selectivity estimate and the average selectivity for 2010-2014 (used for projections) differs from the terminal year in the 2013 assessment, showing higher selectivity for ages 4-5 and age 7, and lower selectivity after age 8 (Figure 17.14).

The fishery catches essentially consist of fish 3-11 years old, although a 15-year-old fish was found in the 1994 fishery. The fishery exhibits a dome-shaped selectivity pattern which is more pronounced prior to 1992 during the foreign and joint venture fisheries (1977-1983 and 1984-1991, respectively (Fig.17.13). After 1991, fishery selectivity patterns are relatively consistent but do show differences at ages 3-7 and more notable differences at age 8 and older. Fish older than age 9 make up a very small percentage of the population each year, and the differences in the selectivity assumptions for the older ages are not likely to have a large impact. However, differences in selectivity for ages 3-8 can have a significant impact. The recent patterns since 2000 reflect the large numbers of fish from the 1999, 2000, 2001, and 2006 year classes (Table 17.4). The age at 50% selectivity is estimated at about age 3 for 2008, and has increased to age 4 in 2012-2013 as the large year classes move through the population. It is important to note the maturity-at-age vector relative to the current selectivity patterns (age at 50% maturity is 3.6 years, Fig. 17.14). The estimated selectivity patterns since about 1991 indicate the fishery is harvesting mature older fish relative to the foreign and joint venture fisheries.

Survey catches are mostly comprised of fish 3-9 years old. However, the 2012 survey still shows significant numbers of 11-13 year olds of the 1999, 2000, and 2001 year classes. A 15-year old fish was found in the 2000 survey, and most recently a 17-year old fish was found in the 2012 survey. The current model configuration estimates a moderately dome-shape selectivity pattern (Fig. 17.15).

Abundance trend

The estimated time series of total numbers at age are given in Table 17.12. The estimated time series of total biomass (ages 1+) with approximate upper and lower 95% confidence limits are given in Table 17.13. A comparison of the spawning biomass trend from the current and previous assessments (Table 17.13 and Figure 17.16) indicates consistent trends throughout the time series, i.e., biomass increased during the early 80s and again in the late 80s to early 90s. After the estimated peak spawning biomass in 1993, spawning biomass declined for nearly 10 years until 2001 (Fig. 17.16). Thereafter, spawning biomass began a steep increase which continued to 2005. The abundance trend has been declining since the most recent peak in 2005 which represented a build-up of biomass from the exceptionally strong 1999-2001 year classes. Estimates from the current assessment are higher throughout the time series which is attributed to higher estimates of recruitment levels, particularly for strong year classes after 1999.

Recruitment trend

The estimated time series of age 1 recruits indicates the strong 1977 and 1999 year class are the most notable in the current assessment, followed by the 1988 and 2001 year classes (Figures 17.17 and 17.18). The 1999, 2000, and 2001 year classes are estimated to be three of the five largest recent year classes in the time series (approximately 2.2, 1.3, and 1.5 billion recruits, respectively) due to the persistent observations of these year classes in the fishery and survey catches. The current assessment estimates above average (greater than 20% of the mean) recruitment from the 1977, 1988, 1992, 1995, 1998, 1999, 2000, 2001, 2006 year classes (Fig 17.17).

The average estimated recruitment from the time series 1978-2013 is 696 million fish and the median is 534 million fish (Table 17.14). The entire time series of recruitments (1977-2013) includes the 1976-2012 year classes. The Alaska Fisheries Science Center has recognized that an environmental "regime shift" affecting the long-term productive capacity of the groundfish stocks in the BSAI occurred during the period 1976-1977. Thus, the average recruitment value presented in the assessment is based on year classes spawned after 1976 through 2013 (1977-2012 year classes). Projections of biomass are based on estimated recruitments from 1978-2013 using a stochastic projection model described below.

Trend in exploitation

The estimated time series of fishing mortalities on fully selected age groups and the catch-to-biomass (age 3+) ratios are given in Table 17.15 and shown in Figure 17.19.

Retrospective analysis

A retrospective analysis was conducted by regressively eliminating the most current year of information extending back to 2000. This allows judgment of the model performance as specified. For a stock with highly variable and uncertain survey information, the change and relative difference in spawning biomass is difficult to predict in subsequent years (Figure 17.20). The current model applied to a shortened time series often gives estimates that vary broadly from the full-data set model used for this assessment. In general, the pattern is consistent with the variability of survey observations in scaling the stock. Although the scale and uncertainty exhibited by the retrospective runs generally fall within the confidence bands of the present model, retrospective patterns are still evident and require further investigation. The revised Mohn's rho statistic for this retrospective analysis was estimated at 0.073.

Projections and Harvest Recommendations

Results and recommendations in this section pertain to the authors' recommended baseline model (Model 1).

Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC ($max\ F_{ABC}$). The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. The overfishing and maximum allowable ABC fishing mortality rates are given in terms of percentages of unfished female spawning biomass ($F_{SPR\%}$), on fully selected age groups. The associated long-term average female spawning biomass that would be expected under average estimated recruitment from 1978-2013 (696 million age-1 recruits) and F equal to $F_{40\%}$ and $F_{35\%}$ are denoted $B_{40\%}$ and $B_{35\%}$, respectively. The Tiers require reference point estimates for biomass level determinations. We present the following reference points for BSAI Atka mackerel for Tier 3 of Amendment 56. For our analyses, we computed the following values from **Model 1** results based on recruitment from post-1976 spawning events:

$B_{100\%}$ = 333,237 t female spawning biomass

$B_{40\%}$ = 133,295 t female spawning biomass

$B_{35\%}$ = 116,633 t female spawning biomass

Specification of OFL and Maximum Permissible ABC

In the current assessment, Model 1 is configured with time-varying selectivity. The average selectivity of the most recent 5-year period (2010-2014) is used for projection purposes. The following rates are based on the average of the 2010-2014 selectivity estimates:

Full selection *F*s	2015
F_{2014}	0.116
$F_{40\%}$	0.403
$F_{35\%}$	0.489
$F_{2014}/F_{40\%}$	0.285

For specification purposes to project the 2015 ABC, we assumed a total 2014 year end catch of 31,670 t based on the assumption that an average of 25% of the catch has occurred after Oct. 1 in recent years. For projecting to 2016, an expected catch in 2015 is required. Typically this value is set to a recommended ABC, in this case the 2015 recommended ABC. However, recognizing that the modified Steller sea lion RPAs due to be implemented in 2015 require a TAC reduction in Area 543, we assume a stock-wide catch based on a reduced overall BSAI-wide Atka mackerel catch for 2015. Under the modified Steller sea lion RPAs, the Area 543 Atka mackerel TAC is set less than or equal to 65 percent of the Area 543 ABC. We estimated that about 80% of the BSAI-wide ABC is likely to be taken. This percentage was applied to the maximum permissible 2015 ABC and that amount was assumed to be caught in order to estimate the 2016 ABC and OFL values.

It is important to note that for BSAI Atka mackerel, projected female spawning biomass calculations depend on the harvest strategy because spawning biomass is estimated at peak spawning (August). Thus, projections incorporate 7 months of the specified fishing mortality rate. The projected 2015 female spawning biomass (SSB_{2015}) is estimated to be 167,136 t under an assumed 2014 catch of 31,670 t and reduced 2015 catch reflecting the RPA adjustment to the 2015 ABC.

The projected 2015 female spawning biomass estimate is above the $B_{40\%}$ value of 133,295 t, placing BSAI Atka mackerel in **Tier 3a**. The 2016 female spawning biomass estimate is also above $B_{40\%}$. The maximum permissible ABC and OFL values under **Tier 3a** are:

Year	Catch*	ABC	F_{ABC}	OFL	F_{OFL}	SSB	Tier
2015	84,800	106,000	0.403	125,297	0.489	167,136	3a
2016	98,137	98,137	0.403	115,908	0.489	146,682	3a

* Catches in 2015 and 2016 are less than the recommended ABCs to reflect expected catch reductions under Steller sea lion RPAs.

Standard Harvest Scenarios and Projection Methodology

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3, of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2014 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2027 using a fixed value of natural mortality of 0.3, the recent schedule of selectivity estimated in the assessment (in this case the average 2010-2014 selectivity), and the best available estimate of total (year-end) catch for 2014 (in this case assumed to be 31,670 t). In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates

determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning (August) and the maturity and population weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 500 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in a Supplemental Environmental Impact Statement prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2015 and 2016, are as follows ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.).

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2015 recommended in the assessment to the *max* F_{ABC} for 2015. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment).

Scenario 3: In all future years, F is set equal to the 2010-2014 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 4: In all future years, F is set equal to $F_{75\%}$. (Rationale: This scenario represents a very conservative harvest rate and was requested by the Alaska Regional Office based on public comment.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2014 or 2) above ½ of its MSY level in 2014 and above its MSY level in 2024 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2027 under this scenario, then the stock is not approaching an overfished condition.)

Status Determination

The projections of female spawning biomass, fishing mortality rate, and catch corresponding to the seven standard harvest scenarios are shown in Table 17.16. Harvest scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest scenarios #6 and #7 are used in these determinations as follows:

Is the stock overfished? This depends on the stock's estimated spawning biomass in 2014:

a) If spawning biomass for 2014 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b) If spawning biomass for 2014 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c) If spawning biomass for 2014 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest scenario #6 (Table 17.16). If the mean spawning biomass for 2024 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest scenario #7

a) If the mean spawning biomass for 2017 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2017 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2017 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2027. If the mean spawning biomass for 2027 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

Based on the above criteria and Table 17.16, the BSAI Atka mackerel stock is not overfished and is not approaching overfishing.

ABC Recommendation

Observations and characterizations of uncertainty in the Atka mackerel assessment are noted for ABC considerations.

1) Trawl survey estimates of Aleutian Islands biomass are highly variable. The 2006 survey estimate of Aleutian Islands biomass decreased 36% relative to the 2004 survey. The planned 2008 survey was not conducted. The 2010 survey increased 25% relative to the 2006 survey, the 2012 survey decreased 70% relative to the 2010 survey, and the most recent 2014 survey increased 161% relative to the 2012 survey. It is noted that all areas in the Aleutian Islands showed increases in the 2014 survey.
2) Under an $F_{40\%}$ harvest strategy and assuming SSL RPA catch reductions in 2015 and 2016, female spawning biomass is projected to be above $B_{40\%}$ in 2015 and 2016, but drop below $B_{40\%}$ in 2017-2018, thereafter, staying above $B_{40\%}$ after 2018 (Fig. 17.21 and Table 17.16 Scenarios 1 and 2). If SSL RPA catch reductions are in place beyond 2016, expected female spawning biomass levels would be higher than projected after 2016.
3) The model's predicted survey biomass trend is very conservative relative to the 2004, 2010, and 2014 observed bottom trawl survey biomass values.
4) The 2012 and 2013 fishery data are dominated by the 2006 and 2007 year classes and the 2013 fishery data show significant numbers of 4 year olds of the 2009 year class (Table 17.4).
5) The 2012 survey age composition is dominated by 3 and 5-year olds of the 2009 and 2007 year classes, respectively. The bottom trawl surveys have been a consistently good indicator of incoming year class strengths.
6) Currently we estimate the 1999 year class to be one of the largest in the time series (but with a moderate degree of uncertainty: CV=17%. Most recently the 2006 year class is estimated to be relatively strong, also with a moderate degree of uncertainty: CV=18%.

We believe the current accepted model configuration (Model 1) which was favorably reviewed by a CIE panel, provides an improved assessment of BSAI Atka mackerel relative to past model configurations. Given the current moderate stock size, an above average 2006 year class, and preliminary indications of good recruitment from the 2009 and 2010 year classes, the maximum permissible is acceptable for Atka mackerel. We note that the maximum permissible reference fishing mortality rate (F_{ABC}) is higher than the natural mortality rate. This is due to the fact that estimated fishery selectivity-at-age is significantly older than the maturity-at-age. That is, the fishery targets the older mature portion of the population that

had opportunities to spawn. Actual fishing mortality rates have been below F_{ABC} . For perspective, a plot of relative harvest rate ($F_t/F_{35\%}$) versus relative female spawning biomass ($B_t/B_{35\%}$) is shown in Figure 17.22. For all of the time series (including the 2014 data point), the current assessment estimates that relative harvest rates have been below 1, and the relative spawning biomass rates have been greater than 1.0.

The 2015 yield associated with the Tier 3a maximum permissible F_{ABC} fishing mortality rate of 0.403 is 106,000 t, which is our 2015 ABC recommendation for BSAI Atka mackerel.

The 2016 yield associated with the Tier 3a maximum permissible F_{ABC} fishing mortality rate and assuming 2015 catch reductions, is 98,137 t, which is our 2016 ABC recommendation for BSAI Atka mackerel.

The 2015 ABC recommendation is 65% higher relative to the Council's 2014 ABC, and is 64% higher relative to the projections from last year's assessment for 2015. These increases are consistent with improved stock abundance trend, the fishery and survey age composition data, and projected increases in female spawning stock biomass through 2016.

Area Allocation of Harvests

Amendment 28 of the BSAI Fishery Management Plan divided the Aleutian subarea into 3 districts at 177° E and 177° W longitude, providing the mechanism to apportion the Aleutian Atka mackerel TACs. The Council used a 4-survey (2004, 2006, 2010, and 2012) weighted average to apportion the 2014 ABC. The rationale for the weighting scheme was described in Lowe *et al.* (2001). The current apportionment drops the 2004 survey and includes the new 2014 survey apportionment. The Plan Teams convened a working group to evaluate methods for averaging surveys for apportionment and Tier 5 biomass. Evaluations are ongoing. This year we retain the status quo methodology until further guidance.

The data used to derive the percentages for the weighting scheme are given below:

	2006	2010	2012	2014	Recommended 2015 & 2016 Apportionment	2014 Apportionment
541[1]	48.90%	51.16%	12.34%	41.97%	**36.31%**	33.76%
542	37.52%	21.38%	39.41%	28.30%	**31.23%**	32.08%
543	13.58%	27.46%	48.25%	29.73%	**31.45%**	34.16%
Weights	8	12	18	27		

[1]Includes eastern Aleutian Islands and southern Bering Sea areas.

The apportionments of the 2015 and 2016 recommended ABCs based on the most recent 4-survey weighted average are:

	2015 (t)	2016 (t)
Eastern (541+S.BSea)	38,492	35,637
Central (542)	33,108	30,652
Western (543)	34,400	31,848
Total	106,000	98,127

Ecosystem Considerations

Steller sea lion food habits data (from analysis of scats) from the Aleutian Islands indicate that Atka mackerel is the most common prey item throughout the year (NMFS 1995, Sinclair and Zeppelin 2002). The prevalence of Atka mackerel and walleye pollock in sea lion scats reflected the distributions of each fish species in the Aleutian Islands region. The percentage occurrence of Atka mackerel was progressively greater in samples taken in the central and western Aleutian Islands, where most of the Atka mackerel biomass in the Aleutian Islands is located. Conversely, the percentage occurrence of pollock was greatest in the eastern Aleutian Islands.

Bottom contact fisheries could have direct negative impacts on Atka mackerel by destroying egg nests and/or removing the males that are guarding nests (Lauth *et al.* 2007b); however, this has not been examined quantitatively. Analyses of historic fishery CPUE revealed that the fishery may create temporary localized depletions of Atka mackerel, and historic fishery harvest rates in localized areas may have been high enough to affect prey availability of Steller sea lions (Section 12.2.2 of Lowe and Fritz 1997). The localized pattern of fishing for Atka mackerel could have created temporary reductions in the size and density of localized Atka mackerel populations which may have affected Steller sea lion foraging success during the time the fishery was operating and for a period of unknown duration after the fishery closed.

Ecosystem Effects on BSAI Atka Mackerel

Prey availability/abundance trends

Figure 17.23 shows the food web of the Aleutian Islands summer survey region, based on trawl survey and food habits data, with an emphasis on the predators and prey of Atka mackerel (see the current Ecosystem Assessment's ecosystem modeling results section for a description of the methodology for constructing the food web).

Adult Atka mackerel in the Aleutians consume a variety of prey, but are primarily zooplanktivors, consuming mainly euphausiids and calanoid copepods (Yang 1996, Yang 2003). Food habits data from 1990-1994 indicates that Atka mackerel feed on calanoid copepods (40%) and euphausiids (25%) followed by squids (10%), juvenile pollock (6%), and finally a range of zooplankton including fish larvae, benthic amphipods, and gelatinous filter feeders (Fig. 17.24a). While Figure 17.24a shows an aggregate diet for the Aleutians management regions, Atka mackerel diet data also show a longitudinal gradient, with euphausiids dominating diets in the east and copepods and other zooplankton dominating in the west. Greater piscivory, especially on myctophids, occurs in the island passes (Ortiz, 2007) Monitoring trends in Atka mackerel prey populations may, in the future, help elucidate Atka mackerel population trends. However, there is no long-term time series of zooplankton, squid, or small forage fish abundance information available.

Some preliminary results of sensitivity analysis suggest that Atka mackerel foraging in the Aleutian Islands may have a relatively strong competitive effect on walleye pollock distribution and abundance, as opposed to the Bering Sea where pollock may be more bottom-up (prey) controlled, or the GOA where pollock may be top-down (predator) controlled (Aydin *et al*. 2007). Since these sensitivity analyses treat the Aleutian Islands as a single "box model", it is possible that this is a mitigating or underlying factor for the geographical separation between Atka mackerel and pollock as a partitioning of foraging habitat.

Predator population trends

Atka mackerel are consumed by a variety of piscivores, including groundfish (e.g., Pacific cod, Pacific halibut, and arrowtooth flounder, Livingston *et al.* unpubl. manuscr.), marine mammals (e.g., northern fur seals and Steller sea lions, Kajimura 1984, NMFS 1995, Sinclair and Zeppelin 2002, Sinclair *et al*.

2013), skates, and seabirds (e.g., thick-billed murres, tufted puffins, and short-tailed shearwaters, Springer *et al.* 1999). Apportionment of Atka mackerel mortality between fishing, predation, and unexplained mortality, based on the consumption rates and food habits of predators averaged over 1990-1994 is shown in Figure 17.25. During these years, approximately 20% of the Atka mackerel exploitation rate (as calculated by stock assessment) was due to the fishery, 62% due to predation, and 18% "unexplained", where "unexplained" is the difference between the stock assessment total mortality and the sum of fisheries exploitation and quantified predation. This unexplained mortality may be due to data uncertainty, or Atka mackerel mortality due to disease, migration, senescence, etc.

Of the 62% of mortality due to predation, a little less than half (25% of total) is due to Pacific cod predation, and one quarter (15% of total) due to Steller sea lion predation, with the remainder spread across a range of predators (Fig. 17.24b), based on Steller sea lion diets published by Merrick *et al.* (1997) and summer fish food habits data from the REEM food habits database.

If converted to tonnages, this translates to 100,000-120,000 t/year of Atka mackerel consumed by predatory fish (of which approximately 60,000 t is consumed by Pacific cod), and 40,000-80,000 t/year consumed by Steller sea lions during the early 1990s. Estimating the consumption of Atka mackerel by birds is more difficult to quantify due to data limitations: based on colony counts and residency times, predation by birds, primarily kittiwakes, fulmars, and puffins, on all forage and rockfish combined in the Aleutian Islands is at most 70,000 t/year (Hunt *et al.* 2000). However, colony specific diet studies, for example for Buldir Island, indicate that the vast majority of prey found in these birds is sandlance, myctophids, and other smaller forage fish, with Atka mackerel never specifically identified as prey items, and "unidentified greenlings" occurring infrequently (Dragoo *et al.* 2001). The food web model's estimate, based on foraging overlap between species, estimates the total Atka mackerel consumption by birds to be less than 2,000 t/year. While this might be an underestimate, it should be noted that most predation would occur on juveniles (<1year old) which is not counted in the stock assessment's total exploitation rates.

The abundance trends of Aleutian Islands Pacific cod has been quite variable, alternating between increases and decreases in recent surveys, and Aleutian Islands arrowtooth flounder has been increasing. Northern fur seals are showing declines, and Steller sea lions have shown some slight increases. The population trends of seabirds are mixed, some increases, some decreases, and others stable. Seabird population trends could potentially affect juvenile Atka mackerel mortality. Declining trends in predator abundance could lead to possible decreases in Atka mackerel mortality, while increases in predator biomass could potentially increase the mortality.

Changes in habitat quality

Climate

Interestingly, strong year classes of AI Atka mackerel have occurred in years of hypothesized climate regime shifts 1977, 1988, and 1999, as indicated by indices such as the Pacific Decadal Oscillation (Francis and Hare 1994, Hare and Mantua 2000, Boldt 2005). Bailey *et al.* (1995) noted that some fish species show strong recruitment at the beginning of climate regime shifts and suggested that it was due to a disruption of the community structure providing a temporary release from predation and competition. It is unclear if this is the mechanism that influences Atka mackerel year class strength in the Aleutian Islands. El Niño Southern Oscillation (ENSO) events are another source of climate forcing that influences the North Pacific. Hollowed *et al.* (2001) found that gadids in the GOA have a higher proportion of strong year classes in ENSO years. There was, however, no relationship between strong year classes of AI Atka mackerel and ENSO events (Hollowed *et al.* 2001). Average eddy kinetic energy (EKE, $cm^2\ s^{-2}$) from south of Amutka Pass in the Aleutian Islands was examined and found to be potentially informative (S. Lowe unpubl. data). Particularly strong eddies were observed in the fall of 1997/1998, 1999, 2004, and 2006/2007 suggesting increased volume, heat, salt, and nutrient fluxes. The

1999-2001 and the 2006 year classes were strong. The role of eddies may be the transport of larva which hatch in the fall, and or the increase in nutrients and favorable environment conditions. Further research is needed to determine the effects of climate on growth and year class strength, and the temporal and spatial scales over which these effects occur.

Bottom temperature

Atka mackerel demonstrate schooling behavior and prefer hard, rough and rocky bottom substrate. Eggs are deposited in nests on rocky substrates between 15 and 144 m depth (Lauth *et al.* 2007b). The spawning period in Alaska occurs in late July to October (McDermott and Lowe 1997, Lauth *et al.* 2007b). During the incubation period egg nests are guarded by males, who will be on the nests until mid-January, given that females have been observed to spawn as late as October and given the length of the egg incubation period (McDermott and Lowe 1997, Lauth *et al.* 2007b, Lauth *et al.* 2007a). The distribution of Atka mackerel spawning and nesting sites are thought to be limited by water temperature (Gorbunova 1962). Temperatures below 3 °C and above 15 °C are lethal to eggs or unfavorable for embryonic development depending on the exposure time (Gorbunova 1962). Temperatures recorded at Alaskan nesting sites, 3.9 - 10.7 ºC, do not appear to be limiting, as they were within this range (Lauth *et al.* 2007b).

The 2000 and 2012 Aleutian Islands summer bottom temperatures indicated that 2000 and 2012 was the coldest years followed by summer bottom temperatures from the 2002 survey, which indicated the second coldest year (Fig. 17.5). The 2004 AI summer bottom temperatures indicated that 2004 was an average year, while the 2006 and 2010 bottom temperatures were slightly below average. The average bottom temperatures measured in the 2014 survey were the second highest of the Aleutian surveys, significantly higher than the 2000 and 2012 surveys and very similar to the 1991 and 1997 surveys. Bottom temperatures could possibly affect fish distribution, but there have been no directed studies, and there is no time series of data which demonstrates the effects on AI Atka mackerel.

Atka Mackerel Fishery Effects on the Ecosystem

Atka mackerel fishery contribution to bycatch

The levels of bycatch in the Atka mackerel fishery of prohibited species, forage fish, HAPC biota, marine mammals, birds, and other sensitive non-target species is relatively low except for the species which are noted in Table 17.17 and discussed below.

The Atka mackerel fishery has very low bycatch levels of some species of HAPC biota, e.g. seapens and whips. The bycatch of sponges and coral in the Atka mackerel fishery is highly variable. It is notable that in the last three years (2011-2013), the Atka mackerel fishery has taken on average about 39 and 22%, respectively of the total Aleutian Islands sponge and coral catches. It is unknown if the absolute levels of sponge and coral bycatch in the Atka mackerel fishery are of concern.

Fishing gear effects on spawning and nesting habitat

Bottom contact fisheries could have direct negative impacts on Atka mackerel by destroying egg nests and/or removing the males that are guarding nests (Lauth *et al.* 2007b); however, this has not been examined quantitatively. It was previously thought that all Atka mackerel migrated to shallow, nearshore areas for spawning and nesting sites. When nearshore bottom trawl exclusion zones near Steller sea lion rookeries were implemented this was hypothesized to eliminate much of the overlap between bottom trawl fisheries and Atka mackerel nesting areas (Fritz and Lowe 1998). Lauth *et al.* (2007b), however found that nesting sites in Alaska were "…widespread across the continental shelf and found over a much broader depth range…". The use of bottom contact fishing gear, such as bottom trawls, pot gear, and longline gear, utilized in July to January could, therefore, still potentially affect Atka mackerel nesting areas, despite trawl closures in nearshore areas around Steller sea lion rookeries.

Indirect effects of bottom contact fishing gear, such as effects on fish habitat, may also have implications for Atka mackerel. Living substrate that is susceptible to fishing gear includes sponges, seapens, sea anemones, ascidians, and bryozoans (Malecha *et al.* 2005). Of these, Atka mackerel sampled in the NMFS bottom trawl survey are primarily associated with emergent epifauna such as sponges and corals (Malecha *et al.* 2005, Stone 2006). Effects of fishing gear on these living substrates could, in turn, affect fish species that are associated with them.

Concentration of Atka mackerel catches in time and space

Steller sea lion protection measures have spread out Atka mackerel harvests in time and space through the implementation of seasonal and area-specific TACs and harvest limits within sea lion critical habitat. Most recently, RPAs from the 2010 BiOp closed the entire western Aleutians (Area 543) to directed fishing for Atka mackerel, and several closures were implemented in critical habitat in the central Aleutians (Area 542) and the TAC for Area 542 was reduced to no more than 47 percent of the Area 543 ABC. These measures were in place from 2011 to 2014. Revised RPAs are due to be implemented in 2015. For 2015, the Area 543 Atka mackerel TAC is set to less than or equal to 65 percent of the Area 543 ABC. In Area 542, there are expanded area closures and no requirement for a TAC reduction. Concentration of catches in time and space is still an issue of possible concern and research efforts continue to monitor and assess the availability of Atka mackerel biomass in areas of concern. Also, in some cases the sea lion protection measures have forced the fishery to concentrate in areas outside of critical habitat that had previously experienced lower levels of exploitation. The impact of the fishery in these areas outside of critical habitat is unknown.

Atka mackerel fishery effects on amount of large size Atka mackerel

The numbers of large size Atka mackerel are largely impacted by highly variable year class strength rather than by the directed fishery. Year to year differences are attributed to natural fluctuations.

Atka mackerel fishery contribution to discards and offal production

There is no time series of the offal production from the Atka mackerel fishery. The Atka mackerel fishery has contributed on average about 469 t of non-target discards in the Aleutian Islands from 2011 to 2013. Most of the Atka mackerel fishery discards of target species are comprised of small Atka mackerel. The average discards of Atka mackerel in the Atka mackerel fishery have been about 1,190 t over 2011-2013.

Atka mackerel fishery effects on Atka mackerel age-at-maturity and fecundity

The effects of the fishery on the age-at-maturity and fecundity of Atka mackerel are unknown. Studies were conducted to determine age-at-maturity (McDermott and Lowe 1997, Cooper *et al*. 2010) and fecundity (McDermott 2003, McDermott *et al*. 2007) of Atka mackerel. These are recent studies and there are no earlier studies for comparison on fish from an unexploited population. Further studies would be needed to determine if there have been changes over time and whether changes could be attributed to the fishery.

Data Gaps and Research Priorities

Regional and seasonal food habits data for Aleutian Islands is very limited. No time series of information is available on copepod and euphausiid abundance in the Aleutian Islands which would provide information on prey availability and abundance trends. Studies to determine the impacts of environmental indicators such as temperature regime on Atka mackerel are needed. Further studies to determine whether there have been any changes in life history parameters over time (e.g. fecundity, and weight- and length-at-age) would be informative. More information on Atka mackerel habitat preferences would be useful to improve our understanding of Essential Fish Habitat (EFH), and improve our

assessment of the impacts to habitat due to fishing. Better habitat mapping of the Aleutian Islands would provide information for survey stratification and the extent of trawlable and untrawlable habitat.

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Tables

Table 17.1. Time series of Bering Sea/Aleutian Islands Atka mackerel catches (including discards and CDQ catches), corresponding Acceptable Biological Catches (ABC), Total Allowable Catches (TAC), and Overfishing Levels (OFL) set by the North Pacific Fishery Management Council from 1978 to the present. Catches, ABCs, TACs, and OFLs are in metric tons.

Year	Catch	ABC	TAC	OFL
1977	21,763	a	a	
1978	24,249	24,800	24,800	
1979	23,264	24,800	24,800	
1980	20,488	24,800	24,800	
1981	19,688	24,800	24,800	
1982	19,874	24,800	24,800	
1983	11,726	25,500	24,800	
1984	36,055	25,500	35,000	
1985	37,860	37,700	37,700	
1986	31,990	30,800	30,800	
1987	30,061	30,800	30,800	
1988	22,084	21,000	21,000	
1989	17,994	24,000	20,285	
1990	22,206	24,000	21,000	
1991	26,626	24,000	24,000	
1992	48,532	43,000	43,000	435,000
1993	66,006	117,100	32,000	771,100
1994	65,360	122,500	68,000	484,000
1995	81,554	125,000	80,000	335,000
1996	103,942	116,000	106,157	164,000
1997	65,842	66,700	66,700	81,600
1998	57,097	64,300	64,300	134,000
1999	56,237	73,300	66,400	148,000
2000	47,230	70,800	70,800	119,000
2001	61,563	69,300	69,300	138,000
2002	45,288	49,000	49,000	82,300
2003	54,045	63,000	60,000	99,700
2004	60,562	66,700	63,000	78,500
2005	62,012	124,000	63,000	147,000
2006	61,894	110,000	63,000	130,000
2007	58,763	74,000	63,000	86,900
2008	58,090	60,700	60,700	71,400
2009	72,806	83,800	76,400	99,400
2010	68,619	74,000	74,000	88,200
2011	51,818	85,300	53,080	101,000
2012	47,826	81,400	50,763	96,500
2013	23,181	50,000	25,920	57,700
2014	31,670[b]	64,131	32,322	74,492

a) Atka mackerel was not a reported species group until 1978.
b) 2014 catch as projected (the projected 2014 value is based on the recent 5 year average of post Oct. 1 catches)

Sources: compiled from NMFS Regional Office web site and various NPFMC reports.

Table 17.2. Time series of Bering Sea/Aleutian Islands Atka mackerel catches (including discards and CDQ catches) by region, corresponding Acceptable Biological Catches (ABC), and Total Allowable Catches (TAC) set by the North Pacific Fishery Management Council from 1995 to the present. Apportioned catches prior to 1995 are available in Lowe *et al*. (2013). Catches, ABCs, and TACs are in metric tons.

Year		Eastern (541)	Central (542)	Western (543)	Total	Year		Eastern (541)	Central (542)	Western (543)	Total
1995	Catch	14,199	50,387	16,966	81,552	2005	Catch	7,201	35,069	19,744	62,014
	ABC	13,500	55,900	55,600	125,000		ABC	24,550	52,830	46,620	124,000
	TAC	13,500	50,000	16,500	80,000		TAC	7,500	35,500	20,000	63,000
1996	Catch	28,173	33,524	42,246	103,943	2006	Catch	7,422	39,836	14,638	61,896
	ABC	26,700	33,600	55,700	116,000		ABC	21,780	46,860	41,360	110,200
	TAC	26,700	33,600	45,857	10,657		TAC	7,500	40,000	15,500	63,000
1997	Catch	16,318	19,990	29,537	65,845	2007	Catch	22,943	26,723	9,097	58,763
	ABC	15,000	19,500	32,200	66,700		ABC	23,800	29,600	20,600	74,000
	TAC	15,000	19,500	32,200	66,700		TAC	23,800	29,600	9,600	63,000
1998	Catch	11,597	20,029	24,248	55,874	2008	Catch	19,112	22,926	16,045	58,083
	ABC	14,900	22,400	27,000	64,300		ABC	19,500	24,300	16,900	60,700
	TAC	14,900	22,400	27,000	64,300		TAC	19,500	24,300	16,900	60,700
1999	Catch	16,245	21,596	15,082	52,923	2009	Catch	26,417	30,137	16,253	72,807
	ABC	17,000	25,600	30,700	73,300		ABC	27,000	33,500	23,300	83,800
	TAC	17,000	22,400	27,000	66,400		TAC	27,000	32,500	16,900	76,400
2000	Catch	13,152	20,575	8,713	42,440	2010	Catch	23,608	26,388	18,650	68,646
	ABC	16,400	24,700	29,700	70,800		ABC	23,800	29,600	20,600	74,000
	TAC	16,400	24,700	29,700	70,800		TAC	23,800	29,600	20,600	74,000
2001	Catch	7,905	30,365	18,264	56,534	2011	Catch	40,891	10,713	205	51,809
	ABC	7,800	33,600	27,900	69,300		ABC	40,300	24,000	21,000	85,300
	TAC	7,800	33,600	27,900	69,300		TAC	40,300	11,280	1,500	53,080
2002	Catch	4,606	20,699	16,737	42,042	2012	Catch	37,308	10,323	195	47,826
	ABC	5,500	23,800	19,700	49,000		ABC	38,500	22,900	20,000	81,400
	TAC	5,500	23,800	19,700	49,000		TAC	38,500	10,763	1,500	50,763
2003	Catch	10,725	25,435	17,885	54,045	2013	Catch	15,777	7,284	120	23,181
	ABC	10,650	29,360	22,990	63,000		ABC	16,900	16,000	17,100	50,000
	TAC	10,650	29,360	19,990	60,000		TAC	16,900	7,520	1,500	25,920
2004	Catch	10,840	30,169	19,555	60,564	2014*	Catch	19,475	11,893	302	31,670
	ABC	11,240	31,100	24,360	66,700		ABC	21,652	20,574	21,905	64,131
	TAC	11,240	31,100	20,660	63,000		TAC	21,652	9,670	1,000	32,322

*2014 catch based on NMFS Regional Office Catch Accounting System apportionments (as of Oct 1, 2014) and projected to total.

Table 17.3. Numbers of Atka mackerel length-weight data, length frequency, and aged samples based on NMFS observer data 1990-2013.

Year	Number of length-weight samples	Length frequency records	Number of aged samples
1990	731	8,618	718
1991	356	7,423	349
1992	90	13,532	86
1993	58	12,476	58
1994	913	13,384	837
1995	1,054	19,653	972
1996	1,039	24,758	680
1997	126	13,412	123
1998	733	15,060	705
1999	1,633	12,349	1,444
2000	2,697	9,207	1,659
2001	3,332	11,600	935
2002	3,135	12,418	820
2003	4,083	13,740	1,008
2004	4,205	14,239	870
2005	4,494	13,142	1,024
2006	4,194	13,598	980
2007	2,100	11,841	884
2008	1,882	19,831	922
2009	2,374	15,207	971
2010	2,462	16,347	879
2011	1,976	11,814	720
2012	1,495	13,794	1,012
2013	1,178	13,327	642

Table 17.4. Estimated catch-in-numbers at age (in millions) of Atka mackerel from the BSAI region, 1977-2013. These data were used in fitting the age-structured model.

Age	2	3	4	5	6	7	8	9	10	11+
1977	6.83	31.52	20.06	15.11	1.22	0.39	0.20	---	---	---
1978	2.70	60.16	15.57	9.22	3.75	0.59	0.34	0.11	---	---
1979	0.01	4.48	26.78	13.00	2.20	1.11	---	---	---	---
1980	---	12.68	5.92	7.22	1.67	0.59	0.24	0.13	---	---
1981	---	5.39	17.11	0.00	1.61	8.10	---	---	---	---
1982	---	0.19	2.63	25.83	3.86	0.68	---	---	---	---
1983	---	1.90	1.43	2.54	10.60	1.59	---	---	---	---
1984	0.09	0.98	7.30	7.07	10.79	21.78	2.21	0.96	---	---
1985	0.63	15.97	8.79	9.43	6.01	5.45	11.69	1.26	0.27	---
1986	0.37	11.45	6.46	4.42	5.34	4.53	5.84	9.91	1.04	0.85
1987	0.56	10.44	7.60	4.58	1.89	2.37	2.19	1.71	6.78	0.75
1988	0.40	9.97	22.49	6.15	1.80	1.54	0.63	0.96	0.20	0.48
1989[a]										
1990	1.74	7.62	13.15	4.78	1.77	0.81	0.11	0.09	0.03	0.17
1991	0.00	4.15	6.49	7.78	5.71	3.94	1.04	0.18	0.35	0.22
1992	0.00	0.93	20.82	2.97	1.40	0.62	0.00	0.00	0.00	0.00
1993	0.00	13.55	18.33	38.88	12.16	6.76	4.17	0.61	0.59	0.00
1994	0.05	9.16	6.83	23.13	36.00	4.64	8.21	5.27	3.04	0.61
1995	0.13	20.65	33.67	9.81	18.78	33.09	4.01	5.84	7.90	2.98
1996	0.02	3.65	63.55	21.94	14.14	19.44	31.59	2.85	3.37	2.53
1997	0.00	17.11	4.66	66.28	3.72	1.56	0.67	3.56	0.36	0.00
1998	0.00	11.15	15.73	15.24	25.07	11.21	4.02	3.55	5.28	1.85
1999	1.17	1.08	38.31	8.85	7.09	9.93	5.24	1.80	1.49	1.79
2000	0.54	8.91	6.40	26.59	7.53	4.33	8.33	1.93	0.78	1.01
2001	1.87	20.59	13.57	8.68	27.20	8.16	4.60	3.86	0.78	0.50
2002	1.94	22.68	25.37	7.88	3.89	16.20	3.23	1.56	1.67	0.53
2003	0.78	19.96	49.54	20.63	5.95	3.27	7.02	0.78	0.49	0.85
2004	0.09	20.44	31.49	44.20	12.32	2.40	1.56	2.21	0.00	0.39
2005	1.43	3.96	35.31	27.23	28.97	9.68	1.54	0.25	0.85	0.00
2006	3.56	16.74	5.66	33.56	20.27	22.62	4.12	0.56	0.36	0.26
2007	2.25	19.63	11.63	5.39	19.94	15.90	12.46	2.69	0.77	0.08
2008	5.49	13.29	16.90	7.61	6.29	20.04	10.53	11.63	1.64	0.54
2009	4.69	31.92	15.73	20.00	8.81	8.56	16.59	8.24	8.71	1.79
2010	1.67	19.00	47.22	13.06	13.59	6.46	3.82	7.90	4.66	1.75
2011	1.05	3.02	17.61	22.41	6.68	4.89	1.16	2.73	4.44	4.82
2012	0.18	7.41	3.54	21.16	20.78	5.69	3.21	2.69	2.36	9.96
2013	1.56	7.42	19.99	4.59	14.75	11.71	2.52	1.32	0.85	3.44

[a] Too few fish were sampled for age structures in 1989 to construct an age-length key.

Table 17.5. Atka mackerel estimated biomass in metric tons from the U.S.-Japan cooperative bottom trawl surveys, by subregion, depth interval, and survey year, with the corresponding Aleutian-wide coefficients of variation (*CV*).

		Biomass		
Area	Depth (m)	1980	1983	1986
Aleutian	1-100	193	239,502	1,013,678
	101-200	62,376	247,256	107,092
	201-300	646	2,565	368
	301-500	0	164	10
	Total	63,215	489,487	1,121,148
	CV	0.80	0.24	0.80
Western	1-100	193	49,115	1,675
543	101-200	692	124,806	40,675
	201-300		1,559	111
	301-500	0	164	0
	Total	885	175,644	42,461
Central	1-100	0	103,588	1,011,991
542	101-200	58,666	1,488	20,582
	201-300	504	303	36
	301-500	0	0	10
	Total	59,170	105,379	1,032,619
Eastern	1-100		86,800	11
541	101-200	3,018	120,962	45,835
	201-300	143	703	222
	301-500	0	0	0
	Total	3,161	208,465	46,068
Southern	1-100	6	0	429
Bering Sea	101-200	20,239	9	5
	201-300	2	0	1
	301-500		0	0
	Total	20,247	9	435

Table 17.6. Aleutian Islands Atka mackerel survey biomass by bottom-depth category by region and subareas including area percentages of total (for each year) and coefficients of variation (*CV*) for 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012 and 2014.

	Depth	Biomass (t)									
Area	**(m)**	**1991**	**1994**	**1997**	**2000**	**2002**	**2004**	**2006**	**2010**	**2012**	**2014**
Aleutian	1-100	429,873	211,562	284,176	160,940	394,092	518,232	374,774	304,909	130,616	286,064
Islands	101-200	277,907	472,725	177,672	344,674	393,159	631,150	326,426	624,294	145,351	436,506
+ S. BS	201-300	520	1,691	130	8,636	48,723	7,410	40,091	1,008	886	716
	301-500	0	30	20	82	221	292	67	41	23	642
	Total	708,299	686,007	461,997	514,332	836,195	1,157,084	741,358	930,252	276,877	723,928
Regional area % of Total		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	CV	*14%*	*32%*	*31%*	*29%*	*20%*	*17%*	*28%*	*35%*	*18%*	*24%*
Western	1-100	168,968	93,847	90,824	120,257	50,481	140,669	64,429	59,449	62,247	115,359
543	101-200	174,182	231,733	43,478	52,948	154,820	229,675	35,926	195,819	70,983	99,102
	201-300	276	1,656	66	7,910	48,362	6,033	318	134	350	172
	301-500	-	6	-	-	8	36	21	17	8	602
	Total	343,426	327,242	134,367	181,115	253,671	376,414	100,693	255,419	133,588	215,235
Regional area % of Total		48%	48%	29%	35%	30%	33%	14%	27%	48%	30%
	CV	*18%*	*57%*	*56%*	*56%*	*32%*	*24%*	*35%*	*58%*	*28%*	*29%*
Central	1-100	187,194	50,513	70,458	38,805	131,770	198,243	192,832	102,211	62,238	86,097
542	101-200	100,329	33,255	116,295	290,766	199,743	70,267	85,215	96,457	46,861	118,612
	201-300	70.4	13	53.4	674.2	168.9	367.1	102.6	207	16.2	119.7
	301-500	0	2.9	5.7	9.3	142.5	194.1	0	0	15.1	39.8
	Total	287,594	83,784	186,813	330,255	331,824	269,071	278,150	198,874	109,130	204,868
Regional area % of Total		41%	12%	40%	64%	40%	23%	38%	21%	39%	28%
	CV	*17%*	*48%*	*36%*	*34%*	*24%*	*35%*	*24%*	*28%*	*27%*	*50%*
Eastern	1-100	73,663	641	27,222	25	152,159	54,424	107,230	44,981	6,029	84,252
541	101-200	3,392	207,707	17,890	772	38,492	188,592	205,108	327,105	26,685	217,748
	201-300	162.8	18.6	10.6	48.4	94.2	970.5	37828.9	338.7	435.2	381.8
	301-500	0	12.3	14	73.1	71.3	57.2	40.1	4.9	0	0
	Total	77,218	208,379	45,137	919	190,817	244,043	350,206	372,429	33,149	302,383
Regional area % of Total		11%	30%	10%	0%	23%	21%	47%	40%	12%	42%
	CV	*83%*	*44%*	*68%*	*74%*	*58%*	*33%*	*55%*	*74%*	*46%*	*43%*
Bering Sea	1-100	47	66,562	95,672	1,853	59,682	124,896	10,284	98,268	103	356
	101-200	3	30	9	187	103	142,616	176	4,914	822	1,044
	201-300	11.4	3.1	0	3.5	97.7	39.3	1841.8	327.4	84.7	42.2
	301-500	0	8	0	0	0	3.8	6	18.7	0	0
	Total	61	66,603	95,680	2,044	59,883	267,556	12,308	103,529	1,010	1,443
Regional area % of Total		0%	10%	21%	0%	7%	23%	2%	11%	0%	0%
	CV	*37%*	*99%*	*99%*	*88%*	*99%*	*43%*	*44%*	*86%*	*77%*	*73%*

Table 17.7. Estimated survey numbers at age (in millions) of Atka mackerel from the Aleutian Islands trawl surveys and numbers of Atka mackerel otoliths aged (*n*).

Age	*n*	2	3	4	5	6	7	8	9	10	11+
1991	478	72.44	846.64	137.33	261.09	81.49	87.53	15.09	6.04	0.00	0.00
1994	745	12.37	166.06	114.83	185.49	217.29	51.23	68.01	22.08	37.98	6.18
1997	433	65.67	142.93	115.25	148.73	45.71	23.18	31.55	43.14	6.44	13.52
2000	831	269.32	76.68	25.25	226.30	68.26	71.07	118.76	37.41	18.70	23.38
2002	789	77.33	933.52	531.22	95.13	32.08	78.05	35.78	14.47	12.71	1.53
2004	598	66.94	726.25	584.22	560.93	120.42	29.00	16.47	19.23	10.67	15.32
2006	525	166.24	159.26	63.30	192.03	200.48	290.68	93.74	11.92	0.27	19.16
2010	560	45.18	386.11	400.88	82.19	86.99	39.26	50.56	98.85	67.84	112.04
2012	417	63.17	100.11	40.52	97.73	66.74	20.26	20.26	17.88	8.34	61.98

Table 17.8. Year-specific fishery and survey and the population weight-at-age (kg) values used to obtain expected survey and fishery catch biomass and population biomass. The population weight-at-age values are derived from the Aleutian trawl survey from the average of years 2006, 2010, and 2012. The 2014 fishery weight-at-age values are the average of the last three years (2011-2013).

		Age										
	Year	1	2	3	4	5	6	7	8	9	10	11+
Survey	1991	0.045	0.185	0.449	0.637	0.652	0.751	0.811	0.693	1.053	1.764	0.878
	1994	0.045	0.177	0.450	0.653	0.738	0.846	0.941	0.988	0.906	0.907	0.516
	1997	0.045	0.191	0.486	0.686	0.753	0.805	0.887	0.970	0.919	1.375	0.935
	2000	0.045	0.130	0.387	0.623	0.699	0.730	0.789	0.810	0.792	0.864	0.871
	2002	0.045	0.139	0.342	0.615	0.720	0.837	0.877	0.773	0.897	0.955	1.084
	2004	0.045	0.138	0.333	0.497	0.609	0.739	0.816	0.956	0.928	0.745	0.824
	2006	0.045	0.158	0.332	0.523	0.516	0.675	0.764	0.719	0.855	1.653	0.991
	2010	0.045	0.161	0.369	0.633	0.667	0.744	0.974	1.075	0.981	1.041	1.244
	2012	0.045	0.161	0.360	0.517	0.627	0.705	0.762	0.820	0.863	0.809	0.949
Avg 2006, 2010, 2012		0.045	0.160	0.354	0.557	0.603	0.708	0.833	0.871	0.900	1.168	1.061
Fishery	1977	0.069	0.132	0.225	0.306	0.400	0.470	0.507	0.379	0.780	0.976	1.072
Foreign	1978	0.069	0.072	0.225	0.300	0.348	0.388	0.397	0.371	0.423	0.976	1.072
	1979	0.069	0.496	0.319	0.457	0.476	0.475	0.468	0.546	0.780	0.976	1.072
	1980	0.069	0.365	0.317	0.450	0.520	0.585	0.630	0.546	0.780	0.976	1.072
	1981	0.069	0.365	0.317	0.450	0.520	0.585	0.630	0.546	0.780	0.976	1.072
	1982	0.069	0.365	0.273	0.443	0.564	0.695	0.795	0.546	0.780	0.976	1.072
	1983	0.069	0.365	0.359	0.499	0.601	0.686	0.810	0.546	0.780	0.976	1.072
	1984	0.069	0.297	0.410	0.617	0.707	0.777	0.802	0.890	0.910	0.976	1.072
	1985	0.069	0.302	0.452	0.552	0.682	0.737	0.775	0.807	1.007	1.011	1.072
	1986	0.069	0.146	0.334	0.528	0.546	0.786	0.753	0.829	0.858	0.954	1.052
	1987	0.069	0.265	0.435	0.729	0.908	0.859	0.964	1.023	1.054	1.088	1.098
	1988	0.069	0.196	0.351	0.470	0.564	0.624	0.694	0.783	0.818	0.850	1.064
Domestic	1989	0.069	0.295	0.440	0.577	0.739	0.838	0.664	0.817	0.906	1.010	1.065
	1990	0.069	0.362	0.511	0.728	0.877	0.885	0.985	1.386	1.039	1.445	1.442
	1991	0.069	0.230	0.207	0.540	0.729	0.685	0.655	0.755	1.014	0.743	1.021
	1992	0.069	0.230	0.390	0.607	0.715	0.895	0.973	0.839	0.865	0.916	1.010
	1993	0.069	0.230	0.572	0.626	0.682	0.773	0.826	0.782	1.041	0.812	1.010
	1994	0.069	0.150	0.363	0.568	0.649	0.697	0.777	0.749	0.744	0.736	0.922
	1995	0.069	0.092	0.228	0.520	0.667	0.687	0.691	0.707	0.721	0.641	0.909
	1996	0.069	0.188	0.294	0.474	0.633	0.728	0.743	0.770	0.799	0.846	0.973
	1997	0.069	0.230	0.397	0.664	0.686	0.862	0.904	0.971	0.884	0.951	1.108
	1998	0.069	0.230	0.296	0.494	0.580	0.644	0.682	0.775	0.707	0.798	0.858
	1999	0.069	0.240	0.406	0.568	0.707	0.755	0.839	0.979	1.170	1.141	0.961
	2000	0.069	0.215	0.497	0.594	0.689	0.734	0.778	0.854	0.813	0.904	0.988
	2001	0.069	0.224	0.418	0.563	0.719	0.765	0.841	0.826	0.946	0.912	1.109
	2002	0.069	0.253	0.293	0.459	0.600	0.601	0.723	0.722	0.791	0.851	0.940
	2003	0.069	0.208	0.304	0.420	0.539	0.667	0.747	0.731	0.669	0.824	0.996
	2004	0.069	0.176	0.316	0.444	0.567	0.624	0.679	0.810	0.728	0.916	1.015
	2005	0.069	0.247	0.406	0.480	0.536	0.558	0.657	0.966	1.184	0.942	1.010
	2006	0.069	0.265	0.393	0.503	0.551	0.613	0.647	0.714	0.848	0.856	0.984
	2007	0.069	0.247	0.437	0.547	0.715	0.697	0.768	0.778	0.776	1.272	1.033
	2008	0.069	0.265	0.388	0.540	0.615	0.727	0.719	0.700	0.798	0.786	0.998
	2009	0.069	0.215	0.395	0.494	0.605	0.667	0.734	0.745	0.770	0.816	0.813
	2010	0.069	0.204	0.362	0.565	0.583	0.673	0.684	0.758	0.723	0.762	0.803
	2011	0.069	0.220	0.445	0.640	0.807	0.753	0.770	0.798	0.931	0.913	0.899
	2012	0.069	0.230	0.374	0.509	0.612	0.658	0.713	0.772	0.822	0.894	0.949
	2013	0.069	0.266	0.280	0.606	0.677	0.740	0.867	0.822	0.803	0.822	1.093
	2014	0.069	0.239	0.366	0.585	0.698	0.717	0.783	0.797	0.852	0.876	0.980

Table 17.9. Schedules of age and length specific maturity of Atka mackerel from McDermott and Lowe (1997) by Aleutian Islands subareas. Eastern - 541, Central - 542, and Western - 543.

	INPFC Area				
Length (cm)	541	542	543	Age	Proportion mature
25	0	0	0	1	0
26	0	0	0	2	0.04
27	0	0.01	0.01	3	0.22
28	0	0.02	0.02	4	0.69
29	0.01	0.04	0.04	5	0.94
30	0.01	0.07	0.07	6	0.99
31	0.03	0.14	0.13	7	1
32	0.06	0.25	0.24	8	1
33	0.11	0.4	0.39	9	1
34	0.2	0.58	0.56	10	1
35	0.34	0.73	0.72		
36	0.51	0.85	0.84		
37	0.68	0.92	0.92		
38	0.81	0.96	0.96		
39	0.9	0.98	0.98		
40	0.95	0.99	0.99		
41	0.97	0.99	0.99		
42	0.99	1	1		
43	0.99	1	1		
44	1	1	1		
45	1	1	1		
46	1	1	1		
47	1	1	1		
48	1	1	1		
49	1	1	1		
50	1	1	1		

Table 17.10. Estimates of key results from AMAK for Bering Sea/Aleutian Islands Atka mackerel from last year's assessment model with updated data (Model 1) and the selected sensitivity runs. Coefficients of variation (*CV*) for some key reference values appearing directly below, are given in parentheses. Note that likelihoods may not be strictly comparable between models due to different variance/weighting assumptions.

Assessment Model	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Model setup				
Survey catchability	1.04	1.06	1.07	0.90
Steepness	0.8	0.8	0.8	0.8
SigmaR	0.47	0.49	0.46	0.45
Natural mortality	0.3	0.3	0.3	0.45
Fishery Average Effective *N*	231	252	270	271
Survey Average Effective *N*	117	136	63	124
RMSE Survey	0.247	0.661	0.852	0.240
-log Likelihoods				
Number of Parameters	471	471	471	472
Survey index	5.75	0.8	0.94	5.8
Catch biomass	0.0	0.1	0.1	0.0
Fishery age comp	92.0	90.0	86.7	84.7
Survey age comp	36.8	38.1	7.7	36.2
Sub total	128.8	128.1	94.5	120.9
-log Penalties				
Recruitment	-3.4	0.2	-5.0	-5.9
Selectivity constraint	74.7	70.8	68.3	72.1
Prior	0.0	0.1	0.1	2.9
Sub total	71.3	71.0	63.3	69.1
Total	205.8	199.9	158.7	195.8
Fishing mortalities (full selection)				
F_{2014}	0.060	0.110	0.150	0.060
$F_{2014}/F_{40\%}$	0.290	0.460	0.440	0.090
$F_{40\%}$	0.207	0.239	0.341	0.667
$F_{35\%}$	0.236	0.273	0.390	0.762
Stock abundance and recruitment				
Initial Biomass (t, 1977)	681,986	453,410	533,202	1,266,710
CV	23%	24%	16%	32%
Assessment year total biomass (t)	657,228	399,347	403,355	1,306,880
CV	22%	30%	21%	30%
2001 year class (millions at age 1)	1,489	1,141	1,087	5,442
CV	17%	14%	11%	41%
2006 year class (millions at age 1)	863	676	685	3,024
CV	18%	19%	18%	41%
Recruitment Variability	0.554	0.571	0.543	0.544

Table 17.11. Estimates of Atka mackerel fishery (over time, 1977-2014) and survey selectivity at age (normalized to have a maximum of 1.0) from Model 1.

	Age										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**
1977	0.010	0.097	0.570	1.000	0.748	0.313	0.139	0.072	0.043	0.032	0.032
1978	0.009	0.119	0.974	1.000	0.899	0.489	0.225	0.110	0.062	0.045	0.045
1979	0.005	0.034	0.275	1.000	0.845	0.439	0.212	0.102	0.054	0.037	0.037
1980	0.005	0.039	0.268	0.846	1.000	0.621	0.394	0.185	0.082	0.048	0.048
1981	0.004	0.031	0.207	0.402	0.405	0.604	1.000	0.283	0.086	0.044	0.044
1982	0.004	0.021	0.093	0.335	1.000	0.894	0.446	0.190	0.086	0.052	0.052
1983	0.004	0.023	0.134	0.332	0.638	1.000	0.615	0.230	0.102	0.063	0.063
1984	0.004	0.025	0.125	0.390	0.689	1.000	0.929	0.425	0.186	0.101	0.101
1985	0.006	0.055	0.499	0.804	0.873	0.960	1.000	0.829	0.432	0.229	0.229
1986	0.005	0.043	0.315	0.505	0.577	0.665	0.850	1.000	0.768	0.363	0.363
1987	0.007	0.065	0.476	0.823	0.850	0.783	0.869	1.000	0.963	0.860	0.860
1988	0.004	0.038	0.350	1.000	0.641	0.423	0.380	0.344	0.305	0.243	0.243
1989	0.006	0.054	0.359	0.951	1.000	0.713	0.503	0.381	0.306	0.263	0.263
1990	0.004	0.044	0.452	1.000	0.781	0.505	0.370	0.274	0.214	0.178	0.178
1991	0.004	0.027	0.154	0.686	0.972	1.000	0.737	0.420	0.272	0.218	0.218
1992	0.004	0.027	0.166	0.722	1.000	0.826	0.620	0.439	0.323	0.265	0.265
1993	0.003	0.027	0.171	0.507	0.821	1.000	0.797	0.604	0.448	0.357	0.357
1994	0.003	0.022	0.163	0.479	0.910	1.000	0.917	0.962	0.745	0.476	0.476
1995	0.003	0.021	0.161	0.659	0.774	0.897	1.000	0.977	0.847	0.638	0.638
1996	0.002	0.013	0.089	0.454	0.597	0.783	0.962	1.000	0.554	0.363	0.363
1997	0.002	0.016	0.132	0.454	1.000	0.827	0.776	0.697	0.550	0.432	0.432
1998	0.002	0.016	0.116	0.525	0.845	0.888	1.000	0.921	0.723	0.527	0.527
1999	0.001	0.017	0.126	0.678	0.676	0.773	0.792	1.000	0.678	0.383	0.383
2000	0.001	0.013	0.271	0.644	0.793	0.808	0.839	1.000	0.541	0.278	0.278
2001	0.001	0.013	0.179	0.566	0.887	0.960	1.000	0.840	0.479	0.248	0.248
2002	0.001	0.013	0.113	0.383	0.568	0.771	1.000	0.677	0.382	0.221	0.221
2003	0.002	0.019	0.188	0.464	0.639	0.826	1.000	0.840	0.421	0.246	0.246
2004	0.004	0.040	0.306	0.790	1.000	0.948	0.953	0.847	0.536	0.307	0.307
2005	0.007	0.057	0.310	0.783	1.000	0.977	0.912	0.632	0.395	0.271	0.271
2006	0.009	0.099	0.649	0.749	0.970	1.000	0.961	0.591	0.376	0.268	0.268
2007	0.008	0.095	0.605	0.840	0.762	0.841	1.000	0.748	0.441	0.279	0.279
2008	0.007	0.078	0.510	0.719	0.698	0.845	1.000	0.882	0.685	0.312	0.312
2009	0.007	0.060	0.370	0.708	0.828	0.819	1.000	0.879	0.615	0.384	0.384
2010	0.005	0.051	0.320	0.893	1.000	0.982	0.908	0.808	0.624	0.334	0.334
2011	0.003	0.029	0.198	0.607	0.945	1.000	0.798	0.634	0.609	0.509	0.509
2012	0.002	0.018	0.141	0.531	0.777	1.000	0.948	0.637	0.531	0.515	0.515
2013	0.002	0.018	0.141	0.531	0.777	1.000	0.948	0.637	0.531	0.515	0.515
2014	0.002	0.018	0.141	0.531	0.777	1.000	0.948	0.637	0.531	0.515	0.515
Ave 2010-2014	0.003	0.027	0.188	0.618	0.855	0.996	0.910	0.670	0.565	0.477	0.477
Survey	0.011	0.143	0.683	0.925	0.860	0.840	1.000	0.953	0.704	0.554	0.554

Table 17.12. Estimated Atka mackerel begin-year numbers at age in millions, 1977-2014 from Model 1.

	Age										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**
1977	340	456	317	132	117	73	64	52	41	31	107
1978	1,620	251	332	212	81	75	51	47	38	30	102
1979	495	1,198	183	211	134	52	52	37	34	28	97
1980	369	366	884	131	137	89	37	37	27	25	92
1981	451	273	270	638	89	92	62	26	27	20	86
1982	321	334	202	196	454	63	64	42	19	20	78
1983	414	238	247	149	142	316	44	46	30	14	72
1984	513	306	176	182	109	103	225	32	34	22	64
1985	614	380	226	129	129	74	68	150	23	25	63
1986	540	454	280	159	88	87	50	45	102	16	63
1987	693	400	335	199	111	60	59	33	30	68	56
1988	452	513	295	240	140	78	43	42	23	21	87
1989	1,596	334	379	211	162	98	55	30	30	17	78
1990	708	1,182	247	275	149	114	70	40	22	22	69
1991	374	524	873	179	194	106	82	51	29	16	67
1992	593	277	387	639	125	132	72	57	36	21	60
1993	1,138	439	205	282	441	84	90	51	41	26	59
1994	402	842	324	148	194	290	54	60	34	28	60
1995	420	298	622	234	102	125	184	35	38	23	61
1996	1,020	311	219	444	149	63	75	108	21	23	53
1997	206	755	229	157	278	89	35	39	56	12	50
1998	377	152	558	166	107	170	56	22	25	37	42
1999	1,043	279	113	403	109	65	103	33	13	16	52
2000	2,174	773	206	82	265	72	42	66	21	9	47
2001	1,347	1,610	571	146	54	172	47	27	42	14	40
2002	1,489	998	1,190	407	96	33	103	28	17	28	38
2003	336	1,103	737	861	278	63	21	62	18	11	46
2004	436	249	815	530	593	187	41	13	40	12	41
2005	586	323	184	587	365	401	127	28	9	28	39
2006	373	434	238	132	403	246	270	86	19	6	48
2007	863	276	318	165	90	270	164	181	60	14	40
2008	633	639	202	221	111	62	182	109	124	42	38
2009	199	469	468	140	148	75	41	118	71	83	57
2010	527	147	343	321	89	92	47	24	72	46	96
2011	643	390	108	238	199	54	56	29	15	47	99
2012	585	476	288	78	161	128	34	37	19	10	100
2013	510	434	351	207	52	103	78	21	24	13	74
2014	515	378	321	257	147	36	70	53	15	17	62
Average	682	507	375	265	179	118	79	53	35	25	65

Table 17.13. Estimates of Atka mackerel biomass in metric tons with approximate lower and upper 95% confidence bounds for age 1+ biomass (labeled as LCI and UCI; computed for period 1977-2014). Also included are female spawning biomass in metric tons from the current recommended assessment model, Model 1 (1977-2015) compared to last year's (2013) assessment results.

	Current assessment age 1+ biomass (t)			Age 3+ biomass (t)		Female spawning biomass (t)	
Year	Estimate	LCI	UCI	Current	2013	Current	2013
1977	681,986	431,712	1,077,350	593,761	508,709	195,918	166,432
1978	710,891	443,705	1,138,970	598,061	511,845	189,565	160,350
1979	755,508	465,559	1,226,040	541,410	459,482	185,867	156,533
1980	819,865	505,193	1,330,540	744,694	644,062	195,253	165,412
1981	847,488	521,218	1,378,000	783,547	684,587	244,974	211,768
1982	780,549	478,735	1,272,640	712,679	620,979	250,169	217,269
1983	733,792	449,918	1,196,770	677,133	587,724	239,507	209,278
1984	713,691	440,278	1,156,890	641,628	550,998	225,315	194,367
1985	673,836	414,003	1,096,750	585,479	495,748	200,113	169,724
1986	657,274	404,271	1,068,610	560,323	468,031	182,730	151,095
1987	679,064	420,972	1,095,390	583,995	487,597	185,382	151,932
1988	689,636	436,751	1,088,950	587,278	488,529	188,732	155,397
1989	745,641	488,279	1,138,650	620,601	511,701	196,234	161,613
1990	844,753	574,617	1,241,880	623,772	516,109	210,342	173,361
1991	930,368	650,277	1,331,100	829,664	699,411	226,247	187,422
1992	965,575	683,152	1,364,760	894,637	758,922	272,842	228,802
1993	925,744	656,944	1,304,530	804,437	679,479	272,427	227,094
1994	897,187	635,529	1,266,570	744,253	630,072	244,682	202,711
1995	875,327	616,748	1,242,320	808,834	689,584	225,392	184,700
1996	815,141	563,816	1,178,500	719,624	611,048	212,854	173,044
1997	710,443	475,491	1,061,490	580,223	485,237	187,886	151,749
1998	693,144	460,797	1,042,650	651,830	556,278	178,579	145,203
1999	668,375	441,309	1,012,270	576,888	493,857	185,635	154,603
2000	721,713	483,894	1,076,410	500,536	427,967	167,116	139,958
2001	915,282	631,037	1,327,560	597,011	508,944	162,810	136,105
2002	1,152,710	808,850	1,642,760	926,235	792,124	211,301	176,725
2003	1,295,170	920,038	1,823,270	1,103,490	945,576	299,643	253,824
2004	1,273,540	904,242	1,793,660	1,214,159	1,037,326	352,769	298,583
2005	1,185,810	835,043	1,683,930	1,107,843	947,472	377,435	319,943
2006	1,037,600	721,983	1,491,180	951,380	810,869	338,829	285,825
2007	939,110	647,415	1,362,230	856,273	727,639	294,742	247,858
2008	883,655	606,778	1,286,870	752,935	632,615	260,525	215,237
2009	828,308	563,965	1,216,550	744,300	615,066	227,748	183,574
2010	746,898	498,080	1,120,010	699,693	567,089	212,093	166,742
2011	665,884	433,215	1,023,510	574,607	460,954	197,127	152,826
2012	631,844	408,976	976,161	529,370	406,694	168,315	127,118
2013	634,682	407,194	989,260	542,400	384,364	166,436	118,446
2014	657,228	423,420	1,020,140	573,648		176,036	117,171
2015	694,421	416,827	1,028,690			167,136	

Table 17.14. Estimates of age-1 Atka mackerel recruitment (millions of recruits) and standard deviation (Std. dev.) from Model 1.

	Age 1 Recruits		
Year	Current	Std. dev	2013 assessment
1977	340	101	299
1978	1,620	406	1,486
1979	495	137	446
1980	369	107	321
1981	451	129	370
1982	321	94	254
1983	414	114	341
1984	513	135	449
1985	614	155	552
1986	540	140	457
1987	693	159	576
1988	452	105	388
1989	1,596	266	1,418
1990	708	138	614
1991	374	83	327
1992	593	111	536
1993	1,138	182	1,042
1994	402	84	363
1995	420	88	394
1996	1,020	179	952
1997	206	49	186
1998	377	83	342
1999	1,043	203	911
2000	2,174	365	1,941
2001	1,347	233	1,174
2002	1,489	249	1,309
2003	336	75	289
2004	436	91	382
2005	586	116	511
2006	373	76	330
2007	863	152	741
2008	633	125	546
2009	199	51	197
2010	527	129	356
2011	643	185	415
2012	585	191	382
2013	510	221	439
2014	515	225	
Average 78-13	696		604
Median 78-13	534		443

Table 17.15. Estimates of full-selection fishing mortality rates and exploitation rates (Catch/Biomass) for Atka mackerel from Model 1.

Year	*F*	Catch/Biomass Rate[b]
1977	0.184	0.037
1978	0.155	0.041
1979	0.134	0.043
1980	0.096	0.028
1981	0.098	0.025
1982	0.064	0.028
1983	0.040	0.017
1984	0.114	0.056
1985	0.107	0.065
1986	0.123	0.057
1987	0.065	0.051
1988	0.094	0.038
1989	0.050	0.029
1990	0.052	0.036
1991	0.082	0.032
1992	0.098	0.054
1993	0.144	0.082
1994	0.156	0.088
1995	0.228	0.101
1996	0.368	0.144
1997	0.193	0.113
1998	0.227	0.088
1999	0.177	0.097
2000	0.162	0.094
2001	0.222	0.103
2002	0.206	0.049
2003	0.156	0.049
2004	0.093	0.050
2005	0.096	0.056
2006	0.105	0.065
2007	0.110	0.069
2008	0.138	0.077
2009	0.213	0.098
2010	0.199	0.098
2011	0.150	0.090
2012	0.196	0.090
2013	0.087	0.043
2014	0.116	0.055

[a] Catch/Biomass rate is the ratio of catch to beginning year age 3+ biomass.

Table 17.16. Projections of female spawning biomass in metric tons, full-selection fishing mortality rates (F) and catch in metric tons for Atka mackerel for the 7 scenarios. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 333,237 t, 133,295 t, and 116,633 t, respectively.

Catch		*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
	2014	31,670	31,670	31,670	31,670	31,670	31,670	31,670
	2015	84,800	84,800	84,800	84,800	84,800	125,297	105,991
	2016	98,137	98,137	21,533	27,090	0	103,374	93,498
	2017	85,867	85,867	22,926	28,497	0	84,411	94,740
	2018	82,958	82,958	25,059	30,927	0	86,801	90,427
	2019	86,817	86,817	27,352	33,605	0	92,760	94,063
	2020	90,573	90,573	29,424	36,023	0	96,981	97,460
	2021	92,739	92,739	30,959	37,791	0	99,189	99,383
	2022	93,536	93,536	31,811	38,752	0	99,853	99,943
	2023	92,832	92,832	32,168	39,116	0	98,735	98,774
	2024	92,588	92,588	32,394	39,336	0	98,351	98,368
	2025	91,948	91,948	32,478	39,398	0	97,700	97,707
	2026	91,531	91,531	32,508	39,407	0	97,308	97,311
	2027	92,173	92,173	32,745	39,681	0	98,099	98,100
Fishing M		*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
	2014	0.116	0.116	0.116	0.116	0.116	0.116	0.116
	2015	0.313	0.313	0.313	0.313	0.313	0.489	0.403
	2016	0.403	0.403	0.079	0.101	0.000	0.477	0.403
	2017	0.393	0.393	0.079	0.101	0.000	0.430	0.455
	2018	0.374	0.374	0.079	0.101	0.000	0.423	0.432
	2019	0.372	0.372	0.079	0.101	0.000	0.427	0.431
	2020	0.374	0.374	0.079	0.101	0.000	0.431	0.433
	2021	0.375	0.375	0.079	0.101	0.000	0.433	0.434
	2022	0.375	0.375	0.079	0.101	0.000	0.433	0.433
	2023	0.375	0.375	0.079	0.101	0.000	0.431	0.432
	2024	0.376	0.376	0.079	0.101	0.000	0.432	0.432
	2025	0.375	0.375	0.079	0.101	0.000	0.432	0.432
	2026	0.374	0.374	0.079	0.101	0.000	0.431	0.431
	2027	0.374	0.374	0.079	0.101	0.000	0.431	0.431
Spawning biomass		*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
	2014	176,036	176,036	176,036	176,036	176,036	176,036	176,036
	2015	167,136	167,136	167,136	167,136	167,136	156,343	161,541
	2016	146,682	146,682	166,651	165,252	172,008	130,147	140,004
	2017	132,362	132,362	177,409	173,882	191,404	118,217	125,166
	2018	131,929	131,929	193,931	188,585	215,803	119,864	123,005
	2019	135,078	135,078	211,147	204,115	240,616	123,245	124,746
	2020	137,146	137,146	225,480	216,899	262,181	125,013	125,751
	2021	138,751	138,751	237,241	227,303	280,502	126,267	126,631
	2022	139,609	139,609	245,889	234,846	294,668	126,863	127,037
	2023	138,635	138,635	250,623	238,713	303,871	125,776	125,851
	2024	138,464	138,464	255,150	242,499	312,310	125,564	125,595
	2025	137,983	137,983	257,563	244,405	317,519	125,111	125,124
	2026	137,799	137,799	259,126	245,616	321,128	124,973	124,978
	2027	138,766	138,766	261,491	247,704	325,115	125,922	125,924

Table 17.17. Ecosystem effects.

Ecosystem effects on Atka mackerel			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys	None	Unknown
Predator population trends			
Marine mammals	Fur seals – Pribilof Island rookeries declining, Bogoslof breeding rookery increasing. Steller sea lions western stock increasing slightly	Mixed potential impact, possibly increased mortality on Atka mackerel	No concern
Birds	Stable, some increasing some decreasing	Affects young-of-year mortality	No concern
Fish (Pacific cod, arrowtooth flounder)	Arrowtooth abundance trends are stabilizing, possibly slight declining trend	Possible changes in predation on Atka mackerel	No concern
Changes in habitat quality			
Temperature regime	2014 AI summer bottom temperature was well above average (2nd highest in the time series, similar to 1991 and 1997 surveys)	Could possibly affect fish distribution	Unknown
***The Atka mackerel* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Variable, heavily monitored	Likely to be a minor contribution to mortality	Unknown
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	Unknown
HAPC biota (seapens/whips, corals, sponges, anemones)	Low bycatch levels of seapens/whips, sponge and coral catches are variable	Unknown	Possible concern for sponges and corals
Marine mammals and birds	Very minor direct-take	Likely to be very minor contribution to mortality	No concern
Fishery concentration in space and time	Steller sea lion protection measures spread out Atka mackerel catches in time and space. Western Aleutians closed to directed Atka mackerel fishery. Atka mackerel TAC reduced in Central Aleutians (≤47% CAI ABC). Fishery has become highly concentrated in areas outside of critical habitat	Mixed potential impact (fur seals vs Steller sea lions). Areas outside of critical habitat may be experiencing higher exploitation rates.	Possible concern
Fishery effects on amount of large size target fish	Depends on highly variable year-class strength	Natural fluctuation (environmental)	Probably no concern
Fishery contribution to discards and offal production	Offal production—unknown From 2011-2013, the Atka mackerel fishery contributed an average of 469 and 1,191 t of the total AI trawl non-target and Atka mackerel discards, respectively.	The Atka mackerel fishery is one of the few trawl fisheries operating in the AI. Numbers and rates should be interpreted in this context.	Unknown
Fishery effects on age-at-maturity and fecundity	Unknown	Unknown	Unknown

Figures

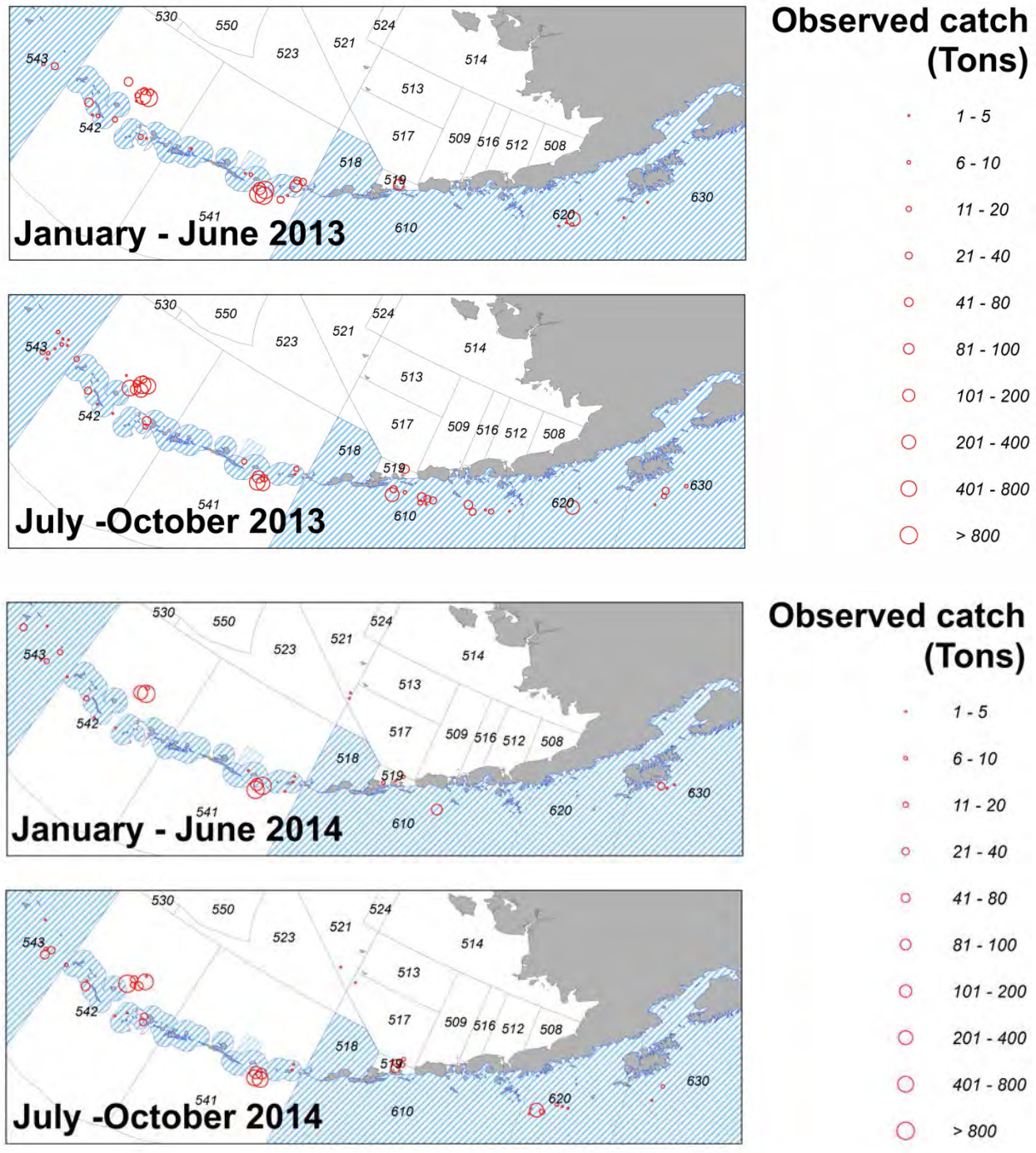


Figure 17.1. Observed catches of Atka mackerel summed for 20 km^2 cells for 2013 and 2014 where observed catch per haul was greater than 1 t. Shaded areas represent areas closed to directed Atka mackerel fishing.

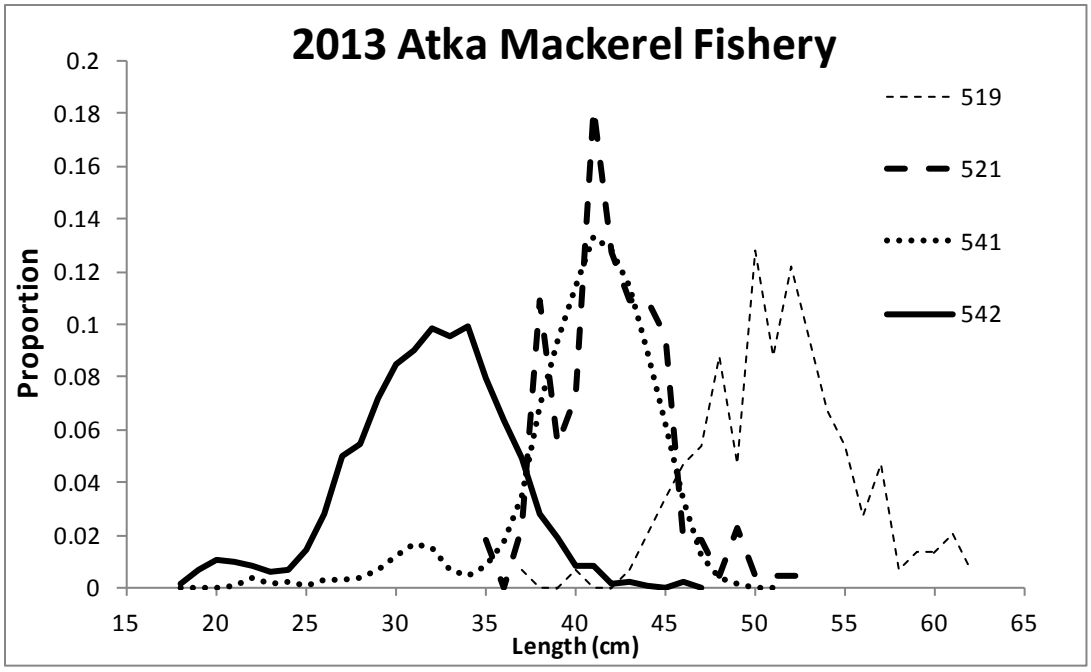


Figure 17.2. 2013 Atka mackerel fishery length-frequency data by area fished (see Figure 17.1). Numbers refer to management areas. Too few fish were measured in area 543 for presentation.

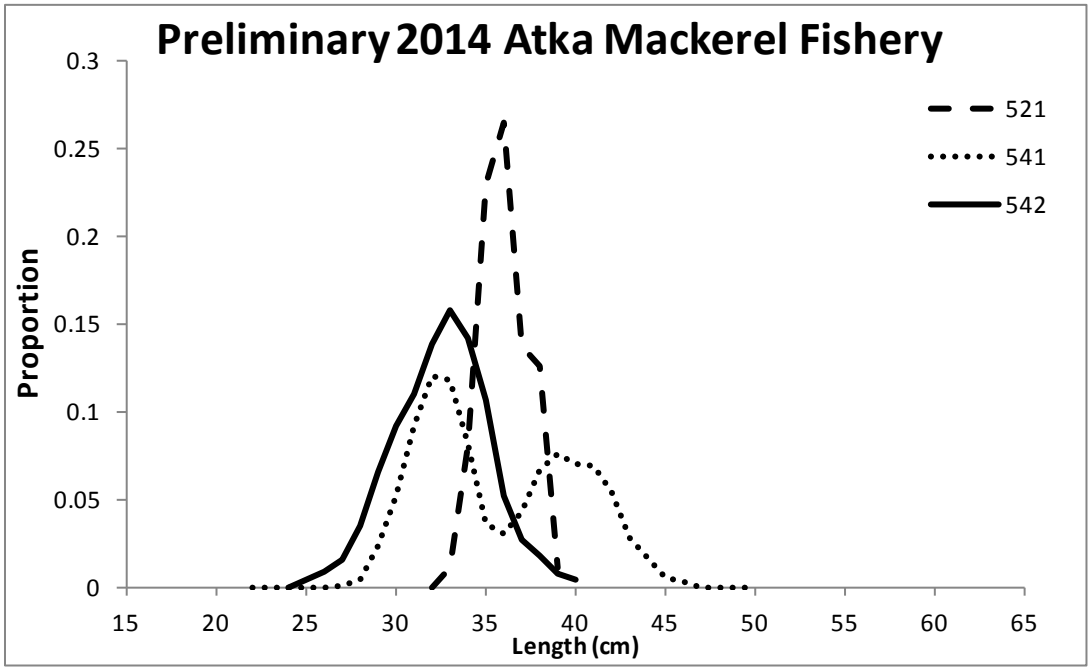


Figure 17.3. Preliminary 2014 Atka mackerel fishery length-frequency data by area fished (see Figure 17.1). Too few fish were measured in areas 519 and 543 for presentation. Numbers refer to management areas.

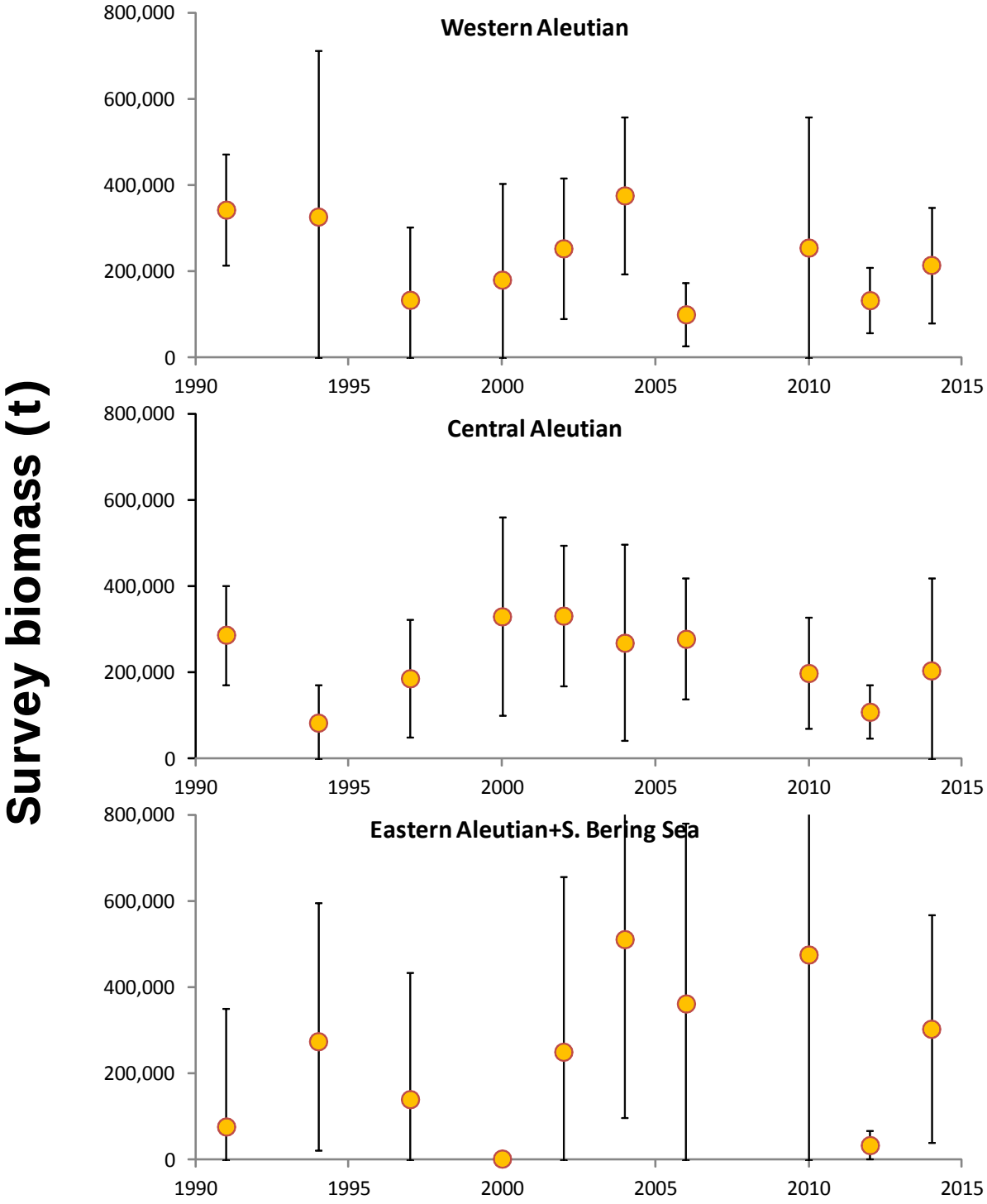


Figure 17.4. Atka mackerel Aleutian Islands survey biomass estimates by area and survey year. Bars represent 95% confidence intervals based on sampling error.

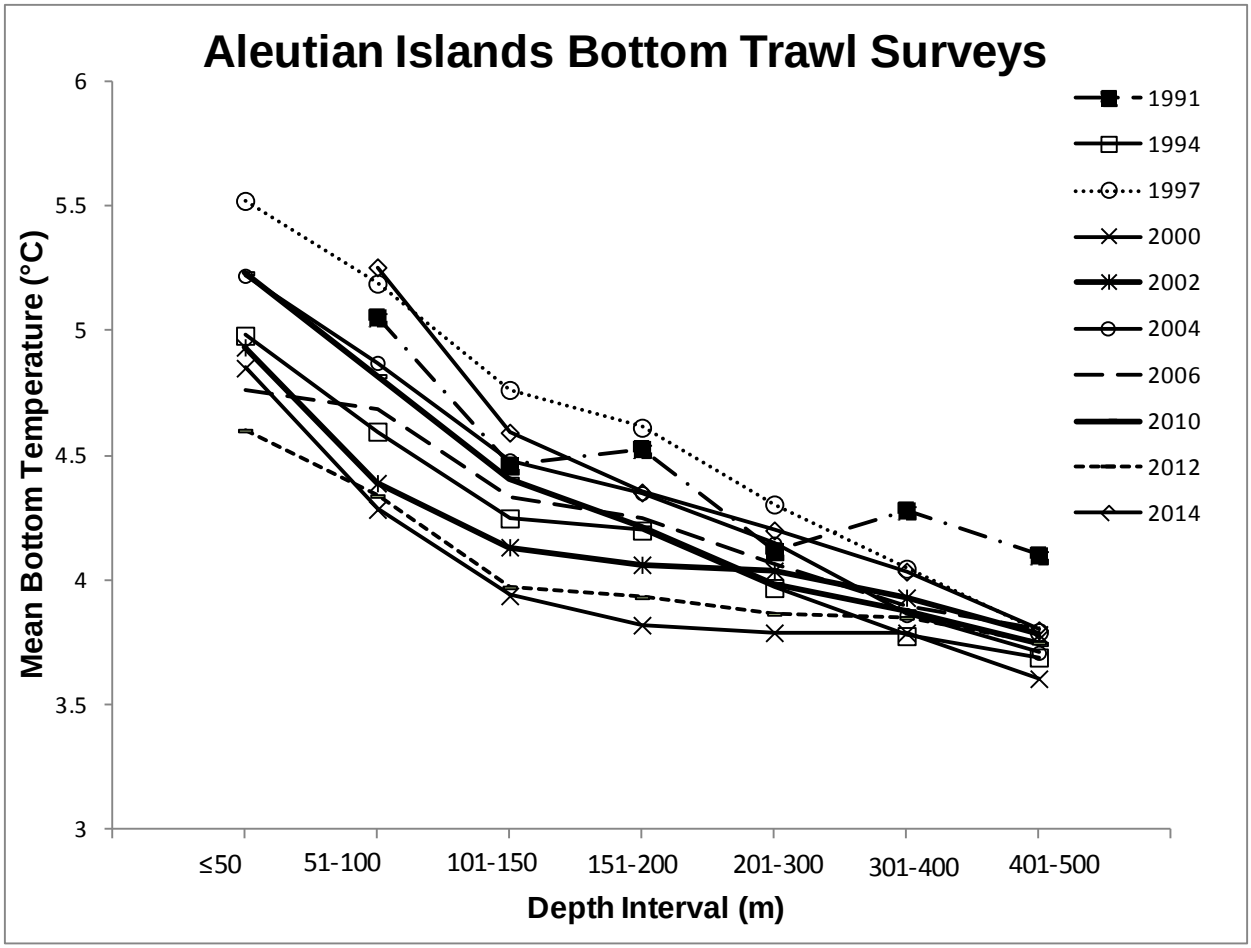


Figure 17.5. Average bottom temperatures by depth interval from Aleutian Islands summer bottom-trawl surveys, 1991 to 2014.

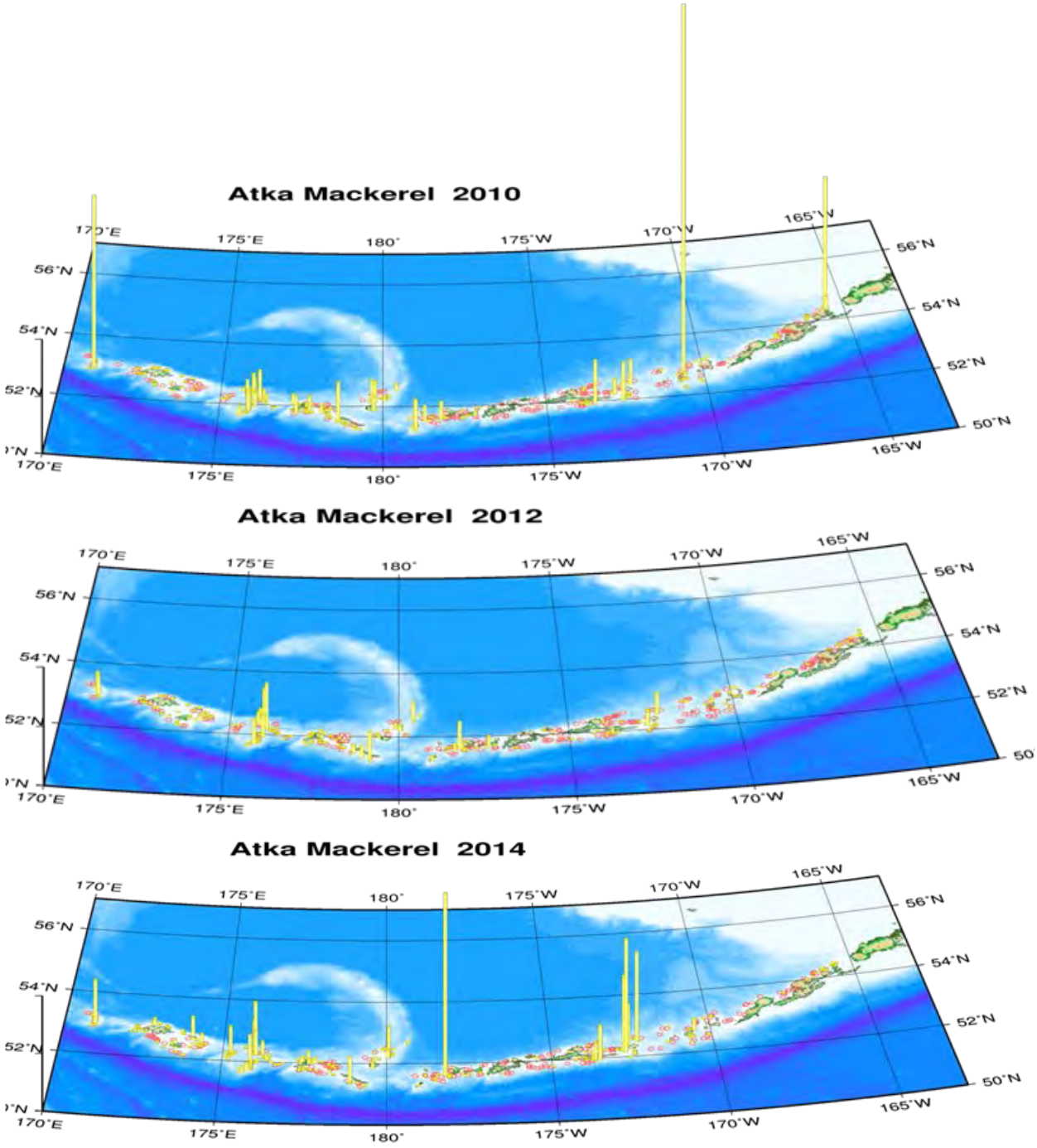


Figure 17.6. Bottom-trawl survey CPUE distributions of Atka mackerel catches during the summers of 2010, 2012, and 2014.

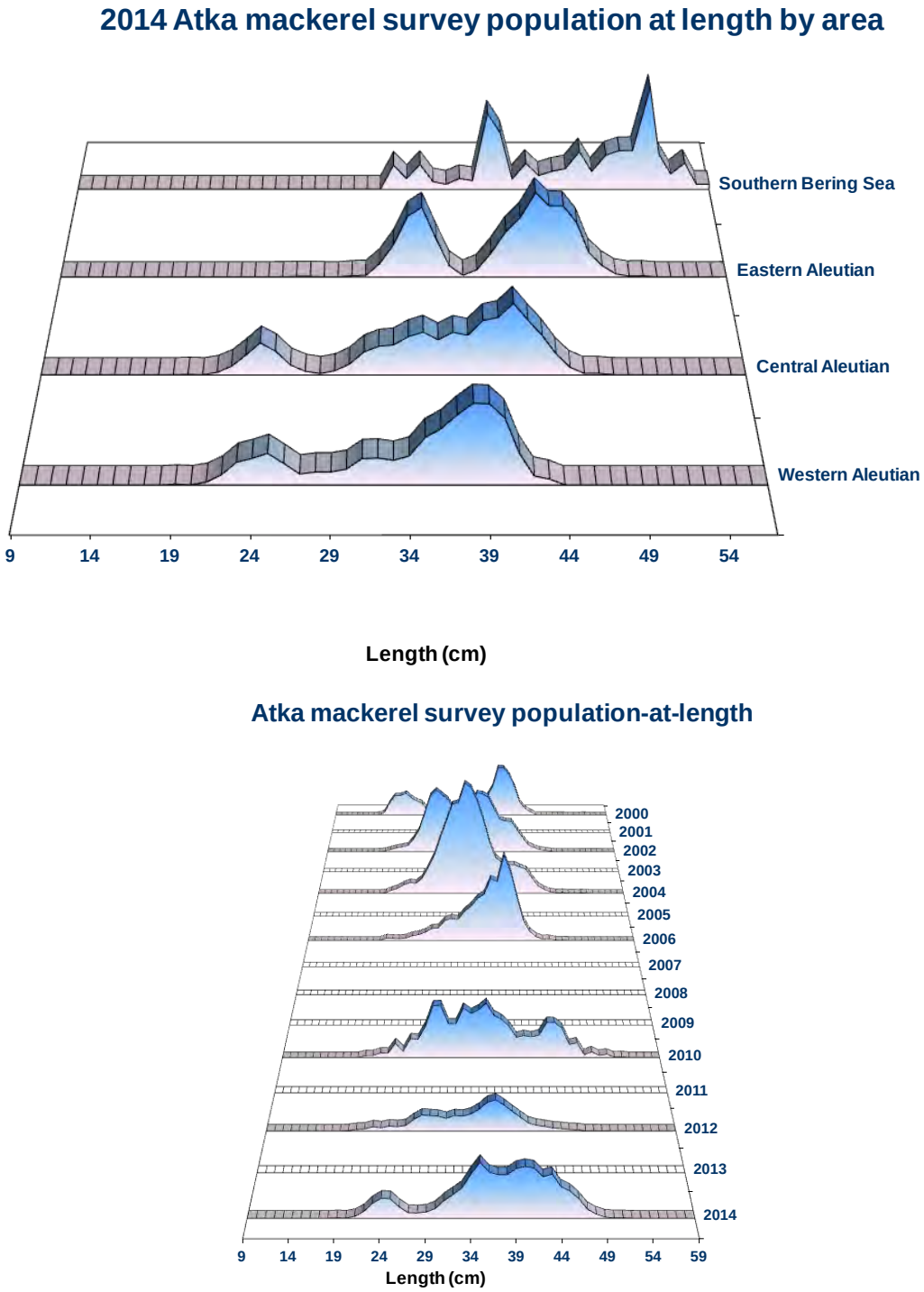


Figure 17.7. Atka mackerel bottom trawl survey length frequency data by subarea in 2014 (top) and for all areas, 2000-2014 (bottom). Vertical scale is proportion in top panel and estimated absolute numbers at age bottom panel.

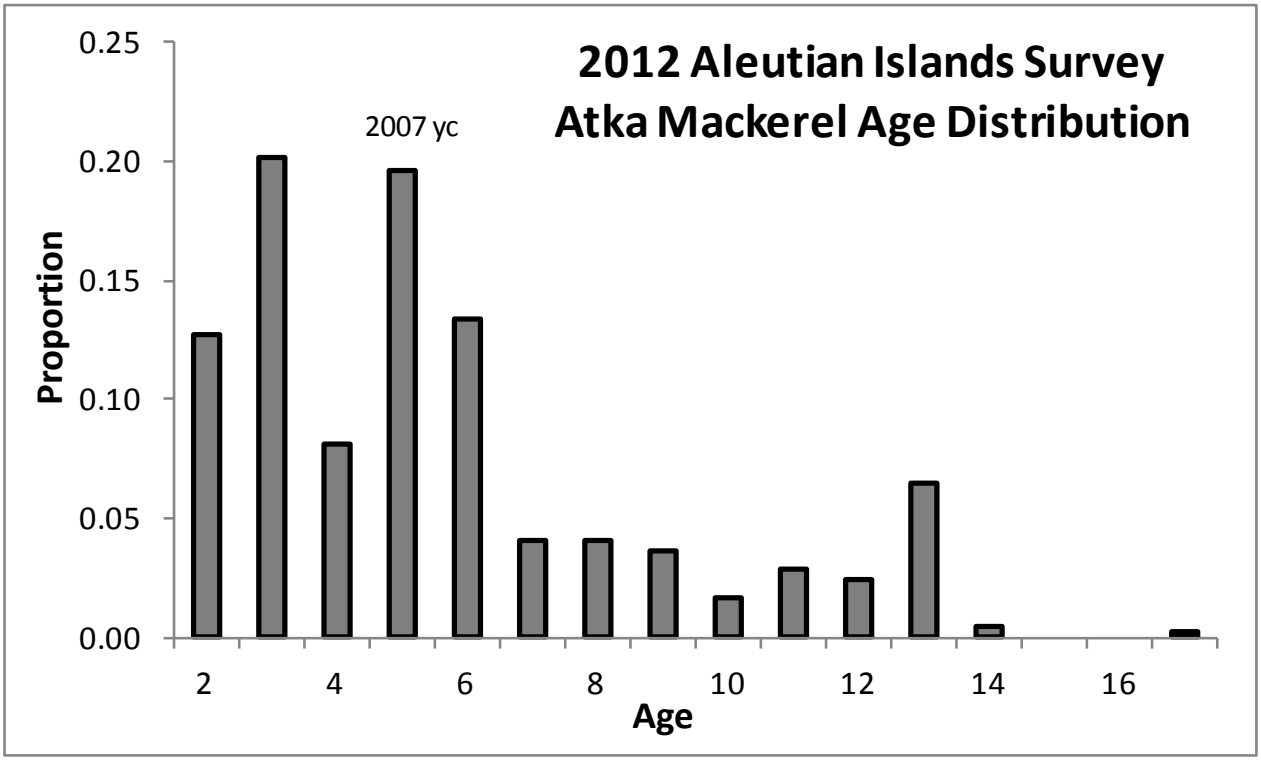


Figure 17.8. Atka mackerel age distribution from the Aleutian Islands 2012 bottom trawl survey. A total of 417 otoliths were aged; mean age from the 2012 survey is 5.6 years.

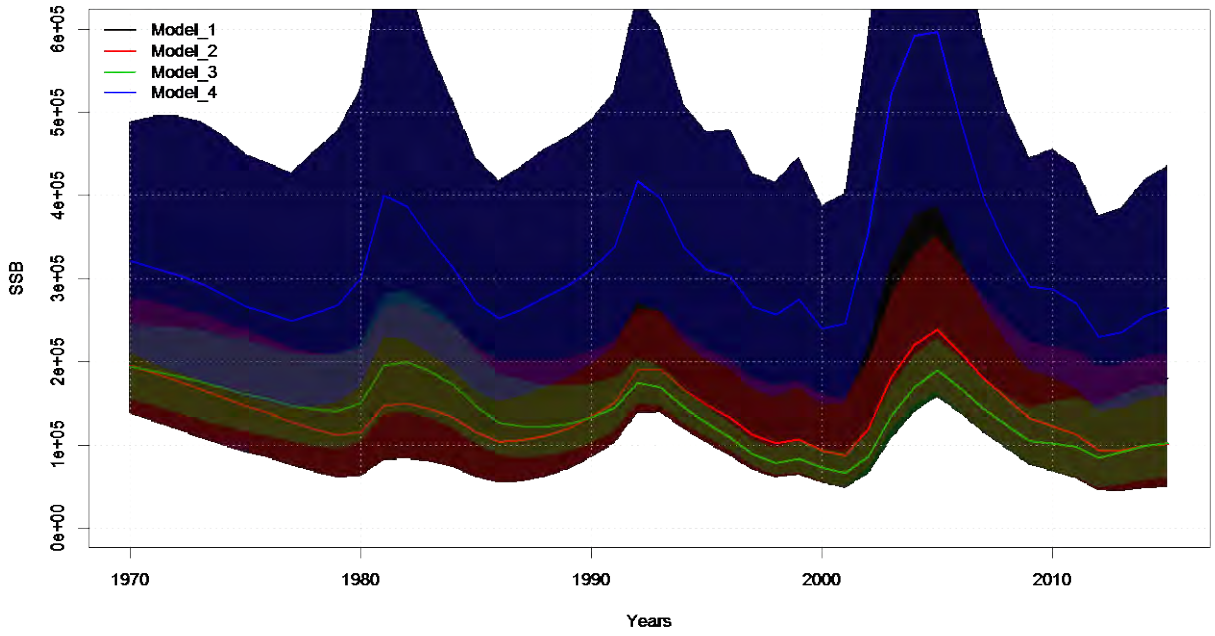


Figure 17.9. Spawning biomass trends and approximate 90% confidence bands for Model 1 compared to the sensitivity runs (Models 2-4).

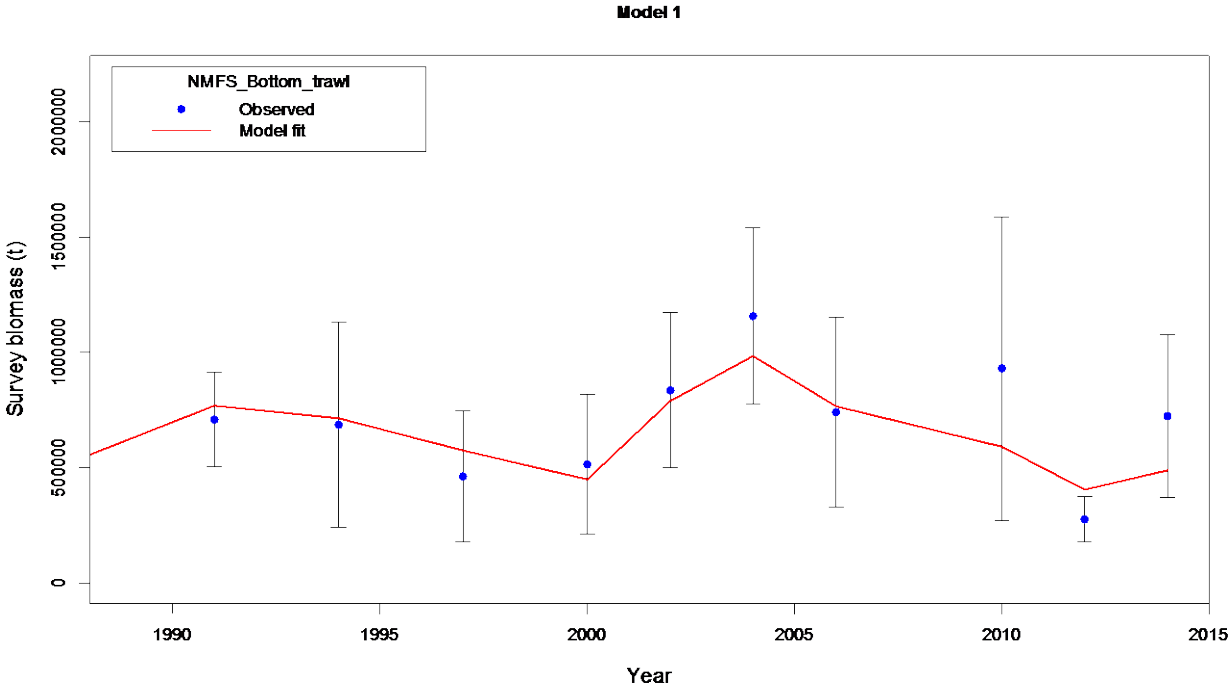


Figure 17.10. Observed (dots) and predicted (trend line) survey biomass estimates (t) for Bering Sea/Aleutian Islands Atka mackerel. Error bars represent two standard errors (based on sampling) from the survey estimates.

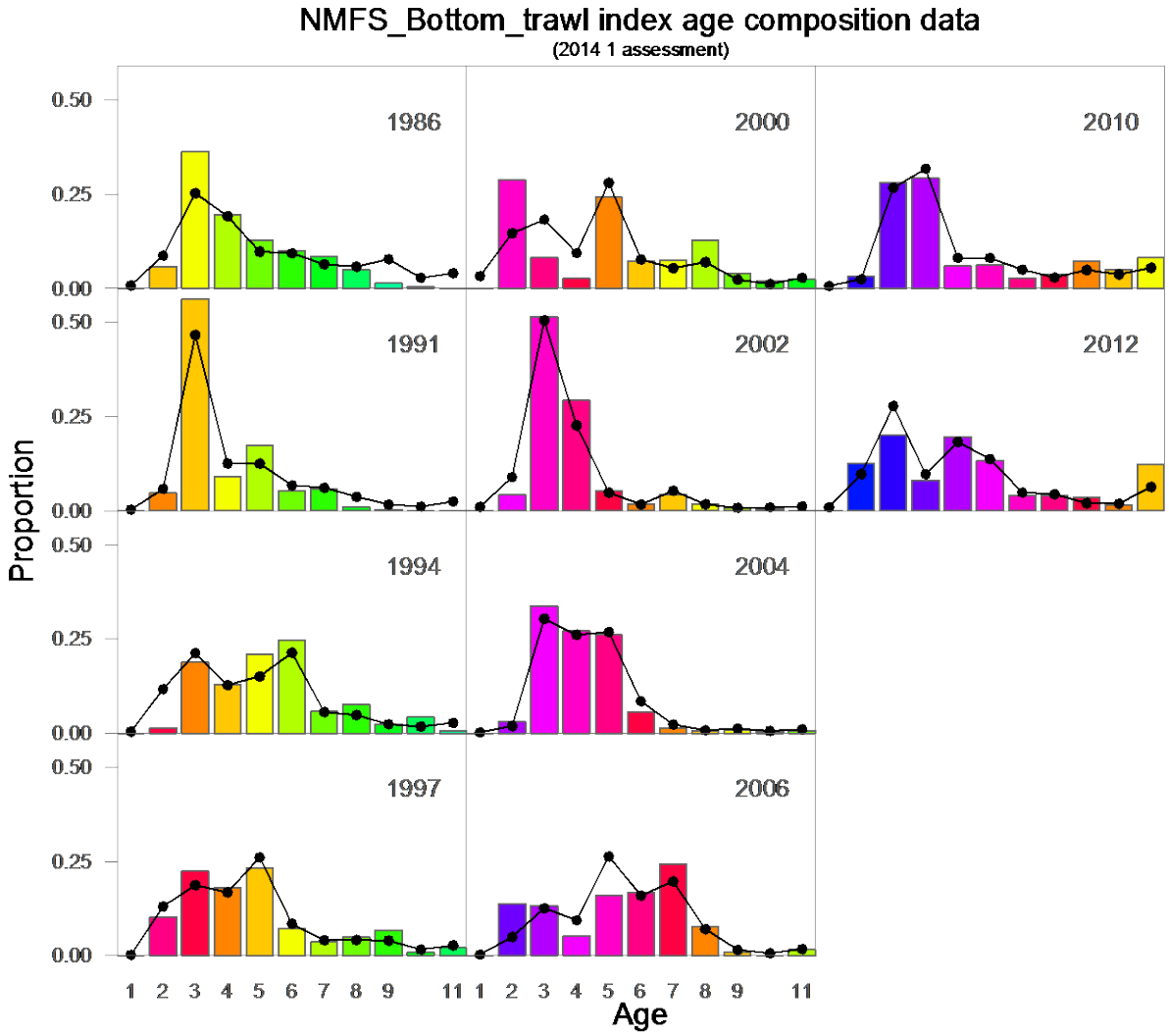


Figure 17.11. Observed and predicted **survey** proportions-at-age for BSAI Atka mackerel. Lines with "●" symbol are the model predictions and columns are the observed proportions at age for Model 1.

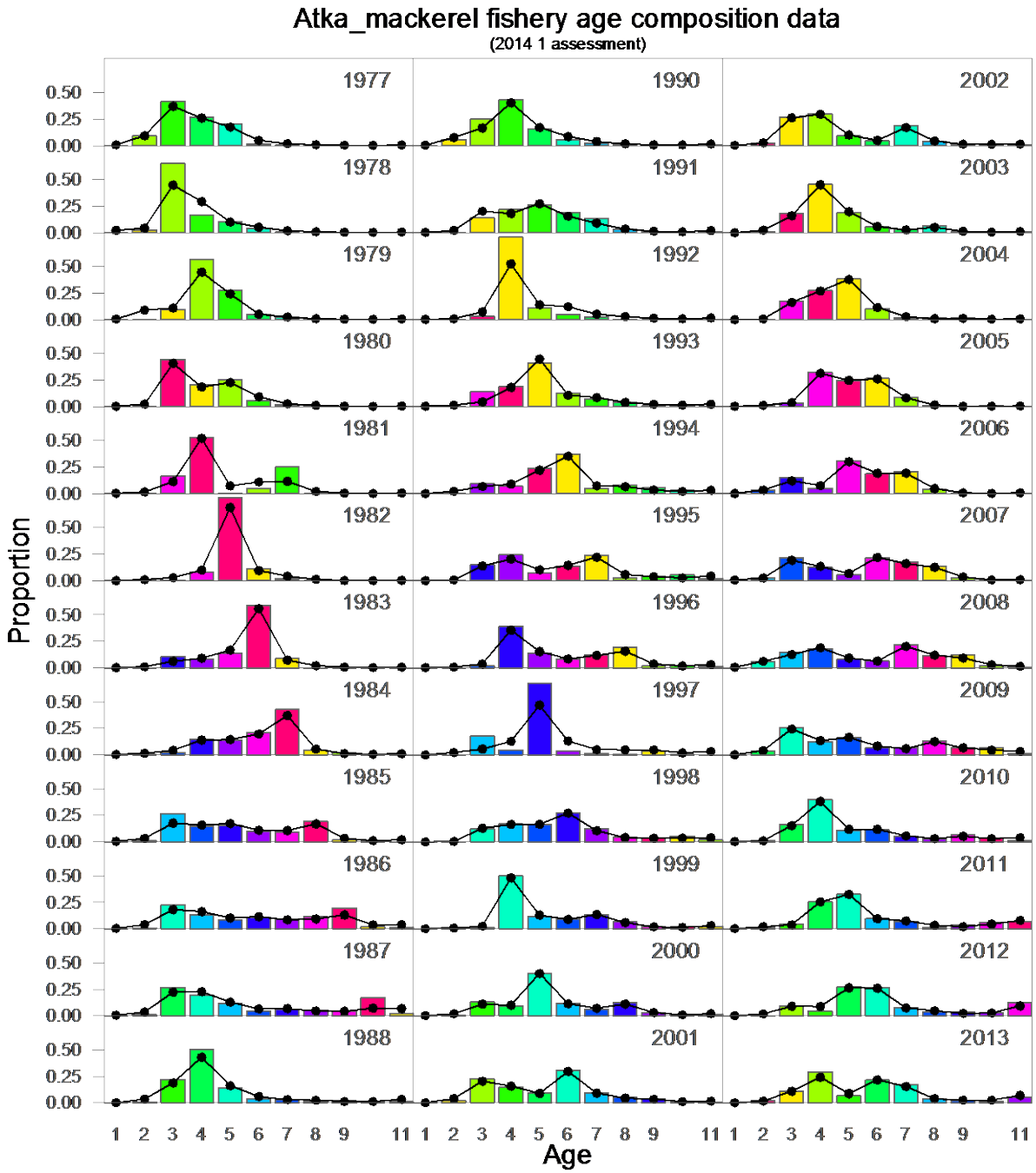


Figure 17.12. Observed and predicted Atka mackerel **fishery** proportions-at-age for BSAI Atka mackerel. Lines with "•" symbol are the model predictions and columns are the observed proportions at age (with colors corresponding to cohorts) for Model 1.

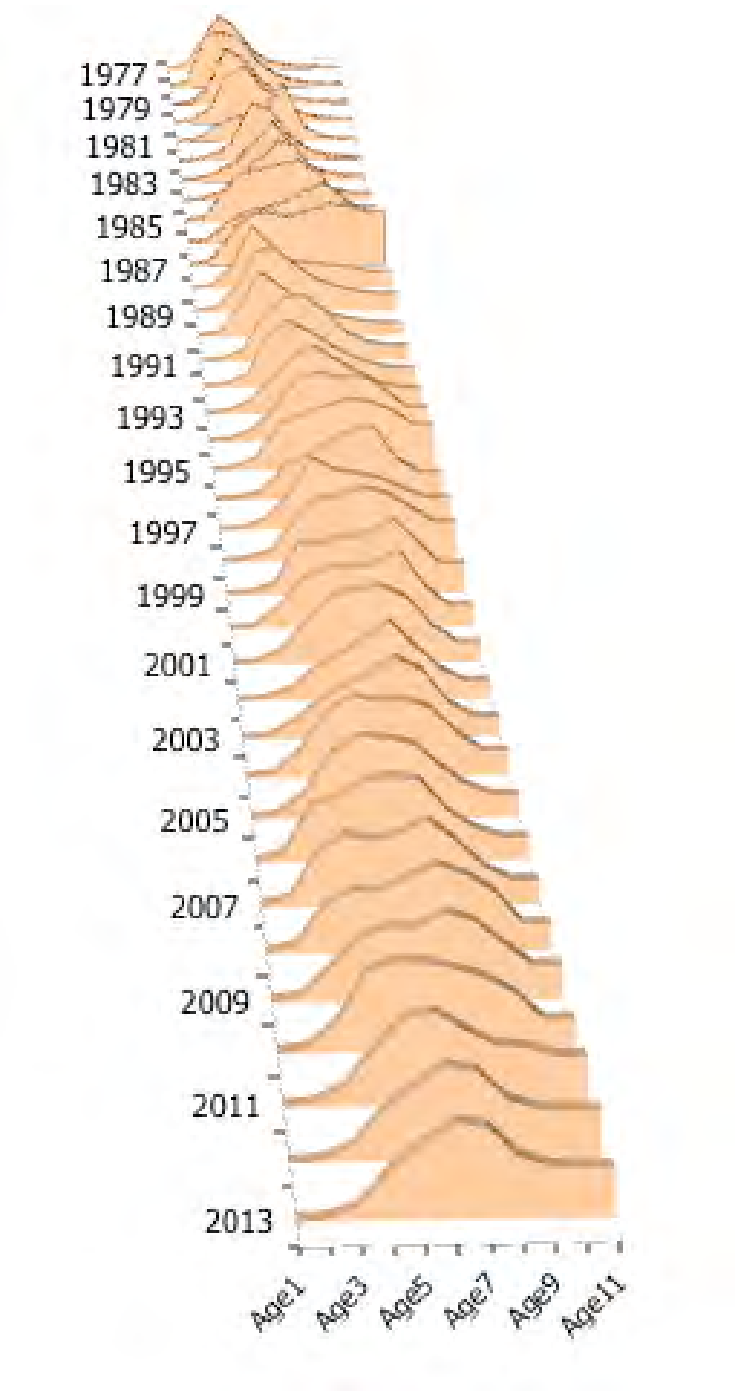


Figure 17.13. Fishery selectivity pattern from the BSAI Atka mackerel assessment Model 1.

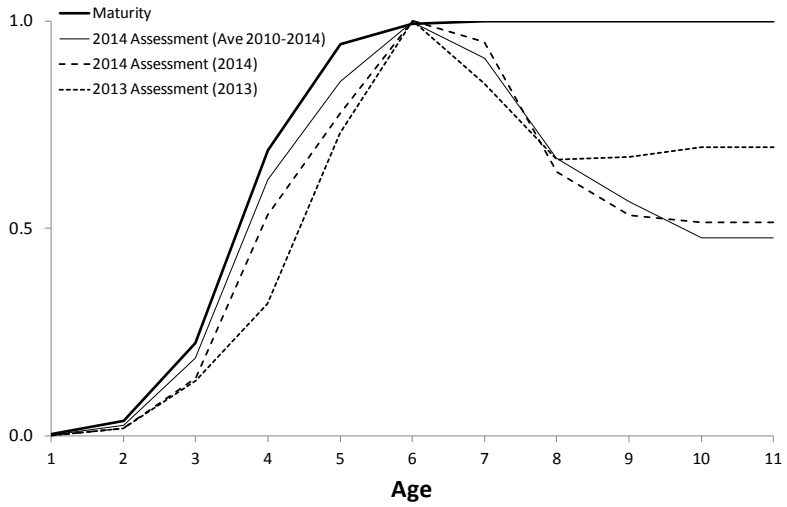


Figure 17.14. Estimated fishery selectivity patterns in the current assessment with a) the 2014 assessment terminal year (2014, Model 1), b) the 2014 assessment average selectivity for 2010-2014 (used for projections), and c) last year's assessment terminal year (2013, 2013 assessment) compared with the maturity-at-age estimates for BSAI Atka mackerel. Selectivity estimates have been normalized to a maximum of 1.0 for presentation.

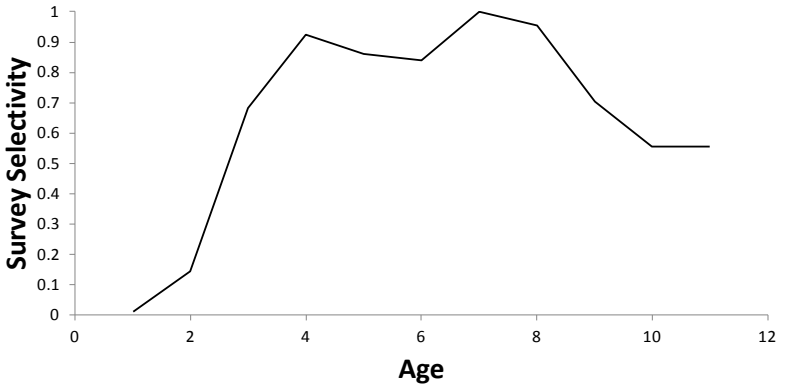


Figure 17.15. Estimated BSAI Atka mackerel survey selectivity-at-age from the current recommended model configuration (Model 1). Selectivity estimates have been normalized to a maximum value of 1.0 for presentation.

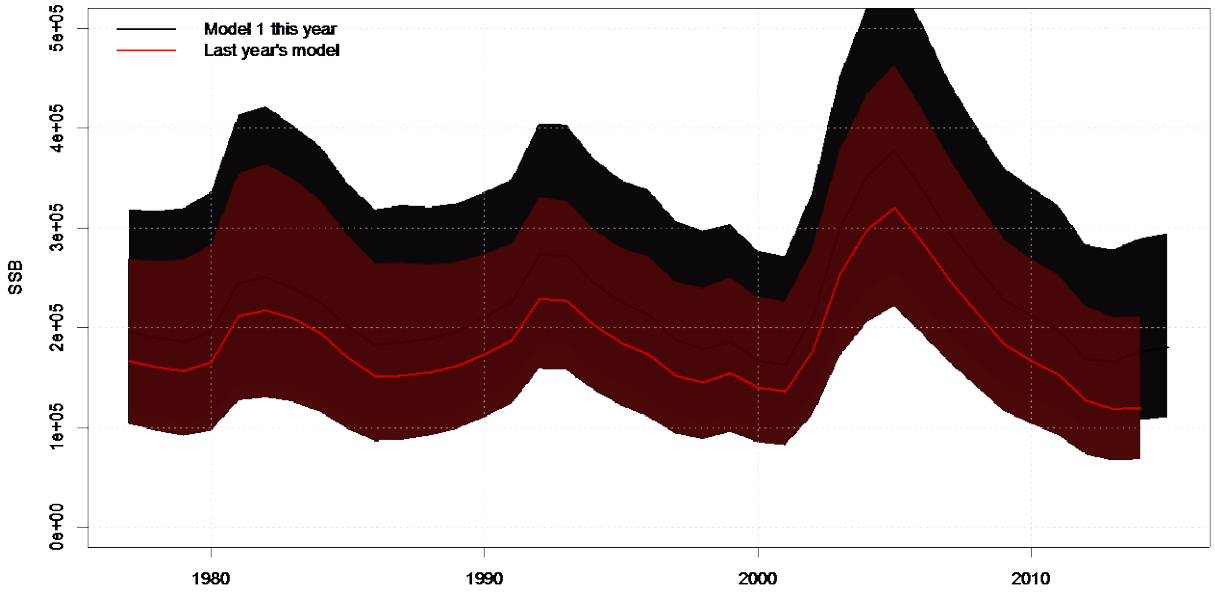


Figure 17.16. Time series of estimated Aleutian Islands Atka mackerel spawning biomass with approximate 95% confidence bounds from Model 1 compared with last year's (2013 assessment) selected model.

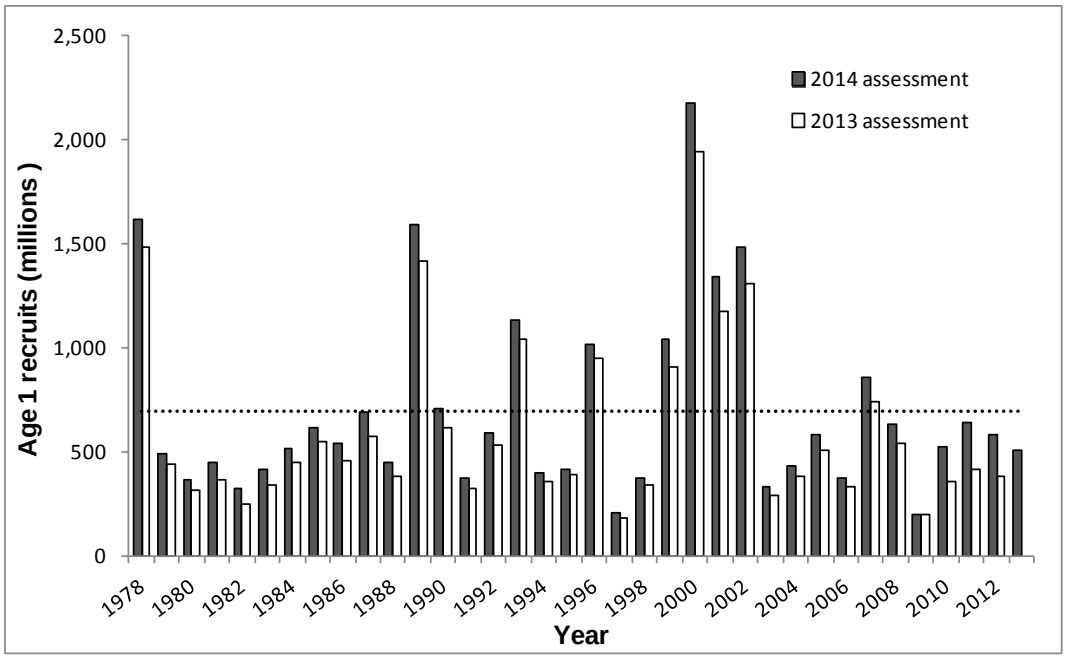


Figure 17.17. Age 1 recruitment from the current assessment (2014) with the dashed line indicating average recruitment (696 million) over 1978-2013, and age 1 recruitment as estimated from the 2013 assessment.

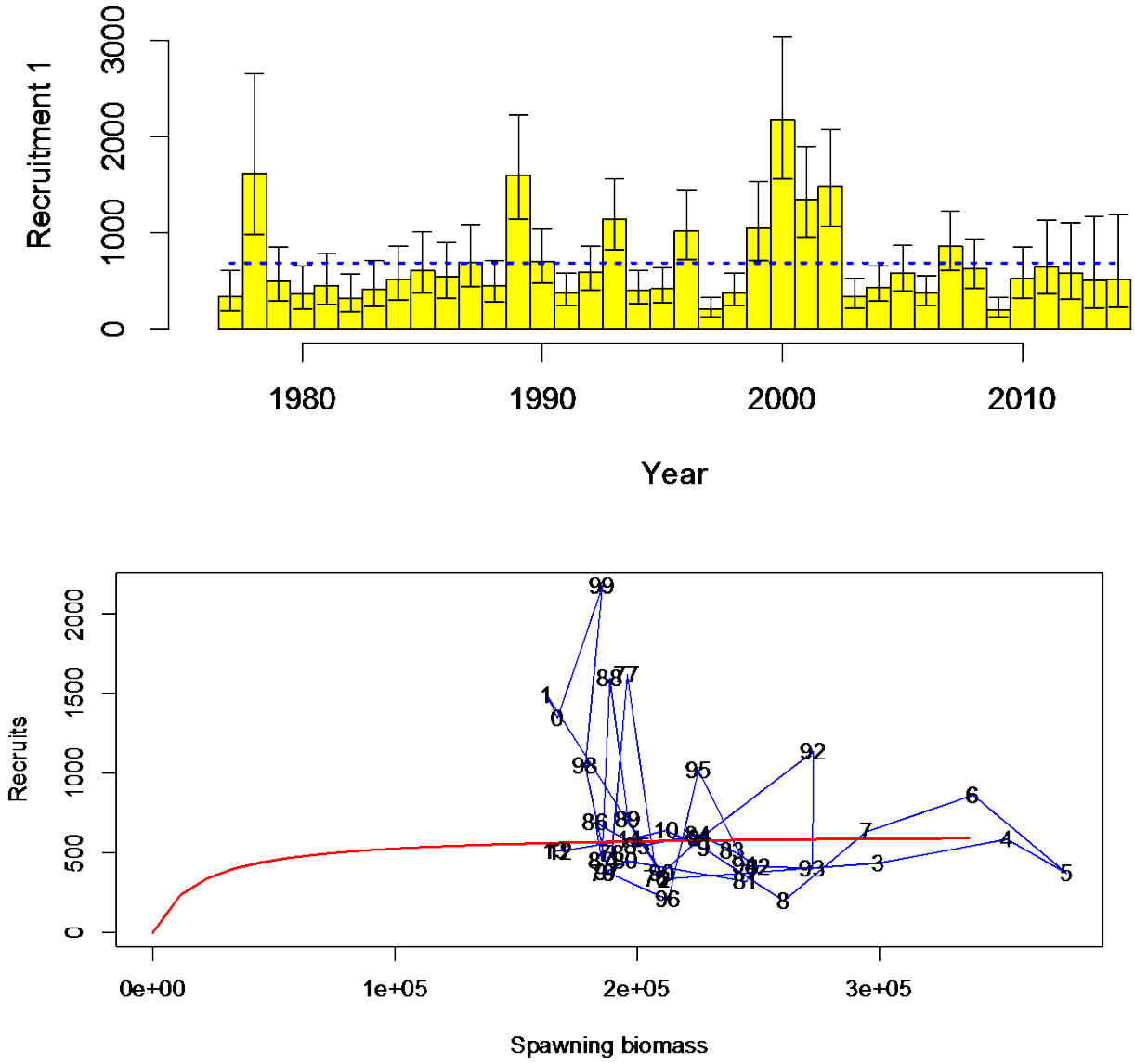


Figure 17. 18. Age 1 recruitment of Atka mackerel as estimated from the current assessment recommended model (Model 1), with error bars representing two standard errors (top panel) and the solid line indicating average recruitment (696 million) over 1978-2013, and estimated female spawning biomass levels in thousands of metric tons (lower panel). Solid line represents the underlying Beverton-Holt stock recruitment curve assumed in the model.

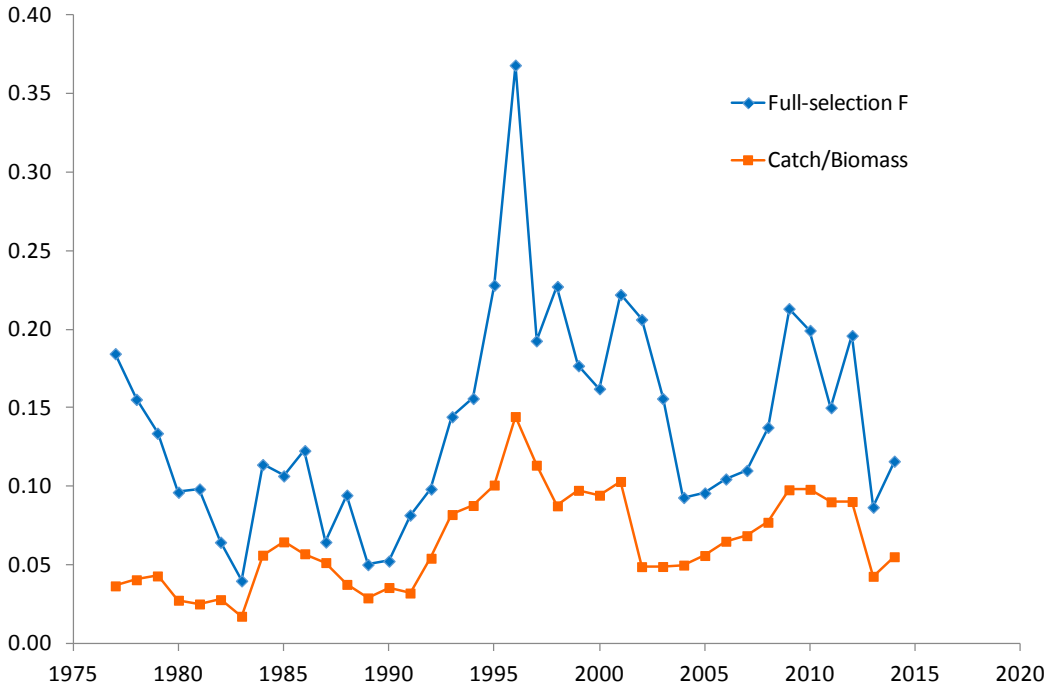


Figure 17. 19. Estimated time series of Model 1 full-selection fishing mortality and catch/biomass exploitation rates of Atka mackerel, 1977-2014. Catch/biomass rates are the ratios of catch to beginning year age 3+ biomass.

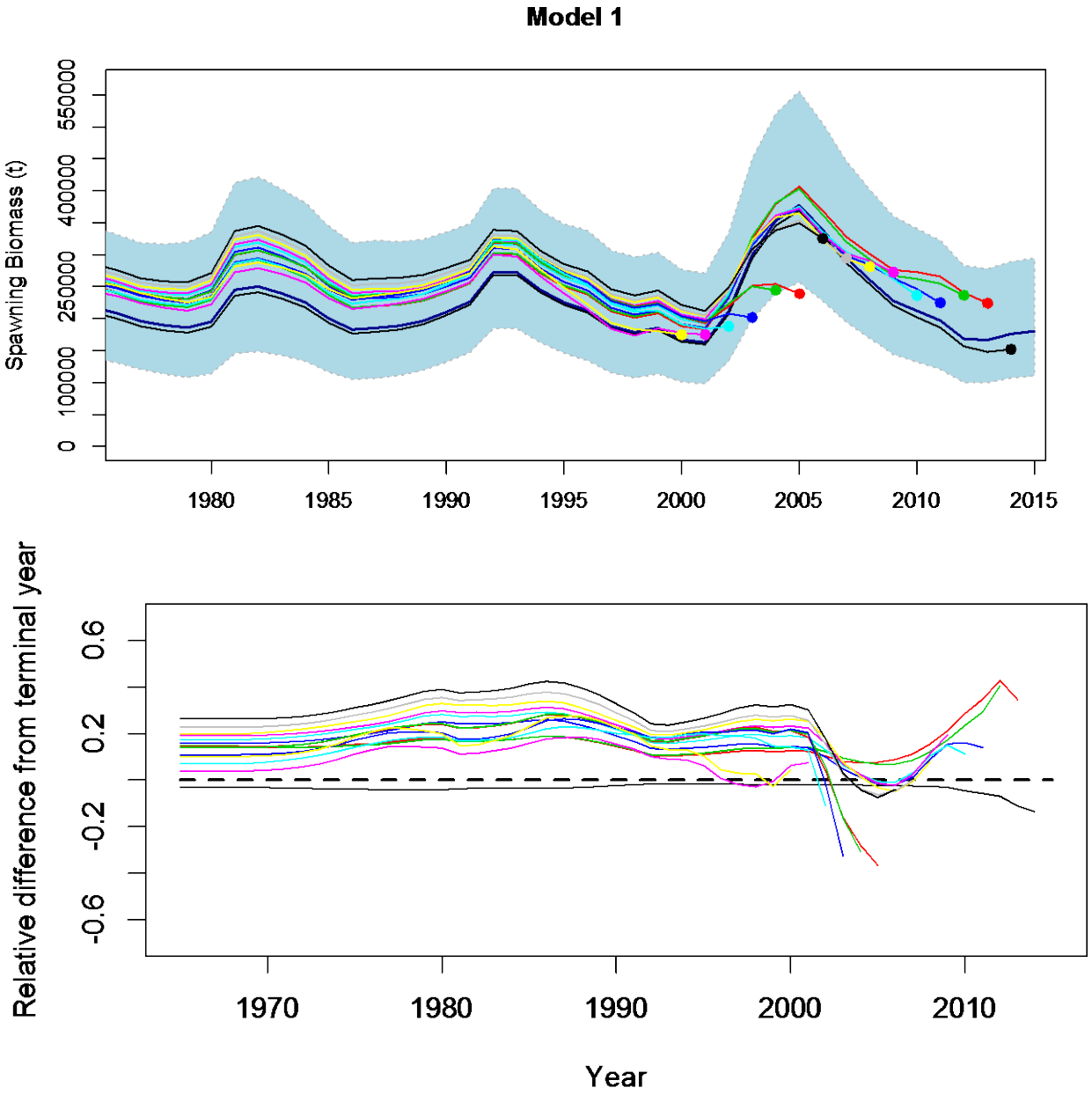


Figure 17.20. Retrospective plots showing the spawning biomass over time (top) and the relative difference (bottom) over 15 different "peels".

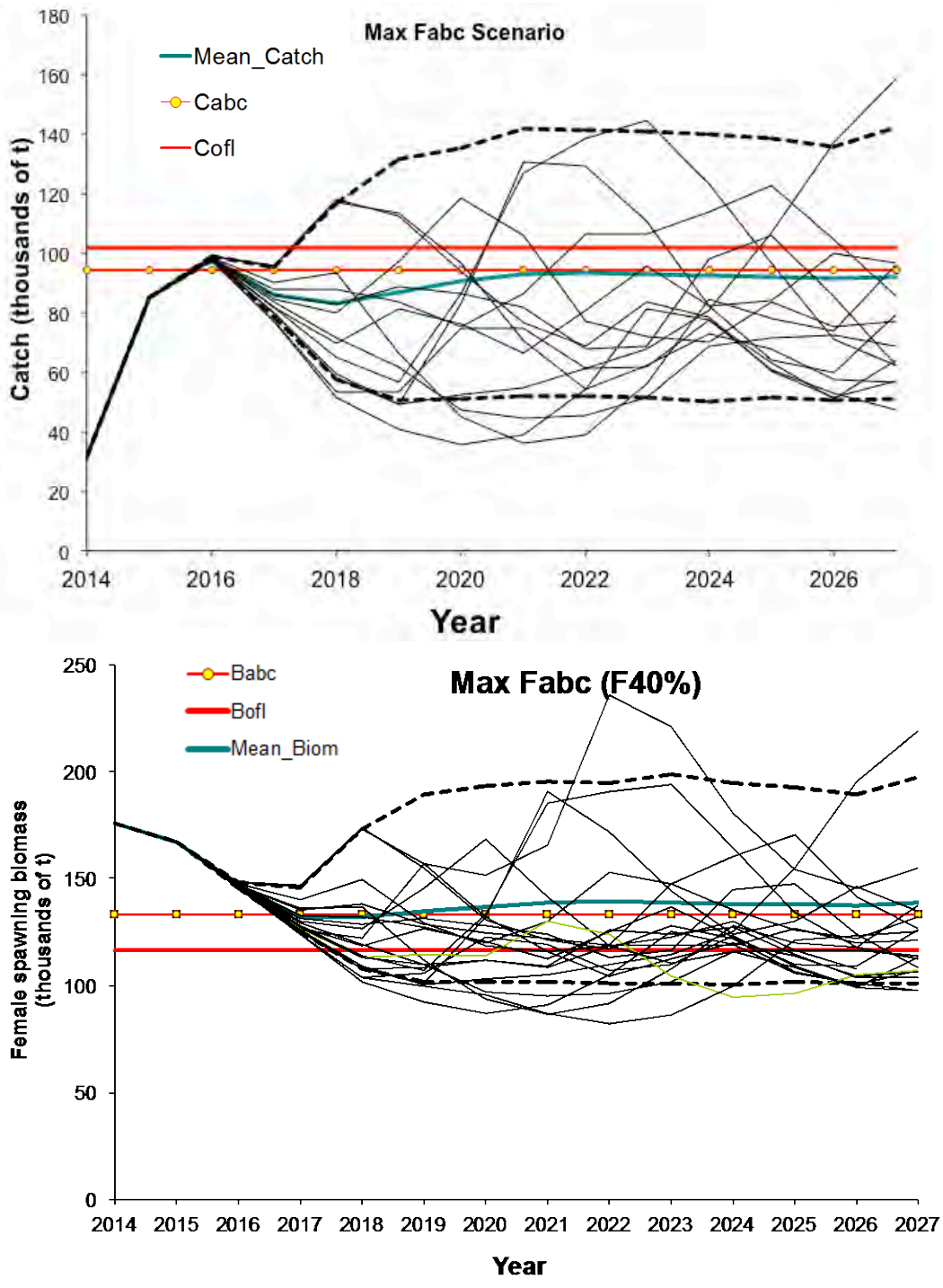


Figure 17. 21. Projected Atka mackerel catch (assuming 80% of ABC taken in 2015; top) and spawning biomass (bottom) in thousands of metric tons under maximum permissible Tier 3a harvest levels for Model 1. The individual thin lines represent samples of simulated trajectories.

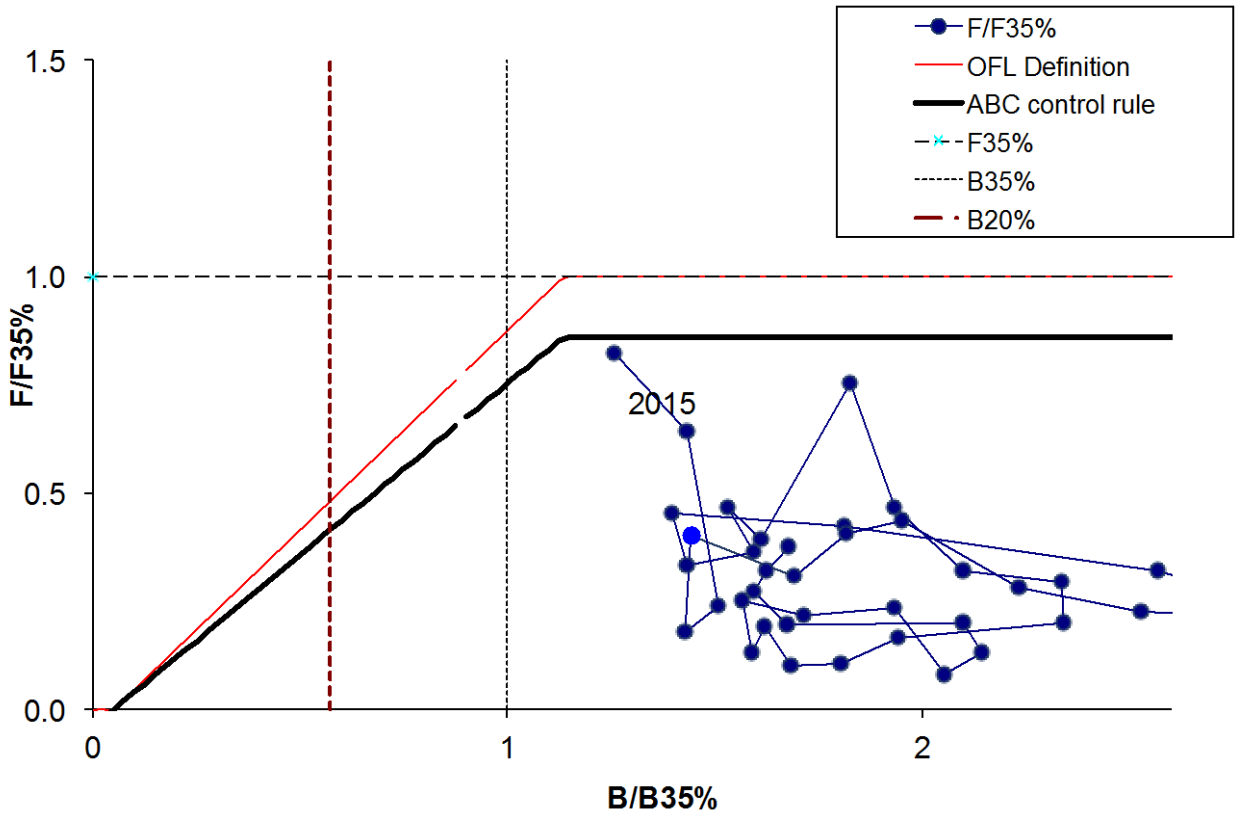


Figure 17. 22. Aleutian Islands Atka mackerel spawning biomass relative to $B_{35\%}$ and fishing mortality relative to F_{OFL} (1977-2016). The ratio of fishing mortality to F_{OFL} is calculated using the estimated selectivity pattern in that year. Estimates of spawning biomass and $B_{35\%}$ are based on current estimates of weight-at-age and mean recruitment. Because these estimates change as new data become available, this figure can only be used in a general way to evaluate management performance relative to biomass and fishing mortality reference levels.

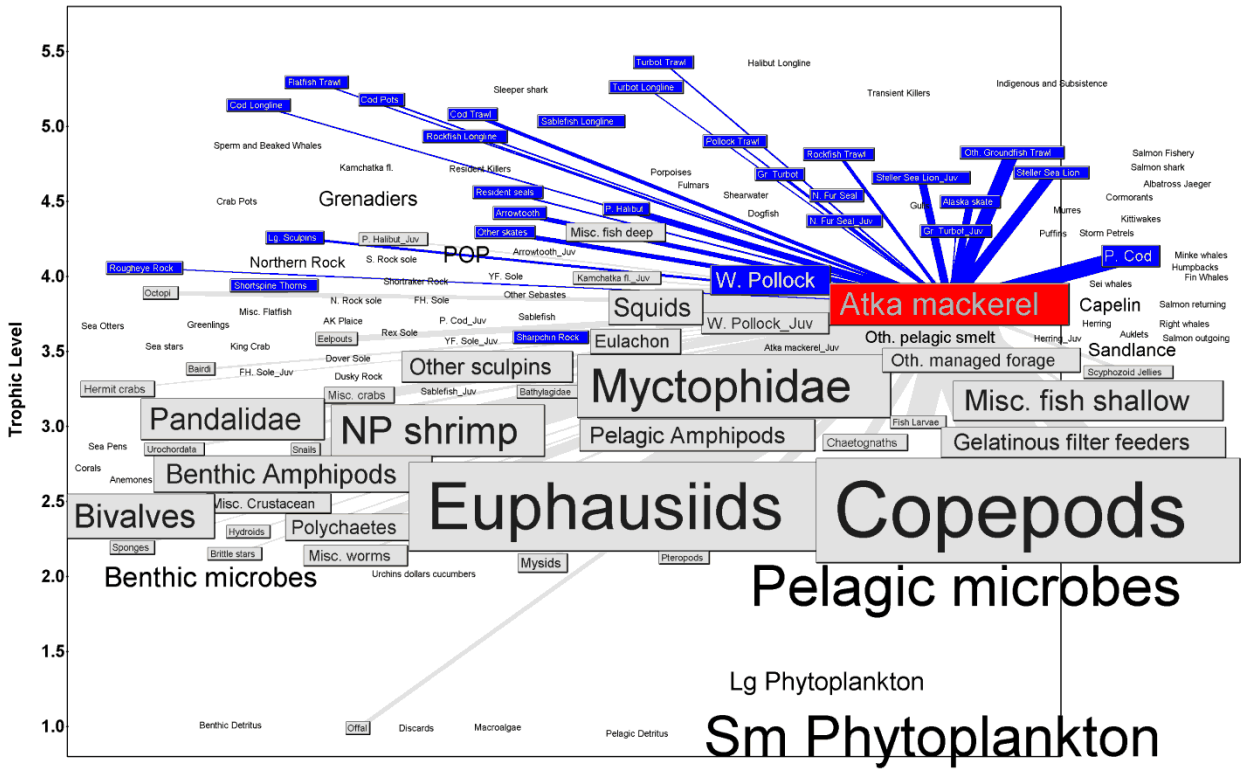
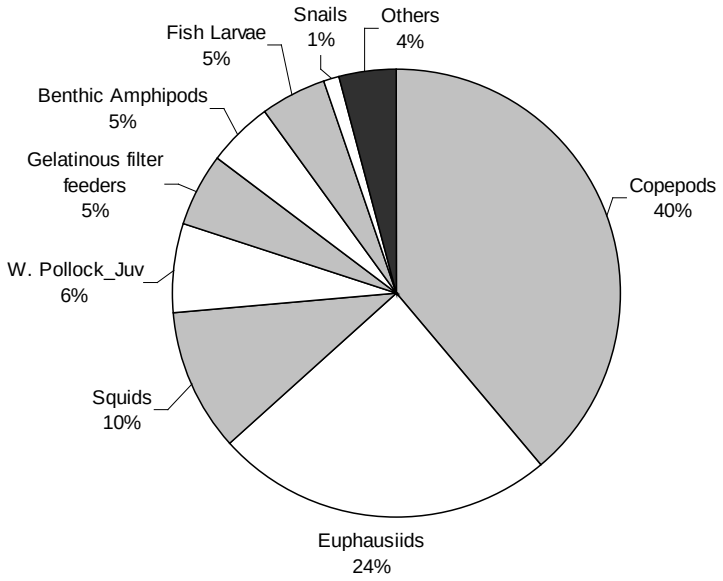
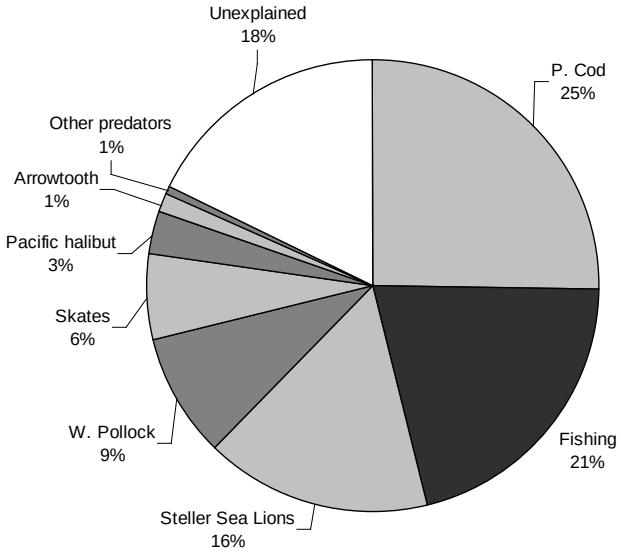


Figure 17.23. The food web of the Aleutian Islands survey region, 1990-1994, emphasizing the position of age 1+ Atka mackerel. Outlined species represent predators of Atka mackerel (dark boxed with light text) and prey of Atka mackerel (light boxes with dark text). Box and text size are proportional to each species' standing stock biomass, while line widths are proportional to the consumption between boxes (t/year). Trophic levels of individual species may be staggered up to +/-0.5 of a trophic level for visibility.



(A)



(B)

Figure 17.24. (A) Diet of age 1+ Atka mackerel, 1990-1994, by percentage wet weight in diet weighted by age-specific consumption rates. (B) Percentage mortality of Atka mackerel by mortality source, 1990-1994. "Unexplained" mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and the predation and fishing mortality, which are calculated independently of the assessment using predator diets, consumption rates, and fisheries catch.

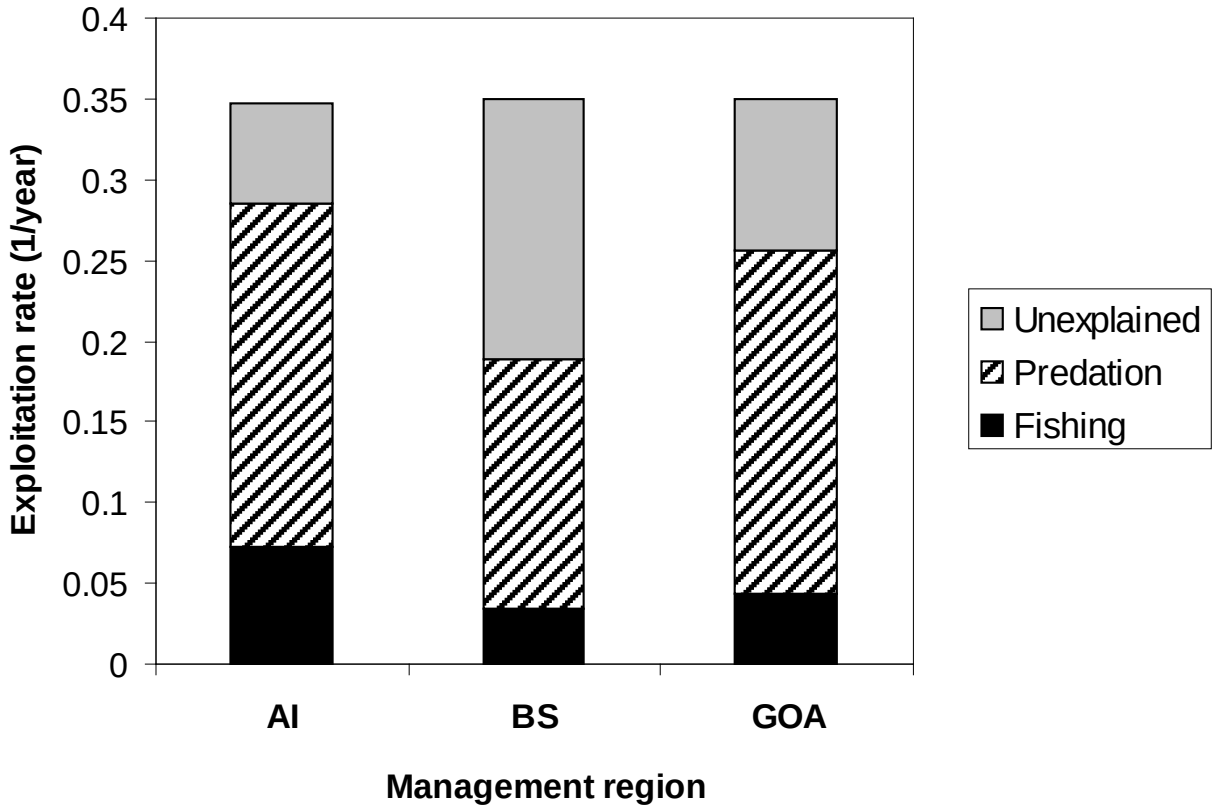


Figure 17.25. Total exploitation rate of age 1+ Atka mackerel, 1990-1994, proportioned into exploitation by fishing (black), predation (striped) and "unexplained" mortality (grey). "Unexplained" mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and the predation and fishing mortality, which are calculated independently of the assessment using predator diets, consumption rates, and fisheries catch.

Appendix 17A

Table A-1. Variable descriptions and model specification.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1977, …., 2014}	i	
Age index: j = {1, 2, 3, …, A}	j	
Mean weight by age j	W_j	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity parameterization
	σ_d^2	Dome-shape penalty variance term
Instantaneous Natural Mortality	M	Fixed M=0.30, constant over all ages
Proportion females mature at age j	p_j	Definition of spawning biomass
Sample size for proportion at age j in year i	T_i	Scales multinomial assumption about estimates of proportion at age
Survey catchability coefficient	q^s	Prior distribution = lognormal(1.0 , σ_q^2)
Stock-recruitment parameters	R_0	Unfished equilibrium recruitment
	h	Stock-recruitment steepness
	σ_R^2	Recruitment variance
Estimated parameters		
	$\phi_i(36),\ R_0,\ \varepsilon_i(46), \sigma_R^2,\ \mu^f, \mu^s,\ M,\ \eta_j^s(10),\ \eta_j^f(10), F_{50\%}, F_{40\%}, F_{30\%}, q^s$	

Note that the number of selectivity parameters estimated depends on the model configuration.

Table A-2. Variables and equations describing implementation of the Assessment Model for Alaska (AMAK).

Description	Symbol/Constraints	Key Equation(s)
Survey abundance index (s) by year	Y_i^s	$\hat{Y}_i^s = q_i^s \sum_{j=1}^{A} s_j^s W_{ij} e^{Z_{i,j}\frac{7}{12}} N_{ij}$
Catch-at-age by year	C_{ij}	$\hat{C}_{ij} = N_{ij} \frac{F_{ij}}{Z_{ij}} \left(1 - e^{-Z_{ij}}\right)$
Catch biomass	$\hat{C}_i^B$	$\hat{C}_i^B = \sum_j W_{ij} \hat{C}_{ij}$
Initial numbers at age	$j = 1$	$N_{1977,1} = e^{\mu_R + \varepsilon_{1977}}$
	A $1 < j < A$	$N_{1977,j} = e^{\mu_R + \varepsilon_{1978-j}} \prod_{j=1}^{j} e^{-M}$
Maximum age	$j = A$	$N_{1977,A} = N_{1977,A-1} \left(1 - e^{-M}\right)^{-1}$
Subsequent years ($i > 1977$)	$j = 1$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
	$1 < j < A$	$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
	$j = A$	$N_{i,15^+} = N_{i-1,14} e^{-Z_{i-1,14}} + N_{i-1,15} e^{-Z_{i-1,15}}$
Year effect, i = 1967, …, 2014	$\varepsilon_i, \sum_{i=1967}^{2014} \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
Index catchability Mean effect	μ^s, μ^f	$q_i^s = e^{\mu^s}$
Age effect	$\eta_j^s, \sum_{j=1}^{A} \eta_j^s = 0$	$s_j^s = e^{\eta_j^s}$ $j \le$ maxage
		$s_j^s = e^{\eta_{\text{maxage}}^s}$ $j >$ maxage
Instantaneous fishing mortality		$F_{ij} = e^{\mu_f + \eta_j^f + \phi_i}$
mean fishing effect	μ_f	
Annual effect of fishing in year i	$\phi_i, \sum_{i=1977}^{2014} \phi_i = 0$	
Age effect of fishing (regularized) in year time variation allowed	$\eta_{ij}^f, \sum_{j=1}^{A} \eta_{ij} = 0$	$s_{ij}^f = e^{\eta_j^f}$, $j \le$ maxage $s_{ij}^f = e^{\eta_{\text{maxage}}^f}$ $j >$ maxage
In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \ne$ change year
Natural Mortality	M	
Total mortality		$Z_{ij} = F_{ij} + M$
Recruitment Beverton-Holt form	$\tilde{R}_i$	$\tilde{R}_i = \frac{\alpha B_i}{\beta + B_i}$, $\alpha = \frac{4hR_0}{5h-1}$ and $\beta = \frac{B_0(1-h)}{5h-1}$ where $B_0 = \tilde{R}_0 \varphi$ $\varphi = \frac{e^{-A_1 M} W_{A_1} p_{A_1}}{1 - e^{-M}} + \sum_{j=1}^{A} e^{-M(j-1)} W_j p_j$

Table A-3. Specification of objective function that is minimized (i.e., the penalized negative of the log-likelihood).

Likelihood /penalty component		Description / notes
Abundance indices	$L_1 = \lambda_1 \sum_i \ln\left(\left.Y_i^s\right/\hat{Y}_i^s\right)^2 \frac{1}{2\sigma_i^2}$	Survey abundance
Prior on smoothness for selectivities	$L_2 = \sum_l \lambda_2^l \sum_{j=1}^{A} \left(\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l\right)^2$	Smoothness (second differencing), Note: $l=\{s,$ or $f\}$ for survey and fishery selectivity
Prior on extent of dome-shape for fishery selectivity	$L_3 = \sum_l \lambda_3^l \sum_{j=5}^{A} \left(I_j d_j\right)^2$ $d_j = \left(\ln\left(s_j^f\right) - \ln\left(s_{j-1}^f\right)\right)$ $I_j = \begin{cases} 1 \text{ if } d_j > 0 \\ 0 \text{ if } d_j \le 0 \end{cases}$	Allows model some flexibility on degree of declining selectivity at age
Prior on recruitment regularity	$L_4 = \lambda_4 \sum_{i=1967}^{2014} \varepsilon_i^2 + 0.5 \sum_{t=1977}^{2012} \left(\ln R_t - \ln \hat{R}_t\right)/\sigma_R^2$	Influences estimates where data are lacking (e.g., if no signal of recruitment strength is available, then the recruitment estimate will converge to median value).
Catch biomass likelihood	$L_5 = \lambda_5 \sum_{i=1977}^{2014} \ln\left(C_i^B \left/ \hat{C}_i^B\right.\right)^2$	Fit to survey
Proportion at age likelihood	$L_6 = -\sum_{l,i,j} T_{ij}^l P_{ij}^l \ln\left(\hat{P}_{ij}^l \cdot P_{ij}^l\right)$	$l=\{s, f\}$ for survey and fishery age composition observations
Fishing mortality regularity	$L_{_} = \lambda_6 \sum_{i=1978}^{2014} \phi_i^2$	(relaxed in final phases of estimation)
Priors	$L_7 = \left[\lambda_7 \frac{\ln\left(M/\hat{M}\right)^2}{2\sigma_M^2} + \lambda_8 \frac{\ln\left(q/\hat{q}\right)^2}{2\sigma_q^2}\right]$	Prior on natural mortality, and survey catchability (reference case assumption that M *is* precisely known at 0.3).
Overall objective function to be minimized	$\dot{L} = \sum_{i=1}^{7} L_i$	

Appendix 17B. Supplemental catch data

In order to comply with the Annual Catch Limit (ACL) requirements, two new datasets have been generated to help estimate total catch and removals from NMFS stocks in Alaska.

The first dataset, non-commercial removals, estimates total available removals that do not occur during directed groundfish fishing activities. These include removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but do not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System (CAS) estimates. Estimates for Atka mackerel from this dataset are shown along with trawl survey removals from 1977-2012 in Table 17B-1. Removals from activities other than directed fishing totaled 140 t in 2010, 1,529 t in 2011, and 62 t in 2012. This is approximately 0.2, 2.0, and <0.1% of the 2010, 2011, and 2012 ABCs respectively, and represent a very low risk to the stock. These removals were not incorporated in the stocks assessment. If these removals were accounted for in the stock assessment model, the recommended ABCs for 2015 and 2016 would likely change very little.

The second dataset, Halibut Fishery Incidental Catch Estimation (HFICE), is an estimate of the incidental catch of groundfish in the halibut IFQ fishery in Alaska, which is currently unobserved. To estimate removals in the halibut fishery, methods were developed by the HFICE working group and approved by the Gulf of Alaska and Bering Sea/Aleutian Islands Groundfish Plan Teams and the Scientific and Statistical Committee of the North Pacific Fishery Management Council. A detailed description of the methods is available in Tribuzio et al. (2011). There are no reported catches >0.5 t of BSAI Atka mackerel from this dataset.

References

Cahalan J., J. Mondragon., and J. Gasper. 2010. Catch Sampling and Estimation in the Federal Groundfish Fisheries off Alaska. NOAA Technical Memorandum NMFS-AFSC-205. 42 p.

Tribuzio, C.A., S. Gaichas, J. Gasper, H. Gilroy, T. Kong, O. Ormseth, J. Cahalan, J. DiCosimo, M. Furuness, H. Shen, and K. Green. 2011. Methods for the estimation of non-target species catch in the unobserved halibut IFQ fleet. August Plan Team document. Presented to the Joint Plan Teams of the North Pacific Fishery Management Council.

Table 17B-1. Total removals of BSAI Atka mackerel (t) from activities not related to directed fishing, since 1977. "Trawl" refers to a combination of the NMFS echo-integration; small-mesh; large-mesh; and Aleutian Islands bottom trawl surveys; and occasional short-term research projects involving trawl gear. "Longline" refers to either the NMFS or IPHC longline survey. "Other" refers to recreational, personal use, and subsistence harvest.

			Longline			
Year	Source	Trawl	NMFS	IPHC	Other	Total
1977	AFSC	0				0
1978	AFSC	0				0
1979	AFSC	0				0
1980	AFSC	48				48
1981	AFSC	0				0
1982	AFSC	1				1
1983	AFSC	151				151
1984	AFSC	0				0
1985	AFSC	0				0
1986	AFSC	130				130
1987	AFSC	0				0
1988	AFSC	0				0
1989	AFSC	0				0
1990	AFSC	0				0
1991	AFSC	77				77
1992	AFSC	0				0
1993	AFSC	0				0
1994	AFSC	147				147
1995	AFSC	0				0
1996	AFSC	0				0
1997	AFSC	85				85
1998	AFSC	0				0
1999	AFSC	0				0
2000	AFSC	105				105
2001	AFSC	0				0
2002	AFSC	171				171
2003	AFSC	0				0
2004	AFSC	240				240
2005	AFSC	0				0
2006	AFSC	99				99
2007	AFSC	0				0
2008	AFSC	0				0
2009	AFSC	0				0
2010	AFSC	140				140
2011	AFSC	1,529				1,529
2012	AFSC	62				62

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18. Assessment of the skate stock complex in the Bering Sea and Aleutian Islands

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Executive Summary

The Bering Sea and Aleutian Islands (BSAI) skate complex is managed in aggregate, with a single set of harvest specifications applied to the entire complex. However, to generate the harvest recommendations the stock is divided into two units. Harvest recommendations for Alaska skate *Bathyraja parmifera*, the most abundant skate species in the BSAI, are made using the results of an age structured model and Tier 3. The remaining species ("other skates") are managed under Tier 5 due to a lack of data. The Tier 3 and Tier 5 recommendations are combined to generate recommendations for the complex as a whole.

In response to the 2013 review by the Center of Independent Experts (CIE), and as part of an ongoing process to improve skate assessments, the BSAI Alaska skate model has been completely reworked for 2014. The most fundamental change is a lengthening of the model time period: the preferred model's start year is 1950, all of the EBS shelf survey data from 1982-present are included, and a reconstruction of historical catches extends the catch time series back to 1954. The model was also simplified, especially in relation to the 2012 model revision. This report presents the existing (i.e. 2012) model, the author's preferred new model, and two additional models requested by the Plan Teams and the SSC. Selected results of all four models are included for purposes of comparison; full model results are included only for the author's preferred model.

Also new for 2014, the random effects (RE) model created by the survey averaging working group of the Joint Plan Teams was used to create biomass estimates for "other skates" and to make harvest recommendations for that group.

Summary of Changes in Assessment Inputs

Changes in the input data:

- The entire time series (1982-present) of EBS shelf bottom trawl biomass estimates for skates was included in the model.
- Reconstructed historical catch data beginning in 1954 were included in the model.
- Four length-at-age (LAA) datasets from the EBS shelf survey were included in the model (2003, 2007-2009); a LAA dataset from the longline fishery in 2005 was determined to be inadequate and was not included in the models.
- Weight-at-length data were obtained from a dataset generated during Alaska skate tagging activities on the EBS shelf survey during 2008-2010.

Changes in assessment methodology:

- For all Alaska skate models, growth parameters are estimated within the model.
- The "embryonic stage" (ages 0-3 in previous models) was eliminated from the model, so that in the model age-0 skates are free-swimming individuals in their first year outside of the eggcase.

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- The recruitment function was returned to the original formulation, a Beverton-Holt curve with steepness fixed at 1.0; this effectively defines an average level of recruitment at all stock sizes.
- The maximum age was returned to its original value of 25 (from 30 in the 2012 model).
- Age selectivity was not included in the model.
- The random effects model was used to develop harvest recommendations for "other skates".

Summary of results

1) The exploration of the alternative models suggests a discrepancy between the length composition data (survey and fisheries) and the LAA datasets. The largest sizes of skates observed in the LAA datasets are encountered in only very small numbers in the length composition data.

2) As a result of the phenomenon described in (1), there appear to be essentially two modeling "states": one approach ("low biomass") that slightly underestimates LAA at the oldest ages, but provides excellent fits to the length composition data and reasonable estimates of selectivity; and an approach ("high biomass") that more closely fits the LAA data but provides unreasonable selectivity curves and poor fits to the length compositions. Biomass estimates for the "low biomass" state are approximately ½ that of the "high biomass" state.

3) All of the models suggest a depletion of skate biomass during the period 1950-1980, followed by a large recruitment event in the early 1980s and a return to the higher biomass levels that exist today. The recruitment event is consistent with the limited data available regarding average skate size and abundance during the time period.

4) The preferred model is of the "low biomass" type described in (2) above, as are the two alternative models (but not the existing 2012 model).

5) The author's preferred model yields an OFL that is approximately 25% higher than the OFL in 2014. The RE model-based OFL for "other skates" is similar to the 2014 OFL.

Alaska skate harvest recommendations

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2016
M (natural mortality rate)	*0.13*	*0.13*	**0.13**	0.13
Tier	*3a*	*3a*	**3a**	3a
Projected total (age 0+) biomass (t)	*603,520*	*579,785*	**528,391**	498,957
Female spawning biomass (t)				
Projected	*185,076*	*178,762*	**115,490**	112,195
$B_{100\%}$	*266,810*	*266,810*	**186,923**	186,923
$B_{40\%}$	*106,724*	*106,724*	**74,769**	74,769
$B_{35\%}$	*93,384*	*93,384*	**65,423**	65,423
F_{OFL}	*0.113*	*0.113*	**0.090**	0.090
$maxF_{ABC}$	*0.098*	*0.098*	**0.077**	0.077
F_{ABC}	*0.098*	*0.098*	**0.077**	0.077
OFL (t)	*32,381*	*30,278*	**39,883**	37,343
maxABC (t)	*28,282*	*26,444*	**34,389**	32,199
ABC (t)	*28,282*	*26,444*	**34,389**	32,199
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

other skate harvest recommendations

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2016
M (natural mortality rate)	*0.1*	*0.1*	**0.1**	0.1
Tier	*5*	*5*	**5**	5
Biomass (t)	*94,684*	*94,684*	**96,923**	96,923
F_{OFL}	*0.1*	*0.1*	**0.1**	0.1
$maxF_{ABC}$	*0.075*	*0.075*	**0.075**	0.075
F_{ABC}	*0.075*	*0.075*	**0.075**	0.075
OFL (t)	*9,468*	*9,468*	**9,692**	9,692
maxABC (t)	*7,101*	*7,101*	**7,269**	7,269
ABC (t)	*7,101*	*7,101*	**7,269**	7,269
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	No	n/a	No	n/a

aggregate harvest recommendations for the BSAI complex

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2016
OFL (t)	**41,849**	39,746	**49,575**	47,035
ABC (t)	**35,383**	33,545	**41,658**	39,468

Responses to SSC and Plan Team Comments on Assessments in General

Plan Team September 2014: "The Teams recommend that stock assessment authors calculate biomass for Tier 5 stocks based on the random effects model and compare these values to status quo."

> *Response*: The random effects model was used to generate biomass estimates and harvest recommendations for "other skates". The results were compared to the 3-survey average using a table and several figures.

Responses to SSC and Plan Team Comments Specific to this Assessment

SSC October 2014: "The SSC supports the Plan Team recommendation that the last accepted version of the model (2012) be included in November as a base model for comparison with the author's preferred model from among the new four alternative models. The SSC requested that the author also include two other models in November: (1) Model 3 (the model with logistic selectivity) and (2) a model with a more recent start date but prior to 1989 (e.g. one possibility is starting around the regime shift in 1977)."

> *Response*: The existing (2012) model was run with updated data and included in this report. In addition two alternatives to the new base model were included: 1) selectivity fixed to be asymptotic and 2) 1977 start year instead of 1950.

General Introduction

Contents of this report

Because two different assessment methodologies are used for skates, this report deviates somewhat from the format of other Stock Assessment and Fishery Evaluation (SAFE) documents. The report contains the following sections:

1) General introduction for all Bering Sea and Aleutian Islands (BSAI) skates
2) Description of the Tier 3 assessment for the Alaska skates
3) Description of the Tier 5 assessment for Other Skates
4) Harvest recommendations for all BSAI skates
5) Ecosystem considerations
6) Tables & Figures
7) Appendix containing supplementary catch information

Description, scientific names, and general distribution

Skates (family Rajidae) are cartilaginous fishes related to sharks. At least 15 species of skates in four genera, *Raja*, *Beringraja*, *Bathyraja*, and *Amblyraja,* are distributed throughout the eastern North Pacific and are common from shallow inshore waters to very deep benthic habitats (Eschmeyer et al. 1983, Stevenson et al. 2006). Table 1 lists the species found in Alaskan waters, with their depth distributions and selected life history characteristics.

The species within the skate assemblage occupy different habitats and regions within the BSAI Fishery Management Plan (FMP) area (Fig. 1). In this assessment, we distinguish three habitat areas: the eastern Bering Sea (EBS) shelf (< 200 m depth), the EBS slope (> 200 m depth), and the Aleutian Islands (AI) region (Fig. 2). Within the EBS, the skate species composition varies by depth, and species diversity is generally greatest on the upper continental slope at 250 to 500 m depth (Fig. 3; Stevenson et al. 2006). The EBS shelf skate complex is dominated by a single species, the Alaska skate (*Bathyraja parmifera*)

(Table 2 & Fig. 2). The Alaska skate is distributed throughout the EBS shelf habitat area (Fig. 4), most commonly at depths of 50 to 200 m (Stevenson 2004), and has accounted for between 91% and 97% of aggregate skate biomass estimates since species identification became reliable in 1999. The Bering or sandpaper skate (*B. interrupta*) is the next most common species on the EBS shelf, and is distributed on the outer continental shelf (Table 2 & Fig. 5).

While skate biomass is much higher on the EBS shelf than on the slope (Table 2 & Fig. 6), skate diversity is substantially greater on the EBS slope (Fig. 2). The dominant species on the EBS slope is the Aleutian skate *B. aleutica* (Table 2 & Fig. 7). A number of other species are found on the slope in significant numbers, including Alaska skate, commander skate *B. lindbergi*, whiteblotched skate *B. maculata*, whitebrow skate *B. minispinosa*, roughtail skate *B. trachura*, and mud skate *B. taranetzi* (Table 2). Two rare species, the deepsea skate *B. abyssicola* and roughshoulder skate *Amblyraja badia*, have only recently been reported from EBS slope bottom trawl surveys (Stevenson and Orr 2005). The Okhotsk skate *B. violacea* is also occasionally found on the EBS slope.

The skate complex in the AI is quite distinct from the EBS shelf and slope complexes, with different species dominating the biomass as well as two endemic species, butterfly skate *Bathyraja mariposa* and leopard skate *Bathyraja* sp. cf. *parmifera* (J. Orr, AFSC, pers. comm.). The leopard skate was previously thought to be a color morph of Alaska skate, which occurs in low numbers in the eastern AI. The most abundant species in the AI is the whiteblotched skate, *B. maculata* (Table 2 & Fig. 2). The whiteblotched skate is found primarily in the eastern and far western Aleutian Islands (Fig. 8). Aleutian skates are also common in the AI. The mud skate (*B. taranetzi*) is relatively common in the AI but represents a lower proportion of total biomass because of its smaller body size.

Management units

In the North Pacific, skate species were originally managed as part of the "Other Species" management category within the BSAI Fishery Management Plan (FMP). In October 2009 the NPFMC approved amendment 95 to the BSAI FMP, which separated skates from the BSAI Other Species complex. Beginning in 2011, skates are managed as a single complex with skate-specific ABC and OFL. Currently skates are taken only as bycatch in fisheries directed at target species in the BSAI, so future catches of skates are mainly dependent on the distribution of and limitations placed on target fisheries.

Stock structure

In September 2012 a report on skate stock structure was submitted to the Plan Team. The report was an evaluation of the potential for conservation concerns arising from among-species differences in spatial distribution within the Bering Sea and Aleutian Islands (BSAI) skate complex and the distribution of fishery catches. Evaluation of spatial management concerns is seriously hampered by a lack of reliable species-level catch accounting, which is the highest priority for enhancing skate conservation and management. Although too sparse to properly evaluate the issue, the available data suggest that the current spatial management practice (i.e. BSAI-wide harvest specifications and catch accounting) is appropriate for this complex. The overall exploitation rate is low relative to natural mortality. The highest catch rates occur in the region where Alaska skate (the most abundant and data-rich of all species in the complex) is predominant. The spatial distribution of catches mirrors the spatial distribution of the various species. Biomass trends for all species in all areas appear to be stable, although biomass timeseries are too short and estimates too variable for proper evaluation.

It is important to note that the difference in species composition among the different BSAI subareas likely violates the requirement, under the current National Standard guidelines, that stock complexes should only include those stocks that are "sufficiently similar in geographic distribution".

Life history

Skates have relatively low fecundity, slow growth to large body sizes, and dependence of population stability on high survival rates of a few well developed offspring (Moyle and Cech 1996). As a result they can be considered "equilibrium" life history strategists (Winemiller and Rose 1992), with very low intrinsic rates of population increase implying that sustainable harvest is possible only at very low to moderate fishing mortality rates (King and McFarlane 2003). Within this general equilibrium life history strategy, there can still be considerable variability between skate species in terms of life history parameters (Walker and Hislop 1998). Major life stages include the egg stage, the juvenile stage, and the adult stage (summarized here based on Frisk et al. 2002). All skate species are oviparous (egg-laying), investing considerably more energy per large, well-protected embryo than most commercially exploited teleost groundfish. The large, leathery egg cases incubate for extended periods in benthic habitats, exposed to some level of predation and physical damage, until the fully formed juveniles hatch. The juvenile stage lasts from hatching through maturity, several years to over a decade depending on the species. The reproductive adult stage may last several more years to decades depending on the species.

Known life history parameters of Alaskan skate species are presented in Table 1. Considerable research has been directed at skates in the Bering Sea within recent years. Graduate students at the University of Washington and California State University (Moss Landing Marine Laboratories) have completed several projects detailing aspects of life history and population dynamics of several Bering Sea species. A comprehensive study on the age, growth, and reproductive biology of the Alaska skate, the most common skate species on the eastern Bering Sea shelf, was completed in 2006 (Matta 2006). Age and size at 50% maturity were 9 years and 92 cm TL for males and 10 years and 93 cm TL for females (Table 1). Von Bertalanffy growth parameters were estimated for males (L_∞ = 126.29 cm TL, k = 0.120 year^{-1}, t_0 = -1.39 year) and females (L_∞ = 144.62 cm TL, k = 0.087 year^{-1}, t_0 = -1.75 year), although length-at-age data were fit slightly better by a Gompertz growth function for both sexes. Based on seasonal reproductive data, including ova diameter, gonadosomatic index (GSI), and the presence of egg cases, the Alaska skate appears to be reproductively active throughout the year. A reproductive resting phase (e.g. 'spent' gonads) was never observed in either large males or females, and females containing egg cases were encountered during each month of collection. Annual fecundity was estimated to average 21 to 37 eggs per year, based on the relationship between annual reproductive effort and natural mortality (Gunderson 1997). While the fecundity estimate needs to be validated using direct methods, fecundity is still likely to be low for the Alaska skate, as is typical for most elasmobranchs.

Hoff (2007) examined skate reproduction and skate nursery habitat of the Alaska skate and the Aleutian skate from the eastern Bering Sea. The relationships between successful skate reproduction and selected nursery grounds were examined. Vulnerability sources, reproductive cycles, habitat selection criteria, and physical factors controlling reproduction were addressed. To date, six nursery sites for three different skate species have been described in the eastern Bering Sea (Fig. 9), and there is ample evidence that additional nursery areas exist. All sites are located along the shelf-slope interface in approximately 140-360 m of water. Two sites, those of the Alaska and Aleutian skates, have been studied in detail through seasonal monitoring. An index location at each nursery site was re-sampled approximately once every 60 days from June 2004 through July 2005 for a total of eight sampling periods. During each sampling period data on mortality, reproductive cycles, embryo developmental, species utilization and adult reproductive states were examined.

The Alaska skate nursery in Bering Canyon (Fig. 9) is located in 149 meters of water near the shelf-slope interface in a highly productive area of the eastern Bering Sea. The nursery is small in area (< 2 nautical miles), persistent, and highly productive. Density estimates from trawling showed the most active part of the nursery contained >100,000 eggs/km^2. Two peak reproductive periods during summer and winter were evident in the Alaska skate nursery. During each active period the nursery showed high densities of mature reproductive adults and high numbers of newly deposited egg cases. Although there are peak

reproductive periods at any single sampling time, the nursery contained embryos in all stages of development, and specific cohorts were easily discernible from frequency stage monitoring. Cohort analysis based on embryo lengths measured at an Alaska skate nursery site in the EBS suggested that the Alaska skate has an egg-case development time of over 3 years, possibly due to the cold ocean temperatures in the EBS (Fig. 10; Hoff 2007). Captive studies are at the Alaska Sealife Center (Seward, AK) have provided preliminary data that validate this conclusion (J. Guthridge, ASLC, pers. comm.). The field observations are also consistent with development times observed in other skate species (Fig. 11; Hoff 2007). For example, thorny skate (*Raja radiata*) embryos spend approximately 2.5 years in the egg-case development stage at warmer temperatures than those found in the EBS (Berestovskii 1994 cited in Hoff 2007).

The Oregon triton *Fusitriton oregonensis* was the most likely predator on newly deposited egg cases and mortality rate was estimated at 3.64% per year (Hoff 2007). After hatching, young skates were vulnerable to predation by Pacific cod, *Gadus macrocephalus* and Pacific halibut, *Hippoglossus stenolepis*. Predation by these two large fish species peaked during the summer and winter periods and was highly correlated with hatching events. The Alaska skate nursery site was occupied by mature male and female skates throughout the year, with juvenile and newly hatched individuals extremely rare. Evidence suggests that newly hatched skates quickly move out of the nursery site and immature skates are infrequent visitors to nursery sites. Some degree of intra-species habitat partitioning is evident and is being examined for the Alaska skate throughout the eastern Bering Sea shelf environment.

Fishery

Directed fishery

In the BSAI, there is no directed fishery for skates at present but there is some interest in developing skate fisheries in Alaska. A directed skate fishery developed in federal waters of the Gulf of Alaska in 2003 (Gaichas et al. 2003), and despite the closure of that fishery interest remains. A small state-waters fishery was conducted in Prince William Sound in 2009 and 2010. Retention of incidentally-caught large skates occurs, indicative of their market value.

Bycatch and discards

Skates are caught incidentally in substantial numbers in BSAI fisheries (Tables 3-4 & Fig. 12). At present the Alaska regional office's Catch Accounting System (CAS) only reports species-specific catch for selected skate species, and these estimates are complicated by limitations of observer data (see below). For the purposes of the age-structured model, the fraction of Alaska skates in the total skate catch is estimated by applying the average species composition encountered during trawl surveys (see Data section below).

Skates are caught in almost all fisheries and areas of the Bering Sea shelf, but most of the skate bycatch is in the hook and line fishery for Pacific cod. Trawl fisheries for pollock, rock sole, flathead sole, and yellowfin sole also catch significant amounts (Table 5). The catch of skates in pollock fisheries has increased in recent years, possibly because the fisheries are targeting pollock closer to the bottom. In this assessment, "bycatch" is interpreted as incidental or unintentional catch regardless of the disposition of catch – it can be either retained or discarded. We do not use the Magnuson Act definition of "bycatch," which always implies discard. When caught as bycatch, skates may be discarded (and may survive depending upon catch handling practices) although skates caught incidentally are sometimes retained and processed. In 2011, 24% of captured skates were retained. Data from Gulf of Alaska fisheries suggests that larger skates are preferentially retained.

Historically, skates were almost always recorded as "skate unidentified", with very few exceptions between 1990 and 2002. Beginning in 2005, additional training greatly increased observers' ability to identify skates to species. However, many skates are still only identified to the genus level because most skates are caught in longline fisheries, and if the animal drops off the longline it cannot be identified to species by the observer. Changes made to the observer manual at the author's request have resulted in a large increase in skate length measurements beginning in 2008.

The NMFS reporting areas encompassing the EBS outer shelf (521 and 517) have historically experienced the highest incidental skate catch rates in the BSAI, but in recent years the catch in area 509 has increased and 509 has the highest catches in some years (Table 6 & Fig. 12). Area 509 includes the part of the middle shelf domain immediately north of the Alaska Peninsula. As skates are caught incidentally, this change likely reflects a change in the fishing behavior of the target Pacific cod and flatfish fisheries where most skate are caught.

ALASKA SKATE – Tier 3 assessment

Overview

The BSAI Alaska skate population model has been used since 2008 for making harvest recommendations. The model was substantially revised in 2012; the main benefit of the revised model was a closer fit to the length-at-age (LAA) data. However aspects of the model, e.g. fits to some of the length composition data, remained problematic. The model was reviewed by the Center for Independent Experts (CIE) in May 2013 as part of their review of non-target assessments conducted by the Alaska Fisheries Science Center (AFSC). The reviewers concluded that they had insufficient time to properly review the Alaska skate model, but did offer some comments. The reviewers noted some problems such as fits to the length composition data, and were unanimous in stating that the model should include the EBS shelf bottom trawl survey time series. That suggestion formed the basis of the modeling approach described in this report.

The 2014 model revision was guided by a conceptual approach with the following aspects:

1) *Determinate growth*: Several features of the data suggest that Alaska skate growth either slows dramatically or stops altogether at older ages. A strong size mode is observed in many of the Alaska skate length compositions at approximately 100 cm, and the proportion of skates at larger sizes decreases abruptly. Skates larger than 100-104 cm appear to be rare in the population. These data suggest that there is an accumulation of large skates in the population that occurs as skates get older but do not grow appreciably in size. All of the growth parameters were estimated within the model, but starting values were chosen and model development was guided assuming determinate growth.

2) *Large recruitment event*: Earlier versions of the model avoided using the full EBS shelf survey time series because a dramatic increase in skate biomass during the 1980s was difficult to explain and seemed counter to the equilibrium life history strategy assumed for skates. In preparation for the model revision, the available data were explored. Although length data for skates do not exist prior to 1999, it was possible to estimate mean weight of captured skates and mean numerical CPUE for survey hauls using the same net configuration from 1975 to 2013. These data (not included in this document but available) suggest that the increase in skate biomass during the 1980s resulted from both an increase in the number of skates AND the mean size of skates, both

of which increased dramatically. This is consistent with a major recruitment event occurring over a small number of years. The data are still being explored, but this apparent recruitment event occurred at approximately the same time as a major ecological regime shift in the late 1970s and may be related to it. Alaska skates have a long (approximately 3.5 years) embryonic development time during which they are growing inside eggcases deposited on the ocean floor, and the duration of the embryonic stage appears to be highly dependent on temperature (Hoff 2007). It may be that fluctuations in development time during this time of environmental change caused the emergence of multiple year classes from their eggcases at the same time. An alternative or additional explanation is that survival of young skates was enhanced by environmental conditions. The development of the model was guided by the assumption that the model should demonstrate a large recruitment event in the late 1970s and/or early 1980s

3) *Simplification*: The model was also developed with an aim towards simplifying it where appropriate. One aspect of this was to use a simpler approach to the stock-recruit function, which is described below. Another aspect was to eliminate the embryonic development period from the model. All previous versions of the model included the embryonic period, and used knife-edged age selectivity to define those ages (0-3.5) where skates were in eggcases and unavailable to either the survey or fisheries. The embryonic period was included because it seemed important for linking year classes to spawning stocks. However there is essentially no relationship between spawning stock size and recruitment (and in earlier versions of the model, very little contrast in spawning stock size). In addition, the inclusion of knife-edged age selectivity seemed to create problems inside the model. Therefore, all versions of the 2014 modeling process assumed that age-0 skates are those that have recently emerged from eggcases and are free-swimming individuals. Age selectivity was effectively removed from the model by specifying an age-selectivity function where all ages were fully selected, and selectivity was only a function of length.

Data

Summary of data used in the Alaska skate model

source	data	years
AKRO Catch Accounting System	catch	2003-2014
KRO historical catch record	catch	1954-2002
NMFS Bottom Trawl Surveys –Eastern Bering Sea Shelf (Annual)	biomass index	1982- 2014
NMFS Bottom Trawl Surveys –Eastern Bering Sea Shelf (Annual)	length composition	2000-2014
NMFS Bottom Trawl Surveys –Eastern Bering Sea Shelf (Annual)	length-at-age	2003, 2007-2009
NMFS Fishery Monitoring & Analysis program- observed skate catch	length composition	2009-2013

Catch

Incidental catches of skates in the BSAI occur in several target fisheries but can be broken down into catches by two gear types: longline and trawl (Table 7 & Fig. 13). These fisheries have different selectivities and the majority of catches occur in the longline fisheries. Retention of skates is high and discard mortality is assumed to be 100%; therefore all captured skates are assumed to be dead.

Four models were included in this report and are described below. Three of the models (1-3) included in this report used catch data from 1954-2014; one model (model 4) used catch data from 1977-2014. All data regarding Alaska skate catches rely to some degree on assumptions regarding the proportion of

Alaska skates in the total skate catch. The earlier data also rely on assumptions regarding removals by gear type:

- *1954-1996*: Reconstruction of skate catches relied heavily on two assumptions: 1) that the proportion of trawl vs. longline effort was represented by the proportion of yellowfin sole catch vs. Pacific cod catch, and 2) that the total catch of Alaska skates could be estimated by subdividing the catch of an "Other Species" group (skates, sculpins, sharks, and octopus) based on the proportion of skates in Other Species catches in the modern era (2003-2013) and the proportion of Alaska skates in recent trawl surveys (1999-2013).
- *1997-2013*: Skate-specific catches are available during the modern era from two sources: the Blend database (1992-2002) and the Catch Accounting System (CAS) maintained by the Alaska Regional Office (AKRO). Specific catch data for Alaska skate either do not exist or are unreliable, due to the difficulty of identifying *Bathyraja* species skates in longline fisheries. Therefore, the catches were partitioned based on survey species composition during 1999-2013 and the distribution of effort among the EBS shelf and slope and the Aleutian Islands (AI). The methodology is described in complete detail in Ormseth and Matta (2007).

Catch data for 2014 were available only through October 8, so the 2014 data are incomplete. To estimate the full 2014 catch, the average increase in reported catch from early October to the end of the year for the last five years was used to create a correction factor for the 2014 data.

Fishery length compositions

Fishery length compositions from 2009-2013 were included for both gear types. Length data for the Alaska skate were collected during 2007 & 2008 as a special project by fishery observers, but the datasets are incomplete. In 2008 the observer manual was changed to require collection of skate lengths on every haul where they were present in the target fisheries for Pacific cod and flatfishes, and this change was fully implemented for 2009. Therefore, 2009 is considered the first year of reliable fishery length composition data for Alaska skate. Length data were aggregated into 4-cm bins and converted to proportions as for the survey data (Table 8). Sample size is discussed below.

Survey biomass

Three bottom trawl surveys are conducted in the BSAI region: EBS shelf, EBS slope, and the Aleutian Islands. Because the Alaska skate population is concentrated on the EBS shelf, and the EBS shelf survey provides yearly estimates of biomass, biomass estimates from only the EBS shelf survey are used in this model. Survey efforts on the EBS shelf began in the 1970s, but survey methodology was only standardized in 1982; as a result, the survey time series is considered to begin in 1982. Biomass estimates from 1982-2013 were included in the model (Table 9). Reliable skate species identification in the survey is only available starting in 1999. For each survey prior to 1999, total skate biomass estimates were partitioned into Alaska skate and "other" skates based on the average proportion (0.95) of Alaska skate in the 1999-2013 surveys. The modeling software employs the coefficient of variation (CV) as the standard deviation (s) associated with each estimate. For the estimates prior to 1999, the value of s for the entire skate complex was used.

Survey length compositions

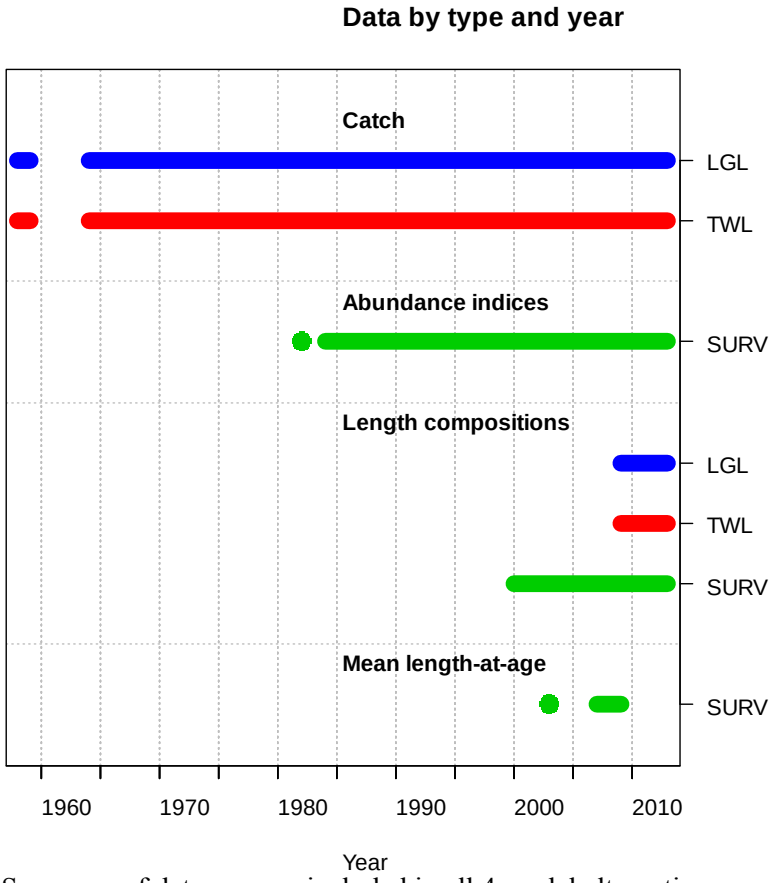
Length composition data from the EBS shelf survey were available from 2000-2013 (Table 10). The survey takes length measurements for every skate in each haul. The haul-specific data are then weighted by the number of skates in each haul to produce an estimate of numbers at length for the entire EBS population. The length data were aggregated into 4-cm bins and converted to proportions for inclusion in the model. Sample size is discussed below.

Length at age

Four LAA datasets from the years 2003 (N=182), 2007 (N=237), 2008 (N=165), and 2009 (N=330) were included in the model. Age was determined through examination of annual growth rings in vertebral thin sections following hatching from the eggcase. All four datasets used vertebrae collected during the EBS shelf survey. The 2003 dataset was generated during a graduate student project (Matta 2006); the remaining datasets resulted from production ageing at the AFSC. A dataset generated from vertebrae collected during the 2005 longline fishery and included in earlier model versions was considered to be flawed (due to a poor sampling design) and was eliminated from the model.

Sample size

Appropriate sample size (N) for the length compositions and LAA data can be difficult to determine. Previous versions of the model used N=100 for all length compositions. After exploring the literature, including other SAFE reports conducted by the AFSC, and through discussions with other assessment authors, the following approach was taken regarding sample size. In general, hauls are considered to be the sampling unit rather than individual length measurements. The total number of hauls each year varies little for the survey, so N=200 was used for all survey length compositions. In the fisheries, a large number of hauls is sampled, so the square root of the number of hauls was used for input N to avoid overemphasis on fishery length compositions. For the LAA data, the actual number of individuals was used as input N. Some exploration of the effect of changing input Ns was performed: for example, fishery length composition N was set equal to the survey N. Unless very large changes were made, these changes had only minor influence on the model.



Summary of data sources included in all 4 model alternatives.

Analytic Approach

Model structure

The 2014 model revisions were conducted using Stock Synthesis 3 (SS3) assessment software[1] (Methot 2005, 2007). Stock Synthesis allows the flexibility to incorporate both age- and size-structured information in an age-structured model. In the models described here, natural mortality is the only parameter that is explicitly age-based; selectivity, maturity, and mean body weight are length-based parameters. Length-at-age data and estimates of ageing error are used by SS3 to convert the size-based information into age-specific values that can be used to model the population through time. In SS3 it is possible to differentially weight the likelihood components by specifying weighting factors (lambdas) in the control file. With one exception, the model alternatives presented here weight all components equally.

Numerous alternative models were explored during the 2014 revision process. Four models were presented to the Plan Team in September 2014; based on the resulting discussion and requests from the Plan Team and SSC the following models are included in this report:

- Model 1: Existing model with updated data (i.e. model used in the 2012 assessment).
- Model 2: Base version of new model, with features described below. **Author's preferred model.**
- Model 3: Base model with selectivity parameter 6 fixed for both fisheries and the survey, creating asymptotic selectivity curves. This model offered a contrast to the dome-shaped selectivity curves generated in the base model.
- Model 4: Base model (Model 2) starting in 1977 rather than 1950.

All of the models continued a number of assumptions used since the model was first created. The entire BSAI was treated as one homogenous area. Because growth and maturity patterns are similar for males and females, only one sex was specified. Spawning was assumed to occur at the midpoint of the year. No informative priors were used. It was assumed that parameters did not vary with season or year and were not influenced by environmental conditions. All parameters are listed in Table 11 and described in more detail below.

Parameters estimated outside the assessment model

Natural mortality (M)

In 2007, a value of 0.13 was chosen from a set of *M* values estimated using different life history parameters (Matta 2006): growth parameters (Alverson and Carney 1975, Pauly 1980, Charnov 1993), longevity (Hoenig 1983), reproductive potential (Rikhter and Efanov 1976, Roff 1986), von Bertalanffy k (Jensen 1996, Gunderson 2003), and age at maturity (Jensen 1996). Previous runs of the model have demonstrated that this value of *M* provides the best model fit, so *M* in the model continues to be fixed at 0.13.

Length at maturity

SS3 incorporates female maturity parameters into the model using the following equation:

$$\text{proportion mature} = \frac{1}{1 + e^{b(L - L_{50})}},$$

where L_{50} is the length at 50% maturity and b is a slope parameter. Maturity parameters were obtained from Matta (2006), where b = -0.548 and L_{50} = 93.28 cm TL. Maturity was estimated directly from paired

[1] NOAA Fisheries Toolbox Version 3.23b, 2011. Stock Synthesis 3, Richard Methot, Northwest Fisheries Science Center, Seattle, WA. [Internet address: http://nft/nefsc.noaa.gov]

length and maturity stage data; maturity stage was easily assessed through macroscopic examination of the reproductive organs.

Ageing error
Each vertebra was aged three independent times by a primary age reader without knowledge of the specimen's biological information. For each true age, the standard deviation of the estimated age was calculated from the three reads of each vertebra and incorporated into the model to account for variability in age determination.

Survey catchability
The approach to survey catchability remains unchanged from previous models. Survey catchability was fixed at 1. The EBS shelf survey appears to sample Alaska skates very reliably, with CVs of approximately 0.05. In addition, we did not adjust catchability for the segments of the Alaska skate population (AI and EBS slope) that are not observed by the EBS shelf survey. Over 96% of the Alaska skate population is on the shelf and surveys from the other areas are infrequent.

Age selectivity
In contrast to earlier versions of the model, selectivity at age was not included in the model, i.e. all ages were fully selected and selectivity was solely a function of length.

Weight at length
Parameters from the allometric length-weight relationship ($W = aTL^b$, where W is weight in kg and TL is total length in cm) were obtained through analysis data obtained during an Alaska skate tagging project conducted aboard EBS shelf surveys 2008-2010 (O. Ormseth, unpublished data). Parameters were not significantly different between sexes, so data were combined. For sexes combined, a was estimated as 9.0×10^{-6} and b was estimated as 2.9617 (Figure 14; $r^2 = 0.93$, N = 1,515).

Spawner-recruit parameters
The 2012 version of the model (Model 1) used a survivorship function developed for low-fecundity species rather than a traditional stock-recruit function. Upon further review, it was decided that insufficient data were available to parameterize the more complex survivorship function. All of the 2014 models returned to the approach used in the original model, where a Beverton-Holt function is specified and steepness fixed at 1.0 to create a mean level of recruitment. All models used a fixed σ_R value of 0.4.

Parameters estimated inside the assessment model

Growth parameters
An analysis by Matta (2006) suggested that a Gompertz growth model best fit the length-at-age data for Alaska skate. As in the 2012 model, the Gompertz growth function was approximated in SS3 by choosing the Schnute 4-parameter growth model option (Schnute 1981). The Schnute model takes the form:

$$Y(t) = \left\{ y_1^{\gamma} + \left(y_2^{\gamma} - y_1^{\gamma}\right) \frac{1 - exp[-\kappa(t - \tau_1)]}{1 - exp[-\kappa(\tau_2 - \tau_1)]} \right\}^{1/\gamma}$$

where $Y(t)$ is length at age t; y_1 and y_2 are the length at ages $\boldsymbol{\tau}_1$ and $\boldsymbol{\tau}_2$, respectively; and κ and γ are parameters that control the shape of the growth curve. In SS3, κ is referred to as the von Bertalanffy k parameter and γ is referred to as the Richards coefficient. All growth parameters were estimated within the model, as were the two uncertainty parameters (CV of LAA at ages $\boldsymbol{\tau}_1$ and $\boldsymbol{\tau}_2$).

Length selectivity

For models 1, 2, & 4 all length selectivity parameters were estimated within the model. All models used a double-normal selectivity function recommended in the documentation for SS3 (Methot 2012). The double-normal is defined by six parameters for each fishery or survey, where p1 is the peak or ascending inflection size, p2 is the width of the plateau, p3 is the ascending width, p4 is the descending width, p5 is the selectivity at the first length bin, and p6 is the selectivity at the last length bin. In model 3, p6 was fixed so that the selectivity function was asymptotic. Selectivity parameters are summarized in Table 11. All bounds were the default values specified in the SS3 documentation.

Spawner-recruit parameters
The natural log of unfished recruitment (R_0) was estimated within the model. In addition, recruitment deviations were estimated for 1950-2013; in SS3 each deviation is considered a separate parameter.

Initial fishing mortality
Initial fishing mortality was estimated within the model for each of the two fisheries.

Results

Model Evaluation

Model evaluation criteria
A summary of model fit comparisons is located in Table 12. The models were evaluated using the following criteria:

1) The standard deviation of the parameter estimates was converted to CV; a lower CV indicated a better fit.
2) Model fit to the survey data was conducted by comparing root mean squared error (RMSE), the average standardized residual, the correlation between observed and predicted values and the proportion of survey biomass estimates where the model estimate was within the 95% confidence interval (CI) of the observed value. For RMSE and the average residual, lower values indicated a better fit. For the correlation and the proportion of model estimates within the CIs, higher values indicated a better fit.
3) Comparison of effective sample sizes (N_{eff}) for length compositions, with higher N_{eff} indicating better fit to the data.
4) Comparison of effective sample sizes (N_{eff}) for LAA datasets, with higher N_{eff} indicating better fit to the data.
5) Visual inspection of model fits to length compositions and LAA data.
6) Reasonable estimates of fishery length selectivity parameters.
7) Reasonable estimates of unfished recruitment and recruitment variability as well as consistency with the conceptual approach described in the overview.

Evaluation of model criteria

1) The CV of parameter estimates varied among the models. Models 1-3 all had an equivalent number of lowest CVs; model 4 had none (Table 12).
2) All of the models showed good fits to the survey data. Model 1 had the lowest RMSE; of the 3 "new" models, Model 2 had the lowest RMSE. Model 2 also had the lowest average standardized residual. Model 2 had the highest proportion of model fits within the CI, while Model 4 had the highest correlation between observations and predictions.
3) Effective Ns for the length compositions were much greater than one for all the models. The highest effective Ns were observed in Models 2 & 4. Effective Ns for Model 1 were generally low relative to the 3 new models.
4) For the LAA data, Model 2 had the highest effective N.

5) Visually, Model 2 had the best fits to the length composition data (Figure 15), although the fit for models 2-4 were very similar. Model 1 had noticeably worse fits to the length composition data; Model 1 did not fit the mode at large sizes in the longline and survey length compositions. All of the models fit the LAA data well (Figures 16 & 17), although all 4 slightly underestimated LAA at larger.
6) There was a substantial difference in the selectivity curves produced by the models (Figure 18). Models 2 & 4 produced moderately descending limbs for both fisheries and the survey. The decrease in selectivity at larger sizes varied by fleet, with final selectivity ranging from 0.5 to 0.8. In contrast, Model 1 produced an unrealistic degree of dome-shaped selectivity, with selectivity rapidly descending to zero above 100 cm. Model 3 was parameterized so that selectivity was asymptotic.
7) Models 2-4 provided different estimates of recruitment (Figure 19), but all of the estimates were consistent with a large recruitment event in the early 1980s. In contrast, the older model configuration (Model 1) included no such event. The recruitment event in Models 2 & 3 occurred over several years, while in Model 4 there was a single year of very high recruitment.

Discussion of model evaluation and designation of preferred model

The new base model (Model 2) provided the best overall fits when the data are considered as a whole (Table 12 & Figs. 15-26), produced results that are consistent with the conceptual approach, and is the author's preferred model. There are two potential issues with Model 2. First, as is the case for the other "low biomass" models, LAA was slightly underestimated which may lead to an underestimate of spawning biomass. However, particularly for the 2008 and 2009 datasets, the underestimate was small. In addition, as described earlier, closer fits are only possible if the selectivity function is allowed to drop to zero. Essentially, the model can only fit the larger sizes in the LAA dataset by reducing the selectivity to an unrealistic level.

An additional issue is the estimation of descending limbs for the selectivity functions. Examination of the distribution of Alaska skate by size in the BSAI (Figure 27) suggests that the fisheries and survey may indeed have limited access to larger skates. Alaska skates display a marked ontogenetic movement from nursery areas on the slope in towards the inner domain of the EBS shelf. They reach the innermost shelf at approximately the age of maturity, at which time they appear to either disperse or return to the slope for spawning. Thus, the largest skates are generally encountered either along the slope or in the innermost domain. The variation in the descending limbs is consistent with this pattern. The trawl fishery, which is conducted mainly in the middle domain where few large skates are found, has the biggest decrease. The longline fishery, which occurs mainly in the outer domain and along the slope, has only a small decrease in selectivity at large sizes. The survey is intermediate to the two fisheries.

Time series results

Results presented below are for the preferred model, Model 2.

Definitions

Biomass is shown as total (age 0+) biomass (metric tons; t) of all Alaska skates in the population, and as spawning biomass (for both sexes; t). Recruitment is reported as the number (in thousands) of Alaska skates at age 0. The CV is included for spawning biomass and age-0 recruits.

Biomass time series

Time series of total biomass and spawning biomass estimates from 1950-2013 are reported in Table 13. Spawning biomass is also shown in Figure 28. The model suggests that the skate population declined beginning in the 1950s, with the steepest decline during the 1970s. The population then rebounded dramatically during the 1980s and has been relatively stable since 1990. Table 14 shows a comparison between the existing model (Model 1) and the new preferred model (Model 2). Unfished biomass was higher in the existing model, but 2014 biomass was fairly similar.

Recruitment

Time series of age-0 recruitment are reported in Table 13 and Fig. 29. The model suggests that a period of increased recruitment occurred between the years 1980-1984, with the highest level of recruitment in 1982. The model also estimates the recruitment was low during the 2000s but has rebounded since 2010. In the comparison between Model 1 & Model 2 (Table 14), unfished and 2014 recruitment was similar but the high recruitments during the early 1980s were not present in the Model 1 model.

Exploitation rate

A time series of exploitation (catch/total biomass) is given in Table 15. These rates suggest that skates experienced the greatest fishing pressure in the 1970s and that most of these removals occurred in the trawl fishery. Exploitation rates have been fairly stable (~0.4-0.5) since the 1990s.

Harvest recommendations

Alaska skate harvest recommendations

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2014	2015	2015	2016
M (natural mortality rate)	*0.13*	*0.13*	**0.13**	0.13
Tier	*3a*	*3a*	**3a**	3a
Projected total (age 0+) biomass (t)	*603,520*	*579,785*	**528,391**	498,957
Female spawning biomass (t)				
Projected	*185,076*	*178,762*	**115,490**	112,195
$B_{100\%}$	*266,810*	*266,810*	**186,923**	186,923
$B_{40\%}$	*106,724*	*106,724*	**74,769**	74,769
$B_{35\%}$	*93,384*	*93,384*	**65,423**	65,423
F_{OFL}	*0.113*	*0.113*	**0.090**	0.090
$maxF_{ABC}$	*0.098*	*0.098*	**0.077**	0.077
F_{ABC}	*0.098*	*0.098*	**0.077**	0.077
OFL (t)	*32,381*	*30,278*	**39,883**	37,343
maxABC (t)	*28,282*	*26,444*	**34,389**	32,199
ABC (t)	*28,282*	*26,444*	**34,389**	32,199
	As determined *last* year for:		As determined *this* year for:	
Status	2012	2013	2013	2014
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

OTHER SKATES – Tier 5 assessment

Data

Survey biomass

The biomass of the skate assemblage as a whole has increased since the early 1980s (Tables 16-20 & Figs. 30-33). Because skates as a group are contiguous and found in nearly all habitats, the uncertainty (measured as the coefficient of variation, CV) in aggregate skate biomass estimates is rather low, but the uncertainty for individual species is greater. Survey species identifications are considered reliable after 1998. Unfortunately, due to taxonomic uncertainty, we cannot evaluate individual species trends within the complex for surveys prior to 1999

Results of the random effects (RE) model for other skates varied by region (Table 21 & Fig. 34). For the EBS slope and AI surveys, the RE estimates showed less annual variability than the survey estimates but greater variability than the 3-survey running average that has historically been used for harvest specifications. For the EBS shelf survey, the RE model was only able to fit an average biomass value that did not vary across the entire 1999-2014 time series. This may have been due to the lack of a trend in the relatively short timeseries, and/or the high interannual variability and CVs in the early part of the time series. The RE model for the EBS shelf was run using a number of different configurations (e.g. truncating the dataset to remove the early values, changing the initial survey estimates, and modifying the CVs). All configurations had the same result. The RE model estimate was very close to the mean of all the survey biomass estimates. The RE model results were determined to be reasonable and were aggregated to produce a BSAI-wide estimate for other skates for use in harvest recommendations.

Analytic Approach

Parameter Estimates

Natural Mortality (*M*)

There is a great deal of uncertainty regarding reliable estimates of *M* for the skate complex. This assessment used the value of *M*=0.1 that has been used consistently in the BSAI and GOA for skates.

Results

Harvest recommendations

other skate harvest recommendations				
	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2014	2015	2015	2016
M (natural mortality rate)	*0.1*	*0.1*	**0.1**	0.1
Tier	*5*	*5*	**5**	5
Biomass (t)	*94,684*	*94,684*	**96,923**	96,923
F_{OFL}	*0.1*	*0.1*	**0.1**	0.1
$maxF_{ABC}$	*0.075*	*0.075*	**0.075**	0.075
F_{ABC}	*0.075*	*0.075*	**0.075**	0.075
OFL (t)	*9,468*	*9,468*	**9,692**	9,692
maxABC (t)	*7,101*	*7,101*	**7,269**	7,269
ABC (t)	*7,101*	*7,101*	**7,269**	7,269
	As determined *last* year for:		As determined *this* year for:	
Status	2012	2013	2013	2014
Overfishing	No	n/a	No	n/a

Ecosystem Considerations

This section focuses on the Alaska skate in both the EBS and AI, with all other species found in each area summarized within the group "Other Skates." We also include supplemental information on the other biomass dominant species in the AI, the Aleutian and whiteblotched skates.

Skates are predators in the BSAI FMP area. Some species are piscivorous while others specialize in benthic invertebrates; additionally, at least three species, deepsea skate, roughtail skate, and longnose skate, are benthophagic during the juvenile stage but become piscivorous as they grow larger (Ebert 2003, Robinson 2006) (Table 1). Each skate species would occupy a slightly different position in EBS and AI food webs based upon its feeding habits, but in general skates as a group are predators at a relatively high trophic level. For simplicity, we show the food webs for all skate species combined in each system (Figure 35; EBS in upper panel, AI in lower panel). In the EBS food web, the skate biomass and therefore the general skate food web position is dominated by the Alaska skate, which eats primarily pollock (as do most other piscivorous animals in the EBS). The food web indicates that aside from sperm whales, most of the "predators" of EBS skates are fisheries, and that cod and halibut are both predators and prey of skates. The AI food web shows skates with different predators and prey than in the EBS, but still at the same moderately high trophic level. Relative to EBS skates, AI skates display more diet diversity (because the species complex is more diverse than in the Alaska skate-dominated EBS), and have more non-fishery predators including sharks and sea lions. These food webs were derived from mass balance ecosystem models assembling information on the food habits, biomass, productivity and consumption for all major living components in each system (Aydin et al. 2007).

The density and mortality patterns for skates also differ greatly between the EBS and AI ecosystems. The biomass density of Alaska skates is much higher in the EBS than in the AI (Fig. 36 upper left panel) and we now know that what was previous thought to be Alaska skate in the AI was likely the leopard skate. The density of Alaska skates in the EBS also far exceeds that of all other *Bathyraja* species in any area (Fig. 36 upper right panel), but the density of other *Bathyraja* skates is highest in the AI. One simple way to evaluate ecosystem (predation) effects relative to fishing effects is to measure the proportions of overall mortality attributable to each source. The lower panels of Fig. 36 distinguish predation from fishing mortality, and further distinguish these measured sources of mortality from sources that are not explained within the ecosystem models. The models are based on early 1990s fishing and food habits information. While there are many uncertainties in estimating these mortality rates, the results suggest that (early 1990s) fishing mortality exceeded predation mortality for Alaska skates and for Other Skates in the EBS and AI. Furthermore, predation mortality appeared to be higher for AI skates than for EBS skates, both for Alaska and Other Skate species in the early 1990s, suggesting that skates experience higher overall mortality in the AI relative to the EBS. One source of uncertainty in these results is that all skate species in all areas were assumed to have the same total mortality rate, which is an oversimplification, but one which is consistent with the assumptions regarding natural mortality rate (the same for all skate species) in this stock assessment. We expect to improve on these default assumptions as data on productivity and catch for the skate species in each area continue to improve.

In terms of annual tons removed, it is instructive to compare fishery catches with predator consumption of skates. We estimate that fisheries were annually removing about 13,000 and 1,000 tons of skates from the EBS and AI, respectively, on average during the early 1990s (Fritz 1996, 1997). While estimates of predator consumption of skates are perhaps more uncertain than catch estimates, the ecosystem models incorporate uncertainty in partitioning estimated consumption of skates between their major predators in each system. The predators with the highest overall consumption of Alaska skates in the EBS are sperm whales, which account for less than 2% of total skate mortality and consumed between 500 and 2,500 tons of skates annually in the early 1990s. Consumption of EBS Alaska skates by Pacific halibut and cod

are too small to be reliably estimated (Fig. 37, left panels). Similarly, sperm whales account for less than 2% of Other Skate mortality in the EBS, but are still the primary predator of Other Skates there, consuming an estimated 50 to 400 tons annually. Pacific halibut consume very small amounts of Other Skates in the EBS, according to early 1990s information integrated in ecosystem models (Fig. 37, right panels). The predators with the highest consumption of Alaska skates in the AI are also sperm whales, which account for less than 2% of total skate mortality and consumed between 20 and 120 tons of skates annually in the early 1990s. Pinnipeds (e.g. Steller sea lions) and sharks also contributed to Alaska skate mortality in the AI, averaging less than 50 tons annually (Fig. 38, left panels). Similarly, sperm whales account for less than 2% of Other Skate mortality in the AI, but are still the primary predator of Other Skates there, consuming an estimated 20 to 150 tons annually. Pinnipeds and sharks consume very small amounts of Other Skates in the AI, according to early 1990s information (Fig. 38, right panels). Gerald Hoff's research on skate nursery areas suggests that gastropod predation on skate egg cases may account for a significant portion of mortality during the embryonic stage, and Pacific cod and Pacific halibut consume substantial numbers of newly hatched juvenile skates within nursery areas. These sources of mortality may be included in future stock assessments.

Diets of skates are derived from food habits collections taken in conjunction with EBS and AI trawl surveys. Skate food habits information is more complete for the EBS than for the AI, but we present the best available data for both systems here. Over 40% of EBS Alaska skate diet measured in the early 1990s was adult pollock, and another 15% of the diet was fishery offal, suggesting that Alaska skates are opportunistic piscivores (Fig. 39, upper left panel). Eelpouts, rock soles, sandlance, arrowtooth flounder, salmon, and sculpins made up another 25 - 30% of Alaska skates' diet, and invertebrate prey made up the remainder of their diet. This diet composition combined with estimated consumption rates and the high biomass of Alaska skates in the EBS results in an annual consumption estimate of 200,000 - 350,000 tons of pollock annually (Fig. 39, lower left panel). EBS Other Skates also consume pollock (45% of combined diets), but their lower biomass results in consumption estimates ranging from 20,000 - 70,000 tons of pollock annually (Fig. 39, right panels). Other Skates tend to consume more invertebrates than Alaska skates in the EBS, so estimates of benthic epifaunal consumption due to Other Skates range up to 50,000 tons annually, higher than those for Alaska skates despite the disparity in biomass between the groups (Fig. 39, lower panels).

Because Alaska skates and all Other Skates are distributed differently in the EBS, with Alaska skates dominating the shallow shelf areas and the more diverse species complex located on the outer shelf and slope, we might expect different ecosystem relationships for skates in these habitats based on differences in food habits among the species. Similarly, in the AI the unique skate complex has different diet compositions and consumption estimates from those estimated for EBS skates. The skate in the AI formerly known as the Alaska skate (now identified as the leopard skate) is opportunistically piscivorous like its EBS relative, feeding on the common commercial forage fish, Atka mackerel (65% of diet) and pollock (14% of diet), as well as fishery offal (7% of diet; Fig. 40 upper left panel). Diets of Other Skates in the AI are more dominated by benthic invertebrates, especially shrimp (42% of diet), but include more pelagic prey such as juvenile pollock, adult Atka mackerel, adult pollock and squids (totaling 45% of diet; Fig. 40 upper right panel). Estimated annual consumption of Atka mackerel by AI leopard skates in the early 1990s ranged from 7,000 to 15,000 tons, while pollock consumption was below 5,000 tons (Fig. 40 lower left panel). Shrimp consumption by AI Other Skates was estimated to range from 4,000 to 15,000 tons annually in the early 1990s, and consumption of pollock ranged from 2,000 to 10,000 tons (Fig. 40 lower right panel). Atka mackerel consumption by AI Other Skates was estimated to be below 5,000 tons annually. The diet composition estimated for AI Other Skates is likely dominated by the biomass dominant species in that system, whiteblotched skate and Aleutian skate. The diet compositions of both Aleutian and whiteblotched skates in the AI appear to be fairly diverse (Fig. 41), and are described in further detail in Yang (2007) along with the diets of big skate, Bering skate, Alaska skate, roughtail skate,

and mud skate in the AI. In the future, we hope to use diet compositions to make separate consumption estimates for whiteblotched and Aleutian skates along with leopard skates in the AI.

Ecosystem Effects on Stock and Fishery Effects on the Ecosystem: Summary

In the following tables, we summarize ecosystem considerations for BSAI skates and the entire groundfish fishery where they are caught incidentally.

Ecosystem effects on BSAI Skates *(evaluating level of concern for skate populations)*

Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Pollock	Currently declining from high biomass levels	Probably still adequate forage available for piscivorous skates	Probably no concern
Atka mackerel	Cyclically varying population with slight upward trend overall 1977 - 2005	Adequate forage available for piscivorous skates	No concern
Shrimp/Benthic invertebrates	Trends are not currently measured directly, only short time series of food habits data exist for potential retrospective measurement	Unknown	Unknown
Predator population trends			
Sperm whales	Populations recovering from whaling?	Possibly higher mortality on skates? But still a very small proportion of mortality	No concern
Steller sea lions	Declined from 1960s, low but level recently	Lower mortality on skates?	No concern
Sharks	Population trends unknown	Unknown	Unknown
Changes in habitat quality			
Benthic ranging from shallow shelf to deep slope, isolated nursery areas in specific locations	Skate habitat is only beginning to be described in detail. Adults appear adaptable and mobile in response to habitat changes. Eggs are limited to isolated nursery grounds and juveniles use different habitats than adults. Changes in these habitats have not been monitored historically, so assessments of habitat quality and its trends are not currently available.	Continue study on small nursery areas to evaluate importance to population production	Possible concern if nursery grounds are disturbed or degraded.

Groundfish fishery effects on ecosystem via skate bycatch *(evaluating level of concern for ecosystem)*

Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Skate catch	Has varied from 12,226 t - 22,982 t from 1992-2007	Largest portion of total mortality for skates	Possible concern
Forage availability	Skates have few predators, and skates are small proportion of diets for their predators	Fishery removal of skates has a small effect on predators	Probably no concern
Fishery concentration in space and time			
	Skate bycatch is spread throughout FMP areas, although higher proportion of skate bycatch occurs on outer continental shelf and upper slope	Potential impact to skate populations if fishery disturbs nursery or other important habitat, but small effect on skate predators	Possible concern for skates, probably no concern for skate predators
Fishery effects on amount of large size target fish			
	Survey length compositions (2000 - 2007) suggest that large size classes of Alaska skates appear to be stable	Fishery removals do not appear to have an effect on size structure	Probably no concern
Fishery contribution to discards and offal production			
	Skate discard is a relatively high proportion of skate catch, some incidentally caught skates are retained and processed	Unclear whether discard of skates has ecosystem effect	Unknown
Fishery effects on age-at-maturity and fecundity			
	Skate age at maturity and fecundity are just now being described; fishery effects on them difficult to determine due to lack of unfished population to compare with	Unknown	Unknown

Data gaps and research priorities

- The most important data gap for BSAI skates is the lack of reliable species-specific catch reporting. Species identification by fishery observers has vastly improved in recent years but it is still difficult to make accurate identifications in the longline fishery, as many skates are dropped off the line without being brought on board. Species-specific accounting is essential for monitoring catch vs. biomass for species in the Other Skates group and to ensure that individual species within the complex are not being overfished.

- In the Alaska skate model, we assumed a catch rate with 100% mortality. In reality, skate mortality is dependent upon the time spent out of water, the type of gear, and handling practices after capture. From fishery observer data, approximately 30% of skates are retained; however we currently have no information regarding the survival of skates that are discarded at sea.

- Biomass indices from the EBS slope and AI are critical pieces of information for managing BSAI skates. The survey efforts in these regions need to continue and should have a high priority.

- We have conducted a tagging program for Alaska skates on the EBS shelf since 2008. Any additional information regarding movement of skates would be valuable.

- Fecundity is a very difficult quantity to measure in skates, as individuals of some species may reproduce throughout the year and thus the number of mature or maturing eggs present in the ovary may represent only a fraction of the annual reproductive output. Reliable fecundity estimates for Alaska skates are a research priority.

- Skate habitat is only beginning to be described in detail. Current efforts to protect eggcase-containing nursery areas should be supported and additional research is required to gauge the importance of the known nursery areas to skate populations. In addition, the defining characteristics of these nursery habitats need to be described.

- Additional information is required regarding the mortality rate of early life stages of skates, both inside their eggcases and when they emerge as free-swimming juveniles.

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Tables

Table 1. Life history and depth distribution information available for BSAI skate species, from Stevenson (2004) unless otherwise noted.

Species	Common name	Max obs. length (TL cm)	Max obs. age	Age, length Mature (50%)	Feeding mode [2]	N embryos/ egg case [1]	Depth range (m) [9]
Bathyraja abyssicola	deepsea skate	135 (M) [10] 157 (F) [11]	?	110 cm (M) [11] 145 cm (F) [13]	benthophagic; predatory [11]	1 [13]	362-2904
Bathyraja aleutica	Aleutian skate	150 (M) 154 (F) [12]	14 [6]	121 cm (M) 133 cm (F) [12]	Predatory	1	15-1602
Bathyraja interrupta	Bering skate (complex?)	83 (M) 82 (F) [12]	19 [6]	67 cm (M) 70 cm (F) [12]	Benthophagic	1	26-1050
Bathyraja lindbergi	Commander skate	97 (M) 97 (F) [12]	?	78 cm (M) 85 cm (F) [12]	?	1	126-1193
Bathyraja maculata	whiteblotched skate	120	?	94 cm (M) 99 cm (F) [12]	Predatory	1	73-1193
Bathyraja mariposa [3]	butterfly skate	76	?	?	?	1	90-448
Bathyraja minispinosa	whitebrow skate	83 [10]	?	70 cm (M) 66 cm (F) [12]	Benthophagic	1	150-1420
Bathyraja parmifera	Alaska skate	118 (M) 119 (F) [4]	15 (M) 17 (F) [4]	9 yrs, 92cm (M) 10 yrs, 93cm(F) [4]	Predatory	1	17-392
Bathyraja sp. cf. *parmifera*	"Leopard" parmifera	133 (M) 139 (F)	?	?	Predatory	?	48-396
Bathyraja taranetzi	mud skate	67 (M) 77 (F) [12]	?	56 cm (M) 63 cm (F) [12]	predatory [13]	1	58-1054
Bathyraja trachura	roughtail skate	91 (M) [14] 89 (F) [11]	20 (M) 17 (F) [14]	13 yrs, 76 cm (M) 14 yrs, 74 cm (F) [14, 12]	benthophagic; predatory [11]	1	213-2550
Bathyraja violacea	Okhotsk skate	73	?	?	Benthophagic	1	124-510
Amblyraja badia	roughshoulder skate	95 (M) 99 (F) [11]	?	93 cm (M) [11]	predatory [11]	1 [13]	1061-2322
Raja binoculata	big skate	244	15 [5]	6-8 yrs, 72-90 cm [7]	predatory [8]	1-7	16-402
Raja rhina	longnose skate	180	25 [5]	7-10 yrs, 65-83 cm [7]	benthophagic; predatory [15]	1	9-1069

[1] Eschemeyer 1983. [2] Orlov 1998 & 1999 (Benthophagic eats mainly amphipods, worms. Predatory diet primarily fish, cephalopods). [3] Stevenson et al. 2004. [4] Matta 2006. [5] Gburski et al. 2007. [6] Gburski unpub data. [7] McFarlane & King 2006. [8] Wakefield 1984. [9] Stevenson et al. 2006. [10] Mecklenberg et al. 2002. [11] Ebert 2003. [12] Ebert 2005. [13] Ebert unpub data. [14] Davis 2006. [15] Robinson 2006.

Table 2. Species composition of the EBS and AI skate complexes from 2012, the last year in which all BSAI areas were surveyed within the same year.

species	EBS shelf		EBS slope		AI		BSAI total	
	biomass estimate	CV	biomass estimate	CV	biomass estimate	CV	biomass estimate	CV
Alaska	369,881	0.06	19,829	0.27	1,503	0.31	391,213	0.06
Aleutian	4,565	0.37	22,657	0.12	6,072	0.18	33,293	0.10
whiteblotched	342	1.00	5,820	0.19	15,360	0.20	21,522	0.16
Bering	10,190	0.16	3,465	0.16	109	0.17	13,764	0.13
misc. skates					10,865	0.23	10,865	0.23
commander			4,378	0.13			4,378	0.13
mud	286	1.00	842	0.31	1,277	0.15	2,405	0.18
roughtail			2,324	0.15	2	0.86	2,326	0.15
whitebrow			1,325	0.15	72	0.69	1,397	0.15
big skate	1,161	0.70			195	0.65	1,356	0.61
longnose	120	1.00					120	1.00
Bathyraja sp			90	1.00			90	1.00
all skates	386,545	0.06	60,730	0.10	35,454	0.12	482,729	0.05

Table 3. Time series of OFL, ABC, TAC, catch, and retention for the BSAI skate complex, 2011-2014*. All values are in metric tons except for retention rate.. Prior to 2011 skates were managed as part of the Other Species complex; data regarding catch in that era can be found in previous BSAI skate assessments. Source: Alaska Regional Office.

year	skate complex OFL	skate complex ABC	skate complex TAC	skate complex catch	skate retention rate
2011	37,800	31,500	16,500	23,748	24%
2012	39,100	32,600	24,700	24,968	29%
2013	45,800	38,800	24,000	27,260	29%
*2014**	41,849	35,383	26,000	*22,446*	*29%*

*2014 data are incomplete; retrieved October 8, 2014

Table 4. Estimated catch (t) of all skate species combined by BSAI area, 1997 - 2014*. Source: Alaska Regional Office.

	EBS	AI	total
1997	16,890	857	17,747
1998	18,189	1128	19,317
1999	13,277	802	14,079
2000	17,068	1808	18,876
2001	18,061	2510	20,571
2002	20,583	695	21,278
2003	18,738	674	19,412
2004	21,993	905	22,897
2005	22,714	709	23,423
2006	19,568	1,033	20,601
2007	17,753	1,040	18,793
2008	20,469	1,422	21,891
2009	19,442	1,227	20,669
2010	16,515	1,403	17,918
2011	23,005	743	23,748
2012	23,873	1,095	24,968
2013	26,165	1,095	27,260
*2014**	*21,319*	*1,126*	*22,446*

. *2014 data are incomplete; retrieved October 8, 2014.

Table 5. Estimated catch (t) of all skate species combined by target fishery, 2003 – 2014*.. Source: Alaska Regional Office..

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	***2014****
Pacific cod	15,153	18,643	19,754	15,443	13,618	14,507	12,756	11,594	17,269	18,613	20,715	*17,290*
yellowfin sole	1,517	600	942	1,133	1,406	1,301	1,799	1,907	2,129	2,219	2,687	*1,619*
walleye Pollock	480	844	733	1,310	1,291	2,761	3,861	1,891	2,358	2,021	1,764	*813*
rock sole	549	530	437	932	1,005	569	955	1,221	713	654	530	*687*
Atka mackerel	92	149	140	144	155	179	185	247	269	511	345	*446*
IFQ halibut	267	283	130	83	20	1,370	0	25	10	48	339	*803*
Rockfish	73	24	31	37	75	65	92	53	108	101	236	*164*
flathead sole	631	1,199	848	855	770	664	362	301	112	75	205	*274*
arrowtooth flounder	104	65	127	281	81	298	193	185	122	207	184	*160*
Sablefish	64	13	27	124	63	42	131	117	138	46	112	*75*
Greenland turbot	222	137	170	121	176	69	209	369	370	360	51	*36*
Kamchatka flounder	0	0	0	0	0	0	0	0	93	101	49	*57*
Alaska plaice	0	0	0	1	0	1	1	5	36	8	42	*0*
other flatfish	30	80	44	7	64	2	14	2	3	3	0	*0*
BSAI total	**19,412**	**22,897**	**23,423**	**20,601**	**18,793**	**21,891**	**20,669**	**17,918**	**23,748**	**24,968**	**27,260**	***22,446***

*2014 data incomplete; retrieved October 8, 2014.

Table 6. Estimated catch (t) of all skate species combined by reporting area, 2003 – 2014*. Source: Alaska Regional Office.

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	***2014 ****
						EBS						
508	0	0	0	0	0	0	0	0	6	0	0	*0*
509	2,046	2,261	3,349	3,571	3,655	4,096	5,027	2,832	6,272	6,174	8,283	*2,920*
512	25	205	15	0	0	33	16	13	7	161	50	*20*
513	2,765	2,831	4,013	2,668	2,324	2,052	2,503	1,862	3,085	1,812	3,414	*3,401*
514	279	67	196	221	445	83	134	78	150	1,585	229	*767*
516	133	409	242	253	399	489	576	664	256	780	971	*369*
517	2,901	3,015	3,703	2,442	2,186	2,502	3,207	2,849	2,760	3,304	4,753	*3,060*
518	25	6	16	12	5	459	57	49	26	21	54	*72*
519	262	501	295	262	154	317	76	147	334	200	196	*255*
521	8,977	10,341	8,490	8,365	7,128	7,770	6,187	6,622	8,696	8,033	7,178	*9,375*
523	309	329	243	283	333	242	264	396	267	1,076	883	*555*
524	1,016	2,027	2,153	1,493	1,123	2,427	1,396	1,003	1,147	728	154	*525*
530	0	0	0	0	0	0	1	0	0	0	0	*0*
EBS total	**18,738**	**21,993**	**22,714**	**19,568**	**17,753**	**20,469**	**19,442**	**16,515**	**23,005**	**23,873**	**26,165**	***21,319***
						AI						
541	312	478	499	593	363	507	459	486	507	783	627	*899*
542	243	285	126	371	398	572	347	474	205	274	378	*178*
543	119	142	83	69	280	344	421	443	30	37	91	*50*
AI total	**674**	**905**	**709**	**1,033**	**1,040**	**1,422**	**1,227**	**1,403**	**743**	**1,095**	**1,095**	***1,126***
BSAI total	**19,412**	**22,897**	**23,423**	**20,601**	**18,793**	**21,891**	**20,669**	**17,918**	**23,748**	**24,968**	**27,260**	***22,446***

*2014 data incomplete; retrieved October 8, 2014.

Table 7. Reconstructed catch data used in the Alaska skate model, by year.

year	longline	trawl	year	Longline	trawl
1955	0	0	1985	1,443	4,045
1956	0	0	1986	1,301	3,675
1957	0	0	1987	1,062	3,006
1958	8	61	1988	1,443	4,287
1959	21	156	1989	588	1,752
1960	0	0	1990	688	2,009
1961	0	0	1991	6,246	1,372
1962	0	0	1992	12,484	2,803
1963	0	0	1993	8,998	2,020
1964	43	304	1994	10,468	2,350
1965	150	928	1995	10,961	2,461
1966	130	924	1996	9,305	2,089
1967	537	1,967	1997	13,059	2,932
1968	1,539	9,252	1998	14,100	3,178
1969	690	4,365	1999	10,288	2,318
1970	1,220	6,502	2000	13,362	3,055
1971	856	5,613	2001	14,244	3,291
1972	1,377	4,916	2002	15,943	3,571
1973	3,264	23,062	2003	14,270	3,386
1974	3,700	24,994	2004	16,724	3,991
1975	3,348	22,736	2005	17,918	3,455
1976	1,702	10,897	2006	15,136	3,401
1977	2,559	15,090	2007	13,751	3,096
1978	3,864	25,571	2008	15,893	3,591
1979	2,609	16,207	2009	15,074	3,399
1980	4,578	12,310	2010	12,868	2,922
1981	4,503	12,553	2011	17,712	3,952
1982	2,349	6,437	2012	18,438	4,133
1983	1,971	5,456	2013	20,189	4,520
1984	1,072	2,995	2014	21,279	4,781

Table 8. Alaska skate length compositions from the BSAI longline and trawl fisheries, 2009-2013. Bin number is the lower limit of each 4 cm length interval. N = sample size used in the model (square root of number of sampled hauls).

bin	longline					trawl				
	2009	2010	2011	2012	2013	2009	2010	2011	2012	2013
4	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0.001	0	0	0
16	0	0	0	0	0	0.001	0.002	0	0	0
20	0	0	0	0	0	0.003	0.004	0.002	0.002	0.001
24	0	0	0	0.001	0	0.011	0.011	0.012	0.003	0.006
28	0	0	0	0.003	0	0.024	0.018	0.02	0.01	0.009
32	0.001	0.001	0	0.007	0	0.034	0.031	0.026	0.011	0.01
36	0.001	0.001	0.001	0.01	0.001	0.051	0.037	0.034	0.017	0.02
40	0.003	0.002	0.003	0.013	0.002	0.063	0.053	0.049	0.034	0.039
44	0.006	0.006	0.007	0.018	0.003	0.064	0.055	0.059	0.042	0.047
48	0.011	0.014	0.014	0.021	0.008	0.056	0.05	0.052	0.052	0.05
52	0.02	0.024	0.02	0.025	0.013	0.051	0.042	0.047	0.049	0.051
56	0.025	0.032	0.027	0.03	0.022	0.044	0.041	0.04	0.043	0.045
60	0.034	0.046	0.041	0.041	0.031	0.043	0.043	0.038	0.044	0.042
64	0.044	0.056	0.05	0.053	0.038	0.048	0.048	0.039	0.046	0.043
68	0.058	0.069	0.064	0.068	0.056	0.049	0.056	0.053	0.054	0.05
72	0.063	0.07	0.077	0.072	0.069	0.048	0.053	0.06	0.069	0.055
76	0.068	0.062	0.074	0.072	0.079	0.041	0.049	0.059	0.07	0.058
80	0.068	0.071	0.077	0.08	0.093	0.052	0.054	0.059	0.08	0.068
84	0.067	0.067	0.076	0.077	0.097	0.044	0.054	0.053	0.071	0.069
88	0.081	0.071	0.082	0.087	0.105	0.059	0.056	0.06	0.077	0.08
92	0.094	0.09	0.095	0.094	0.115	0.059	0.069	0.069	0.073	0.081
96	0.124	0.103	0.112	0.098	0.117	0.056	0.068	0.068	0.069	0.077
100	0.119	0.104	0.106	0.078	0.089	0.049	0.055	0.058	0.051	0.058
104	0.067	0.057	0.049	0.034	0.04	0.029	0.029	0.025	0.022	0.029
108	0.03	0.028	0.018	0.013	0.013	0.01	0.013	0.01	0.008	0.007
112	0.009	0.013	0.004	0.003	0.003	0.006	0.004	0.002	0.002	0.002
116	0.005	0.006	0.001	0.001	0.002	0.002	0.003	0.002	0	0.001
120	0.001	0.004	0.001	0.001	0.001	0.001	0.001	0.001	0	0.001
124	0.001	0.001	0	0	0	0	0	0	0	0
128	0	0	0	0	0	0	0	0	0	0
132	0	0	0	0	0	0	0	0	0.001	0
N	67	65	72	77	85	56	61	56	50	61

Table 9. Estimates of Alaska skate biomass (t) from the EBS shelf bottom trawl survey, 1982-2013. Estimates and CVs in bold (1999-2013) were obtained directly from trawl survey data when species identification was reliable. Estimates and CVs prior to 1999 were partitioned using species composition data from 1999-2013.

year	biomass	CV
1982	166,457	0.10
1983	-	-
1984	188,482	0.08
1985	163,239	0.13
1986	253,342	0.14
1987	337,865	0.09
1988	349,786	0.12
1989	392,634	0.08
1990	457,619	0.11
1991	429,660	0.09
1992	378,474	0.09
1993	368,769	0.07
1994	383,556	0.08
1995	342,536	0.08
1996	400,012	0.06
1997	396,800	0.07
1998	350,056	0.05
1999	**323,240**	**0.17**
2000	**311,977**	**0.06**
2001	**414,539**	**0.06**
2002	**364,004**	**0.07**
2003	**372,379**	**0.05**
2004	**424,808**	**0.05**
2005	**487,742**	**0.05**
2006	**437,737**	**0.05**
2007	**478,872**	**0.07**
2008	**361,298**	**0.06**
2009	**350,233**	**0.06**
2010	**366,186**	**0.06**
2011	**410,340**	**0.05**
2012	**369,881**	**0.06**
2013	**386,816**	**0.06**
2014	**404,380**	**0.05**

Table 10. Alaska skate EBS shelf survey length compositions, 2000-2013. Bin number is the lower limit of each 4 cm length bin; data are proportions of each bin. N = sample size used in the model.

bin	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000
20	0.005	0.010	0.007	0.005	0.003	0.005	0.004	0.007	0.004	0.009	0.003	0.004	0.004	0.003	0.003
24	0.034	0.032	0.025	0.027	0.015	0.019	0.025	0.030	0.016	0.021	0.016	0.015	0.009	0.012	0.007
28	0.044	0.047	0.037	0.024	0.027	0.024	0.026	0.020	0.019	0.020	0.017	0.021	0.017	0.012	0.017
32	0.038	0.048	0.048	0.042	0.029	0.030	0.031	0.027	0.026	0.032	0.017	0.025	0.017	0.020	0.015
36	0.049	0.043	0.049	0.041	0.032	0.039	0.033	0.037	0.036	0.042	0.027	0.027	0.020	0.028	0.026
40	0.051	0.047	0.054	0.044	0.049	0.045	0.043	0.052	0.048	0.052	0.036	0.039	0.028	0.031	0.027
44	0.047	0.052	0.057	0.048	0.052	0.059	0.048	0.050	0.058	0.055	0.048	0.054	0.042	0.042	0.035
48	0.055	0.046	0.054	0.080	0.060	0.055	0.055	0.062	0.059	0.055	0.041	0.064	0.049	0.049	0.045
52	0.063	0.052	0.065	0.049	0.067	0.054	0.051	0.052	0.066	0.064	0.049	0.063	0.056	0.066	0.042
56	0.059	0.047	0.053	0.041	0.053	0.058	0.055	0.054	0.064	0.067	0.054	0.061	0.059	0.061	0.056
60	0.061	0.055	0.047	0.044	0.052	0.061	0.056	0.048	0.060	0.067	0.053	0.065	0.059	0.055	0.063
64	0.045	0.046	0.039	0.040	0.044	0.051	0.055	0.059	0.062	0.057	0.060	0.065	0.061	0.056	0.059
68	0.036	0.047	0.048	0.052	0.052	0.044	0.050	0.056	0.047	0.050	0.066	0.061	0.059	0.052	0.066
72	0.035	0.046	0.042	0.042	0.047	0.046	0.048	0.051	0.051	0.053	0.057	0.061	0.068	0.061	0.064
76	0.027	0.038	0.042	0.045	0.050	0.040	0.049	0.044	0.050	0.043	0.055	0.051	0.069	0.064	0.055
80	0.039	0.032	0.029	0.047	0.040	0.040	0.038	0.045	0.046	0.047	0.056	0.047	0.063	0.064	0.052
84	0.030	0.027	0.026	0.039	0.042	0.040	0.045	0.036	0.042	0.041	0.061	0.047	0.047	0.054	0.058
88	0.036	0.036	0.045	0.045	0.045	0.051	0.039	0.042	0.045	0.045	0.057	0.046	0.067	0.061	0.077
92	0.052	0.065	0.054	0.054	0.060	0.051	0.061	0.063	0.055	0.049	0.070	0.053	0.064	0.067	0.088
96	0.074	0.072	0.070	0.079	0.073	0.063	0.069	0.060	0.057	0.056	0.072	0.058	0.065	0.070	0.070
100	0.066	0.069	0.060	0.061	0.068	0.070	0.065	0.059	0.054	0.047	0.048	0.047	0.050	0.043	0.046
104	0.040	0.029	0.030	0.037	0.030	0.041	0.039	0.031	0.026	0.021	0.026	0.018	0.020	0.022	0.022
108	0.012	0.012	0.012	0.011	0.008	0.012	0.012	0.010	0.009	0.006	0.008	0.006	0.005	0.005	0.005
112	0.002	0.002	0.005	0.003	0.003	0.002	0.002	0.004	0.001	0.000	0.001	0.001	0.001	0.001	0.002
116	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
120	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
124	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
128	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
132	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
N	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200

Table 11. Input parameter values for the base model (Model 2). Where parameters were estimated freely within the model, minimum and maximum bounds are shown. Superscripts indicate how parameters were changed in the alternative models.

parameter		value	min	max	fix?
growth and natural mortality	natural mortality (*M*)	0.13			X
	length at A1 (L1)	20	-10	30	
	length at A2 (L2)	110	70	150	
	von Bertalanffy coefficient (κ)	0.15	0.05	0.15	
	Richards coefficient (γ)	0.1	-1	2	
	CV of LAA @ L1	0.1	0.05	0.35	
	CV of LAA @ L2	0.1	0.05	0.25	
length-weight relationship	coefficient (a)	2.44×10^{-6}			X
	exponent (b)	3.35			X
length at maturity	length at 50% maturity (a)	93.28			X
	slope (b)	-0.548			X
length-fecundity relationship	intercept	-14.7			X
	slope	0.214			X
stock-recruit function	ln virgin recruitment level (R_0)	10.00	5	15	
	steepness	1			X
	σ_R	0.4			X
EBS shelf survey catchability	ln catchability (q)	0			X
longline length selectivity[a]	peak (p1)	111	7.6	126	
	top (p2)	-0.1	-6	4	
	ascending width (p3)	4.9	-1	9	
	descending width (p4)	4.7	-1	9	
	selectivity at first size bin (p5)	-2.2	-5	9	
	selectivity at last size bin (p6)	9	-5	9	
trawl length selectivity[a]	peak (p1)	49	7.6	126	
	top (p2)	-5	-6	4	
	ascending width (p3)	4.8	-1	9	
	descending width (p4)	4.4	-1	9	
	selectivity at first size bin (p5)	-0.7	-5	9	
	selectivity at last size bin (p6)	9	-5	9	
survey length selectivity[a]	peak (p1)	49	7.6	126	
	top (p2)	-5	-6	4	
	ascending width (p3)	4.8	-1	9	
	descending width (p4)	4.4	-1	9	
	selectivity at first size bin (p5)	-0.7	-5	9	
	selectivity at last size bin (p6)	9	-5	9	
initial fishing mortality	longline fishery F	0.030	0	1	
	trawl fishery F	0.005	0	1	

a In model 3, p6 was fixed at the starting value for all fleets.

Table 12. Results from models 1-4 for use in model comparison and evaluation.

model number		1	2	3	4
Description		existing (2012) model	new base model (preferred)	new base model w/ asymptotic selectivity	new base model starting in 1977
likelihood components					
	survey	-28.3094	-37.4977	-33.6539	-33.7349
	length comps	91.8971	82.0901	86.0581	84.8489
	LAA	51.7705	130.047	133.826	129.01
	recruitment	-26.4296	-41.0622	-42.1409	-5.3949
	total	96.1761	133.599	144.109	174.822
parameters estimated		68	89	86	64
L_amin		23.8	14.0	15.9	14.2
	CV	*0.0356*	*0.0367*	*0.0431*	*0.0377*
L_amax		110.0	101.9	102.6	102.0
	CV	*0.0132*	*0.0037*	*0.0040*	*0.0039*
K		0.20	0.38	0.35	0.37
	CV	*0.0000*	*0.0222*	*0.0226*	*0.0230*
CV young		0.21	0.35	0.30	0.35
	CV	*0.1159*	*0.0002*	*0.0918*	*0.0005*
CV old		0.05	0.05	0.05	0.05
	CV	*0.0445*	*0.0575*	*0.0582*	*0.0594*
ln (Rzero)		10.2	10.2	10.0	10.2
	CV	*0.0033*	*0.0046*	*0.0024*	*0.0043*
spawnbio_unfished		460,075	354,080	295,425	346,340
	CV	*0.068*	*0.052*	*0.027*	*0.050*
recruit_unfished		27,472	26,619	22,565	25,991
	CV	*0.034*	*0.046*	*0.024*	*0.044*
RMSE_survey		0.106	0.125	0.131	0.132
% within survey CI		74%	81%	78%	75%
correlation obs-pred		0.299	0.834	0.816	0.846
average standardized residual		0.815	0.813	0.819	0.835
mean longline input N		94.6	73.2	73.2	73.2
mean longline eff N		322.5	924.3	884.3	1038.3
mean longline effN/N		3.41	12.63	12.08	14.18
mean trawl input N		87.3	56.8	56.8	56.8
mean trawl eff N		371.2	1160.5	747.3	921.2
mean trawl effN/N		4.25	20.43	13.16	16.22
mean survey input N		113.3	200.0	200.0	200.0
mean survey eff N		451.1	836.5	751.2	782.4
mean survey effN/N		3.98	4.18	3.76	3.91
mean LAA N		337.0	223.8	223.8	223.8
mean LAA eff N		532.7	2976.2	2627.0	2970.0
mean LAA eff N/N		1.58	13.30	11.74	13.27

Table 13. Time series of total (age 0+) biomass, spawning biomass and the number of age 0 recruits predicted by Model 2.

	spawning biomass		age-0 recruits			spawning biomass		age-0 recruits	
	Estimate	CV	estimate	CV		estimate	CV	estimate	CV
unfished	354,080	0.05	26,619	0.05	1982	135,083	0.13	64,018	0.69
1950	354,080	0.05	23,074	0.39	1983	130,718	0.13	50,212	0.70
1951	354,080	0.05	22,908	0.39	1984	128,180	0.13	35,448	0.49
1952	354,080	0.05	22,723	0.39	1985	128,534	0.12	28,555	0.42
1953	354,080	0.05	22,519	0.39	1986	129,777	0.11	25,203	0.39
1954	354,080	0.05	22,295	0.39	1987	133,130	0.10	23,927	0.38
1955	354,080	0.05	22,049	0.38	1988	139,339	0.10	23,952	0.38
1956	354,080	0.05	21,783	0.38	1989	148,662	0.09	25,117	0.38
1957	354,080	0.05	21,497	0.38	1990	165,158	0.09	27,520	0.39
1958	354,080	0.05	21,193	0.38	1991	195,168	0.09	28,345	0.38
1959	352,630	0.05	20,875	0.37	1992	226,054	0.08	24,308	0.37
1960	350,213	0.06	20,546	0.37	1993	250,008	0.08	24,455	0.36
1961	347,064	0.06	20,211	0.37	1994	269,757	0.08	30,257	0.36
1962	343,299	0.07	19,872	0.37	1995	281,032	0.08	34,630	0.34
1963	339,178	0.07	19,534	0.36	1996	285,147	0.08	29,120	0.35
1964	334,899	0.08	19,201	0.36	1997	285,578	0.08	32,430	0.34
1965	330,373	0.08	18,876	0.36	1998	280,649	0.08	35,271	0.34
1966	325,424	0.09	18,571	0.35	1999	274,456	0.08	36,077	0.32
1967	320,522	0.09	18,297	0.35	2000	271,391	0.08	40,151	0.28
1968	314,761	0.09	18,057	0.35	2001	265,412	0.08	32,360	0.28
1969	304,019	0.10	17,842	0.35	2002	258,879	0.08	29,687	0.29
1970	296,729	0.10	17,625	0.34	2003	253,372	0.08	33,816	0.30
1971	287,823	0.10	17,402	0.34	2004	251,757	0.08	41,450	0.29
1972	279,714	0.10	17,201	0.34	2005	248,737	0.08	37,412	0.31
1973	271,752	0.10	17,057	0.34	2006	247,111	0.08	34,872	0.30
1974	251,945	0.11	17,012	0.34	2007	248,826	0.08	30,565	0.33
1975	230,901	0.11	17,098	0.34	2008	252,801	0.08	32,041	0.29
1976	211,712	0.12	17,419	0.34	2009	257,724	0.08	23,666	0.30
1977	200,905	0.12	18,176	0.34	2010	261,787	0.08	19,245	0.30
1978	187,626	0.12	19,722	0.35	2011	265,739	0.07	17,211	0.30
1979	168,237	0.13	22,649	0.38	2012	266,615	0.07	18,290	0.32
1980	155,678	0.13	27,976	0.42	2013	269,042	0.07	20,678	0.35
1981	144,910	0.13	37,857	0.52	2014	269,884	0.07	26,619	0.05

Table 14. Comparison of spawning biomass and age-0 recruits between Model 1 and Model 2.

	spawning biomass		age-0 recruits	
	Model 2	Model 1	Model 2	Model 1
unfished	354,080	460,075	26,619	27,472
1980	155,678	330,065	27,976	22,616
1981	144,910	330,065	37,857	22,574
1982	135,083	330,065	64,018	22,666
1983	130,718	330,065	50,212	22,948
1984	128,180	330,065	35,448	23,515
1985	128,534	330,064	28,555	24,390
1986	129,777	330,059	25,203	25,362
1987	133,130	330,044	23,927	26,013
1988	139,339	330,007	23,952	26,043
1989	148,662	329,928	25,117	25,949
1990	165,158	329,781	27,520	28,659
1991	195,168	329,542	28,345	32,150
1992	226,054	327,895	24,308	37,926
1993	250,008	323,063	24,455	34,723
1994	269,757	319,671	30,257	30,967
1995	281,032	314,480	34,630	28,976
1996	285,147	308,740	29,120	25,775
1997	285,578	304,606	32,430	34,771
1998	280,649	298,672	35,271	30,467
1999	274,456	293,026	36,077	26,163
2000	271,391	291,014	40,151	31,864
2001	265,412	287,864	32,360	25,920
2002	258,879	285,524	29,687	30,146
2003	253,372	284,065	33,816	27,962
2004	251,757	286,605	41,450	26,483
2005	248,737	289,137	37,412	23,505
2006	247,111	291,476	34,872	19,875
2007	248,826	294,640	30,565	17,314
2008	252,801	296,889	32,041	12,620
2009	257,724	298,136	23,666	11,032
2010	261,787	299,002	19,245	12,422
2011	265,739	300,132	17,211	28,228
2012	266,615	298,371	18,290	28,466
2013	269,042	294,489	20,678	28,686
2014	269,884	289,241	26,619	28,886

Table 15. Time series of exploitation rates (catch/total biomass) as estimated by the preferred new model (Model 2).

year	longline	trawl	total F	year	longline	trawl	total F
1950	0.000	0.000	0.000	1983	0.009	0.026	0.035
1951	0.000	0.000	0.000	1984	0.005	0.013	0.018
1952	0.000	0.000	0.000	1985	0.006	0.016	0.022
1953	0.000	0.000	0.000	1986	0.005	0.013	0.018
1954	0.000	0.000	0.000	1987	0.003	0.009	0.013
1955	0.000	0.000	0.000	1988	0.004	0.012	0.016
1956	0.000	0.000	0.000	1989	0.001	0.004	0.006
1957	0.000	0.000	0.000	1990	0.002	0.005	0.006
1958	0.000	0.000	0.000	1991	0.013	0.003	0.017
1959	0.000	0.000	0.000	1992	0.026	0.006	0.032
1960	0.000	0.000	0.000	1993	0.019	0.005	0.023
1961	0.000	0.000	0.000	1994	0.022	0.005	0.027
1962	0.000	0.000	0.000	1995	0.023	0.006	0.029
1963	0.000	0.000	0.000	1996	0.020	0.005	0.025
1964	0.000	0.001	0.001	1997	0.028	0.007	0.035
1965	0.000	0.002	0.003	1998	0.031	0.008	0.039
1966	0.000	0.002	0.003	1999	0.023	0.006	0.028
1967	0.001	0.005	0.006	2000	0.030	0.008	0.037
1968	0.003	0.024	0.027	2001	0.032	0.008	0.040
1969	0.002	0.011	0.013	2002	0.035	0.009	0.044
1970	0.003	0.018	0.020	2003	0.032	0.008	0.040
1971	0.002	0.016	0.018	2004	0.037	0.010	0.046
1972	0.003	0.014	0.017	2005	0.039	0.008	0.047
1973	0.008	0.069	0.078	2006	0.033	0.008	0.041
1974	0.010	0.081	0.091	2007	0.029	0.007	0.036
1975	0.010	0.080	0.090	2008	0.033	0.008	0.042
1976	0.005	0.041	0.046	2009	0.031	0.008	0.039
1977	0.009	0.059	0.068	2010	0.026	0.007	0.033
1978	0.014	0.108	0.122	2011	0.036	0.009	0.045
1979	0.010	0.074	0.084	2012	0.037	0.009	0.047
1980	0.019	0.058	0.078	2013	0.041	0.010	0.052
1981	0.020	0.062	0.081	2014	0.045	0.011	0.056
1982	0.011	0.032	0.042				

Table 16. Total BSAI biomass estimates by species for the 4 years since 2000 when surveys were conducted in each area (EBS shelf, EBS slope, AI) in the same year. The "other skates" row in the first part of the table includes all the species listed in the second part of the table.

	2002		2004		2010		2012	
	Biomass	CV	biomass	CV	biomass	CV	biomass	CV
Alaska	456,687	0.09	450,830	0.05	371,093	0.06	391,213	0.06
other skates	75,723	0.08	83,884	0.10	101,091	0.08	91,516	0.06
all skates	532,410	0.08	534,714	0.04	472,183	0.05	482,729	0.05
other skates:								
Aleutian	26,261	0.18	29,000	0.20	30,775	0.15	33,293	0.10
whiteblotched	20,892	0.15	29,697	0.22	28,339	0.17	21,522	0.16
Bering	15,848	0.13	13,310	0.10	14,828	0.12	13,764	0.13
misc skates	37	0.84	140	0.39	13,196	0.21	10,865	0.23
commander	3,662	0.16	4,194	0.15	3,393	0.15	4,378	0.13
mud	2,706	0.15	2,509	0.14	2,122	0.17	2,405	0.18
roughtail	1,656	0.14	1,678	0.12	2,103	0.16	2,326	0.15
whitebrow	1,570	0.23	1,789	0.20	1,908	0.19	1,397	0.15
big skate	1,692	0.53	1,373	0.52	4,081	0.57	1,356	0.61
longnose	915	0.71					120	1.00
Bathyraja sp	69	0.59	21	0.49	1	1.00	90	1.00
Okhotsk	415	0.56	8	1.00				
deepsea			164	0.73	345	0.64		

Table 17. Survey biomass estimates for Alaska skate, other skates, and total skates by area and year.

		Alaska		other skates		all skates	
		biomass	CV	biomass	CV	biomass	CV
EBS slope	2002	35,932	0.95	33,344	0.14	69,275	0.50
	2004	4,248	0.33	28,909	0.08	33,156	0.08
	2008	4,516	0.32	33,033	0.08	37,548	0.08
	2010	1,296	0.32	33,882	0.12	35,177	0.12
	2012	19,829	0.27	40,901	0.08	60,730	0.10
AI	1980	643	0.80	3,615	0.25	4,257	0.25
	1983	322	0.25	9,428	0.13	9,750	0.12
	1986	259	0.53	15,257	0.19	15,515	0.19
	1991	1,624	0.50	13,388	0.18	15,013	0.17
	1994	7,133	0.20	17,917	0.11	25,051	0.10
	1997	7,862	0.17	21,159	0.18	29,021	0.14
	2000	9,578	0.15	19,551	0.12	29,129	0.09
	2002	10,739	0.20	23,732	0.13	34,471	0.11
	2004	12,923	0.22	40,319	0.21	53,242	0.16
	2006	13,279	0.19	40,643	0.14	53,922	0.12
	2010	3,681	0.20	48,307	0.12	51,988	0.11
	2012	1,503	0.31	33,951	0.12	35,454	0.12
	2014	3,515	0.40	39,468	0.12	42,983	0.12
EBS shelf	1982	733	0.37	72,736	0.19	73,469	0.18
	1983	48,512	0.13	58,023	0.12	106,535	0.09
	1984	88,017	0.11	98,767	0.15	186,783	0.10
	1985	66,786	0.30	105,465	0.10	172,251	0.13
	1986	58,043	0.30	78,590	0.26	136,633	0.20
	1987	127,686	0.12	114,953	0.16	242,639	0.10
	1988	107,323	0.21	180,544	0.12	287,867	0.11
	1989	767	1.00	370,237	0.08	371,004	0.08
	1990			540,502	0.11	540,502	0.11
	1991			384,972	0.09	384,972	0.09
	1992	18,597	0.22	380,198	0.09	398,794	0.09
	1993			388,950	0.07	388,950	0.07
	1994			433,979	0.08	433,979	0.08
	1995			404,460	0.08	404,460	0.08
	1996	374,406	0.06	69,017	0.19	443,423	0.06
	1997	336,930	0.07	86,044	0.21	422,974	0.07
	1998	357,095	0.05	7,063	0.34	364,158	0.05
	1999	349,571	0.16	18,600	0.37	368,171	0.15
	2000	311,970	0.06	24,743	0.21	336,713	0.05
	2001	414,539	0.06	17,405	0.15	431,944	0.06
	2002	410,016	0.06	18,647	0.14	428,664	0.06
	2003	372,257	0.05	32,381	0.25	404,639	0.05
	2004	433,660	0.05	14,656	0.13	448,316	0.05
	2005	547,031	0.05	16,815		563,846	0.06
	2006	437,737	0.05	18,515	0.15	456,252	0.05
	2007	478,872	0.07	17,236	0.22	496,108	0.07
	2008	361,298	0.06	19,617	0.22	380,915	0.05
	2009	350,233	0.06	20,162	0.17	370,395	0.06
	2010	366,116	0.06	18,902	0.16	385,018	0.06
	2011	410,340	0.05	17,771	0.24	428,111	0.05
	2012	369,881	0.06	16,664	0.15	386,545	0.06
	2013	386,816	0.06	26,961	0.41	413,776	0.06
	2014	404,380	0.05	24,465	0.21	428,845	0.05

Table 18. Survey biomass estimates for miscellaneous, Aleutian, Bering, and whiteblotched skates by area and year (part of the "other skates" category in Table 16). Miscellaneous skates includes skates not identified to species; in the AI in 2010 and 2012 it also includes the leopard skate.

		misc skates		Aleutian		Bering		whiteblotched	
		biomass	CV	biomass	CV	biomass	CV	biomass	CV
EBS slope	2002			18,658	0.24	2,873	0.18	3,927	0.23
	2004			14,987	0.14	1,953	0.11	3,450	0.16
	2008			17,160	0.15	2,520	0.16	4,574	0.17
	2010			18,721	0.22	2,780	0.16	4,055	0.14
	2012			22,657	0.12	3,465	0.16	5,820	0.19
AI	1980	3,044	0.30	86	1.00	91	1.00		
	1983	5,556	0.16	1,651	0.36	307	0.83	1,560	0.30
	1986	8,703	0.29	3,434	0.36	119	0.91	1,886	0.22
	1991	6,274	0.31	2,423	0.21	39	0.71	142	0.64
	1994	2,685	0.19	3,376	0.22	938	0.36	7,989	0.19
	1997	1,171	0.80	4,455	0.30	42	0.33	13,379	0.26
	2000	153	0.54	3,329	0.19	2	1.00	13,721	0.15
	2002	37	0.84	4,711	0.17	229	0.93	16,728	0.18
	2004	139	0.39	11,519	0.45	147	0.75	26,247	0.25
	2006	598	0.42	6,592	0.23	186	0.55	29,715	0.19
	2010			8,721	0.21	56	0.45	24,151	0.20
	2012	1	0.87	6,072	0.18	109	0.17	15,360	0.20
	2014	80	0.35	7,563	0.24	137	0.36	22,400	0.18
EBS shelf	1982	72,478	0.19	257	0.52				
	1983	38,491	0.14	16,410	0.21	2,710	0.51		
	1984	88,299	0.16	8,759	0.57	254	0.69		
	1985	95,400	0.10	6,495	0.46	1,121	0.45		
	1986	53,669	0.16	2,971	0.58	1,580	0.83		
	1987	69,548	0.22	5,096	0.44	31,089	0.26		
	1988	166,540	0.12	6,566	0.68	6,443	0.39		
	1989	370,237	0.08						
	1990	540,502	0.11						
	1991	384,972	0.09						
	1992	380,181	0.09			16	1.00		
	1993	388,950	0.07						
	1994	433,979	0.08						
	1995	404,460	0.08						
	1996	2,195	0.91	56,580	0.22	9,018	0.22		
	1997	12,880	0.60	65,427	0.25	7,738	0.19		
	1998	2,868	0.57	794	0.37	1,760	0.33		
	1999	2,159	0.55			9,949	0.20		
	2000	66	1.00	2,232	0.54	16,842	0.16		
	2001			1,232	0.61	14,263	0.14		
	2002			2,893	0.47	12,746	0.16	237	1.00
	2003			18,253	0.43	13,602	0.12		
	2004	1	1.00	2,494	0.41	11,209	0.12		
	2005			8,223	0.56	8,585	0.17		
	2006			5,568	0.41	11,674	0.13	182	1.00
	2007			2,718	0.43	9,480	0.14	3,234	0.92
	2008			6,278	0.57	9,943	0.16	238	1.00
	2009			2,171	0.49	13,274	0.18	216	1.00
	2010			3,332	0.35	11,992	0.14	133	1.00
	2011			2,525	0.54	9,795	0.17		
	2012			4,565	0.37	10,190	0.16	342	1.00
	2013			11,483	0.35	12,099	0.30	0	n/a
	2014			8,149	0.41	12,570	0.15	0	n/a

Table 19. Survey biomass estimates (t) for big, mud, roughtail, commander, and whitebrow skates (part of the "other skates" category in Table 16) by area and year.

		big skate		mud		roughtail		commander		whitebrow	
		biomass	CV	biomass	CV	biomass	CV	biomass	CV	biomass	CV
EBS slope	2002			927	0.32	1,656	0.14	3,662	0.16	1,539	0.23
	2004			702	0.20	1,677	0.12	4,194	0.15	1,755	0.20
	2008			1,018	0.22	2,213	0.14	3,437	0.15	1,934	0.17
	2010			576	0.25	2,103	0.16	3,393	0.15	1,908	0.19
	2012			842	0.31	2,324	0.15	4,378	0.13	1,325	0.15
AI	1980	376	0.23			17	0.43				
	1983	26	0.72			318	0.51			10	0.71
	1986	127	0.71			976	0.58				
	1991	26	1.00	90	0.39	749	0.36				
	1994	973	0.40	885	0.17	69	1.00			36	1.00
	1997	381	0.51	952	0.25	45	0.86			25	0.77
	2000	1,049	0.56	1,296	0.13	0	1.31				
	2002	203	0.62	1,779	0.16					30	0.71
	2004	422	0.53	1,807	0.17	1	0.98			34	1.00
	2006	568	0.72	2,971	0.28						
	2010	637	0.83	1,546	0.22	0	1.21				
	2012	195	0.65	1,277	0.15	2	0.86			72	0.69
	2014			1,831	0.25					8	0.73
EBS shelf	1982										
	1983	412	1.00								
	1984	1,387	1.00								
	1985	2,449	0.77								
	1986	20,370	0.91								
	1987	9,220	0.62								
	1988	995	1.00								
	1989										
	1990										
	1991										
	1992										
	1993										
	1994										
	1995										
	1996	988	1.00								
	1997										
	1998	1,642	1.00								
	1999	6,492	1.00								
	2000	5,155	0.83	448	0.48						
	2001	1,811	0.78								
	2002	1,489	0.59								
	2003			526	0.37						
	2004	951	0.71								
	2005										
	2006	1,036	0.68	55	1.00						
	2007	1,804	0.76								
	2008	2,870	0.63	125	1.00						
	2009	4,500	0.50								
	2010	3,445	0.66								
	2011	5,263	0.72	189	0.70						
	2012	1,161	0.70	286	1.00						
	2013	3,378	1.00								
	2014	3,596	0.60	149	1.00						

Table 20. Survey biomass estimates for longnose, Okhotsk, deepsea, leopard, and butterfly skates, by area and year.

		longnose		Okhotsk		deepsea		leopard		butterfly	
		biomass	CV	biomass	CV	biomass	CV	biomass	CV	biomass	CV
EBS slope	2002			47	0.59						
	2004			8	1.00	164	0.73				
	2008	12	1.00			165	0.62				
	2010					345	0.64				
	2012										
AI	1980										
	1983										
	1986										
	1991	97	0.99								
	1994	28	1.00								
	1997	368	1.00								
	2000										
	2002										
	2004										
	2006										
	2010							12,958	0.21	123	0.49
	2012							10,421	0.24	307	0.32
	2014							7,040	0.23	409	0.37
EBS shelf	1982										
	1983										
	1984					68	1.00				
	1985										
	1986										
	1987										
	1988										
	1989										
	1990										
	1991										
	1992										
	1993										
	1994										
	1995										
	1996	236	1.00								
	1997										
	1998										
	1999										
	2000										
	2001			98	1.00						
	2002	915	0.71	368	0.62						
	2003										
	2004										
	2005										
	2006										
	2007										
	2008	162	1.00								
	2009										
	2010										
	2011										
	2012	120	1.00								
	2013										
	2014										

Table 21. Comparison of "other skate" biomass estimates (t) from 3 sources: single survey estimates, 3-survey averages, and a random effects (RE) model, 1999-2014, for each subarea of the BSAI region.

	EBS slope				**AI**				**EBS shelf**			
yrs	survey estimate	3-survey average	RE estimate	RE CV	survey estimate	3-survey average	RE estimate	RE CV	survey estimate	3-survey average	RE estimate	RE CV
1999									31,148		19,595	0.063
2000					19,551		20,483	0.112	24,743		19,595	0.063
2001							22,549	0.148	17,405	24,432	19,595	0.063
2002	33,344		31,347	0.090	23,732		24,823	0.111	18,648	20,265	19,595	0.063
2003			30,903	0.084			29,361	0.156	32,381	22,811	19,595	0.063
2004	28,909		30,465	0.073	40,319	27,868	34,730	0.148	14,656	21,895	19,595	0.063
2005			31,161	0.084			37,109	0.163	20,828	22,622	19,595	0.063
2006			31,873	0.086	40,643	34,898	39,650	0.123	18,515	17,999	19,595	0.063
2007			32,601	0.080			40,918	0.178	17,236	18,859	19,595	0.063
2008	33,033	31,762	33,346	0.063			42,226	0.192	19,617	18,456	19,595	0.063
2009			34,336	0.073			43,576	0.174	20,162	19,005	19,595	0.063
2010	33,882	31,941	35,355	0.070	48,260	43,074	44,970	0.111	18,902	19,560	19,595	0.063
2011			36,893	0.078			40,495	0.144	17,771	18,945	19,595	0.063
2012	40,901	35,939	38,498	0.080	33,902	40,935	36,466	0.107	16,664	17,779	19,595	0.063
2013							37,630	0.145	26,961	20,465	19,595	0.063
2014		35,939			39,468	40,543	38,830	0.110	24,465	22,696	19,595	0.063

Figures

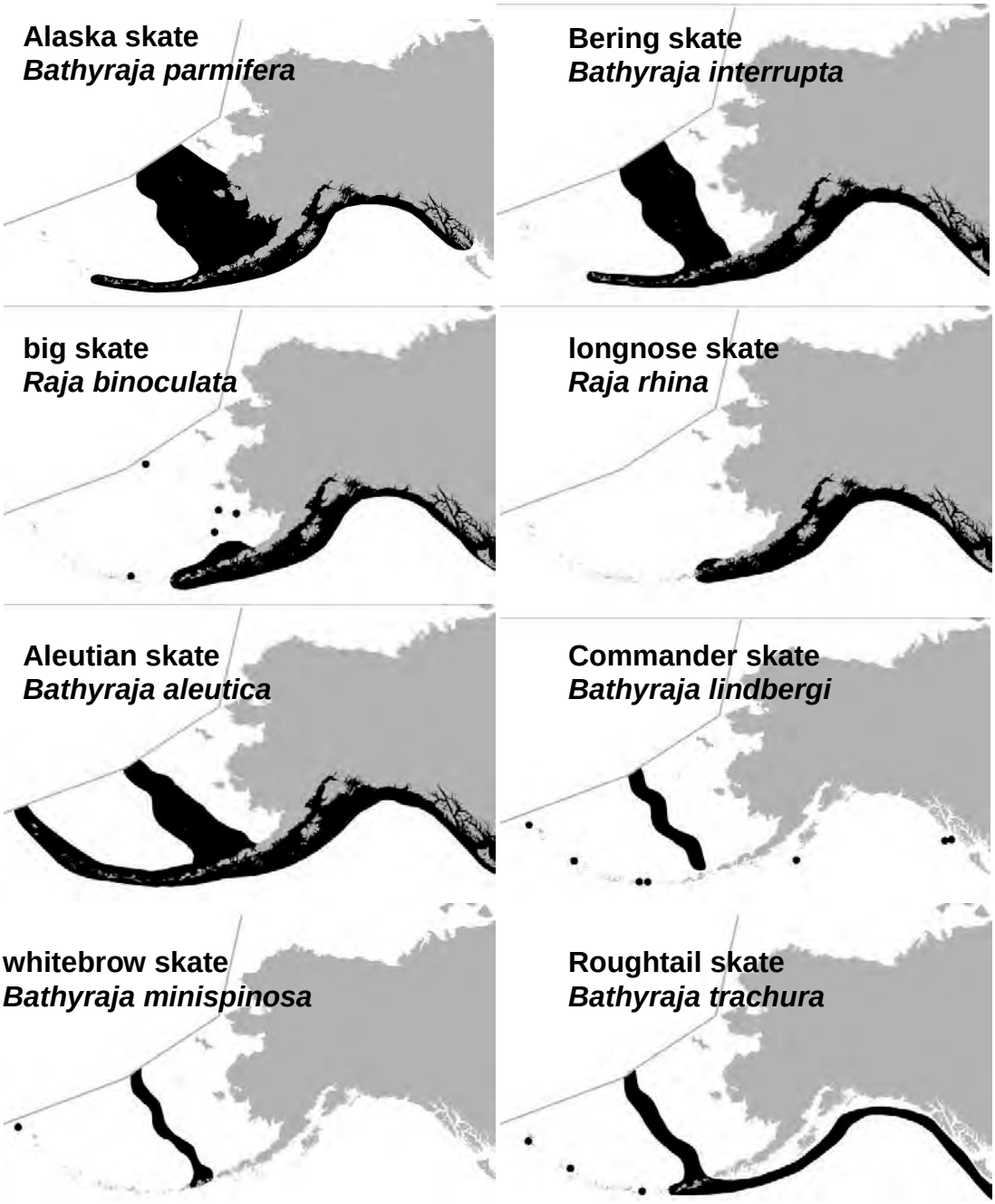


Figure 1. Distribution of skate species in Alaskan waters. These maps were created primarily using survey data, although observer records were included whenever positive species identification was possible (through voucher specimens or photographs). (Source: Stevenson et al. 2007)

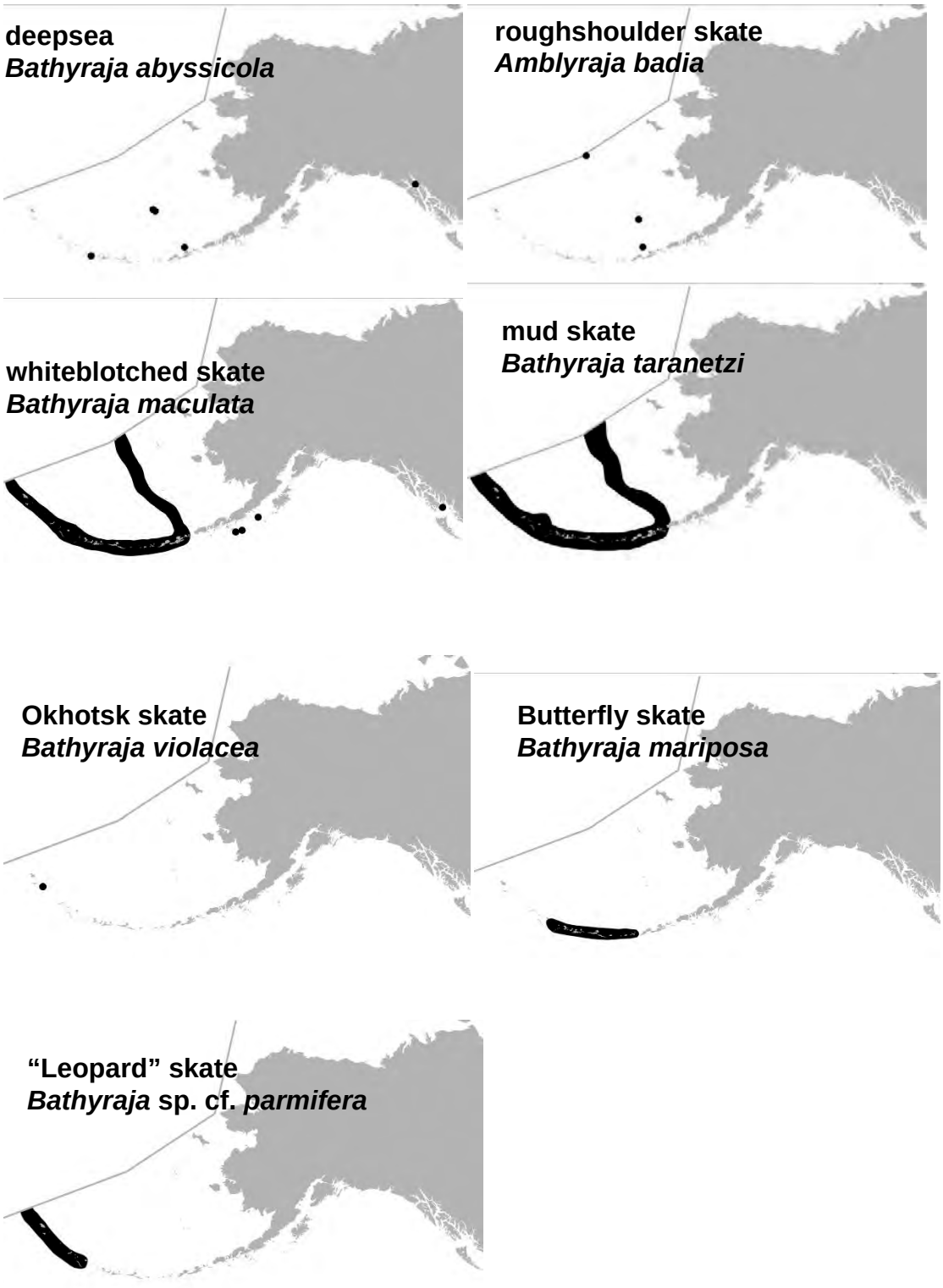


Figure 1 continued. Distribution of skate species in Alaskan waters. (Source: Stevenson et al. 2007)

Figure 2. Skate species composition (by weight) by BSAI subregion, from surveys conducted in each region in 2012. In the AI, "misc skates" includes leopard skates.

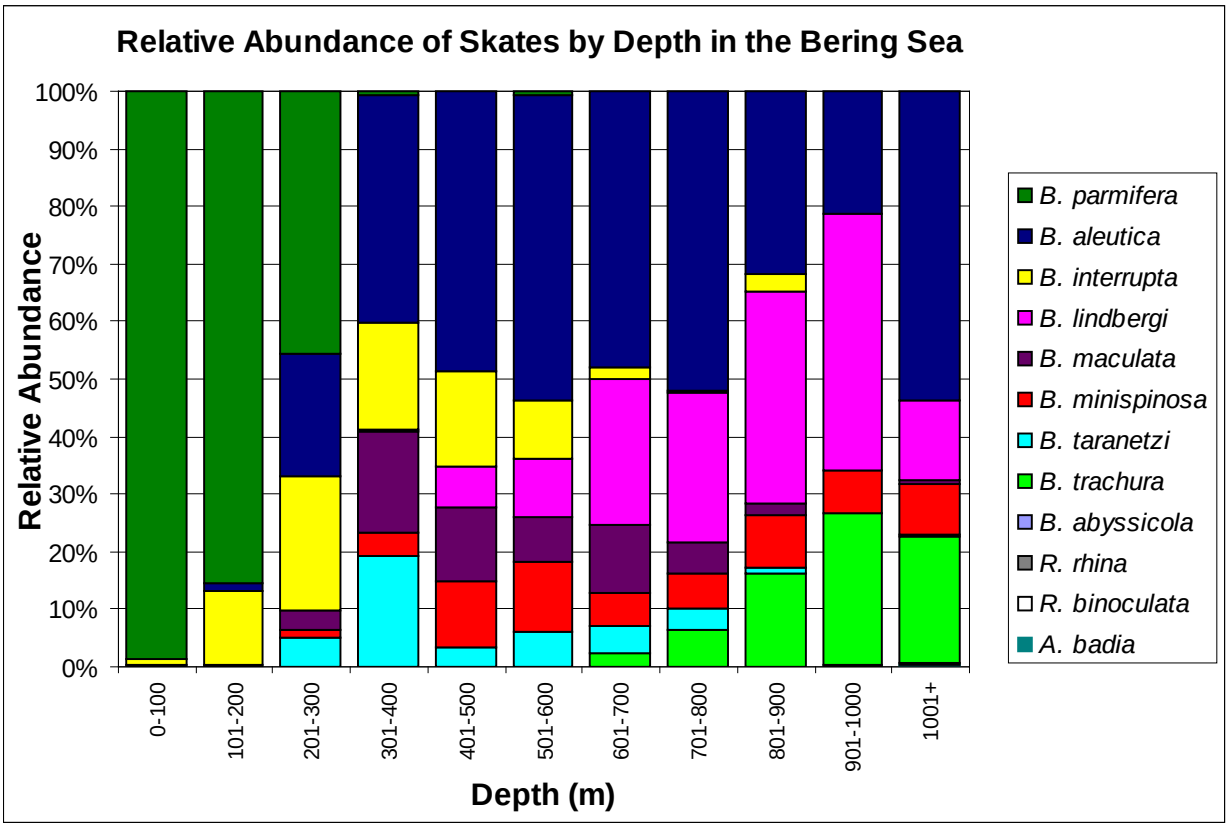


Figure 3. Relative abundance of skate species in the EBS by depth. (Source: Stevenson et al. 2006.)

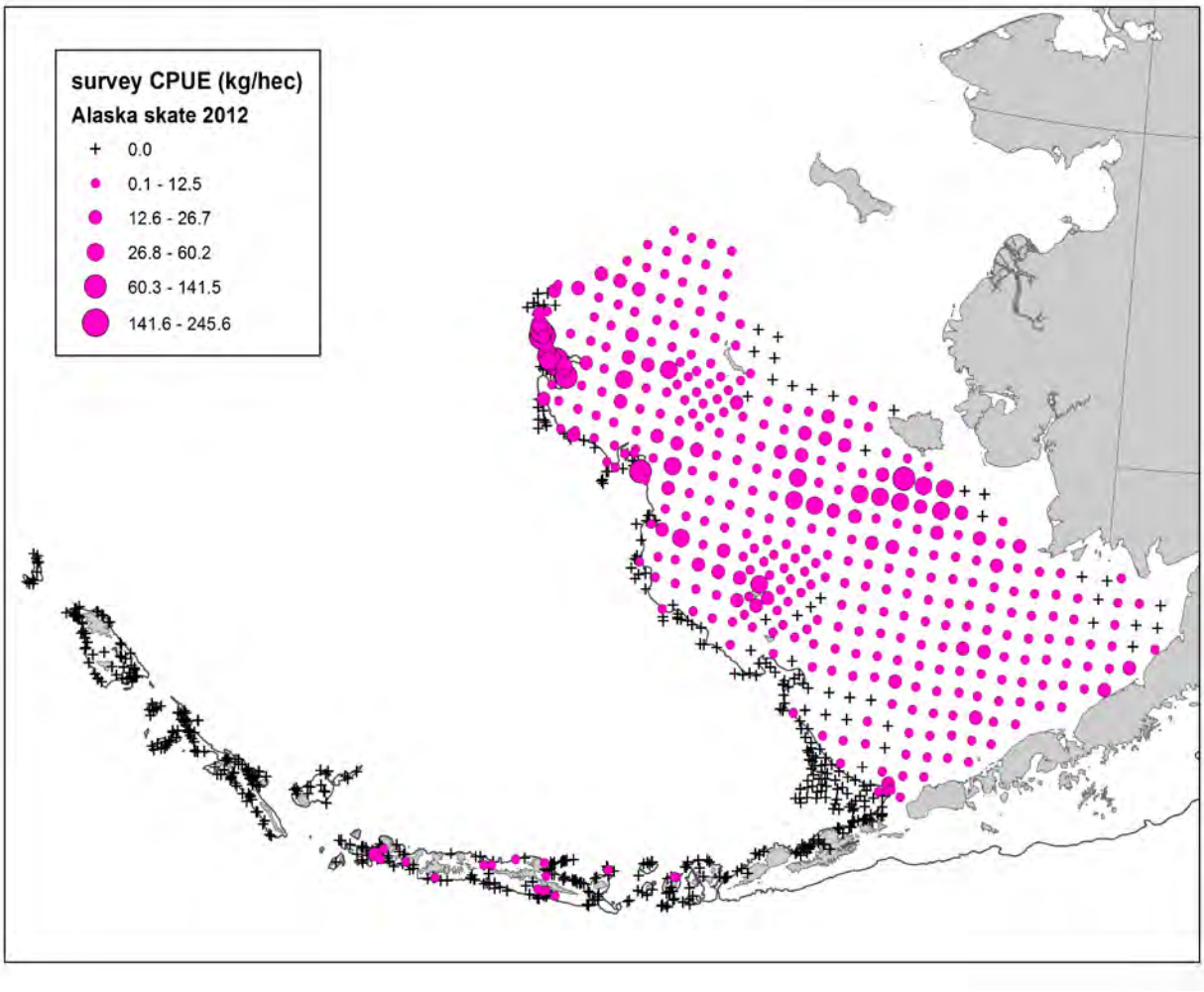


Figure 4. AFSC bottom trawl survey catch-per-unit-effort (CPUE) of Alaska skate in 2012, the last year when all 3 BSAI areas were surveyed in the same year. Symbol size is proportional to CPUE at each survey station and crosses indicate no catch of Alaska skate at that station. Data include the EBS shelf survey, the EBS slope survey, and the Aleutian Islands survey.

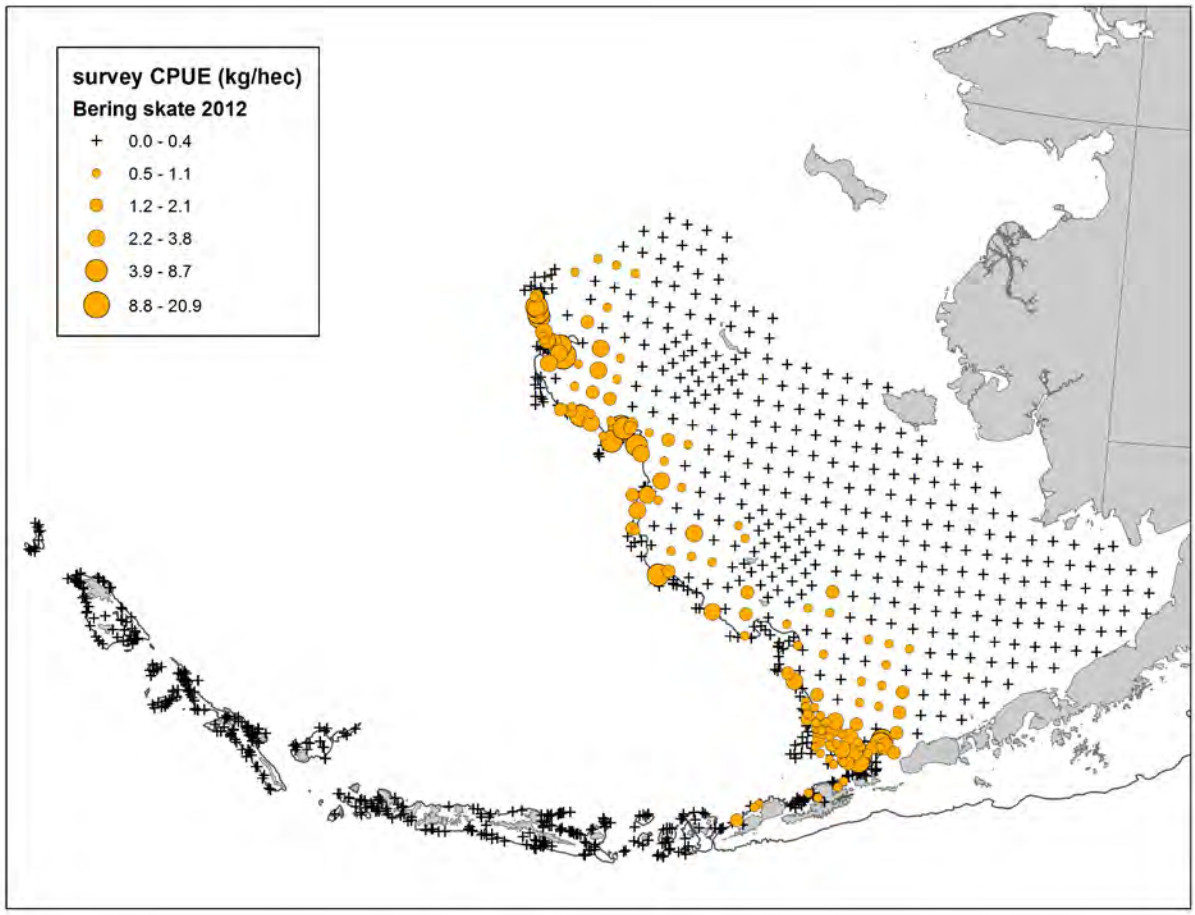


Figure 5. AFSC bottom trawl survey catch-per-unit-effort (CPUE) of Bering skate in 2012, the last year when all 3 BSAI areas were surveyed in the same year. Symbol size is proportional to CPUE at each survey station.and crosses indicate no catch of Alaska skate at that station. Data include the EBS shelf survey, the EBS slope survey, and the Aleutian Islands survey.

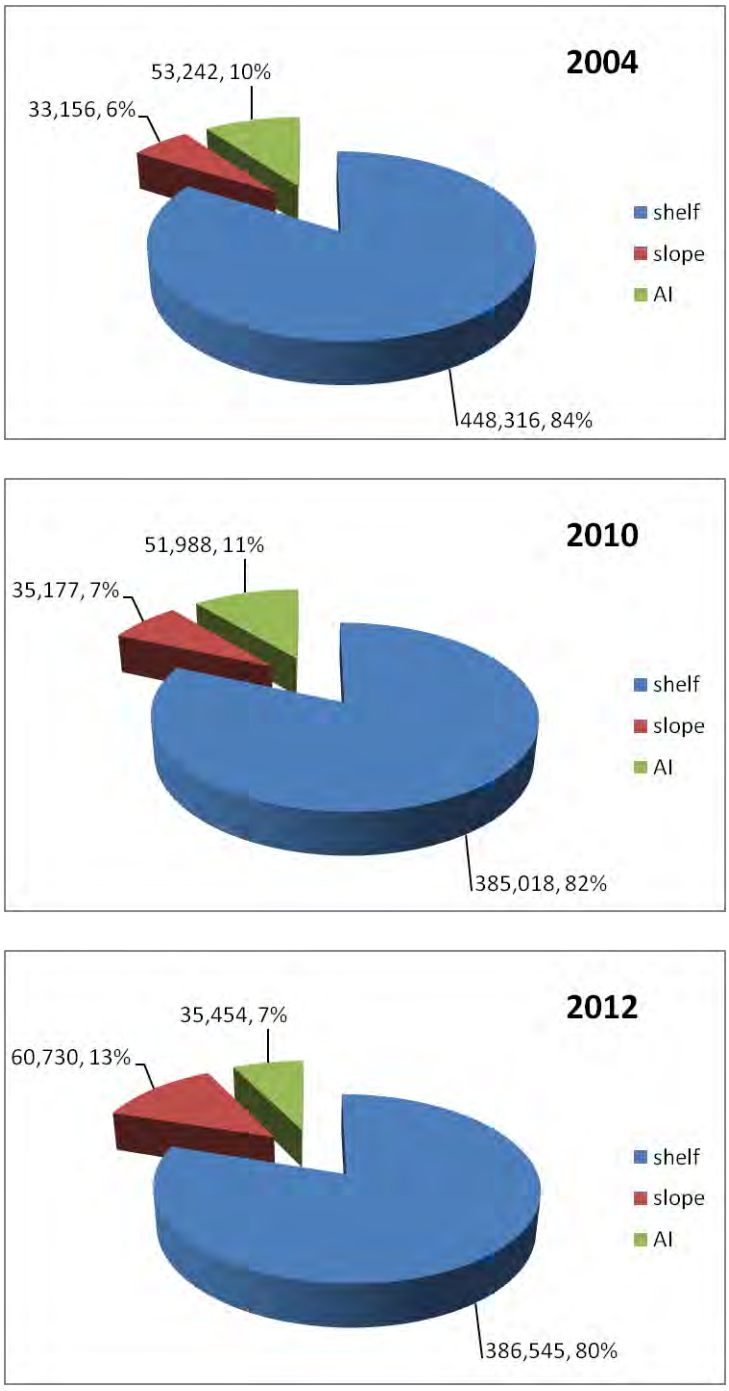


Figure 6. Distribution of skate biomass in the 3 subregions of the BSAI in 2004, 2010, and 2012. These are the 3 most recent years when all 3 surveys in the BSAI were conducted in the same year. Data are biomass estimates (t) and relative proportions from AFSC groundfish surveys.

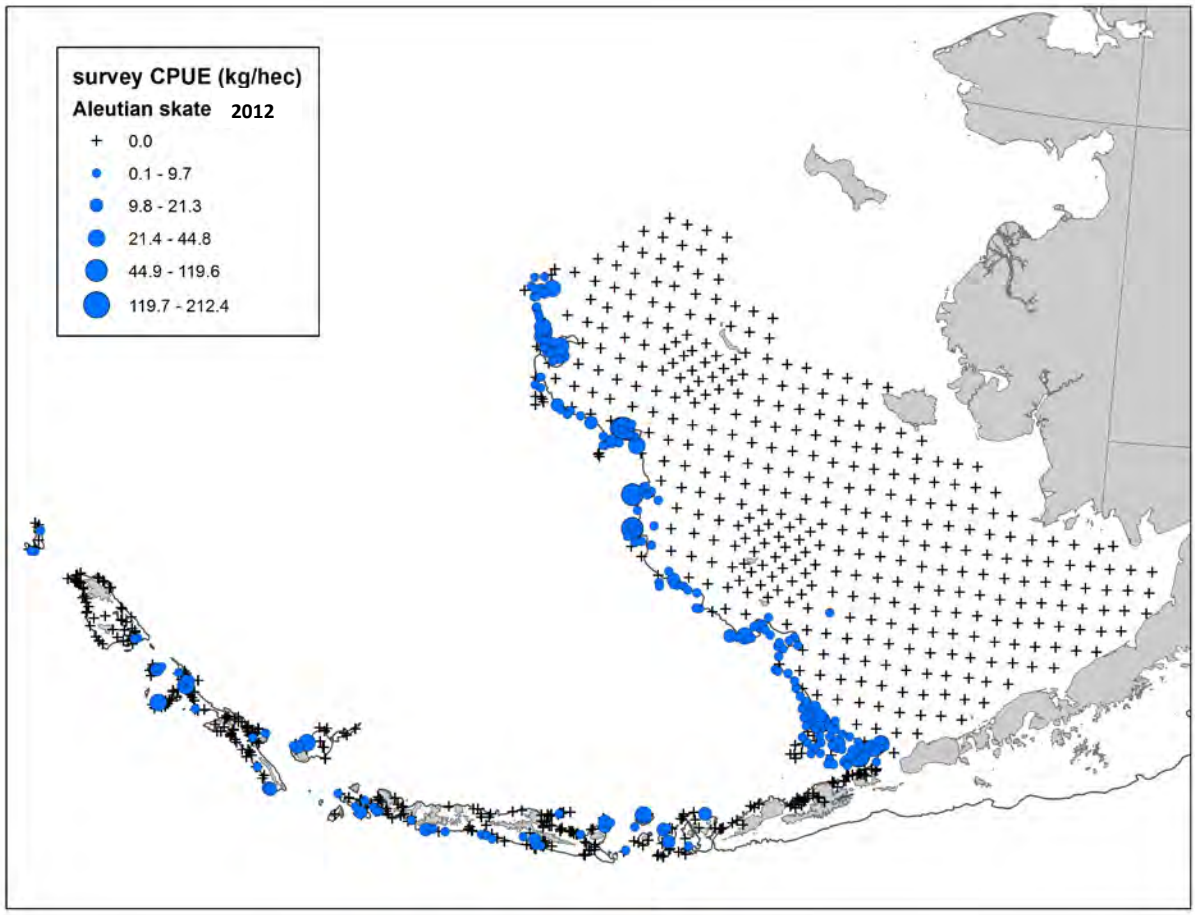


Figure 7. AFSC bottom trawl survey catch-per-unit-effort (CPUE) of Aleutian skate in 2012 , the last year when all 3 BSAI areas were surveyed in the same year. Symbol size is proportional to CPUE at each survey station.and crosses indicate no catch of Alaska skate at that station. Data include the EBS shelf survey, the EBS slope survey, and the Aleutian Islands survey.

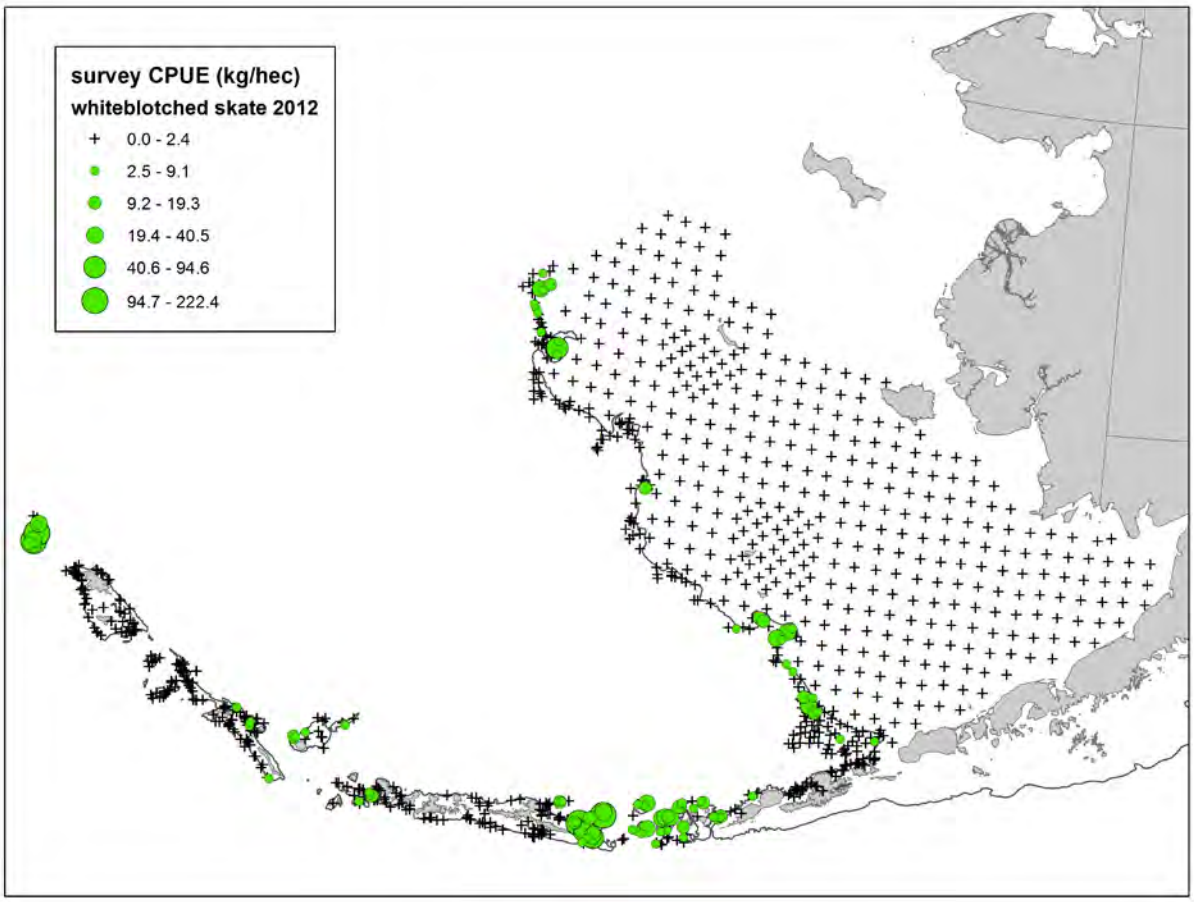


Figure 8. AFSC bottom trawl survey catch-per-unit-effort (CPUE) of whiteblotched skate in 2012 , the last year when all 3 BSAI areas were surveyed in the same year. Symbol size is proportional to CPUE at each survey station.and crosses indicate no catch of Alaska skate at that station. Data include the EBS shelf survey, the EBS slope survey, and the Aleutian Islands survey.

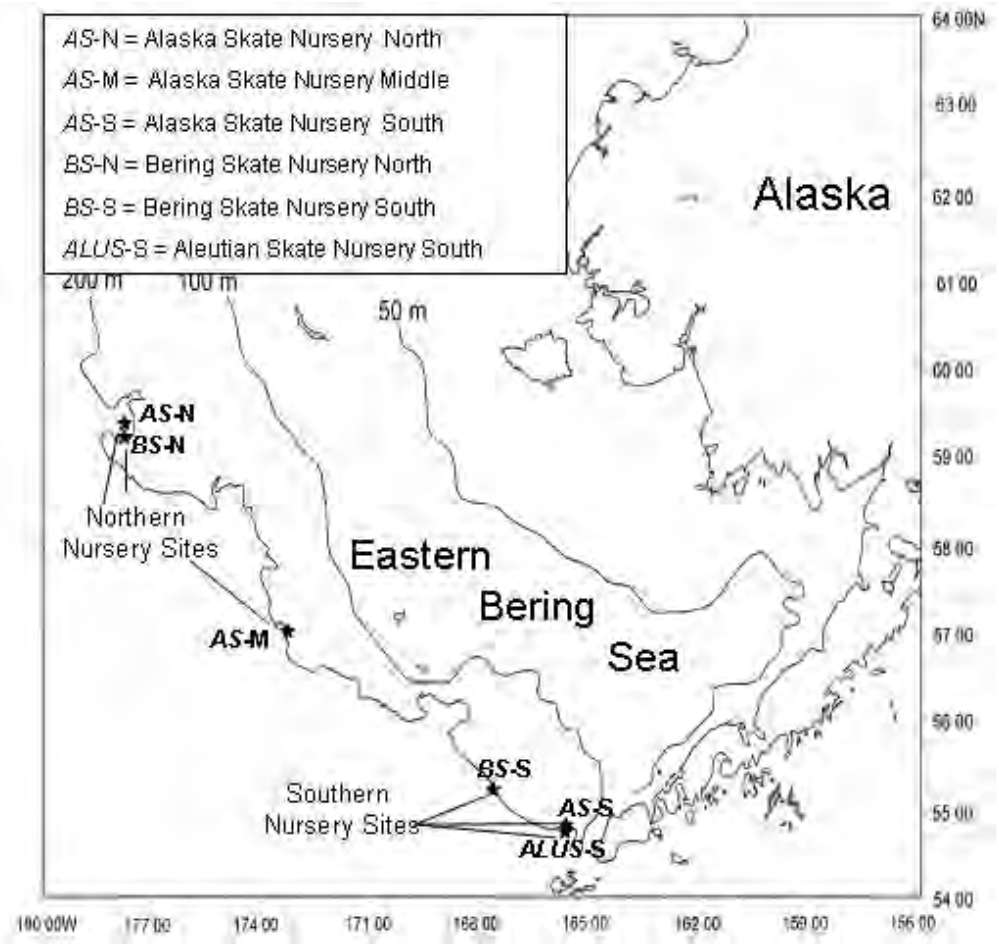


Figure 9. Map of the eastern Bering Sea with the six known skate nursery site locations and designations as a northern or southern nursery site. (See the legend for nursery site designation.) Source: Gerald Hoff, AFSC, unpublished data.

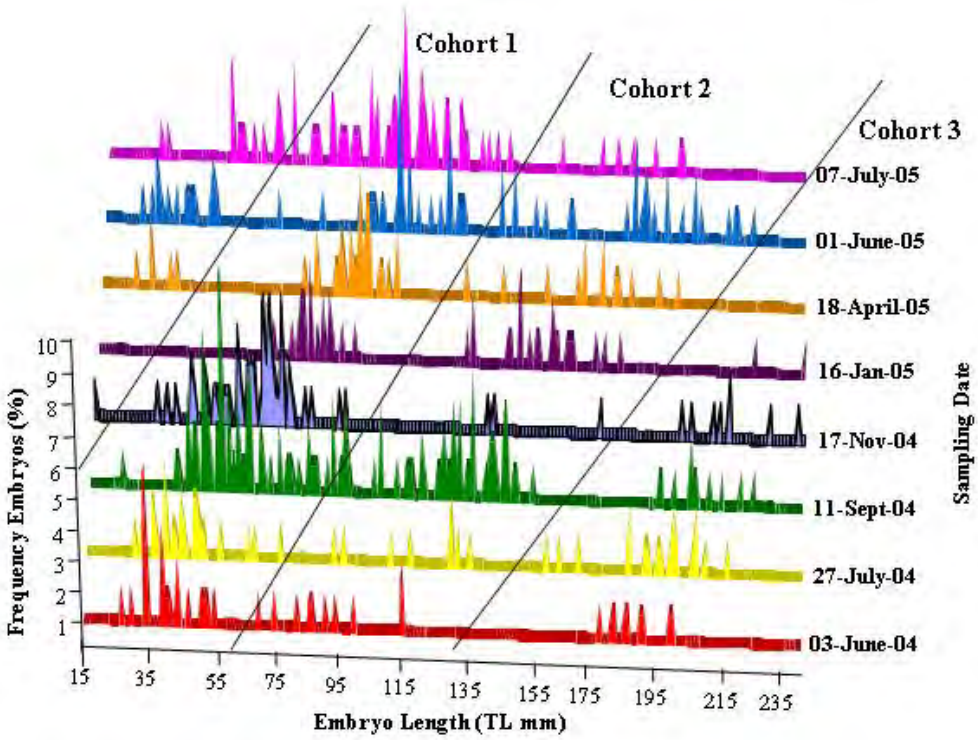


Figure 10. Embryo length composition data used in a cohort analysis of embryo development time. Figure is from G. Hoff (AFSC, pers. comm.).

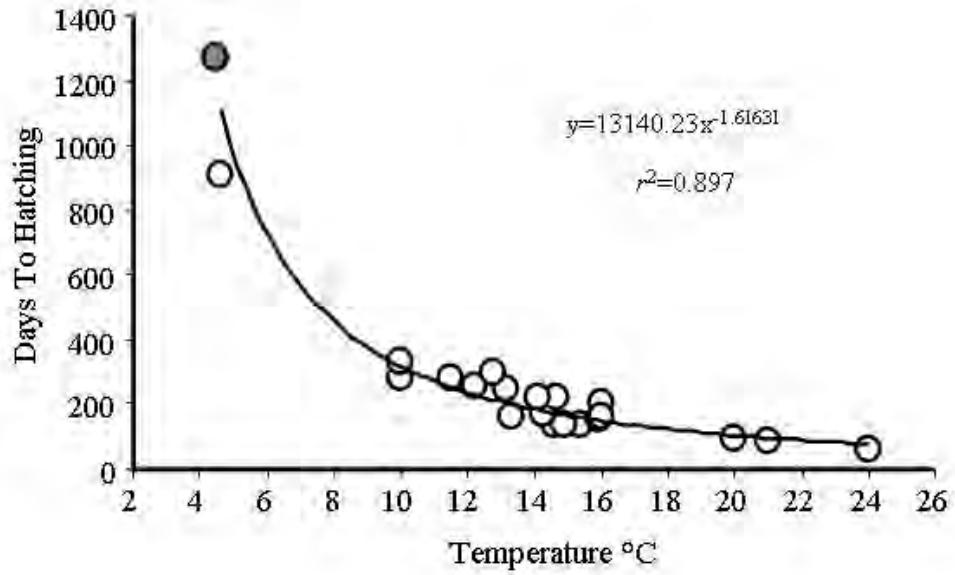


Figure 11. Ocean temperature versus embryo development time for 21 skate species. Dark grey circle is the Alaska skate. Equation and R^2 are the values of the fitted relationship. Figure is from G. Hoff (AFSC, pers. comm.)

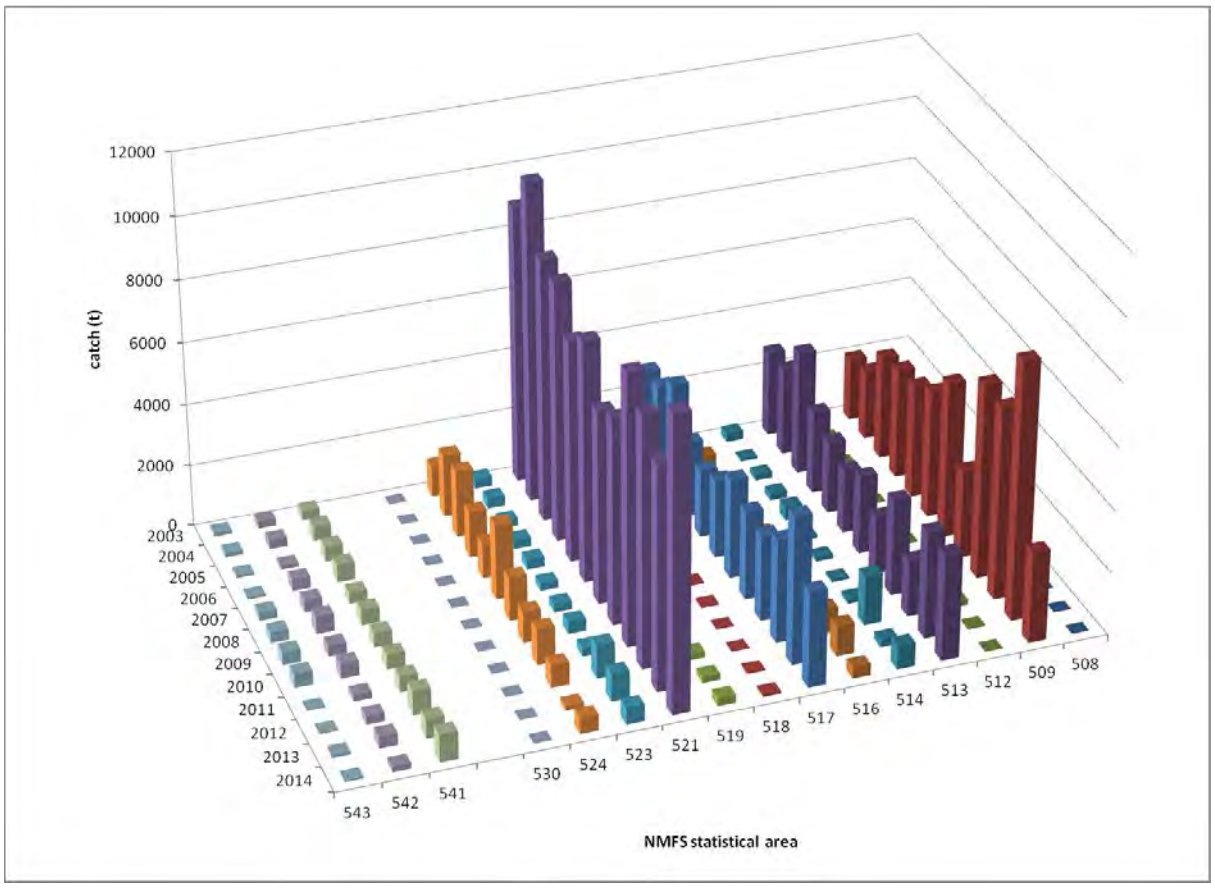


Figure 12. Total skate catch (all species combined) by FMP reporting area for both the EBS and the AI, 2003 - 2014. Source: AKRO CAS. 2014 data incomplete; retrieved October 8, 2014.

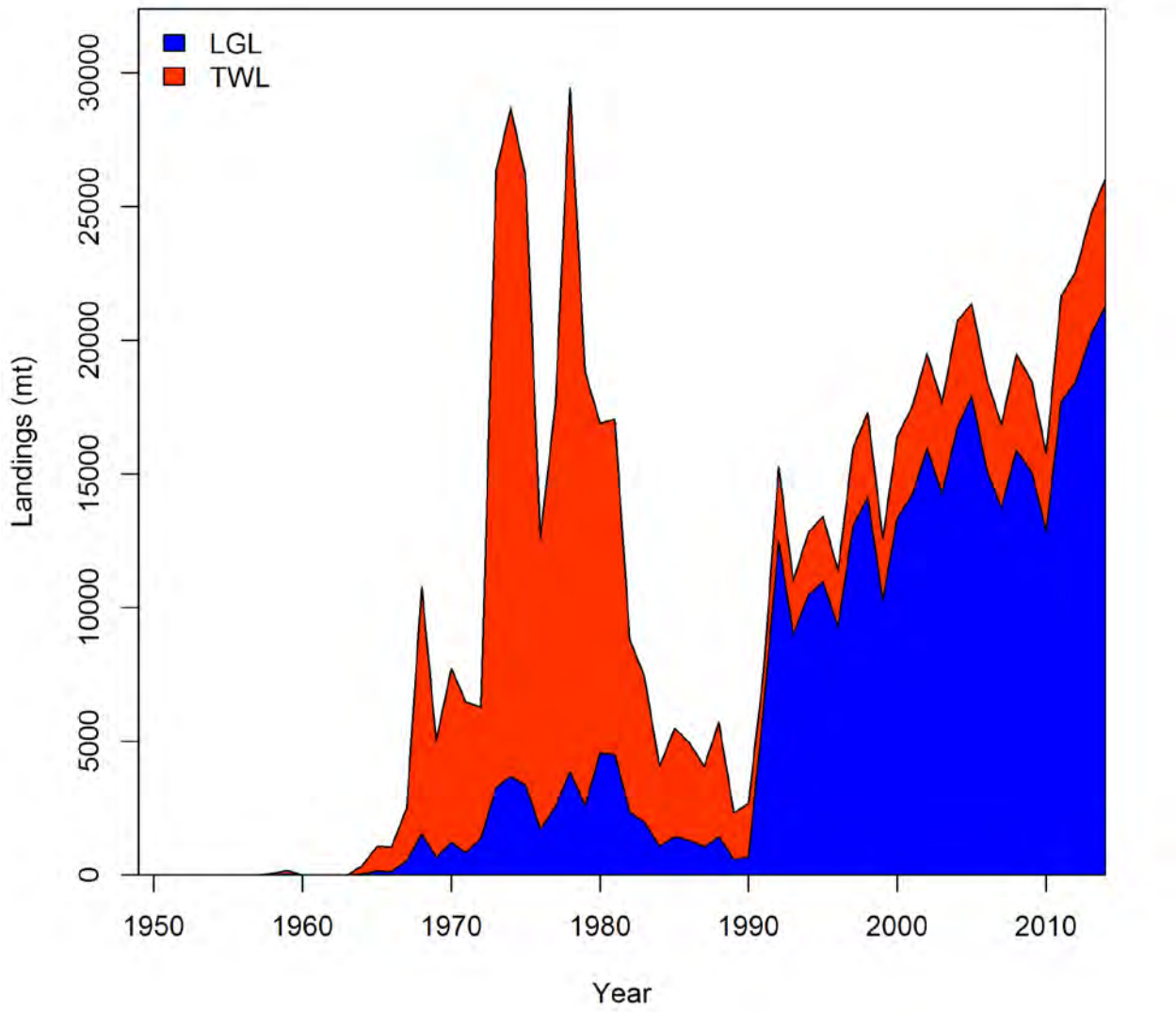


Figure 13. Estimated catch of Alaska skates (t) in the BSAI 1954-2014. LGL = longline fishery, TWL = trawl fishery. Source:……

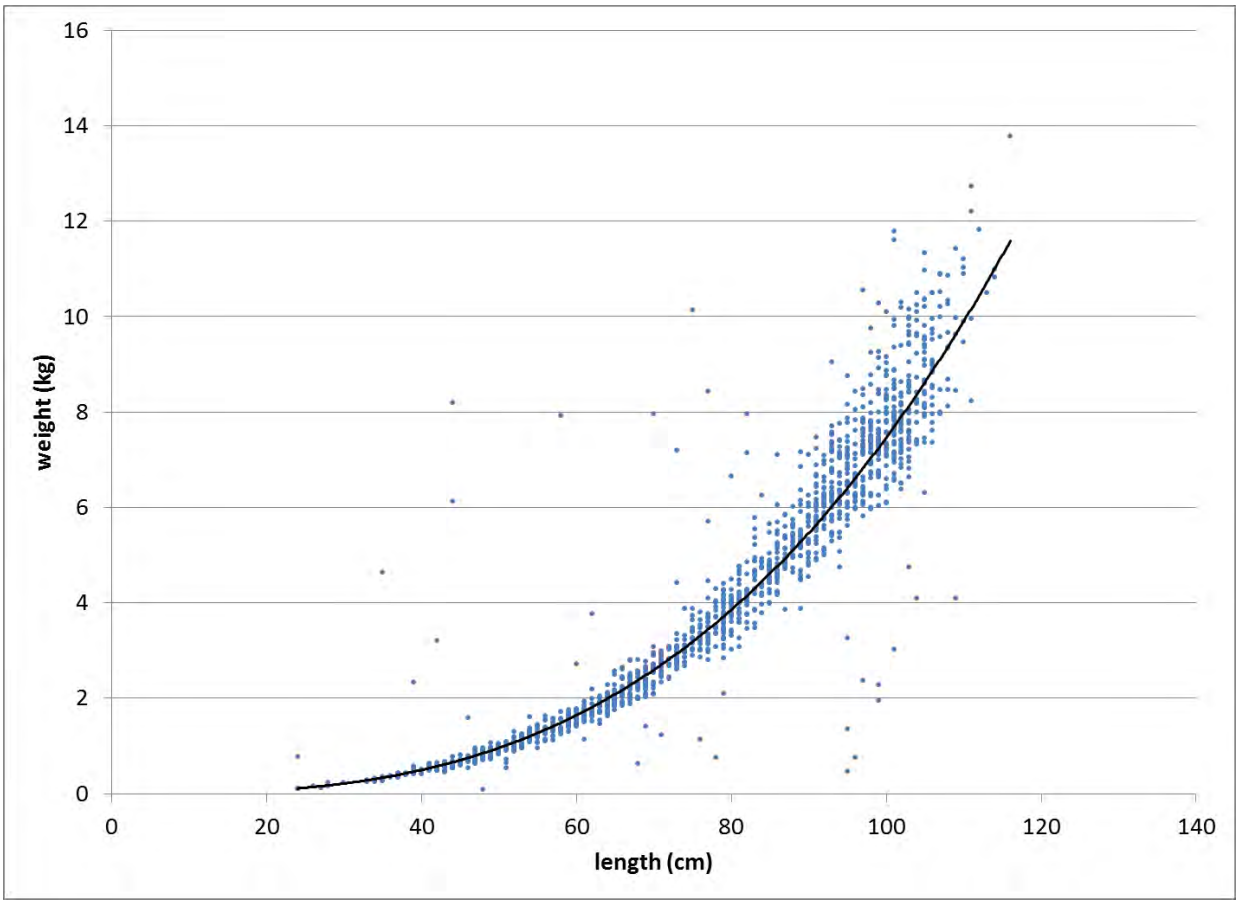


Figure 14. Length-weight relationship for Alaska skates captured in the EBS shelf trawl survey, 2008-2010. Black line indicates line of best fit to the data, $r^2 = 0.93$, N = 1,515.

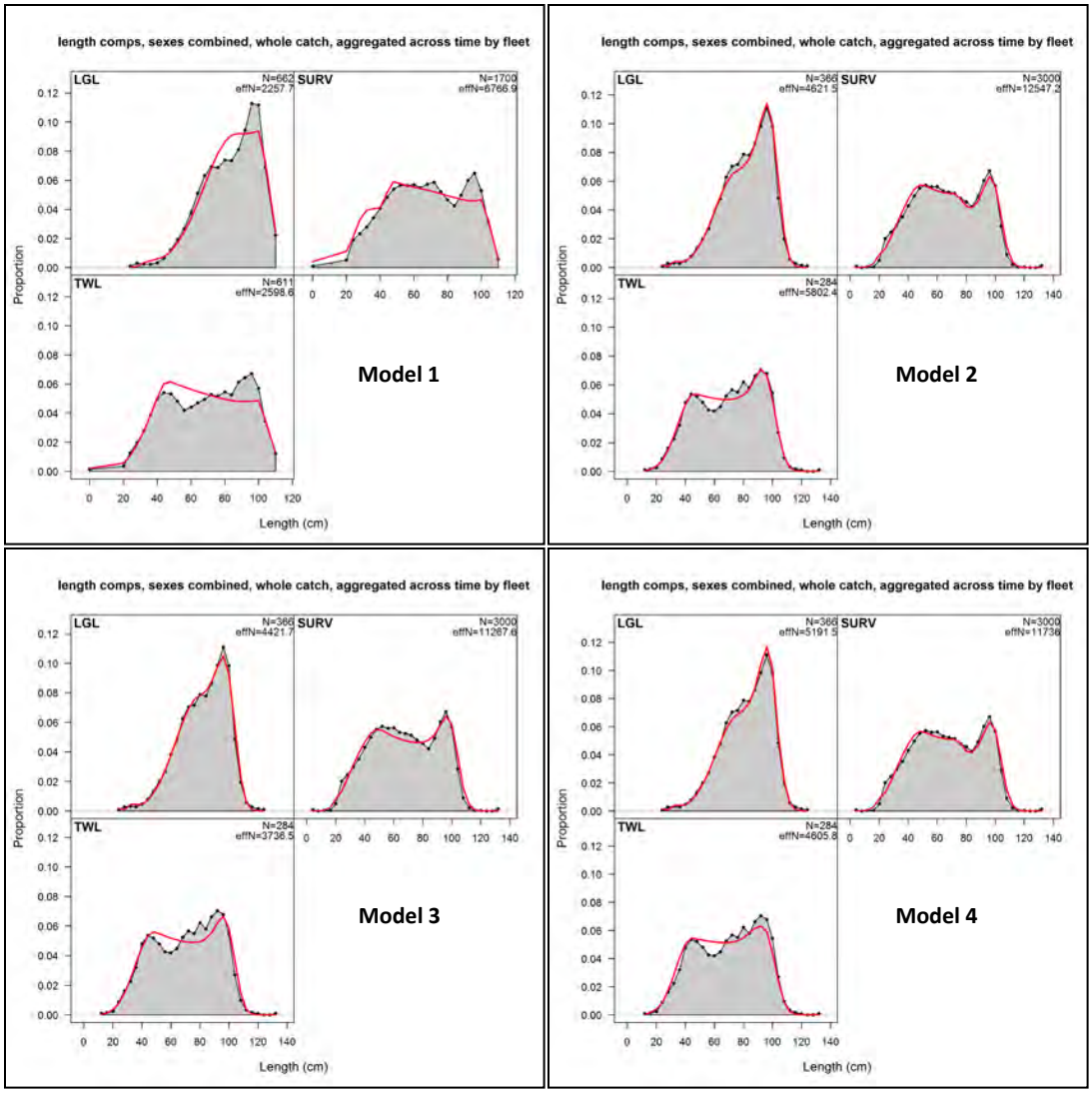


Figure 15. Fits to length composition data for the 4 alternative models. For each fleet, observed data (grey) and model fit (red line) are aggregated across years. LGL = longline fishery, TWL = trawl fishery, SURV = trawl survey.

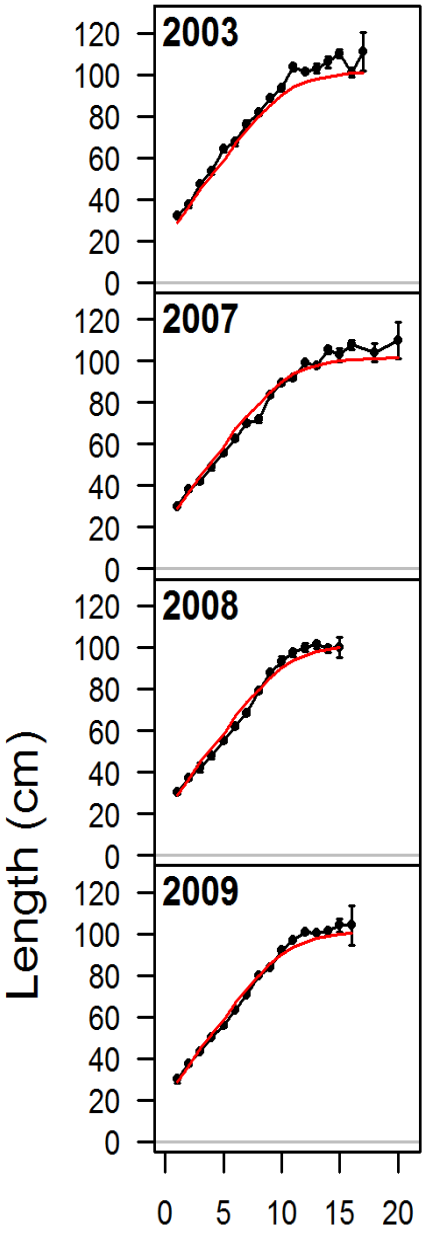


Figure 16. Observed (black circles) and model-predicted (red line) length-at-age for Model 2, the author's preferred model.

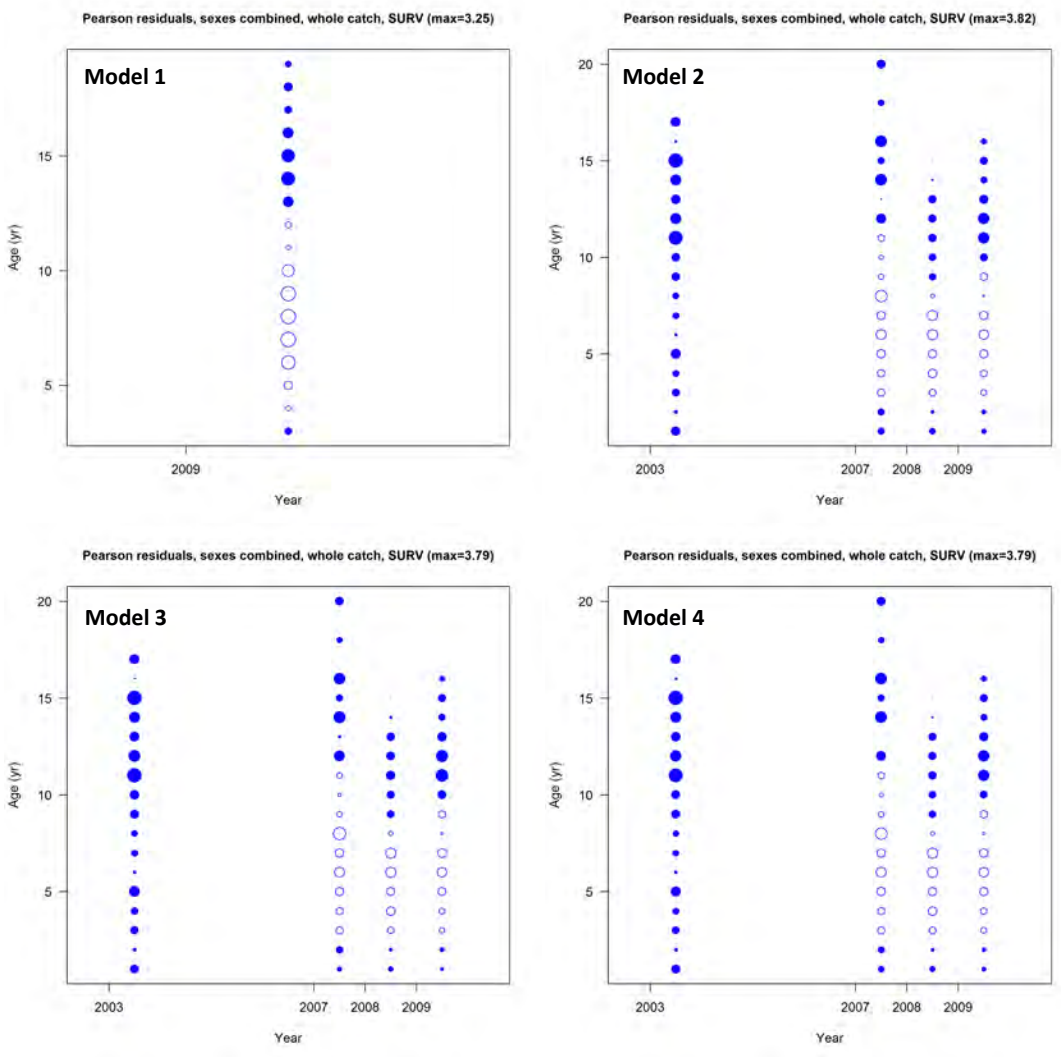


Figure 17. Pearson residuals for the length-at-age-datasets for the four models included in this report.

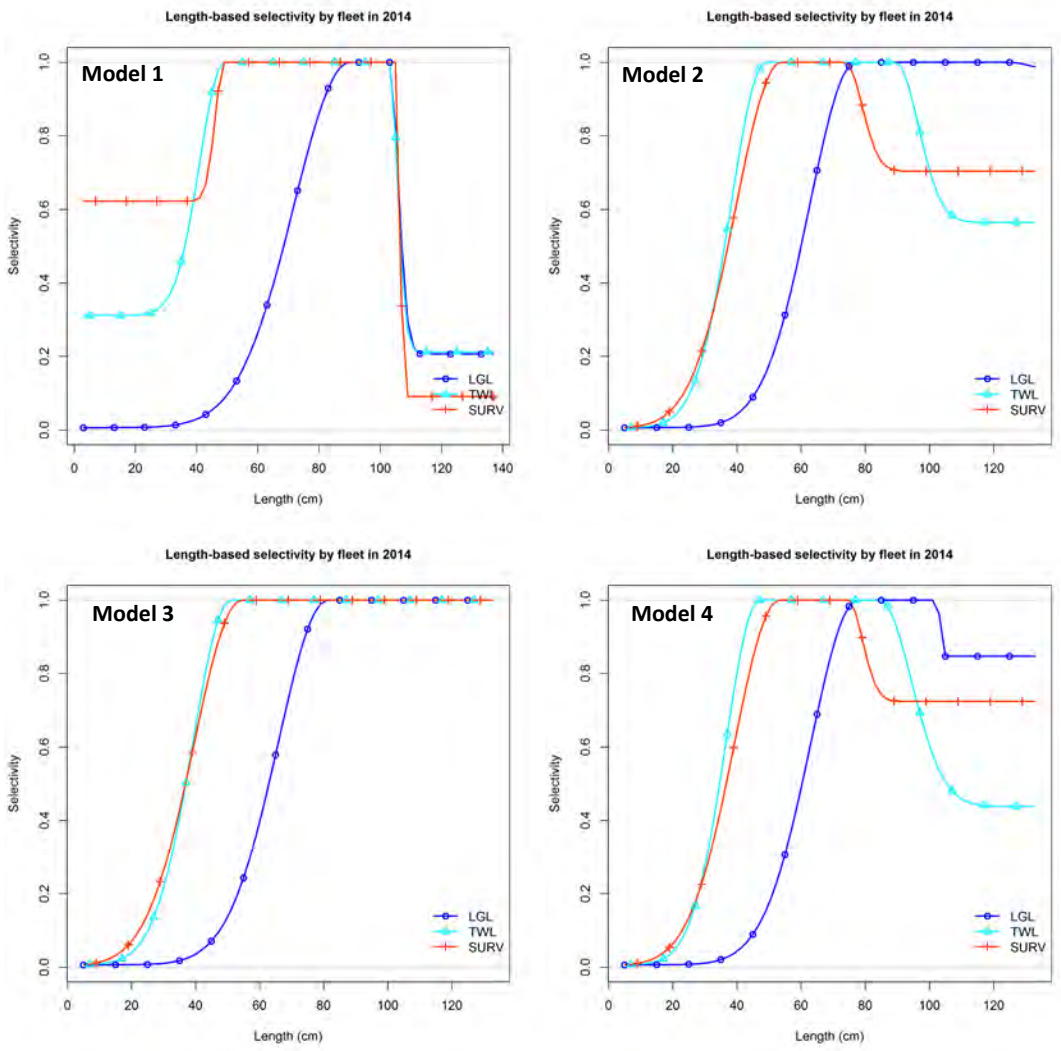


Figure 18. Selectivity functions for the four model alternatives. LGL = longline fishery, TWL = trawl fishery, SURV = trawl survey.

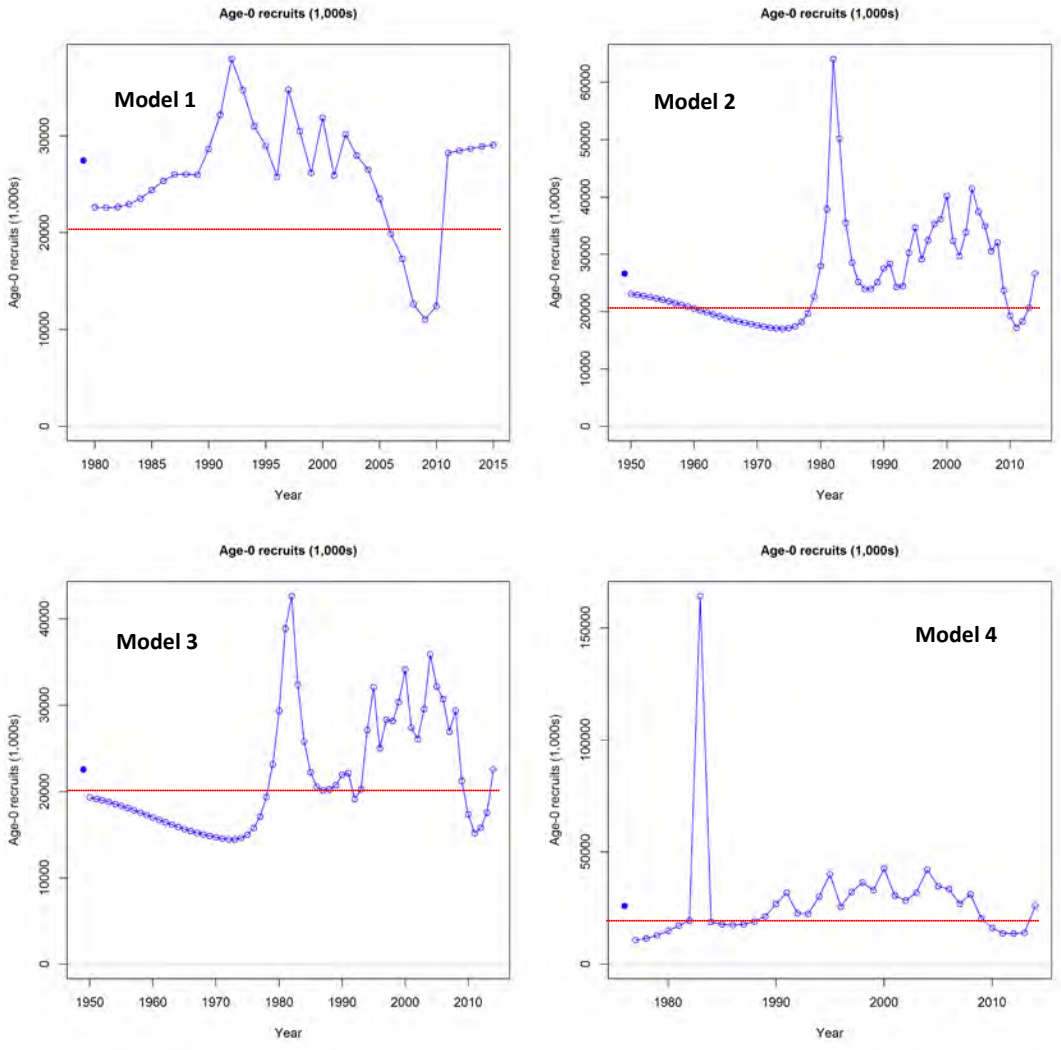


Figure 19. Time series of recruitment for the 4 alternative models. Filled blue circle indicates unfished recruitment. Vertical axis scales differ among plots; dashed red horizontal line indicates identical values among plots.

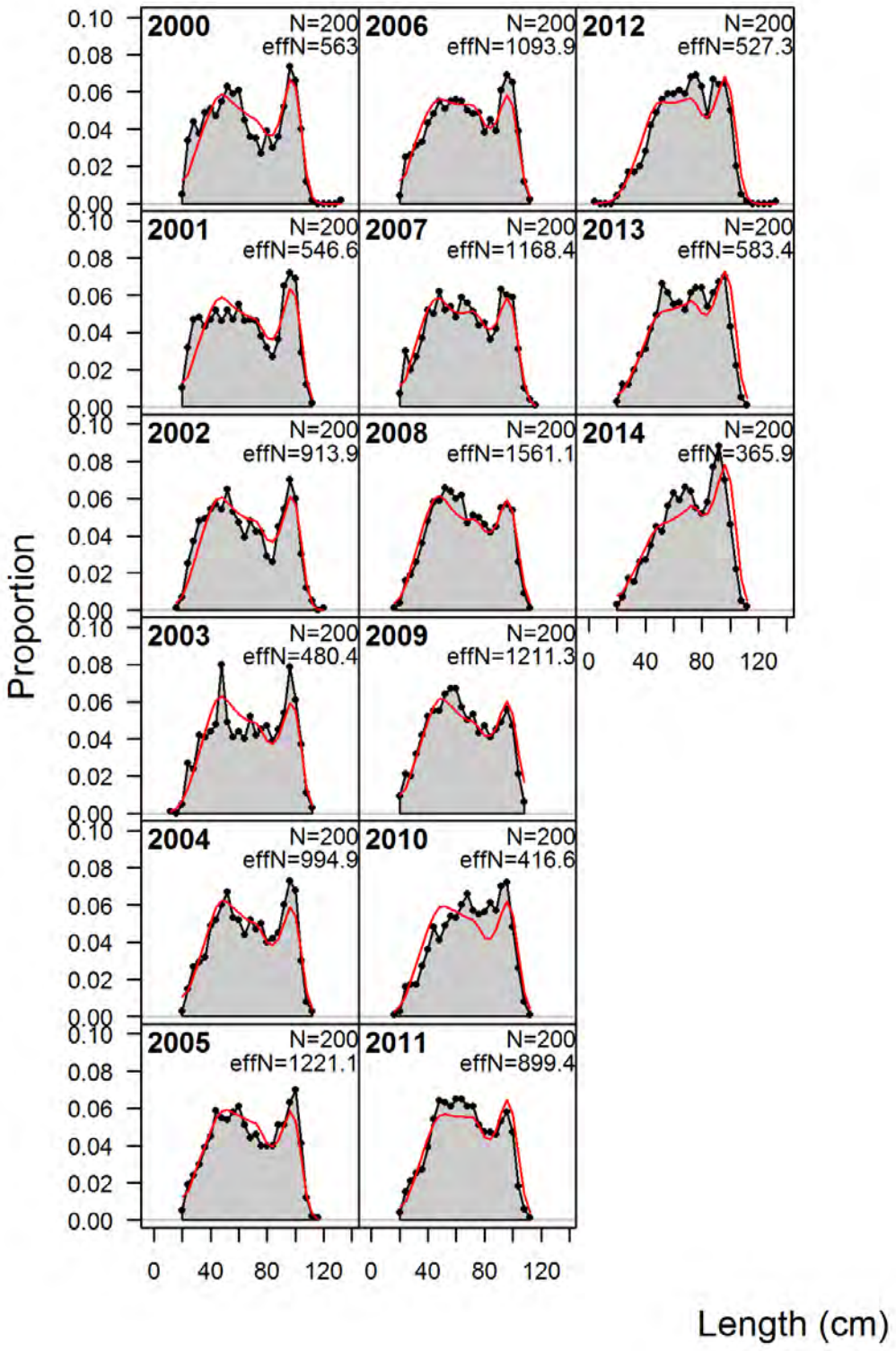


Figure 20. EBS shelf survey length compositions from 2000-2014. Grey shading = observed proportions; red line = model predictions. X-axis values are lengths in cm.

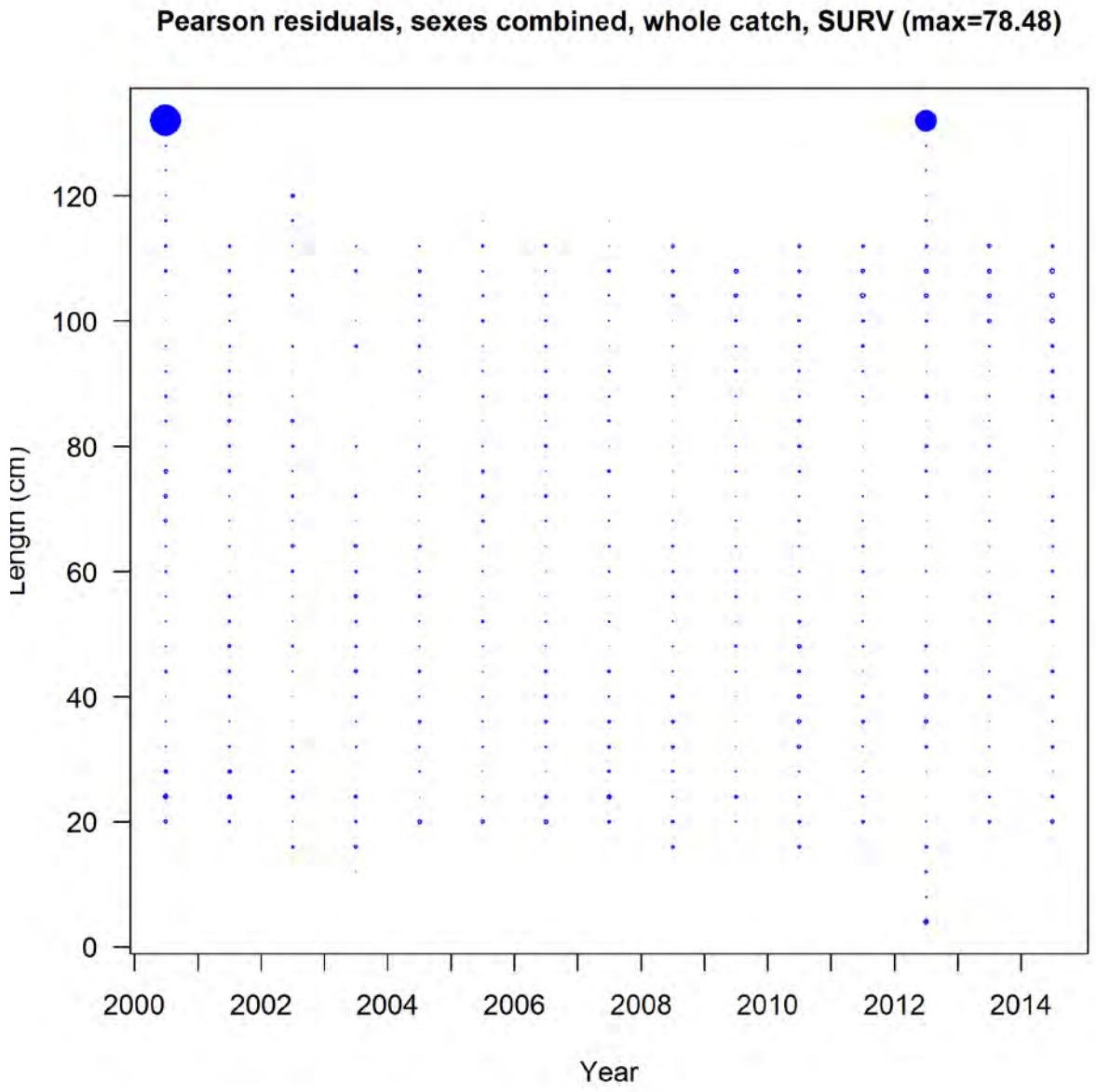


Figure 21. Pearson residuals for model fit to survey length composition data. Circles indicate the relative size of the residual, with the largest circle equivalent to a maximum residual value of 78.48. Solid circles indicate positive residuals, open circles indicate negative residuals.

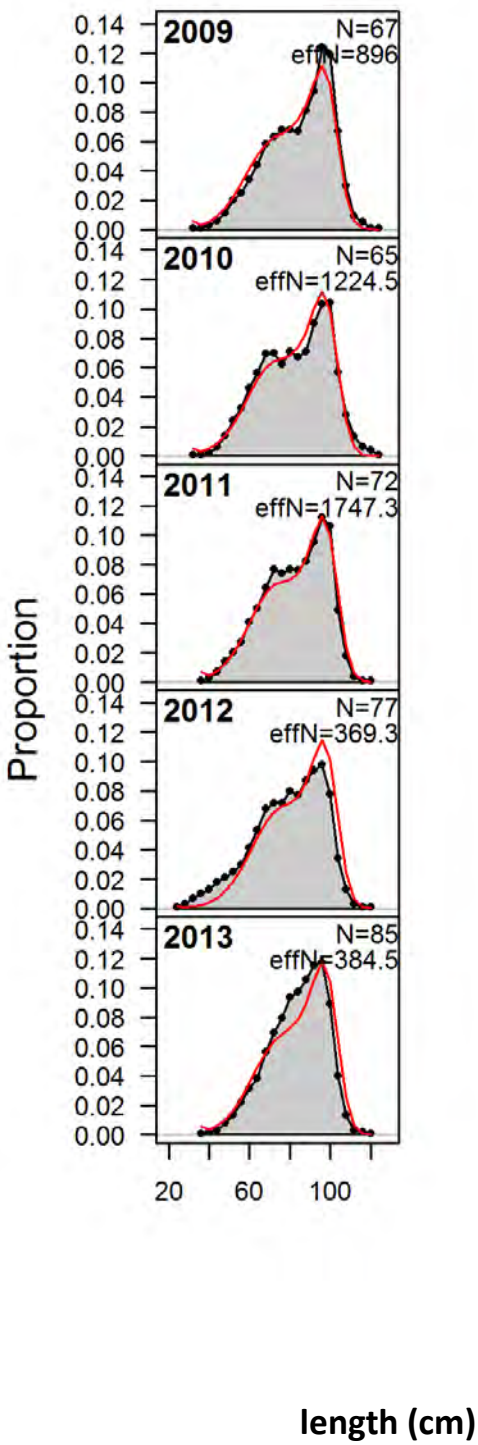


Figure 22. Observed and model-predicted length compositions from the 2009-2013 longline fisheries, with model predictions. Grey shading = observed proportions; red line = model predictions.

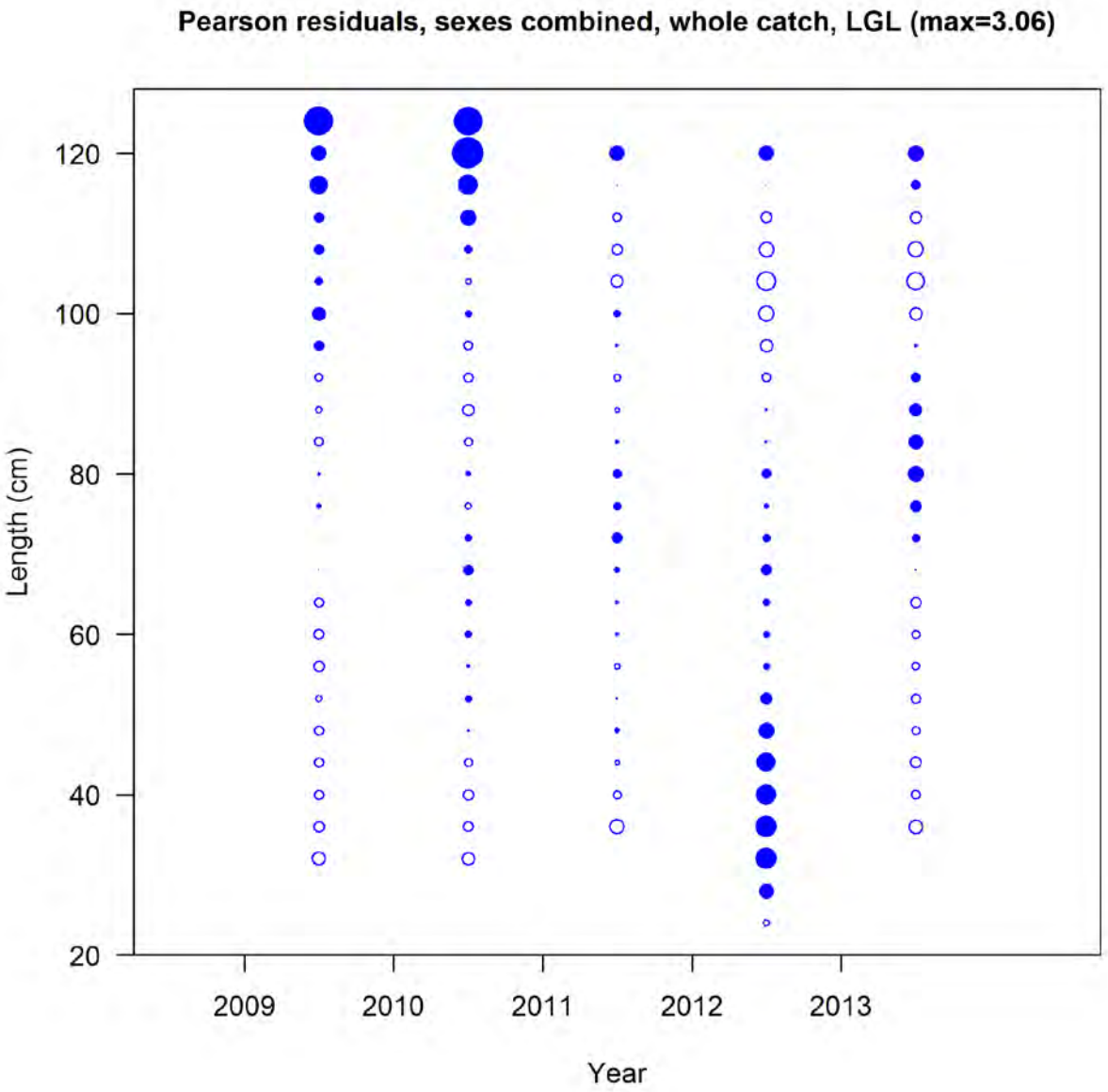


Figure 23. Pearson residuals for model fit to longline fishery length composition data, 2009-2013. Circles indicate the relative size of the residual, with the largest circle equivalent to a maximum residual value of 3.06. Solid circles indicate positive residuals, open circles indicate negative residuals.

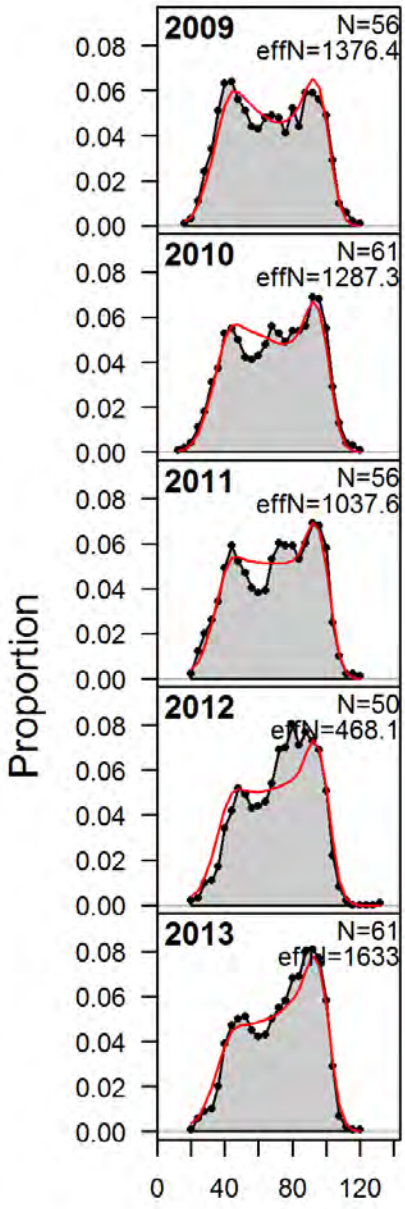


Figure 24. Observed and model-predicted length compositions from the 2009-2013 trawl fisheries, with model predictions. Grey shading = observed proportions; red line = model predictions.

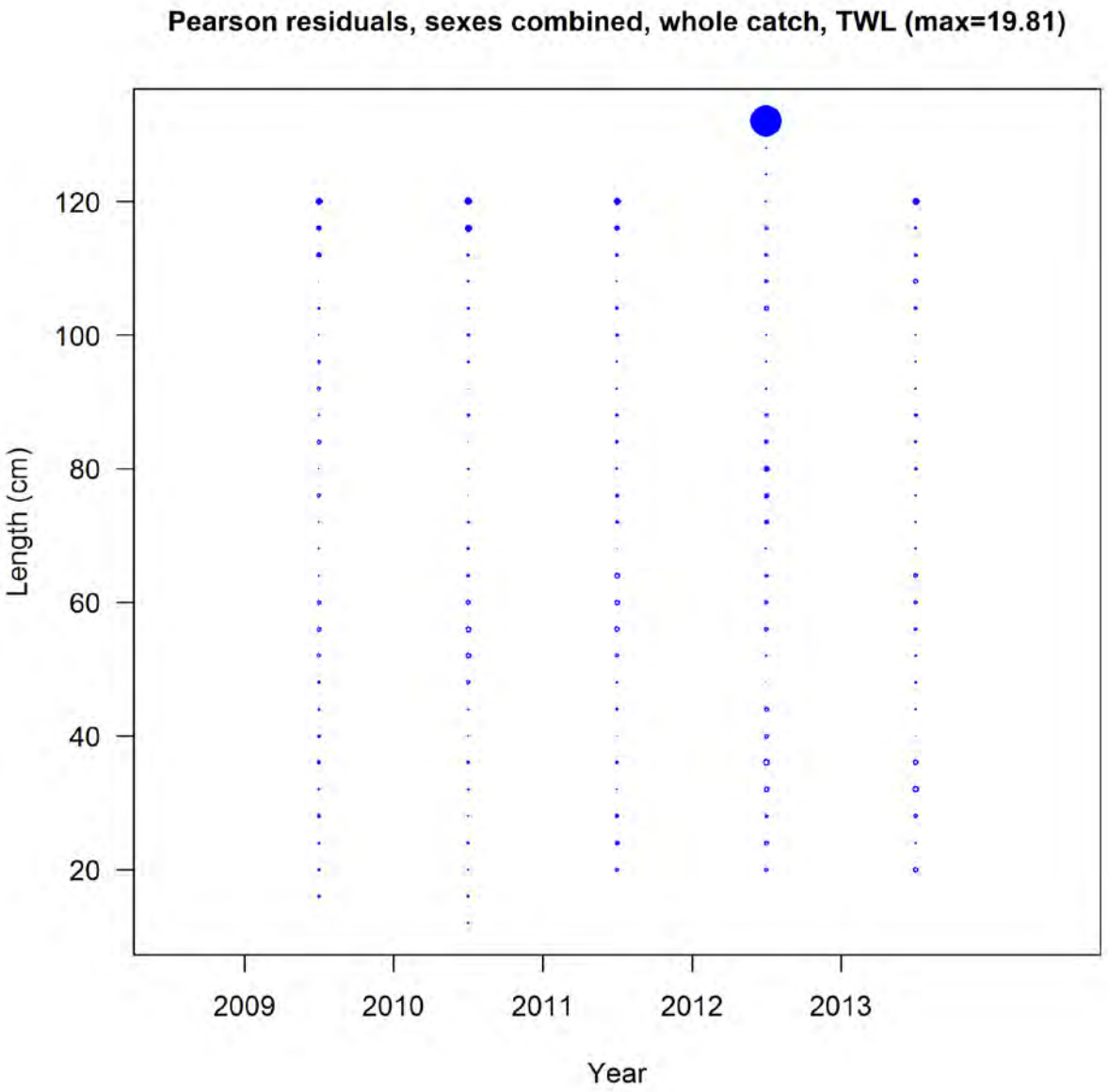


Figure 25. Pearson residuals for model fit to trawl fishery length composition data, 2009-2013. Circles indicate the relative size of the residual, with the largest circle equivalent to a maximum residual value of 19.81. Solid circles indicate positive residuals, open circles indicate negative residuals.

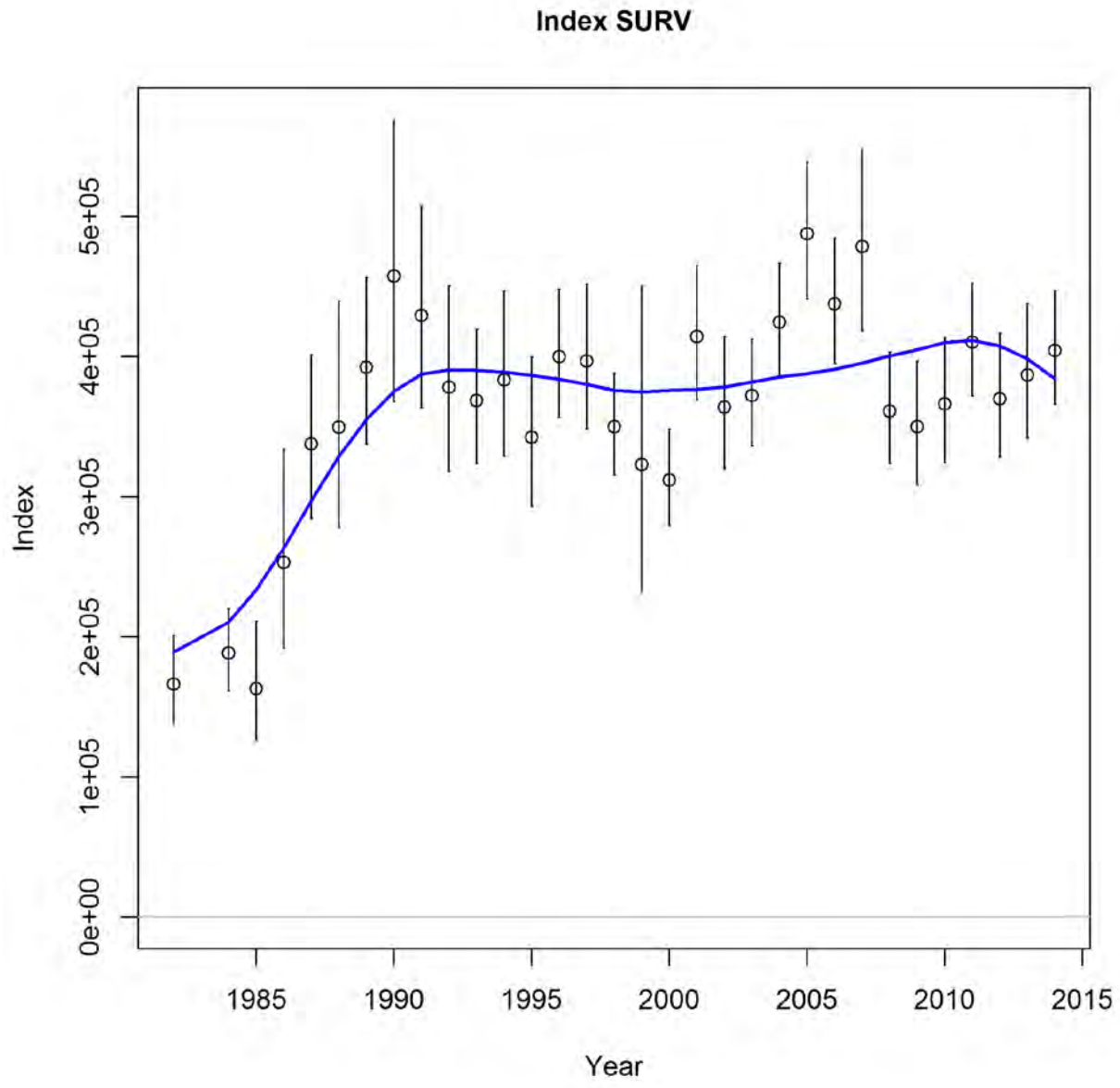


Figure 26. Observed biomass (circles) from EBS shelf surveys 1982-2014, with confidence intervals (± 2 SE), and predicted survey biomass from the model (blue line).

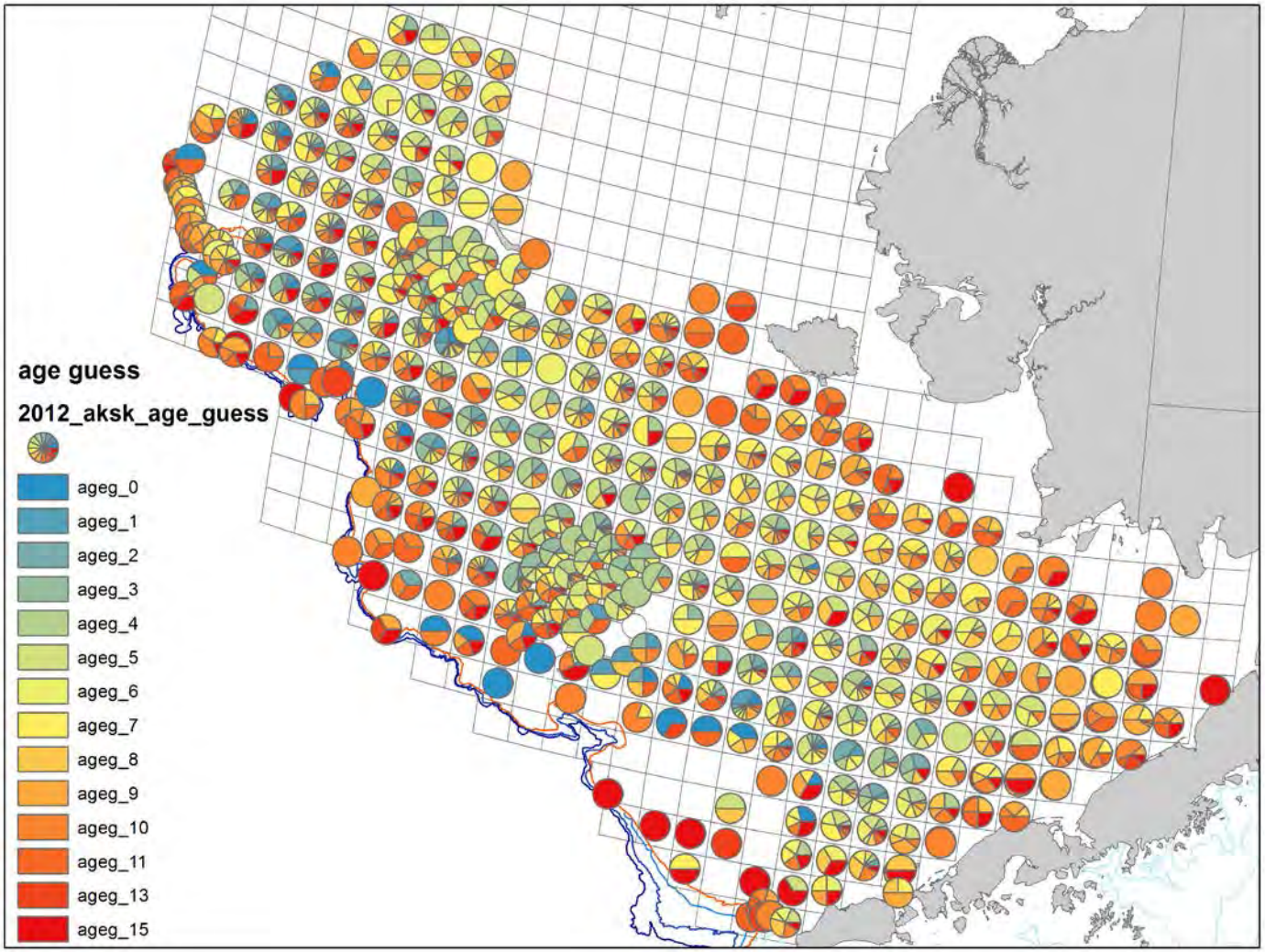


Figure 27. Proportional distribution of Alaska skates in the BSAI by estimated age ("age guess"). Data include the EBS shelf and slope surveys, and each circle indicates a survey haul. Length data were converted to estimated age by interpolating mean length-at-age data from the 2009 survey.

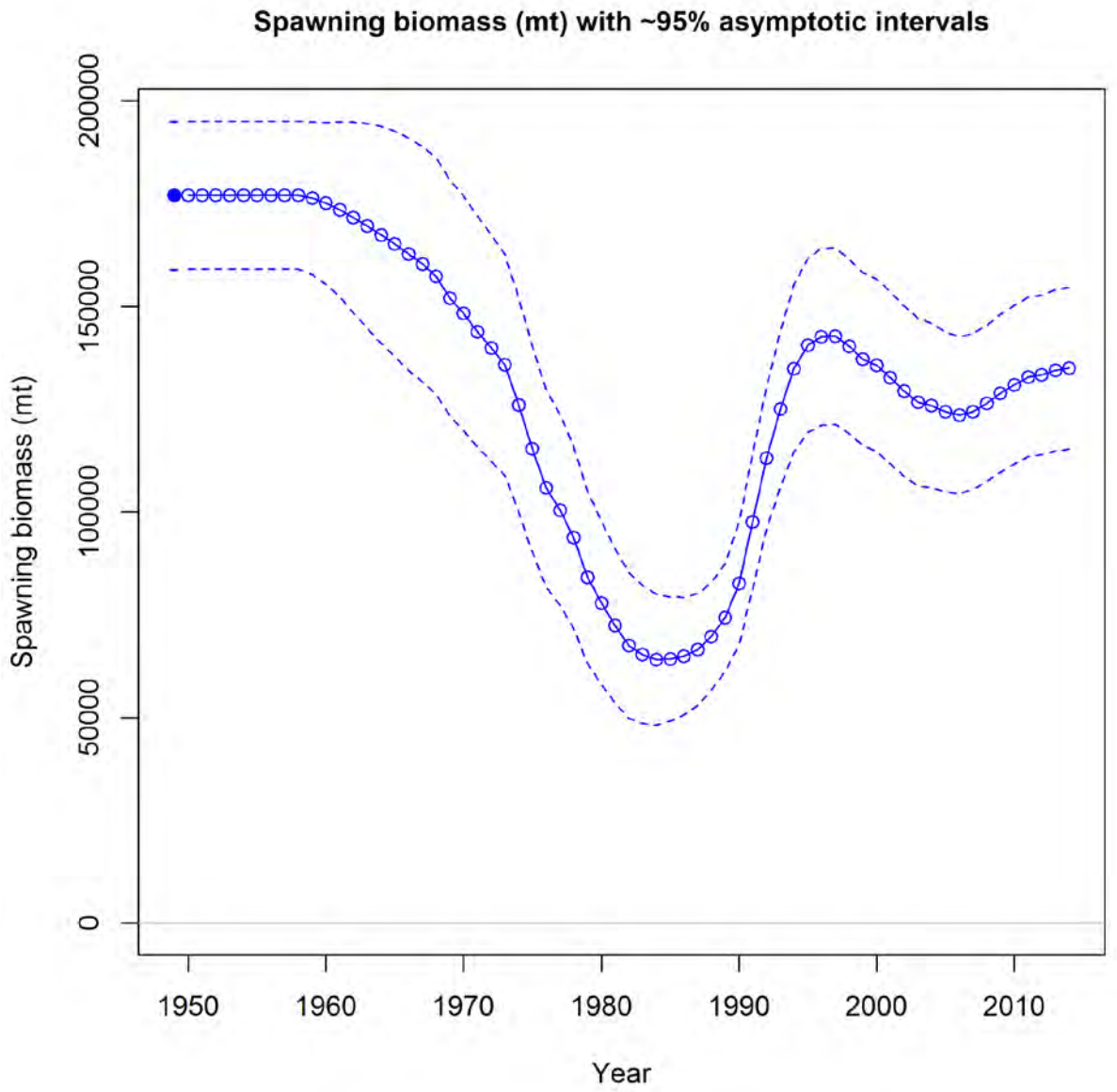


Figure 28. Model estimate of Alaska skate female spawning biomass. Dashed lines indicate 95% confidence interval.

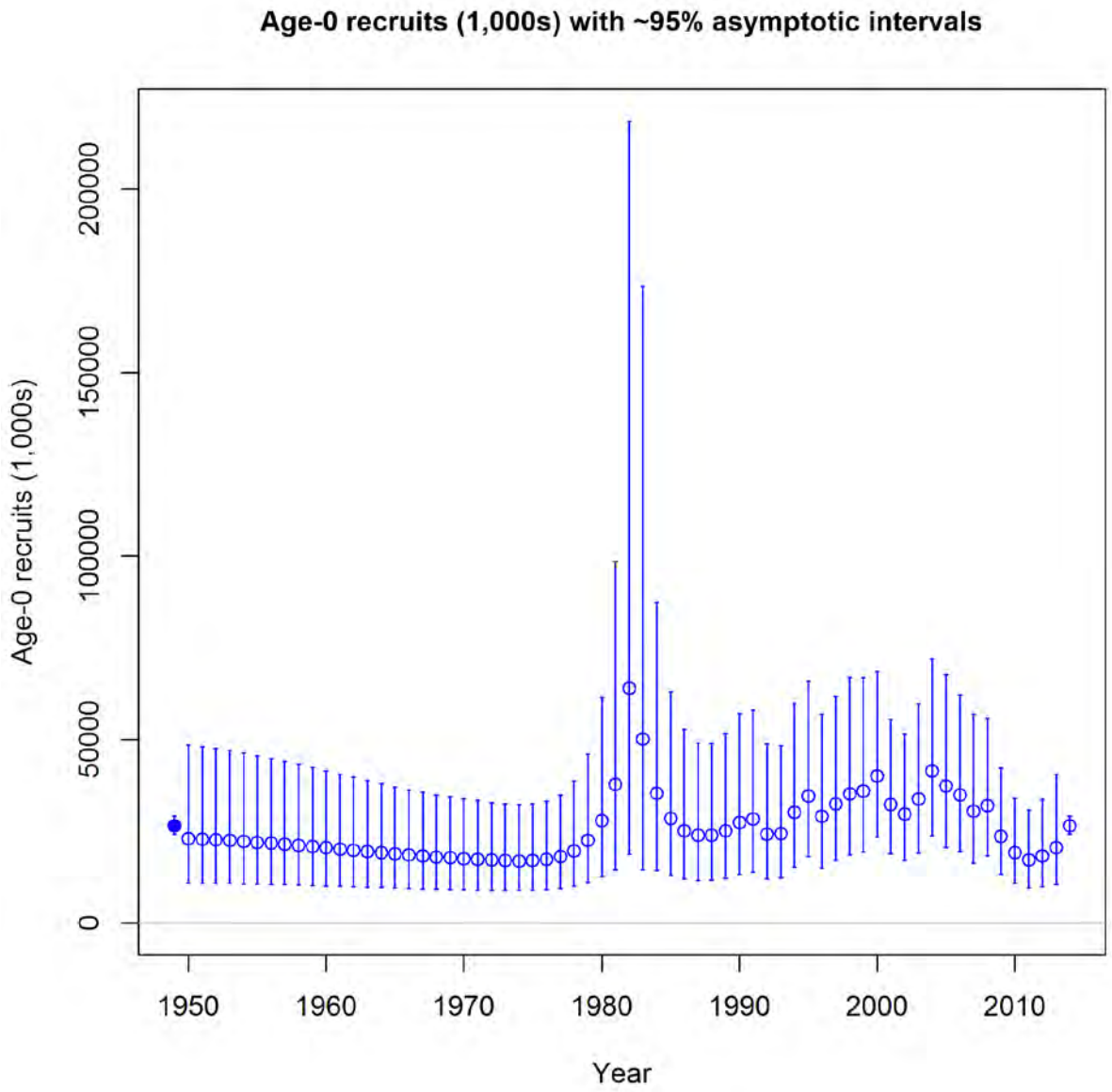


Figure 29. Model estimate of age-o recruitment of Alaska skates, with 95% confidence interval.

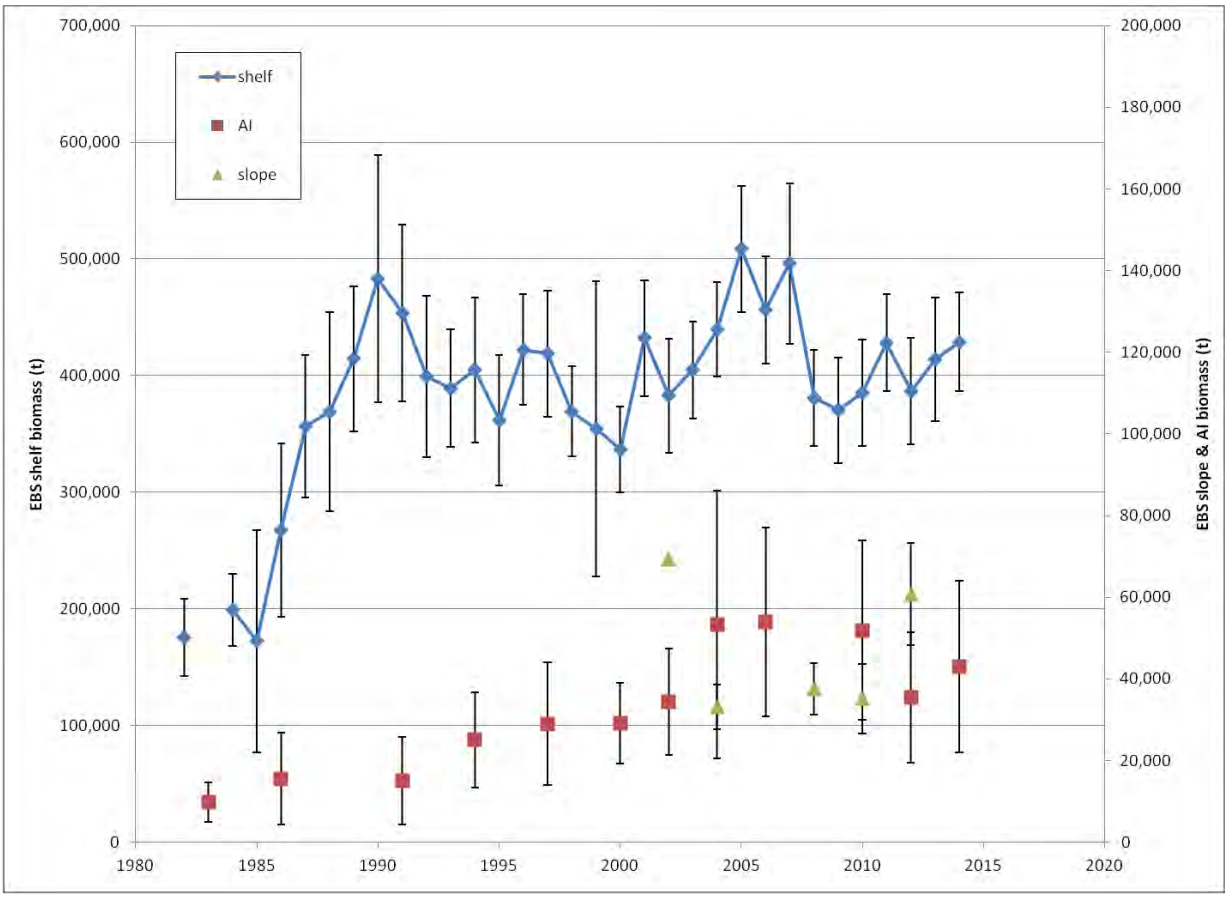


Figure 30. Aggregated skate biomass (t) and 95% confidence intervals estimated from RACE bottom trawl surveys in each of the three major habitat areas (1982 – 2014). Note that slope and AI estimates are much smaller and pertain to the secondary y-axis.

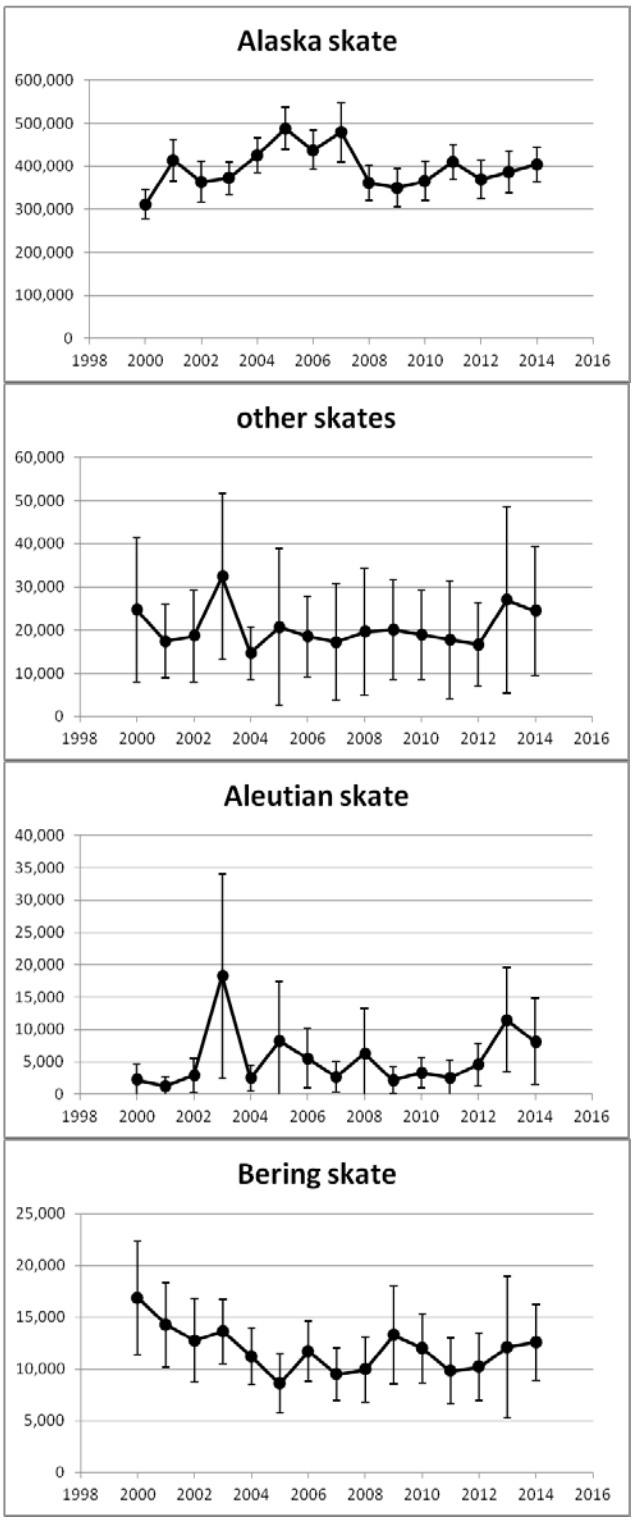


Figure 31. Timeseries of survey biomass estimates (t) and 95% confidence intervals for skates on the EBS shelf. "Other skates" includes Aleutian and Bering skates and is included here to complement the skate management units. Vertical axes vary substantially in scale; species are arranged in order of decreasing biomass, with greatest biomass at the top.

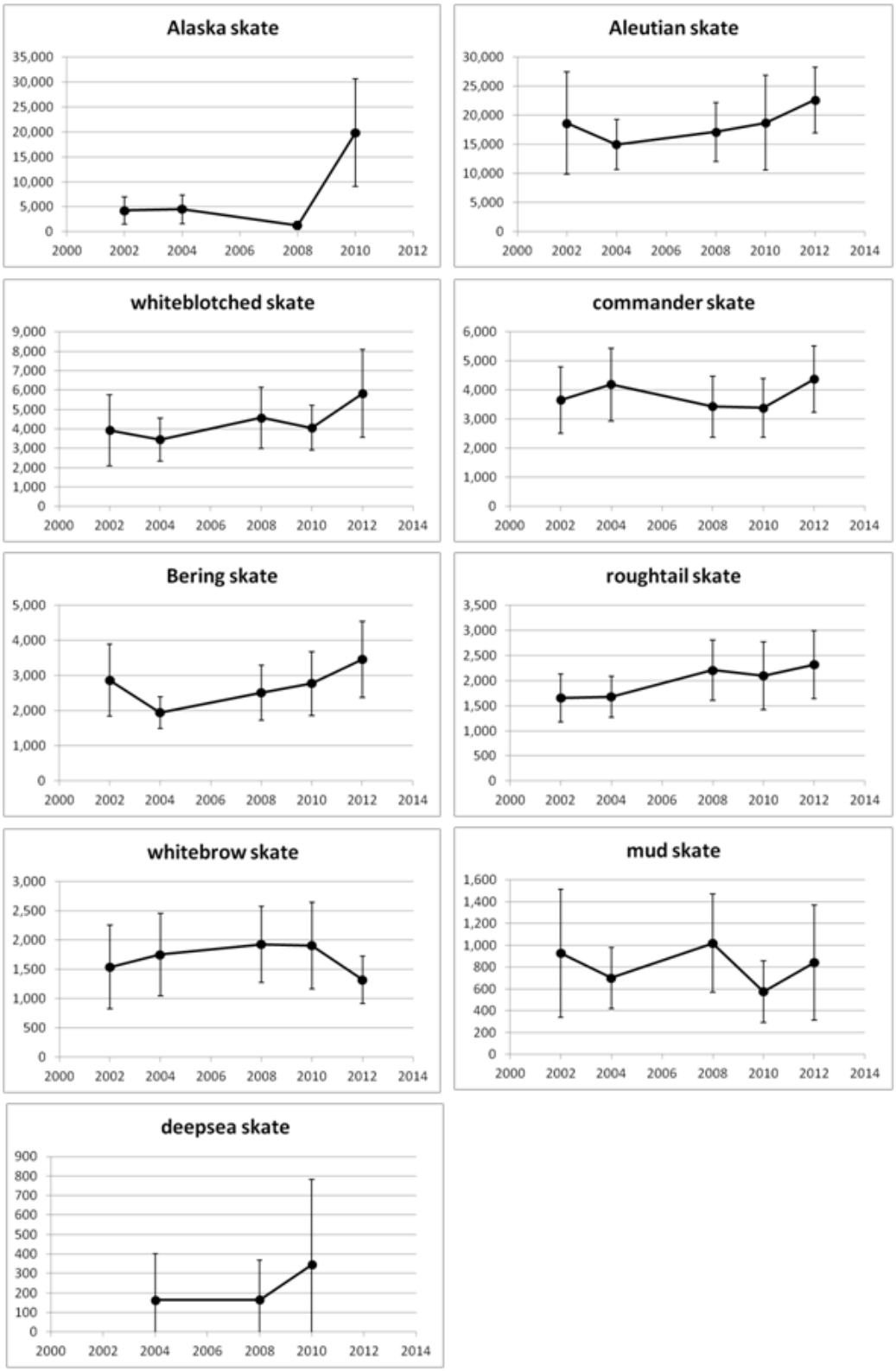


Figure 32. Timeseries of survey biomass estimates (t) and 95% confidence intervals for skates on the EBS slope. Vertical axes vary substantially in scale; species are arranged in order of decreasing biomass, from top left.

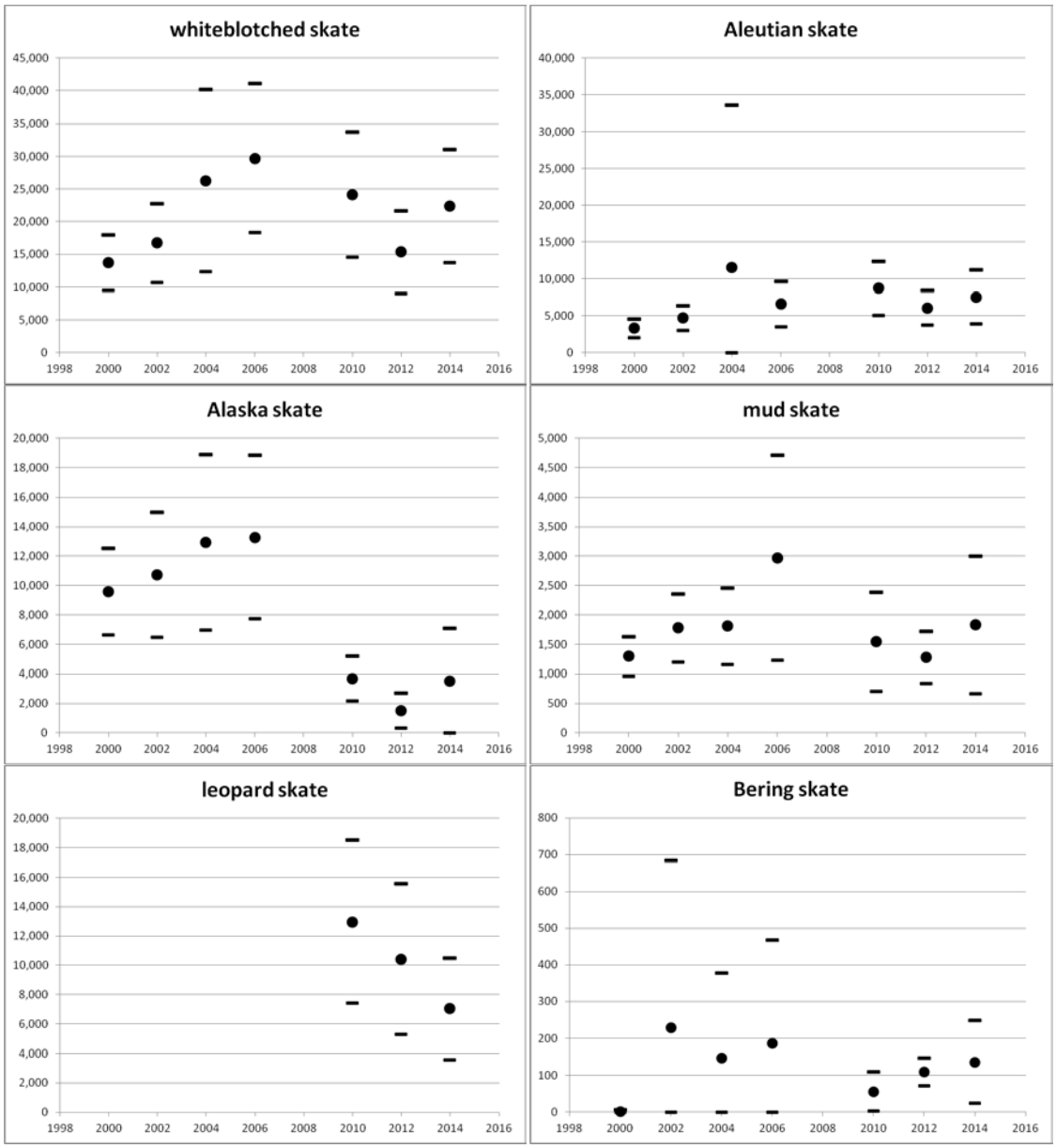


Figure 33. Timeseries of survey biomass estimates (t) and 95% confidence intervals for skates in the Aleutian Islands. Vertical axes vary substantially in scale; species are arranged in order of decreasing biomass, from top left.

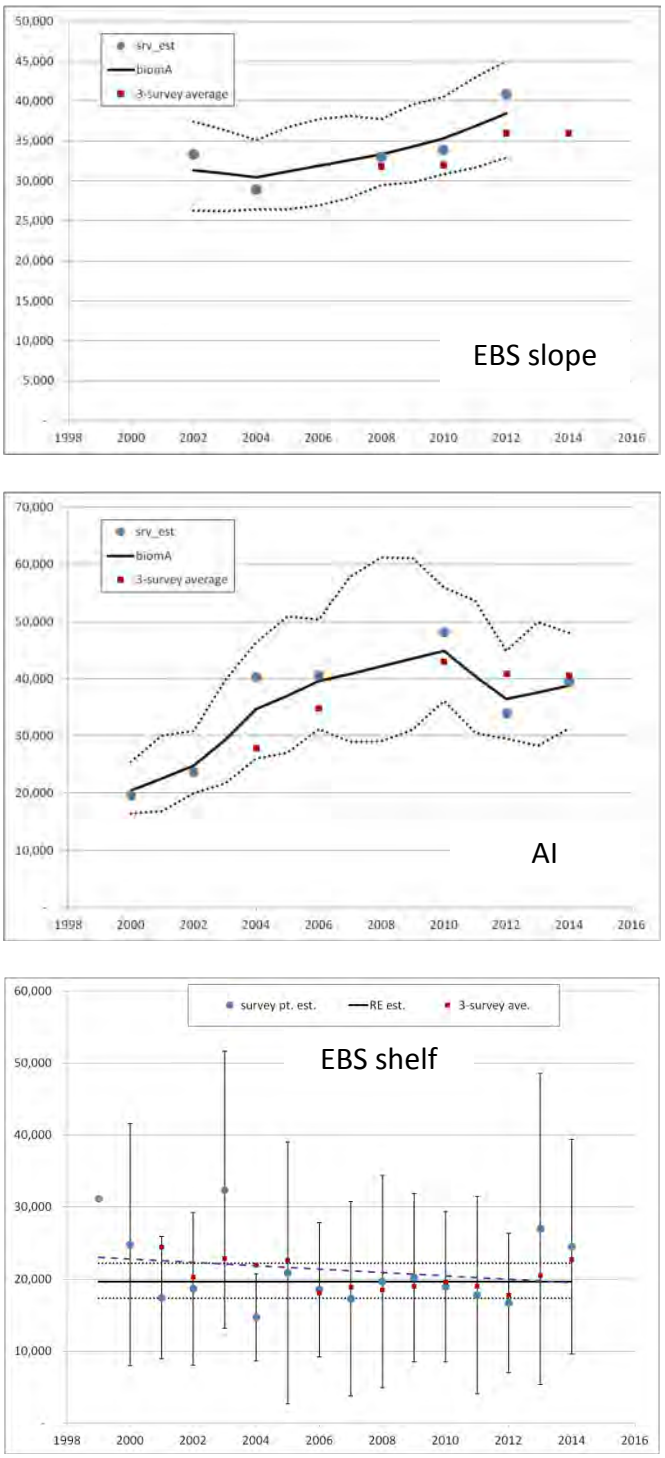


Figure 34. Estimates of "other skate" biomass from different sources for each of the 3 bottom trawl surveys conducted in the BSAI region (EBS slope, top; Aleutian Islands, middle; EBS shelf, bottom). Estimates are: point estimates from the bottom trawl survey (blue circles), 3-survey running averages (red squares), and random effects (RE) model results (black line). Dashed black lines indicate 95% confidence interval for the RE estimate. For the EBS shelf plot, error bars are the 95% confidence interval for the survey point estimates and the purple dashed line indicates the linear fit to the survey point estimates.

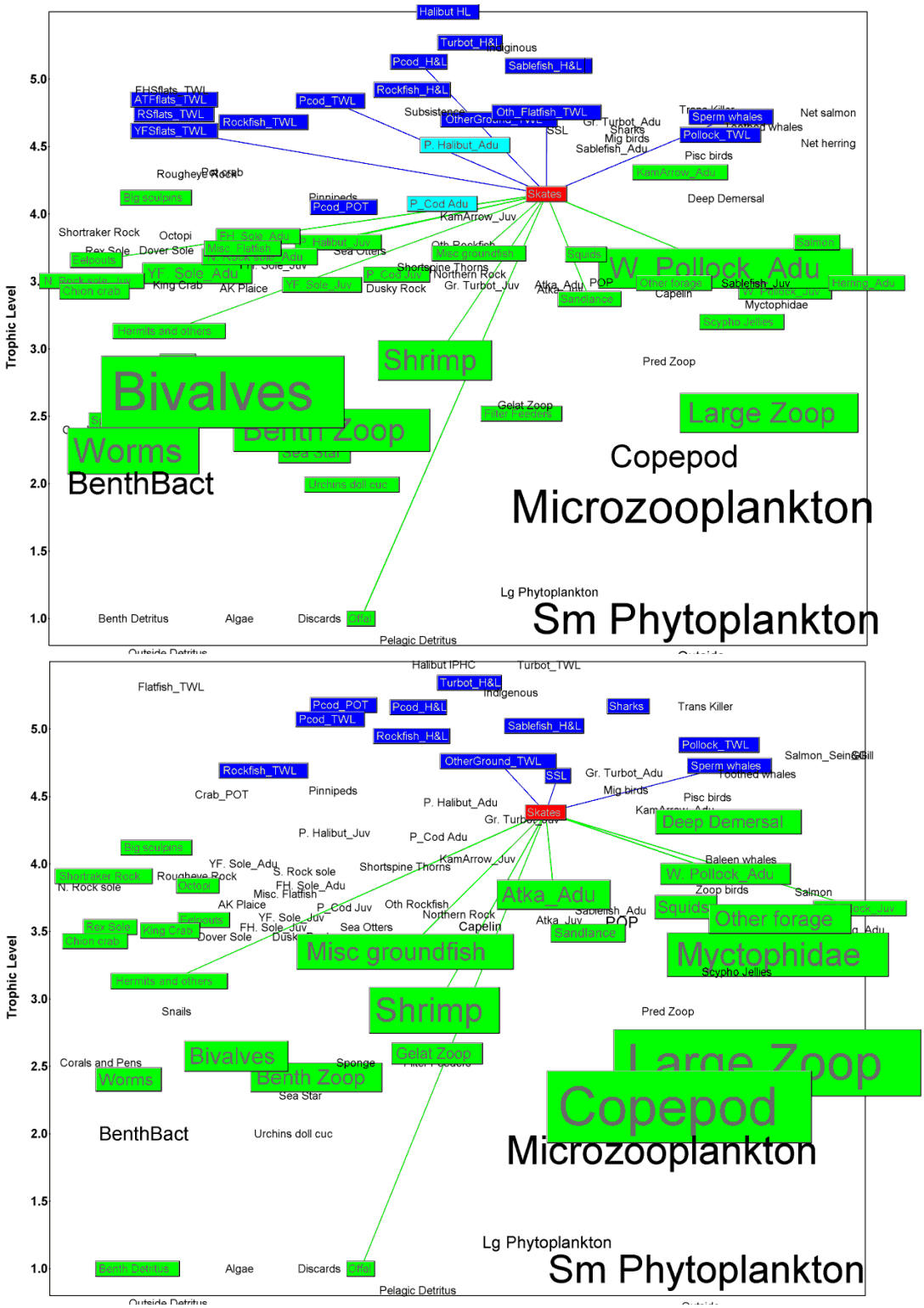


Figure 35. EBS (upper panel) and AI (lower panel) skate food webs derived from mass balance ecosystem models, with skate species aggregated in each area. Source: K. Aydin, AFSC, code available upon request.

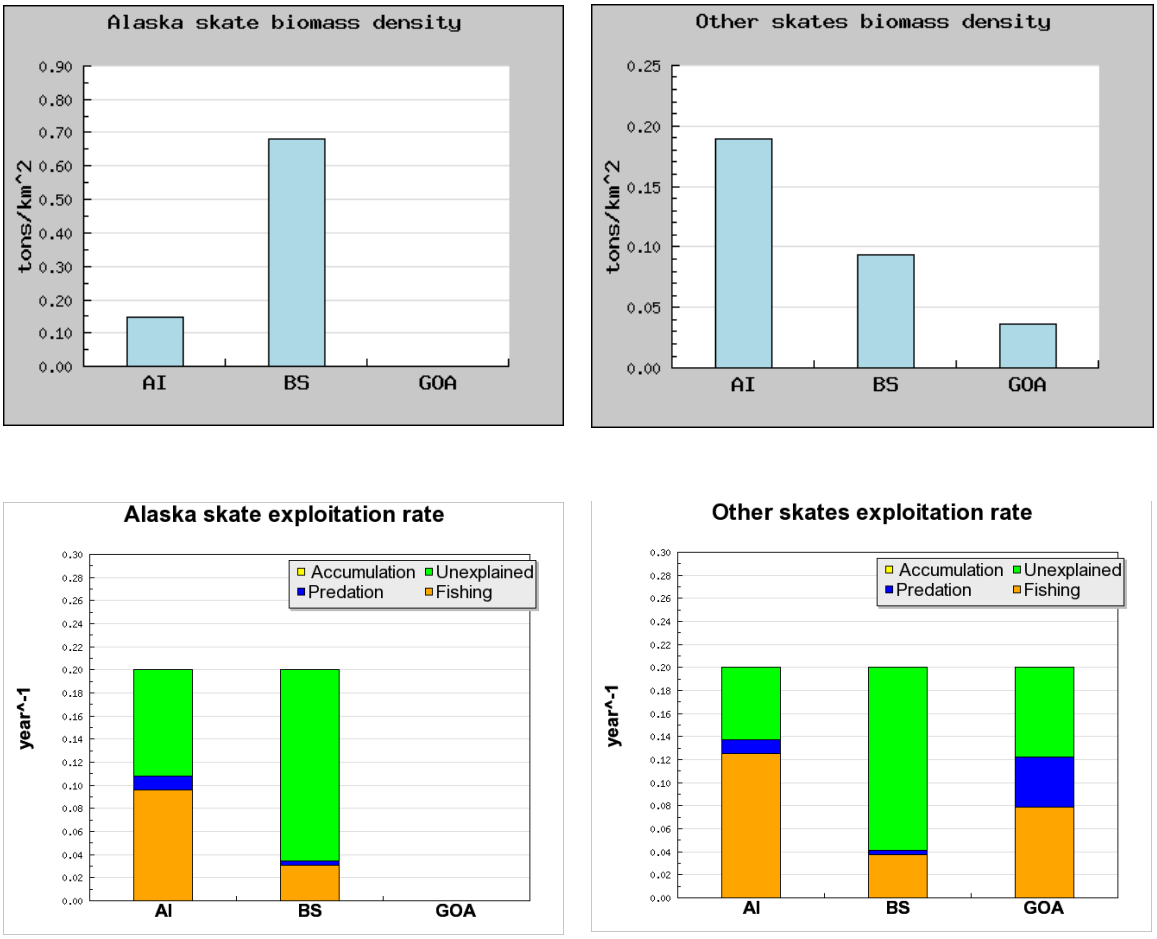


Figure 36. Comparative density (upper panels) and exploitation rate (lower panels) of Alaska (left panels) and all other *Bathyraja* (right panels) skates in the AI, EBS, and GOA (early 1990s, before fishery in GOA). (Alaska skates are a very small component of skate biomass in the GOA, and are therefore not modeled separately.) Note that the Other skates plot does not include the most common species in that region, the big skate and longnose skate—see the GOA skate SAFE for information on those skates. Biomass density plots are from trawl survey data; exploitation rate plots are derived from catch and biomass estimates and from assumed estimates of skate productivity (approximated from Frisk et al. 2001).

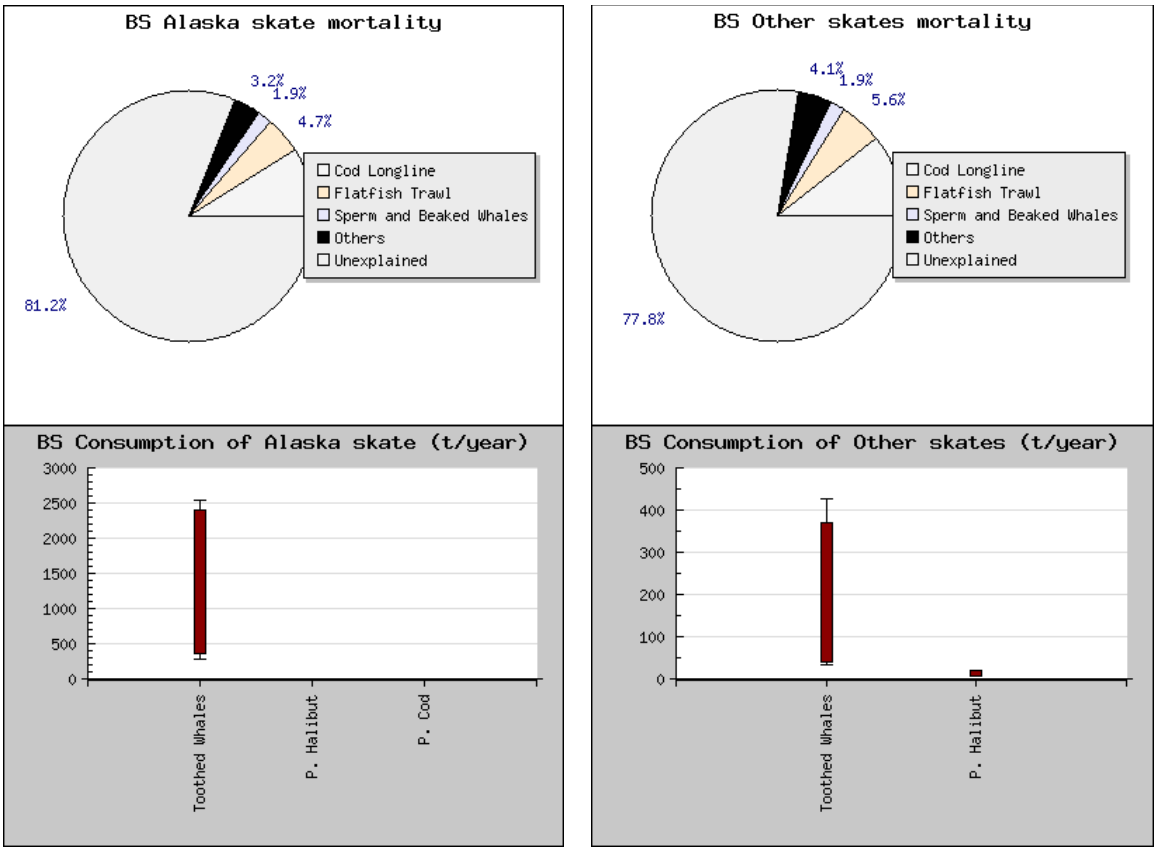


Figure 37. Mortality sources and consumption of skates in the EBS—mortality pie (upper panels) and estimates of annual consumption by predators (lower panels) for EBS Alaska skates (left panels) and all other EBS skates (right panels). Model outputs were derived from diet compositions, production rates, and consumption rates of skate predators, and from skate catch data.

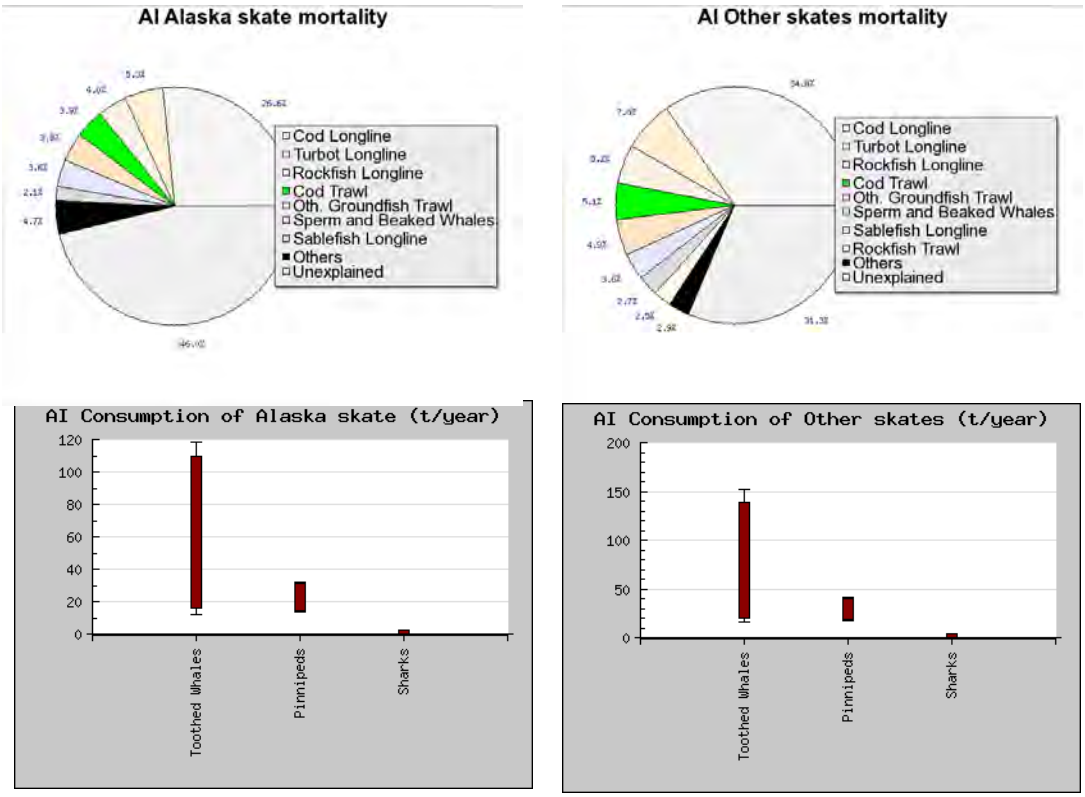


Figure 38. Mortality sources and consumption of skates in the AI—mortality pie (upper panels) and estimates of annual consumption by predators (lower panels) for AI (former) Alaska skate (left panels) and AI Other Skates (right panels). Model outputs were derived from diet compositions, production rates, and consumption rates of skate predators, and from skate catch data.

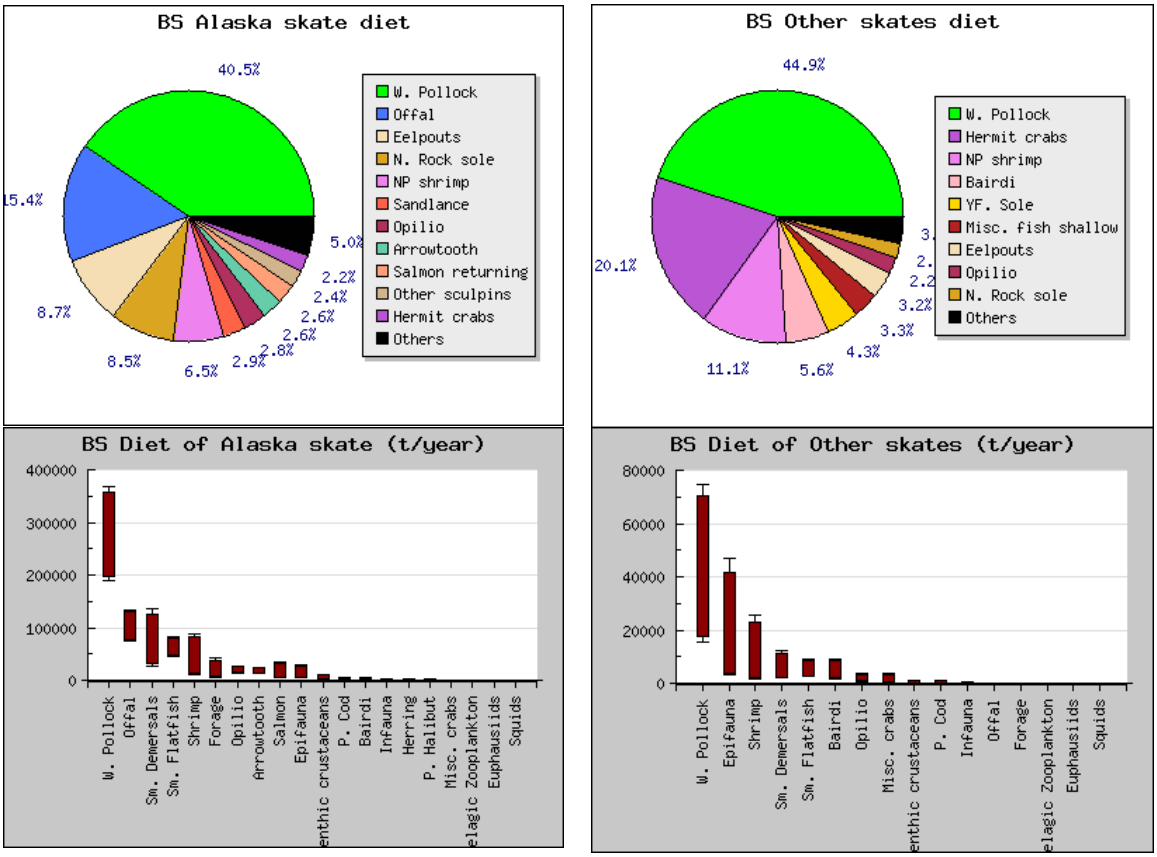


Figure 39. Diet composition (upper panels) and annual estimated prey consumption by skates (lower panels) for EBS Alaska skates (left panels) and Other Skates (right panels). Results were generated from stomach content collections occurring during RACE trawl surveys.

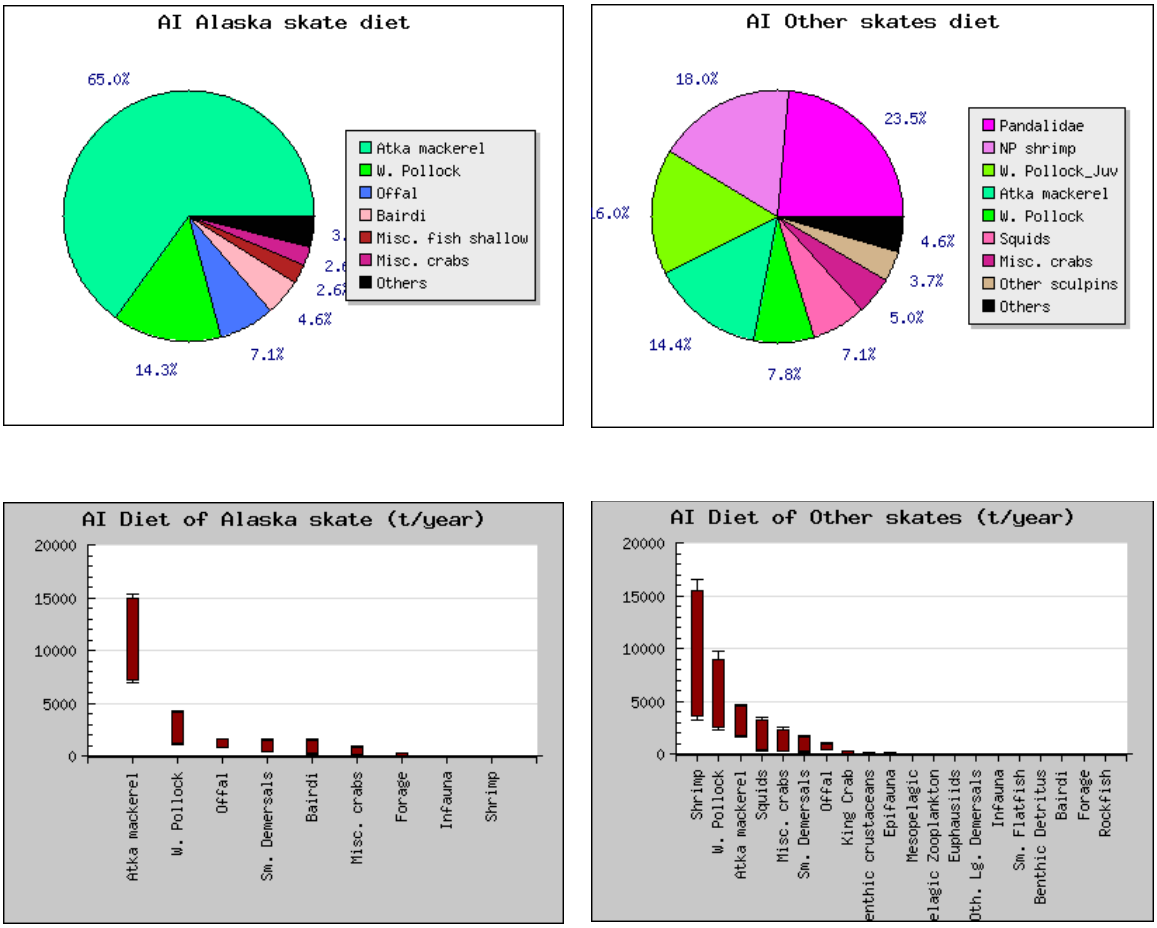
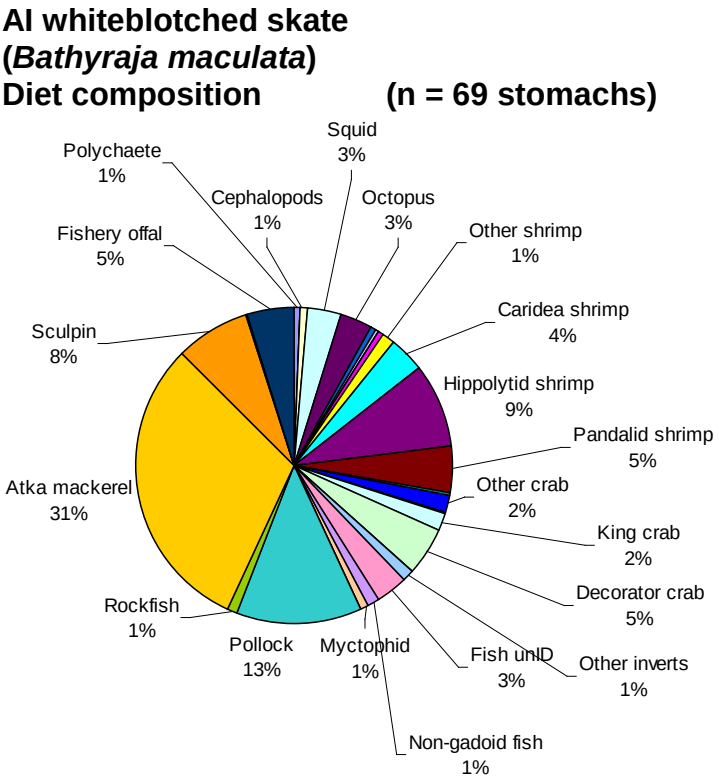


Figure 40. Diet composition (upper panels) and annual estimated prey consumption by skates (lower panels) for AI Alaska skates (left panels) and Other Skates (right panels). Consumption rates were estimated using published diet data from the Kuril Islands (Orlov 1998, 1999) and estimated prey densities.



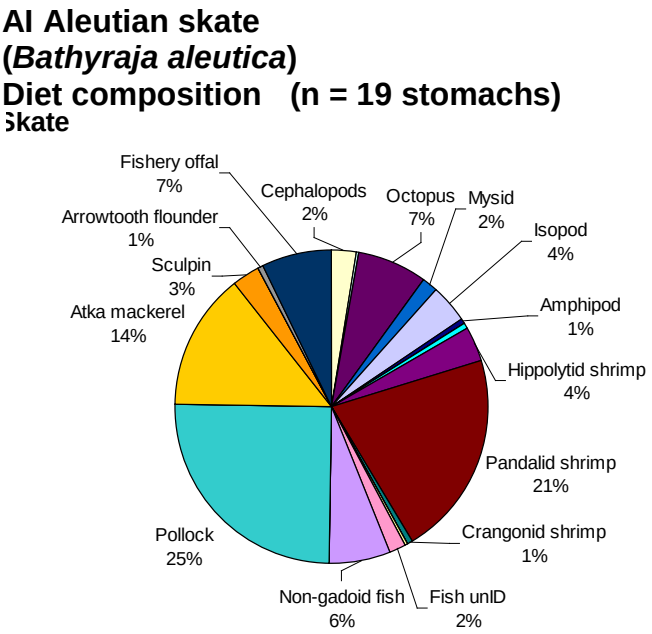


Figure 41. Diet composition (by weight) for the other two biomass-dominant skate species in the Aleutian Islands (AI,which are included in the "Other Skates" group in the previous figure): whiteblotched skate (top) and Aleutian skate (bottom). Results were generated from stomach content collections occurring during trawl surveys, and are described in more detail in Yang (2007).

Appendix: Supplementary catch information

This section is provided to comply with the National Standard guidelines requirement for complete catch accounting. The appendix contains data concerning non-commercial catches of skates (in kilograms) and was obtained from the Alaska regional office.

	Aleutian Island Bottom Trawl Survey	Aleutian Islands Cooperative Acoustic Survey	Annual Longline Survey	Atka Tagging Survey	Bering Sea Bottom Trawl Survey	Bering Sea Slope Survey	Eastern Bering Sea Bottom Trawl Survey	Golden King Crab Pot Survey	Gulf of Alaska Bottom Trawl Survey	IPHC Annual Longline Survey	Large-Mesh Trawl Survey	Northern Bering Sea Bottom Trawl Survey	Pollock EFP 11-01	Pribilof Islands Crab Survey	St. Mathews Crab Survey	Summer EBS Survey with Russia	**Grand Total**
1996			5,359														**5,359**
1997			14,827														**14,827**
1998			10,849														**10,849**
1999			14,076														**14,076**
2000			8,926														**8,926**
2001			14,832														**14,832**
2002			8,104														**8,104**
2003			17,131														**17,131**
2004			6,886														**6,886**
2005			14,046														**14,046**
2006			10,570														**10,570**
2007			22,576														**22,576**
2008		3	11,326														**11,329**
2009			7,455														**7,455**
2010	7,675		6,093		31,118	9,567				41,976	232	4,929			568		**102,157**
2011			5,393	19,786			34,540		25	25,617	215		1,451	2			**87,029**
2012	4,889		7,459			17,593	29,330	23		27,786	139		1.1E+06			70	**1.2E+06**
2013			7,980				28,925		211	42,782	138						**80,036**
2014	6,166						29,396										**35,562**

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19. Assessment of the sculpin stock complex in the Bering Sea and Aleutian Islands

Ingrid Spies, Dan Nichol, Olav A. Ormseth, and Todd T. TenBrink

Alaska Fisheries Science Center
National Marine Fisheries Service

Executive Summary

Summary of Changes in Assessment Inputs

1. Catch and retention data are updated with partial data for 2014.
2. Biomass estimates and length compositions from the 2013 and 2014 Bering Sea shelf survey and the 2014 Aleutian Islands survey have been added.

There are no changes to the assessment methodology.

Summary of Results

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2016
M (natural mortality rate)*	0.28	0.28	0.29	0.29
Tier	5	5	5	5
Biomass (t)	215,713	215,713	194,783	194,783
F_{OFL}	0.28	0.28	0.29	0.29
$maxF_{ABC}$	0.21	0.21	0.22	0.22
F_{ABC}	0.21	0.21	0.22	0.22
OFL (t)	56,424	56,424	56,487	56,487
maxABC (t)	42,318	42,318	42,852	42,852
ABC (t)	42,318	42,318	42,852	42,852
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing		n/a		n/a

** The sculpin complex mortality rate is a biomass-weighted average of the instantaneous natural mortality rates for the six most abundant sculpins in the BSAI: bigmouth (Hemitripterus bolini), great (Myoxocephalus polyacanthocephalus), plain (Myoxocephalus jaok), threaded (Gymnocanthus pistilliger), warty (Myoxocephalus verrucosus), and yellow Irish lord (Hemilepidotus jordani). The complex mortality rate may change as new survey data become available. See "results" section for more detail.*

Responses to SSC and Plan Team Comments on Assessments in General

There were no comments to be addressed.

This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Marine Fisheries Service and should not be construed to represent any agency determination or policy.

Responses to SSC and Plan Team Comments Specific to this Assessment

There were no comments specific to the 2013 BSAI sculpin assessment.

Introduction

Forty-eight species of sculpins have been identified in the Bering Sea Aleutian Islands (BSAI) region (Families Cottidae, Hemitripteridae, Psychrolutidae, and Rhamphocottidae; Table 1). These species are managed as a complex, and biomass estimates are based on the six most abundant sculpins in the BSAI: bigmouth (*Hemitripterus bolini*), great (*Myoxocephalus polyacanthocephalus*), plain (*Myoxocephalus jaok*), threaded (*Gymnocanthus pistilliger*), warty (*Myoxocephalus verrucosus*), and yellow Irish lord (*Hemilepidotus jordani*). This non-target species complex is assessed biennially, to coincide with the frequency of trawl surveys in the Bering Sea and Aleutian Islands, with full assessments in even years. The 2013 executive summary can be found at http://www.afsc.noaa.gov/REFM/Docs/2013/BSAIsculpin.pdf. BSAI sculpins are managed as a Tier 5 stock, and a weighted average of species-specific natural mortality rates (*M*) is applied to the aggregate sculpin biomass to estimate standard reference points.

Sculpins belong to the superfamily **Cottoidea** in the order Scorpaeniformes, and are found in both freshwater and marine habitats. Sculpins are distributed throughout the BSAI and they occupy all benthic habitats and depths. They are relatively small, benthic-dwelling teleost fish with modified pectoral fins that allow them to grip the substrate, and they lack swim bladders. The six most common sculpin species in the BSAI appear to have a range of natural mortality, from 0.14-0.45 (TenBrink and Aydin 2009; Hutchinson and TenBrink 2011).

Little is known about stock structure of BSAI sculpin species, and little research on stock structure has been done for sculpins in general. However, other known aspects of their life history are relevant to this question. Most if not all sculpins lay adhesive eggs in nests, and many exhibit parental care for eggs (Eschemeyer et al. 1983). Markevich (2000) observed the sea raven, *Hemitripterus villosus*, releasing eggs into crevices of boulders and stones in shallow waters in Peter the Great Bay, Sea of Japan. This type of reproductive strategy may make sculpin populations more sensitive to changes in benthic habitats than other groundfish species such as walleye pollock, which are broadcast spawners with pelagic eggs. In the western Pacific, great sculpins (*Myoxocephalus polyacanthocephalus*) are reported to have relatively late ages at maturity (5-8 years, Tokranov, 1985) despite being relatively short-lived (13-15 years). This suggests a limited reproductive portion of the lifespan relative to other groundfish species. Fecundity for the great sculpin in East Kamchatka waters ranged from 48,000 to 415,000 eggs (Tokranov 1985). Age and growth information is available for the great sculpin, yellow Irish lord, bigmouth, plain and warty sculpin based on samples collected from the 2005-2008 Eastern Bering Sea (EBS) shelf survey (TenBrink and Aydin 2009). Known life history characteristics for the most abundant sculpin species along the EBS shelf are presented in Table 2. Recent work has also provided information on diet and reproduction in large sculpins in the BSAI.

The diversity of sculpin species in the BSAI suggests that each sculpin population might react differently to natural or anthropogenic environmental changes. Within each sculpin species, observed spatial differences in fecundity, egg size, and other life history characteristics points to local population structure (Tokranov 1985). All of these characteristics indicate that sculpins as a group might be managed most efficiently within a spatial context rather than with a global annual aggregate BSAI total allowable catch (TAC). A recent study by TenBrink and Buckley (2012) found evidence for habitat partitioning among species *M. jaok, M. polyacanthocephalus*, and *M. scorpius*. They found that within species, larger individuals tend to be found in deeper water and diet composition differed among and within species.

Fishery

Historically, sculpins have been managed as part of the BSAI Other Species complex (sculpins, skates, sharks, and octopus). Specifications for this group were set by summing the individual ABCs and OFLs for each species group to create an aggregate OFL, ABC, and TAC. In 2010, the North Pacific Fishery Management Council passed amendment 87 to the GOA Fishery Management Plan, which separated the Other Species complex into its constituent species groups. Since that time, BSAI sculpins have been managed as an independent complex with its own harvest specifications. Sculpins are currently taken only as bycatch in fisheries directed at target species in the BSAI, and it is likely that future catch of sculpins will continue to be dependent on the distribution and limitations placed on target fisheries, rather than on any harvest level established for this category. Sculpin catch since 1998 is summarized in Table 3. There is no directed fishing for any sculpin species in the BSAI at this time.

Sculpins are caught by a wide variety of fisheries, but primarily trawl fisheries for Atka mackerel and the Pacific cod hook-and-line fishery in the Aleutian Islands and the Pacific cod hook-and-line fishery and yellowfin sole and pollock fisheries in the EBS (Table 4a). Total sculpin catch was calculated for each target fishery responsible for sculpin bycatch from 2003-2014 (Table 4b). In the Aleutian Islands sculpins are primarily caught in the Pacific cod and Atka mackerel fisheries. In the EBS, sculpins are primarily caught in the Pacific cod and yellowfin sole fisheries. Sculpins, in general, are not retained by fisheries in the BSAI region, and fishery observer data indicate that the retention rate has been 4-5% for the past three years (Table 3).

In 2002-2003, the observer program of the Alaska Fisheries Science Center (AFSC) initiated a species identification project which was prompted by the need to gather basic population data for groups in the Other Species complex. Beginning in January 2004, sculpin catch was identified to genus for the larger sculpin species: *Hemilepidotus, Myoxocephalus, and Hemitripterus.* In the BSAI region, *Hemitripterus* probably represents only one species, the bigmouth sculpin (Stevenson 2004). Another member of this genus, the sea raven, may occur in Alaskan waters but has never been identified in any of the BSAI shelf and slope trawl surveys conducted by AFSC. Therefore, it is reasonable to assume that all sculpins identified by observers as *Hemitripterus* sculpins were bigmouth sculpins. Beginning in 2008, most observers were required to identify to species all sculpins in the genera *Hemilepidotus, Myoxocephalus, and Hemitripterus.* According to observer catch totals, these genera form over 90% of all sculpin catch in the BSAI (Table 5). On longline vessels, bigmouth sculpin are identified to species, but not Irish lords and *Myoxocephalus.*

Data

Fishery:

Total sculpin catch is available from 1998-2014 (Table 3), but catches by genus are not available before 2004.

Removals from sources other than those that are included in the Alaska Region's official estimate of catch (e.g., removals due to scientific surveys, subsistence fishing, recreational fishing, fisheries managed under other FMPs) are presented in Table 6.

Catch-at-length data is available for yellow Irish lord, and bigmouth, great, warty, and plain sculpin from the EBS shelf (Figure 1), spinyhead, darkfin, bigmouth, and blob sculpin in the EBS slope (Figure 2), and for yellow Irish lord, and bigmouth, and great sculpin from the Aleutian Islands (Figure 3).

Survey:

Research surveys provide biomass estimates for sculpin species in the BSAI (Figures 4, 5, and 6 and Tables 7, 8, 9, and 10). All three regions of the BSAI were sampled in 2004, 2010, and 2012. The EBS shelf survey is performed annually, the Aleutian survey was most recently performed in 2014, and the slope survey has not been run since 2012. Length measurements (fork length, FL) have been collected for a variety of sculpin species during AFSC trawl surveys. The five most abundant species from the EBS shelf survey have been measured annually since 2003: plain sculpin, warty sculpin, great sculpin and bigmouth sculpin, and yellow Irish lord since 2003 (Figures 1, 4). Size compositions of blob, bigmouth, spinyhead, and darkfin sculpin are measured on the slope survey, and are shown in Figure 2. Length frequency samples have been taken for great and bigmouth sculpin, and yellow Irish lord on the Aleutian Islands survey since 2002 (Figure 3).

Analytic Approach

There are no changes in the analytic approach since the last assessment. Sculpins in the BSAI are managed under Tier 5, where OFL = M * average survey biomass and ABC ≤ 0.75 * M * average survey biomass. Average biomass for the six most common species (threaded sculpin, yellow Irish lord, bigmouth sculpin, great sculpin, plain sculpin, warty sculpin, as well as "other" sculpin) was calculated as the average of the last 3 surveys (2004, 2010, and 2012 for the EBS slope and 2010, 2012, and 2014 for the EBS shelf and Aleutian Islands) in each area (Table 10). Average biomass for "other sculpins" is an average of the last 3 surveys for the rest of the species surveyed, including unidentified sculpins (Table 10). For this assessment, a weighted average of species-specific Ms is applied to the aggregate sculpin biomass, with the proportional 3-most-recent-survey average biomass of each of the most common species (threaded sculpin, yellow Irish lord, bigmouth sculpin, great sculpin, plain sculpin, warty sculpin) providing the weights.

Parameter Estimates

Natural mortality

In 2006, an analysis was undertaken to estimate natural mortality (M) for sculpin species found in the BSAI. Several methods were employed based on life history parameters including growth parameters (Alverson and Carney 1975, Pauly 1980, Charnov 1993, Jensen 1996), longevity (Hoenig 1983), and reproductive potential (Rikhter and Efanov 1976). Prior to 2007, little information was available for sculpin stocks in the BSAI FMP area, so M was estimated using reproductive potential methods applied to data for Russian sculpin species (Rikhter and Efanov 1976). From 2006 to 2008, the results of aging studies for EBS sculpin were used to produce M estimates specific to this area (Table 11). Estimates generated using different methods vary widely.

Results

Fishery catch of sculpins has been between 5,000 and 7,500 t since 1998. Comparison of the species composition of observed fishery catches to the species composition of the 3-survey average sculpin biomass estimates provides some information on the proportion of sculpin caught relative to their abundance. The proportion of sculpins in the catch varies between the Eastern Bering Sea and the Aleutian Islands (Table 5). Similar numbers of bigmouth sculpin are caught in each region, but approximately three times more yellow Irish lord and unidentified Hemilepidotus are caught in the Aleutian Islands. Plain sculpin and great sculpin are rarely caught in the Aleutians but each comprises approximately 30-40% of the catch in the EBS. Darkfin sculpin are not caught in the EBS but comprise approximately 25% of the Aleutian Island catches. These values generally follow the proportion caught in NMFS surveys, with a few exceptions. More darkfin sculpin are caught in the AI fishery than in the AI survey (31% fishery, 16% survey). In contrast, more great sculpin are caught in the AI survey than the AI

fishery (1% fishery, 7% survey). In the EBS, more bigmouth sculpin are caught in the survey than the fishery (8% fishery, 16% survey).

The species composition of the sculpin complex as estimated by bottom trawl surveys of the EBS shelf, EBS slope, and AI demonstrates the diversity of this complex and the regional differences in its composition. The larger species dominate the EBS shelf, with great and plain sculpins being the most common, followed by bigmouth sculpins and yellow Irish lords (Table 7a, Figures 1 and 4). A low coefficient of variation for most of the biomass estimates of these more abundant species reflects that the EBS shelf bottom trawl survey adequately estimates the biomass of these species (Table 7). Biomass estimates for the 5 most abundant sculpin species in the Eastern Bering Sea shelf seem to be relatively stable (Figure 4). Five trawl surveys conducted on the EBS slope (in 2002, 2004, 2008, 2010, 2012, and 2014) show that the slope contains a different sculpin community from the shelf and the AI, likely as a result of greater depths (Figure 7). In the AI, yellow Irish lord account for the highest proportion of sculpin biomass, followed by spectacled sculpin. These are followed by darkfin sculpin, great sculpin, and bigmouth sculpin, which are similar in proportion (Table 9 and Figure 5). The spectacled and scissortail sculpins are not found on EBS surveys. The smaller sculpin species may be less vulnerable to capture by the gear used during the bottom trawl survey because they may pass through the net. Biomass trends of sculpin species in the AI seem to be stable except for an overall increase in yellow Irish lord biomass and a decrease in great sculpin since 1980 (Figure 5).

Total BSAI sculpin biomass estimates have been in the range of 200,000 t since 2004 to 2010 but increased in 2012 (2004: 239,174 t, 2010: 207,658 t, 2012: 215,713 t, and 2014: 194,783 t; Table 10). The single most recent estimate is the lowest since 2004, but does not necessarily indicate a trend, due to the uncertainty in the survey estimates. The relative proportions of sculpins in the Bering Sea shelf and slope and Aleutian Islands has remained stable between 2012-2014, consisting of 86%, 4%, and 10% respectively (Figure 8).

The length compositions by species are generally consistent, with few small sculpins caught by the survey. There appears to be considerable annual variability in the data, which may indicate incomplete sampling of sculpins on the slope (Figure 2). The length composition data for blob and bigmouth sculpins consistently show two size modes, which are unrelated to gender but may indicate that two separate life stages of bigmouth inhabit the slope.

For the great and bigmouth sculpin sampled in the Aleutians, thus the length frequency analysis does not yield a complete representation of the sculpin species population's size composition, whereas yellow Irish lords show a consistent size composition (Figure 3). Specimens smaller than 70 mm have not been collected for many sculpins, which may be due to size selectivity of the survey gear.

Harvest recommendations

2014 shelf average of threaded, YIL, bigmouth, warty, and other were all slightly lower. In the AI, YIL was up and great was down, as was other.

2015-2016 sculpin complex harvest specifications						
species	3-survey average biomass				*M*	weighted contribution to mort. est.
	EBS shelf	EBS slope	AI	**BSAI**		
threaded	2,350	0	2	**2,352**	0.45	0.01
YIL	17,630	54	14,443	**32,127**	0.17	0.03
bigmouth	26,711	2,908	614	**30,233**	0.21	0.04
great	44,873	134	1,267	**46,275**	0.28	0.07
plain	59,468	0	0	**59,468**	0.40	0.13
warty	6,870	0	0	**6,870**	0.26	0.01
other	5,884	5,659	5,916	**17,459**		
total	**163,785**	**8,755**	**22,242**	**194,783**		0.29

weighted-average mortality rate	0.29
F_{OFL}	0.29
max F_{ABC}	0.22
rec. F_{ABC}	0.22
OFL	56,487
max. ABC	42,852
rec. ABC	42,852

A random effect biomass estimate was calculated by combining all species for each region (AI, slope, shelf), and then combining regions: 180,570 t (95%CI: 158,772, 202,368). This estimate is lower than the 194,783 t estimated with the 3 survey average approach (Figure 9). The random effects model estimate is used to calculate ABC and OFL in Appendix 1.

Ecosystem Considerations

Ecosystem Effects on Stock

Aydin et al. (2007) have produced some diet analyses and consumption/predation tables based on ecosystem modeling and direct species data for the BSAI. Limited information indicates that in the EBS the larger sculpin species prey on shrimp and other benthic invertebrates, as well as some juvenile walleye pollock (Figure 10). In the EBS the main predator of large sculpins (sculpins from the genera *Myoxocephalus*, *Hemitripterus* and *Hemilepidotus*) is Pacific cod (Figure 10). Although the greatest mortality of large sculpins is unexplained in the ecosystem model, their fishing mortality is due to the flatfish trawl fishery and Pacific cod longline, trawl and pot fisheries (Table 4a). Other sculpins (those sculpins not in the above genera) in the EBS feed mainly on shrimp and benthic amphipods (Figure 11). Other sculpins are preyed upon by pinnipeds, Pacific cod and small demersal fish, but their main source

of mortality is from consumption by eelpouts, wintering seals and the Alaska skate (Figure 11). In the AI large sculpin have a different diet than in the EBS, consisting of crabs, Atka mackerel and miscellaneous shallow water fish (Figure 11). Large sculpins in the AI are preyed upon mainly by Pacific halibut, but the main source of their mortality is from the groundfish bottom trawl fishery (Figure 11). Diet of other sculpins in the AI consists of infauna such as polychaetes and benthic crustaceans (Figure 12). Pacific cod and walleye pollock are the main predators of other sculpins and are the main source of mortality of other sculpins in the AI (Figure 13).

Fishery Effects on the Ecosystem

Analysis of ecosystem considerations for those fisheries that affect the stocks within this complex (see Table 5) is given in the respective SAFE chapters for those fisheries The BSAI sculpin complex is not a targeted fishery; therefore reference to the effects of the fishery on the ecosystem will be described in those chapters of the fisheries that catch sculpins incidentally.

Ecosystem effects on *Sculpin complex*			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys, changes mean wt-at-age	No effect	Probably no concern
a. Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	No effect	Probably no concern
Birds	Stable, some increasing some decreasing	No effect	Probably no concern
Fish (Pollock, Pacific cod, halibut)	Stable to increasing	Effects not known	Probably no concern
b. Changes in habitat quality			
Temperature regime	Butterfly sculpin biomass increases during years the cold pool extends throughout EBS shelf.	Warming of EBS shelf may shift population northward	Unknown
Winter-spring environmental conditions	None	Probably a number of factors	Unknown
Production	Fairly stable nutrient flow from upwelled BS Basin	Inter-annual variability low	No concern
***Targeted fisheries* effects on ecosystem (see relative chapters)**			

Data Gaps and Research Priorities

Sculpin life history has been studied more extensively in the western Bering Sea and associated waters than in the EBS or AI. Although we have recently acquired substantially more life history data for five species in the EBS concerning age and growth, diet, and some reproductive data, data gaps continue to persist for other species in the eastern Bering Sea and Aleutian Island regions. Age validation studies could be conducted to validate the newly acquired age data from the five species in the EBS. Genetic

analysis of species found in different regions would help determine if there are several stocks of sculpin species within the BSAI. Studies of habitat use and catchability studies of smaller sculpin species would be useful for determining why larger species make up most of the sculpin complex biomass. These data are necessary to improve management strategies and stock assessments for this non-target species group.

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Table 1. Members of the Sculpin complex observed during eastern Bering Sea and Aleutian Islands bottom trawl surveys. Updated 2004.

Family	Scientific name	Common name
Cottidae	*Archistes biseriatus*	Scaled sculpin
	Artediellus miacanthus	Bride sculpin
	Artediellus pacificus	Pacific hookhorn sculpin
	Bolinia euryptera	Broadfin sculpin
	Enophrys diceraus	Antlered sculpin
	Enophrys lucasi	Leister sculpin
	Gymnocanthus detrisus	Purplegray sculpin
	Gymnocanthus galeatus	Armorhead sculpin
	Gymnocanthus pistilliger	Threaded sculpin
	Gymnocanthus tricuspis	Arctic staghorn sculpin
	Hemilepidotus gilberti	Banded Irish lord
	Hemilepidotus hemilepidotus	Red Irish Lord
	Hemilepidotus jordani	Yellow Irish Lord
	Hemilepidotus papilio	Butterfly sculpin
	Hemilepidotus zapus	Longfin Irish lord
	Icelinus borealis	Northern sculpin
	Icelus canaliculatus	Blacknose sculpin
	Icelus euryops	Wide-eye sculpin
	Icelus spatula	Spatulate sculpin
	Icelus spiniger	Thorny sculpin
	Icelus uncinalis	Uncinate sculpin
	Jordania zonope	Longfin sculpin
	Leptocottus armatus	Pacific staghorn sculpin
	Myoxocephalus jaok	Plain sculpin
	Myoxocephalus polyacanthocephalus	Great sculpin
	Myoxocephalus quadricornis	Fourhorn sculpin
	Myoxocephalus verrucocus	Warty sculpin
	Radulinus asprellus	Slim sculpin
	Rastrinus scutiger	Roughskin sculpin
	Thyriscus anoplus	Sponge sculpin
	Triglops forficatus	Scissortail sculpin
	Triglops macellus	Roughspine sculpin
	Triglops metopias	Crescent-tail sculpin
	Triglops pingelii	Ribbed sculpin
	Triglops septicus	Spectacled sculpin
	Triglops xenostethus	Scalybreasted sculpin
	Zesticelus profundorum	Flabby sculpin
Hemitripteridae	*Blepsias bilobus*	Crested sculpin
	Hemitripterus bolini	Bigmouth sculpin
	Nautichthys oculofasciatus	Sailfin sculpin
	Nautichthys pribilovius	Eyeshade sculpin
Psychrolutidae	*Dasycottus setiger*	Spinyhead sculpin
	Eurymen gyrinus	Smoothcheek sculpin
	Malacoccottus zonurus	Darkfin sculpin
	Malacocottus kincaidi	Blackfin sculpin
	Psychrolutes paradoxus	Tadpole sculpin
	Psychrolutes phrictus	Blob sculpin
Rhamphocottidae	*Rhamphocottus richardsoni*	Grunt sculpin

Table 2. Life history information available for selected BSAI sculpin species. "O" refers to data from regions outside the EBS and AI (e.g. Kamchatka).

Species	Common Name	Maximum Length (cm)			Maximum Age		Fecundity (x1000)	Age at 50% Maturity
		O	AI	EBS	O	BSAI		
Myoxocephalus joak	Plain sculpin	75	NA	63	15	16	25.4 - 147	5 - 8
M. polyacanthocephalus	Great sculpin	82	76	82	13	17	48 - 415	6.9
M. verrucosus	Warty sculpin	78	NA	78		18	2.7	
Hemitripterus bolini	Bigmouth sculpin	83	83	78		23		
Hemilepidotus jordani	Yellow Irish lord	65	65	50	13	30	54 - 389	6-7
H. papilio	Butterfly sculpin	38		38				
Gymnocanthus pistilliger	Threaded sculpin	27		20	13	10	5 - 41	
G. galeatus	Armorhead sculpin	46		36	13		12 - 48	
Dasycottus setiger	Spinyhead sculpin	45		34	11			
Icelus spiniger	Thorny sculpin	17		17				
Triglops pingeli	Ribbed sculpin	20			6		1.8	
T. forficata	Scissortail sculpin	30		30	6		1.7	
T. scepticus	Spectacled sculpin	25	25	NA	8		3.1	
Malacoccottus zonurus	Darkfin sculpin		30	NA				

References: AFSC; Panchenko 2001; Panchenko 2002; Tokranov 1985; Andriyashev 1954; Tokranov 1988; Tokranov 1989; Tokranov 1995; Hoff 2000; Tokranov and Orlov 2001; TenBrink unpublished data.

Table 3. Total catch in metric tons (t) of sculpin complex compared to Other species catch (including squid), 1998-2009. Source: NMFS AKRO BLEND/Catch Accounting System, complete as of October 23, 2014.

Year	EBS sculpin catch	AI sculpin catch	BSAI sculpin catch	% of sculpins retained
1998	5,204	1,081	6,285	
1999	4,503	967	5,470	
2000	5,673	1,413	7,086	
2001	6,067	1,603	7,670	
2002	6,043	1,133	7,176	
2003	5,184	599	5,614	1%
2004	5,242	894	6,020	1%
2005	5,114	621	5,642	2%
2006	4,907	911	5,733	3%
2007	6,505	1,016	7,702	5%
2008	6,682	935	7,368	6%
2009	5,915	1,263	7,039	9%
2010	4,227	1,397	5,624	4%
2011	5,146	488	5,634	5%
2012	5,420	819	6,239	5%
2013	5,194	632	5,827	4%
2014	4,204	420	4,624	5%

Table 4a. Total catch in metric tons (t) of all sculpins by target fishery in the eastern Bering Sea and Aleutian Islands, 2003-2014 by gear type (NPT: non-pelagic trawl, PTR: pelagic trawl, TRW: trawl, HAL: hook and line, POT: pot). *Source: NMFS AK regional office catch accounting system. * 2014 catch data are incomplete; retrieved October 8, 2014.*

Aleutian Islands	**Gear Type**					
Target fishery	**NPT**	**PTR**	**TRW**	**HAL**	**POT**	**Total**
arrowtooth flounder	779	0	0	121	0	900
Atka mackerel	7692	0	0	0	0	7692
flathead sole	1	0	0	0	0	1
Greenland turbot	57	0	0	208	0	265
IFQ halibut	0	0	0	1758	0	1758
Kamchatka flounder	441	0	0	0	0	441
other species	0	0	0	174	0	174
Pacific cod	1913	0	0	7216	322	9451
pollock	0	0	0	0	0	0
rock sole	1892	0	0	16	0	1908
rockfish	0	0	0	816	8	824
sablefish	13	2	0	0	0	15
Total	12,788	2	0	10,309	330	23,429

Eastern Bering Sea	**Gear Type**					
Target fishery	**NPT**	**PTR**	**TRW**	**HAL**	**POT**	**Total**
Alaska plaice	192	0	0	0	0	192
arrowtooth flounder	2,628	0	4	37	0	2,669
Atka mackerel	359	0	0	0	0	359
flathead sole	10,505	9	36	0	0	10,550
Greenland turbot	45	0	0	2,065	0	2,110
IFQ halibut	0	0	0	1,836	0	1,836
other flatfish	455	0	3	0	0	458
other species	326	0	0	207	253	786
Pacific cod	17,948	2	0	192,666	4,850	215,466
pollock	566	34,416	0	9	0	34,991
rock sole	18,575	11	0	0	0	18,586
rockfish	287	0	0	28	0	315
sablefish	7	0	0	159	20	186
yellowfin sole	40,281	7	0	0	0	40,288
Total	92,174	34,445	43	197,007	5,123	328,792

Table 4b. Total catch in metric tons (t) of all sculpins by target fishery in the eastern Bering Sea and Aleutian Islands, 2003-2014. *Source: NMFS AK regional office catch accounting system. * 2014 catch data are incomplete; retrieved October 8, 2014.*

	Eastern Bering Sea											
Target fishery	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Alaska plaice	0	0	0	4	11	3	4	7	62	19	82	0
arrowtooth flounder	138	128	262	256	105	399	278	103	214	345	245	181
Atka mackerel	25	65	69	35	119	13	15	0	1	7	2	0
flathead sole	1058	1805	1376	1405	1257	1286	772	544	230	108	264	443
Greenland turbot	221	146	158	106	84	66	191	315	364	327	50	39
IFQ halibut	38	28	25	29	9	820	2	11	6	13	262	559
other flatfish	89	124	98	18	95	4	16	4	3	5	2	1
other target	232	290	33	38	64	57	7	7	2	0	0	21
Pacific cod	17849	21551	22144	17396	15451	15595	13298	11876	18901	15626	22018	19089
pollock	2089	2159	2201	3397	2883	4676	4467	2478	3018	2745	2168	2626
rock sole	988	800	912	1595	1772	1663	2230	2137	1621	1595	1793	1461
rockfish	12	10	5	5	4	2	7	40	73	13	62	9
sablefish	9	5	5	15	21	18	26	4	11	1	23	10
yellowfin sole	2916	1562	2106	2260	3880	4199	4376	3540	3933	3257	4618	2749
Total catch (mt)	25,664	28,673	29,394	26,559	25,755	28,801	25,689	21,066	28,439	24,061	31,589	27,188

Table 4b continued. Total catch in metric tons (t) of all sculpins by target fishery in the eastern Bering Sea and Aleutian Islands, 2003-2014.
*Source: NMFS AK regional office catch accounting system. * 2014 catch data are incomplete; retrieved October 8, 2014.*

	Aleutian Islands											
Target fishery	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
arrowtooth flounder	0	0	0	110	8	27	90	236	106	39	142	147
Atka mackerel	383	596	517	631	687	643	900	837	494	867	497	639
flathead sole	0	0	0	0	1	0	0	0	0	0	0	0
Greenland turbot	22	4	15	19	92	11	43	45	8	0	1	0
IFQ halibut	254	267	106	61	9	562	24	29	9	27	139	323
Kamchatka flounder	0	0	0	0	0	0	0	0	111	182	97	51
other target	11	6	3	89	13	6	27	0	18	0	0	0
Pacific cod	478	862	635	857	1077	995	1250	1607	280	733	545	136
pollock	0	0	1	0	1	1	0	3	0	0	10	0
rock sole	0	0	0	0	0	0	0	0	0	0	0	0
rockfish	122	70	67	80	149	161	169	84	201	150	364	295
sablefish	75	11	26	111	45	27	82	75	95	46	91	65
Total catch (mt)	1345	1816	1370	1958	2082	2433	2585	2916	1211	1451	1,885	1,656

Table 5. Composition of observed fishery catches, 2012-2014, and species composition of the 3-survey average biomass estimate of sculpin complex biomass, by species and/or genus. Fishery catch proportions are based on on fishery observer data. *Source: NORPAC database.* Most sculpins are not identified to species; therefore percentages represent relative proportions of those identified to species here.

taxon	EBS (shelf and slope)				AI			
	fishery catch composition			proportion of average survey biomass	fishery catch composition			proportion of average survey biomass
	2012	2013	2014		2012	2013	2014	
Hemitripterus* spp.*				**16%**				**1%**
H. bolini (bigmouth)	8%	8%	8%	16%	8%	8%	9%	1%
***Hemilepidotus* spp.**				**13%**				**50%**
Hemilepidotus unidentified	4%	8%	11%	n/a	27%	35%	15%	n/a
H. hemilepidotus (RIL)	<1%	< 1%	< 1%	< 1%	< 1%	< 1%	< 1%	< 1%
H. jordani (YIL)	11%	9%	22%	13%	38%	33%	40%	50%
H. spinosus (BIL)	<1%	< 1%	< 1%	< 1%	<1%	< 1%	< 1%	< 1%
***Myoxocephalus* spp.**				**60%**				**7%**
Myoxocephalus unidentified	2%	2%	2%	n/a	1%	< 1%	< 1%	n/a
M. verrucosus (warty)	1%	1%	2%	4%	<1%	< 1%	< 1%	< 1%
M. jaok (plain)	32%	36%	23%	31%	<1%	< 1%	< 1%	< 1%
M. polyacanthocephalus (great)	41%	39%	30%	24%	2%	1%	1%	7%
Malacottus spp.								
M. zonurus (darkfin)	1%	2%	1%	1%	24%	23%	35%	16%

** *Hemitripterus* spp. is likely all *H. bolini.*

§ Miscellaneous sculpins comprises unidentified sculpins as well as a number of minor sculpin species.

Table 6. Total removals from sources other than those that are included in the Alaska Region's official estimate of catch (e.g., removals due to scientific surveys, subsistence fishing, recreational fishing, fisheries managed under other FMPs) for BSAI sculpins through November 9, 2014, and for arrowtooth only from 2008 onwards. Source: AKR.V_NONCOMMERCIAL_FISHERY_CATCH table.

Year	Non-commercial catch (t)
1990	0.1
1991	0.1
1992	0
1993	0
1994	0
1995	0
1996	1.2
1997	0
1998	1.4
1999	1.1
2000	2.1
2001	1.1
2002	2.3
2003	1.8
2004	3.1
2005	2.4
2006	2.2
2007	2
2008	2
2009	1.6
2010	27.6
2011	26.8
2012	19.1
2013	16.6
2014	8.9

Table 7a. Eastern Bering Sea (EBS) shelf sculpin complex biomass estimates (t) and coefficients of variation (CV) for the five most abundant BSAI sculpin species, from EBS shelf surveys 1982-2014. YIL = yellow Irish lord. Asterisks represent cases in which sculpin were not identified to species.

	YIL		**bigmouth**		**great**		**plain**		**warty**	
	biomass	CV	biomass	CV	biomass	CV	biomass	CV	biomass	CV
1982	52,700	0.33	22,841	0.22	6,026	0.29	58,297	0.19	*	
1983	46,475	0.40	19,945	0.21	37,989	0.27	86,344	0.16	2,008	0.63
1984	31,569	0.32	27,644	0.21	19,204	0.33	57,482	0.12	54,900	0.33
1985	13,116	0.24	14,219	0.22	30,234	0.19	37,122	0.10	1,985	0.78
1986	25,810	0.31	11,234	0.23	56,836	0.11	48,549	0.09	293	0.50
1987	41,574	0.48	22,996	0.18	50,845	0.13	55,852	0.11	3,938	0.24
1988	24,867	0.33	22,038	0.25	47,806	0.13	53,772	0.13	3,794	0.32
1989	22,047	0.39	16,636	0.22	37,244	0.16	57,857	0.15	*	
1990	10,212	0.18	16,123	0.24	37,573	0.26	36,991	0.26	*	
1991	10,258	0.17	20,483	0.23	67,848	0.23	113,180	0.08	3,306	0.45
1992	17,091	0.20	18,300	0.21	95,097	0.15	74,712	0.13	*	
1993	22,031	0.46	19,630	0.18	67,549	0.12	87,653	0.13	49	1.00
1994	17,911	0.28	28,426	0.22	99,271	0.10	44,319	0.15	*	
1995	19,112	0.28	29,492	0.18	88,622	0.18	67,240	0.13	*	
1996	14,573	0.19	31,250	0.22	90,999	0.13	54,096	0.10	*	
1997	23,727	0.28	29,722	0.17	85,371	0.24	73,287	0.08	3,915	0.48
1998	13,913	0.31	36,276	0.24	65,840	0.22	57,306	0.09	8,968	0.33
1999	13,229	0.20	24,681	0.18	50,039	0.14	47,324	0.12	11,090	0.19
2000	11,249	0.22	26,200	0.19	62,963	0.40	43,618	0.08	11,744	0.18
2001	9,121	0.35	25,760	0.16	41,071	0.28	48,449	0.10	15,726	0.15
2002	9,415	0.35	32,180	0.34	65,888	0.19	52,525	0.17	9,630	0.20
2003	14,205	0.25	29,161	0.14	67,357	0.19	80,187	0.09	7,098	0.17
2004	33,637	0.33	34,409	0.14	61,176	0.11	69,363	0.10	10,212	0.18
2005	27,444	0.26	31,289	0.13	60,100	0.09	76,426	0.10	25,500	0.51
2006	31,720	0.44	30,118	0.13	57,804	0.10	66,851	0.10	16,136	0.25
2007	23,765	0.34	27,859	0.18	66,000	0.11	77,922	0.11	13,370	0.27
2008	32,389	0.35	30,846	0.14	70,223	0.13	56,914	0.15	11,392	0.27
2009	23,056	0.43	20,196	0.16	44,901	0.12	47,322	0.09	7,952	0.26
2010	21,518	0.45	32,477	0.13	49,665	0.14	55,132	0.12	6,991	0.27
2011	20,212	0.59	31,643	0.11	54,177	0.17	59,306	0.09	6,472	0.27
2012	22,154	0.54	24,080	0.14	40,733	0.14	53,271	0.12	6,477	0.24
2013	7,990	0.42	27,005	0.12	32,185	0.16	47,273	0.15	4,040	0.18
2014	9,218	0.69	23,576	0.13	44,222	0.16	69,999	0.09	7,136	0.21

Table 7b. Eastern Bering Sea (EBS) shelf sculpin complex biomass estimates (t) and 2014 coefficients of variation (CV) for the less abundant BSAI sculpin species, from EBS shelf surveys 1994-2014.

species	1994	1995	1996	1997	1998	1999	2000	2001	2002
Pacific hookhorn	7	3	0	0	12	2	3	4	2
crested	0	0	0	0	0	4	4	2	2
spinyhead	1,384	1,245	684	874	958	1,462	1,816	1,681	1,194
purplegray	0	0	0	0	21	0	0	0	0
armorhead	5,313	605	523	1,252	916	254	347	289	1,708
threaded	0	0	0	3,867	1,801	3,572	1,697	423	1,560
red Irish lord	0	0	0	0	0	42	0	0	3
butterfly	18,619	13,056	2,664	6,070	1,334	3,810	4,501	2,710	2,921
spatulate	0	0	0	0	14	12	23	16	19
thorny	397	71	191	931	1,351	1,036	992	858	814
darkfin	0	0	16	45	0	130	49	220	529
sailfin	0	0	5	0	0	0	0	0	0
scissortail	0	14	10	0	3	3	1	9	2
roughspine	0	11	0	6	50	12	35	7	3
crescent-tail	0	0	0	0	0	0	0	0	0
ribbed	0	6	108	33	71	220	78	188	156
spectacled	0	0	9	652	168	200	491	174	255
total	25,720	15,011	4,210	13,730	6,699	10,759	10,037	6,581	9,168

species	2003	2004	2005	2006	2007	2008	2009	2010	2011
Pacific hookhorn	0	0	4	1	4	3	8	17	45
crested	2	0	0	23	0	0	5	0	0
spinyhead	1,272	1,027	4,520	2,479	1,949	870	1,586	1,277	1,554
purplegray	0	0	14	4	0	6	29	14	17
armorhead	729	801	1,554	1,734	990	2,113	1,859	1,794	2,102
threaded	1,154	1,295	1,983	2,385	4,126	2,174	1,166	1,663	962
red Irish lord	0	73	15	0	5	0	106	0	0
butterfly	1,067	1,069	1,319	2,766	1,956	541	794	939	1,948
spatulate	4	13	23	47	52	23	60	60	118
thorny	748	696	627	667	558	940	1,159	2,384	1,394
darkfin	11	124	36	69	46	1	3	22	17
sailfin	0	0	0	0	0	0	0	1	0
scissortail	0	0	0	42	20	27	77	9	0
roughspine	10	62	111	168	57	176	64	77	56
crescent-tail	0	0	0	1	0	0	0	0	0
ribbed	140	558	261	400	309	368	581	477	84
spectacled	298	29	113	365	217	184	224	503	648
total	5,435	5,747	10,580	11,151	10,289	7,426	7,721	9,237	8,945

Table 7b. continued.

species	2012	2013	2014	*2014 CV*
Pacific hookhorn	9	7	3	*0.50*
crested	0	0	0	-
spinyhead	707	661	1,155	*0.24*
purplegray	21	144	46	*0.61*
armorhead	907	909	569	*0.81*
threaded	4,990	1,217	559	*0.40*
red Irish lord	85	0	0	-
butterfly	2,426	568	477	*0.29*
spatulate	49	92	39	*0.35*
thorny	784	522	1,177	*0.16*
darkfin	142	40	25	*0.70*
sailfin	0	0	0	-
scissortail	0	0	0	-
roughspine	19	12	146	*0.80*
crescent-tail	0	0	0	-
ribbed	292	86	85	*0.31*
spectacled	156	269	529	*0.56*
total	10,587	4,527	4,812	

Table 8. Eastern Bering Sea (EBS) slope sculpin biomass estimates (t) from the 2002-2012 EBS slope surveys and the coefficient of variation (CV) for 2012.

common name	**2002**	**2004**	**2008**	**2010**	**2012**	***2012 CV***
armorhead	1	0	0	0	0	
bigmouth	1,920	1,286	3,053	3,191	4,245	*0.17*
blacknose	122	50	39	17	21	*0.39*
blob	1,471	1,431	1,110	3,325	1,030	*0.21*
darkfin	1,525	1,804	1,073	1,082	1,530	*0.44*
flabby	0	0	0	0	0	
great	44	5	9	88	309	*0.47*
roughskin	1	0	0	0	0	
spatulate	0	0	0	0	0	
spectacled	58	57	30	29	61	*0.71*
spinyhead	1,158	698	374	372	229	*0.23*
thorny	74	39	6	8	18	*0.34*
wide-eye	12	4	4	0	2	*0.85*
yellow Irish lord	0	113	6	20	29	*0.59*
total	**6,409**	**5,497**	**5,705**	**8,136**	**7,479**	

Table 9. Aleutian Islands (AI) sculpin biomass estimates (t) from 1980-2014 AI trawl surveys and the coefficient of variation (CV) for 2014.

	biomass estimate (t)						
species	**1980**	**1983**	**1986**	**1991**	**1994**	**1997**	**2000**
yellow Irish lord	2,462	5,049	10,065	3,813	7,227	4,667	6,711
darkfin	2,535	3,442	4,245	2,874	3,795	3,442	2,533
great	8,749	11,973	6,325	4,117	2,329	2,138	1,168
spectacled	214	454	1,137	523	1,245	1,344	1,122
bigmouth	1,430	8,644	2,557	1,137	1,830	1,617	1,005
armorhead	8	641	32	168	257	105	288
scissortail	61	14	58	317	298	219	67
unidentified sculpins	436	114	74	3,531	193	75	49
spinyhead	9	7	6	8	7	71	19
threaded	0	0	11	0	0	8	0
thorny	0	36	1	1	8	0	1
antlered	0	5	180	16	0	0	0
butterfly	0	0	1	58	0	0	0
crested	0	0	0	0	0	0	0
Pacific staghorn	0	0	8,253	24	2	0	0
plain	0	0	0	0	0	0	0
warty	0	0	318	3	12	0	0
total	**15,905**	**30,377**	**33,261**	**16,589**	**17,202**	**13,687**	**12,963**

	biomass estimate (t)						
species	**2002**	**2004**	**2006**	**2010**	**2012**	**2014**	***2014 CV***
yellow Irish lord	4,240	8,357	10,797	15,247	14,166	13,916	*0.16*
darkfin	3,971	4,521	4,520	5,431	4,514	3,231	*0.15*
great	1,494	1,519	2,121	1,067	1,930	805	*0.32*
spectacled	2,393	1,040	993	956	746	821	*0.28*
bigmouth	1,191	790	1,647	794	339	709	*0.35*
armorhead	208	506	424	637	416	210	*0.30*
scissortail	442	2,073	136	155	83	129	*0.30*
unidentified sculpins	138	100	181	124	108	89	*0.23*
spinyhead	23	72	12	59	3	35	*0.44*
threaded	0	0	0	4	0	1	*0.94*
thorny	2	0	0	0	1	1	*0.78*
antlered	20	17	8	0	0	0	-
butterfly	0	0	0	0	0	0	-
crested	0	0	0	0	0	0	-
Pacific staghorn	0	9	0	0	0	0	-
plain	32	0	0	0	0	0	-
warty	0	0	0	0	0	0	-
total	**14,155**	**19,003**	**20,838**	**24,473**	**22,306**	**19,947**	

Table 10. Sculpin biomass estimates for the three most recent survey years; 2004, 2010, and 2012 for the EBS slope and 2010, 2012, and 2014 for the EBS shelf and the Aleutian Islands (AI). YIL = yellow Irish lord. Biomass estimates are based on these values, the mean of the most recent three surveys.

	EBS shelf			EBS slope			AI		
species	**2010**	**2012**	**2014**	**2004**	**2010**	**2012**	**2010**	**2012**	**2014**
antlered	-	9	-	-	-	-	0	0	0
armorhead	1,956	907	569	-	-	-	637	416	210
bigmouth	32,477	24,080	23,576	1,289	3,191	4,245	794	339	709
blacknose	-	-	-		17	21	-	-	-
blob	-	-	-		3,325	1,030	-	-	-
butterfly	965	2,426	477	-	-	-	-	-	-
crescent-tail	-	-	-	-	-	-	-	-	-
crested	-	-	-	-	-	-	-	-	-
darkfin	22	142	25	1,798	1,082	1,530	5,431	4,514	3,231
flabby	-	-	-	-	0.39	0.21	-	-	-
great sculpin	49,665	40,733	44,222	5	88	309	1,067	1,930	805
Pacific hookhorn	17	9	3	-	-	-	-	-	-
Pacific staghorn	-	-	-	-	-	-	0	0	0
plain	55,135	53,271	69,999	-	-	-	-	-	-
purplegray	14	21	46	-	-	-	-	-	-
red Irish lord	0	85	0	-	-	-	-	-	-
ribbed	474	291	85	-	-	-	-	-	-
roughspine	77	19	146	-	-	-	-	-	-
sailfin	1	0	0	-	-	-	-	-	-
scissortail	9	0	0	-	-	-	155	83	129
spatulate	60	49	39	-	-	-	-	-	-
spectacled	503	156	529	57	29	61.2	956	746	821
spinyhead	1,277	707	1,155	701	372	229	59	3	35
thorny	2,385	784	1,177	39	8	19	0.10	1	1
threaded	1,501	4,990	559	-	-	-	4	0	1
unidentfied	-	-	-	1,486	-	-	124	108	89
warty	6,998	6,477	7,136	-	-	-	-	-	-
wide-eye	-	-	-	-	0.14	2.35	-	-	-
YIL	21,518	22,154	9,218	113	20	29	15,247	14,166	13,916
total	**175,054**	**157,310**	**158,963**	**5,488**	**8,131**	**7,476**	**24,473**	**22,306**	**19,947**

Table 11. Natural mortality estimates from recent life history analyses of BSAI sculpins. All values are unpublished data from T. Tenbrink. "SAFE *M*" indicates the value used in the computation of harvest recommendations for the 2010 assessment.

species	area	sex	Hoenig	Jensen	Charnov	catch curve	SAFE *M*
yellow Irish lord	EBS	*M*	0.17	0.41	0.45	0.17	0.17
	EBS	*F*	0.14	0.47	0.51	0.17	
	AI	*M*	0.15	0.23	0.27	0.17	
	AI	*F*	0.15	0.27	0.31	0.17	
threaded sculpin	EBS	*M*	0.42	0.6	0.65	n/a	0.45
	EBS	*F*	0.47	0.36	0.4	n/a	
great sculpin	EBS	*M*	0.28	0.39	0.43	0.25	0.28
	EBS	*F*	0.25	0.27	0.3	0.31	
plain sculpin	EBS	*M*	0.28	0.38	0.42	0.39	0.40
	EBS	*F*	0.26	0.27	0.55	0.41	
warty sculpin	EBS	*M*	0.28	0.58	0.63	n/a	0.26
	EBS	*F*	0.23	0.41	0.47	n/a	
bigmouth sculpin	EBS	*both*	0.20 M 0.18 F	0.21	0.24	n/a	0.21

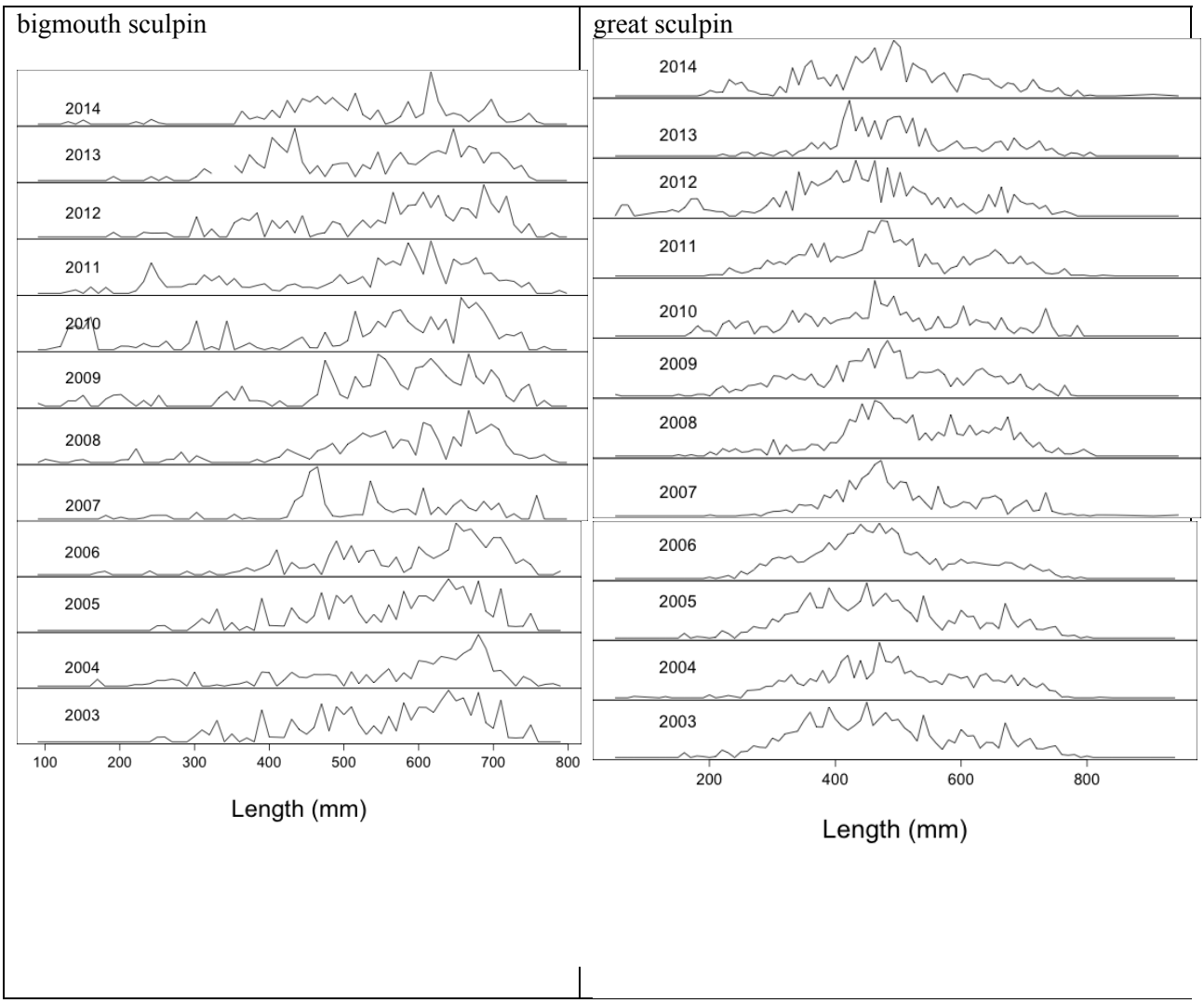


Figure 1. Length frequencies (fork length, FL in mm) from EBS shelf survey data for the five most abundant sculpin species in EBS, 2001-2012 (2003-2012 for Yellow Irish Lord). Length scale differs among plots.

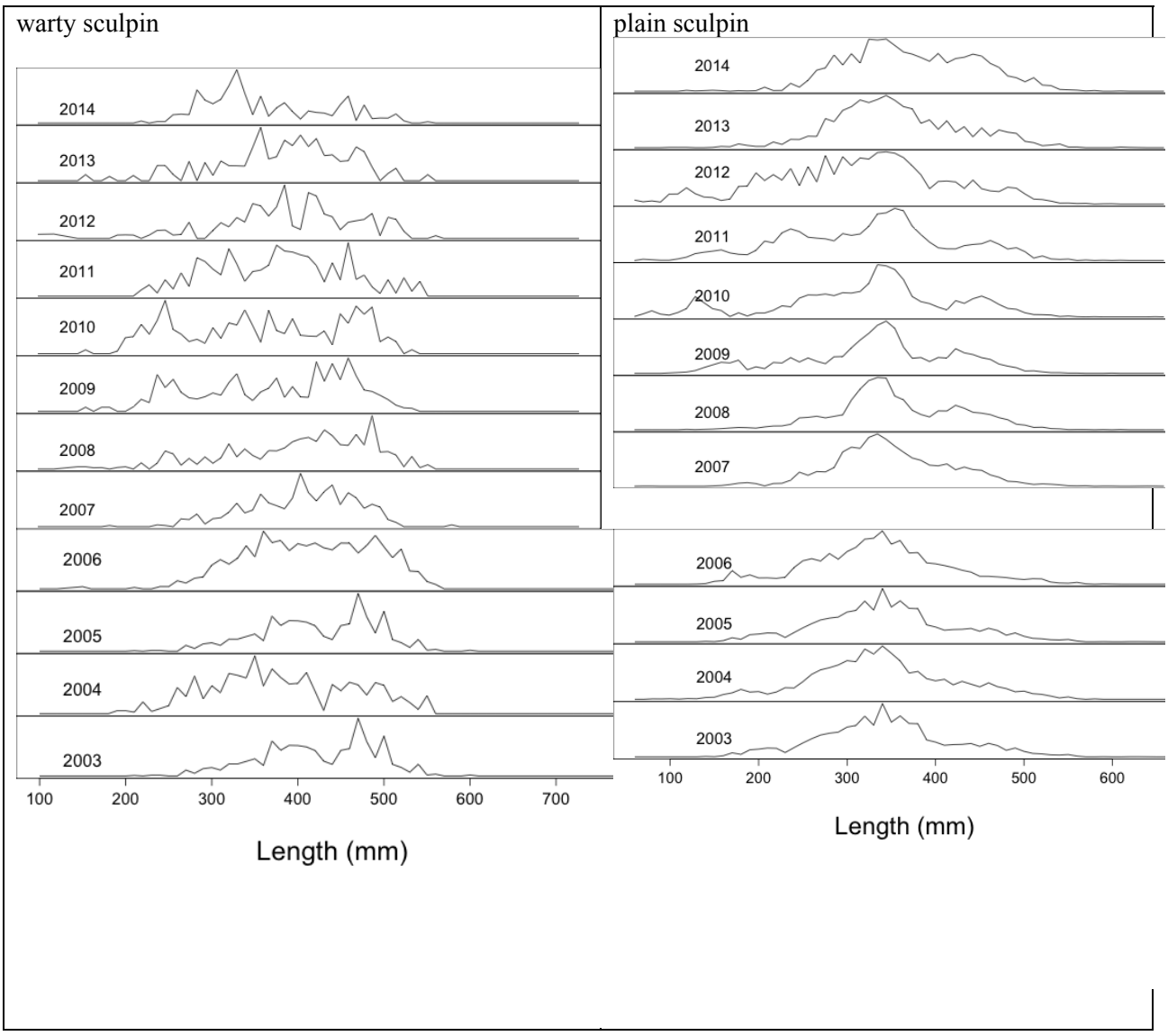


Figure 1 (continued). Length frequencies (fork length, FL in mm) from EBS shelf survey data for the five most abundant sculpin species in EBS, 2001-2012 (2003-2012 for Yellow Irish Lord). Length scale differs among plots.

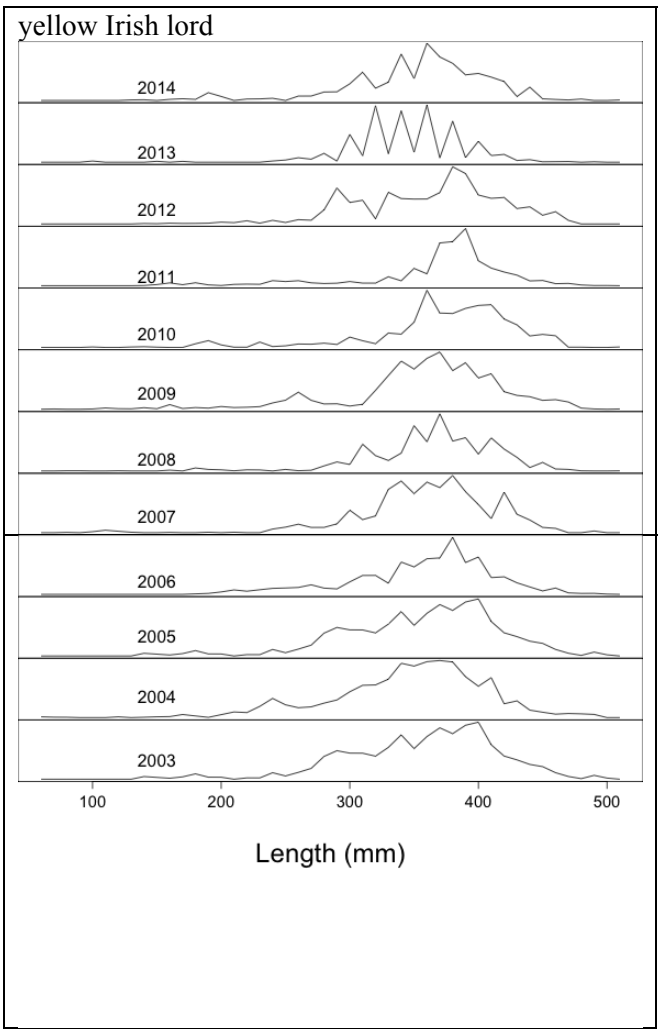


Figure 1 (continued). Length frequencies (fork length, FL in mm) from EBS shelf survey data for the five most abundant sculpin species in EBS, 2001-2012 (2003-2012 for Yellow Irish Lord). Length scale differs among plots.

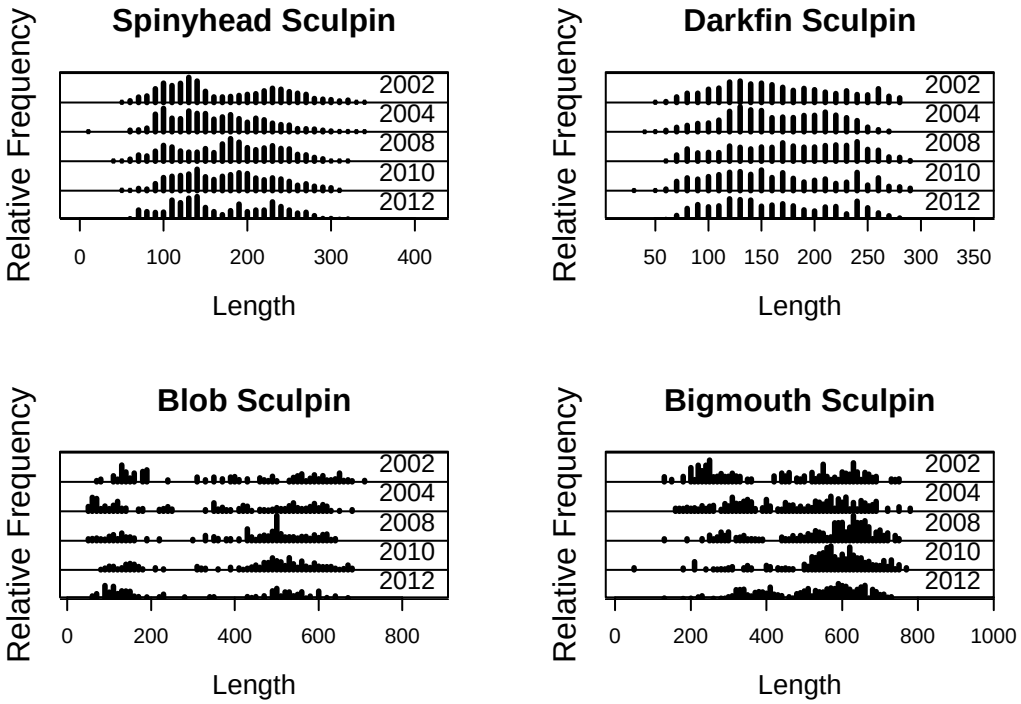


Figure 2. Length frequencies (fork length, FL in mm) from EBS slope survey data for the four most abundant sculpin species in these surveys.

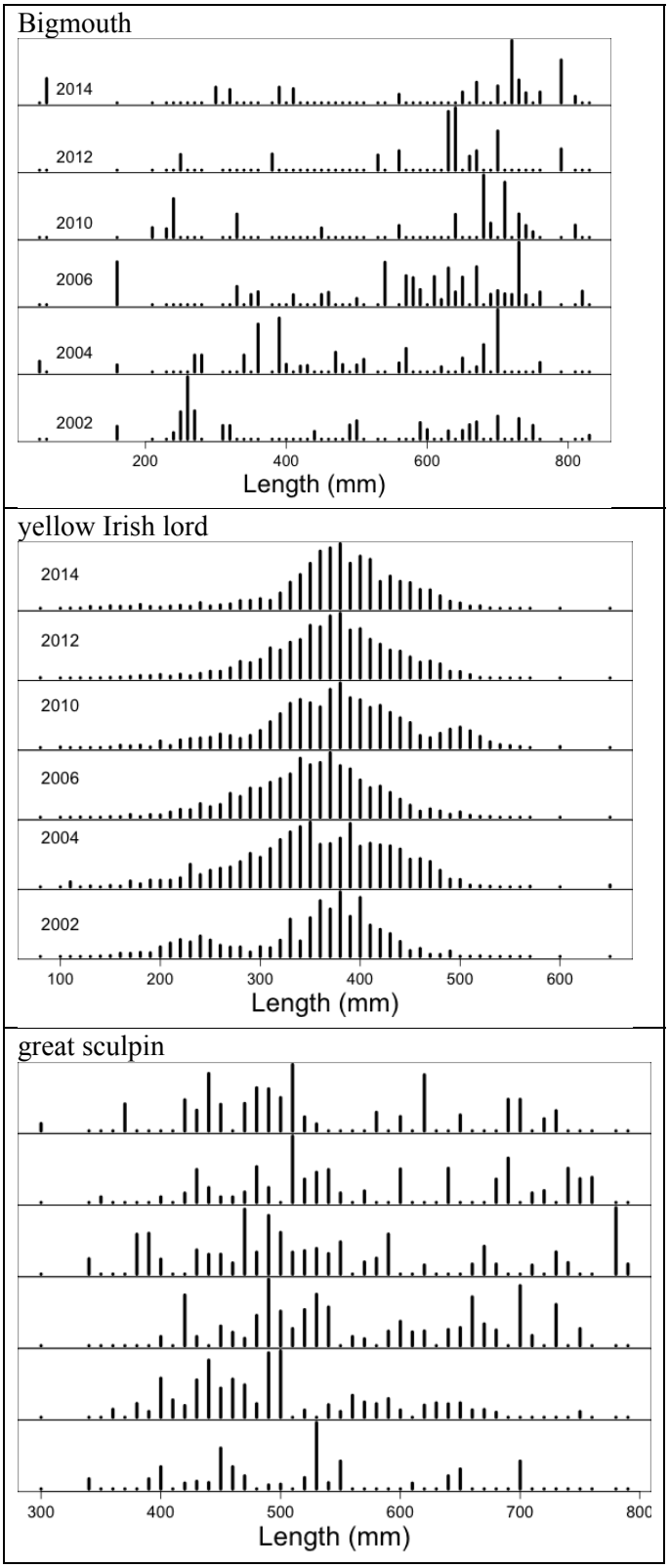


Figure 3. Survey length composition for the 3 most abundant sculpin species in the AI, 2004-2014 bigmouth (upper panel, yellow Irish lord (middle panel), and great sculpin (lower panel).

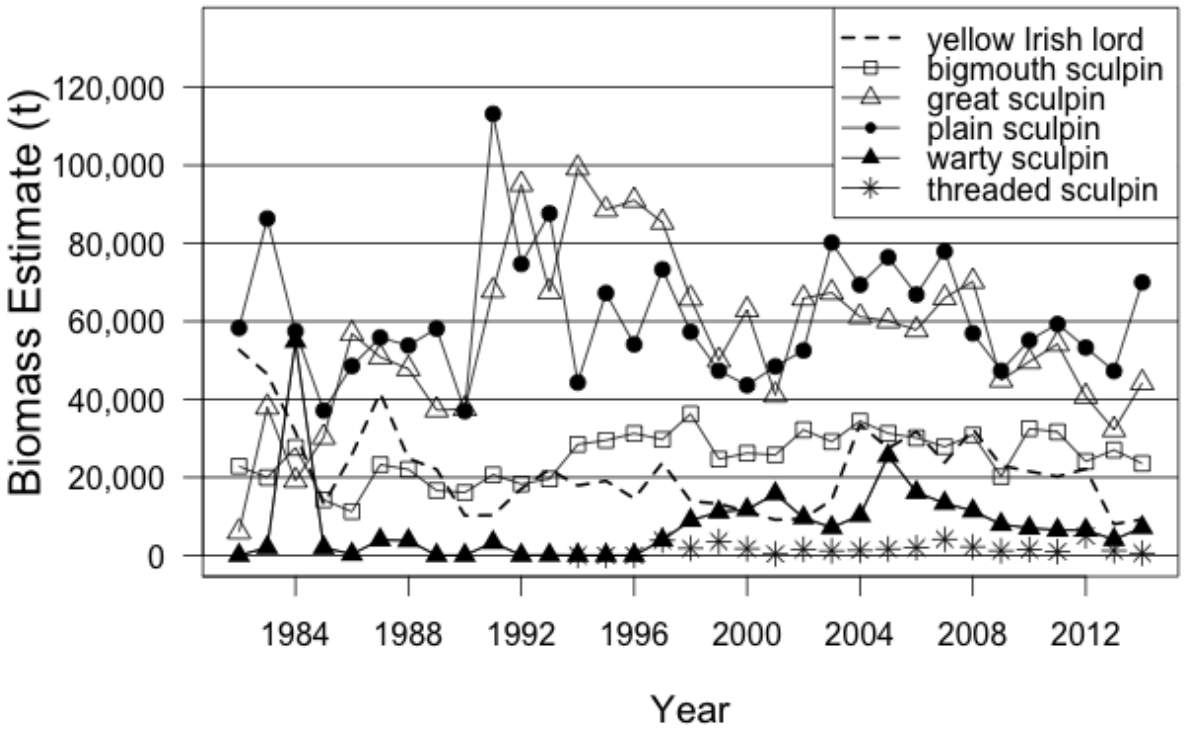


Figure 4. EBS shelf survey biomass estimates for the six most abundant sculpin species, from annual EBS shelf bottom trawl surveys for selected sculpin species, 1982-2014.

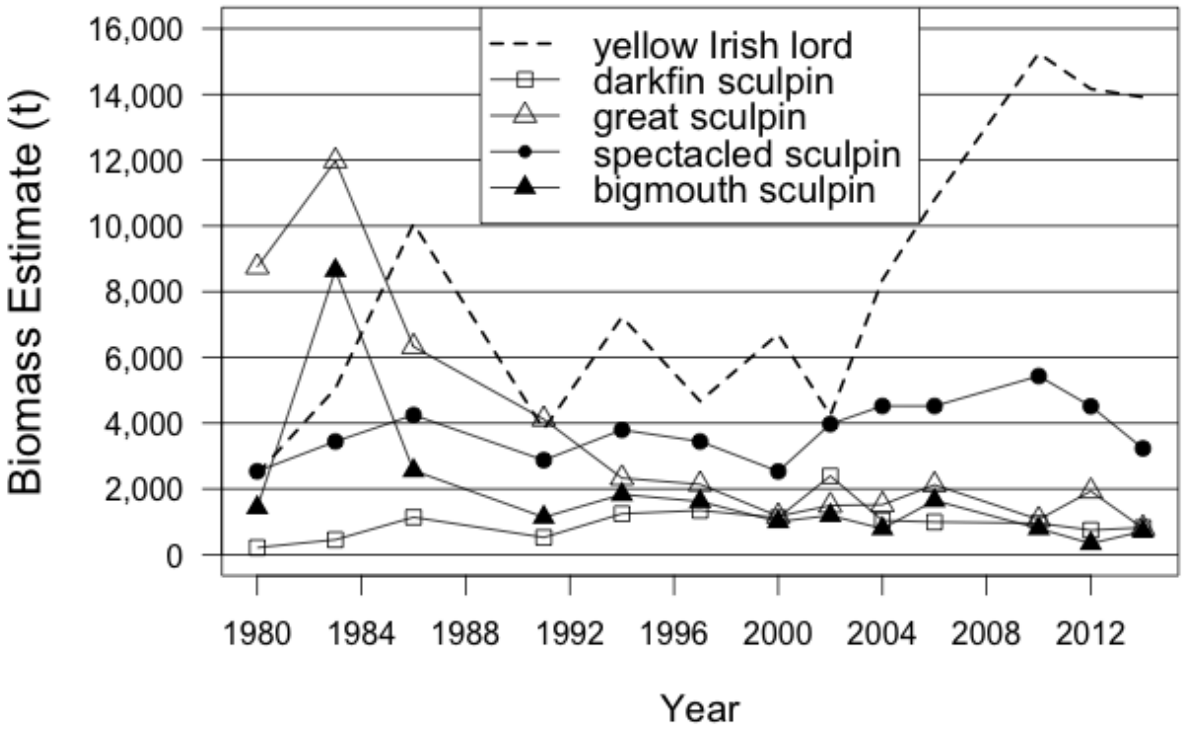


Figure 5. Aleutian Islands (AI) survey biomass estimates for the five most abundant sculpin species, from AI trawl surveys 1980-2014.

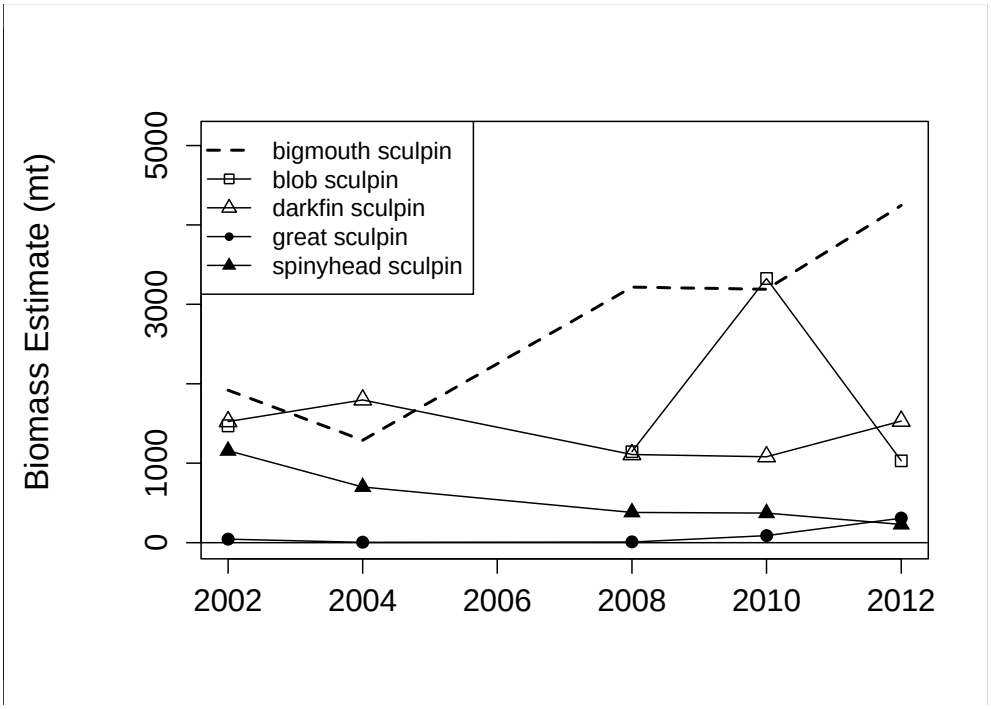


Figure 6. Bering sea slope survey biomass estimates for the five most abundant sculpin species, from slope trawl surveys 2002-2012.

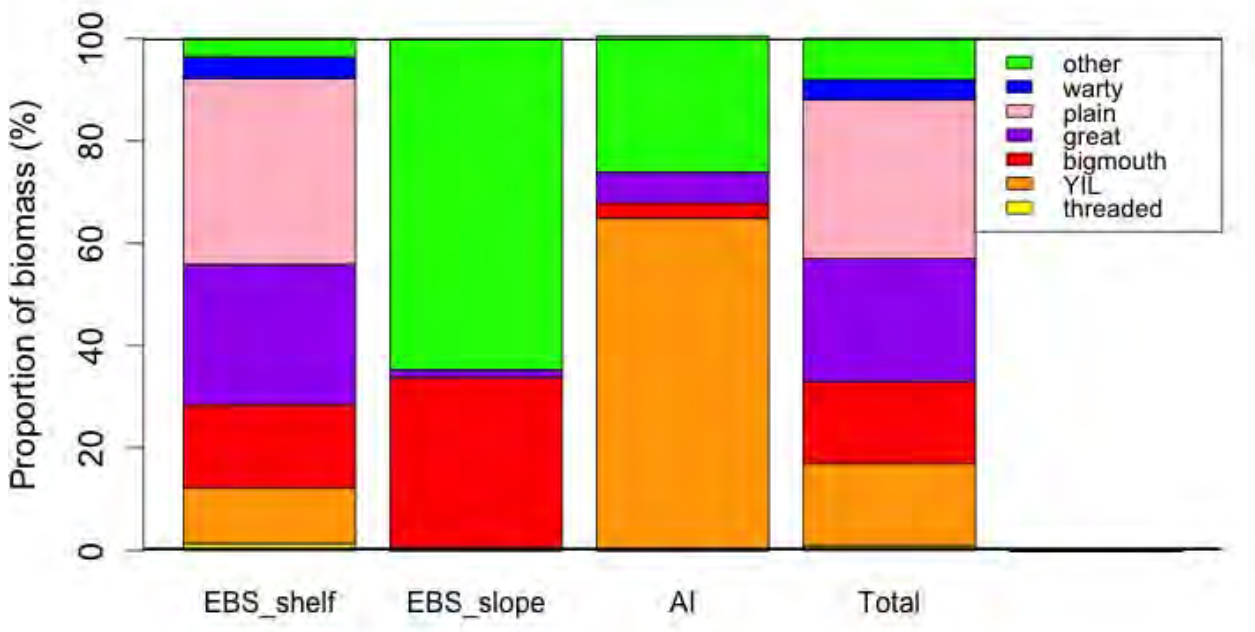


Figure 7. Species composition of the sculpin complex in the three subregions of the BSAI, as well as the BSAI as a whole, for the entire time series based on the 3 most recent surveys in each region. "Other" sculpins contains a variety of species; see tables 6, 7, and 8 for more detail.

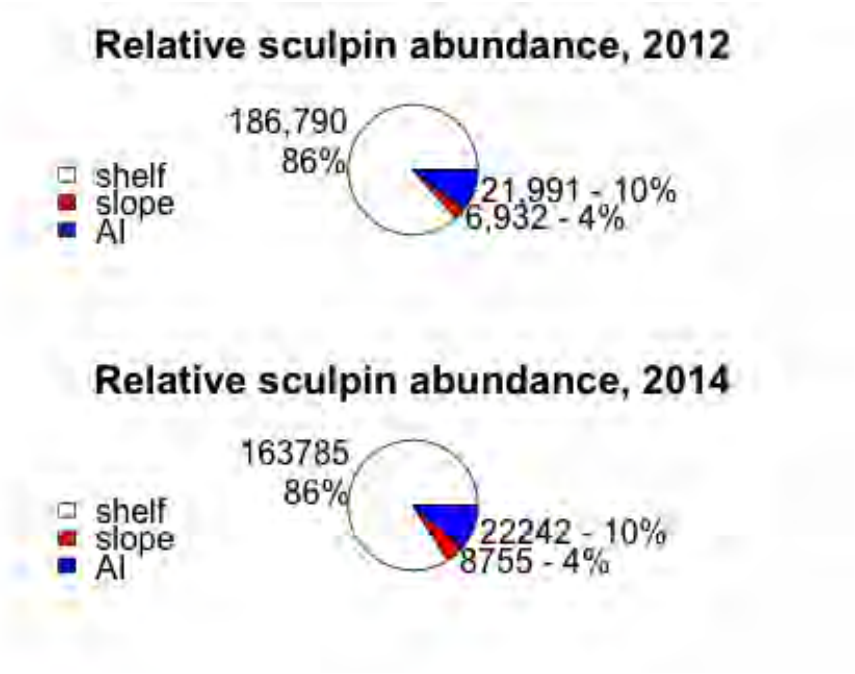


Figure 8. Relative abundance of sculpins in three subregions of the BSAI for 2012 and 2014. Data shown in plot are biomass (t).

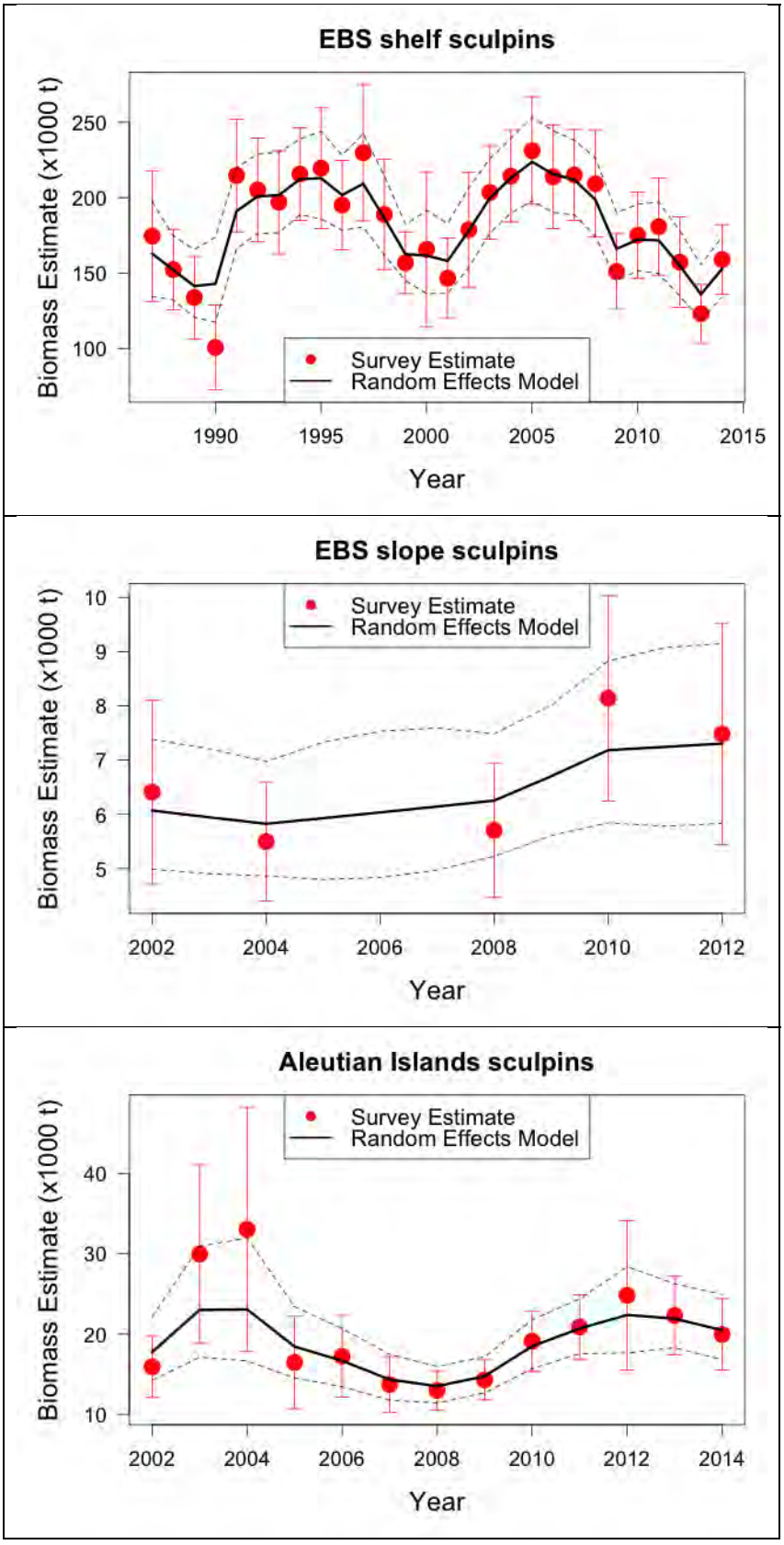


Figure 9. Random effects model estimates of biomass for all shelf sculpins (top), slope (middle), and Aleutians (bottom).

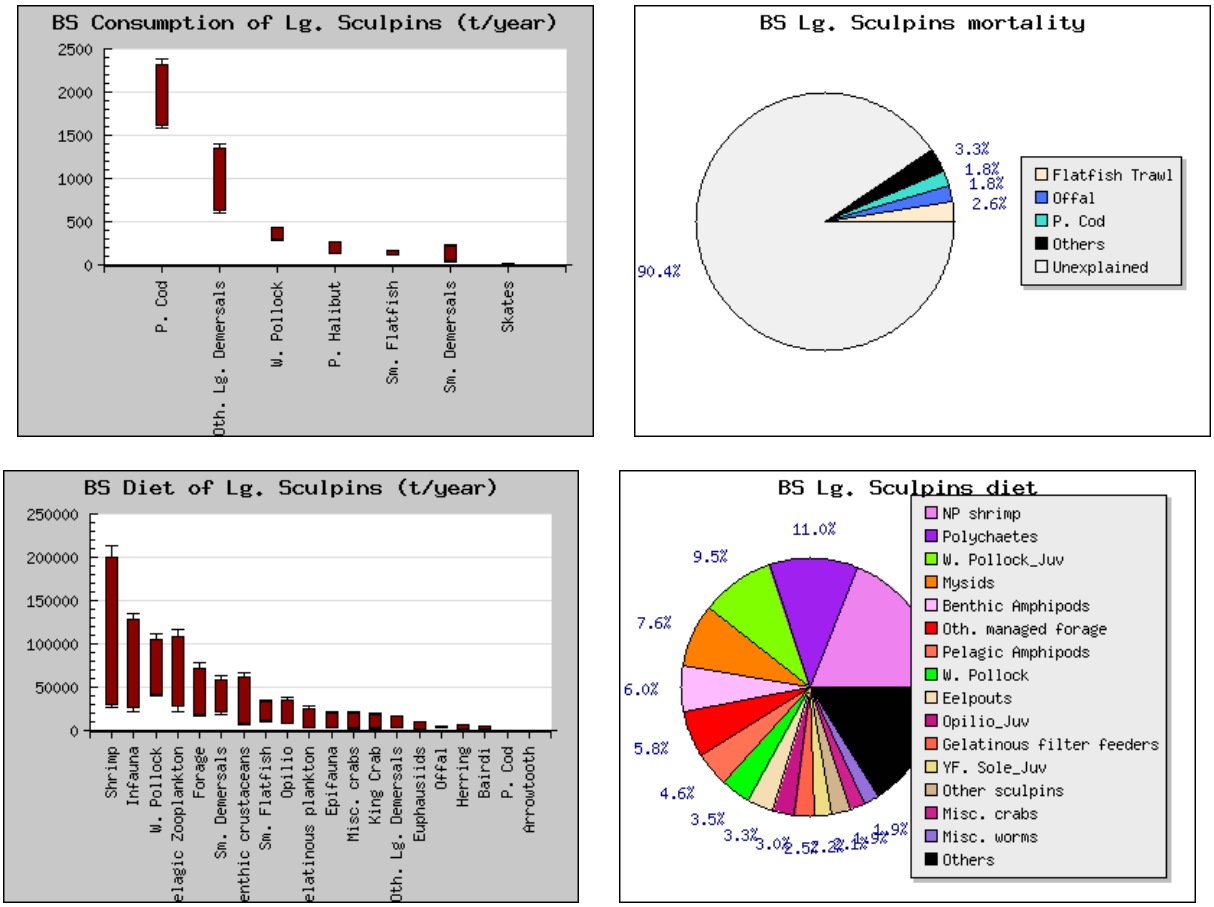
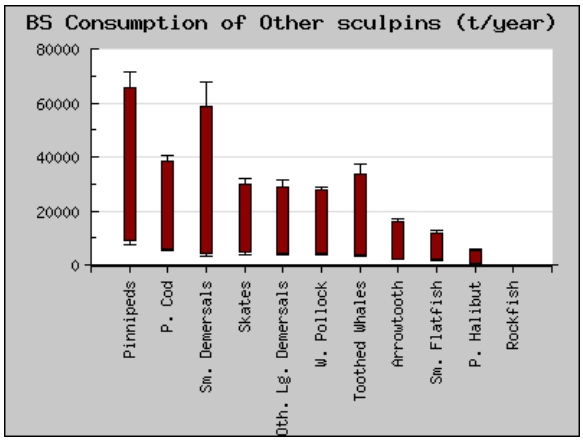
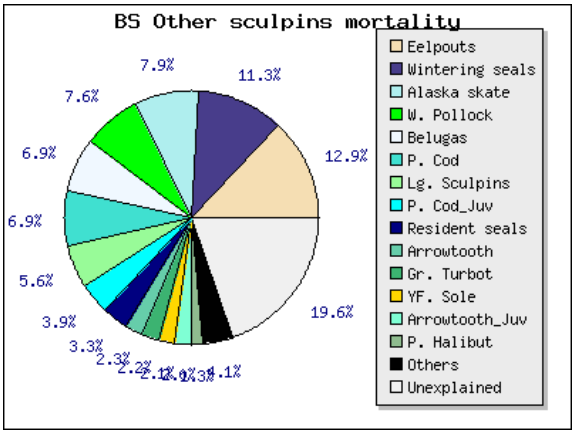
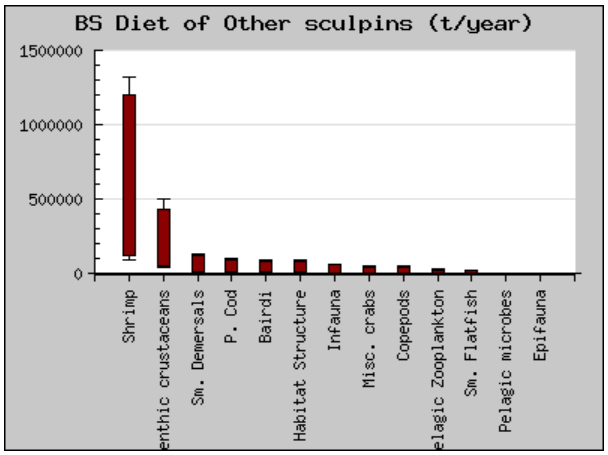


Figure 10. Figures showing Consumption, mortality, and diet of large sculpins from the eastern Bering Sea. Source: REEM ecosystem website.
*Disclaimer: The above figures are in part the result of ecosystem modeling. The use of direct diet data for sculpins in the BSAI is limited.







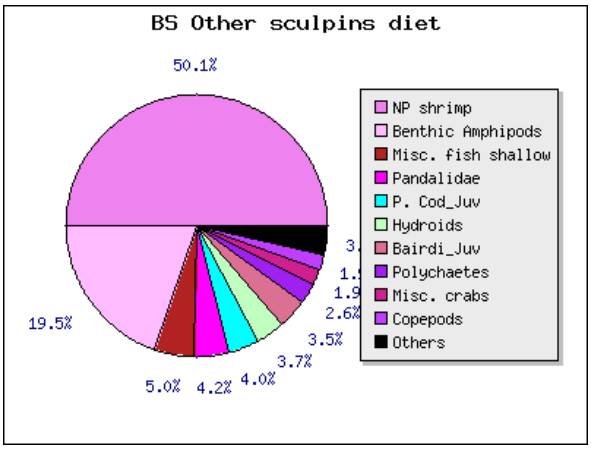


Figure 11. Figures showing Consumption, mortality, and diet of other sculpins from the eastern Bering Sea. Source: REEM ecosystem website.
*Disclaimer: The above figures are in part the result of ecosystem modeling. The use of direct diet data for sculpins in the BSAI is limited.

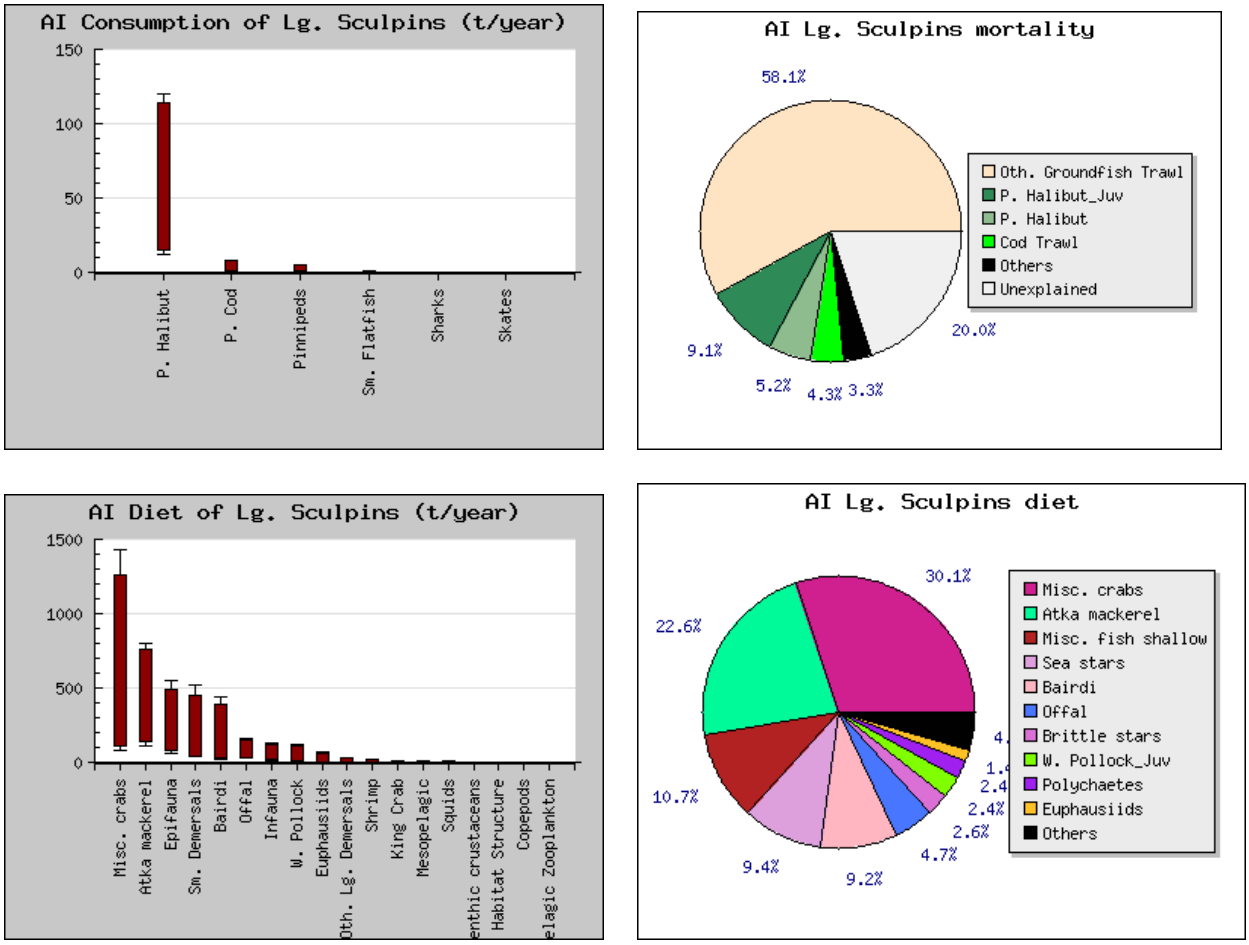


Figure 12. Figures showing Consumption, mortality, and diet of large sculpins from the Aleutian Islands. Source: REEM ecosystem website.
*Disclaimer: The above figures are in part the result of ecosystem modeling. The use of direct diet data for sculpins in the BSAI is limited.

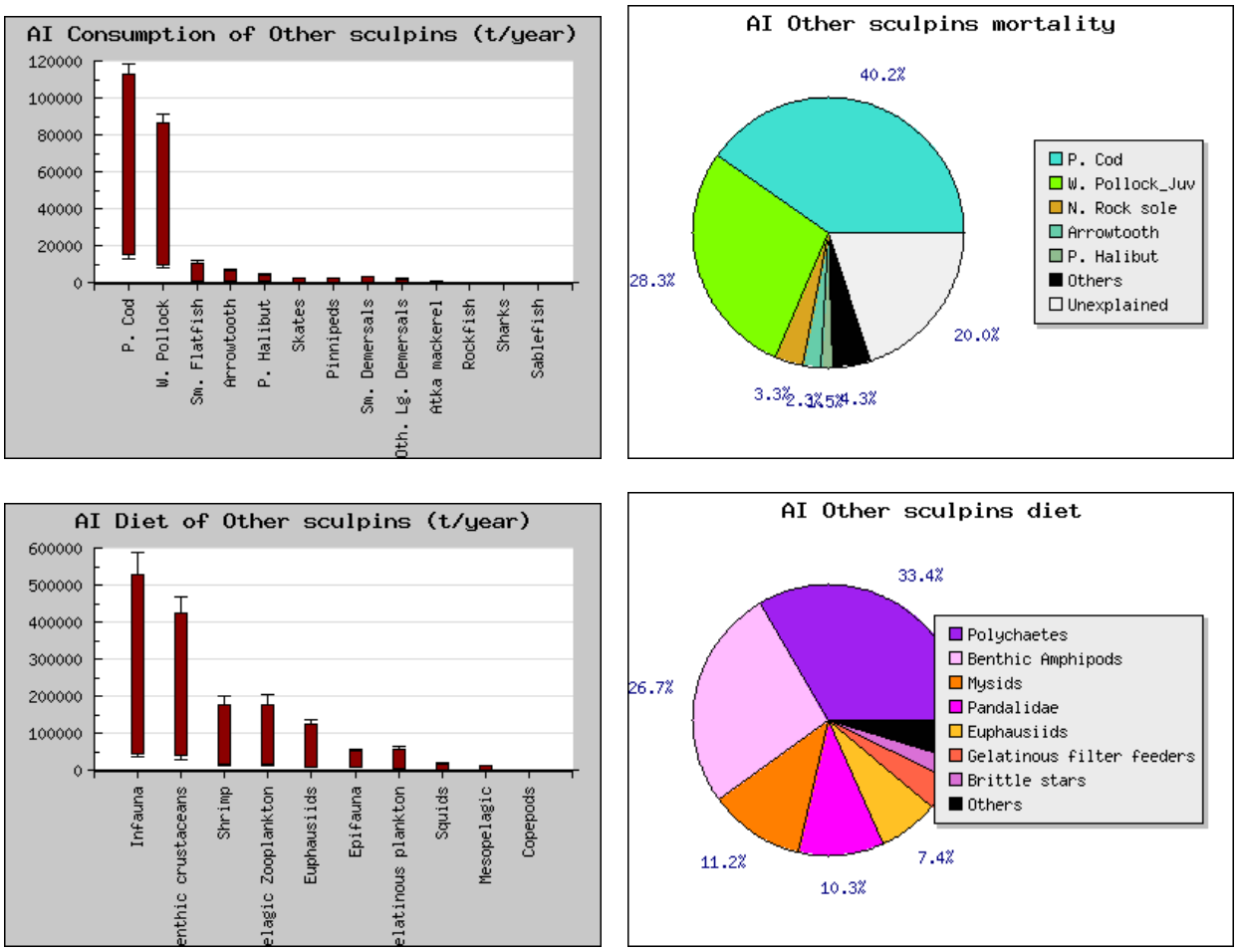


Figure 13. Figures showing Consumption, mortality, and diet of other sculpins from the Aleutian Islands. Source: REEM ecosystem website.
*Disclaimer: The above figures are in part the result of ecosystem modeling. The use of direct diet data for sculpins in the BSAI is limited.

Appendix 1. Assessment of the sculpin stock complex in the Bering Sea and Aleutian Islands, using alternative methodology

Introduction

Here we explore alternative methodology for calculating the estimate of BSAI sculpin biomass. In the past, and in the main assessment presented here, a strict average of three most recent surveys for each region (Aleutian Islands, Bering Sea shelf, and Bering Sea slope) has been used. This appendix calculates the BSAI estimate of biomass using the random effects model. The model was applied separately to survey biomass estimates from the Aleutian Islands, Bering Sea shelf, and Bering Sea slope surveys (Figure 9). The 2014 random effects model estimate of sculpin biomass in the BSAI is the sum of the random effects biomass estimate for the Bering Sea slope, Shelf, and Aleutian Islands. The variance is summed to obtain 95% confidence intervals. The resulting estimate of biomass is 180,570 t (158,772, 202,368; Table A1). The biomass weighted M is 0.29, the same value obtained using the 3 year average of each of the six most common sculpin species (Table A2).

The random effects estimate of BSAI sculpin biomass is lower than the 3 survey average, 180,570 t vs. 194,783 t. The ABC with the random effects method is also lower, 39,725 t, compared to 42,852 t, and the OFL is lower as well, 52,365 t compared to 56,487 t.

Summary of Results

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2014	2015	2015	2016
M (natural mortality rate)*	0.28	0.28	0.29	0.29
Tier	5	5	5	5
Biomass (t)	215,713	215,713	180,570	180,570
F_{OFL}	0.28	0.28	0.29	0.29
$maxF_{ABC}$	0.21	0.21	0.22	0.22
F_{ABC}	0.21	0.21	0.22	0.22
OFL (t)	56,424	56,424	52,365	52,365
maxABC (t)	42,318	42,318	39,725	39,725
ABC (t)	42,318	42,318	39,725	39,725
	As determined *last* year for:		As determined *this* year for:	
Status	2012	2013	2013	2014

Table A1. Random effects model estimates of all sculpin species from the Bering Sea shelf, slope, and Aleutian Islands. The total includes 95% confidence intervals in parentheses.

	Shelf	Slope	Aleutian Islands	Total (95% confidence intervals)
1987	162,897			
1988	152,030			
1989	141,416			
1990	142,858			
1991	191,032			
1992	200,837			
1993	201,563			
1994	212,245			
1995	212,881			
1996	201,678			
1997	209,148			
1998	186,396			
1999	162,545			
2000	161,606			
2001	158,034			
2002	178,080	6,069	17,751	201,900 (173,213, 230,587)
2003	199,695	5,946	23,001	228,642 (201,365, 255, 918)
2004	213,058	5,825	23,065	241,948 (214,265, 269,636)
2005	223,669	5,929	18,427	248,025 (218,221, 277,829)
2006	215,516	6,035	16,667	238,218 (209,168, 267,267)
2007	211,804	6,143	14,330	232,277 (205,989, 258,565)
2008	198,538	6,252	13,497	218,288 (190,478, 246,098)
2009	166,016	6,701	14,735	187,452 (163,267, 211,637)
2010	172,174	7,182	18,475	197,832 (174,078, 221,585)
2011	171,693	7,243	20,681	199,616 (174,032, 225,201)
2012	154,809	7,304	22,374	184,487 (160,512, 208,462)
2013	135,917	7,304	21,922	165,143 (144,966, 185,319)

Table A2. Weighted contribution to M estimate, based on random effect model estimates of each of the six most common sculpin species in the BSAI in each of the three regions.

2015-2016 sculpin complex harvest specifications						
	3-survey average biomass					
species	EBS shelf	EBS slope	AI	**BSAI**	*M*	weighted contribution to mort. est.
threaded	690	0	0	**690**	0.45	0.00
YIL	9,409	27	13,947	**23,383**	0.17	0.02
bigmouth	24,080	4,007	621	**28,708**	0.21	0.04
great	49,628	277	1,790	**51,695**	0.28	0.09
plain	55,132	0	0	**55,132**	0.40	0.13
warty	6,879	0	0	**6,879**	0.26	0.01
total	**145,818**	**4,311**	**16,358**	**166,487**		0.29

20. Assessment of the shark stock complex in the Bering Sea and Aleutian Islands

Cindy A. Tribuzio, Katy Echave, Cara Rodgveller, and Peter-John Hulson
November 2014

EXECUTIVE SUMMARY

Summary of Changes in Assessment Inputs

Changes to the input data

1. Total catch for BSAI sharks is updated to include 2014 (as of Nov 20, 2014)
2. IPHC survey RPNs have been calculated for 1997 – 2013
3. Biomass estimates have been updated for the Aleutian Islands and EBS shelf surveys for 2014

Changes in assessment methodology

The recommended method for calculating OFL and ABC has changed. We are now recommending OFL=Average catch (1997-2007) and ABC=0.75*OFL, rather than maximum historical catch from those years. This change is based on the recommendations made by the Center for Independent Experts (CIE) reviewers and concerns expressed by the Science and Statistical Committee (SSC) and Plan Team regarding declining catch trends for Pacific sleeper sharks. Recent catches are well below the average historical catch, thus shark catch is unlikely to limit the fishery. We recommend this more conservative approach until more data become available to justify setting a higher ABC/OFL.

Summary of Results

For 2014 we recommend the maximum allowable ABC of 454 t and an OFL of 605 t for the shark complex. Catch in 2013 was 116 t and 118 t in 2014 as of November 20, 2014. The stock complex was not subject to overfishing last year, and data do not exist to determine if the species in the complex are overfished.

ABC and OFL calculations and Tier 6 recommendations for 2014 - 2015. OFL = average shark catch from 1997 - 2007. ABC = OFL*0.75.

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2014	2015	2015	2016
Tier	6	6	6	6
OFL (t)	1,363	1,363	**605**	605
maxABC (t)	1,022	1,022	454	454
ABC (t)	1,022	1,022	**454**	454
	As determined *last* year for:		As determined *this* year for:	
Status	2012	2013	2013	2014
Overfishing	No	n/a	No	n/a

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Summaries for Plan Team

Species	Year	Biomass[1]	OFL	ABC	TAC	Catch[2]
Shark Complex	2013		1,363	1,022	100	116
	2014		1,363	1,022	125	118
	2015		605	454		
	2016		605	454		

[1]The shark complex in the BSAI is a Tier 6 complex with no reliable estimates of biomass
[2]Catch as of November 20, 2014

Responses to SSC and Plan Team Comments on Assessments in General

"*The Teams recommend that the whole time series of each category of "other" catches be made available on the NMFS "dashboard," so that they may be listed in all SAFE chapters.*" (Plan Team, November 2012)
This has been done and is reported in Table 20.12

SSC and Plan Team Comments Specific to this Assessment

"The SSC continues to encourage authors to pursue studies to collect life history information for sharks and to identify methods for estimating abundance of species that are rarely captured in standard surveys. The SSC remains concerned that the LL RPNs for Pacific sleeper shark stock remain low." (SSC, December 2012)
The authors agree and intend to investigate this further.

"The SSC encourages the authors to explore the possibility of advancing Pacific sleeper shark to a Tier 5 status. To accomplish this, the authors need to understand the absence of mature Pacific sleeper sharks in the surveys and fishery observations." (SSC, December 2012)
Data do not support moving the Pacific sleeper shark to Tier 5. Existing surveys do not sample Pacific sleeper sharks well and the life history is largely unknown. A life history working group has been formed to prioritize research and to foster and promote investigations into the life history of lesser known species, of which Pacific sleeper shark have been proposed as a priority species.

"In the future, the SSC encourages the authors to carefully consider whether the restructured observer program has impacted catch estimates for BSAI sharks, perhaps necessitating changes to the procedure for estimating average catches used in the catch specification process. The SSC also encourages the authors to address comments and suggestions made by the non-target CIE review team that are relevant to this assessment. (SSC, December 2013)
The authors presented a document to the September Plan Team, which is attached here as an appendix, detailing our current understanding of the changes in observer coverage and changes in catch estimation. There is limited data since restructuring and more years of data are needed before any adjustments to the catch time series can be investigated. In the future we would like to compare HFICE estimates to catch estimates post restructuring.

"*With respect to the historical catch time series, the Team recommends that authors complete an evaluation of a comparison of HFICE estimates to the new time series."* (Plan Team, September 2014)
The authors are expecting to do a comparison of the new catch time series and the HFICE catch estimates when more data become available.

"Team members also suggested that the authors look into the feasibility of establishing discard mortality rates for shark species and summarize what data and studies have evaluated this." (Plan Team, September 2014)
There is very little literature on the discard mortality of the shark species in the BSAI or GOA. The limited research that has been conducted on spiny dogfish was based on animals captured during

research trawls. Hook and line gear is the predominant gear type which catches both spiny dogfish and Pacific sleeper shark and research into the discard mortality from that gear type is necessary. There is ongoing research into the mortality of skates from hook and line gear type, which the authors will consider upon the completion of that project.

CIE Review of Non-Target Assessments, comments specific to this assessment

"Until recommendation 6 is addressed (review of bottom trawl survey) the bottom trawl surveys as combined are not generally useful as an absolute estimate of stock biomass; and further should not be used for management purposes until these issues (i.e. trawl survey review) are successfully resolved."
The authors agree and do not recommend moving any of the sharks in the BSAI to a Tier 5 method.

"That all shark stocks in the BSAI/GOA area are split to have separate OFL/ABC by species and region, and that the OFL be based on the Tier 6 approach as the average catch of each species individually."
Splitting the shark species in the BSAI may not be feasible, as the ABC/OFLs would be quite small and likely difficult to manage.

"Using the maximum or average catch for Tier 6 may not be appropriate; alternatives could be to use an upper bound of a one-sided 95% or 99% confidence interval."
Alternatives to average and maximum catch (e.g. percentiles of the maximum catch) have been presented in the past for the shark assessments (e.g. Tribuzio et al. 2010a). For this assessment, we present and recommend using the average historical catch. The concern about using average catch is that, by rule, the catch will exceed the average in half of years. In the case of BSAI sharks, current catch is well below the historical average (the historical time series used to calculate ABCs and OFLs is from 1997-2007), and unlikely to increase to that level. Thus, using the average catch is currently the most appropriate option.

Species Specific CIE comments

*"Dogfish: Clearly, there is some connection to the stock of dogfish residing the Pacific Northwest region just to the south. The connection with the assessed unit to the south should be explored further. One method of doing so would be to simply treat the BSAI through the NWP as a single unit. In the interim, average catch in the 1997-2007 should be feasible for both components. It is recognized that the GOA dogfish uses a biomass*M approach. However, in keeping with conclusion 1 the average catch is probably a more robust measure."*
A coast-wide assessment may be the most biologically appropriate strategy, but it is not possible at this time. In the BSAI, sharks have been managed using the maximum historical catch for the whole complex. The authors agree with the CIE reviewers that using average catch would be more conservative than maximum. Current catch is well below the historical average.

"Salmon shark: they might be better off being assessed outside of the AFSC jurisdiction as a highly migratory species. Regardless, catches and encounters with inshore fisheries needs to be addressed sooner rather than later for this stock. In the interim, average catch can serve as a good proxy, but that suggestion is made grudgingly given how little is known about this stock."
The authors agree that salmon shark (and the other shark species) may be more appropriately managed as highly migratory species; however, that system does not exist in the GOA or BSAI at this time. Further, catch in Alaska state fisheries is not accounted for, which needs to be addressed to accurately monitor the species.

"Pacific sleeper shark: What data are available is disturbing. While most of the individuals encountered are juvenile, the overall fishery dependent and independent data suggests a declining trend. As such, while average catch is probably the only measure available for informing an OFL, SSC and managers should be aware that more precaution is warranted until further information is gathered."

The authors agree with the CIE reviewers that trends in Pacific sleeper shark catches are concerning and a more conservative approach may be warranted.

Introduction

Alaska Fisheries Science Center (AFSC) surveys and fishery observer catch records provide biological information on shark species that occur in the Bering Sea and Aleutian Islands (BSAI) (Table 20.1 and Figure 20.1). The three shark species most likely to be encountered in BSAI fisheries and surveys are the Pacific sleeper shark (*Somniosus pacificus)*, the spiny dogfish (*Squalus suckleyi)*, and the salmon shark (*Lamna ditropis*).

Squalus acanthias is the scientific name that has historically been used for the spiny dogfish of the North Pacific and many areas of the world, however, the *S. acanthias* "group" is not monospecific and has a history of being taxonomically challenging. The North Pacific spiny dogfish were reclassified by Girard (1854) as *S. suckleyi*, but the description was vague and no type specimens were preserved, thus it remained *S. acanthias*. In a 2010 study, *S. suckleyi* was resurrected based on morphological, meristic and molecular data (Ebert et al. 2010). This scientific name has subsequently been accepted by the American Fisheries Society naming committee. The spiny dogfish has been classified as *S. suckleyi* in the SAFE since 2010, but both names may be used to be consistent with data sources which still use *S. acanthias* (e.g. RACEBASE survey data).

General Distribution

Pacific Sleeper Shark

Pacific sleeper sharks range as far north as the Arctic Circle in the Chukchi Sea (Benz et al. 2004), west off the Asian coast and the western Bering Sea (Orlov and Moiseev 1999), and south along the Alaskan and Pacific coast and possibly as far south as the coast of South America (de Astarloa et al. 1999). They are the most commonly encountered shark in the BSAI. However, Yano et al. (2007) reviewed the systematics of sleeper sharks and suggested that sleeper sharks in the southern hemisphere and the southern Atlantic were misidentified as Pacific sleeper sharks and are actually *Somniosus antarcticus*, a species of the same subgenera. Pacific sleeper sharks have been documented at a wide range of depths, from surface waters (Hulbert et al. 2006) to 1,750 m (seen on a planted grey whale carcass off Santa Barbara, CA, www.nurp.noaa.gov/Spotlight/Whales.htm) but are found in relatively shallow waters at higher latitudes and in deeper habitats in temperate waters (Yano et al. 2007).

Salmon Shark

Salmon sharks range in the North Pacific from Japan through the Bering Sea and GOA to southern California and Baja, Mexico. They are considered common in coastal littoral and epipelagic waters, both inshore and offshore. Salmon sharks tend to be more pelagic and surface oriented than the other shark species in the GOA, spending 72% of their time in water shallower than 50 m (Weng et al. 2005). While some salmon sharks migrate south during the winter months, others remain in Alaskan waters throughout the year (Weng et al. 2005, Hulbert et al. 2005).

Spiny Dogfish

Spiny dogfish occupy shelf and upper slope waters from the Bering Sea to the Baja Peninsula in the North Pacific. They are considered more common off the U.S. west coast and British Columbia (BC) than in the Gulf of Alaska (GOA) or BSAI (Hart 1973, Ketchen 1986, Mecklenburg et al. 2002). In Alaska, they are more common in the GOA than in the BSAI. Spiny dogfish inhabit both benthic and pelagic environments with a maximum recorded depth of 677 m (Tribuzio, unpublished data). Spiny dogfish are commonly found in the water column and at surface waters (Tribuzio, unpublished data).

Evidence of Stock Structure

The stock structure of the BSAI and GOA shark complexes was examined and presented to the joint Plan Teams in September 2012 (Tribuzio et al. 2012). There is very little data available to evaluate whether different stocks exist among regions within the GOA or BSAI for any of the three species. Sharks are generally long-lived and slow growing. There is insufficient life history data for any of the species to compare between or within the GOA and BSAI. Additionally, no genetic information is available to infer any genetic stock structure between or within areas.

Life History Information

There is little data specific to the BSAI region for any of the three primary shark species, thus GOA information is used as proxy. Sharks are long-lived species with slow growth to maturity, a large maximum size, and low fecundity. Therefore, the productivity of shark populations is very low relative to most commercially exploited teleosts (Holden 1974, Compagno 1990, Hoenig and Gruber 1990). Shark reproductive strategies in general are characterized by long gestational periods (6 months - 2 years), with small broods of large, well-developed offspring (Pratt and Casey 1990). Because of these life history characteristics, many large-scale directed fisheries for sharks have collapsed, even where management was attempted (Castro et al. 1999). In 2009, staff at AFSC calculated vulnerability scores for 21 Alaskan species based on life history and fishery susceptibility characteristics (http://www.afsc.noaa.gov/refm/docs/2009/GOAvulnerability.pdf). Sharks were 3 of the 4 most vulnerable species, with salmon shark the least vulnerable shark at 1.96 (lower scores are less vulnerable), spiny dogfish at 2.10 and Pacific sleeper shark at 2.24, the most vulnerable of all species calculated.

Pacific Sleeper Shark

Sleeper sharks (*Somniosus* spp.) attain large sizes, most likely possess a slow-growth rate and are likely long-lived (Fisk et al. 2002). A Greenland shark (*Somniosus microcephalus*), the North Atlantic congener of the Pacific sleeper shark, was sampled in 1999 and was determined to have been alive during the 1950's - 1970's because it had high levels of DDT (Fisk et al. 2002). The average lengths of *Somniosus* sp. captured in mid-water trawls in the Southern Ocean are 390 cm *TL* (total length with the tail in the natural position) +/- 107 cm (range 150-500 cm, n=36, Cherel and Duhamel 2004). Large *Somniosus* sharks observed in photographs from deep water have been estimated at lengths up to 700 cm (Compagno 1984). The maximum lengths of captured Pacific sleeper sharks were 440 cm for females and 400 cm for males (Mecklenburg et al. 2002). Pacific sleeper sharks as large as 430 cm have been caught in the western North Pacific (WNP), where the species exhibits sexual dimorphism, with females being shorter and heavier (avg. length = 138.9 cm, avg. weight = 28.4 kg) than males (avg. length = 140 cm, avg. weight = 23.7 kg) (Orlov 1999). The cartilage in sleeper sharks does not calcify to the degree of many other shark species, therefore ageing is difficult and methods of ageing are under investigation.

Published observations suggest that mature female Pacific sleeper sharks are in excess of 365 cm *TL*, mature male Pacific sleeper sharks are in excess 397 cm *TL*, and that size at birth is approximately 40 cm *TL* (Gotshall and Jow 1965, Yano et al. 2007). The reproductive mode of sleeper sharks is thought to be aplacental viviparity. Three mature females 370 - 430 cm long were opportunistically sampled off the coast of California. One of these sharks had 372 large vascularized eggs (24 - 50 mm) present in the ovaries (Ebert et al. 1987). Another mature Pacific sleeper shark 370 cm long was caught off Trinidad, California (Gotshall and Jow 1965) with ovaries containing 300 large ova. Two recently born 74 cm sharks have been caught off the coast of California at depths of 1300 and 390 m; one still had an umbilical scar (Ebert et al. 1987). Unfortunately, the date of capture was not reported. A newly born shark of 41.8 cm was also caught at 35 m depth off Hiraiso, Ibaraki, Japan (Yano et al. 2007). Additionally, three small sharks, 65 - 75 cm long, have been sampled in the Northwest Pacific, but the date of sampling was not reported (Orlov and Moiseev 1999). In summer 2005, an 85 cm *PCL* female was caught during the annual AFSC longline survey near Yakutat Bay and in spring 2009 another 85 cm *PCL* female was

caught by a commercial halibut fisherman inside Chatham Strait in Southeast Alaska (Tribuzio unpublished data). Because of a lack of observations of mature and newly born sharks, and the absence of dates in literature, the spawning and pupping seasons are unknown for sleeper sharks.

Salmon Shark

Like other lamnid sharks, salmon sharks are active and highly mobile, maintaining body temperatures as high as 21.2^{o}C above ambient water temperatures and appear to maintain a constant body core temperature regardless of ambient temperatures (Goldman et al. 2004). Adult salmon sharks typically range in size from 180 - 210 cm *PCL* (Goldman and Musick 2006) in the eastern North Pacific and can weigh upwards of 220 kg. Length-at-maturity in the WNP has been estimated to occur at approximately 140 cm *PCL* for males and 170 - 180 cm *PCL* for females (Tanaka 1980). These lengths correspond to ages of approximately five years and 8 - 10 years, respectively. Length-at-maturity in the ENP has been estimated to occur between 125 - 145 cm *PCL* (3 – 5 years) for males and between 160 - 180 cm *PCL* (6 – 9 years) for females (Goldman and Musick 2006). Tanaka (1980) (see also Nagasawa 1998) states that maximum age from vertebral analysis for WNP salmon shark is at least 25 years for males and 17 years for females and growth coefficients are 0.17 and 0.14 for males and females, respectively. Goldman and Musick (2006) gave maximum ages for ENP salmon shark (also from vertebral analysis) of 17 years for males and 30 years for females, with growth coefficients of 0.23 and 0.17 for males and females, respectively. Salmon sharks in the ENP and WNP attain the same maximum length (approximately 215 cm *PCL* for females and about 190 cm *PCL* for males). However, males past approximately 140 cm *PCL* and females past approximately 110 cm *PCL* in the ENP are of a greater weight-at-length than their same-sex counterparts in the WNP (Goldman and Musick 2006).

The reproductive mode of salmon sharks is aplacental viviparity and includes an oophagous stage when embryos feed on eggs produced by the ovary (Tanaka 1986 cited in Nagasawa 1998). Litter size in the WNP is four to five pups, and litters have been reported to be male dominated 2.2:1 (Nagasawa 1998). Gestation times throughout the North Pacific appear to be nine months, with mating occurring during the late summer and early fall and parturition occurring in the spring (Nagasawa 1998, Tribuzio 2004, Goldman and Musick 2006, Conrath et al. 2014). Salmon shark appear to have at least a two year reproductive cycle, with an extended resting period between pregnancies (Conrath et al. 2014). Size at parturition is between 60 - 65 cm *PCL* in both the ENP and WNP (Tanaka 1980, Goldman and Musick 2006).

Spiny Dogfish

Eastern North Pacific spiny dogfish grow to a maximum size of 160 cm (Compagno 1984). Recent studies estimated ages-at-50% maturity to be 36 years for females and 21 years for males (Tribuzio and Kruse 2012), which is similar to estimates from BC of 35 years and 19 years respectively (Saunders and McFarlane 1993). Longevity in the ENP is between 80 and 100 years (Campana et al. 2006). Growth coefficients (κ) for this species are among the slowest of all shark species, $\kappa = 0.03$ for females and 0.06 for males (Tribuzio et al. 2010b).

The mode of reproduction for spiny dogfish is aplacental viviparity. Embryos are nourished by their yolk sac while being retained in utero for 18 - 24 months. In the GOA, pupping may occur during winter months, based on the size of embryos observed during summer and fall sampling (Tribuzio and Kruse 2012). Ketchen (1972) reported timing of parturition in BC to be October through December, and in the Sea of Japan, parturition occurred between February and April (Kaganovskaia 1937, Yamamoto and Kibezaki 1950). Washington State spiny dogfish have a long pupping season, which peaks in October and November (Tribuzio et al. 2009). Pupping is believed to occur in estuaries and bays or mid-water over depths of about 165 - 370 m (Ketchen 1986). Small juveniles and young-of-the-year tend to inhabit the water column near the surface or in areas not fished commercially and are therefore not available to commercial fisheries until they grow or migrate to fished areas (Beamish et al. 1982, Tribuzio and Kruse

2012). The average litter size is 8.5 pups for spiny dogfish in the GOA (Tribuzio and Kruse 2012), 6.9 in Puget Sound, WA (Tribuzio et al. 2009), and 6.2 in BC (Ketchen 1972). The number of pups per female also increases with the size of the female, with estimates ranging from 0.20 - 0.25 more pups for every centimeter in length after the onset of maturity (Ketchen 1972, Tribuzio et al. 2009, Tribuzio and Kruse 2012).

Fishery

Management History and Management Units

The shark complex is managed as an aggregate species group in the BSAI Fishery Management Plan (FMP). Prior to the 2011 fishery, sharks were managed as part of the "Other Species" complex, with sculpins, skates and octopus. The breakout was in response to the requirements for annual catch limits contained within the reauthorization of the Magnuson Stevens Fishery Conservation and Management Act. The NPFMC passed amendment 87 (http://www.fakr.noaa.gov/sustainablefisheries/amds/95-96-87/amd87.pdf) to the BSAI FMP, requiring sharks to be managed as a separate complex and Annual Catch Limits (ACLs) be established annually by the SSC starting in the 2011 fishery. The total allowable catch (TAC), acceptable biological catch (ABC), and overfishing limits (OFL) for the shark complex (and previously the Other Species complex) are set in aggregate (Table 20.2).

Directed Fishery, Effort and CPUE

There are currently no directed commercial fisheries for shark species in federally- or state- managed waters of the BSAI.

Discards

Nearly all incidental shark catch is discarded. Mortality rates of discarded catch are unknown, but are conservatively estimated in this report as 100%. Discard rates for sharks are presented in Table 20.3. Generally, > 90% of sharks are discarded however, other/unidentified sharks are discarded at a lower rate (67% and 82% discarded on average in the Aleutian Islands and Bering Sea, respectively, which is ~4 t on average) than identified shark species. The reason for the lower discard rate of other/unidentified sharks is unclear. We surmise that much of the catch in the other/unidentified shark category is Pacific sleeper shark (Tribuzio et al. 2012), but that does not explain why the discard rate is lower for this category than other categories. About 16 t of sharks are retained on average annually (~11 t is Pacific sleeper shark), and nearly all is used for fishmeal (T. Hiatt, pers. comm.).

Historical Catch

Historical catches of sharks in the BSAI are composed entirely of incidental catch. This report summarizes incidental shark catches by species as two data time series: 1997 – 2002 and 2003 – present (Table 20.4). Shark catch by species was estimated by staff at the AFSC using a pseudo-blend approach for 1997 – 2002 and since has been estimated by the NMFS AKRO Catch Accounting System (CAS). Aggregate incidental catches of the shark management category from federally prosecuted fisheries for Alaskan groundfish in the BSAI are tracked in-season by NMFS AKRO (Table 20.2 and Table 20.4).

The estimated catch of sharks is broken into four groups: Pacific sleeper shark, spiny dogfish, salmon shark and other/unidentified sharks. Historically, Pacific sleeper shark are the primary species caught in the BSAI (67% of total shark catch on average, 282 t on average, Table 20.4, Figure 20.2). The other/unidentified sharks, salmon sharks and spiny dogfish are smaller components of the complex (19% and 79 t, 11% and 48 t, and 3% and 11 t, on average, respectively).

Beginning in 2013, the restructured observer program added coverage on vessels under 60 ft as well as vessels operating in the Pacific halibut IFQ fishery. It is possible that this change to observer coverage

may affect estimates of shark catch, but the magnitude is unknown at this time. In 2013 in the BSAI there was an increase in the proportion of total catch caught in the under 60 vessel category and there was also an increase in the estimate of shark catch in the Pacific halibut target group. An examination of the potential impacts of the 2013 change in observer coverage on the estimates of shark catch is included in Appendix 20.A.

Most of the shark catch in the BSAI occurs in the Pacific cod and walleye pollock fisheries. Pacific sleeper shark are caught primarily in the Pacific cod (37%, 93 t on average, Table 20.5) and the walleye Pollock (36%, 89 t on average) fishery. Salmon shark are almost entirely caught in the walleye pollock fishery (92%, 44 t on average, Table 20.6). The Pacific cod fishery catches about 87% of the spiny dogfish (10 t on average, Table 20.7). Similar to Pacific sleeper shark, the other/unidentified sharks are caught in both the walleye Pollock (48%, 27 t on average) and Pacific cod fisheries (25% and 14 t on average, Table 20.8).

Catches of Pacific sleeper shark have been declining and have been well below average since 2005 (Figure 20.2). Trends in catch of the other/unidentified sharks mirrors that of Pacific sleeper shark and it is likely that the majority of those are Pacific sleeper shark (Tribuzio et al. 2012). The declining trend in Pacific sleeper shark catch was investigated with respect to environmental conditions. Various Bering climate indices (e.g. Aleutian Low, Pacific Decadal Oscillation, etc. http://www.beringclimate.noaa.gov/data/index.php) were compared to the catch of Pacific sleeper sharks and correlation coefficients calculated. None of the indices were significantly related to Pacific sleeper shark catches, however, the Pacific/North American Index was the most closely related ($p = 0.07$, corr = 0.49). A more detailed time series analysis is planned for future assessments.

Catch distribution: Observer catch data from the FMA website (http://www.afsc.noaa.gov/FMA/spatial_data.htm) was mapped to analyze spatial distribution of catch. Observers cover 90% of the groundfish tonnage in the BSAI. Data presented here represent non-confidential data aggregated by 400 km^2 grids from fisheries that occurred during 2010 - 2013.

Bycatch of Pacific sleeper sharks (Figure 20.3) within observed commercial fisheries was relatively high on the EBS shelf to approximately longitude 178°50'W, northwest of St. Matthews Island.. While there were fewer hauls observed with Pacific sleeper shark bycatch in 2012, there were a higher number of hauls containing large amounts of Pacific sleeper shark. The same was observed in 2013, in addition to a higher amount of observed bycatch closer to Unimak Pass.

Observed bycatch of salmon shark in commercial fisheries in the Bering Sea is generally low, but occasional large catches occur (Figure 20.4). Most of the catch occurs along the EBS shelf, with a small amount occurring in the southern Bering Sea near the Pribilof and Bering Canyons, in addition to shelf waters in the EBS outside of Bristol Bay. Observed bycatch of salmon shark was noticeably higher in 2011, specifically in shelf waters in the EBS off the Alaska Peninsula and outside Bristol Bay.

Observed bycatch of spiny dogfish in commercial fisheries in the Bering Sea (Figure 20.5) is less than Pacific sleeper shark bycatch, but the spatial distribution is similar. Spiny dogfish bycatch occurs throughout the EBS shelf, generally along the shelf break heading northwest from Unimak Pass. In addition, spiny dogfish are observed within the Aleutian Islands. Observed spiny dogfish bycatch was particularly high in 2013, specifically around Unimak Pass and heading northeast along the Alaska Peninsula.

Observed bycatch of other/unidentified sharks within commercial fisheries in the Bering Sea (Figure 20.6) is generally patchy in comparison to Pacific sleeper shark and spiny dogfish with only a small number of hauls reporting other/unidentified sharks.

Data

Data regarding sharks were obtained from the following sources:

Source	Data	Years
AKRO Catch Accounting System	Nontarget catch	2003 – 2014
Improved Pseudo Blend (AFSC)	Nontarget catch	1997 – 2002
NMFS Bottom Trawl Surveys –Eastern Bering Sea Shelf (Annual)	Biomass Index	1979 – 2014
NMFS Bottom Trawl Surveys –Eastern Bering Sea Slope (Historical)	Biomass Index	1979 – 1991
NMFS Bottom Trawl Surveys –Eastern Bering Sea Slope	Biomass Index	2002 - 2012
NMFS Bottom Trawl Surveys –Aleutian Islands	Biomass Index	1980 – 2014
NMFS Longline Surveys	Catch Numbers	1989 - 2014
IPHC Longline Surveys	Catch Numbers	1997 - 2013

Fishery

Historical catch estimates presented in Table 20.4 for the shark complex and by species in Table 20.5 - Table 20.8.

Catch at length (Fishery and Survey)

A formal stock assessment population model does not exist for the shark complex or any of the component species in the BSAI; therefore, length frequency data are not used in the assessment specifications procedures. However, length data has and is being collected on surveys. The data presented here is from the AFSC bottom trawl surveys (GOA, EBS shelf, EBS slope and AI), AFSC and IPHC longline surveys, targeted research surveys, as well as special projects conducted by the Observer Program. We include GOA data because for both Pacific sleeper sharks and spiny dogfish, genetic evidence suggests that both species are a continuous stock within the eastern North Pacific Ocean. There is very little length data from the BSAI (i.e. a small number of sharks are caught each year). Therefore, for Pacific sleeper sharks lengths for the BSAI and GOA are combined for each data source (Figure 20.7, sexes combined). Despite summing both areas, data are still extremely limited. In even years (BSAI surveys only) the AFSC trawl survey catches smaller animals, many < 100 cm; while in odd years (GOA survey included) the surveys catch larger animals, some > 300 cm. None of the data sources report catching Pacific sleeper sharks at or greater than the reported size at maturity (365 cm for males, 397 cm for females). Length data collections are part of standard collections on the AFSC longline and trawl surveys, as well as regularly collected on the IPHC longline survery, thus a time series of length frequency data are being created. Due to a paucity of BSAI length data, only the GOA data for spiny dogfish is presented (Figure 20.8 & Figure 20.9). The length frequency data appears to cover the full size range of the species, with the IPHC longline survey tending to catch more of the larger females, likely due to sampling in near shore waters. Catch of salmon shark is extremely rare in surveys and length frequencies are not presented.

Survey

AFSC Trawl Survey Biomass Estimates

Biomass estimates are available for shark species from NMFS AFSC bottom trawl surveys conducted in the BSAI on the eastern Bering Sea (EBS) slope (1979 - 1991 and 2002 - 2012; Table 20.9 and Figure 20.10), Aleutian Islands (AI, 1980 – 2014, Table 20.10 and Figure 20.10), and the EBS shelf (1979 – 2014, Table 20.11 and Figure 20.10). The shelf survey is annual, but the other surveys take place as funding allows. Sharks in the BSAI may not be sampled well by bottom trawl surveys. In many years, surveys fail to capture a single specimen of some shark species. As a result, the estimation procedure

often indicates a biomass of zero or biomass estimates with high levels of uncertainty. Thus trends in biomass estimates from trawl surveys are not informative. Spiny dogfish, for example, occurred in < 1% of survey hauls for all three of the BSAI surveys. The efficiency of bottom trawl gear varies by species, and trends in these biomass estimates should be considered, at best, a relative index of abundance for shark species until more formal analyses of survey efficiencies by species can be conducted. In particular, pelagic shark species, such as salmon sharks, are encountered by the trawl gear not while it is in contact with the bottom, but rather during gear deployment or retrieval, resulting in unreliable biomass estimates since the estimates are based, in part, on the amount of time the net spends in contact with the bottom. Although Pacific sleeper sharks are demersal, they are large animals that may be able to avoid bottom trawl gear. As a result biomass estimates are very uncertain since the gear may not efficiently capture this species. These surveys are not informative for spiny dogfish because they are rarely caught in the surveys. However, catches are reported in the observer data and in other surveys sampling the same area; differences in catch rates are likely due to gear differences, as spiny dogfish may be more susceptible to longline gear.

Analysis of the EBS slope survey biomass time series is subject to the following caveats: the slope survey was standardized in 2002 to its current gear type, survey strata, and survey design. Because the survey stratification changed in 2002, biomass estimates are not comparable between the historical EBS slope survey (1979 – 1991) and the new slope survey (2002 – 2012). Consequently, surveys from 2002 – 2012 may be useful for estimating relative abundance of commonly encountered species, while surveys between 1979 and 1991 should only be used for identifying the relative distribution of species (Gary Walters, pers. comm.).

Pacific sleeper sharks are the most abundant catch of all shark species within BSAI surveys. They are most consistently caught on the annual EBS slope survey in a relatively high number of hauls (at least 15 hauls each year, 8 - 14% of hauls, compared to < 5 hauls, <3% of hauls in the other surveys during the same time frame), with biomass estimates ranging from 833 t (2010) to 25,445 t (2002) from 2002 through 2012 (Table 20.9 and Figure 20.10). These large fluctuations are suspect for such a large and late to mature species. Pacific sleeper sharks are also captured consistently in NMFS bottom trawl surveys of the Aleutian Islands, but biomass estimates are based on a fewer number of hauls (at most 10 hauls in 1997, 2.5% of the survey hauls) and biomass estimates are generally lower than in the EBS slope area (22 t in the AI in 2012, Table 20.10 and Figure 20.10). There were no Pacific sleeper sharks caught during the AI trawl survey in 2014, the first time that has occurred since 1980. Pacific sleeper sharks are not often caught during the annual EBS shelf survey and biomass estimates range from zero to 5,602 t (2002) (Table 20.11 and Figure 20.10). It is likely that most surveys and fisheries are not sampling much of the adult population because no mature Pacific sleeper sharks have been documented in Alaska.

Spiny dogfish and salmon shark are rarely captured during any of the NMFS bottom trawl surveys in the EBS or Aleutian Islands. Often, catches are zero, with a resultant zero biomass estimates or are based on very few hauls with catch. During the EBS slope survey, spiny dogfish have only been caught in one haul (in 2008) and no other spiny dogfish have been caught since the new survey design in 2002 (Table 20.9 and Figure 20.10). Spiny dogfish are caught sporadically in the Aleutian Islands survey and the resultant biomass is always low, ranging from 2 - 62 t (Table 20.10 and Figure 20.10). Salmon shark have never been caught in the EBS slope survey (Table 20.9). One salmon shark was caught in 2002 in the Aleutian Island survey (Table 20.10 and Figure 20.10) and one in 1988 in the EBS shelf survey (Table 20.11 and Figure 20.10).

Longline Surveys

The International Pacific Halibut Commission (IPHC) conducts a longline survey each year to assess Pacific halibut. This is a fixed station survey that samples down to 500 m in the Aleutian Islands, Eastern Bering Sea, and the Gulf of Alaska, as well as areas south of Alaska. More information on this survey can be found in Soderlund et al. (2009). Total catch of sharks in the IPHC survey is presented in Table 20.12.

Relative population numbers (RPNs) for spiny dogfish and Pacific sleeper shark were calculated using the same methods that are used for the AFSC longline survey, the only difference being the depth stratum increments. First an average CPUE was calculated by depth stratum for each FMP sub-area (e.g., east Yakutat, west Yakutat, central GOA, etc.). The CPUE was then multiplied by the area size of that stratum. A FMP-wide RPN was calculated by summing the RPNs for all strata in the area. Area sizes used to calculate biomass in the RACE trawl surveys were utilized for IPHC RPN calculations.

For Pacific sleeper sharks, which are the primary shark species caught in the BSAI, RPNs from the IPHC survey have declined steeply since the late 1990s and have remained at low levels since 2005 (Figure 20.11). Spiny dogfish are not commonly caught; however, RPNs appear to be trending up slightly since 2005. Salmon shark are extremely rare in the IPHC survey, thus the RPNs do not provide useful information. Almost all of the IPHC survey catch of sharks occurs in the Bering Sea and only limited catch occurs in the Aleutian Islands.

The AFSC longline survey samples stations in the Bering Sea in odd years (e.g., 2013) and the Aleutian Islands in even years. Overall shark catch is low on the AFSC longline survey. For this reason, RPNs from the AFSC longline survey are not presented. The AFSC longline survey samples fewer stations with longer sets along the slope, whereas the IPHC survey samples many stations with less gear set at shallower depths across the shelf. The AFSC longline survey likely does not sample shark habitat as well as the IPHC longline survey.

Distribution of catch in surveys

An examination of the spatial distribution of survey catches shows that Pacific sleeper shark are consistently caught in low numbers throughout the EBS shelf in the IPHC LL (during years 2010 – 2013, Figure 20.12) and NMFS trawl surveys (Figure 20.13) with rare scattered catches in the Aleutian Islands. The distribution of Pacific sleeper sharks spreads from Unimak Pass and follows the shelf break northwest beyond the Pribilof Islands, until approximately longitude 178°40'W. The IPHC LL survey caught relatively higher numbers of sleeper sharks off Unimak Pass in 2010. Catch of sleeper sharks in the NMFS 2008 and 2010 trawl surveys was highest near Unimak Pass as well. There were no sleeper sharks caught on the NMFS trawl survey in 2014.

In contrast, spiny dogfish catch is mostly distributed throughout the Aleutian chain. Spiny dogfish occurrences are rare in both the NMFS trawl and IPHC longline surveys (Figure 20.14), but there are fewer spiny dogfish caught in the NMFS trawl survey.. Only one spiny dogfish was caught on the Bering shelf during the 2010 trawl survey, and three in 2014.

Analytic Approach

Model Structure

Sharks in the BSAI are managed under Tier 6 (harvest specifications based on the historical catch or alternatives accepted by the Science and Statistical Committee), so no stock assessment modeling is performed.

Parameter Estimates

Although a model is not used to provide stock assessment advice for BSAI sharks we provide estimates of life history parameters, where available (Table 20.13). Estimates are not available for BSAI stocks and thus GOA or North Pacific values are used as a proxy. Parameters include weight at length, length at age, natural mortality (*M*), maximum age and age at first recruitment, when available. Weight at length and average length parameters were derived from both directed research projects (all three species) and standard survey collections (spiny dogfish only).

A method for ageing Pacific sleeper shark has not yet been developed. However, samples of a similar species, the Greenland shark, were determined to have been between 20 - 40 years old because of DDT levels (Fisk et al. 2002). If we assume that this age range is a minimum estimate of maximum age and apply Hoenig's (1983) natural mortality estimate, $M = 0.223 – 0.113$. The size range of the animals in that study suggests that they were immature, thus the estimate of maximum age is an underestimate and the range of natural mortalities is likely an over estimate. There are not sufficient resources or ages to investigate *M* by tagging studies or catch curve analysis with Pacific sleeper shark, and the lack of life history data (e.g. no mature animals caught or sampled in Alaska) precludes using life history invariant methods.

Numerous age and growth studies have been conducted on spiny dogfish in the GOA and North Pacific Ocean. An estimate of the natural mortality rate ($M = 0.097$) is derived for spiny dogfish in the GOA (Tribuzio and Kruse, 2012). The value of *M* (0.097) for the GOA is similar to an estimate for British Columbia spiny dogfish (0.094) (Wood et al. 1979). Maximum age of spiny dogfish in the ENP is between 80 and 100 years (Beamish and McFarlane 1985, Campana et al. 2006). Age of first recruitment is not available for spiny dogfish, however, Tribuzio et al. (2010b) report the youngest dogfish encountered in fishery dependent sampling was 8 years old.

Salmon shark are a fairly well studied species. Natural mortality has been estimated to be $M = 0.18$ (Goldman 2002). Maximum reported age for central GOA salmon shark is 30 years (Goldman and Musick 2006). Age at first recruitment to a commercial fishery is 5 years old for central GOA salmon sharks (Goldman 2002).

Results

Harvest Recommendations

Sharks have been considered a Tier 6 species because they are not targeted and biomass estimates are unreliable. The current Tier 6 method adopted in 2010 for sharks uses the catch time series during 1997 - 2007 where OFL is equal to the maximum catch and ABC is 75% of OFL. The status quo approach is unlikely to constrain the fishery, as current shark catches are substantially lower than the maximum historical catch.

The SSC, Plan Teams and CIE reviewers have all expressed concerns over the declining population trends in Pacific sleeper sharks. Further, the CIE recommended using an average catch, as a more conservative management strategy than the maximum historical catch. Below we present the OFL and ABC recommendations based on average catch as well as the maximum catch (status quo). Either approach is unlikely to constrain the fishery. Examining the catch history from 1997 to the present shows that catches are not likely to have exceeded the ABCs from either calculation (Figure 20.15), as catch estimates for the last 5 years have been < 20% of the ABC.

We recommend using the average historical catch=OFL (ABC=OFL*0.75) method for calculating OFL and ABC for all sharks until more data on Pacific sleeper shark abundance and biology is available. Tier 6 ABC and OFL calculations using both methods for the BSAI shark complex are presented below for both individual species and the shark complex as a whole. The individual species ABC/OFLs are presented for information purposes, the recommendations are made for the total shark complex.

Tier 6 calculations by species and total of all species (t) and recommendations for 2015-2016 (in bold).

Species	Spiny dogfish	Pacific sleeper shark	Salmon shark	Other/Unidentified shark	Total shark Complex
Maximum Catch	17	839	199	468	1,363*
ABC	13	629	149	351	1,022
OFL	17	839	199	468	1,363
Average Catch	8	422	48	126	605
ABC	6	317	36	95	**454**
OFL	8	422	48	126	**605**

*The complex total is based on the maximum catch of the whole complex, not the sum of the individual species maximums.

Ecosystem Considerations

The ecosystem considerations for the BSAI shark stock complex are summarized in Table 20.14.

Ecosystem Effects on Stock

Pacific sleeper shark

Pacific sleeper sharks were once thought to be sluggish and benthic because their stomachs commonly contain offal, cephalopods, and bottom dwelling fish such as flounder (*Pleuronectidae*) (e.g., Yang and Page 1999). In contrast, another diet analysis documented prey from different depths in the stomachs of a single shark, such as giant grenadier (*Albatrossia pectoralis*) and pink salmon (*Oncorhynchus gorbuscha*), indicating that they make depth oscillations in search of food (Orlov and Moiseev 1999). Other diet studies have found that Pacific sleeper sharks prey on fast moving fish such as salmon (*O. spp.)* and tuna (*Thunnus spp*.), and marine mammals such as harbor seals (*Phoca vitulina*), that live near the surface (e.g., Bright 1959; Ebert et al. 1987; Crovetto et al. 1992; Sigler et al. 2006), suggesting that these sharks may not be as sluggish and benthic oriented as once thought. Recent research using stable isotope concentrations in both liver and muscle tissue determined that Pacific sleeper sharks likely get a significant portion of their energy from lower trophic prey (i.e. Pacific herring, walleye pollock; Schauffler et al. 2005) and that they also feed on prey from a wide variety of trophic levels (Courtney and Foy, 2012). Similar to spiny dogfish, fluctuations in environmental conditions and prey availability may not significantly affect this species because of its wide dietary niche. There are no known predators of Pacific sleeper sharks. Data suggests that most of the Pacific sleeper sharks caught in the BSAI and GOA are immature and there is no information on spawning or mating or gestation, so it is unknown how the fishery affects their recruitment.

Salmon Shark

Salmon sharks are opportunistic feeders, sharing the highest trophic level of the food web in subarctic Pacific waters with marine mammals and seabirds (Brodeur 1988, Nagasawa 1998, Goldman and Human 2004). They feed on a wide variety of prey, from squid and shrimp to salmon (*Oncorhynchus* sp.) and rockfishes (family Sebastes) and even other sharks (Sano 1962, Hart 1973, Compagno 1984, Nagasawa 1998). The species is a significant seasonal predator of returning salmon in some areas (e.g. Prince William Sound), but the species is broadly dispersed across the North Pacific Ocean and likely does not have an overall significant impact on prey species. Salmon shark are endothermic, which enables them to have a broad thermal tolerance range and inhabit highly varying environments. Because of this ability, they can adapt to changing climate conditions and prey availability. Salmon shark generally mate in the fall and give birth the following spring. Much of the salmon shark catch in the BSAI occurs in the summer months after spawning.

Spiny dogfish

Previous studies have shown spiny dogfish to be opportunistic feeders that are not wholly dependent on one food source (Alverson and Stansby 1963). Small dogfish are limited to consuming smaller fish and

invertebrates, while the larger animals will eat a wide variety of foods (Bonham 1954). In the GOA, preliminary diet studies further suggest that spiny dogfish are highly generalized, opportunistic feeders (Tribuzio, unpublished data). Thus, fluctuations in the environmental conditions and prey availability likely have little effect on the species because of its ability to switch prey, although this also depends on the overall abundance of the prey species. The primary predator on spiny dogfish are other sharks, but data suggest other potential predators could be orcas, lingcod and halibut (Tribuzio, unpublished data). It is not well known if fishing activity occurs when and where sharks spawn. Spiny dogfish have an 18 – 24 month gestation, therefore, fishing activity overlaps with reproduction, regardless of when it occurs.

Fishery Effects on Ecosystem

Because there has been virtually no directed fishing for sharks in Alaska, the reader is referred to the discussion on Fishery Effects in the SAFE reports for the species that generally have the greatest shark catches, Pacific cod and walleye pollock. It is assumed that all sharks presently caught in commercial fishing operations that are discarded do not survive. This could constitute a source of dead organic material to the ecosystem that would not otherwise be there, but also the removal of a top predator. Removing sharks can have the effect of releasing competitive pressure or predatory pressures on prey species. Studies have shown that removal of top predators may alter community structure in complex and non-intuitive ways, and that indirect demographic effects on lower trophic levels may occur (Ruttenberg et al. 2011).

Data Gaps and Research Priorities

Data limitations are severe for shark species in the BSAI, making effective management of sharks extremely difficult. Gaps include inadequate catch estimation, unreliable biomass estimates, lack of fishery size frequency collections, and a lack of life history information including age and maturity, especially for Pacific sleeper sharks. It is essential to continue to improve the collection of biological data on sharks in the fisheries and surveys. Future shark research priorities will focus on the following areas:

1. Examine catchability for sharks on trawl surveys.
    a. Actions: Investigating methods of using tagging data to estimate q for sharks.
2. Define the stock structure and migration patterns (i.e. tagging studies, genetics)
    a. Actions: Continued tagging of spiny dogfish with pop-off satellite archival tags; investigating population genetics of Pacific sleeper shark.
3. Determine or clarify existing estimates of life history parameters for use in models
    a. Actions: NPRB funded study underway to examine improved aging methods for spiny dogfish and to examine methods to age Pacific sleeper sharks.

Summary

The OFL catch limits of the shark complex have not been exceeded, thus overfishing is not occurring. There are currently no directed commercial fisheries for shark species in federally or state managed waters of the BSAI, and most incidentally captured sharks are not retained. Incidental catches of shark species in the BSAI fisheries have been very small compared to catches of target species. The recommendations are for the whole complex, but the ABC/OFL by species are shown for informational purposes as well.

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2016
Tier	6	6	6	6
OFL (t)	1,363	1,363	**605**	605
maxABC (t)	1,022	1,022	454	454
ABC (t)	1,022	1,022	**454**	454
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	No	n/a	No	n/a

	Spiny Dogfish	Pacific Sleeper Shark	Salmon Shark	Other/unid Shark	Total Shark Complex
Tier	6	6	6	6	6
M	0.097	unk	0.18	unk	NA
Avg catch (t) (1997-2007)	8	422	48	126	605
ABC (t)	6	317	36	95	**454**
OFL (t)	8	422	48	126	**605**

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Table 20.1. Biological characteristics and depth ranges for shark species in the eastern Bering Sea and Aleutian Islands (BSAI). Missing information is denoted by "?".

Scientific Name	Common Name	Max. Obs. Length (TL, cm)	Max. Obs. Age	Age, Length, 50% Maturity	Feeding Mode	Fecundity	Depth Range (m)
Apristurus brunneus	brown cat shark	68[1]	?	?	Benthic[3]	?	1,306[2]
Carcharodon carcharias	White shark	792[4]	36[7]	15 yrs, 5 m[7]	Predator[6]	7-14[5]	1,280[3]
Cetorhinus maximus	basking shark	1,520[1]	?	5 yrs, 5m[8]	Plankton[6]	?	?
Hexanchus griseus	sixgill shark	482[9]	?	4m[1]	Predator[6]	22-108[1]	2,500[10]
Lamna ditropis	salmon shark	305[1]	20[11]	6-9 yrs, 165 cm PCL[11]	Predator[6]	3-5[7]	668[12]
Prionace glauca	blue shark	400[16]	15[13]	5 yrs[5], 221 cm[14]	Predator[6]	15-30 (up to 130)[15]	150[16]
Somniosus pacificus	Pacific sleeper shark	700[1]	?	?	Benth/Scav[17]	Up to 300[1]	2,700[18]
Squalus suckleyi	Spiny dogfish	125[19]	80-100[19]	34 yrs, 80 cm[19]	Pred/Scav/Bent[19]	7-14[19]	300[3]

[1]Compagno, 1984; [2]Eschmeyer et al., 1983; [3]Mecklenburg et al. 2002; [4]Scott and Scott, 1988; [5]Smith et al. 1998; [6]Cortes, 1999; [7]Gilmore, 1993; [8]Mooney-Seus and Stone, 1997; [9]Castro, 1983; [10]Last and Stevens, 1994; [11]Goldman and Musick 2006, [12]Hulbert et al. 2005; [13]Stevens, 1975; [14] ICES 1997; [15] White et al. 2006; [16]Smith, 1997; [17]Yang and Page, 1999; [18]www.nurp.noaa.gov; [19]Tribuzio and Kruse 2012.

Table 20.2. Time series of Other Species TAC, Other Species and shark catch, and ABC for sharks and the shark species complex (management method) for 1997 - 2012.

Year	TAC	Est. other spp. catch	Est. shark catch	ABC	Management Method
1997	25,800	25,176	368	N/A	Other Species TAC
1998	28,800	25,531	497	N/A	Other Species TAC
1999	32,860	20,562	530	N/A	Other Species TAC
2000	31,360	26,108	590	N/A	Other Species TAC
2001	26,500	27,178	764	N/A	Other Species TAC
2002	30,825	26,296	1,362	N/A	Other Species TAC
2003	32,309	27,010	520	N/A	Other Species TAC
2004	27,205	30,492	515	N/A	Other Species TAC
2005	29,000	30,761	417	N/A	Other Species TAC
2006	29,000	28,525	689	N/A	Other Species TAC
2007	37,355	27,837	331	463	Other Species TAC
2008	50,000	31,172	185	463	Other Species TAC
2009	50,000	28,352	144	447	Other Species TAC
2010	50,000	23,362	53	449	Other Species TAC
2011	50		105	1,020	Shark Complex TAC
2012	200		96	1,020	Shark Complex TAC
2013	100		116	1,020	Shark Complex TAC
2014	125		118	1,022	Shark Complex TAC

Data Sources: TAC, ABC and management category came from AKRO catch statistics website. Catch data was queried from AKFIN on Nov 20, 2014.

Table 20.3. Estimated discard rates of sharks (by species) in the BSAI. Source: AKFIN database, Oct 1, 2014. Blanks are where there was no catch reported.

Year	Spiny dogfish	Pacific sleeper shark	Salmon shark	Other/Unidentified shark
	Aleutian Islands			
1999				
2000		100%	100%	
2001				
2002	100%	100%		
2003	100%	99%	40%	0%
2004	100%	100%		100%
2005	100%	100%	100%	
2006	100%	100%	100%	
2007	99%	100%	100%	
2008	100%	100%		
2009	100%	100%	100%	100%
2010	100%	100%	100%	
2011	100%	100%	100%	
2012	100%	100%	100%	
2013	100%	100%	100%	
2014	100%	100%	100%	
Average	100%	100%	95%	67%
	Bering Sea			
1999	60%	98%	99%	100%
2000	96%	95%	97%	100%
2001	100%	96%	84%	100%
2002	96%	86%	91%	97%
2003	83%	78%	98%	87%
2004	98%	98%	94%	97%
2005	99%	96%	97%	74%
2006	98%	95%	98%	97%
2007	98%	93%	99%	47%
2008	100%	94%	97%	47%
2009	99%	96%	100%	63%
2010	100%	95%	99%	60%
2011	100%	92%	96%	76%
2012	100%	95%	97%	90%
2013	100%	96%	100%	86%
2014	100%	97%	98%	95%
Average	95%	94%	96%	82%

Table 20.4. Estimated incidental catch (t) of sharks in the eastern Bering Sea and Aleutian Islands (BSAI) by species as of October 1, 2014. 1997 – 2002 from the NMFS pseudo-blend catch estimation procedure (Gaichas 2001, 2002), 2003 – 2014 from NMFS AKRO blend-estimated annual catches.

Year	Spiny dogfish	Pacific sleeper shark	Salmon shark	Other/ Unidentified shark	Total sharks	Total other species	Shark % of other species
1997	4	304	7	53	368	25,176	1%
1998	6	336	18	136	496	25,531	2%
1999	5	319	30	176	530	20,562	3%
2000	9	490	23	68	590	26,108	2%
2001	17	687	24	35	763	27,178	3%
2002	9	839	47	468	1363	26,296	5%
2003	13	343	199	34	589	25,559	2%
2004	9	420	26	60	515	29,363	2%
2005	11	333	47	26	417	29,482	1%
2006	7	313	63	305	689	27,021	3%
2007	3	257	44	28	332	26,829	1%
2008	17	127	41	8	194	29,439	1%
2009	20	51	71	10	151	27,852	1%
2010	15	28	12	6	60	23,362	0%
2011	8	48	47	5	107		
2012	20	47	26	3	96		
2013	24	69	23	1	116		
2014	10	54	52	2	118		
species % of total sharks	3%	68%	11%	19%			
Species avg. catch	11	282	48	17			
For ABC/OFL Calculations							
Avg. 1997 – 2007	8	422	48	126	605		
Max. 1997 – 2007	17	839	199	468	1,363		

Table 20.5. Estimated catches (t) of Pacific sleeper sharks in the eastern Bering Sea and Aleutian Islands (BSAI) by target fishery. Years 1997 - 2002 from the pseudo-blend catch estimation procedure (Gaichas 2002), 2004 - 2014 are from NMFS AKRO blend-estimated annual catches, as of Nov 20, 2014. Estimated catch of Pacific sleeper shark by target fishery are not available for 2002 because the Gaichas (2002) catch estimates ended in 2001 and CAS did not begin until 2003.

Year	Atka Mackerel	Flatfish	Pacific Cod	Walleye Pollock	Rockfish	Sablefish	Turbot	Halibut	Total
1997	0.1	0.9	74.8	105.2	0.9	45.3	77	0	304.2
1998	0	0.9	146.7	74.4	0	0	113.5	0	335.5
1999	2.4	39.4	103.3	76.8	3	15.1	78.2	0	318.2
2000	0.3	42	114.7	103.8	2.7	143.7	83.2	0	490.4
2001	27.8	179.6	252.7	205.7	0	1.8	19.3	0	686.9
2002									
2003	0.7	35.7	172.6	85.0	0.5	19.8	9.7	18.6	342.5
2004	2.0	37.3	230.0	144.0	0.7	2.3	2.7	1.1	420.2
2005	0.0	7.7	191.0	127.6	0.1	3.8	2.7	0.1	333.0
2006	0.0	9.5	123.1	178.1	0.1	1.0	1.3	0.1	313.2
2007	1.1	9.1	44.3	181.6	14.5	2.5	0.5	0.0	253.6
2008	0.1	6.3	20.0	97.9	1.2	1.3	0.4	0.0	127.2
2009	0.6	8.2	14.4	24.6	0.6	2.1	0.1	0.0	50.6
2010	0.0	1.2	15.1	10.4	0.1	1.2	0.2	0.0	28.2
2011	0.0	2.4	20.4	18.1	4.8	1.7	0.0	0.5	47.9
2012	0.9	8.2	9.8	27.5	0.6	0.2	0.1	0.0	47.3
2013	0.0	1.2	19.8	21.1	1.6	0.8	0.0	24.1	68.6
2014	0.0	1.1	28.0	23.5	0.8	0.0	0.0	0.5	53.8
Avg. Catch	2.1	23.0	93.0	88.6	1.9	14.3	22.9	2.7	
Avg. % of Total	1%	9%	37%	36%	1%	6%	9%	1%	
Avg. % 2013-2014	0%	2%	39%	36%	2%	1%	0%	20%	

Table 20.6. Estimated catches (t) of salmon sharks in the eastern Bering Sea and Aleutian Islands (BSAI) by target fishery. Years 1997 - 2002 from the pseudo-blend catch estimation procedure (Gaichas 2002), 2003 - 2014 are from NMFS AKRO blend-estimated annual catches, as of Nov 20, 2014. Estimated catch of salmon sharks by target fishery are not available for 2002 because the Gaichas (2002) catch estimates ended in 2001 and CAS did not begin until 2003.

Year	Atka Mackerel	Flatfish	Pacific Cod	Walleye Pollock	Rockfish	Sablefish	Turbot	Halibut	Total
1997	0.1	0	0	6.7	0	0	0		6.8
1998	0	0.1	0.8	16.2	0	0	0.8		17.9
1999	0.2	2.5	1.2	24.7	0	0	1.5		30.1
2000	0	0	3.8	19.5	0	0	0		23.3
2001	0.4	0.4	1.2	22.5	0	0	0		24.5
2002									
2003	0.2	0.5	1.2	197.4	0	0	0	0	199.3
2004	0.0	0.1	0.1	25.5	0	0	0	0	25.6
2005	18.2	0.6	2.0	25.7	0	0	0	0	46.6
2006	0.2	25.9	1.2	36.2	0	0	0	0	63.4
2007	0.1	0.0	0.0	44.1	0	0	0	0	44.2
2008	0.0	0.3	0.0	40.7	0	0	0	0	40.9
2009	0.3	0.1	0.1	70.0	0	0	0	0	70.5
2010	0.1	0.0	0.0	11.1	0	0	0	0	11.2
2011	0.2	0.4	0.1	45.3	0	0	0	0	46.0
2012	0.3	0.0	0.0	25.4	0	0	0	0	25.7
2013	0.3	0.1	0.2	21.3	0	0	0	0	21.9
2014	0.6	0.1	0.0	51.0	0	0	0	0	51.7
Avg. Catch	1.2	1.8	0.7	40.2	0	0	0.1	0	
Avg. % of Total	3%	4%	2%	91%	0%	0%	0%	0%	
Avg. % 2013-2014	1%	0%	0%	98%	0%	0%	0%	0%	

Table 20.7. Estimated catches (t) of spiny dogfish in the eastern Bering Sea and Aleutian Islands (BSAI) by target fishery. Years 1997 - 2002 from the pseudo-blend catch estimation procedure (Gaichas 2002), 2003 - 2014 are from NMFS AKRO blend-estimated annual catches, as of Nov 20, 2014. Estimated catch of spiny dogfish by target fishery are not available for 2002 because the Gaichas (2002) catch estimates ended in 2001 and CAS did not begin until 2003.

Year	Atka Mackerel	Flatfish	Pacific Cod	Walleye Pollock	Rockfish	Sablefish	Turbot	Halibut	Total
1997	0	0	4.1	0	0	0	0		4.1
1998	0.2	0.4	5.6	0.1	0	0	0		6.3
1999	0	0	4.9	0	0	0	0		4.9
2000	0	0.2	8.6	0	0	0	0		8.8
2001	2.8	1.6	12.7	0.1	0	0.1	0		17.3
2002									
2003	0.1	0.0	13.0	0.0	0.0	0.0	0.0	0.0	13.3
2004	0.0	0.2	8.3	0.0	0.0	0.1	0.0	0.0	8.6
2005	0.0	0.1	11.2	0.0	0.0	0.0	0.0	0.0	11.4
2006	0.0	0.1	6.6	0.2	0.0	0.2	0.0	0.0	7.1
2007	0.0	0.3	2.5	0.2	0.0	0.1	0.0	0.0	3.0
2008	0.1	0.2	10.2	0.2	0.1	0.0	0.0	6.2	17.1
2009	0.0	0.6	18.4	0.4	0.0	0.2	0.0	0.0	19.7
2010	0.0	0.7	13.8	0.3	0.0	0.0	0.0	0.0	14.9
2011	0.0	0.4	7.3	0.2	0.0	0.0	0.0	0.0	7.8
2012	0.1	0.0	19.6	0.1	0.3	0.0	0.0	0.0	20.1
2013	0.4	0.2	18.3	0.1	0.0	0.0	0.0	4.6	23.5
2014	0.0	0.8	6.8	0.1	0.0	0.0	0.0	2.4	10.1
Avg. Catch	0.2	0.3	10.0	0.1	0	0	0	1.1	
Avg. % of Total	2%	3%	87%	1%	0%	0%	0%	7%	
Avg. % 2013-2014	1%	3%	75%	0%	0%	0%	0%	21%	

Table 20.8. Estimated catches (t) of other and unidentified sharks in the eastern Bering Sea and Aleutian Islands (BSAI) by target fishery. Years 1997 - 2002 from the pseudo-blend catch estimation procedure (Gaichas 2002), 2003 - 2014 are from NMFS AKRO blend-estimated annual catches, as of Nov 20, 2014. Estimated catch of other and unidentified sharks by target fishery are not available for 2002 because the Gaichas (2002) catch estimates ended in 2001 and CAS did not begin until 2003.

Year	Atka Mackerel	Flatfish	Pacific Cod	Walleye Pollock	Rockfish	Sablefish	Turbot	Halibut	Total
1997	0	0.4	26.8	15.6	2.5	1.2	6.3		52.8
1998	13.1	0	48.4	45.4	0	2.1	26.9		135.9
1999	0	0.2	18.8	10.3	0	1.8	144.9		176
2000	0	1.2	56.1	0.1	0	7.2	3		67.6
2001	0	0	19.6	2.3	0	10.4	2.7		35
2002									
2003	0	0.0	20.8	11.9	0	0.1	1.3	0	34.1
2004	0	22.2	20.2	17.6	0	0.0	0.0	0	60.1
2005	0	0.0	10.1	16.0	0	0.0	0.0	0	26.2
2006	0	2.1	3.6	298.0	0	0.1	1.6	0	305.5
2007	0	5.9	2.1	19.8	0	0	0.0	0	27.8
2008	0	0.3	1.6	5.9	0	0	0.2	0	8.0
2009	0	0.0	4.5	5.5	0.2	0.0	0.0	0	10.2
2010	0	0.0	1.6	4.1	0	0	0.0	0	5.7
2011	0	0.0	2.6	2.0	0	0	0.0	0	4.6
2012	0	0.0	1.0	1.7	0	0	0.0	0	2.7
2013	0	0.0	0.8	0.4	0	0	0.0	0	1.1
2014	0	0.0	1.4	0.6	0	0	0.0	0	2.0
Avg. Catch	0.8	1.9	14.1	26.9	0.2	1.4	11.0	0	
Avg. % of Total	1%	3%	25%	48%	0%	2%	20%	0%	
Avg. % 2013-2014	0%	0%	70%	30%	0%	0%	0%	0%	

Table 20.9. Eastern Bering Sea slope AFSC trawl survey estimates of individual shark species total biomass (metric tons) with CV, and number of hauls (Jerry Hoff, pers. comm., October, 2012). There was no slope survey in 2014.

		Spiny Dogfish			Pacific sleeper Shark			Salmon Shark		
Year	Total Survey Hauls	Hauls w/catch	Biomass Est.	CV	Hauls w/catch	Biomass Est.	CV	Hauls w/catch	Biomass Est.	CV
1979	105	0			0			0		
1981	205	1	1	0.83	0			0		
1982	299	3	8	0.73	1	12	1.02	0		
1985	325	3	2	0.66	19	543	0.1	0		
1988	131	0			10	1,993	0.39	0		
1991	85	0			6	1,235	0.44	0		
Change in slope survey design										
2002	141	0			15	25,445	0.87	0		
2004	231	0			24	2,282	0.34	0		
2008	207	1	13	1	28	1,968	0.27	0		
2010	200	0			19	833	0.27	0		
2012	210	0			16	1,337	0.28	0		

Table 20.10. Aleutian Islands AFSC trawl survey estimates of individual shark species total biomass (metric tons) with CV, and number of hauls (Wayne Palsson, pers. comm., October 2014).

		Spiny Dogfish			Pacific sleeper Shark			Salmon Shark		
Year	Total Survey Hauls	Hauls w/catch	Biomass Est.	CV	Hauls w/catch	Biomass Est.	CV	Hauls w/catch	Biomass Est.	CV
1980	129	0			0			0		
1983	372	3	2	0.61	3	249	0.66	0		
1986	443	6	14	0.51	12	1,995	0.36	0		
1991	331	0			3	2,927	0.69	0		
1994	381	9	47	0.37	3	374	0.64	0		
1997	397	2	11	0.71	10	2,486	0.29	0		
2000	419	3	25	0.62	3	2,638	0.57	0		
2002	417	0			4	536	0.55	1	1,021	1.00
2004	420	0			2	1,017	0.96	0		
2006	358	6	62	0.49	1	76	1.00	0		
2010	418	0			1	74	1.00	0		
2012	420	0			1	22	1.00	0		
2014	410	2	23	0.72	0			0		

Table 20.11. Eastern Bering Sea shelf AFSC trawl survey estimates of individual shark species total biomass (metric tons) with CV and number of hauls (Bob Lauth, pers. comm., October, 2014).

		Spiny Dogfish			Pacific sleeper Shark			Salmon Shark		
Year	Total Survey Hauls	Hauls w/catch	Biomass Est.	CV	Hauls w/catch	Biomass Est.	CV	Hauls w/catch	Biomass Est.	CV
1979	452	4	389	0.56	0			0		
1980	342	0			0			0		
1981	290	0			0			0		
1982	329	0			0			0		
1983	354	2	403	0.78	0			0		
1984	355	0			0			0		
1985	353	1	47	1.00	0			0		
1986	354	0			0			0		
1987	342	3	216	0.60	0			0		
1988	353	1	246	1.00	0			1	3,808	1.0
1989	353	0			0			0		
1990	352	0			0			0		
1991	351	0			0			0		
1992	336	0			2	2,564	0.72	0		
1993	355	0			0			0		
1994	355	0			2	5,012	0.82	0		
1995	356	0			1	1,005	1.00	0		
1996	355	0			2	2,804	0.82	0		
1997	356	1	37	1.00	0			0		
1998	355	1	254	1.00	1	2,124	1.00	0		
1999	353	0			2	2,079	0.71	0		
2000	352	0			1	1,463	1.00	0		
2001	355	0			0			0		
2002	355	0			3	5,602	0.65	0		
2003	356	0			1	2,104	0.74	0		
2004	355	1	28	1.00	2	3,093	0.71	0		
2005	353	0			2	1,679	0.76	0		
2006	356	0			2	2,944	0.78	0		
2007	356	0			0			0		
2008	375	0			0			0		
2009	376	1	72	1.00	0			0		
2010	376	1	89	1.00	4	5,300	0.53	0		
2011	376	0			1	760	1.00	0		
2012	376	0			1	267	1.00	0		
2013	376	0			0			0		
2014	376	0			0			0		

Table 20.12. Research survey catch of sharks 1977 - 2012 in the Bering Sea/Aleutian Islands (BSAI). The AFSC LL and IPHC LL survey catches are provided in numbers prior to 2010. The total catch numbers from the IPHC survey are estimated based on the subsample of observed hooks, the estimated catch (t) is directly from the survey. Beginning in 2010 all research and other non-commercial catch is provided by the AKRO.

Year	Source	AFSC Trawl Surveys (t)	AFSC LL Survey (#s)	AFSC LL Survey (t)	IPHC LL Survey (#s)	IPHC LL Survey (t)	ADF&G (t) (includes sport and research)
1977	Assessment of the sharks in the Bering Sea and Aleutian Islands (Tribuzio et al. 2010a)	0					
1978							
1979		0.03	4	NA			
1980		0	4	NA			
1981		0.07	5	NA			
1982		0.16	15	NA			
1983		0.01	33	NA			
1984			40	NA			
1985		0.59	53	NA			
1986			52	NA			
1987		0.01	61	NA			
1988		1.06	30	NA			
1989		0.07	27	NA			
1990		0	4	NA			
1991		0.56	18	NA			
1992		0.09	55	NA			
1993			75	NA			
1994		0.17	111	NA			
1995		0.04	0	NA			
1996		0.1	3	NA			
1997		0.11	59	NA			
1998		0.09	1	NA	207	NA	
1999		0.08	20	NA	152	NA	
2000		8.5	2	NA	723	NA	
2001			12	NA	164	NA	
2002		5.74	1	NA	169	NA	
2003		0.03	22	NA	368	NA	
2004		0.76	3	NA	251	NA	
2005		0	6	NA	237	NA	
2006		0	3	NA	241	NA	
2007		0	34	NA	170	NA	
2008		0.47	8	NA	208	NA	
2009		2.02	2	NA	234	NA	
2010	AKRO	0.43	2	<0.01	NA	8.38	<0.01
2011		2.76	5	0.03	NA	1.50	0.03
2012		3	0	0	NA	1.62	0.12
2013							

Table 20.13. Life history parameters for spiny dogfish, Pacific sleeper, and salmon sharks. Top: Length-weight coefficients and average lengths and weights are provided for the formula $W=aL^b$, where W = weight in kilograms and L = PCL (precaudal length in cm). Bottom: Length at age coefficients from the von Bertalanffy growth model, where L_∞ is PCL or the TL_{ext} (total length with the upper lobe of the caudal fin depressed to align with the horizontal axis of the body).

Species	Area	Gear type	Sex	Average size PCL (cm)	Average weight (kg)	A	b	Sample size
Spiny dogfish	GOA	NMFS bottom trawl surveys	M	63.4	2	1.40E-05	2.86	92
Spiny dogfish	GOA	NMFS bottom trawl surveys	F	63.8	2.29	8.03E-06	3.02	140
Spiny dogfish	GOA	Longline surveys	M	64.6	1.99	9.85E-06	2.93	156
Spiny dogfish	GOA	Longline surveys	F	64.7	2.2	3.52E-06	3.2	188
Pacific sleeper shark	Central GOA	Longline surveys	M	166	69.7	2.18E-05	2.93	NA
Pacific sleeper shark	Central GOA	Longline surveys	F	170	74.8	2.18E-05	2.93	NA
Salmon shark	Central GOA	NA	M	171.9	116.7	3.20E-06	3.383	NA
Salmon shark	Central GOA	NA	F	184.7	146.9	8.20E-05	2.759	NA

Species	Sex	L_∞ (cm)	κ	t_0 (years)	M	Max Age	Age at first Recruit
Spiny Dogfish	M	93.7 (TL_{ext})	0.06	-5.1	0.097	80-100	NA
Spiny Dogfish	F	132.0 (TL_{ext})	0.03	-6.4			
Pacific Sleeper Shark	M	NA	NA	NA	NA	NA	NA
Pacific Sleeper Shark	F	NA	NA	NA			
Salmon Shark	M	182.8 (PCL)	0.23	-2.3	0.18	30	5
Salmon Shark	F	207.4 (PCL)	0.17	-1.9			

Sources: NMFS GOA bottom trawl surveys in 2005; Wood et al. (1979); Goldman (2002); Sigler et al (2006); Goldman and Musick (2006); and Tribuzio and Kruse (2012).

Table 20.14. Analysis of ecosystem considerations for the shark complex.

Ecosystem effects on *GOA Sharks*			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys, changes mean wt-at-age	Stable, data limited	Unknown
Non-pandalid shrimp and other benthic organism	Trends are not currently measured directly, only short time series of food habits data exist for potential retrospective measurement	Composes the main portion of spiny dogfish diet	Unknown
Sandlance, capelin, other forage fish	Trends are not currently measured directly, only short time series of food habits data exist for potential retrospective measurement	Unknown	Unknown
Salmon	Populations are stable or slightly decreasing in some areas	Small portion of spiny dogfish diet, maybe a large portion of salmon shark diet	No concern
Flatfish	Increasing to steady populations currently at high biomass levels	Adequate forage available	No concern
Walleye pollock	High population levels in early 1980's, declined to stable low level at present	Primarily a component of salmon shark diets	No concern
Other Groundfish	Stable to low populations	Varied in diets of sharks	No concern
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	Not likely a predator on sharks	No concern
Birds	Stable, some increasing some decreasing	Affects young-of-year mortality	No concern
Fish (walleye pollock, Pacific cod, halibut)	Stable to increasing	Possible increases to juvenile spiny dogfish mortality	
Sharks	Stable to increasing	Larger species may prey on spiny dogfish	Currently, no concern
Changes in habitat quality			
Temperature regime	Warm and cold regimes	May shift distribution, species tolerate wide range of temps	No concern
Benthic ranging from inshore waters to shelf break and down slope	Sharks can be highly mobile, and benthic habitats have not been monitored historically, species may be able to move to preferred habitat, no critical habitat defined for GOA	Habitat changes may shift distribution	No concern
***GOA Sharks* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Not Targeted	None	No concern	No concern
Fishery concentration in space and time	None	No concern	No concern
Fishery effects on amount of large size target fish	If targeted, could reduce avg size of females, reduce recruitment, reduce fecundity, skewed sex ratio (observed in areas targeting species)	No concern at this time	No concern at this time
Fishery contribution to discards and offal production	None	No concern	No concern
Fishery effects on age-at-maturity and fecundity	Age at maturity and fecundity decrease in areas that have targeted species	No concern at this time	No concern at this time

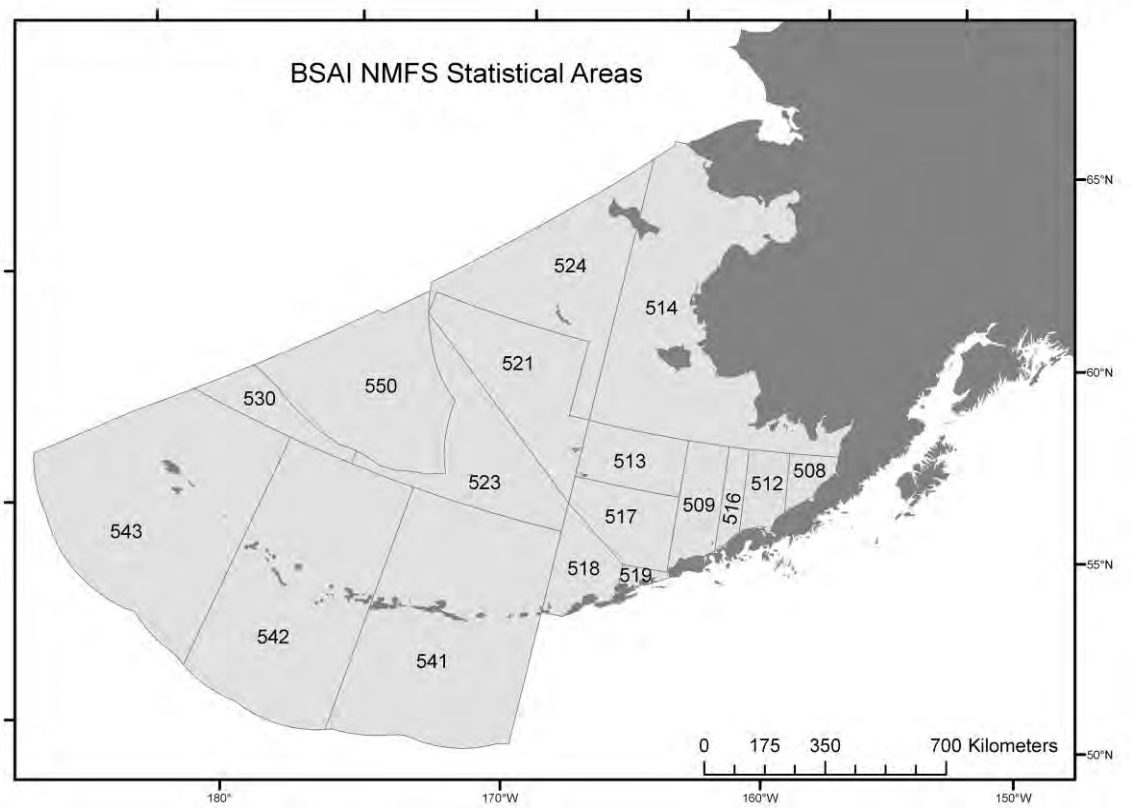

Figure 20.1. NMFS statistical areas in the Bering Sea (NMFS Areas 508-530) and Aleutian Islands (NMFS Areas 541-542).

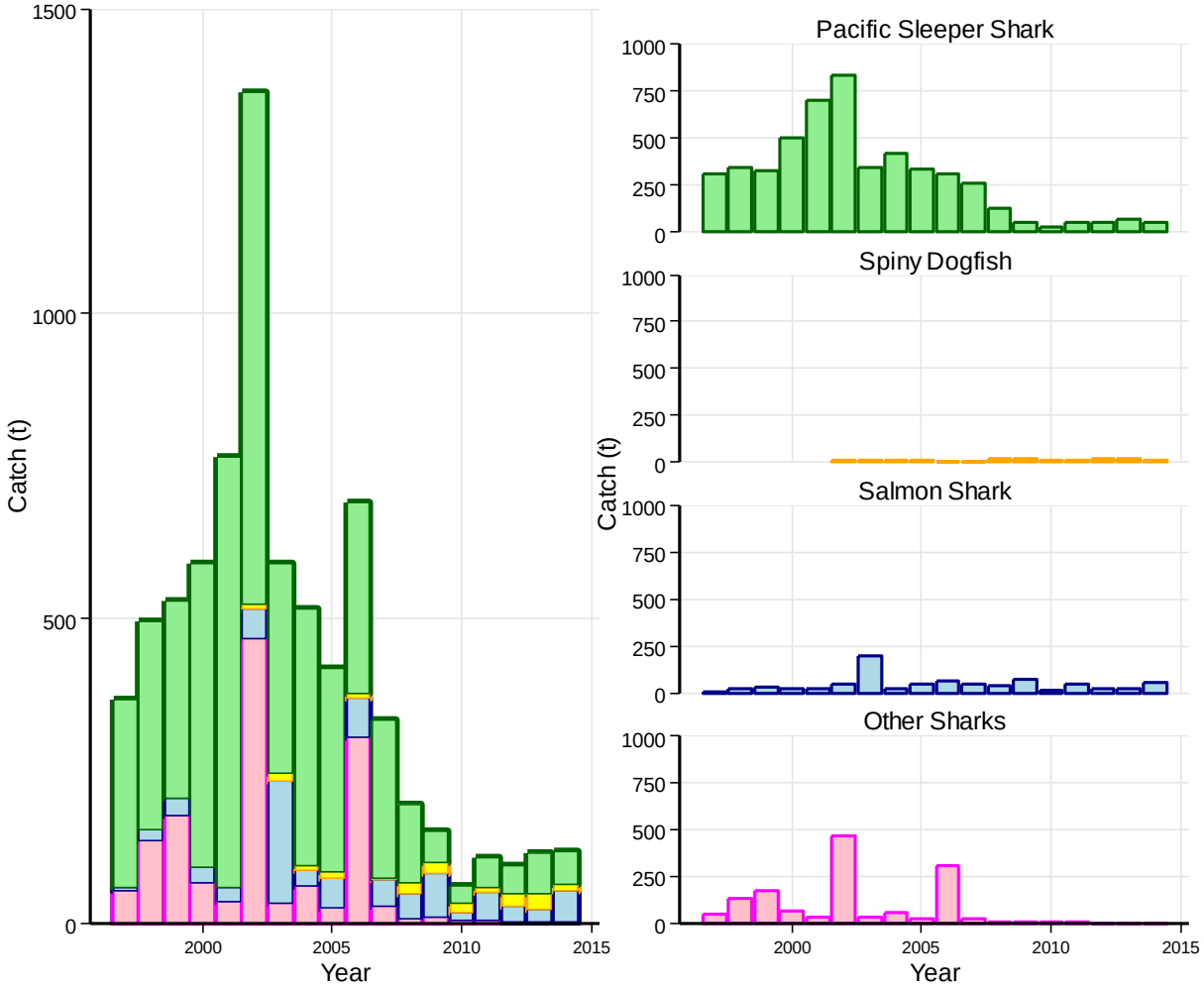

Figure 20.2. Estimated incidental catch (t) of sharks in the eastern Bering Sea and Aleutian Islands (BSAI) by species as of October 1, 2014. 1997 – 2002 from the NMFS pseudo-blend catch estimation procedure (Gaichas 2001, 2002), 2003 – 2014 from NMFS AKRO blend-estimated annual catches.

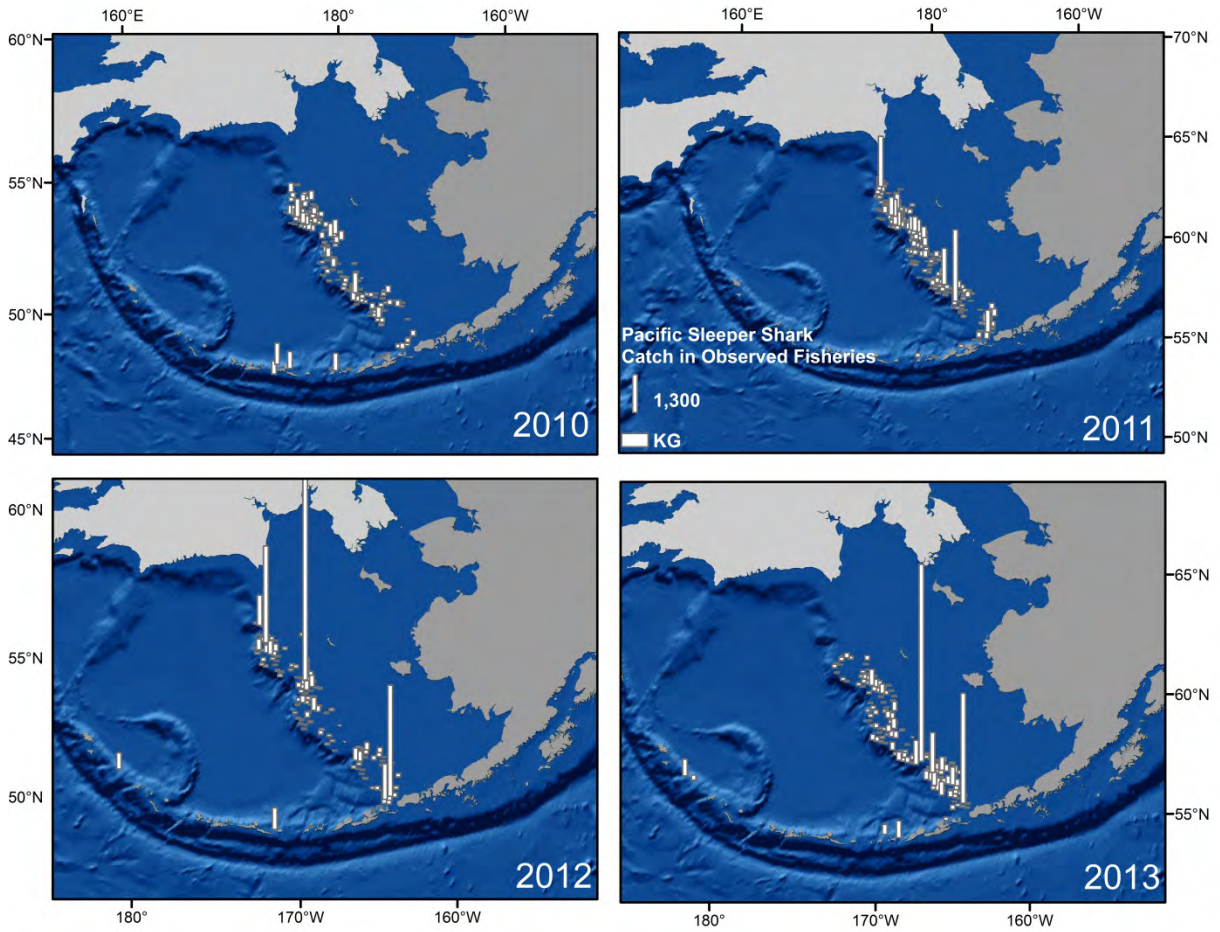

Figure 20.3. Spatial distribution of observed Pacific sleeper shark catch in the BSAI from 2010 - 2013. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400km^2 grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 2, 2014 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

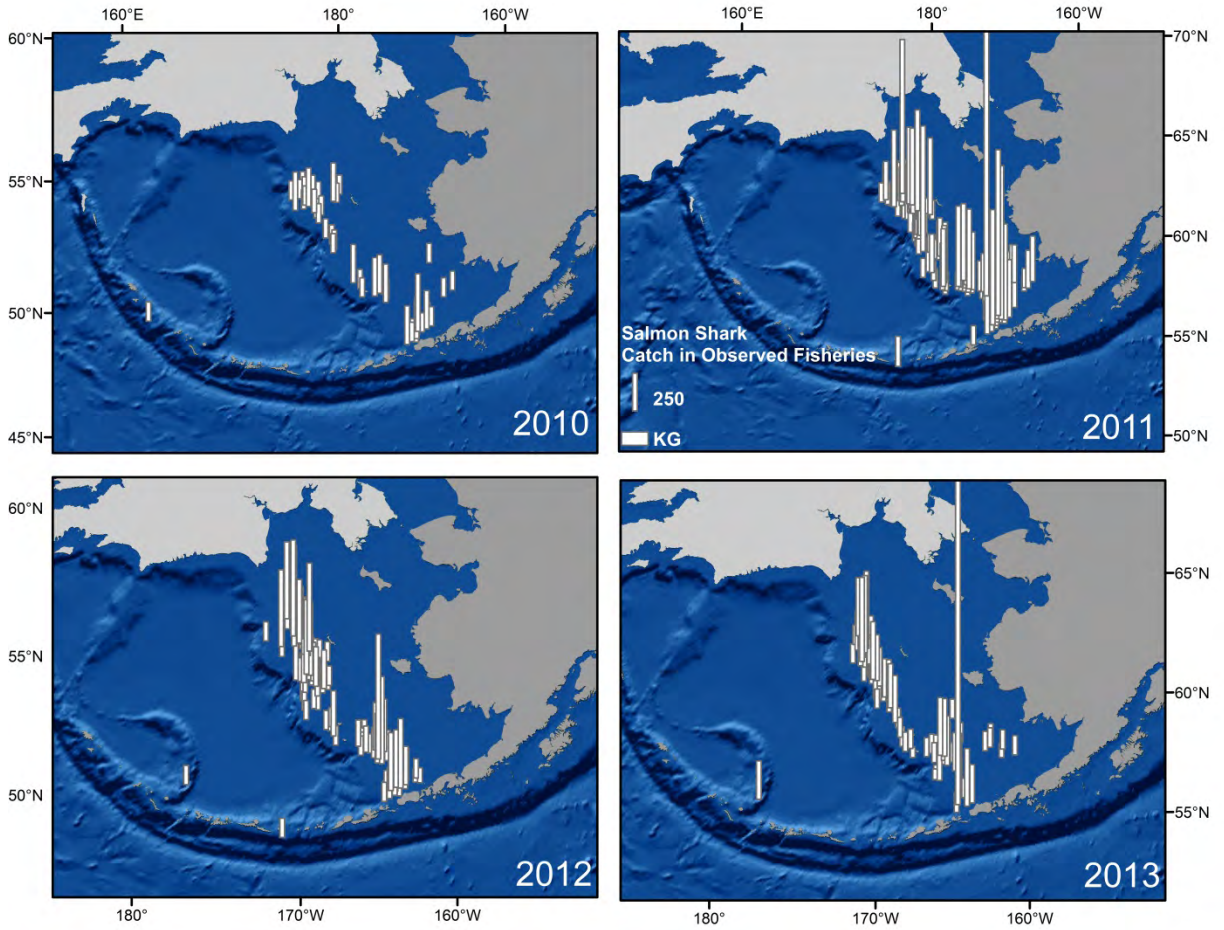

Figure 20.4. Spatial distribution of salmon shark catch in the BSAI from 2010 - 2013. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400km^2 grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 2, 2014 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

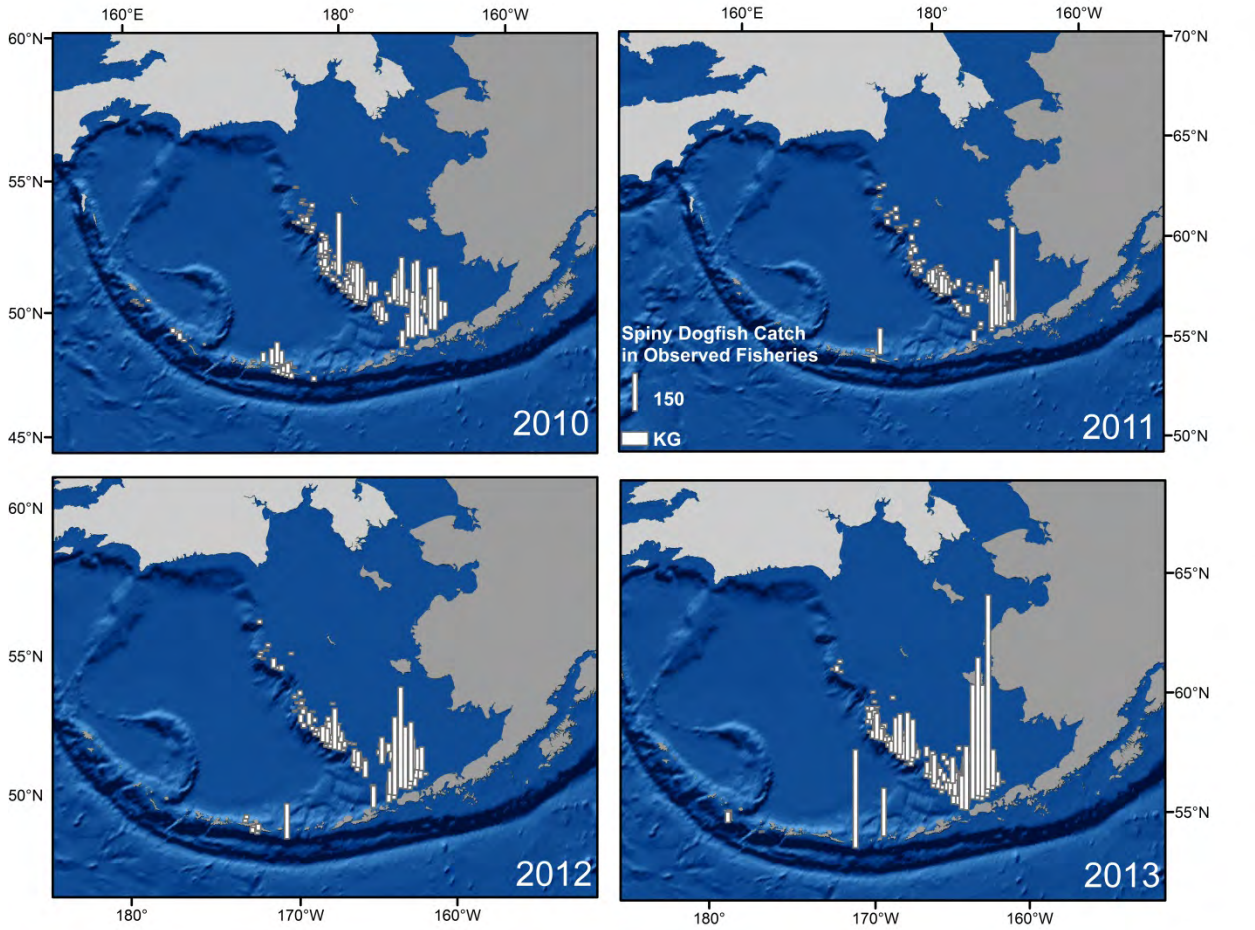

Figure 20.5. Spatial distribution of observed spiny dogfish catch in the BSAI from 2010 - 2013. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400km^2 grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 2, 2014 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

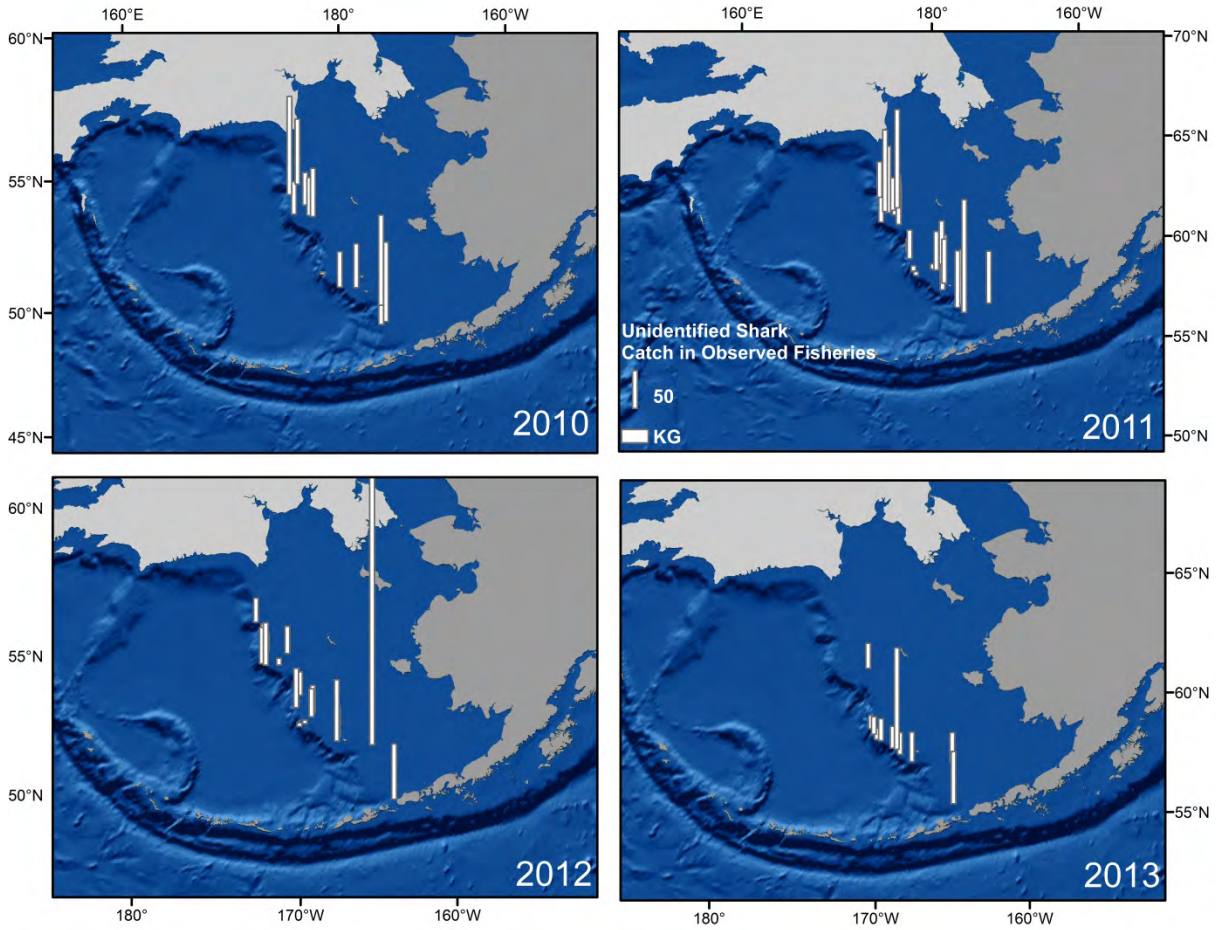

Figure 20.6. Spatial distribution of observed unidentified shark catch in the BSAI from 2010 - 2013. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400km^2 grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 2, 2014 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

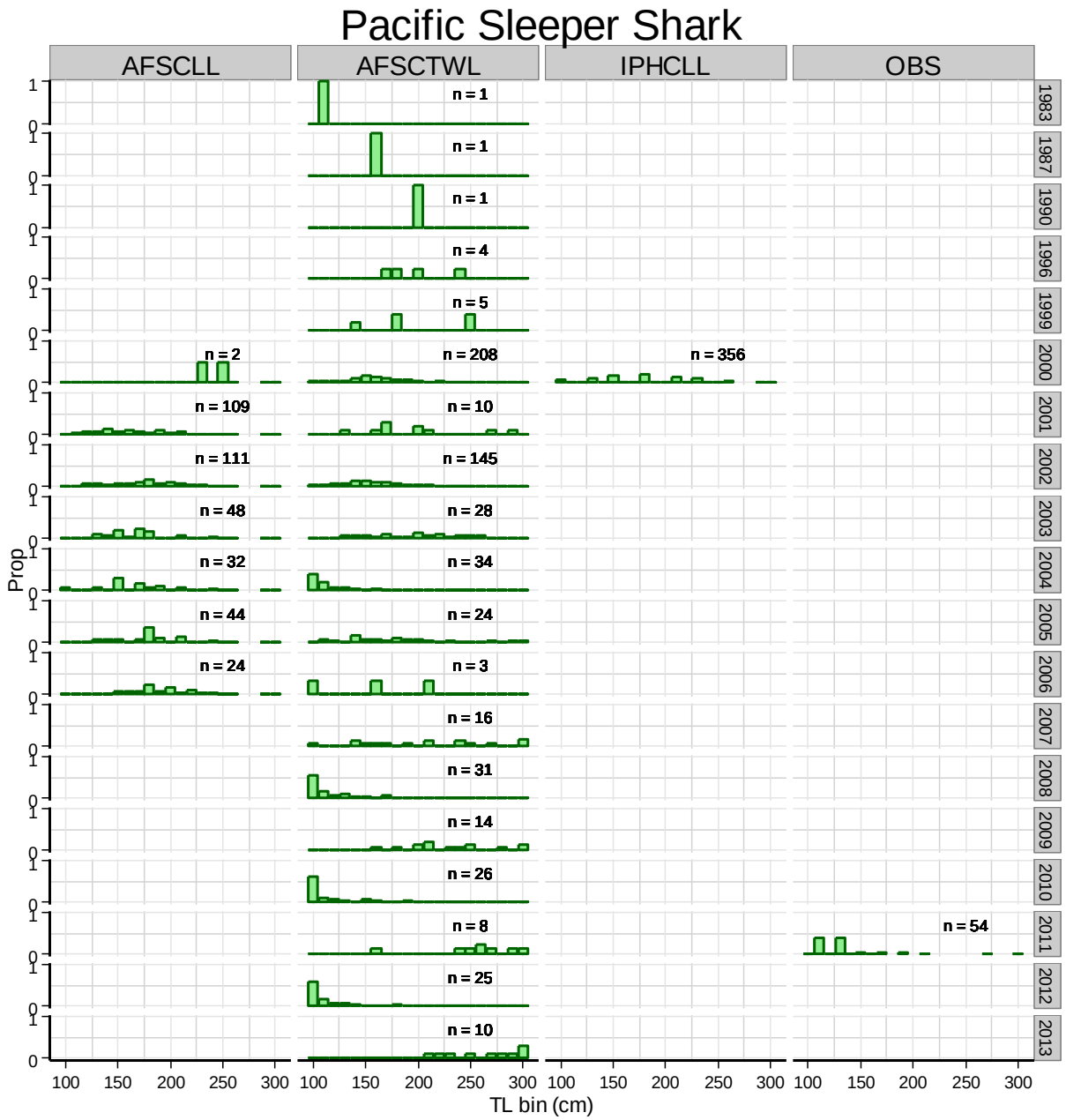

Figure 20.7. Observed length frequencies and sample sizes for Pacific sleeper shark. Data are limited, so sexes are combined as well as GOA and BSAI data. The AFSC longline survey data (AFSCLL) are from a number of targeted research surveys, AFSC trawl survey data (AFSCTWL) are from AFSC GOA, EBS shelf and slope, and AI trawl surveys, and the IPHC longline survey lengths (IPHCLL) are from a special project conducted in 2000. The OBS data are from a special project conducted by the Observer Program in 2011.

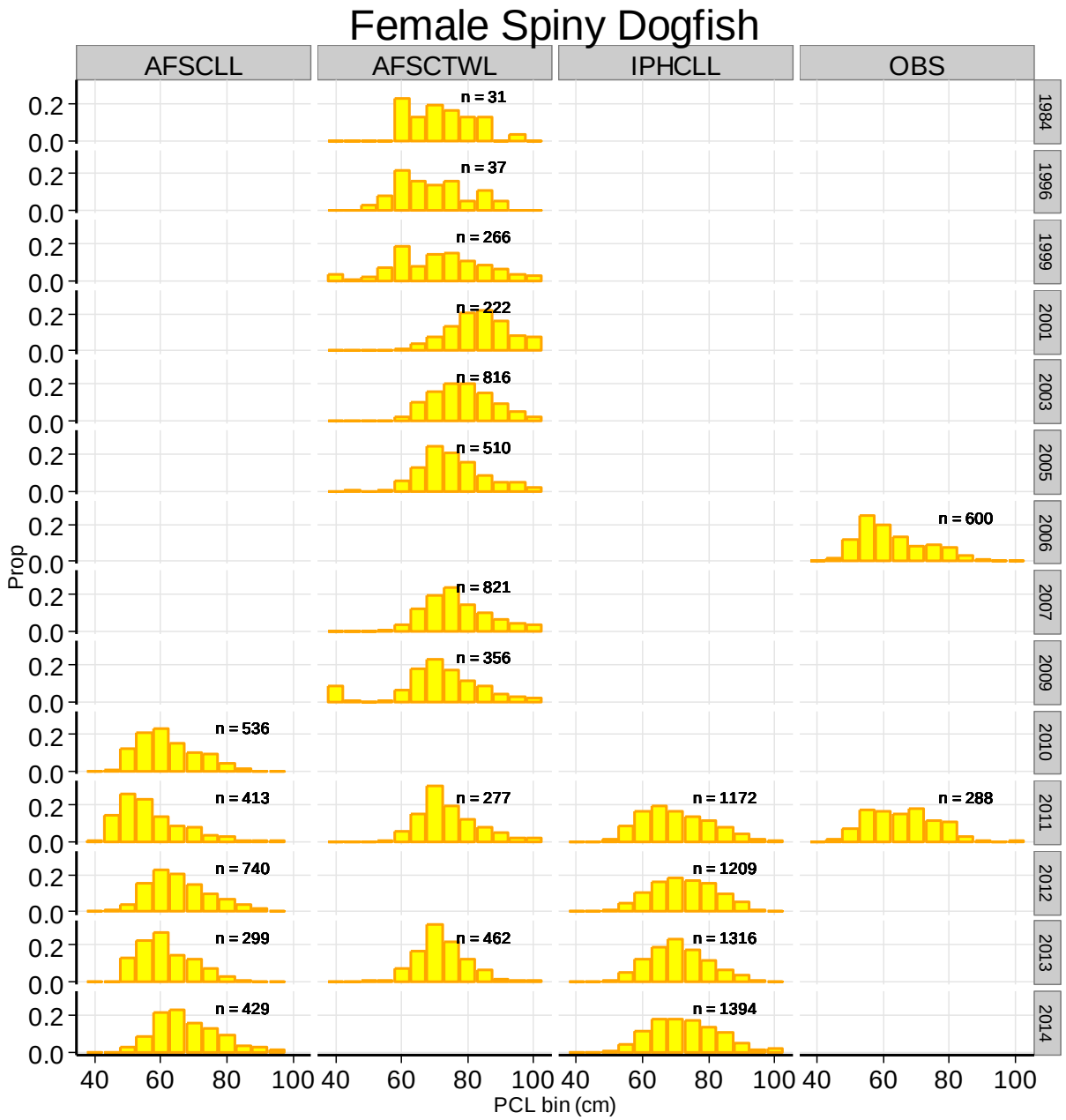

Figure 20.8. Observed length frequencies and sample sizes for female spiny dogfish. Data for spiny dogfish is rare in the BSAI, thus GOA data are presented here. The AFSC longline survey data (AFSCLL) and IPHC longline survey data (IPHCLL) are from the annual surveys operated by the AFSC and the IPHC. The AFSC trawl survey data (AFSCTWL) are from the biennial trawl survey. The Observer program data (OBS) are from a special project conducted by the Observer Program in 2006 and 2011.

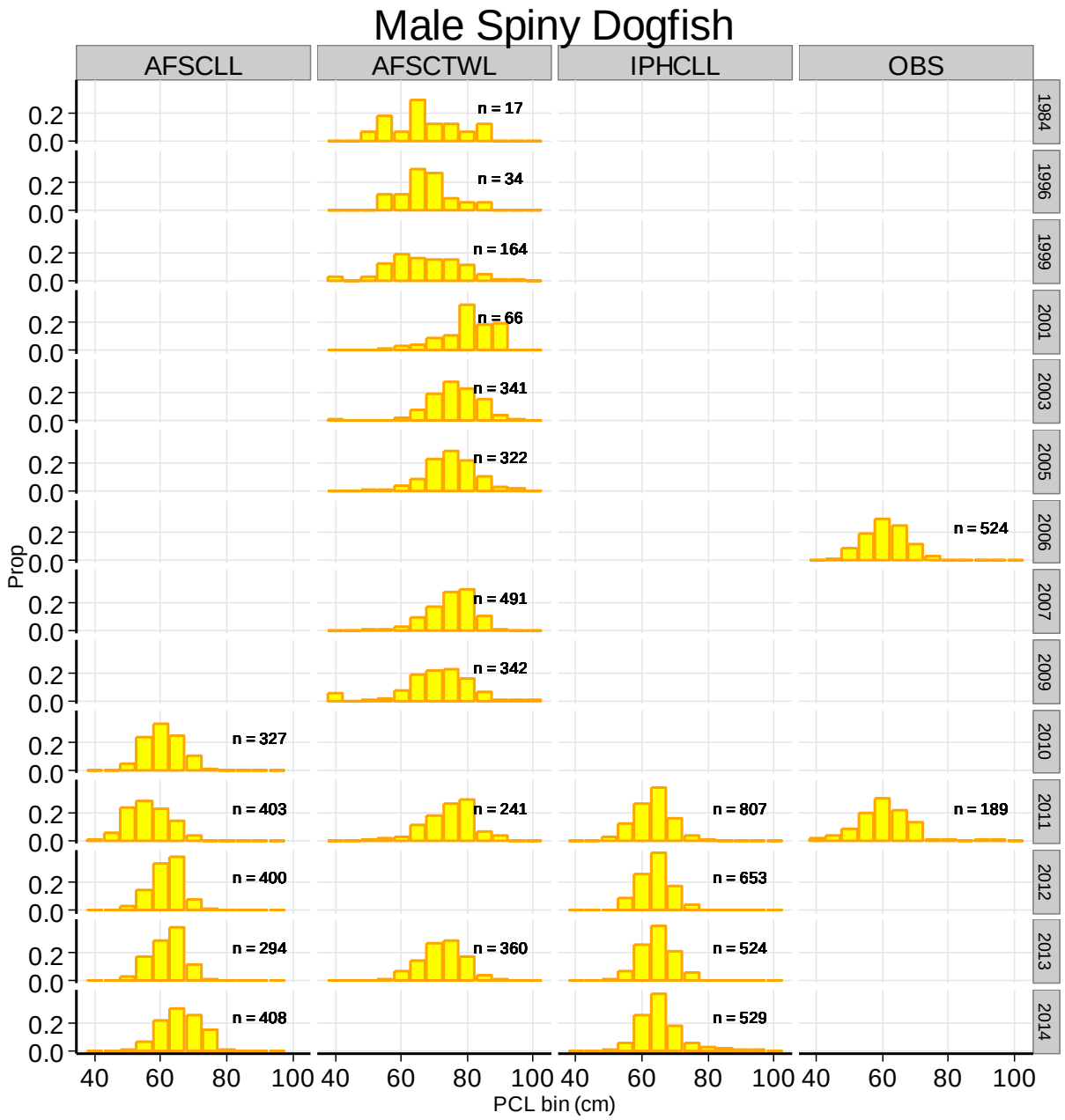

Figure 20.9. Observed length frequencies and sample sizes for male spiny dogfish. Data for spiny dogfish is rare in the BSAI, thus GOA data are presented here. The AFSC longline survey data (AFSCLL) and IPHC longline survey data (IPHCLL) are from the annual surveys operated by the AFSC and the IPHC. The AFSC trawl survey data (AFSCTWL) are from the biennial trawl survey. The Observer program data (OBS) are from a special project conducted by the Observer Program in 2006 and 2011.

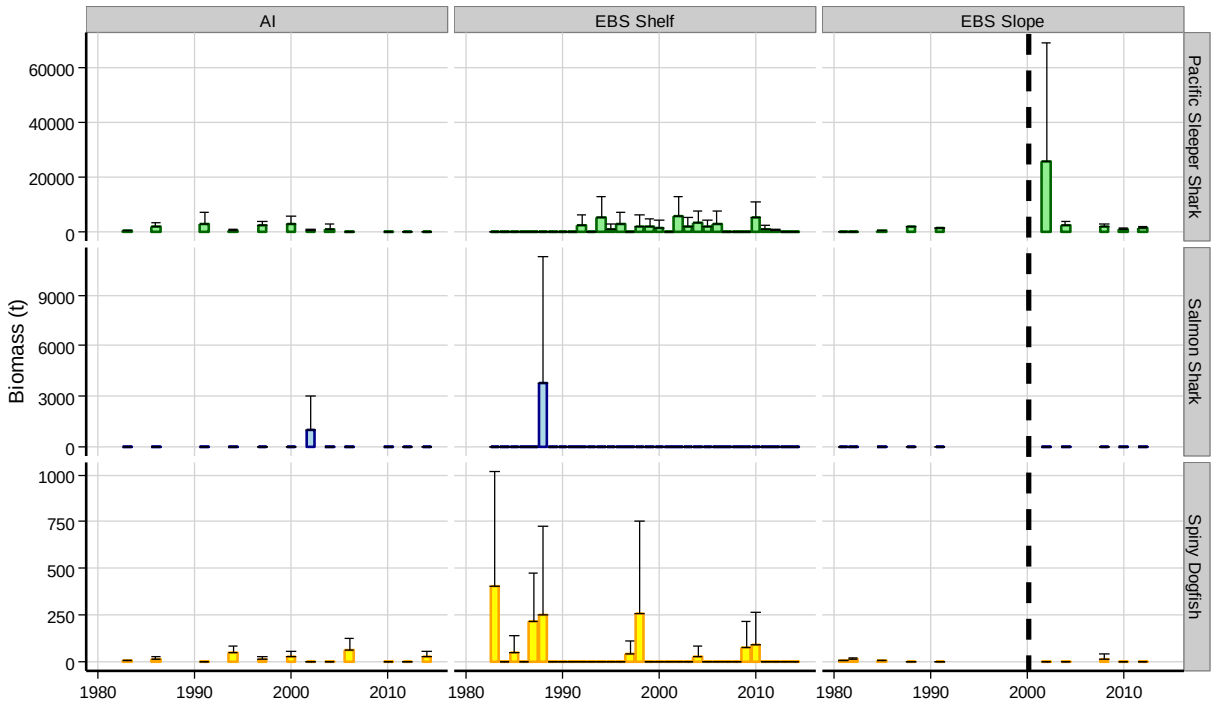

Figure 20.10. Time series of biomass estimates (t) of sharks in the AFSC eastern Bering Sea (EBS) slope, shelf, and Aleutian Islands (AI) bottom trawl surveys. Biomass values are reported here as an index of relative abundance. Error bars are 95% confidence intervals. Analysis of EBS slope survey biomass trends is subject the following time series caveats: the slope survey was standardized in 2002 to its current gear type, survey strata, and survey design; biomass estimates are not comparable between the historical EBS slope survey (1979 – 1991) and the new slope survey biomass (2002 - present) due to differences in stratification; and prior to 2002, the survey utilized a mix of commercial and research vessels with various gear configurations. The break in the time series is signified by the dashed line.

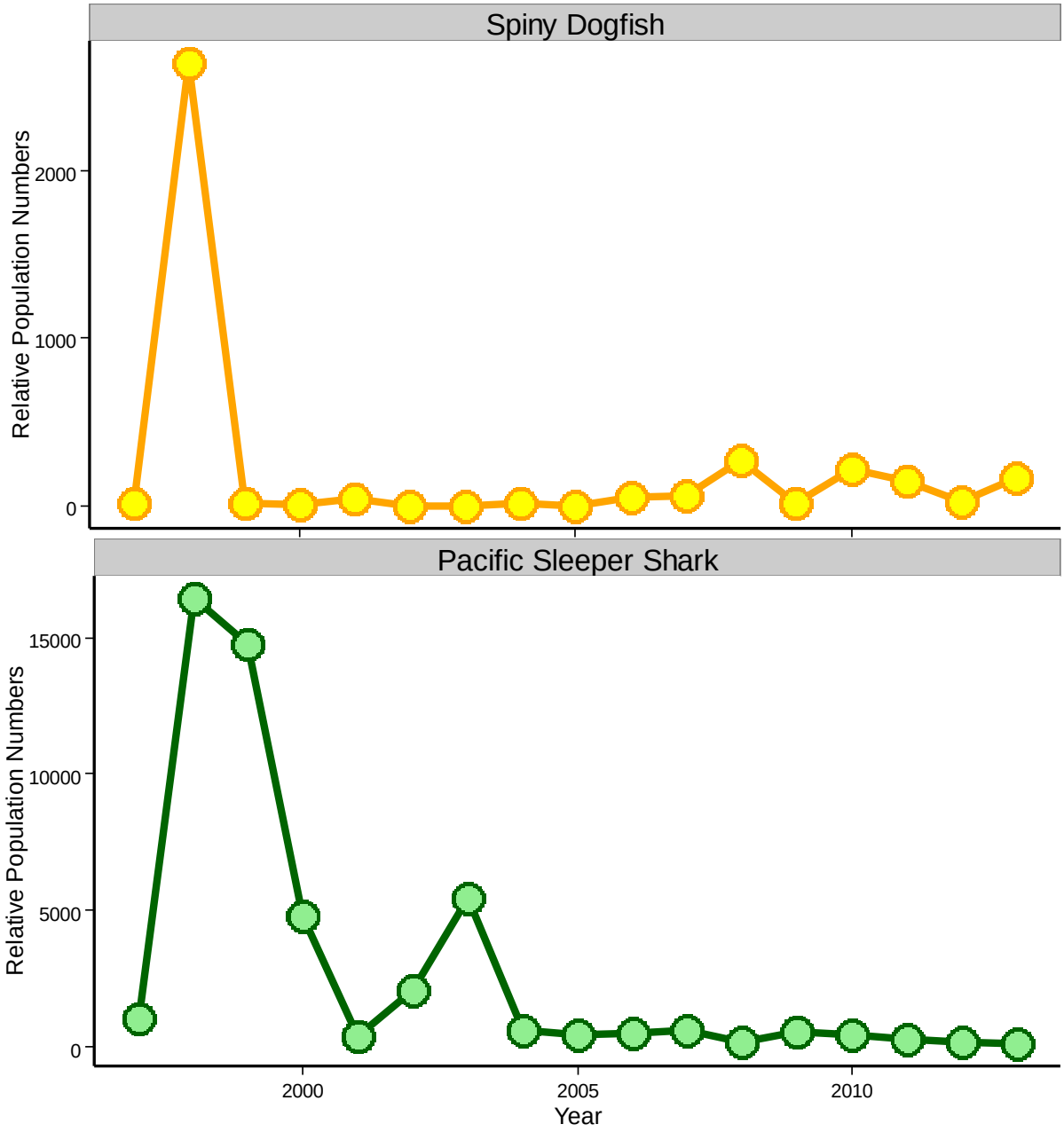

Figure 20.11. Estimated relative population numbers from the IPHC annual longline survey in the BSAI.

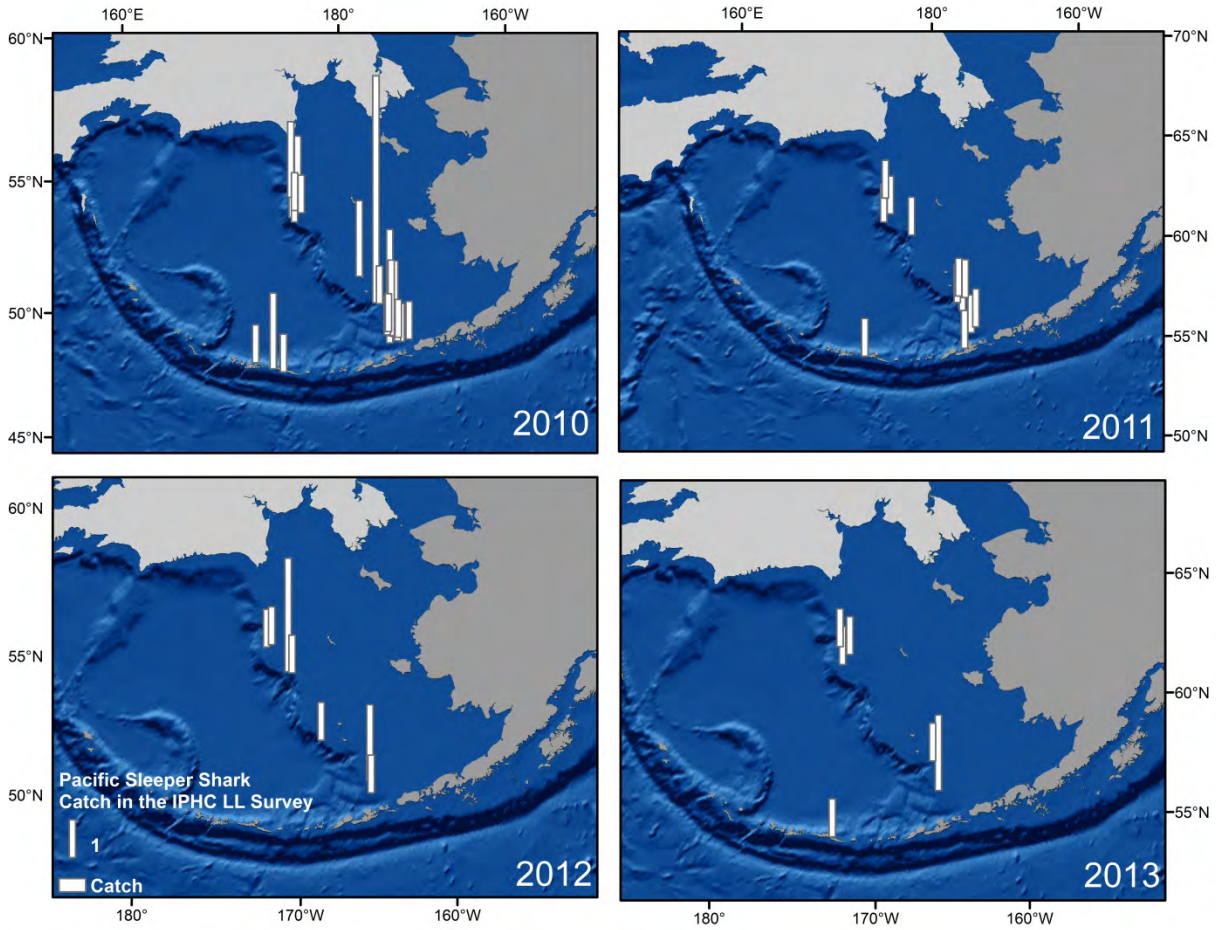

Figure 20.12. Spatial distribution of the catch of Pacific sleeper shark during the 2010 - 2013 IPHC longline surveys. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

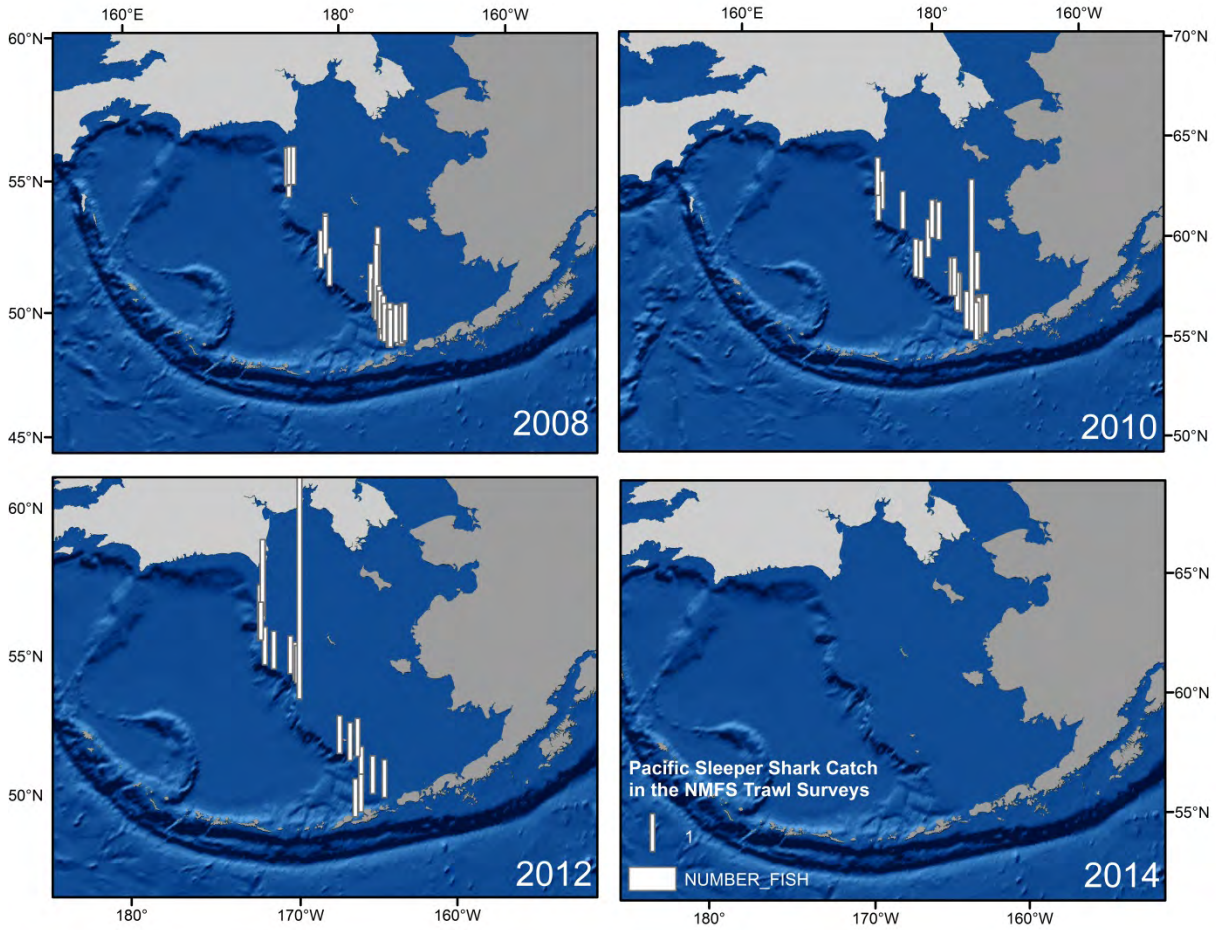

Figure 20.13. Spatial distribution of the catch of Pacific sleeper shark during the 2008-2014 NMFS Eastern Bering Sea (EBS) and Aleutian Islands trawl surveys. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity. There was not Aleutian Islands survey in 2008 and no Eastern Bering Sea slope survey in 2014. Neither the Aleutian Islands nor the EBS shelf survey caught any Pacific sleeper sharks in 2014.

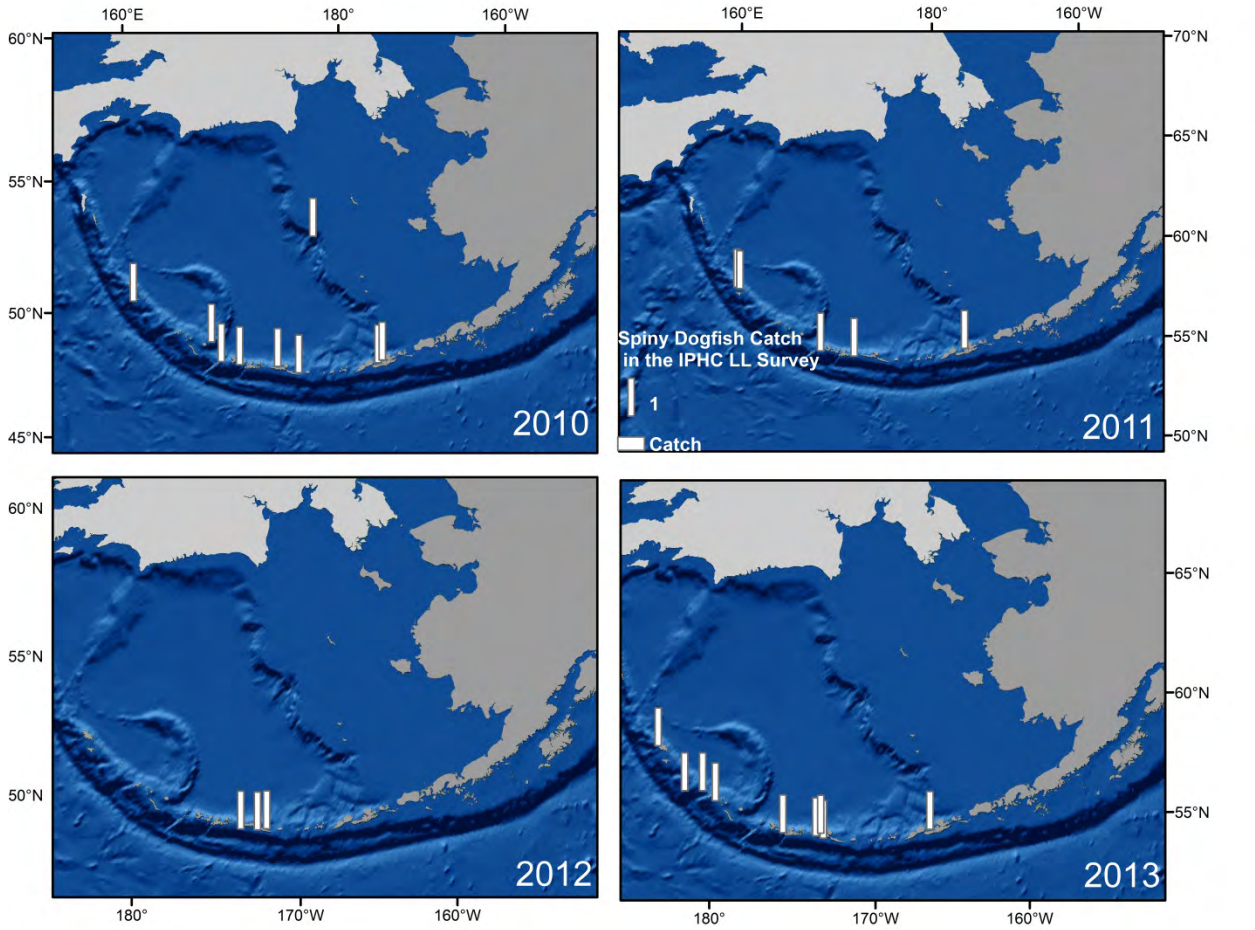

Figure 20.14. Spatial distribution of the catch of spiny dogfish during 2010 - 2013 IPHC longline surveys. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

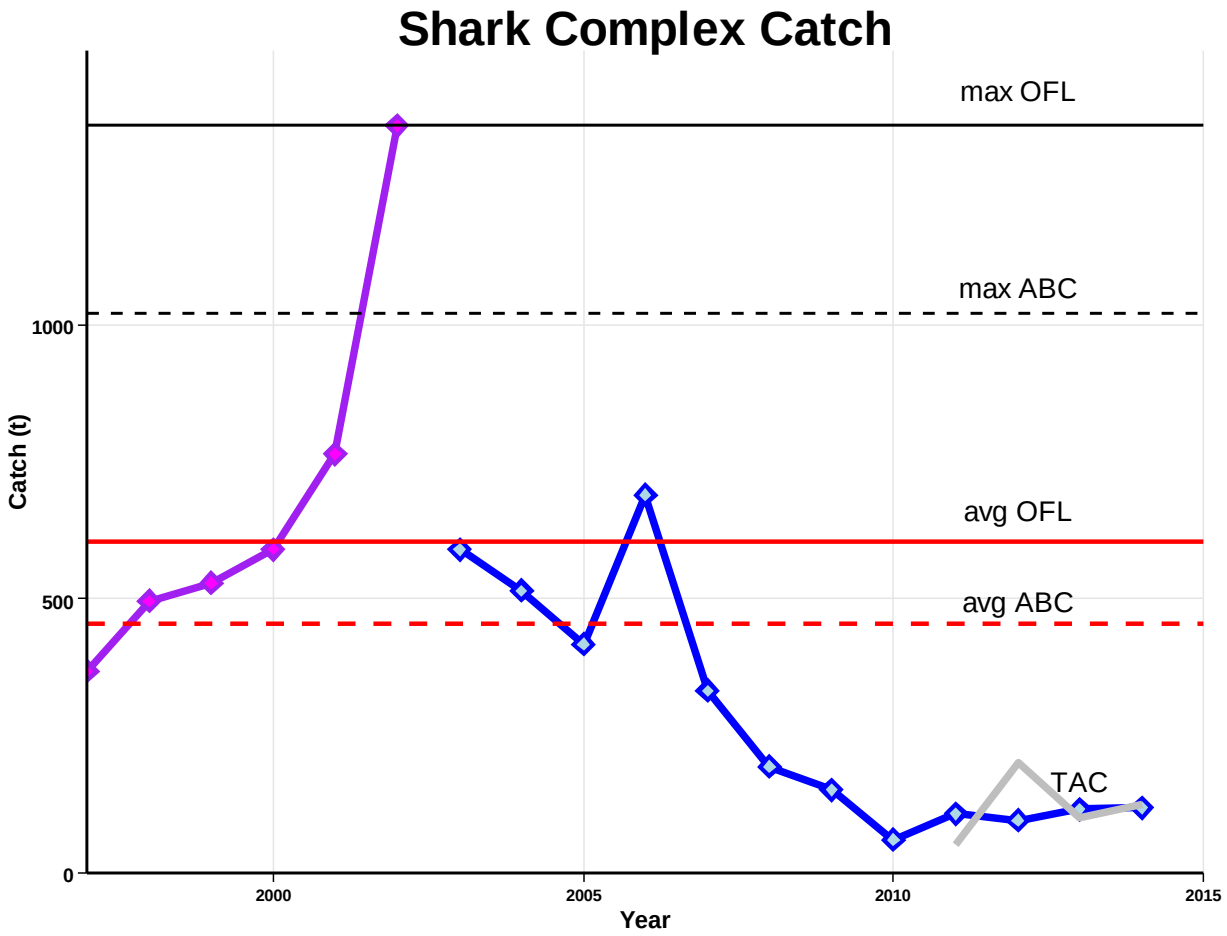

Figure 20.15. Total BSAI shark catch represented as two time series: the pseudo-blend (purple line, 1997 - 2002): and Catch Accounting (blue line, 2003 - present). Catch is shown relative to the OFL/ABCs calculated from using the maximum catch ("max OFL" and "max ABC", black solid and dashed lines, respectively) and the average catch ("avg OFL" and "avg ABC", red solid and dashed lines, respectively) over 1997-2007. The 2014 TAC (grey line) is included for reference.

Appendix 20A. GOA and BSAI Shark Assessments

Cindy A. Tribuzio, Cara Rodgveller, and Pete Hulson
September 2014

Executive Summary

At the December, 2013 council meeting, the SSC requested a full Gulf of Alaska (GOA) shark assessment for the 2014 assessment cycle (typically full assessments for the GOA sharks are conducted in odd years) to address questions specific to the assessment regarding the catch estimates based on data from the newly restructured observer program. We are presenting this document in lieu of a full assessment to address SSC comments for the following reasons: 1) there was no GOA survey in 2014; 2) the shark complex is dominated by spiny dogfish in the GOA and ABC/OFL calculations are based on the survey biomass for that species; 3) the contribution to the ABC/OFL from the remaining Tier 6 species (catch history) is small (~7% in 2013), thus the impacts to the complex from adjustments (if any) in the ABC/OFL from the observer restructuring would be small; and 4) with only 1 year of the new time series of catch estimates, it is not reasonable to make comparisons to the old time series. A full assessment for the Bering Sea/Aleutian Islands (BSAI) sharks is planned, as is normal for an even year.

Aside from the request for a full GOA assessment, the SSC made the below comments:

"The SSC discussed observed increases in shark catch in 2013 and the implications of incorporating shark catches in areas 649 and 659 in the assessment. With respect to adding catch from areas 649 and 659, the SSC recognizes that if the authors account for catch from additional regions, then they will need to consider how they will adjust the historical catch time series for shark removals from areas 649 and 659. Furthermore, the authors will need to consider the connectivity of the subset of the population in areas 649 and 659 to the other regions in the GOA. Finally, the authors will need to consider whether the catch reported in 2013 is representative of the historical catch or whether it was impacted by the new observer deployment program. The SSC requests a full stock assessment in 2014 because of the importance of these issues when estimating biological reference points for a species managed in Tier 6.

The SSC notes that the CIE non-target review provided comments on the utility of continued exploration of the length-based and surplus production models. The SSC requests that the authors consider these comments and that they report to their justification for continuing or dropping this line of research. The SSC looks forward to the authors' responses to the CIE review comments."

The sections below address these comments. We address the above comments in regards to the BSAI areas as well.

SSC Comments Regarding The Impacts Of Observer Restructuring On The Shark Assessments

The SSC comments can be paraphrased into four questions:

1) Are the 2013 estimates of shark catch comparable to the historical time series of estimated shark catch?
2) Will (how will) the catch history time series be adjusted if areas 649/659 are included in assessment?
3) Is there connectivity between sharks in 649/659 and the other regions of the GOA?
4) How do these issues affect Tier 6 (catch history) species ABC/OFL estimates?

1) Are the 2013 estimates of shark catch comparable to the historical times series of estimated shark catch?

The restructured observer program was put into effect to address longstanding concerns associated with the old program about data quality and cost equity among participants (77 FR 770062). Implementation of this program is considered an improvement over the previous observer system and an analysis of the first year under the restructured program was presented at the June 2014 council meeting (Faunce et al. 2014). The report presented to the Council explains how the observer program changed, thus we will not be covering the finer points of the restructured observer program in this document. The change from the previous observer deployment regime may result in relatively small changes in estimated catch for target species, but for sharks, there is potential for significant additional estimated catch. In particular, the restructuring includes newly available catch estimates from the Pacific halibut (*Hippoglossus stenolepis*) IFQ fishery, which was not available prior to 2013 due to the lack of observer coverage on vessels participating in this fishery. Here we report the estimated catch from 2003-2012 (historical time series) and from 2013 (restructured observer program data). However, we make no conclusions here regarding changes in the catch time series because of confounding issues in the catch estimates which may or may not be a result of observer restructuring.

The shark assessments include three main species of sharks: spiny dogfish (*Squalus suckleyi*), the Pacific sleeper shark (*Somniosus pacificus*) and the salmon shark (*Lamna ditropis*). However, the salmon shark is rare in federal fisheries and thus this response will focus on spiny dogfish and Pacific sleeper shark. The majority of shark catch occurs in the GOA, hence this response focuses primarily on the GOA region, but for informational purposes we are also including data for shark species in the BSAI.

The restructured observer program covers previously unobserved vessels operating in the Pacific halibut IFQ fishery and small vessels (40-60 ft). In previous assessments we have speculated that these sectors of the fleet (smaller vessels, Pacific halibut IFQ vessels) were a substantial source of catch for sharks in the GOA (Tribuzio et al. 2014), and that the catch estimates from the Alaska Regional Office Catch Accounting System (CAS) were not representative of true catch because of the lack of observer coverage on those vessels and because CAS programming procedures did not include Pacific halibut-only landings. In 2013, modifications were made to CAS so that catch and bycatch estimates could be made for the IFQ Pacific halibut fishery. These changes resulted in shark catch being estimated for all IFQ trips, including those on vessels <60 ft, which comprise a substantial portion of the IFQ fleet and those vessels which do not also land federal groundfish species (which were included prior to 2013). Estimates of shark catch in CAS (both spiny dogfish and Pacific sleeper sharks) on vessels <60 ft substantially increased in the GOA in 2013 (Figure 1) and proportionally contributed to the total catch more than in any other year (Figure 2). In the BSAI, the increase in estimated catch in 2013 was relatively small, but the portion of the catch resulting from vessels <60 ft was substantially larger (Figures 1 & 2).

In 2013, the estimated shark catch in the Pacific halibut fishery was relatively large, possibly due to the new observer coverage and changes in the estimation methods made in CAS. In the GOA, 2006 and 2009 (similarly in 2003 and 2008 in the BSAI) also had large catch estimates of sharks in the Pacific halibut fishery (Figure 3). While the Pacific halibut IFQ fleet was unobserved prior to 2013, catch estimates from vessels landing Pacific halibut would be generated by CAS when those vessels would also land federal groundfish and the catch estimates were based only on the federal groundfish. The anomalous catches have been investigated by staff at the Alaska Regional Office. In general, prior to 2013, there is little to no observer data available to calculate a rate of shark catch for the Pacific halibut target fishery, thus data were from observed mixed sablefish (*Anoplopoma fimbria*) and Pacific halibut IFQ trips. The observer data were used to estimate shark discards when a groundfish species was landed using post-strata described in Cahalan et al. (2010). In brief, post-stratification rules in CAS aggregate observer data to create discard rates using information of the highest possible resolution of spatial and temporal scale that corresponds with the trip characteristics of landed catch. However, when observer data with similar characteristics to the landed catch are lacking, discards must still be estimated. The post-stratification

rules in CAS allow estimates to be made using available observer information, which may require observer data to be aggregated across an entire FMP area to create a bycatch rate and estimate (Cahalan et al. 2010). For example, in 2006 and 2009 in the GOA and 2003 and 2008 in the BSAI, the aggregated post-stratification discard rates were driven by a small number of observed hauls in which there were relatively large catches of sharks and a small amount of groundfish retained, resulting in a large shark to groundfish rate. This rate represented the best available information from which to estimate, but it also resulted in relatively large estimates of shark catches. This scenario is not the case in 2013, where there was observer data available to create estimates of shark catch from the Pacific halibut fleet and CAS incorporates landing and discard information from the Pacific halibut fishery. However, it is not possible to determine if the large estimated shark catch in the 2013 Pacific halibut target group was an anomaly, a change in fishing behavior, or a result of the restructured observer program. Regardless, the catch accounting is more comprehensive in 2013 than prior years.

In 2013, the estimated catch of sharks in areas 649/659 also substantially increased (Figure 4). These areas also include the Pacific halibut IFQ fishery, which may occur in conjunction with state managed fisheries (e.g., a trip may include both Chatham sablefish and Pacific halibut). Shark discards are estimated on any trips where a groundfish species or Pacific halibut are landed, thus estimates were made regardless of whether the primary species landed was a state-managed species. It is not possible to determine if the increased 2013 catch estimates are a result of change in fishing behavior or the observer restructuring since discards were estimated for a portion of Pacific halibut fleet prior to 2013. The catch in these two areas is relatively small when compared to the total shark catch: on average, 3% of total shark catch prior to 2013 and 10% in 2013. A longer time series is needed to understand catch trends.

The 2013 catch estimates are not directly comparable to the prior 2013 catch estimates. The methods CAS uses to estimate catch of non-retained species have changed. Not only are trips where only Pacific halibut is landed included in CAS, but Pacific halibut is included in the calculation of discard rates. Two procedures would need to be completed to accurately compare 2013 catch estimates to historical catch estimates. First, the estimated catch resulting from Pacific halibut only landings will have to be removed. Second, a new discard rate will have to be calculated which does not include Pacific halibut. Such an analysis is beyond the scope of this document, but may also not be feasible given the structure of CAS.

2) Will (how will) the catch history time series be adjusted if areas 649/659 are included in the federal catch?

Catch of sharks in the Prince William Sound and inside waters of Southeast Alaska (NMFS areas 649/659) comes from a mixture of federal and state managed fisheries that are sometimes landed on the same trip, including Pacific halibut IFQ. Prior to 2013, if a vessel landed both Pacific halibut IFQ and groundfish on the same trip, a discard estimate was generated based on the federal groundfish landings only. However, if a vessel only landed Pacific halibut,discard estimates were not calculated. Starting in 2013, discards were estimated for all trips where Pacific halibut or groundish species were landed, and estimates are based on both Pacific halibut and groundfish landings. The only trips where discards were not estimated are those containing only non-groundfish species (e.g., lingcod). Due to the complex mixture of fishing activity in state waters, and the lack of observer information on Pacific halibut vessels prior to 2013, the estimated catch in federal fisheries in 649/659 has historically not been included in the shark assessment. While it is not possible to determine if the recent increase in catch in these areas is a result of the observer restructuring and changes to CAS, an anomaly (meaning not representative of the time series), or a change in fishing behavior, these catch estiamtes are generated when landings of groundfish and Pacific halibut occur (i.e. federal landings) and we recommend that they be included in the GOA federal shark assessment. Further, there is not accounting of shark catch by the State of Alaska and the sharks occurring in areas 649/659 are not biologically distinct from the other regions of the GOA (see below).

Estimates of shark catch in federal groundfish fisheries in areas 649/659 are available for the historical time series. The estimated shark catch in 649/659 over the entire time series is small relative to the other areas of the GOA (Figure 4). At this point, it is unknown if the higher magnitude of 649/659 shark catch estimates (10% of total GOA shark catch) is representative of the new time series or an anomaly. Regardless, including the historical estimated catch from those areas, will have a small impact on the total estimated shark estimated catch.

The addition of estimated catch from the Pacific halibut IFQ fishery may result in an increase in estimated shark catch, particularly in areas 649/659, in which case the historical time series of catch used will need to be adjusted. At this time, we are not prepared to speculate on the appropriate method for making adjustments. Any adjustment methods will need to consider separating estimated catch from vessels fishing only Pacific halibut (added to CAS in 2013) from those that landed both Pacific halibut and groundfish on a trip (in CAS prior to 2013), as well as compare HFICE catch estimates (currently only available 2001-2011, Tribuzio et al. 2014) to the 2013 and forward time series.

We recommend delaying adjusting the time series of estimated shark catch in areas 649/659 for three reasons: 1) it would be unwise to conduct such a calculation based on one year of data under the restructured observer program, and it is unknown how the restructured time series compares to the period prior to restructuring; 2) the estimated shark catch in areas 649/659 is small relative to the estimated shark catch in the rest of the GOA and the impact of including that catch in the total estimated shark catch is small; and 3) it appears likely the observer program restructure will continue to evolve over the next several years. Therefore, it is preferable to delay until sufficient data are available to better assess the magnitude of additional catches and the best method of adjustment.

3) Is there connectivity between sharks in 649/659 and the other regions of the GOA?

There are a number of biological justifications for including 649/659 estimated catches into the assessment. Research on the movement and genetics of the shark species has indicated that the populations are mixed across the full extent of the Gulf of Alaska, including areas 649/659, and much of the North Pacific Ocean. A stock structure analysis was presented for the GOA and BSAI shark assessments in September, 2012 (Tribuzio et al. 2012). The stock structure analysis demonstrated that there is no biological justification for managing the shark species as separate stocks within the GOA (including areas 649/659).

Tagging studies have provided an indication of the connection of these species within and outside of 649/659. Spiny dogfish are highly migratory, with some animals overwintering in GOA waters and others undertaking large migrations as far south as southern California and west to Japan. Spiny dogfish moved both into and out of area 659, and while no fish were tagged in area 649, tagged fish did move into area 649 (Tribuzio, unpublished data). Tagging studies of Pacific sleeper sharks suggested that they had potential for movements into and out of 649/659. Hulbert et al. (2006) showed Pacific sleeper sharks moving into 649 and the data suggested that they likely move regularly in and out of the area. Tagging of Pacific sleeper sharks within area 659 showed that they are highly mobile and have potential to move between areas. Detailed analysis of the tagging effort in area 659 is still underway (D. Courtney, NMFS, SEFSC, pers. comm.).

Genetic analyses support the tagging data, suggesting that the shark species are mixed across the extent of the eastern North Pacific Ocean. For example, Verissimo et al. (2010) did not find any discrete stocks across the range in the North Pacific Ocean for spiny dogfish. Similarly, preliminary results of an ongoing genetics study of Pacific sleeper sharks show that there are two lineages of Pacific sleeper sharks, but that they are evenly mixed across the range of the species, including areas 649/659 (S. Wildes, NMFS, AFSC pers. comm.).

4) How do these issues affect Tier 6 (catch history) species ABC/OFL estimates?

The ABC/OFLs for the shark complex in the GOA are calculated using a blend of Tier 5 and 6 approaches. The spiny dogfish ABC and OFL are calculated using a Tier 5-like approach (but they are still considered a Tier 6 species), where OFL=survey biomass*M and ABC =OFL*75%, which is then summed with the average catch history ABCs and OFLs of other shark species to arrive at a combined ABC and OFL for the whole complex. The majority of the estimated shark catch in the GOA is from spiny dogfish (total GOA estimated shark catch in 2013 was 2,420 t, of which 2,178 t was spiny dogfish, Figure 5), as well as much of the ABC and OFL coming from that species (ABC = 6,028 t, of which 5,600 t was spiny dogfish). Therefore, adjustments to the catch history in the GOA will likely have a small impact on the complex ABC/OFL because the tier 5-like approach for spiny dogfish is based on survey biomass rather than catch history and this component represents the majority of ABC/OFL.

In the BSAI, the entire complex ABC/OFL is based on the maximum of the catch history. However, the impacts of the observer restructuring are likely less substantial. Estimated shark catch in the BSAI (2013 total estimated shark catch = 116 t, oh which 69 t was Pacific sleeper shark) is substantially lower than the ABC of 1,022 t (Figure 5). Thus, the potential increase in catch from observer restructuring is unlikely to cause the shark catch in the BSAI to approach the ABC. When there is sufficient data (i.e. more years of catch estimates from the restructured observer program), the historical time series of catch may need to be corrected. It is not appropriate at this time to correct the historical time series based on only one year of data.

CIE Comments Regarding The Shark Assessments

The CIE reviewers did not have extensive comments regarding the shark assessments. Below are the key comments made in both the reviewers' documents and discussions during the meeting.

From reviewer comments:

1) *Until the relative biomass from the various trawl surveys can be appropriately converted to absolute biomass, it may be better to use Tier 6 methods for sharks.*

   Spiny dogfish ABC and OFLs in the GOA are calculated based on a Tier 5-like approach (but still considered a Tier 6 species). All other species specific ABCs and OFLs are catch history based (average catch in the GOA and maximum historical catch in the BSAI). The Tier 5-like approach for spiny dogfish was adopted for the 2011 fishery (see the SSC minutes from the 2010 December Council meeting: http://www.npfmc.org/wp-content/PDFdocuments/minutes/SSC1210.pdf), based on the 2010 stock assessment (Tribuzio et al. 2010). The justification was that due to pelagic and transitory nature of spiny dogfish it was likely that trawl catchability was low and that the survey biomass estimates were like a minimum biomass estimate.

2) *If using the Tier 5 methods, investigate appropriate means of converting survey biomass to absolute biomass (i.e. catchability) and alternative Fmsy proxies besides F=M.*

   The authors are investigating approaches for converting survey biomass estimates to absolute biomass. These include length based and surplus production models, as well as age-structured models. We are not presenting these models for PT and SSC review yet, as we plan to incorporate results of ongoing projects. These include results of an NPRB funded ageing study and an investigation into trawl catchability using tag data.

   An alternative F_{msy} proxy of F=0.04 was presented in the 2010 and 2011 assessment, based on demographic analyses (Tribuzio and Kruse 2011), and were not accepted by the PT and SSC. If the alternative were applied to the most recent 3 year biomass, the ABC/OFL for spiny dogfish would be 2,294 and 3,058 t, respectively (down from 5,562 and 7,416 t, respectively). The resultant total complex ABC/OFL would be 2,722 and 3,629 t, respectively.

3) *Using the maximum or average catch for Tier 6 may not be appropriate; alternatives could be to use an upper bound of a one-sided 95% or 99% confidence interval.*

   Alternatives to average and maximum catch have been presented in the past (e.g. Tribuzio et al. 2010), for the shark and other assessments (e.g. GOA Octopus). However, this is an issue we hope to revisit for the 2015 GOA assessment. A recent study came out demonstrating how static catch history methods have a high probability of resulting in overfishing (Carruthers et al. 2014). Catch based methods with a dynamic adjusted scalar or depletion correction methods resulted in a substantially improved probability of resulting in an overfished population (defined as $B/B_{msy}<50\%$). We plan to explore these depletion methods for Tier 6 alternatives.

4) *Other suggestions: species specific ABC/OFLs; incorporating state of Alaska survey data; coast wide spiny dogfish assessment; move salmon sharks to a highly migratory group for management*

   Unfortunately, many of these suggestions are not possible at this time. Species specific ABC/OFLs are likely too small to be managed for many of the shark species and moving the salmon shark to a highly migratory group is not possible because we do not have such a group in the Alaska region. We are beginning to compile data from state of Alaska surveys to incorporate into the assessment. A coast wide assessment for spiny dogfish makes sense biologically, but the infrastructure is not in place for such a management plan at this time.

Other items that came up during presentations/discussions

5) *Data does not support building a spiny dogfish model at this time*

   See response to #2 above.

6) *Need to continue efforts to improve age estimates*

   The authors are involved in a project attempting to improve age estimates. This project is funded by the North Pacific Research Board and is scheduled to conclude January of 2015. The goals of the project are to investigate a new method for ageing spiny dogfish and determine if growth estimates can be improved (i.e. reduce the uncertainty in the age estimates and growth parameters).

7) *Need to get more years of new observer data before constructing catch history to use in model*

   The authors agree with this comment, see discussion above.

8) *Investigate Pacific sleeper shark declining catches and survey indices.*

   This is an important topic that is currently under investigation.

Acknowledgements

We would like to acknowledge Craig Faunce and Jennifer Cahalan (FMA) and Jason Gasper and Jennifer Mondragon (AKRO) for their efforts to help us understand the observer restructuring and CAS and their assistance in writing this document.

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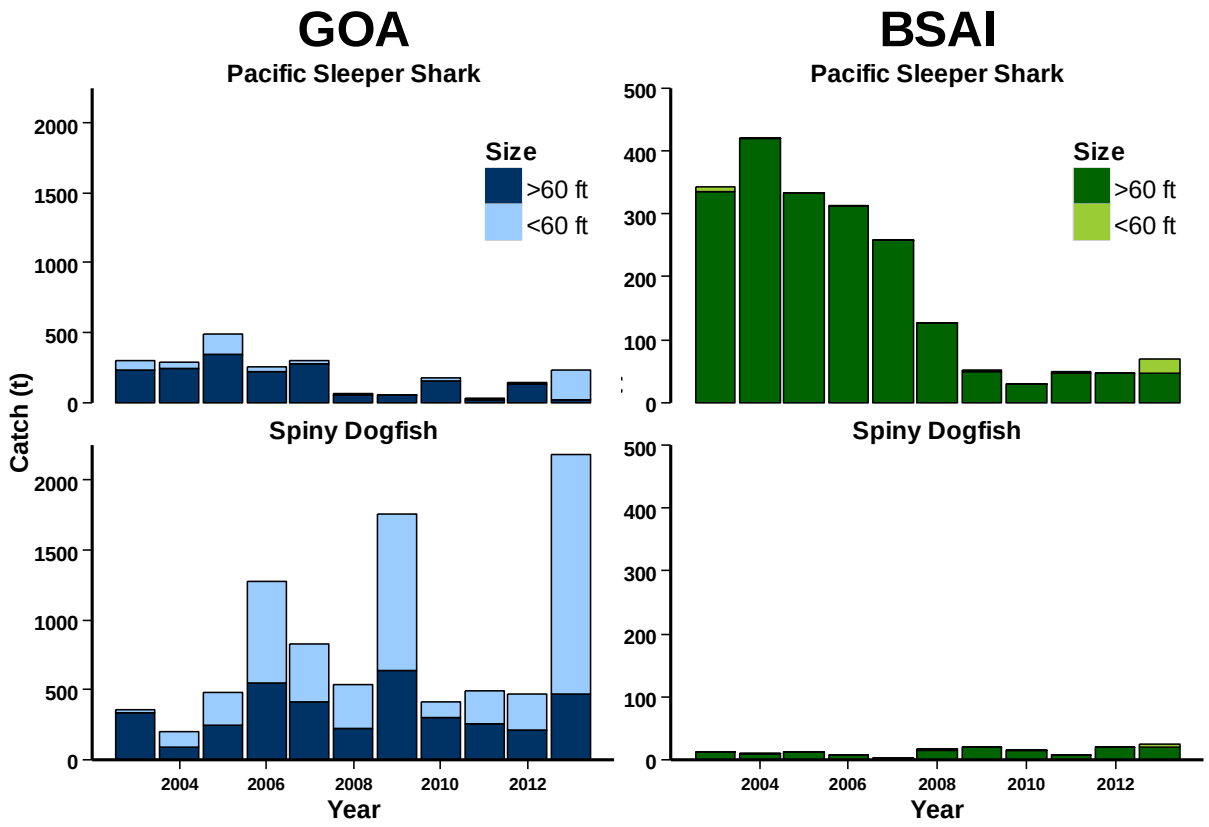

Figure 20A.1. Catch accounting system catch estimates (t) for Pacific sleeper shark and spiny dogfish in the Gulf of Alaska (GOA) and Bering Sea/Aleutian Islands (BSAI) by vessel size class.

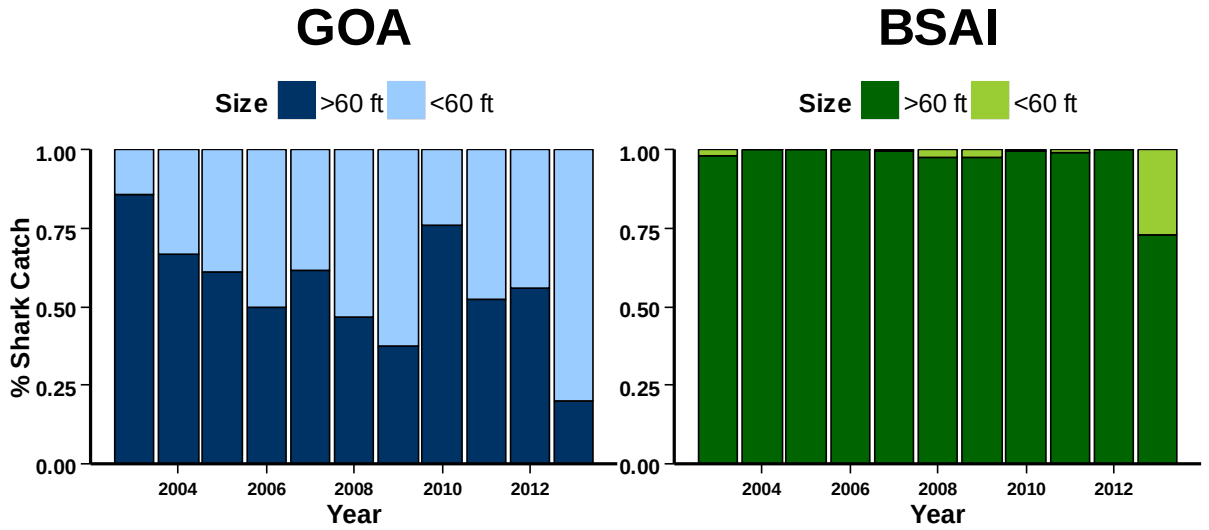

Figure 20A.2. Proportional representation of shark catch by vessel size.

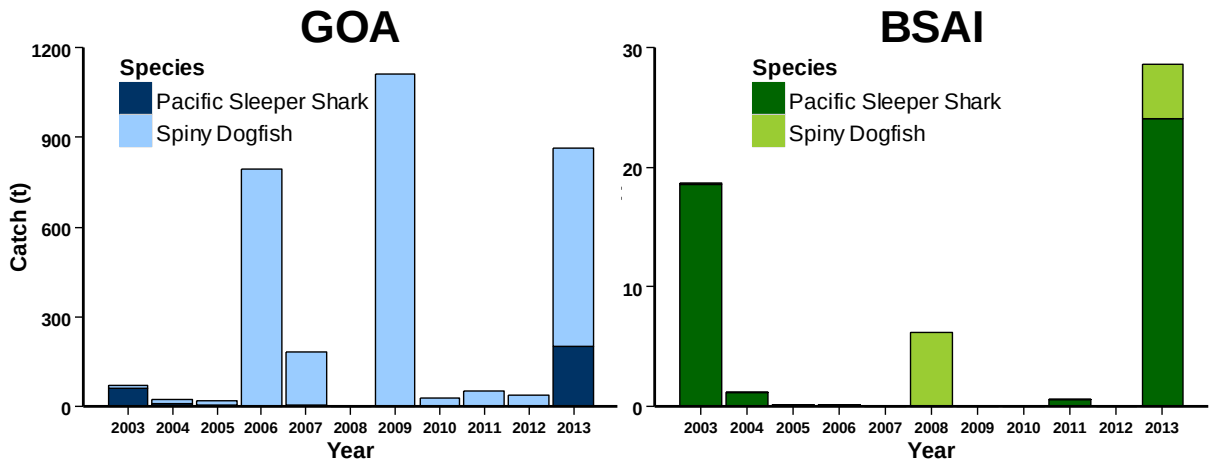

Figure 20A.3. Catch Accounting System catch estimates (t) of spiny dogfish and Pacific sleeper shark in the Pacific halibut target category. Prior to 2013, estimated catch in the Pacific halibut target category results from vessels fishing both Pacific halibut and groundfish (generally sablefish IFQ), beginning in 2013 the estimated catches include vessels fishing only Pacific halibut IFQ.

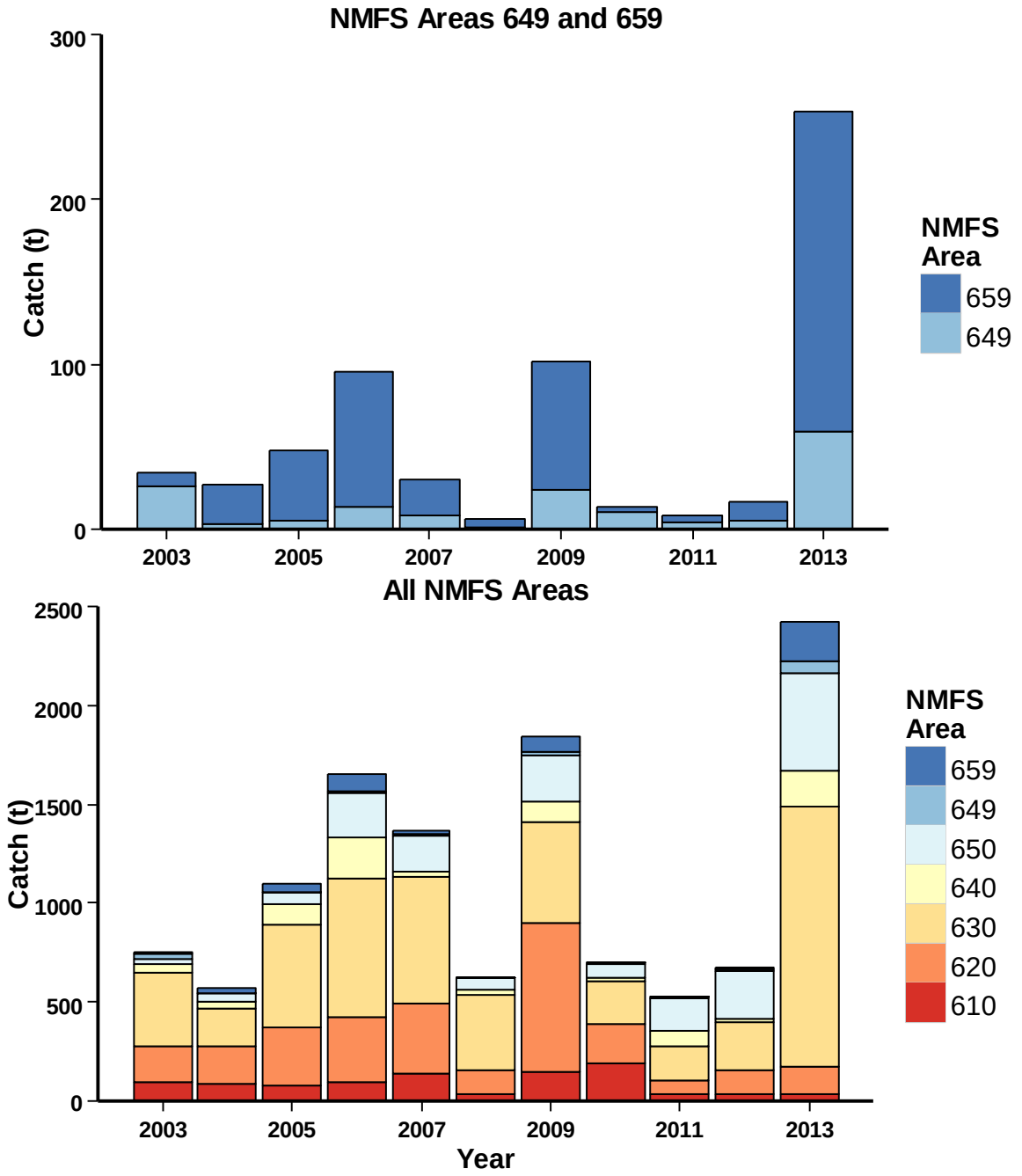

Figure 20A.4. Top panel: Catch accounting system catch estimates (t) for all sharks in NMFS Areas 649 and 659. Bottom panel: Catch accounting system catch estimates (t) for all sharks in all Gulf of Alaska NMFS Areas.

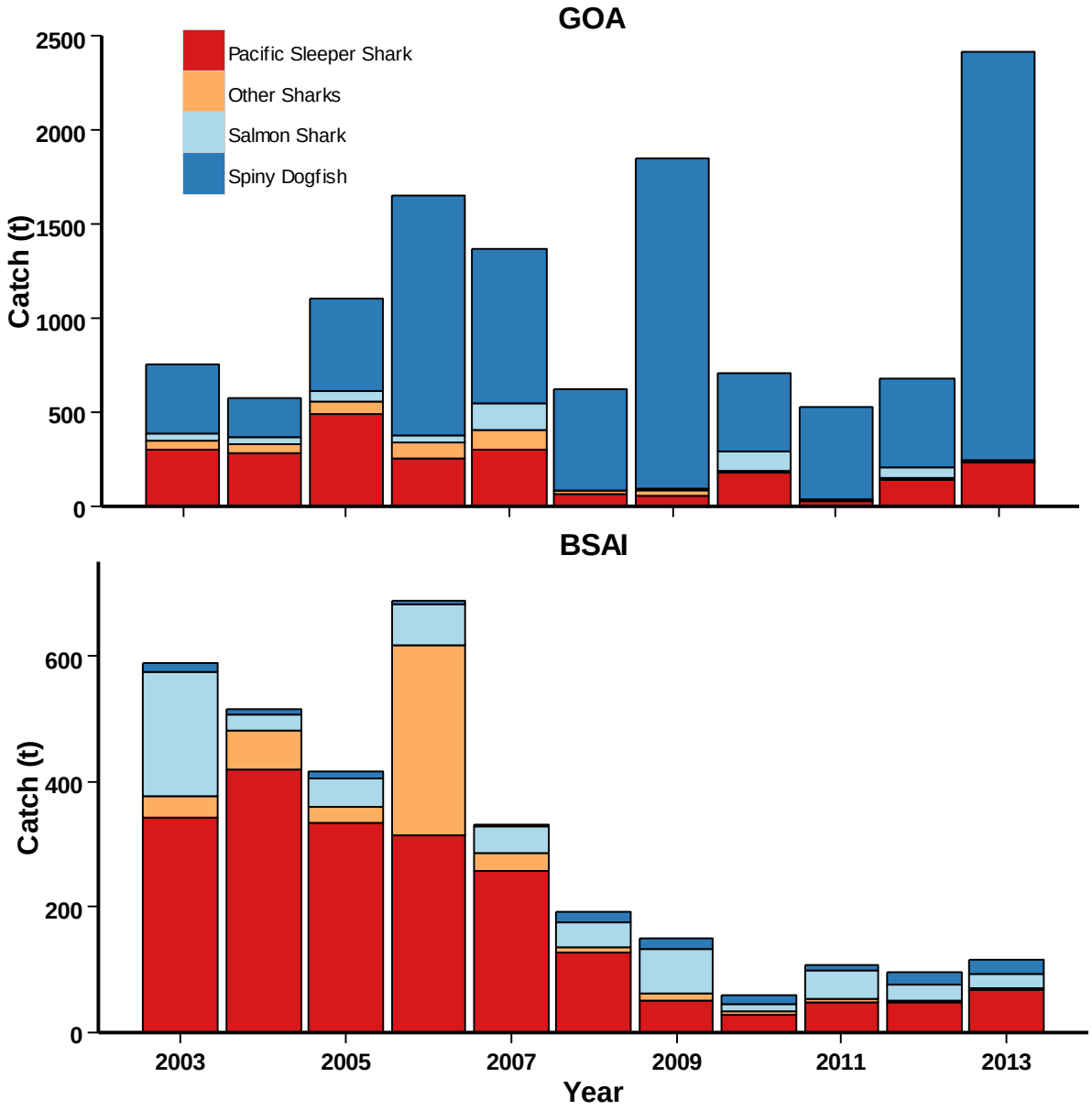

Figure 20A.5. Catch accounting system catch estimates (t) for all sharks in the GOA (top) and BSAI (bottom).

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21. Assessment of the squid stock complex in the Bering Sea and Aleutian Islands

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Executive Summary

Summary of changes in assessment inputs

Because reliable biomass estimates do not exist for squids in the Bering Sea and Aleutian Islands (BSAI), harvest recommendations are made using Tier 6 criteria. Under Tier 6 Acceptable Biological Catch (ABC) and Overfishing Level (OFL) are calculated using catch data from 1978-1995, and as a result the harvest recommendations do not change from year to year. However, additional data and analyses are included to improve the understanding of squid biology and their interaction with fisheries. The following changes have been made for the 2014 assessment:

1) Catch data have been updated through October 8, 2014.
2) 2014 biomass estimates from the EBS shelf and AI surveys were added; the planned 2014 EBS slope survey did not occur.
3) Alternatives to the current Tier 6 assessment methodology were presented at the September 2014 Joint Plan Team meetings; a table detailing those alternatives is included in this report.

Summary of results

The recommended allowable biological catch (ABC) for squids in 2015 and 2016 is calculated as 0.75 multiplied by the average catch from 1978-1995, or 1,970 t; the recommended overfishing level (OFL) for squid in the years 2013-2014 is calculated as the average catch from 1978-1995, or 2,624 t.

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	*2014*	*2015*	**2015**	2016
Tier	6	6	6	6
OFL (t)	*2,620*	*2,620*	**2,620**	2,620
maxABC (t)	*1,970*	*1,970*	**1,970**	1,970
ABC (t)	*1,970*	*1,970*	**1,970**	1,970
	As determined *last* year for:		As determined *this* year for:	
Status	2012	2013	2013	2014
Overfishing	no	n/a	no	n/a

This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Marine Fisheries Service and should not be construed to represent any agency determination or policy.

Responses to SSC and Plan Team comments on assessments in general

There were no general comments relevant to BSAI squids.

Responses to SSC and Plan Team comments specific to this assessment

From the SSC October 2014: "an option should be brought forward for a Tier 6 method with a time period for the BSAI that does not include years during the foreign fishing eras (1987-1995; see CIE reviewer appendix)."

> *Response*: The options presented in September 2014 are included in the 2014 SAFE report. These options include several options that do not contain the years 1987-1995. Harvest recommendations using the period 1997-2007 option are presented and discussed in the report.

Introduction

Description, scientific names, and general distribution

Squids are marine molluscs in the class Cephalopoda (Group Decapodiformes). They are streamlined animals with ten appendages (2 tentacles, 8 arms) extending from the head, and lateral fins extending from the rear of the mantle. Squids are active predators which swim by jet propulsion, reaching swimming speeds up to 40 km/hr, the fastest of any aquatic invertebrate. Squids also hold the record for largest size of any invertebrate (Barnes 1987).

In the Bering Sea/Aleutian Islands regions there are at least 15 species of squid (Table 1). The most abundant species is *Berryteuthis magister* (magistrate armhook squid). Members of these 15 species come from six families in two orders and can be found from 10 m to greater than 1500 m. All but one, *Rossia pacifica* (North Pacific bobtail squid), are pelagic but *Berryteuthis magister* and *Gonatopsis borealis* (boreopacific armhook squid) are often found in close proximity to the bottom. The vertical distribution of these three species is the probable cause of their predominance in the BSAI bottom trawl surveys relative to other squid species, although no squid species appear to be well-sampled by BSAI surveys. Most species are associated with the slope and basin, with the highest species diversity along the slope region of the Bering Sea between 200 – 1500 m. Since most of the data come from groundfish survey bottom trawls, the information on abundance and distribution of those species associated with the bottom is much more accurate than that of the pelagic species.

Family Chiroteuthidae

This family is represented by a single species, *Chiroteuthis calyx*. *Chiroteuthis calyx* is a pelagic, typically deep water squid that is known to mate in the Aleutian Islands region. Larvae are common off the west coast of the US.

Family Cranchiidae

There are two species of this family found in the Bering Sea and Aleutian Islands, *Belonella borealis* (formerly *Taonius pavo*) and *Galiteuthis phyllura*. Mated *Galiteuthis phyllura* have been observed along the Bering Sea slope region and their larvae are common in plankton samples. Mature adults and larvae of *Belonella borealis* have not been identified in the region.

Family Gonatidae

This is the most speciose family in the region, represented by nine species: *Berryteuthis anonychus*, *Berryteuthis magister*, *Eogonatus tinro*, *Gonatus berryi*, *Gonatus madokai*, *Gonatus middendorffi*, *Gonatus onyx*, *Gonatopsis borealis*, and *Gonatopsis* sp. All are pelagic however, *B. magister*, *G. borealis*, and *Gonatopsis* sp. live very near the bottom as adults. Larvae of all species except the unknown *Gonatopsis* have been found in the Bering Sea. *Gonatus onyx* is known to brood its eggs to

hatching, however no evidence of that behavior exists for other members of the family. *B. magister* is known to form enormous spawning aggregations in the Bering Sea, and large schools of late juvenile stages of *B. magister* have been observed elsewhere in the North Pacific Ocean.

Family Onychoteuthidae
Immature adults of two species from this family have been observed in the BSAI: *Moroteuthis robusta* and *Onychoteuthis borealijaponicus*, the latter of which is only known from the Aleutian Islands region. *Moroteuthis robusta* is the largest squid in the region, reaching mantle lengths of three feet. Mature adults, eggs, and larvae of either species have not been collected from the Bering Sea or Aleutian Islands regions.

Family Sepiolidae
This family is represented by a single species, *Rossia pacifica*. This small animal is found throughout the Bering Sea and Aleutian Islands regions to 1000 m. Eggs are deposited on substrate in the summer months and larva are benthic. Adults are believed to live 18 – 24 months and females may lay egg masses more than once in life time. Mature and mated females are common in the summer along the Bering Sea slope.

Management Units
Squids in the BSAI are currently managed as a single stock complex that includes all known squid species in the management area. Although no directed fishery exists for squids, they are caught and retained in sufficiently large numbers for them to be considered as "in the fishery".

Life history and stock structure
The life histories of squids in this area are almost entirely unknown. Of all the species, only *Rossia pacifica* has benthic larvae and only members of the family Gonatidae and Cranchiidae are known to spawn in the Bering Sea region. All other species are likely migrating to the area to feed and possibly mate.

Life history information for BSAI squids can be inferred from data on squid species elsewhere. Relative to most groundfish, squids are highly productive, short-lived animals. They display rapid growth, patchy distribution and highly variable recruitment (O'Dor, 1998). Unlike most fish, squids may spend most of their life in a juvenile phase, maturing late in life, spawning once, and dying shortly thereafter. Whereas many groundfish populations (including skates and rockfish) maintain stable populations and genetic diversity over time with multiple year classes spawning repeatedly over a variety of annual environmental conditions, squids have no such "reserve" of biomass over time. Instead, it is hypothesized that squids maintain a "reserve" of biomass and genetic diversity in space. Many squid populations are composed of spatially segregated schools of similarly sized (and possibly related) individuals, which may migrate, forage, and spawn at different times of year over a wide geographic area (Lipinski 1998; O'Dor 1998). Most information on squids refers to *Illex* and *Loligo* species which support commercial fisheries in temperate and tropical waters. Of North Pacific squids, life history is best described for western Pacific stocks (Arkhipkin et al., 1995; Osako and Murata, 1983).

The most commercially important squid in the north Pacific is the magistrate armhook squid, *Berryteuthis magister*. This species is distributed from southern Japan throughout the Bering Sea, Aleutian Islands, and Gulf of Alaska to the U.S. west coast as far south as Oregon (Roper et al. 1984). The maximum size reported for *B. magister* is 28 cm mantle length. Prior to 2008, most of the information available regarding *B. magister* was from the western Bering Sea. A study completed in 2008 investigated life history and stock structure of this species in the EBS (Drobny 2008). In the EBS, *B. magister* appear to have an approximately 1-year life cycle. This is half the longevity of *B. magister* in the western Bering Sea (Arkhipkin et al., 1995). *B. magister* in the EBS appear to grow and mature more quickly than their

conspecifics in Russian and Japanese waters. Squid growth appears to be heavily influenced by ocean temperature (Forsythe 2004), which may account for some of the regional and temporal variability.

Populations of *B. magister* and other squids are complex, being made up of multiple cohorts spawned throughout the year. *B. magister* are dispersed during summer months in the western Bering Sea, but form large, dense schools over the continental slope between September and October. Three seasonal cohorts are identified in the region: summer-hatched, fall-hatched, and winter-hatched. Growth, maturation, and mortality rates vary between seasonal cohorts, with each cohort using the same areas for different portions of the life cycle. For example, the summer-spawned cohort used the continental slope as a spawning ground only during the summer, while the fall-spawned cohort used the same area at the same time primarily as a feeding ground, and only secondarily as a spawning ground (Arkhipkin et al., 1995). In the EBS, hatch dates of *B. magister* varied by year but were generally in the first half of the year (Drobny 2008). Analysis of statolith chemistry suggested that adult squids were hatched in at least three different locations, and these locations were different from the capture locations. Juvenile and adult *B. magister* also appear to be separated vertically in the water column.

Fishery

Directed fishery

Historically squid were targeted by foreign vessels (from Japan and Korea) in the BSAI, but directed squid fisheries do not currently exist in Alaskan waters at this time. Squids could potentially become targets of Alaskan fisheries, however. There are many fisheries directed at squid species worldwide, although most focus on temperate squids in the genera *Ilex* and *Loligo* (Agnew et al. 1998, Lipinski et al 1998). There are fisheries for *B. magister* in the western Pacific, including Russian trawl fisheries with annual catches of 30,000 - 60,000 metric tons (Arkhipkin et al., 1995), and coastal Japanese fisheries with catches of 5,000 to 9,000 t in the late 1970s-early 1980s (Roper et al. 1982, Osaka and Murata 1983). Therefore, monitoring of catch trends for species in the squid complex is important because markets for squids exist and fisheries might develop rapidly.

Incidental catches and retention

Catch records for squids exist from 1977 (Table 2) and can be broken into three overlapping periods: "foreign" (1977-1987; when foreign vessels dominated the Alaska fleet), "joint venture" (1981-1989; shared fishing activities between domestic and foreign partners), and "domestic" (1987-present). Since 1990, only domestic vessels have operated in Alaskan waters. The foreign catches are much larger than present-day catches and likely present a mix of directed and incidental catches. Currently in the BSAI, squids are generally taken in target fisheries for pollock. Squid species can be difficult to identify, and fishery observers in the BSAI currently record almost all incidentally-caught squid as "Squid unidentified". The predominant species of squid in commercial catches in the EBS is believed to be the magistrate armhook squid, *B. magister*. Squids are often retained (Table 2). We assume complete mortality of incidentally caught squids because squids are fragile and are almost certainly all killed in the process of being caught, regardless of gear type or depth of fishing.

Data

Fishery data

Catch

After reaching 9,000 t in 1978, total squid catches steadily declined to only a few hundred tons in 1987-1995 (Table 2 & Figures 1-2). From 2000-2008 squid catches fluctuated around an average of approximately 1,000 t, with anomalously high catches in some years. From 2009 to 2013 catches were much smaller, ranging from 360 to 598 t. In 2014, the catch was the highest since 2001, greatly exceeding the TAC which had been set at a low level based on the low catch levels of recent years. Most of the squid catch continues to be in the walleye pollock fishery (Table 3). Retention rates of squid by BSAI groundfish fisheries have ranged between 43% and 67% since 2008.

Catch size composition

In 2007, fishery observers began collecting data on the mantle length of squids captured in BSAI pollock fisheries. Examination of past length compositions on a seasonal basis revealed two length modes that might indicates the presence of seasonal cohorts (e.g. Ormseth 2012). Aggregate length compositions for each year (Figure 3) suggest that the representation of the two modes in the annual catch (whether as a result of differences in species or age) varies among years. In recent years (2010-2013) the catch is dominated by a single size mode.

Catch distribution

The majority of catches occur in the Bering Canyon region of the southeastern Bering Sea (areas 517 & 519; Table 4 & Figure 2). Catches in the Aleutian Islands appear to have increased slightly since 2008. In the EBS, the distribution of squid catch appears to have remained fairly constant over time. While squids were caught throughout the EBS slope and outer domain of the EBS shelf, the highest catches consistently occurred near the major canyons (Figure 4). Bering Canyon, the southernmost, appears to have the highest catches. Large mean catches were also associated with Pribilof Canyon, and particularly the southern part of this canyon. In some years large catches also occurred in Zhemchug Canyon.

A survey conducted in 2009 in the Bering Canyon region suggested that the density of B. magister increases considerably below 200 m (J. Horne, pers. comm.). This is supported by the depth distribution of B. magister in the AI trawl survey. Incidental catches of squids may thus increase when fishing activity occurs at greater depths. These results suggest a possible mechanism for voluntary avoidance of squid bycatch by the pollock fishery.

Survey data

Distribution and abundance

The AFSC bottom trawl surveys are directed at groundfish species, and therefore do not employ the appropriate gear or sample in the appropriate places to provide reliable biomass estimates for the generally pelagic squids. Squid records from these surveys tend to appear at the edges of the continental shelf (Figure 5). This is consistent with results from 1988 and 1989 Japanese / U.S. pelagic trawl research surveys in the EBS that indicated that the majority of squid biomass is distributed in pelagic waters off the continental shelf (Sinclair et al. 1999), beyond the current scope of the AFSC surveys. It is also consistent with the observation that the largest biomass of squids is found at depths below 200 m (Figure 6). Survey information is included in this assessment for general information only (Table 5), and the survey biomass estimates cannot be considered reliable measures of squid abundance. Catches of squids in the EBS shelf survey are highly variable and uncertain, and it is likely that few squid inhabit the bottom waters of the shelf (Table 5). The EBS slope survey, which samples the shelf break area and much deeper waters, generally catches greater numbers of squids. *B. magister*, *G. borealis*, and *R. pacifica* are the most common squids in the slope survey (Table 5). In the AI, *B. magister* is the only squid species captured in abundance (Table 5).

Analytic approach and results

Harvest recommendations

Squids in the BSAI are currently managed under Tier 6, meaning that ABC and OFL are based on average commercial fishery catch between 1978 and 1995:

2013-2014 Tier 6 harvest recommendations for BSAI squids	
average catch 1978-1995	2,624 t
ABC (0.75 * avg. catch)	1,970 t
OFL (avg. catch)	2,624 t

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Based on discussions during the September 2014 Plan Team meetings, the SSC requested that an alternative Tier 6 recommendation be brought forward that used a time period excluding the foreign and joint venture fishing eras. Table 6 has all of the alternatives discussed in the September meetings. If the approach used in the GOA was adopted (OFL = maximum catch 1997-2007), recommendations would be as follows: OFL = 1,766 and ABC = 1,325.

Ecosystem Considerations

Fishery management should attempt to prevent negative impacts on squid populations not only because of their potential fishery value, but because of the crucial role they play in marine ecosystems. Squid are important components in the diets of many seabirds, fish, and marine mammals, as well as voracious predators themselves on zooplankton and larval fish (Caddy 1983, Sinclair et al. 1999). The prey and predators of squids depend on their life stage. Adult squid of many species will actively prey upon fish, squid, and crustaceans, while the larvae likely share the same prey items as larval fish, including copepods, euphausiids, and larval fish. Adult squid will be preyed upon by marine mammals, fish, and other squid, whereas, larval and juvenile squids will be taken by fish, squid, and seabirds.

Squids are central in food webs in both the AI (Figure 7, upper panel) and the EBS (Figure 7, lower panel). These food webs were derived from mass balance ecosystem models assembling information on the food habits, biomass, productivity and consumption for all major living components in each system. The EBS and AI are physically very different ecosystems, especially when viewed with respect to available squid habitat and densities. While direct biomass estimates are unavailable for squids, ecosystem models can be used to estimate squid densities based upon the food habits and consumption rates of predators of squid. The AI has much more of its continental shelf area in close proximity to open oceanic environments where squid are found in dense aggregations, hence the squid density as estimated by predator demand in each system is much greater in the AI relative to the EBS (labeled "BS" in the figures) and GOA (Figure 8, upper panel).

In contrast with predation mortality, estimated fishing mortality on squid is currently very similarly low in all three ecosystems. Figure 8 (lower panel) demonstrates the estimated proportions of total squid mortality attributable to fishing vs. predation, according to food web models built based on early 1990's information from the AI, EBS, and the GOA for comparison. Fishing mortality is so low relative to predation mortality that it is not visible in the plot, suggesting that current levels of overall fishery bycatch may be insignificant relative to predation mortality on squid populations. While estimates of squid consumption are considered uncertain, the ecosystem models incorporate uncertainty in partitioning estimated consumption of squid between their major predators in each system. The predators with the highest overall consumption of squid in the AI are Atka mackerel, which consume between 100 and 700 thousand metric tons of squid annually in that ecosystem, followed by "other large demersal species"

(mostly grenadiers), which consume a similar range of squid annually (Figure 9, upper panel). In the EBS, estimated consumption of squid is dominated by "other large demersal species" (grenadiers) taking in the range of 200,000 to over a million metric tons annually, followed by pinnipeds which consume up to 500,000 tons annually (Figure 9, lower panel). Squid make up about 10% of the diet of AI Atka mackerel, 30% of the diet of EBS fur seals (both adults and juveniles), and between 45 and 50% of the diet of grenadiers in both systems (Figure 10). In addition, squids are important constituents of seabird diets (Figure 11). The input data for the AFSC ecosystem models suggests that squids make up nearly half the diet of fulmars, storm petrels, and the albatross/jaegers group (Figure 11; Aydin et al. 2007). These input data are largely based on diet composition and preference data reported by Hunt et al. (2000).

Diets of squids are poorly studied, but currently believed to be largely dominated by euphausiids, copepods and other pelagic zooplankton in the AI and EBS. Assuming these diets are assessed correctly, squids are estimated to consume on the order of one to five million metric tons of these zooplankton species in both systems annually. Squids are also reported to consume forage fish as a small portion of their diet, which could amount to as much as one million metric tons annually in the AI and EBS ecosystems. While there is much uncertainty surrounding the quantitative ecological interactions of squids, as is apparent in the wide ranges of these estimates from food web models, it is clear that squids are intimately connected with both very low trophic level processes affecting secondary production of zooplankton, and in turn they comprise a significant portion of the diet of both commercially important (Atka mackerel) and protected species (pinnipeds) in the AI and EBS.

While overall fishing removals of squid are very low relative to predation at the ecosystem scale, local-scale patterns of squid removals should still be monitored to ensure that fishing operations do not have significant impacts on squid and their predators. Many squid populations are composed of spatially segregated schools of similarly sized (and possibly related) individuals, which may migrate, forage, and spawn at different times of year (Lipinski, 1998). The timing and location of fishery interactions with squid spawning aggregations may affect the availability of squid as prey for other animals as well as the age, size, and genetic structure of the squid populations themselves (Caddy 1983, O'Dor 1998). Monitoring these fishery interactions with squid could be especially important within the foraging areas for the currently declining Northern fur seals, which rely on squids for a significant portion of their diets. The essential position of squids within North Pacific pelagic ecosystems combined with our limited knowledge of the abundance, distribution, and biology of squid species in the FMP areas make squids a good case study to illustrate management of an important nontarget species complex with little information.

Data gaps and research priorities

Clearly, there is little information for stock assessment of the squid complex in the BSAI. However, ecosystem models estimate that the proportion of squid mortality attributable to incidental catch in groundfish fisheries in the BSAI region is extremely small relative to that attributable to predation mortality. Therefore, improving the information available for squid stock assessment seems a low priority as long as the catch remains at its current low level.

However, investigating potential impacts of incidental removal of squids on foraging by protected species of concern (pinnipeds, specifically northern fur seals) seems a higher priority for research. Limited data suggest that squids may make up nearly a third of the diet (by weight) for northern fur seals in the EBS. Research should investigate whether the location and timing of incidental squid removals potentially overlap with foraging seasons and areas for northern fur seals (for example, as described in Robeson 2000), and whether the magnitude of squid catch at these key areas and times is sufficient to limit the forage available for these pinnipeds. This research would require a local estimate of squid abundance but would not require a full BSAI population assessment.

Ecosystem Effects on Stock and Fishery Effects on the Ecosystem: Summary

In the following table, we summarize ecosystem considerations for BSAI squids and the entire groundfish fishery where they are caught incidentally. The observation column represents the best attempt to summarize the past, present, and foreseeable future trends. The interpretation column provides details on how ecosystem trends might affect the stock (ecosystem effects on the stock) or how the fishery trend affects the ecosystem (fishery effects on the ecosystem). The evaluation column indicates whether the trend is of: *no concern, probably no concern, possible concern, definite concern,* or *unknown.*

Ecosystem effects on BSAI Squids *(evaluating level of concern for squid populations)*

Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton Forage fish	Trends are not currently measured directly, only short time series of food habits data exist for potential retrospective measurement	Unknown	Unknown
Predator population trends			
Pinnipeds	Fur seals declining, Steller sea lions level	Possibly lower mortality on squids	No concern
Atka mackerel (AI)	Cyclically varying population with slight upward trend overall 1977-2005	Variable mortality on squids slightly increasing over time	Probably no concern
Grenadiers (BSAI)	Unknown population trend	Unknown	Unknown
Changes in habitat quality			
North Pacific gyre	Physical habitat requirements for squids are unknown, but are likely linked to pelagic conditions and currents throughout the North Pacific at multiple scales.	Unknown	Unknown

Groundfish fishery effects on ecosystem via squid bycatch *(evaluating level of concern for ecosystem)*

Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Squid catch	Stable, generally <2000 tons annually	Extremely small relative to predation on squids	No concern
Forage availability for Atka mackerel (AI)	Minor pollock fisheries in AI so very little squid catch in Atka mackerel foraging areas	Little change in forage for Atka mackerel	Probably no concern
Forage availability for grenadiers (BSAI)	Squid catch overlaps somewhat with grenadier foraging areas along slope	Small change in forage for grenadiers	Probably no concern
Forage availability for pinnipeds (EBS)	Depends on magnitude of squid catch taken in pinniped foraging areas, most catch in fur seal foraging area at shelf break by Pribilofs	Mixed potential impact (fur seals vs Steller sea lions)	Possible concern
Fishery concentration in space and time	Bycatch of squid is mostly in shelf break and canyon areas, no matter what the overall distribution of the pollock fishery is	Potential impact to spatially segregated squid cohorts and squid predators	Possible concern
Fishery effects on amount of large size target fish	Effects of squid bycatch on squid size are not measured	Unknown	Unknown
Fishery contribution to discards and offal production	Squid discard an extremely small proportion of overall discard and offal in groundfish fisheries	Addition of squid to overall discard and offal is minor	No concern
Fishery effects on age-at-maturity and fecundity	Effects of squid bycatch on squid or predator life history are not measured	Unknown	Unknown

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Tables

Table 1. Taxonomic grouping of squid species found in the BSAI.

Class Cephalopoda; Order Oegopsida	
Family Chiroteuthidae	
Chiroteuthis calyx	
Family Cranchiidae	"glass squids"
Belonella borealis	
Galiteuthis phyllura	
Family Gonatidae	"armhook squids"
Berryteuthis anonychus	minimal armhook squid
Berryteuthis magister	magistrate armhook squid
Eogonatus tinro	
Gonatopsis borealis	boreopacific armhook squid
Gonatus berryi	Berry armhook squid
Gonatus madokai	
Gonatus middendorffi	
Gonatus onyx	clawed armhook squid
Family Onychoteuthidae	"hooked squids"
Moroteuthis robusta	robust clubhook squid
Onychoteuthis borealijaponicus	boreal clubhook squid
Class Cephalopoda; Order Sepioidea	
Rossia pacifica	North Pacific bobtail squid

Table 2. Estimated total (retained and discarded) catches of squid (t) in the eastern Bering Sea and Aleutian Islands by groundfish fisheries, 1977-2012, and estimated retention rates. JV=Joint ventures between domestic catcher boats and foreign processors.

	Eastern Bering Sea				Aleutian Islands				BSAI	%
Year	foreign	JV	domestic	total EBS	foreign	JV	domestic	total AI	total	retained
1977	4,926			4,926	1,808			1,808	6,734	
1978	6,886			6,886	2,085			2,085	8,971	
1979	4,286			4,286	2,252			2,252	6,538	
1980	4,040			4,040	2,332			2,332	6,372	
1981	4,178	4		4,182	1,763			1,763	5,945	
1982	3,833	5		3,838	1,201			1,201	5,039	
1983	3,461	9		3,470	509	1		510	3,980	
1984	2,797	27		2,824	336	7		343	3,167	
1985	1,583	28		1,611	5	4		9	1,620	
1986	829	19		848	1	19		20	868	
1987	96	12	1	109		23	1	24	131	
1988		168	246	414		3		3	417	
1989		106	194	300		1	5	6	306	
1990			532	532			94	94	626	
1991			544	544			88	88	632	
1992			819	819			61	61	880	
1993			611	611			72	72	683	
1994			517	517			87	87	604	
1995			364	364			95	95	459	
1996			1,083	1,083			84	84	1,167	
1997			1,403	1,403			71	71	1,474	
1998			891	891			25	25	915	
1999			432	432			9	9	441	
2000			375	375			8	8	384	
2001			1,761	1,761			5	5	1,766	
2002			1,334	1,334			10	10	1,344	
2003			1,246	1,246			36	36	1,282	
2004			1,000	1,000			14	14	1,014	
2005			1,170	1,170			17	17	1,186	
2006			1,403	1,403			15	15	1,418	
2007			1,175	1,175			13	13	1,188	
2008			1,494	1,494			49	49	1,542	67%
2009			269	269			91	91	360	51%
2010			305	305			105	105	410	63%
2011			237	237			99	99	336	43%
2012			560	560			128	128	688	66%
2013			158	158			141	141	300	37%
*2014**			*1,561*	*1,561*			*107*	*107*	*1,668*	*40%*

* 2014 catch and retention data are incomplete; retrieved October 8, 2014.

Data Sources: Foreign and JV catches-U.S. Foreign Fisheries Observer Program, AFSC Domestic catches before 1989 (retained only; do not include discards): Pacific Fishery Information Network (PacFIN). Domestic catches 1989-2002: NMFS Alaska Regional Office BLEND. Domestic catches 2003-present: NMFS AKRO Catch Accounting System.

Table 3. Estimated catch (t) of all squid species combined by target fishery, 2003-2014. Data sources as in Table 2.

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	***2014****
pollock	1,226	977	1,150	1,399	1,169	1,452	209	277	178	495	118	*1,478*
arrowtooth	7	6	10	4	3	46	96	104	67	60	68	*69*
rockfish	12	6	7	6	8	25	18	12	37	33	60	*50*
Kamchatka	0	0	0	0	0	0	0	0	48	76	36	*42*
Atka	21	7	9	9	5	12	14	16	5	23	15	*28*
other flatfish	3	2	6	0	2	1	0	0	0	0	1	*0*
flathead sole	0	4	1	0	0	0	0	0	0	0	1	*0*
yellowfin sole	1	0	0	0	0	0	0	0	0	0	0	*0*
Pacific cod	9	6	3	1	1	0	0	0	0	0	0	*1*
rock sole	0	0	0	0	0	0	0	0	0	0	0	*0*
sablefish	0	0	0	0	0	1	0	0	0	0	0	*0*
Grn turbot	3	6	0	0	0	4	23	1	0	0	0	*1*
Alaska plaice	0	0	0	0	0	0	0	0	0	0	0	*0*
BSAI total	**1,282**	**1,014**	**1,186**	**1,418**	**1,188**	**1,542**	**360**	**410**	**336**	**688**	**300**	***1,668***

* 2014 catch estimate as of October 8, 2014.

Table 4. Estimated catch (t) of all squid species combined by area, 2003-2014*. Data sources as in Table 2.

Aleutian Islands (AI)												
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	*2014**
541	9	4	3	2	2	25	66	90	75	114	107	*73*
542	10	7	2	6	3	6	5	4	8	6	5	*13*
543	17	3	12	7	8	18	20	11	16	8	30	*21*
AI total	**36**	**14**	**17**	**15**	**13**	**49**	**91**	**105**	**99**	**128**	**141**	***107***

eastern Bering Sea (EBS)												
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	*2014*
508	0	0	0	0	0	0	0	0	0	0	0	*0*
509	2	7	5	162	13	25	1	5	3	16	5	*19*
513	2	2	0	1	12	9	2	0	1	2	1	*0*
514	0	0	0	0	0	0	0	0	0	0	0	*0*
516	0	0	0	0	0	0	0	0	0	0	0	*0*
517	746	587	539	965	690	1,066	143	133	119	306	63	*935*
518	0	0	0	0	0	23	40	17	30	17	2	*42*
519	484	398	527	261	419	344	74	145	52	189	41	*548*
521	12	5	95	15	26	25	9	5	17	20	33	*12*
523	0	0	3	0	0	1	0	1	3	0	1	*0*
524	0	0	0	0	15	0	0	0	12	9	11	*5*
EBS total	**1,246**	**1,000**	**1,170**	**1,403**	**1,175**	**1,494**	**269**	**305**	**237**	**560**	**158**	***1,561***
BSAI total	**1,282**	**1,014**	**1,186**	**1,418**	**1,188**	**1,542**	**360**	**410**	**336**	**688**	**300**	***1,668***

* 2014 catch estimate as of October 8, 2014.

Table 5. Survey biomass estimates ("bio", in metric tons) and coefficients of variation (CV) for the EBS shelf, EBS slope, and AI. Estimates are included for the principal species caught in each survey. Numerous species occur on the slope and are included in the "total squids" category for that region. Red cells mark CVs in excess of 0.5.

	EBS shelf				**EBS slope**								**AI**	
	R. pacifica		*B. magister*		*R. pacifica*		*B. magister*		*G. borealis*		total squids		*B magister*	
	bio	CV	bio	CV	bio	CV	bio	CV	bio	CV	bio	CV	bio	CV
1983	100	0.32	0	-									9,557	0.33
1984	61	0.30	14	0.94										
1985	4	0.75	13	1.00										
1986	34	0.35	0	-									15,761	0.51
1987	46	0.41	80	1.00										
1988	97	0.63	0	-										
1989	3	1.00	0	-										
1990	5,680	0.99	0	-										
1991	0	-	0	-									28,934	0.89
1992	0	-	0	-										
1993	0	-	0	-										
1994	0	-	0	-									11,084	0.84
1995	6	0.70	0	-										
1996	23	0.42	0	-										
1997	3	1.00	0	-									2,689	0.24
1998	60	0.46	0	-										
1999	19	0.48	0	-										
2000	13	0.45	42	0.82									2,758	0.18
2001	20	0.51	280	0.42										
2002	33	0.39	0	-	52	0.18	1,198	0.12	2	0.74	1,270	0.11	2,088	0.14
2003	27	0.37	16	1.00										
2004	6	0.82	0	-	58	0.19	1,418	0.14	52	0.37	1,642	0.13	3,250	0.37
2005	13	0.67	0	-										
2006	9	0.74	47	1.00									1,468	0.14
2007	11	0.71	0	-										
2008	8	0.52	0	-	36	0.32	1,717	0.10	54	0.41	1,826	0.09		
2009	19	0.41	623	1.00										
2010	42	0.60	9	1.00	72	0.25	1,831	0.10	8	0.32	1,928	0.10	2,444	0.22
2011	25	0.51	1	1.00										
2012	25	0.43	43	1.00	43	0.23	1,298	0.09	13	0.40	1,361	0.09	4,011	0.28
2013	146	0.84	28	1.00										
2014	21	0.49	0	-									6,178	0.30

Table 6. Alternative approaches for determining squid harvest recommendations in the BSAI.

	BSAI	
current approach	OFL = 1978-1995 average	
current specifications	OFL	ABC
	2,620	1,970
catch-based approaches	OFL	ABC
78-85 average	5,204	3,903
78-85 max	8,971	6,728
90-07 average	970	728
90-07 max	1,766	1,325
90-07 CI 95%UB	1,158	868
90-07 CI 99%UB	1,217	913
97-07 average	1,128	846
97-07 max	1,766	1,325
97-07 CI 95%UB	1,377	1,033
97-07 CI 99%UB	1,455	1,091
F x *B* approaches		
recent biomass average	4,932	
ecosystem model estimate	880,006	
	OFL	ABC
F=0.3 (survey)	1,479	1,110
decay function (survey)	2,132	1,936
F=0.3 (ecosystem model)	264,002	198,001
decay function (ecosystem model)	380,455	345,471

Figures

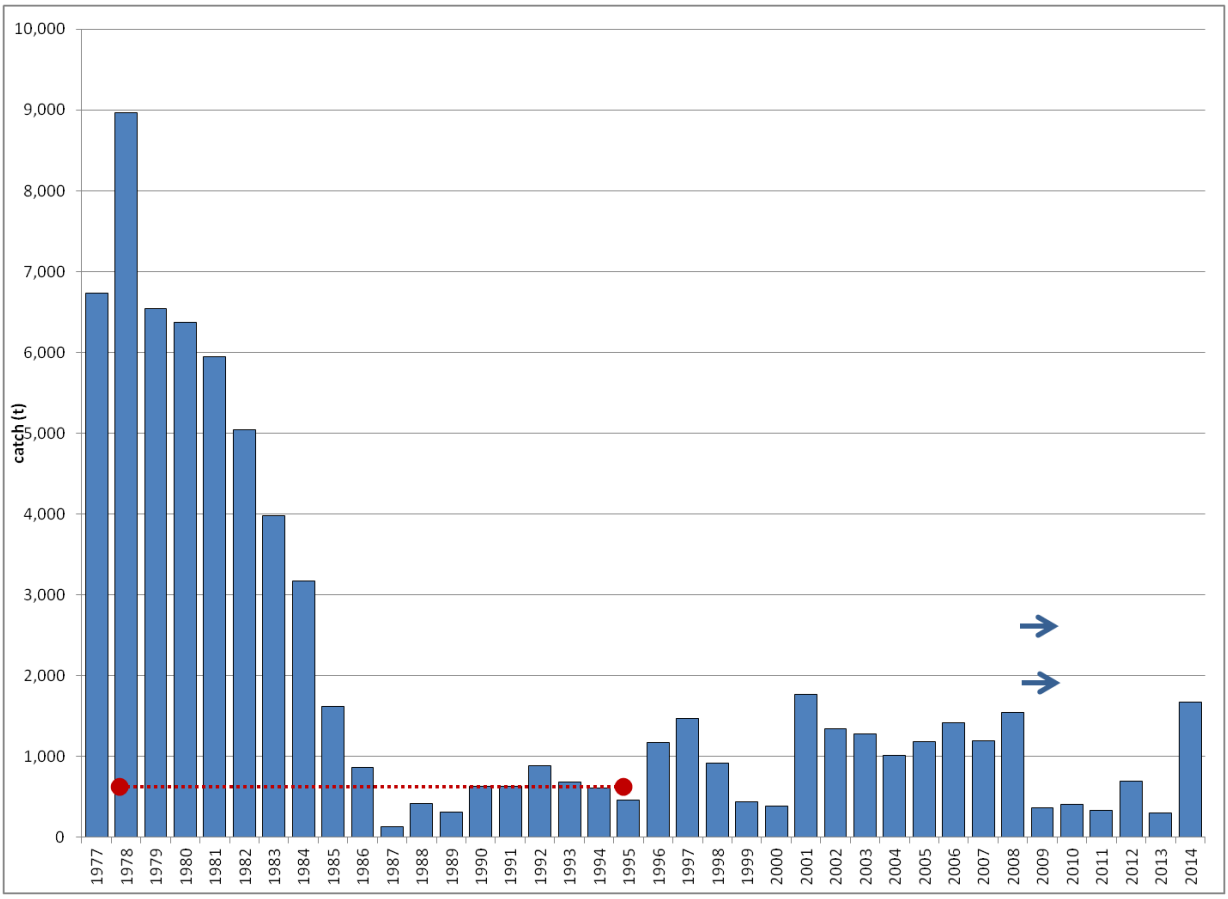

Figure 1. Historical catches of squids in the Bering Sea and Aleutian Islands, 1977-present. Dashed red line indicates period currently used for developing harvest recommendations. Blue arrows indicate current ABC and OFL for BSAI squids. .

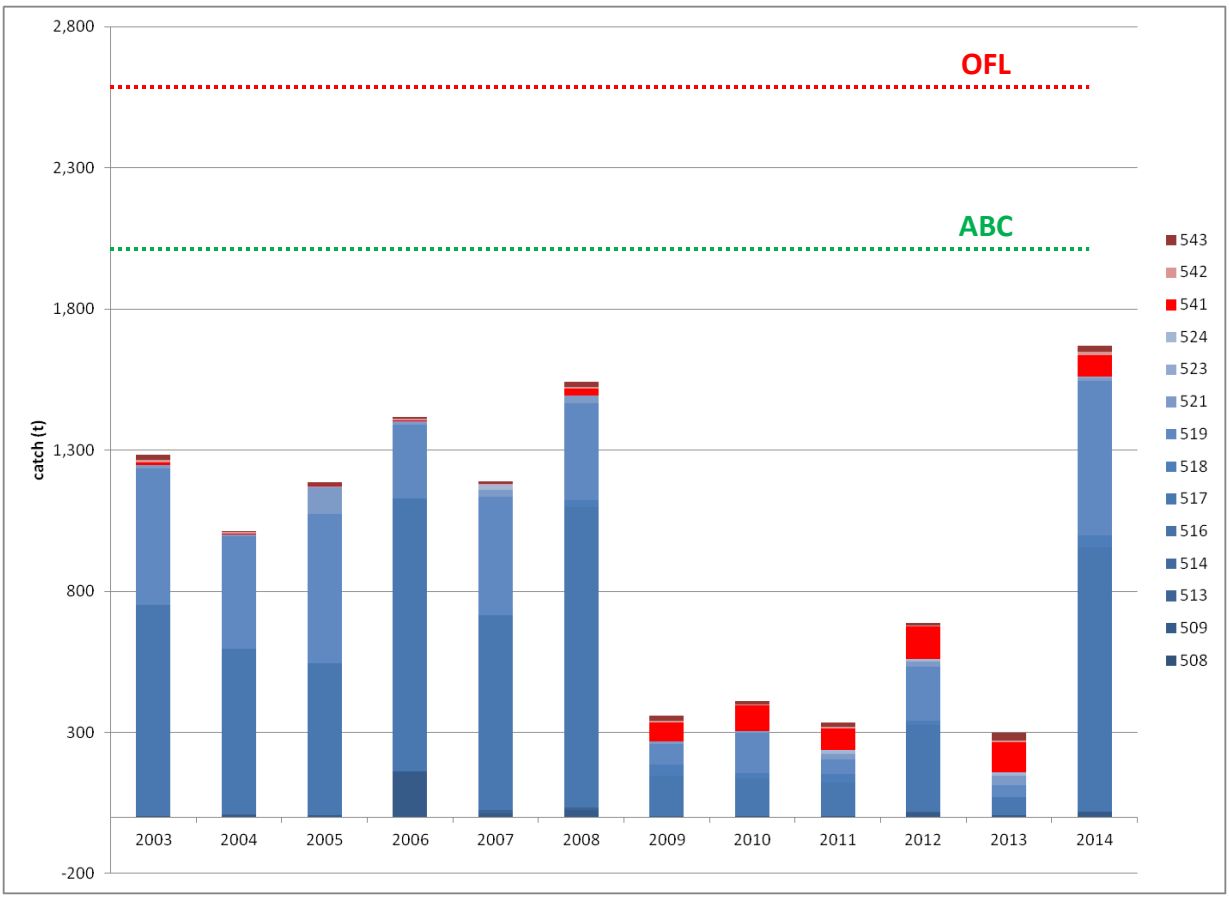

Figure 2. Estimated total fishery catch (t) of all squid species in NMFS management areas of the BSAI region, 2003-2014(2014 data as of October 8, 2014). Numbers in legend refer to management area. Blue indicates EBS areas; red indicates AI areas. The current OFL and ABC are indicated on the plot.

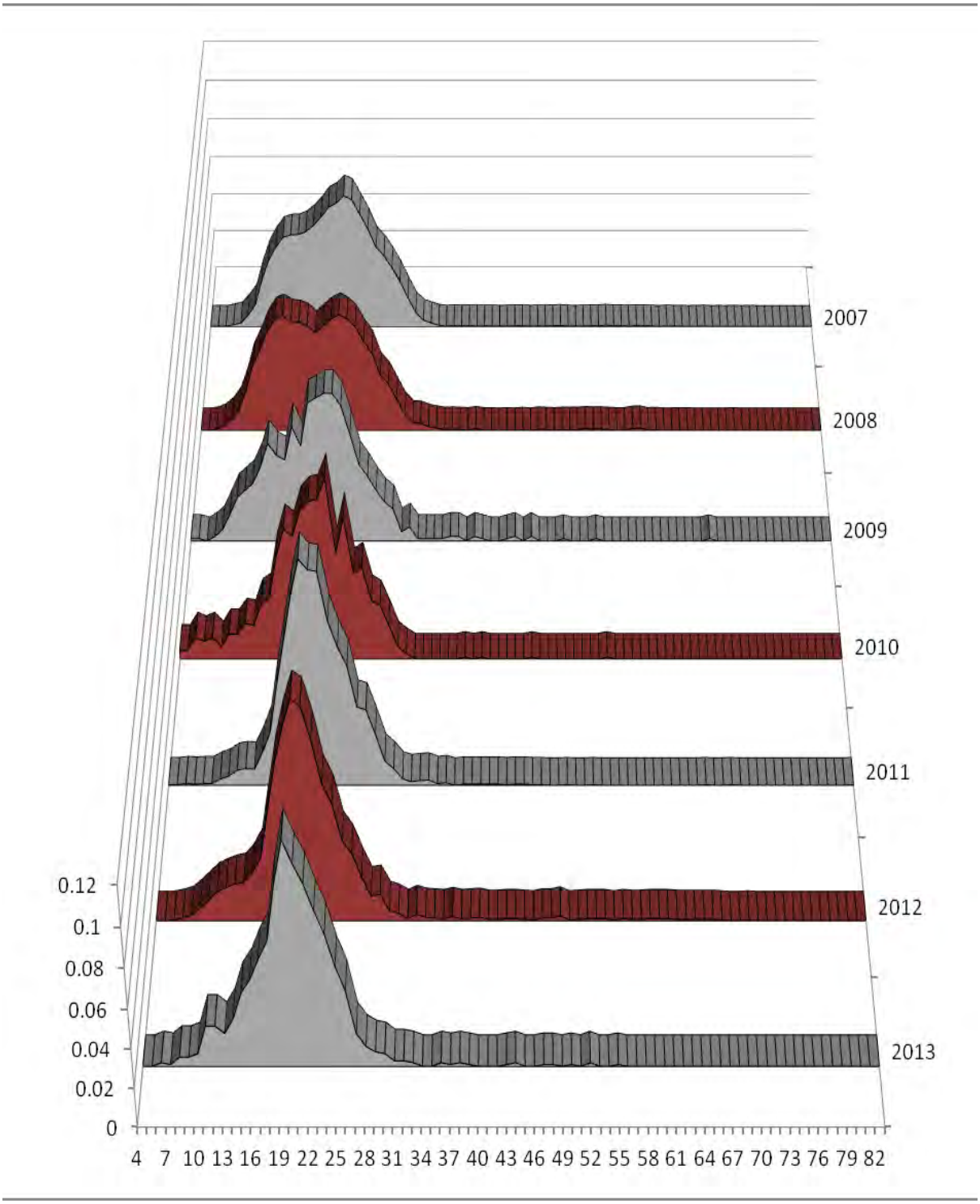

Figure 3. Length compositions by year, of squids captured in BSAI federal fisheries, 2007-2013. Data are from the AFSC's Fishery Monitoring and Analysis program.

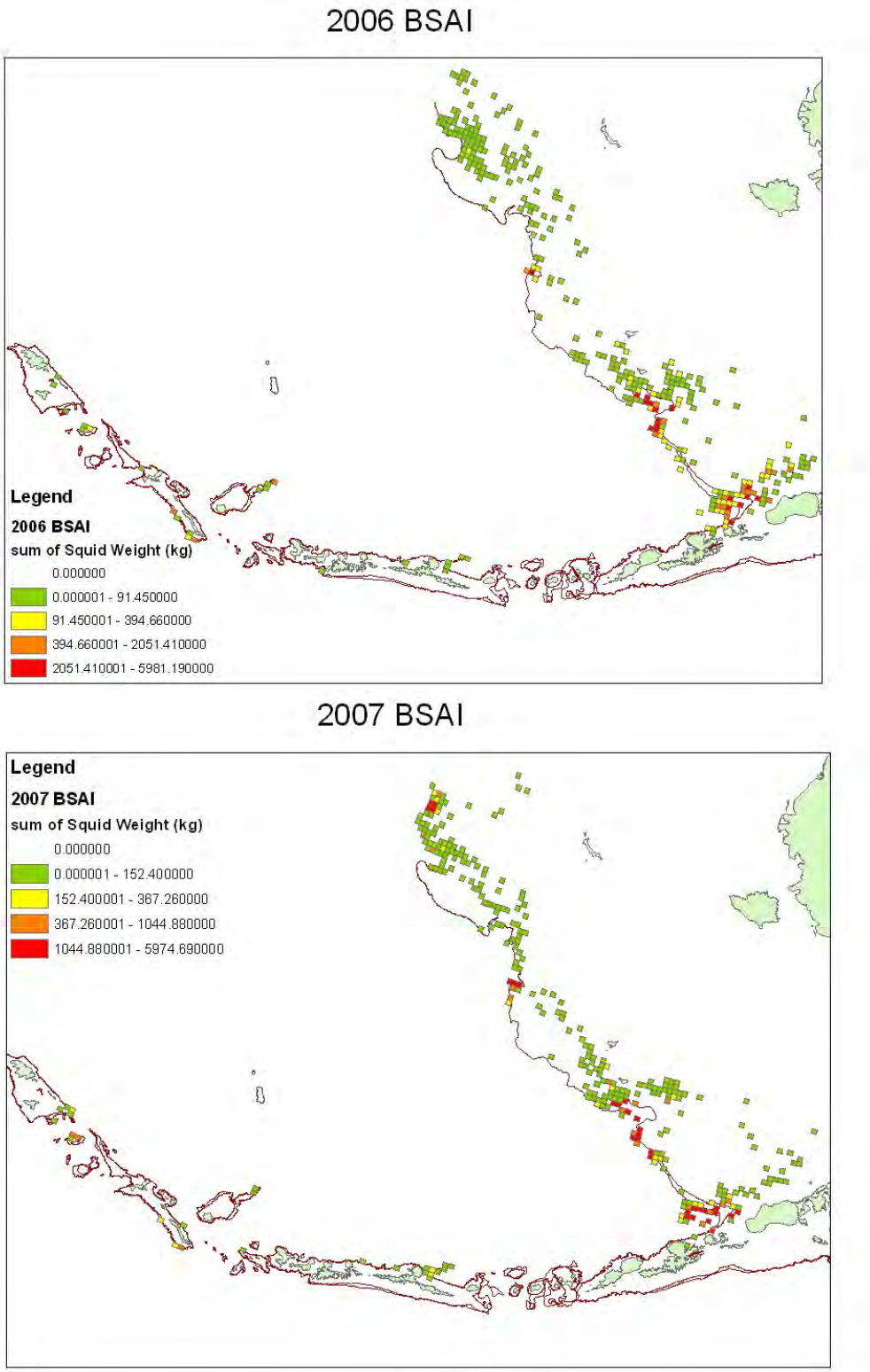

Figure 4. . Distribution of observed annual squid catches from 2006-2007. Each 100 km^2 grid cell depicts the total observed catch in kg. For confidentiality, only grid cells containing data from three unique vessels are shown. Data are from the AFSC Fisheries Monitoring and Analysis program. Catch values delineating color legend are not consistent among years.

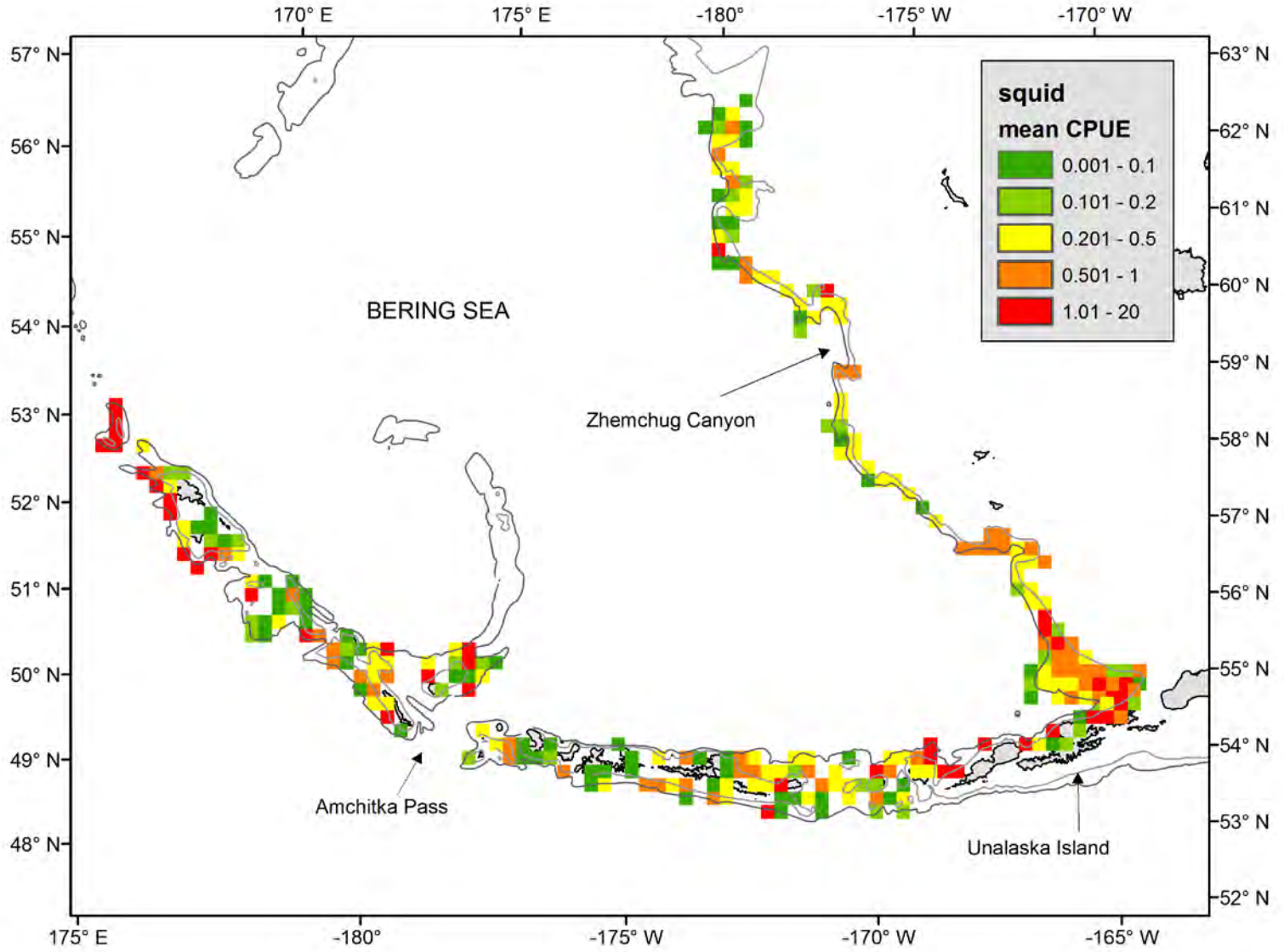

Fig. 5. Mean trawl survey CPUE of all squid species combined in the BSAI, 2000-2012. Grid cells are 20 km X 20 km.

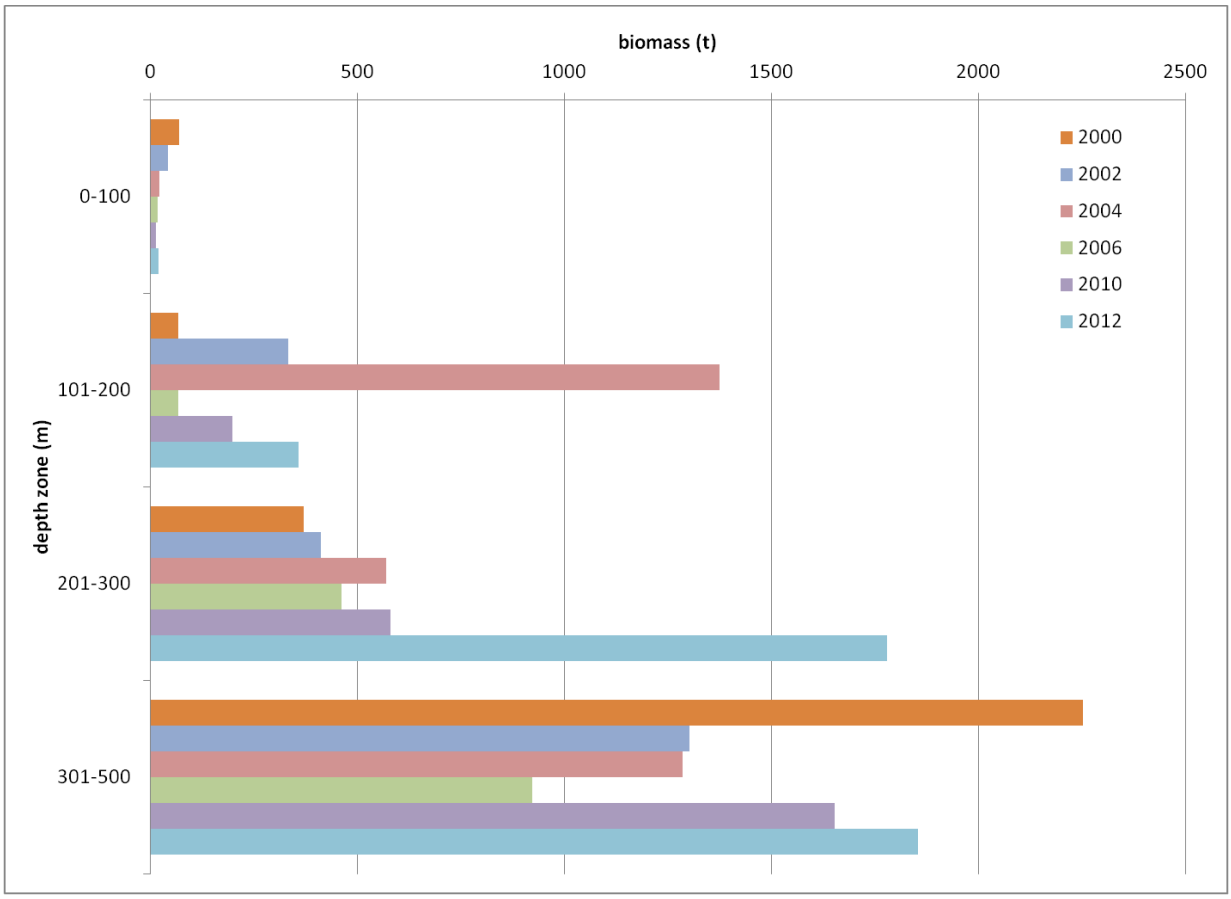

Figure 6. Depth distribution of *Berryteuthis magister* survey biomass estimates in the AI, 2000-2012.

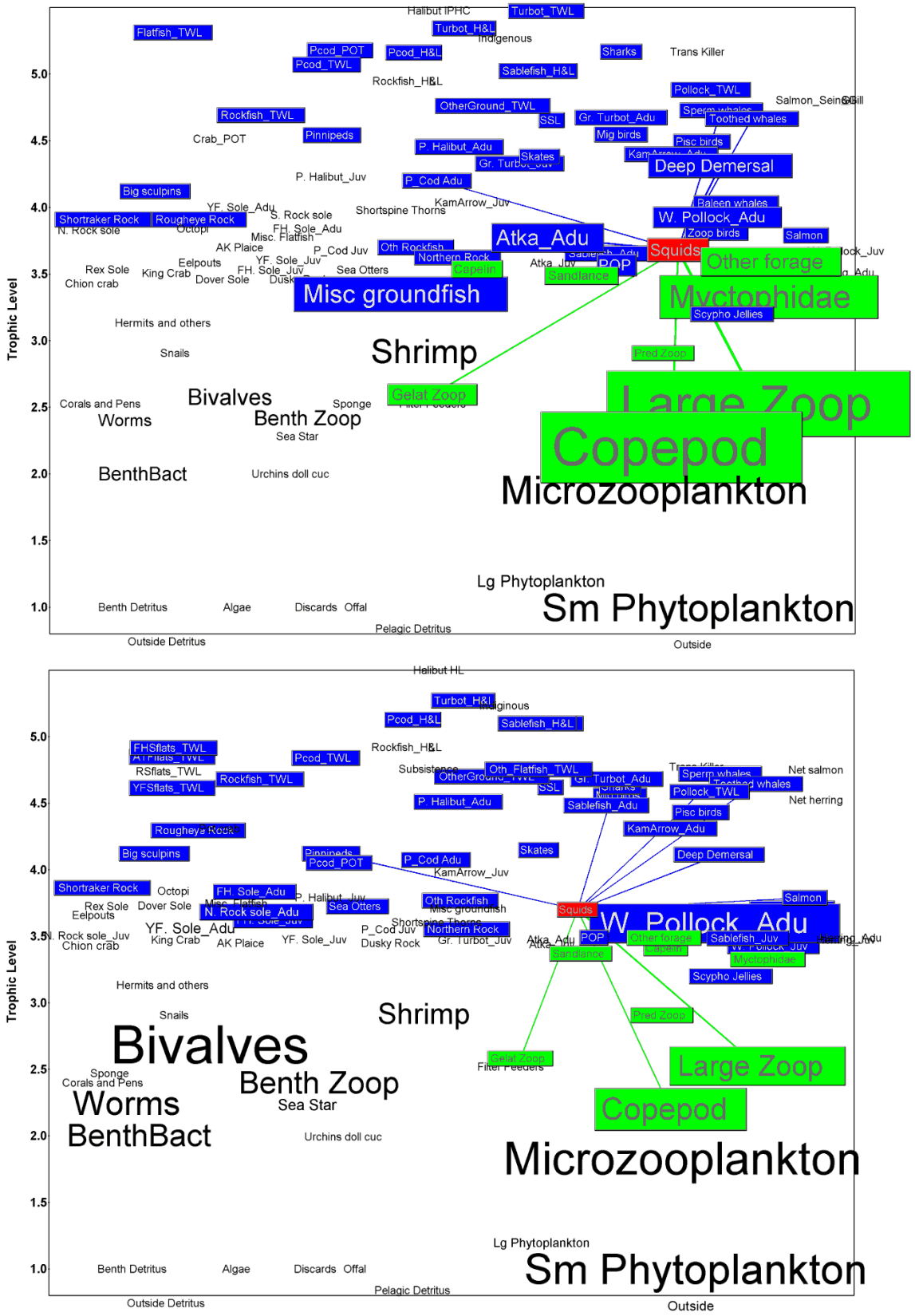

Figure 7. AI (upper) and EBS (lower) food webs of squids (red), predators (blue), and prey (green).

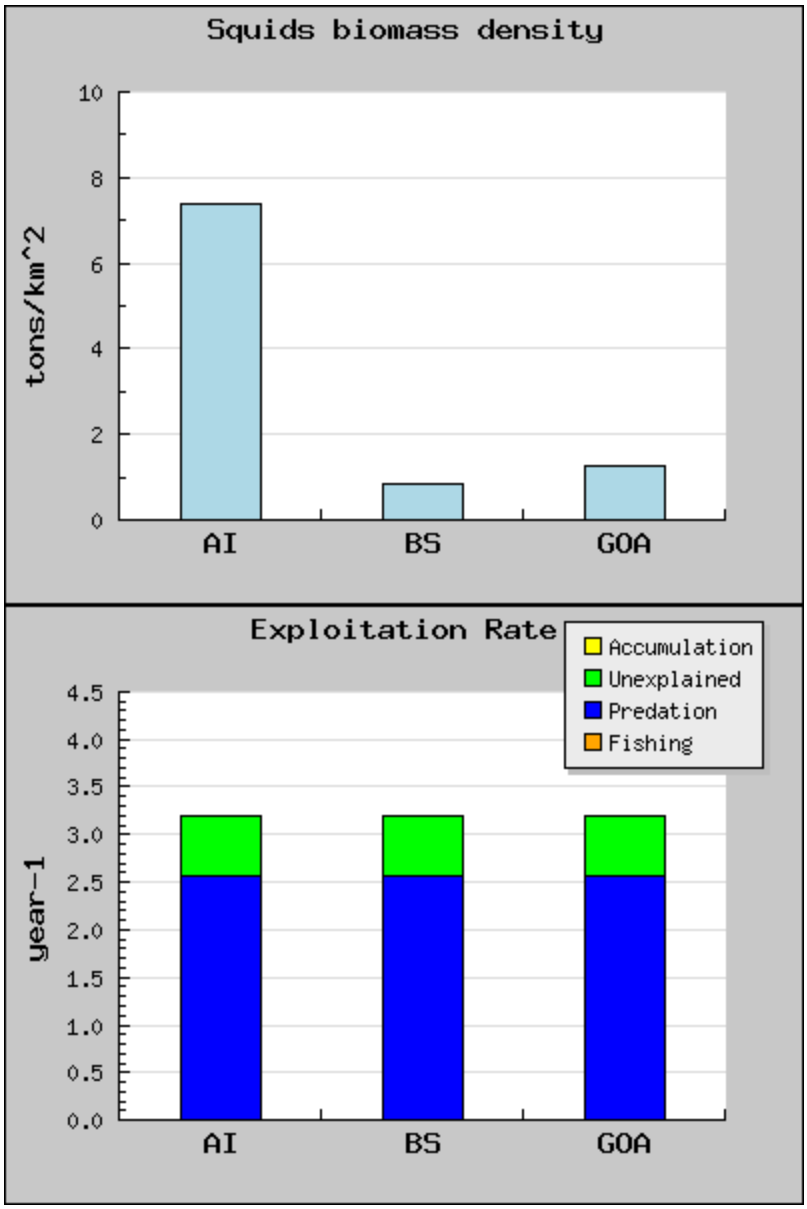

Figure 8. Biomass density (tons per square kilometer) come from direct estimates of consumption by groundfish of the AI, EBS, and GOA (upper panel), and exploitation rates partitioned into mortality due to predation, fishing, and unexplained sources (lower panel). Fishing mortality has been included in this calculation, but is too small to show on the plot.
Disclaimer: Figures generated in October 2005, we are currently awaiting updated figures. The calculation for this is Equation 1.1 in Appendix 1 of the Ecosystem Assessment (page 83).

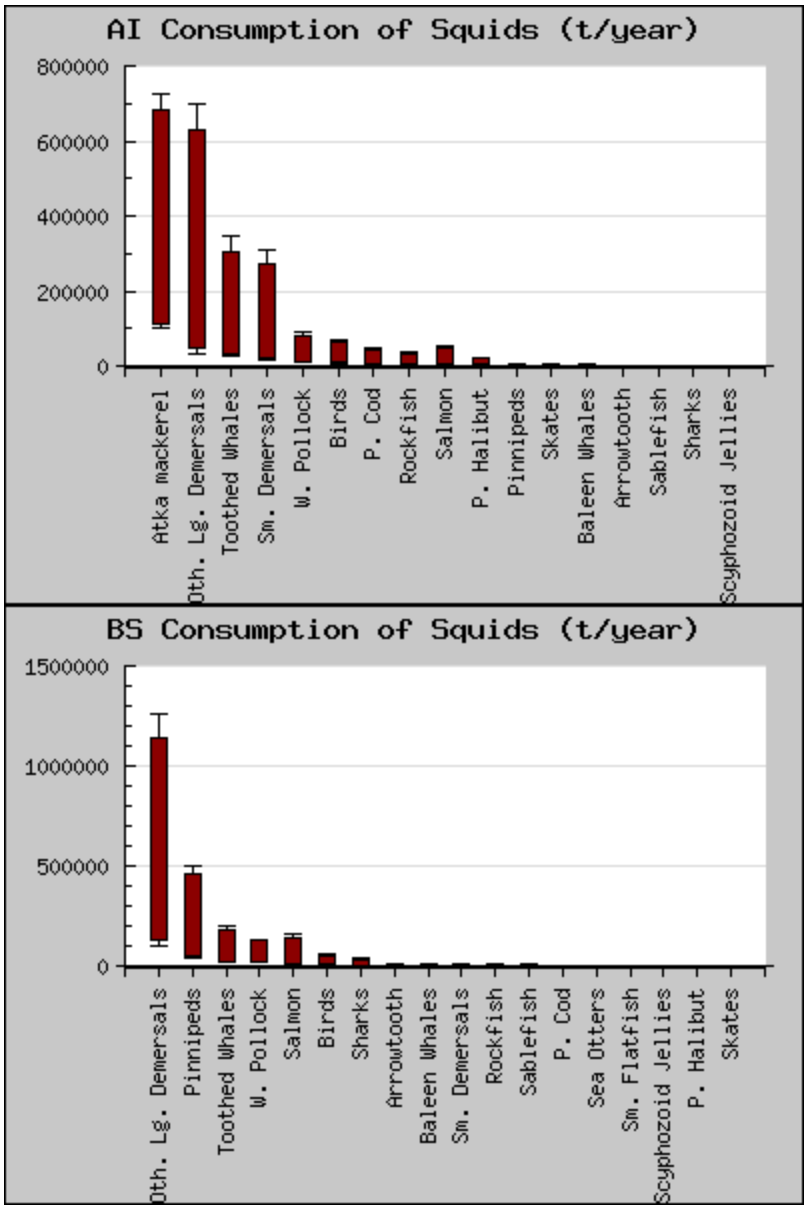

Figure 9. Consumption of squids estimated from ecosystem models for the AI (upper) and EBS (lower), based on early 1990's data and incorporating uncertainty. "Other large demersals" is primarily grenadiers (Macrouridae) in both ecosystems.

Disclaimer: Figures generated in October 2005, we are currently awaiting updated figures. Description of method is in an appendix of the Ecosystem considerations chapter.

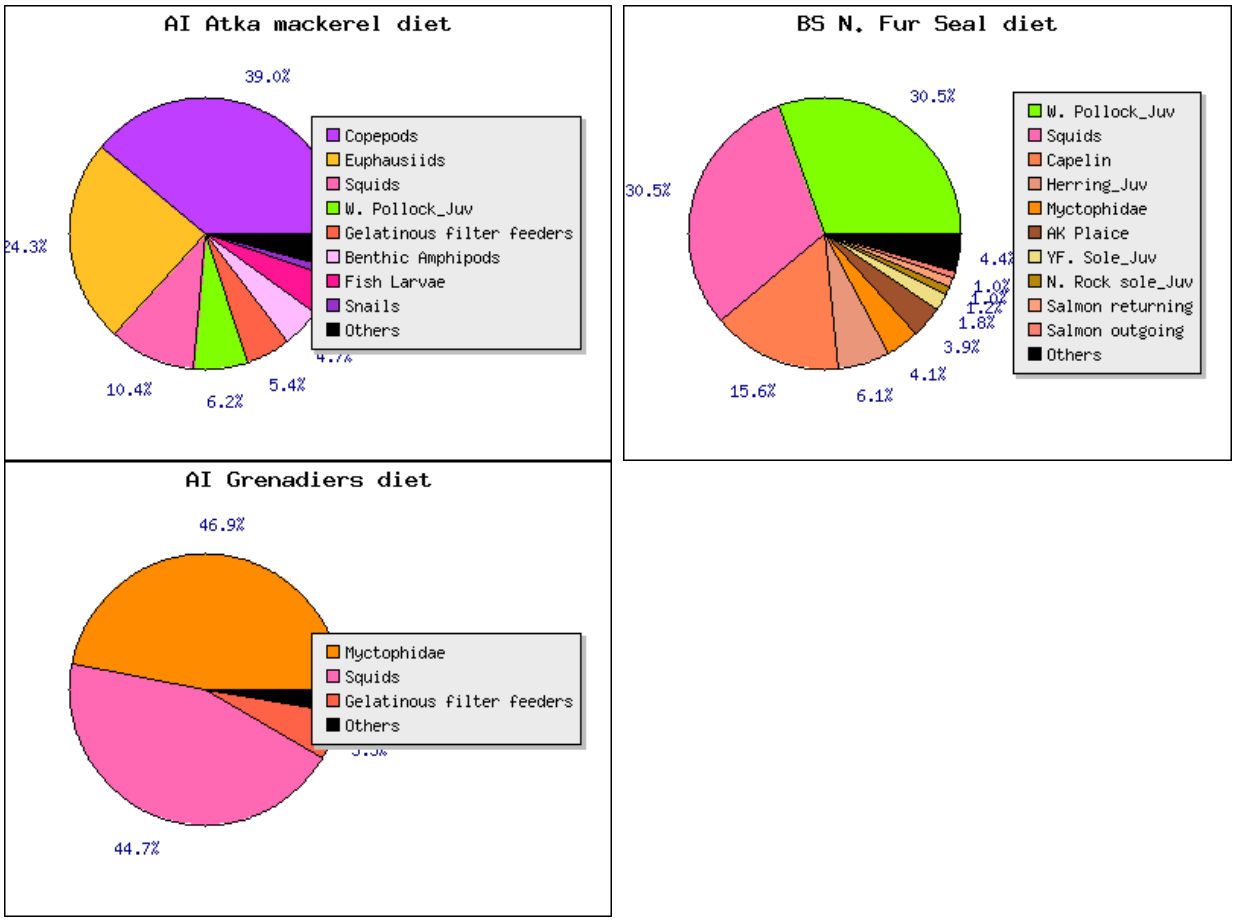

Figure 10. Proportion of squids in diets of major squid consumers in BSAI: Atka mackerel (top), northern fur seals (center), and grenadiers (bottom). EBS grenadier diets (not shown) are similar to AI.
Disclaimer: Figures generated in October 2005, we are currently awaiting updated figures. Description of method is in an appendix of the Ecosystem considerations chapter.

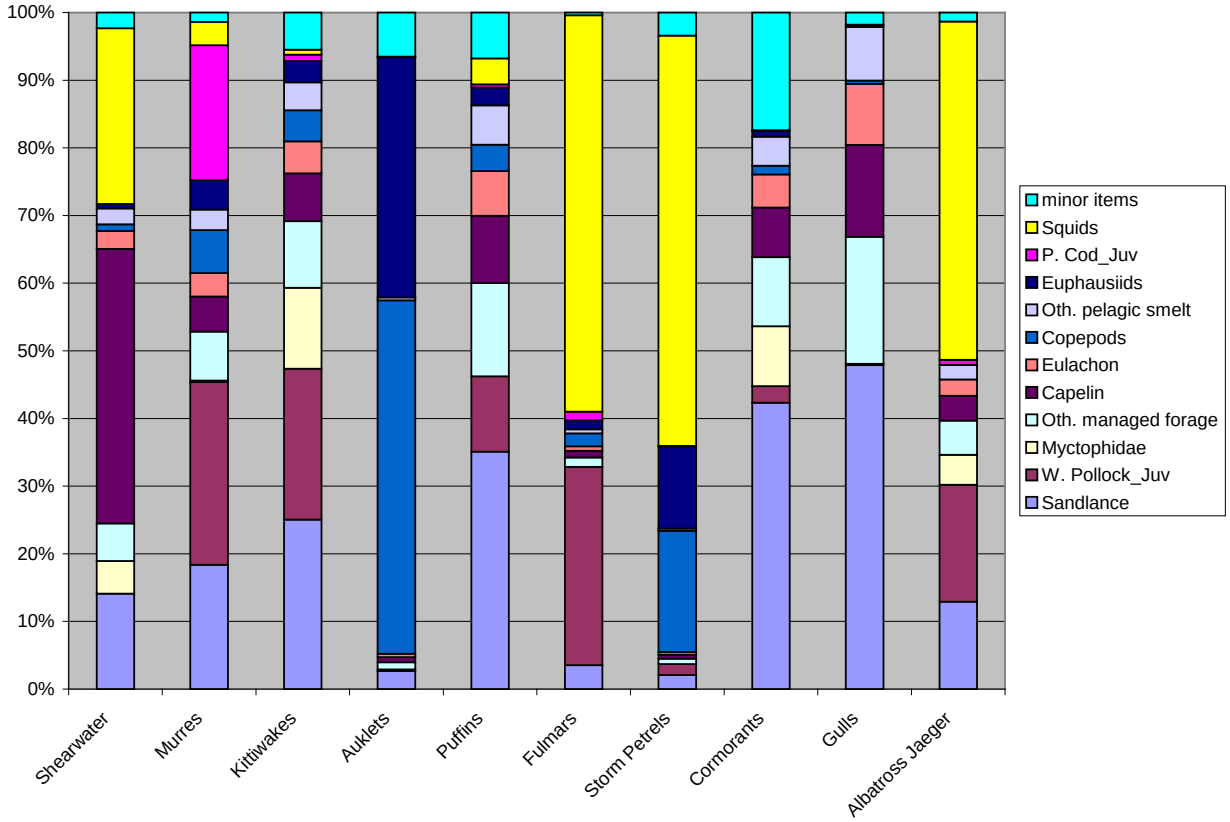

Figure 11. Estimated diet composition of seabirds in the GOA. Data are the inputs used in ecosystem modeling performed at the AFSC (Aydin et al. 2007) and are based largely on Hunt et al. (2000). Albatrosses and jaegers are considered a single functional group for modeling purposes.

Appendix 1. Non-commercial catches of squids in the BSAI, 2010-2014. 2014 data may be incomplete. Data are from the Alaska Regional Office.

Source of removal	2010	2011	2012	2013	2014
Aleutian Island Bottom Trawl Survey	1.9		4.0		29.5
Aleutian Islands Cooperative Acoustic Survey					
Bering Sea Acoustic Survey	6.5				
Bering Sea Bottom Trawl Survey	1.4				
Bering Sea Slope Survey	16.3		9.4		
Bogoslof EIT Survey with Northern Extensions			6.8		
Eastern Bering Sea Bottom Trawl Survey		0.8	0.8	5.3	0.7
Gulf of Alaska Bottom Trawl Survey		0.0			
Large-Mesh Trawl Survey			1.1	1.2	
Pollock EFP 11-01			12,143.3		
Grand Total	**26.1**	**0.8**	**12,165.4**	**6.5**	**30.2**

22. Assessment of the Octopus Stock Complex in the Bering Sea and Aleutian Islands

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Alaska Fisheries Science Center
November 2014

Executive Summary

Through 2010, octopuses were managed as part of the BSAI "other species" complex, along with sharks, skates, and sculpins. Historically, catches of the other species complex were well below TAC and retention of other species was small. However, due to recent increased market values, retention of some of the other species complex members increased. Beginning in 2011, the BSAI fisheries management plan was amended to provide separate management for sharks, skates, sculpins, and octopus and set separate catch limits for each species group. Catch limits for octopus for 2011 were set using Tier 6 methods based on the maximum historical incidental catch rate. In 2012, a new methodology based on consumption of octopus by Pacific cod was introduced; this method was accepted and used for 2013 and 2014. The consumption estimate has not been revised from 2012; the authors recommend that this calculation be revisited once every five years.

In this assessment, all octopus species are grouped into one assemblage. At least seven species of octopus are found in the BSAI. The species composition of the octopus community is not well documented, but data indicate that the giant Pacific octopus *Enteroctopus dofleini* is most abundant in shelf waters and predominates in commercial catch. Octopuses are taken as incidental catch in trawl, longline, and pot fisheries throughout the BSAI; a portion of the catch is retained or sold for human consumption or bait. The highest octopus catch rates are from Pacific cod fisheries in the three reporting areas around Unimak Pass. The Bering Sea and Aleutian Island trawl surveys produce estimates of biomass for octopus, but these estimates are highly variable and do not sample the same sizes of octopus caught by industry. Examination of size frequency from survey and fishery data shows that both commercial and survey trawls catch predominantly small animals (<5 kg), while commercial pot gear catches or retains only larger animals (10-20 kg). In general, the state of knowledge about octopus in the BSAI is poor. A number of research studies and special projects have been initiated in recent years to increase knowledge for this assemblage; results of these studies are summarized in Appendix 1 to this assessment.

Summary of Changes in Assessment Inputs

Changes in the input data
Survey data have been updated with the 2014 Bering Sea shelf survey and Aleutian Islands survey results. Incidental catch has been updated to include estimated catch for the entirety of 2013 and for 2014 through October 17, 2014.

Changes in the assessment methodology
There are no changes to the assessment methodology.

Summary of Results

This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Marine Fisheries Service and should not be construed to represent any agency determination or policy.

The estimated total catch for 2013 and the preliminary 2014 catch are just over 220 tons, higher than in 2012 but substantially lower than the very high catch in 2011. The TAC for octopus in 2014 was set at 225 t, which was exceeded by the catch of 233 t in 2014 as of October 17, 2014 . Because this TAC is well below the ABC, the TAC was increased slightly by reallocating from the non-specified reserves in order to accommodate fall 2014 incidental catch. The retained percentage of octopus in 2013 and 2014 was about 25%.

The current data are not sufficient for a model-based assessment. From 2006 through 2010, preliminary stock assessments of octopus were prepared that presented both Tier 5 and Tier 6 estimates of OFL and ABC. The SSC and plan teams have discussed the difficulties in applying groundfish methodologies to octopus and have agreed to treat octopus as a Tier 6 species, owing to inadequate data for estimating Tier 5 parameters. There are no historical catch records for octopus. Estimates of incidental catch rates from 1997-2014 are available, but do not represent catch rates under any directed fishery. The SSC and Plan Teams have approved an alternative methodology for setting octopus catch limits in the BSAI. This method uses a predation-based estimate of total natural mortality and the logistic fisheries model to set the OFL equal to a highly conservative estimate of total natural mortality; the OFL and ABC from this approach are much higher than the historical incidental catch. This approach was used to set catch limits for 2013 and 2014 and is brought forward without change (consumption estimates have not been recalculated) for 2015 and 2016. The authors and plan teams note that the standard Tier 6 approach based on the incidental catch would yield an overly conservative limit. The current methodology is based on extensive diet data and includes estimation of uncertainty in calculations.

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2013	2014	2015	2016
Tier 6 (consumption estimate)				
OFL (t)	*3,452*	*3,452*	**3,452**	3,452
Maximum permissible ABC (t)	*2,589*	*2,589*	**2,589**	2,589
ABC (t)	*2,589*	*2,589*	**2,589**	2,589
	As determined *last* year for:		As determined *this* year for:	
Status	2012	2013	2013	2014
Overfishing	n/a	n/a	n/a	n/a

Responses to SSC and Plan Team Comments on Assessments in General

Responses to SSC and Plan Team Specific to this Assessment

The SSC reviewed and approved the consumption-based methodology for octopus in December 2011, but noted that both survey and consumption estimates are highly uncertain and encouraged development of a species-specific survey or other assessment approaches. Research toward both survey feasibility and a size-based population model is currently being conducted, and is described in Appendix 1. The 2011 stock assessment included analyses requested by the SSC on spatial and temporal patterns in octopus catch and more detailed analysis of diet data used in forming the consumption estimate. Results of that analysis have been carried forward into this assessment. Temporal catch patterns in the pot fishery are primarily determined by seasonal timing of pot fishing for Pacific cod, and spatial patterns in octopus catch are primarily determined by gear conflict considerations and proximity to processors. Requested

research on octopus discard mortality is nearing conclusion; preliminary results are included in Apppendix 1.

At their December 2013 meeting, the SSC did not request any specific additions or changes to the stock assessment, but made several recommendations to the Council for factors to be considered before allowing a directed octopus fishery. These included further development of survey techniques through an experimental fishery, a possible minimum size limit, and 100% observer coverage of any directed fishery. The assessment authors are in full concurrence with these recommendations. The SSC also encouraged further research on ageing techniques for octopus, spatial migration studies, and examination of stock structure for octopus. These activities will be pursued as funding and staffing allow, but are not likely to be resolved in the immediate future. A limited amount of research has been conducted recently on octopus genetics; this information has been added to the description of life history of *Enteroctopus dofleini*. The work to date identifies a possible sub-species within Prince William Sound, but does not indicate any strong variation between octopus sampled at GOA locations from British Columbia to Dutch Harbor (Toissant et al. 2012).

Responses to CIE Review Comments

In May 2013, a panel from the Center for independent Experts (CIE) reviewed the AFSC stock assessments for non-target species. The panel reviewed assessments for sculpins, sharks, skates, grenadiers, squid, and octopus. The panel provided comments both on individual assessments and on the overall Tier 5 and Tier 6 process. All of the reviewers agreed that for Tier 5, "The main problem is the assumption that trawl survey biomass indices are legitimate estimates of absolute biomass". The reviewers suggested that issues of survey coverage, catchability, selectivity, and habitat coverage (i.e. extending survey data to represent untrawlable areas) make it difficult to treat survey estimates as absolute biomass. These issues are being addressed by the AFSC survey groups given funding and staffing constraints, but probably cannot be fully resolved. Specific to octopus, the difficulties with survey biomass estimates include lack of survey coverage of shallow areas and rocky habitats; an unknown but probably large catchability effect, size selectivity issues, and large variance estimates due to the fairly rare occurrence of octopus in trawl catch. These issues have already been recognized for octopus and are discussed under "Model Parameters". The reviewers agreed with the non-target assessments that "The bottom trawl is likely inadequate for sampling other nontarget species such as squid, sharks and octopus."

The reviewers also recommended that the determination of ABC be based on a species-specific assessment of uncertainty rather than a fixed percentage of OFL. Changing this procedure is feasible but would require changes to the regulatory structure of FMPs and is best addressed by the Plan Teams, SSC, and Council. All three reviewers also noted various problems with the use of historical incidental catch data for stock assessment, and recommended that when there was no other alternative, the time period of historical catch be selected on a species-specific basis.

Specific to the octopus assessment, the reviewers primarily noted difficulties and limitations with all of the methods that have been used or proposed to date. One reviewer stated "*If budget allows, I recommend that a dedicated survey with habitat pot gear as developed by Conners et al. (2012), with some refinement, be used to track year-to-year variation in octopus biomass overtime in different areas*." Research to develop and refine the pot gear is currently being conducted (see Appendix 1). Another reviewer concluded that the consumption estimate approach was probably the best of a set of poor alternatives, and suggested several ways to check and refine consumption model estimation. While the consumption model estimates have not been updated for this assessment, the suggested modifications will be examined during the next update of consumption estimates.

The third reviewer strongly advocated that "*The use of M as a proxy for F_{MSY} is unnecessary and may be inappropriate for many species (as F_{MSY} depends strongly on the stock-recruitment relationship and the fishery selectivity). It is preferable to construct a simple species/stock-specific simulation model and use it to explore the plausible parameter space to determine an appropriate proxy for F_{MSY}.*" and provided an example of such a model for octopus. This model suggested that $F_{40\%}$ would be a better alternative to catch regulation than F_{MSY}. In the absence of any reliable estimate of biomass, however, it would be difficult to calculate this quantity.

Based on CIE comments, the author has started to examine a size-based assessment model for octopus, to use as a simulation model for indentifying monitoring and management metrics, and for possible fitting to habitat pot data. This model is not yet ready to present to the plan teams, but will be brought forward in 2015.

Introduction

Description of biology and gDistribution

Octopuses are marine mollusks in the class Cephalopoda. The cephalopods, whose name literally means head foot, have their appendages attached to the head and include octopuses, squids, and nautiluses. The octopuses (order Octopoda) have only eight appendages or arms and unlike other cephalopods, they lack shells, pens, and tentacles. There are two groups of Octopoda, the cirrate and the incirrate. The cirrate have cirri (cilia-like strands on the suckers) and possess paddle-shaped fins suitable for swimming in their deep ocean pelagic and epibenthic habitats (Boyle and Rodhouse 2005) and are much less common than the incirrate which contain the more traditional forms of octopus. Octopuses are found in every ocean in the world and range in size from less than 20 cm (total length) to over 3 m (total length); the latter is a record held by *Enteroctopus dofleini* (Wülker 1910). *E. dofleini* is one of at least nine species of octopus (Table 1) found in the Bering Sea, including one newly identified species. Members of these nine species represent seven genera and can be found from less than 10 m to greater than 1500 m depth. All but two, *Japetella diaphana* and *Vampyroteuthis infernalis*, are benthic octopuses. The state of knowledge of octopuses in the BSAI, including the true species composition, is very limited.

In the Bering Sea octopuses are found from subtidal waters to deep areas near the outer slope (Figure 1). The highest species diversity is along the shelf break region between 200 – 750 m. The observed take of octopus from both commercial fisheries and AFSC RACE surveys indicates that few octopus occupy federal waters of Bristol Bay and the inner front region. Some octopuses have been observed in the middle front, especially in the region south of the Pribilof Islands. The majority of observed commercial and survey hauls containing octopus are concentrated in the outer front region and along the shelf break, from the horseshoe at Unimak Pass to the northern limit of the federal regulatory area. Octopuses have also been observed throughout the western GOA and Aleutian Island chain. The spatial distribution of commercial octopus catch is dependent primarily on the use of pot gear for Pacific cod, and is concentrated in the three statistical areas near Unimack Pass.

Life History and Stock Structure

In general, octopus life spans are either 1-2 years or 3-5 years depending on the species. Life histories of six of the seven species in the Bering Sea are largely unknown. *Enteroctopus dofleini* has been studied extensively, and its life history will be reviewed here. General life histories of the other six species are inferred from what is known about other members of the genus.

Giant Pacific Octopus

Enteroctopus dofleini samples collected during research in the Bering Sea indicate that *E. dofleini* are reproductively active in the fall with peak spawning occurring in the winter to early spring months. Like most species of octopods, *E. dofleini* are terminal spawners, dying after mating (males) and the hatching of eggs (females) (Jorgensen 2009). *Enteroctopus dofleini* within the Bering Sea have been found to mature between 10 to 13 kg with 50% maturity values of 12.8 kg for females and 10.8 kg for males (Brewer and Norcross 2013). *Enteroctopus dofleini* are problematic to age due to a documented lack of beak growth checks and soft chalky statoliths (Robinson and Hartwick 1986). Therefore the determination of age at maturity is difficult for this species. In Japan this species is estimated to mature at 1.5 to 3 years and at similar size ranges (Kanamaru and Yamashita 1967, Mottet1975). Within the Bering Sea, female *E. dofleini* show significantly larger gonad weight and maturity in the fall months (Brewer and Norcross 2013). Due to differences in the timing of peak gonad development between males and females it is likely that females have the capability to store sperm. This phenomenon has been documented in aquarium studies of octopus in Alaska and British Columbia (Gabe 1975). Fecundity for this species in the Gulf of Alaska ranges from 40,000 to 240,000 eggs per female with an average fecundity of 106,800 eggs per female (Conrath and Conners 2014). Fecundity was significantly and positively related to the size of the female. The fecundity of *E. dofleini* within this region is higher than that reported for other regions. The fecundity of this species in Japanese waters has been estimated at 30,000 to 100,000 eggs per female (Kanamaru 1964, Mottet 1975, Sato 1996). Gabe (1975) estimated that a female in captivity in British Columbia laid 35,000 eggs. Hatchlings are approximately 3.5 mm. Mottet (1975) estimated survival to 6 mm at 4% while survival to 10 mm was estimated to be 1%; mortality at the 1 to 2 year stage is also estimated to be high (Hartwick, 1983). Large numbers of planktonic larvae of this species have been captured in offshore waters of the Aleutian Islands during June through August. These juveniles were assumed have hatched in the coastal waters along the Aleutian Islands and been transported by the Alaska Stream (Kubodera 1991). Since the highest mortality occurs during the larval stage it is likely that ocean conditions have the largest effect on the number of *E. dofleini* in the Bering Sea and large fluctuations in numbers of E. dofleini should be expected. Based on larval data, *E. dofleini* is the only octopus in the Bering Sea with a planktonic larval stage.

The giant Pacific octopus is found throughout the northern Pacific Ocean from northern Japanese waters, throughout the Aleutian Islands, the Bering Sea and the Gulf of Alaska and along the Pacific Coast as far south as northern California (Kubodera, 1991). The stock structure and phylogenetic relationships of this species throughout its range have not been well studied. Three sub-species have been identified based on large geographic ranges and morphological characteristics including *E. dofleini dofleini* (far western North Pacific), *E. dofleini apollyon* (waters near Japan, Bering Sea, Gulf of Alaska), and *E. dofleini martini* (eastern part of their range, Pickford 1964). A recent genetic study (Toussaint et al. 2012) indicated the presence of a cryptic species of *E. dofleini* in Prince William Sound, Alaska, but did not find substantial genetic differences between specimens from Dutch Harbor, Kachemak Bay, and Montague Strait. A microsattelite study by Barry (2010) also identified two subgroups within *E dofleini* from Prince William Sound, but similar genetic structure in octopus from Kachemak Bay, Prince William Sound, and Glacier Bay in southeast Alaska.

There is little information available about the migration and movements of this species in Alaska waters. Kanamaru (1964) proposed that *E. dofleini* move to deeper waters to mate during July through October and then move to shallower waters to spawn during October through January in waters off of the coast of Hokkaido, Japan. Studies of movement in British Columbia (Hartwick et al. 1984) and south central Alaska (Scheel and Bisson 2012) found no evidence of a seasonal or directed migration for this species, but longer term tagging studies may be necessary to obtain a complete understanding of the migratory patterns of this species.

Other Octopus Species

Sasakiopus salebrosus is a small benthic octopus recently identified from the Bering Sea slope in depths ranging from 200 to1,200 m (Jorgensen 2010). It was previously identified in surveys as *Benthoctopus sp*. or as *Octopus sp. n.* In recent groundfish surveys of the Bering Sea slope this was the most abundant octopus collected; multiple specimens were collected in over 50% of the tows. *Sasakiopus salebrosus* is a small-sized species with a maximum total length < 25 cm. Mature females collected in the Bering Sea carried 100 to 120 eggs (Laptikhovsky 1999). Hatchlings and paralarvae have not been collected or described (Jorgensen 2009).

Benthoctopus leioderma is a medium sized species, with a maximum total length of approximately 60 cm. Its life span is unknown. It occurs from 250 to 1,400 m and is found throughout the shelf break region. It is a common octopus and often occurs in the same areas where *E. dofleini* are found. The eggs are brooded by the female but mating and spawning times are unknown. Members of this genus in the North Pacific Ocean have been found to attach their eggs to hard substrate under rock ledges and crevices (Voight and Grehan 2000). *Benthoctopus* tend to have small numbers of eggs (< 200) that develop into benthic hatchlings.

Benthoctopus oregonensis is larger than *B. leioderma*, with a maximum total length of approximately 1 m. This is the second largest octopus in the Bering Sea and based on size could be confused with *E. dofleini*. We know very little about this species of octopus. Other members of this genus brood their eggs and we would assume the same for this species. The hatchlings are demersal and likely much larger than those of *E. dofleini*. The samples of *B. oregonensis* all come from deeper than 500 m. This species is the least collected incirrate octopus in the Bering Sea and may occur in depths largely outside of the sampling range of AFSC surveys.

Graneledone boreopacifica is a deep water octopus with only a single row of suckers on each arm (the other benthic incirrate octopuses have two rows of suckers). It is most commonly collected north of the Pribilof Islands but occasionally is found in the southern portion of the shelf break region. This species has been shown to occur at hydrothermal vent habitats and prey on vent fauna (Voight 2000). Samples of *G. boreopacifica* all come from deeper than 650 m and this deep water species has not been found on the continental shelf. *Graneledone* species have also been shown to individually attach eggs to hard substrate and brood their eggs throughout development. Recently collected hatchlings of this species were found to be very large (55 mm long) and advanced (Voight 2004) and this species has been shown to employ multiple paternity (Voight and Feldheim 2009).

Opisthoteuthis californiana is a cirrate octopus with fins and cirri (on the arms). It is common in the Bering Sea but would not be confused with *E. dofleini*. It is found from 300 to 1,100 m and likely common over the abyssal plain. *Opisthoteuthis californiana* in the northwestern Bering Sea have been found to have a protracted spawning period with multiple small batch spawning events. Potential fecundity of this species was found to range from 1,200 to 2,400 oocytes (Laptikhovsky 1999). There is evidence that *Opisthoteuthis* species in the Atlantic undergo 'continuous spawning' with a single, extended period of egg maturation and a protracted period of spawning (Villanueva 1992). Other details of its life history remain unknown.

Japetella diaphana is a small pelagic octopus. Little is known about members of this family. In Hawaiian waters gravid females are found near 1,000 m and brooding females near 800 m. Hatchlings have been observed to be about 3 mm mantle length (Young 2008). This is not a common octopus in the Bering Sea and would not be confused with *E. dofleini*.

Vampyroteuthis infernalis is a cirrate octopus. It is not common in the BSAI, being reported only from the slope immediately north of the easternmost Aleutian Islands (Jorgensen 2009). It is easily distinguishable from other species of octopus by its black coloration. Very little is known about its reproduction or early life history. An 8 mm ML hatchling with yolk was captured near the Hawaiian Islands indicating an egg size of around 8 mm for this species (Young and Vecchione 1999).

In summary, there are eight species of octopus present in the BSAI, and the species composition both of natural communities and commercial harvest is not well known. It is likely that some species, particularly *G. boreopacifica*, are primarily distributed at greater depths than are commonly fished. At depths less than 200 meters *E. dofleini* appears to be the most abundant species, but could be found with *S. salebrosus*, or *B. leioderma.*

Fishery

Directed Fishery

There is no federally-managed directed fishery for octopus in the BSAI. The State of Alaska allows directed fishing for octopus in state waters under a special commissioner's permit. A small directed fishery in state waters around Unimak Pass and in the AI existed from 1988-1995; catches from this fishery were reportedly less than 8 t per year (Fritz 1997). In 2004, commissioner's permits were given for directed harvest of Bering Sea octopus on an experimental basis (Karla Bush, ADF&G, personal communication). Nineteen vessels registered for this fishery, and 13 vessels made landings of 4,977 octopus totaling 84.6 mt. The majority of this catch was from larger pot boats during the fall season cod fishery (Sept.-Nov.). Average weight of sampled octopus from this harvest was 14.1 kg. The sampled catch was 68% males. Only one vessel was registered for octopus in 2005. From 2006 - 2012, few permits were requested and all catch of octopus in state waters has been incidental to other fisheries (Bowers et al. 2010, Sagalkin and Spalinger, 2011). In 2013 and 2014, there has been some directed fishing of octopus in conjunction with research projects, but the total harvest has been less than 2 t per year.

Management Units

Through 2010, octopuses were managed as part of the BSAI "other species" complex, with catch reported only in the aggregate with sharks, skates, and sculpins. In the BSAI, catch of other species was limited by a Total Allowable Catch (TAC) based on an Allowable Biological Catch (ABC) estimated by summing estimates for several subgroups (Gaichas 2004). Historically, catches of "other species" were well below TAC and retention of other species was small. Due to increasing market value of skates and octopuses, retention of other species complex members began to increase in the early 2000's. In 2004, the TAC established for the other species complex was close to historical catch levels, so all members of the complex were placed on "bycatch only" status, with retention limited to 20% of the catch weight of the target species. This status continued each year through 2009. In several years, the "other species" complex TAC was reached and all members of the complex were then placed on discard-only status, with no retention allowed, for the remainder of the year.

In October 2009, the North Pacific Fishery Management Council amended both the BSAI and GOA Fishery Management Plans to eliminate the "other species" category. Plan amendments moved species groups formerly included in "other species" into the "in the fishery" category and provide for management of these groups with separate catch quotas under the 2007 reauthorization of the Magnuson-Stevens Act and National Standard One guidelines. These amendments also created an 'Ecosystem Component' category for species not retained commercially.

Separate catch limits for groups from the former "other species" category, including octopus, were implemented in January 2011. Octopus remained on "bycatch only" status, with a TAC of 150 tons. As it happened, 2011 turned out to be an unusually high catch year for octopus in the BSAI. The TAC was reached in August 2011, and retention of octopus was prohibited for the remainder of the year. The OFL of 528 tons was reached in mid-October, 2011. To prevent further incidental catch of octopus, NMFS Regional Office closed directed fishing for Pacific cod with pots in the BSAI effective October 24, 2011. Since 2012, octopus TAC and catches have been low.

Draft revisions to guidelines for National Standard One instruct managers to identify core species and species assemblages. Species assemblages should include species that share similar regions and life history characteristics. The BSAI octopus assemblage does not fully meet these criteria. All octopus species have been grouped into a species assemblage for practical reasons, as it is unlikely that fishers will identify octopus to species. Octopus are currently recorded by fisheries observers as either "octopus unidentified" or "pelagic octopus unidentified". *Enteroctopus dofleini* is the key species in the assemblage, is the best known, and is most likely to be encountered at shallower depths. The seven species in the assemblage, however, do not necessarily share common patterns of distribution, growth, and life history. One avenue being explored for the future is to split this assemblage by size, allowing retention of only larger animals. This could act to restrict harvest to the larger *E. dofleini* and minimize impact to the smaller animals which may be other octopus species.

Incidental Catch

Octopus are caught incidentally throughout the BSAI in both state and federally-managed bottom trawl, longline, and pot fisheries. Until around 2003, retention of octopus when caught was minor, because of a lack of commercial market. Retained octopus were used and sold primarily for bait. In 2004-2007 a commercial market for human consumption of octopus developed in Dutch Harbor, with ex-vessel prices running as high as $0.90/lb. The main processor marketing food-grade octopus went out of business in 2009 due to decreasing demand; however, other processors continued to buy octopus for bait at ex-vessel prices in the $0.40 - $0.60/lb range. The worldwide demand for food-grade octopus remains high (www.fao.org), so the possibility of increased future marketing effort for octopus exists.

From 1992-2002 total incidental catch of octopus in federal waters was estimated from observed hauls (Gaichas 2004). Since 2003 the total octopus catch in federal waters (including discards) has been estimated using the NMFS Alaska Regional Office catch accounting system. Minor updates and changes to this system in 2010 produced estimated catch numbers slightly different from previous assessments. Incidental catch rates are presented in the data section. The majority of both federal and state incidental catch of octopus continues to come from Pacific cod fisheries, primarily pot fisheries (Table 22.2; Bowers et al. 2010, Sagalkin and Spalinger, 2011). Some catch is also taken in bottom trawl fisheries for Pacific cod, flatfish, and pollock. The overwhelming majority of catch in federal waters occurs around Unimak Pass in statistical reporting areas 519, 517, and 509. The species of octopus taken is not known, although size distributions suggest that the majority of the catch from pots is *E. dofleini* (see below).

Catch History

Prior to 2003, there was little market for octopus and no directed fishery in federal waters; historical rates of incidental catch (prior to 2003) do not necessarily reflect fishing patterns where octopus are part of retained market catch. Estimates of incidental catch (Table 2) suggest substantial year-to-year variation in harvest, some of which is due to changing regulations and market forces in the Pacific cod fishery. A large interannual variability in octopus abundance is also consistent with anecdotal reports (Paust 1988, 1997) and with life-history patterns for *E. dofleini*. Incidental catch was particularly high in fall 2011 with a total catch rate over 500 tons. It is estimated that only about 35 tons of this catch was retained, the rest was discarded either at sea or during plant delivery. Some of this increase in catch may come from

better recordkeeping and reporting as octopus was moved into its own regulatory category. Incidental catch rates were very low during 2012 but back to approximately 200 tons in 2013 and 2014.

Fisheries in Other Countries

Worldwide, fisheries for *Octopus vulgaris* and other octopus species are widespread in waters off southeast Asia, Japan, India, Europe, West Africa, and along the Caribbean coasts of South, Central, and North America (Rooper et al.1984). World catches of *O. vulgaris* peaked at more than 100,000 tons per year in the late 1960's and are currently in the range of 30,000 tons (www.fao.org). Octopus are harvested with commercial bottom trawl and trap gear; with hooks, lures and longlines; and with spears or by hand. Primary markets are Japan, Spain, and Italy, and prices in 2004 were near record highs (www.globefish.org). Prices were also high in 2011, due to a decrease in exports from two of the major suppliers, Morocco and Mauritania. Declines in octopus abundance due to overfishing have been suggested in waters off western Africa, off Thailand, and in Japan's inland sea. Morocco has recently set catch quotas for octopus as well as season and size limits (www.globefish.org). Caddy and Rodhouse (1998) suggest that cephalopod fisheries (both octopus and squid) are increasing in many areas of the world as a result of declining availability of groundfish.

Fisheries for *E. dofleini* occur in northern Japan, where specialized ceramic and wooden pots are used, and off the coast of British Columbia, where octopus are harvested by divers and as bycatch in trap and trawl fisheries (Osako and Murata 1983, Hartwick et al. 1984). A small harvest occurs in Oregon as incidental catch in the Dungeness crab pot and groundfish trawl fisheries. In Japan, the primary management tool is restriction of octopus fishing seasons based on seasonal migration and spawning patterns. In British Columbia, effort restriction (limited licenses) is used along with seasonal and area regulation.

Descriptions of octopus management in the scientific literature tend to be older (before 1995) and somewhat obscure; formal stock assessments of octopus are rare. Cephalopods in general (both octopus and squid) are difficult to assess using standard groundfish models because of their short life span and terminal spawning. Caddy (1979, 1983) discusses assessment methods for cephalopods by separating the life cycle into three stages: 1) immigration to the fishery, including recruitment; 2) a period of relatively constant availability to the fishery; and 3) emigration from the fishery, including spawning. Assuming that data permit separation of the population into these three stages, management based on estimation of natural mortality (equivalent to Tier 5) can be used for the middle stage. He also emphasizes the need for data on reproduction, seasonal migration, and spawner-recruit mechanisms. General production models have been used to estimate catch limits for *O. vulgaris* off the African coast and for several squid fisheries (Hatanaka 1979, Sato and Hatanaka 1983, Caddy 1983). These models are most appropriate for species with low natural mortality rates, high productivity, and low recruitment variability (Punt 1995), which makes them difficult to apply to cephalopods. Another approach, if sufficient data are available, is to establish threshold limits based on protecting a minimum spawning biomass (Caddy 2004).

Data

Incidental Catch Data

Octopus are captured in both state and federal waters off Alaska. Reported harvest of octopus from incidental catch in state fisheries in the BSAI ranged from 18-69 t between 1996 and 2002, but was 100-300 t in 2003-2006 (Sagalkin and Spalinger 2011). From 1992-2002 total incidental catch of octopus in federal waters, estimated from observed hauls, was generally between 100 and 400 t (Table 2). Since 2003 the total octopus catch in both state and federal waters (including discards) has been estimated using the NMFS Alaska Regional Office catch accounting system. Minor updates and changes to this system in

2010 changed estimated catch numbers slightly from previous assessments. Total incidental catch during this period has continued to be 200-400 tons in most years, with very high year-to year variation from 2006 - 2011. Total catch was generally high (300-500 tons) in 2003-2006 and low (<200 tons) in 2007-2010, with only 72 tons caught in 2009. The low octopus catch during this period may be a result of a decline in processor demand and a drop in cod pot-fishing effort due to a decline in the market price of cod and increased fuel prices. Catch in 2011 was the highest ever observed, reaching 534 tons by mid-October. The majority of this catch was not retained, but discarded either at sea or at processing plants. Catch for 2012 was much lower, at only 89 tons. Catch in 2013 and in 2014 through October 17, 2014 was back in the 200-250 ton range. Retention of incidentally caught octopus in 2013-14 was 21-27% overall.

AFSC Survey Data

Catches of octopus are recorded during the annual NMFS bottom trawl survey of the Bering Sea shelf and biennial surveys of the Bering Sea slope and Aleutian Islands. In older survey data (prior to 2002), octopus were often not identified to species; other species may also have been sometimes misidentified as *E. dofleini*. Since 2002, increased effort has been put into cephalopod identification and species composition data are considered more reliable. Species composition data from the most recent Bering Sea shelf, Bering Sea slope, and Aleutian Island surveys are shown in Tables 3 and 4. These catches are our only source of species-specific information within the species group. In general, the shelf survey rarely encounters octopus (less than 15% of the tows contain octopus), while the slope survey finds octopus in over half the tows. The dominant species on the shelf is *E. dofleini*, accounting for over 80% of the estimated shelf octopus biomass. The slope survey, which covers deeper waters, encounters a much wider variety of octopus species. The species most abundant numerically in the slope survey is the newly identified *Sasakiopus salebrosus* (previously thought to be a *Benthoctopus* species). Numerous tows contained several individuals of this species. As this species is very small-bodied, however, the estimated biomass of the slope is still dominated by *E. dofleini* (Table 4). Recent slope surveys also included substantial catches of *Opisthoteuthis californiana, Benthoctopus leioderma, and Graneledone boreopacifica.* The Aleutian Islands survey encounters octopus in about a quarter of the tows, primarily *E. dofleini.*

Survey data are beginning to provide information on the spatial and depth distribution of octopus species. Octopuses are rarely caught in Bristol Bay and the inner front. Survey catches of octopus in the Bering Sea shelf are most frequent on the outer shelf adjacent to the slope and in the northernmost portions of the survey. The majority of survey-caught octopuses are caught at depths greater than 60 fathoms (110 meters), with roughly a third of all survey-caught octopuses coming from depths greater than 250 fathoms (450 meters). Biomass estimates from the slope surveys suggest that *Opisthoteuthis californiana,* and *Benthoctopus leioderma* are distributed primarily toward the southern portion of the slope, while *Granoledone boreopacifica* and *Benthoctopus oregonensis* are found primarily at the northern end. *E. dofleini* were found throughout the slope survey.

Species are stratified by size and depth with larger (and fewer) animals living deeper and smaller animals living shallower. *Enteroctopus dofleini* have a peak frequency of occurence at 250 m, *Sasakiopus salebrosus* peaks at 450 m, *B. leioderma* peaks at 450 and 650 m, and *G. boreopacifica* peaks at 1,050 m. At depths less than 200 m, *E. dofleini* is the most common species. The Aleutian Island survey in 2010 caught octopus throughout the Aleutian Island chain, primarily at depths of 75-200 m. It is important to note that survey data only reflect summer spatial distributions and that seasonal migrations may result in different spatial distribution in other seasons.

The size distribution by weight of individual octopus collected by the Bering Sea shelf bottom trawl surveys from 2008 through 2011 is shown in Figure 2 (compared to size frequencies in commercial catch in Figure 3). Survey-caught octopus ranged in weight from less than 5 g up to 25 kg; 50% of all

individuals captured in the shelf survey were <0.5 Kg. This pattern continues into the most recent shelf survey data. The slope survey captures more *E. dofleini* in the 0.5-3 kg range than the shelf survey; both surveys collect the occasional animal over 10 kg. In general, the large individuals of *E. dofleini* typically seen in pot gear may be under-represented in trawl survey data because of increased ability to avoid the trawl.

Biomass estimates for the octopus species complex based on bottom trawl surveys are shown in Table 5. These estimates show high year-to-year variability, ranging over two orders of magnitude. There is a large sampling variance associated with estimates from the shelf survey because of a large number of tows that have no octopus. It is impossible to determine how much of the year to year variability in estimated biomass reflects true variation in abundance and how much is due to sampling variation. In 1997, the biomass estimate from the shelf survey was only 211 t, approximately equal to the estimated Bering Sea commercial catch (Table 2). This suggests that the 1997 biomass estimate was unreasonably low. In general, shelf survey biomass was high in 1990-1992; low in 1993-1999; and fairly high in 2003-2005, and low again in 2006 -2010 (Figure 4). Shelf survey biomass increased to 3,554 mt in 2011 and was 2,567 mt in 2012. The shelf survey biomass dropped to 1,810 t in 2013 but was back up to 2,351 tons in 2014. The estimated total biomass from the 2012 slope survey was double the 2010 catch at 1,421 t, due in part to large catches of *O. californiana* and *G. boreopacifica.* The 2014 estimate of biomass in the Aleutian Islands was very close to the 2012 estimate at 2,762 t.

Federal Groundfish Observer Program Data

Groundfish observers record octopus in commercial catches as either "octopus unidentified" or "pelagic octopus unidentified". Therefore, we do not know which species of octopus are in the catch. Observer records do, however, provide a substantial record of catch of the octopus species complex. Figure 1 shows the spatial distribution of observed octopus catch in the BSAI. The majority of octopus caught in the fishery come from depths of 40-80 fathoms (70-150 m). This is in direct contrast to the depth distribution of octopus caught by the survey. This difference is probably reflective of the fact that octopus are generally taken as incidental catch at preferred depths for Pacific cod. The size distribution of octopus caught by different gears is very different (Figure 3); commercial cod pot gear clearly selects for larger individuals. Over 86% of octopus with individual weights from observed pot hauls weighed more than 5 kg. Based on size alone, these larger individuals are probably *E. dofleini*. Commercial trawls and longlines show size distributions more similar to that of the survey, with a wide range in sizes and a large fraction of octopus weighing less than 2 kg. These smaller octopuses may be juvenile *E. dofleini* or may be any of several species, including the newly identified *Sasakiopus salebrosus*.

Temporal catch patterns in the pot fishery are primarily determined by seasonal timing of pot fishing for Pacific cod; the overwhelming majority of octopus incidental catch comes during the primary cod seasons January-March and September-October. There is very little pot fishing effort, and very little octopus catch, during May-August and November-December. Spatial patterns in octopus catch are primarily determined by gear conflict considerations and proximity to processors. The majority of pot boats are catcher boats with a 72-hour limit for delivery of Pacific cod, so the pot effort is concentrated close to processing ports in the southeast Bering Sea and the Pribilov Islands. Most pot fishing and most octopus catch is concentrated in the regulatory no-trawl zones around Unimak Pass, where gear conflict with trawlers is avoided and trip duration is brief. It is unlikely that either of the predominant temporal or spatial patterns represents significant seasonal or spatial trends of the octopus population. What is apparent from the available data is that octopus catch rates are often notably higher in the fall cod season than in the winter; this may reflect seasonal movements of octopus related to mating. Both pot effort and octopus catch rates are consistently highest in NMFS statistical reporting area 519, on the north side of Akutan and Akun Islands, just west of Unimak Pass. This area is heavily fished in part because the regulatory no-trawl zones around Steller sea lion rookeries and haulouts make it easy to avoid conflicts with trawlers, and cod catches are consistent. Since octopus are a Steller sea lion prey item in the BSAI,

the proximity of the major incidental catch to rookeries is a factor that should be noted (see discussion under "Ecosystem Considerations").

Observer Special Project Data

Since 2006, some fishery observers have also been collecting data for a special project on octopus. These observers record the individual weights of all octopus caught to improve size frequency distribution data. The observers also determine and record the sex of each octopus from external characters (male octopus have one arm especially adapted for mating). Octopus are also sampled in processing plants. Data collection for this project continues through 2014.

The special project data reflect the size selectivity in gear, as seen in Figure 3. Octopus collected on cod pot boats were generally in the range of 5-20 kg, while octopus caught in trawl gear were often less than 2 kg. All of the octopus observed at the processing plants were over 3 kg gutted weight, with average gutted weights of 13.3 and 13.4 kg for males and females respectively. Male octopus predominated in pot catch and processing plant deliveries in both years by a factor of at least 2:1. Sex ratios from octopus observed on vessels differed between the two years, in part because the 2007 data includes both winter 2007 and fall 2006 data. In the first year of the study, males predominated in pot catch but females dominated in other gear types. In 2007, males were more common in bottom trawl catch; the sex ratio in pot catch was near even, and females predominated in pelagic trawl and longline observations. The reason that pot catch seems to include more males than other gear types is not known, but probably reflects the fact that pots select for larger animals and draw catch by scent. It is possible that male octopus move around more than females in searching for mates, and so have a higher chance of encountering pots (Roland Anderson, Seattle Aquarium, personal communication Oct 2007).

Analytic Approach

The available data do not support population modeling for either individual species of octopus in the BSAI or for the multi-species complex. As better catch and life-history data become available, it may become feasible to assess the key species *E. dofleini* with methods such as general production models, estimation of reproductive potential, seasonal or area regulation, or size limits. Parameters for Tier 5 catch limits can be estimated (poorly) from available data and are discussed below. Catch limits under Tier 6 have also been calculated. An alternative Tier 6 method, based on predation mortality, is the alternative recommended by the authors and accepted by the BSAI Plan Team and SSC in 2011-2013.

Parameters Estimated Outside the Assessment Model – Biomass B

Estimates of octopus biomass based on the annual Bering Sea trawl surveys (Table 5, Figure 4) represent total weight for all species of octopus, and are formed using the sample procedures used for estimating groundfish biomass based on the area-swept method (National Research Council 1998, Wakabayashi et al 1985). The positive aspect of these estimates is that they are founded on fishery-independent data collected by proper design-based sampling. The standardized methods and procedures used for the surveys make these estimates the most reliable biomass data available for many groundfish and invertebrate species. The survey methodology has been carefully reviewed and approved in the estimation of biomass for other federally-managed species. There are, however, some serious drawbacks to use of the trawl survey biomass estimates for octopus.

Older trawl survey data, as with fishery or observer data, are commonly reported as octopus *sp*., without full species identification. In surveys from 1997 – 2001, from 50 to 90% of the total biomass of octopus collected was not identified to species. In more recent years up to 90% of collected octopus were identified to species, but some misidentification may still occur. Efforts to improve species identification and collect biological data from octopus are being made, and biomass estimates by species are available

from the most recent surveys, but the variability associated with these estimates is very high. In most survey strata, over 90% of the hauls do not contain any octopus at all, so the estimation of biomass is based on only a few tows where octopus are present. This leads to high uncertainty in the biomass estimate, especially in years when the estimate is large (Figure 4).

Secondly, a trawl is probably not the most appropriate gear for sampling octopus. The bottom trawl net used for the Bering Sea shelf survey has no roller gear and tends the bottom fairly well, especially on the smooth sand and silt bottoms that are common to the shelf. The nets used in the Bering Sea slope, Aleutian Island, and GOA surveys, however, have roller gear on the footrope to reduce snagging on rocks and obstacles. Given the tendency of octopus to spend daylight hours near dens in rocks and crevices, it is entirely likely that both types of net have poor efficiency at capturing benthic octopus (D. Somerton, AFSC, personal communication, 7/22/05). Trawl sampling is not feasible in areas with extremely rough bottom and/or large vertical relief, exactly the type of habitat where den spaces for octopus would be most abundant (Hartwick and Barringa 1997). The survey also does not sample in inshore areas and waters shallower than 30m, which may contain sizable octopus populations (Scheel 2002).

The estimates of biomass in Table 5 are based on a gear selectivity coefficient of one, which is probably not realistic for octopus. One of the major recommendations from the CIE review in 2013 was to estimate catchability before treating trawl CPUE as an absolute abundance estimate. Because many octopus presumably avoid the trawl by staying hidden under rocks, the true catchability for octopus is likely much less than 1, and the survey estimates are likely much less than the true octopus biomass in the regions covered by the survey. In addition, the sampling variability of survey biomass estimates is very high, which may mask year-to-year variability or trends in octopus abundance.

Finally, there is considerable lack of overlap between the trawl survey and fishery data in the size range of octopus caught, the depth distribution of octopus catch, and the timing of catch. The average weight for individual octopus in survey catches is less than 2 kg; over 50% of survey-collected individuals weigh less than 0.5 kg. Larger individuals are strong swimmers and may disproportionately escape trawl capture. In contrast, the average weight of individuals from experimental pot gear was 18 kg. Pot gear is probably selective for larger, more aggressive individuals that respond to bait, and smaller octopus can easily escape commercial pots while they are being retrieved. The trawl survey also tends to catch octopus in deeper waters associated with the shelf break and slope; in 2002-2004 less than 30% of the survey-caught octopus came from depths less than 100 fathoms, where nearly all of the observed commercial catch is taken. Both rapid growth of individual octopus and possible seasonal movements make it difficult to compare the summer trawl survey with octopus vulnerable to fall and winter cod fisheries. Given the large differences in size and depth frequency, it is unlikely that the survey accurately represents the part of the octopus population that is subject to commercial harvest.

If future management of the octopus complex is to be based on biomass estimates, then species-specific methods of biomass estimation should be explored. Octopuses are readily caught with commercial or research pots. Recent research projects have shown that a species-specific index survey using habitat pot gear is feasible. Given the strong spatial focus of the harvest, an index survey of regional biomass in the Unimak Pass area would give useful information on population trends in the portion of the population most susceptible to harvest. It is expected that estimates of regional octopus biomass based on mark-recapture studies will be available soon, but it may be difficult to determine how to appropriately scale theses estimates to the entire BSAI region.

Parameters Estimated Inside the Assessment Model

Mortality Rate M

Since *E. dofleini* are terminal spawners, care must be taken to estimate mortality for the intermediate stage of the population that is available to the fishery but not yet spawning (Caddy 1979, 1983). If detailed, regular catch data within a given season were available, the natural mortality could be estimated from catch data (Caddy 1983). When this method was used by Hatanaka (1979) for the west African *O. vulgaris* fishery, the estimated mortality rates were in the range of 0.50-0.75. Mortality may also be estimated from tagging studies; Osako and Murata (1983) used this method to estimate a total mortality of 0.43 for the squid *Todarodes pacificus*. Empirical methods based on the natural life span (Hoenig 1983, Richter and Efanov 1976) or von Bertalanffy growth coefficient (Charnov and Berrigan 1991) have also been used. While these equations have been widely used for finfish, their use for cephalopods is less well established. Perry et al. (1999) and Caddy (1996) discuss their use for invertebrate fisheries.

We attempted to estimate mortality for Bering Sea octopus from survey-based estimates of biomass and population numbers, however the values were too variable to allow accurate estimation. If we apply Hoenig's (1983) equation to *E. dofleini*, which have a maximum age of five years, we obtain an estimated M of 0.86. Rikhter and Efanov's (1976) equation gives a mortality value of 0.53 based on an age of maturity of 3 years for *E. dofleini*. The utility of maturity/ mortality relationship for cephalopods needs further investigation, but these estimates represent the best available data at this time. The Rikhter and Efanov estimate of M=**0.53** represents the most conservative estimate of octopus mortality, based on information currently available. If future management of octopus is to be based on Tier 5 methods, a direct estimate of octopus mortality in the Bering Sea, based on either experimental fishing or tagging studies, is desirable. The tagging study currently underway in the Bering Sea, when completed, should provide natural mortality rate estimates for the octopus that are vulnerable to commercial pot gear.

Parameters Estimated Independently – Natural Mortality N

The 2011 BSAI octopus assessment introduced a new methodology for examining population trends in octopus. This approach uses the underlying model from Tier 5, where fishing catch is equated to a total natural mortality (in tons). For Tier 5 stocks, the total natural mortality is usually estimated as the product of biomass and instantaneous mortality rate N=MB. The new method uses a different approach to estimate total natural mortality that does not rely on being able to estimate biomass.

While we have unreliable data on octopus biomass, we have reliable data on one of the octopus' major predators – Pacific cod. The new method uses data from the AFSC's food habits database to estimate the total amount of octopus consumed by Pacific cod. This number could be considered a conservative estimate of the total natural mortality N for octopus, since it does not include mortality from other predators (*i.e*. marine mammals; Fig. 5) or non-predation mortality.

Pacific cod food habits analysis

Since 1982, the Alaska Fisheries Science Center has collected and analyzed the stomachs of 48,665 Pacific cod stomachs from the Bering Sea, 9,200 from the Gulf of Alaska, and 4,528 from the Aleutian Islands. Stomachs are primarily collected on RACE groundfish surveys during the summer, but substantial additional samples have been collected by fisheries observers throughout the winter (Figure 6). For these estimates, we have used samples collected during the summer groundfish survey only, as winter samples, associated with observed fishing operations, do not provide full geographic coverage for making population-level estimates (Figure 6, bottom panel). Stomachs are analyzed on shipboard or preserved in formalin and analyzed in the lab, where the weight composition of each prey type in the stomach is measured. Prey are identified to the lowest possible taxonomic resolution; to date, octopus are not generally identified to species.

Octopus occur in cod stomachs in both the summer and the winter (red circles, Figure 6) and so represent a regular, but not majority diet item for Pacific cod. Pooling across all years and regions, octopus is considerably lower in diets in water shallower than 75m, increasing to approximately 10% occurrence in cod captured between 100-250m depth (Figure 7, top). Octopus consumption also shows a strong relationship with Pacific cod length, being rare in cod with fork lengths less than 30cm, increasing to 7% for 50cm+ cod (Figure 7, bottom). Initial exploration with Generalized Additive Models (GAMs) suggests that the depth and length relationships are relatively independent and not a function of season or year.

The diets of Pacific cod for all years and seasons combined, broken out by region (AI, BS, and GOA) and depth (<100m and ≥100m) are shown in Figures 8-9. Generally, small cod feed on zooplankton, transitioning to benthos and shrimp, and finally to fish, primarily pollock in the BS and GOA and Atka mackerel (part of "other fish") in the AI. Octopus are nearly absent from the diet of cod in shallower water (Figure 8). In deeper water, for larger size classes of cod, octopus are up to 10% of prey by weight (Figure 9).

The weight (and therefore age or life stage) of octopus consumption is an important consideration when comparing to fisheries data. Octopus specimens recovered from Pacific cod stomachs are not directly measureable to individual weight, due to digestion. However octopus beaks are hard parts that are frequently recovered whole. To measure the size of consumed octopus, in 2012 we worked to obtain data to calibrate regressions between octopus weight and octopus beak hood length (both the upper and lower beaks). This year, we obtained whole octopus from fisheries samples and developed an initial regression between beak size and octopus weight (Figure10, top); the regressions showed a strong relationship. Further, we are currently measuring all octopus beaks found in Pacific cod stomachs, the initial data (from 2011 samples) are shown in Figure 10, bottom).

Results of these measurements indicate that the largest beaks eaten by cod generally correspond with the smallest (1-2kg) octopus in the commercial samples, with the majority of octopus eaten by cod being smaller (Figure10, compare top and bottom graphs). However, an exact weight frequency is not obtainable at this time, both due to limited sampling to date, and the lack of smaller octopus in the regression set. We have obtained samples of smaller whole octopus to extend the regression, and expect to develop better weight frequency over the next 1-2 years.

However, it is also important to note that there is a strong relationship between size of octopus beak and size of cod, with larger cod feeding on larger octopus (Figure11); the larger cod, with higher ration and larger percentage of octopus in diet, do overlap in size composition with the smaller octopus in the fisheries, although insufficient data exists for a quantitative weight frequency or weight-specific mortality calculation.

Estimation of annual consumption of octopus by Pacific cod

Cod predation on octopus was estimated using the following formula: $C_y = \sum_{s,l} N_{y,s,l} \cdot R_l \cdot DC_{y,s,l}$, where C_y is the total consumption (t/year) of octopus by cod in a given year y; $N_{y,s,l}$ is the number of cod in the bottom trawl survey for year y, survey stratum s, and length l; R_l is the annual ration for a cod (t prey/cod), and $DC_{y,s,l}$ is the proportion by weight of octopus in the diet of cod by year, stratum, and cod length. Therefore, the units of t/year octopus are the same as the units of the combined **M·B** caused by cod, while not relying on separate estimates of M or B for octopus. **It is important to note that, while this combined estimate of C_y (octopus consumed by cod) replaces the usual Tier 5 M·B reference point, it is neither possible nor necessary for this method to provide separate estimates for either of M or B.** Further, it should be noted that the quantity **M·B is an equilibrium reference quantity, so multiple years of estimates should be treated as improving the single reference point, rather than used as a moving average for catch.** This is especially important to the extent interannual variation is driven by predator fluctuations (cod); changing the reference point to track changing annual estimates would have the effect of increasing catch limits when predation is higher overall, leading in theory to greater fluctuations in the stock.

The EBS was divided into a total of 6 (standard areas 1-6) survey strata based on NW/NE orientation and depth. Each of the quantities N, R, and DC were estimated as follows:

1. Predator numbers $N_{y,s,l}$ were directly estimated from trawl survey numbers of Pacific cod for 1cm increments of cod, including 95% confidence intervals from the survey for each stratum and length bin. Since a comparison between survey biomass and stock assessment biomass of Pacific cod indicates that survey catchability is less than 1, using survey numbers therefore leads to a conservative estimate of overall cod numbers, and therefore a conservative estimate for predation.

2. Ration R_l was estimating following the methods of Essington et al. (2001) by fitting the generalized von Bertalanffy growth equation to weight-at-age data for GOA Pacific cod. The generalized Von Bertalanffy growth equation assumes that both consumption and respiration scale allometrically with body weight, and change in body weight over time (dW/dT) is calculated as follows:

$$\frac{dW_t}{dt} = H \cdot W_t^d - k \cdot W_t^n \qquad (1)$$

Here, W_t is body mass, t is the age of the fish (in years), and H, d, k, and n are allometric parameters. The term $H \cdot W_t^d$ is an allometric term for "useable" consumption over a year, in other words, the consumption (in wet weight) by the predator after indigestible portions of the prey have been removed and assuming constant caloric density between predator and prey. Total consumption is calculated as $(1/A) \cdot H \cdot W_t^d$, where A is a scaling fraction between predator and prey wet weights that accounts for indigestible portions of the prey and differences in caloric density (A=0.6 was used as an approximation from bioenergetics calculations; Aydin et al. 2008). The term $k \cdot W_t^n$ is an allometric term for the amount of biomass lost yearly as respiration.

Based on an analysis performed across a range of fish species, Essington et al. (2001) suggested that it is reasonable to assume that the respiration exponent n is equal to 1 (respiration linearly proportional to body weight). In this case, the differential equation above can be integrated to give the following solution for weight-at-age:

$$W_t = W_\infty \cdot \left(1 - e^{-k(1-d)(t-t_0)}\right)^{\frac{1}{1-d}} \qquad (2)$$

Where W_∞ (asymptotic body mass) is equal to $(H/k)^{\frac{1}{1-d}}$, and t_0 is the weight of the organism at time=0. From measurements of body weight and age, equation 2 can be used to fit four parameters (W_∞, d, k, and t_0) and the relationship between W_∞ and the H, k, and d parameters can then be used to determine the consumption rate $H \cdot W_t^d$ for any given length class of fish.

For these calculations, weight-at-age data available and specific to the modeled regions were fit by minimizing the difference between log(observed) and log(predicted) body weights from Pacific cod survey weight-at-age data. Separate estimates were performed for the GOA and EBS using AD Model Builder; estimates included MCMC-generated confidence intervals for ration (Figure12). Interannual differences in consumption were not calculated.

2. Ration $DC_{y,s,l}$ was calculated for each year and stratum for three size classes of Pacific cod: (0-40cm, 40-60cm, and 60cm+). These size classes were determined based on sample size, and the size dependence of octopus consumption (Figure 22.9, bottom). **If a stratum, year, and size class combination contained less than 10 samples, the consumption of octopus in that stratum was assumed to be 0.** This was done to represent a conservative effort; methods of smoothing from neighboring strata were attempted but the noise of the data led to low confidence in such smoothed estimates. For each fish in the sample, stomach content weight was normalized by predator body weight; the total normalized octopus weight for all the fish in that stratum, and the normalized sum of all prey items, was converted into a percentage by weight. Confidence intervals were calculated by performing 10,000 Monte Carlo simulations for each stratum.

The **Total consumption of octopus (t/year)** estimated for the EBS is shown in Figure 13. There is no direct and evident relationship between total cod biomass and octopus consumption; a multivariate examination including differences in cod size composition and depth over time is planned. Estimates of annual predation mortality by Bering Sea cod on octopus range from <200 to almost 20,000 tons; the larger values have a high level of uncertainty. The majority of the annual estimates, however, lie in the range of 3,000 to 6,000 tons. We used the geometric mean of the posterior distribution to estimate annual predation for each year in the time series. The geometric mean is used rather than the arithmetic mean because the posterior distribution is right-skewed (higher values have higher uncertainty). We then used a geometric mean of the annual values to calculate a conservative long-term average predation rate over the 24 years of annual estimates. The geometric mean of all of the annual estimates is 3,452 tons, which is a full order of magnitude higher than the estimated rate of fishery catch of octopus. This calculation and mean value were presented in the 2011 stock assessment, and have been used since 2012 to set catch limits.

Harvest recommendations

We recommend that octopus be managed conservatively due to the poor state of knowledge of the species, life history, distribution, and abundance of octopus in the BSAI, and due to their important role in the diet of Steller sea lions. Continued monitoring and catch accounting for the octopus complex is essential. Efforts to set appropriate overfishing limits for octopus will continue to be limited by poor information on octopus abundance. Further research is needed in several areas before octopus could be managed by a quantitative stock assessment model.

Despite the lack of good information about octopus, the recent reauthorization of the Magnuson-Stevens act mandates that annual catch limits be set for all species and species complexes within the fishery management plan, even those that are not targets. Several possible methods for setting catch limits for

octopus have been proposed in previous assessments (Conners and Jorgensen 2007, 2008; Conners and Conrath 2009, 2010, 2012). In 2011, the Plan Team and SSC recommended using biological reference points derived from consumption estimates for Pacific cod. This estimate of natural mortality (N) can then be combined with the general logistic fisheries model that forms the basis of Tier 5 assessments (Alverson and Petreyra 1969, Francis 1974) to set OFL = N and ABC = 0.75*OFL. Because the logistic model assumes equilibrium, we propose using a mean over all of the years of available data to estimate N. Because the posterior distribution of the estimates is right-skewed (higher variability at higher values), we have used geometric means both to for m the annual estimates from the posterior distribution and to take the long-term average of the annual estimates. When this method is used, the resulting catch limits are OFL = 3,452 mt and ABC = 2,589 mt. This number is considerably higher than the rate of current or historical incidental octopus catch, and similar to the estimate based on survey biomass.

Another issue that has been discussed is whether or not it is desirable to incorporate gear-specific discard mortality estimates into catch accounting for octopus. Preliminary data on octopus condition at discard and short-term discard mortality has been collected (See Appendix 1.), and a study of long-term discard mortality will be completed in 2015. Studies to date indicate that discard mortality of octopus is highly gear-specific, but that the mortality of octopus discarded form the pot fishery is probably well below the 100% used in current catch accounting. Since the majority of octopus incidental catch comes from pot gear, adding a discard mortality calculation would substantially affect the accumulation of discarded octopus catch toward OFL for the assemblage. Whether the increased accuracy of catch accounting merits the increased complexity of introducing a separate calculation for this assemblage is a policy issue best decided through consultation between the Council, AKFIN, the AFSC, and the NMFS Alaska Regional Office.

We do not recommend a directed fishery for octopus in federal waters at this time, because data are insufficient for adequate management. We anticipate that octopus harvest in federal waters of the BSAI will continue to be largely an issue of incidental catch in existing groundfish fisheries.

Ecosystem Considerations

Ecosystem Effects on the Stock

Little is known about the role of octopus in North Pacific ecosystems. In Japan, *E. dofleini* prey upon crustaceans, fish, bivalves, and other octopuses (Mottet 1975). Food habits data and ecosystem modeling of the Bering Sea and AI (Livingston et al 2003, Aydin et al 2008) indicate that octopus diets in the BSAI are dominated by other benthic invertebrates such as mollusks, hermit crabs (particularly in the AI), starfish, and snow crabs (*Chinoecetes sp.*). The Ecopath model (Figure 14) uses diet information on all predators in the ecosystem to estimate what proportion octopus mortality is caused by which predators and fisheries. Results from the early 1990s indicate that octopus mortality in the Bering Sea comes primarily from Pacific cod, resident seals (primarily harbor seal, *Phoca vitulina richardsi*), walrus and bearded seals, and sculpins; in the AI principal predators are Pacific cod, Pacific halibut, and Atka mackerel. Adult and juvenile Steller sea lions account for approximately 7% of the total mortality of octopus in the Bering Sea, but cause insignificant octopus mortality in the GOA and AI. Modeling suggests that fluctuations in octopus abundance could affect resident seals, Pacific halibut, Pacific cod, and snow crab populations. Modeling suggests that primary and secondary productivity and abundance of hermit crabs, snow crabs, resident seals, Pacific cod, and Pacific halibut affect octopus production.

While Steller sea lions (*Eumetopias jubatus*) are not a dominant predator of octopus, however, octopus are important prey item in the diet of Stellers in the Bering Sea. According to diet information from Perez (1990; Fig. 14) octopus are the second most important species by weight in the sea lion diet, contributing

18% of adult and juvenile diets in the Bering Sea. Diet information from Merrick et al (1997) for the AI, however, do not show octopus as a significant item in sea lion diets. Analysis of scat data (Sinclair and Zeppelin 2002) shows unidentified cephalopods are a frequent item in Steller sea lion diets in both the Bering Sea and Aleutians, although this analysis does not distinguish between octopus and squids. The frequency of cephalopods in sea lion scats averaged 8.8% overall, and was highest (11.5-18.2%) in the Aleutian Islands and lowest (<1 – 2.5%) in the western GOA. Based on ecosystem models, octopus are not significant components of the diet of northern fur seals (*Callorhinus ursinus*). Proximate composition analyses from Prince William Sound in the GOA (Iverson et al 2002) show that squid had among the highest high fat contents (5 to 13%), but that the octopus was among the lowest (1%).

Little is known about habitat use and requirements of octopus in Alaska (Table 6). In trawl survey data, sizes are depth stratified with larger (and fewer) animals living deeper and smaller animals living shallower. However, the trawl survey does not include coastal waters less than 30 m deep, which may include large octopus populations. Hartwick and Barriga (1997) reported increased trap catch rates in offshore areas during winter months. Octopus require secure dens in rocky bottom or boulders to brood its young until hatching, which may be disrupted by fishing effort. Activity is believed to be primarily at night, with octopus staying close to their dens during daylight hours. Hartwick and Barriga (1997) suggest that natural den sites may be more abundant in shallow waters but may become limiting in offshore areas. In inshore areas of Prince William Sound, Scheel (2002), noted highest abundance of octopus in areas of sandy bottom with scattered boulders or in areas adjacent to kelp beds.

Distributions of octopus along the shelf break are related to water temperature, so it is probable that changing climate and ice cover in the Bering Sea is having some effect on octopus, but data are not adequate to evaluate these effects.

Data Gaps and Research Priorities

Recent efforts have improved collection of basic data on octopus, including catch accounting of retained and discarded octopus and species identification of octopus during research surveys. Both survey and observer efforts provide a growing amount of data on octopus size distributions by species and sex and spatial separation of species. Studies currently underway are expected to yield new information on discard mortality of octopus and habitat pot gear for index surveys. The AFSC has kept in communication with the state of Alaska regarding directed fisheries in state waters, gear development, octopus biology, and management concerns.

Identification of octopus to species is difficult, and we do not expect that either fishing industry employees or observers will be able to accurately determine species on a routine basis. A publication on cephalopod taxonomy and identification in Alaska has been published (Jorgensen 2009). Identification of octopus to species and collection of size-frequency information will continue in AFSC surveys. Because of seasonal differences between the survey and most fisheries, questions of species composition of octopus incidental catch may still be difficult to resolve. Methods for octopus species identification from tissue samples by genetic analysis have been developed, if funding for sample collection and lab analysis were available. Special projects and collections in octopus identification and biology will be pursued as funding permits.

Recent and ongoing studies have increased knowledge of fecundity and reproductive biology of *E. dofleini* in Alaska, but information on octopus recruitment patterns and stock-recruit relations will probably be difficult to obtain. *E. dofleini* in Japan and off the US west coast reportedly undergo seasonal movements, but the timing and extent of migrations in Alaska is still unknown. While many octopus

move into shallower coastal waters for egg-laying, it is probable that at least some BSAI octopus reproduction occurs within federal waters. The distribution of octopus biomass and extent of movement between federal and state waters could become important if a directed state fishery develops. Tagging studies to determine seasonal and reproductive movements of octopus in Alaska will enhance our ability to appropriately manage commercial harvest. If feasible, it would be desirable to avoid harvest of adult females following mating and during egg development. Larger females, in particular, may have the highest reproductive output (Hartwick 1983).

Factors determining year-to year patterns in octopus abundance are poorly understood. Octopus abundance is probably controlled primarily by survival of the planktonic larval stage; substantial year-to-year variations in abundance due to climate and oceanographic factors are expectedThe high variability in trawl survey estimates of octopus biomass make it difficult to depend on these estimates of great benefit.for time-series trends; trends in CPUE from observed cod fisheries are available, but are strongly influenced by year-to-year variation in pot fishing effort and spatial distribution. Techniques to determine the size or age structure of the population would be extremely useful, but are not available at present. There has been considerable recent work on aging methods for various species of octopus using beaks or stylets. A project to develop aging methods for *E. dofleini* would be of great benefit.

Fishery-independent methods for assessing biomass of the harvested size group of octopus are feasible, but would be species-specific and could not be carried out as part of existing multi-species surveys. Pot surveys are effective both for collecting biological and distribution data and as an index of abundance. Gear suitable for index surveys is being investigated for possible future use, but it is unclear if funding and staffing for such surveys could be provided. Further exploration of survey gear and methods may be feasible through an experimental fishery, if there is sufficient interest from industry. Mark-recapture methods have been used with octopus both to document seasonal movements and to estimate local biomass and mortality rates. More extensive use of tagging methods would be effective but would require either extensive industry cooperation or funding for directed field research.

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Table .1. Species of Octopodae found in the BSAI.

Scientific Name	Common Name	General Distribution	Age at Maturity	Size at Maturity
Class Cephalopoda				
Order Vampyromorpha				
Genus *Vampyroteuthis*				
Specie ***Vampyroteuthis infernalis***	vampire squid	Southeast BS Slope >300 m	unknown	unknown
Order Octopoda				
Group Cirrata				
Family Opisthoteuthidae				
Genus *Opisthoteuthis*				
Species ***Opisthoteuthis*** cf ***californiana***	flapjack devilfish	BS deeper than 200 m	unknown	unknown
Group Incirrata				
Bolitaenidae				
Japetella				
Japetella diaphana	pelagic octopus	Pelagic	unknown	< 300 g
Family Octopodidae				
Genus *Benthoctopus*				
Species ***Benthoctopus leioderma***	smooth octopus	Southern BS deeper than 250 m	unknown	< 500 g
Benthoctopus oregonensis	none	BS shelf break	unknown	> 2 kg
Genus *Enteroctopus*				
Species ***Enteroctopus dofleini***	giant octopus	all BSAI, from 50 - 1400 m	3 - 5 yr	>10 kg
Genus *Graneledone*				
Species ***Graneledone boreopacifica***	none	BS shelf break 650 - 1550 m	unknown	unknown
Genus *Sasakiopus*				
Sasakiopus salebrosus	stubby octopus	BS shelf break, 200 - 1200 m	unknown	75 - 150 g

Table .2. Estimated catch (mt) of all octopus species in state and federal waters. 1997-2002 estimated from blend data. 2003-2014 data from AK region catch accounting, as provided in October 2014. Catch is shown separately for the two target fisheries that have the highest rate of incidental octopus catch, Pacific cod and flatfish. The estimated percentage of total catch retained is shown for 2003-2014. *2014 data includes only part of the year, January – October 17, 2014.

	Target Species				
Year	P cod	FlatF	Other	Total	% Retained
1997	160	86	3	248	
1998	168	13	9	190	
1999	310	14	2	326	
2000	359	57	3	418	
2001	211	9	7	227	
2002	334	21	19	374	
2003	211	34	19	269	38%
2004	279	45	246	338	24%
2005	311	17	10	338	64%
2006	332	5	14	351	55%
2007	156	7	9	181	39%
2008	196	11	8	212	37%
2009	58	10	6	72	23%
2010	162	11	6	177	33%
2011	565	9	14	587	6%
1212	127	4	8	86	17%
2013	218	2	4	223	21%
2014*	185	17	7	233	27%

Table 3. Species composition of octopus from recent AFSC Bering Sea and Aleutian Islands bottom trawl surveys: numbers of hauls containing octopus and numbers of octopus caught by species.

	Bering Sea Shelf Survey						Slope Survey			A.I. Survey		
	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2008**	**2010**	**2012**	**2010**	**2012**	**2014**
Number of Hauls	376	376	422	376	376	376	200	200	187	418	420	210
No. Hauls w/ Octopus	37	47	43	39	28	17	113	110	114	99	80	84
Species												
Enteroctopus dofleini	47	124	69	48	13	10	57	63	76	162	69	84
Sasakiopus salebrosus		17				1	73	94	72		3	1
Benthoctopus leioderma	35	4	14	29	9	3	89	62	66		3	2
Graneledone boreopacifica							41	33	57			
Opisthoteuthis californiana							39	39	190		1	6
Benthoctopus oregonensis					1	1	8	3				
Benthoctopus sibiricus					1							
Japetella diaphana							16	1	3			
Octopus sp.	2				2		1		3			3
Benthoctopus sp.	2				1		1	18		1		
octopus unident.			11	1	1	2		1		6	4	2
All species	86	145	94	78	28	17	325	315	467	169	162	98

Table 4. Species composition of octopus from recent AFSC Bering Sea bottom trawl surveys: biomass estimates by species.

	Estimated Biomass (mt)								
	BS Slope Survey			BS Shelf Survey					
Species	**2008**	**2010**	**2012**	**2008**	**2010**	**2011**	**2012**	**2013**	**2014**
Enteroctopus dofleini	356.8	216.3	659.2	1,017	653.2	2,844	2,087	1,654	2,095
Graneledone boreopacifica	84.0	96.1	248.1						
Benthoctopus leioderma	155.8	86.6	134.7					97.3	157.2
Benthoctopus sp.	0.44	76.9						1.5	
Benthoctopus sibiricus								39.9	
Opisthoteuthis californiana	156.1	70.4	342.4						
Sasakiopus salebrosus	23.6	32.2	28.6						3.6
Benthoctopus oregonensis	28.1	27.8						13.0	93.4
Opisthoteuthis sp.		14.6							
Japetella diaphana	10.0	0.5	6.4						
Vampyroteuthis infernalis		0.1							
octopus unident.	0.01	0.0	1.3					0.3	2.0
All species	814.9	621.4	1,421	1,179	823.2	3,554	2,567	2,567	2,567

Table 5. Biomass estimates in tons for octopus (all species) from AFSC bottom trawl surveys.

Year	EBS Shelf Survey Biomass	EBS Slope Survey Biomass	AI Survey Biomass	Total BSAI
1982	12,442	180		
1983	3,280		440	
1984	2,488			
1985	2,582	152		
1986	480		781	
1987	7,834			
1988	9,846	138		
1989	4,979			
1990	11,564			
1991	7,990	61	1,148	
1992	5,326			
1993	1,355			
1994	2,183		1,728	
1995	2,779			
1996	1,746			
1997	211		1,219	
1998	1,225			
1999	832			
2000	2,041		775	
2001	5,407			
2002	2,435	979	1,384	
2003	8,264			
2004	4,902	1,957	4,099	
2005	9,562			
2006	1,877		3,060	
2007	2,192			
2008	1,179	815		
2009	1,031			
2010	823	621	3,075	
2011	3,554			
2012	2,567	1,421	2,779	
2013	1,810			
2014	2,351		2,762	
Average All	3,913	703	1,937	6,553
Most Recent	2,351	1,421	2,762	6,534
Avg Last 3	2,243	952	2,872	6,067

Table 6. Analysis of ecosystem considerations for the octopus complex.

Ecosystem effects on *BSAI octopus*			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys, changes mean wt-at-age	Stable, data limited	Unknown
Non-pandalid shrimp and other benthic organism	Trends are not currently measured directly, only short time series of food habits data exist for potential retrospective measurement	Benthic bivalves and crustaceans principal prey for all sizes	Unknown
Sandlance, capelin, other forage fish	Trends are not currently measured directly, only short time series of food habits data exist for potential retrospective measurement	Prey of larger octopus	Unknown
Salmon	Populations are stable or slightly decreasing in some areas	Unlikely to be important in octopus diet	No concern
Flatfish	Increasing to steady populations currently at high biomass levels	May be part of adult diet	No concern
Pollock	High population levels in early 1980's, declined to stable low level at present	Unlikely to be important in octopus diet	No concern
Other Groundfish	Stable to low populations	May be part of adult diet	No concern
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	Both prey on octopus; importance unknown	Unknown
Birds	Stable, some increasing some decreasing	Unlikely to affect octopus	Unknown
Fish (Pollock, Pacific cod, halibut)	Stable to increasing	Possible increases to mortality	Unknown
Sharks	Stable to increasing	Predation on octopus unknown	Unknown
Changes in habitat quality			
Temperature regime	Warm and cold regimes	May shift distribution, depth selection, or growth rates	Unknown

***BSAI octopus* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Not Targeted	Some market value, retention of incidental catch. Current level of fishery catch small in relation to estimated predation mortality.	No concern	No concern
Fishery concentration in space and time	Octopus catch concentrated in areas of Pacific cod pot fishing, esp. around Unimak pass.	Possible overlap of fishery with two SSL rookeries	Unknown
Fishery effects on amount of large size target fish	Pot fishing catches predominantly large males, unknown seasonal timing of fishing vs. mating	No concern at this time	Unknown
Fishery contribution to discards and offal production	None. Discards from pot vessels have low immediate and short-term mortality.	No concern	No concern
Fishery effects on age-at-maturity and fecundity	Unknown	No concern at this time	Unknown

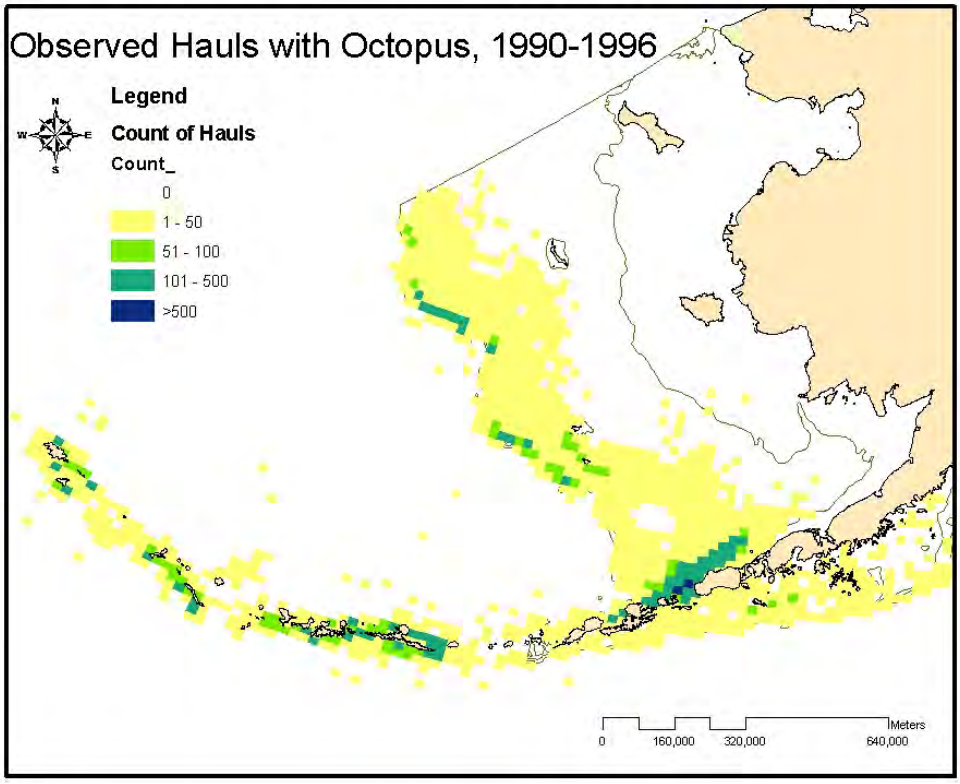


Figure 1. Distribution of octopus (all species) in the BSAI, based on octopus occurring in observed hauls during the period 1990-1996.

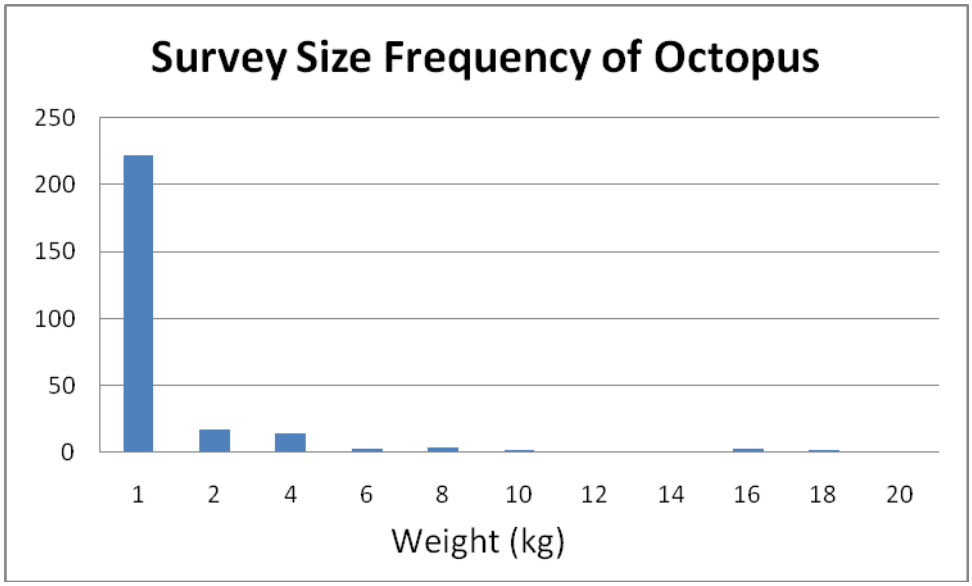
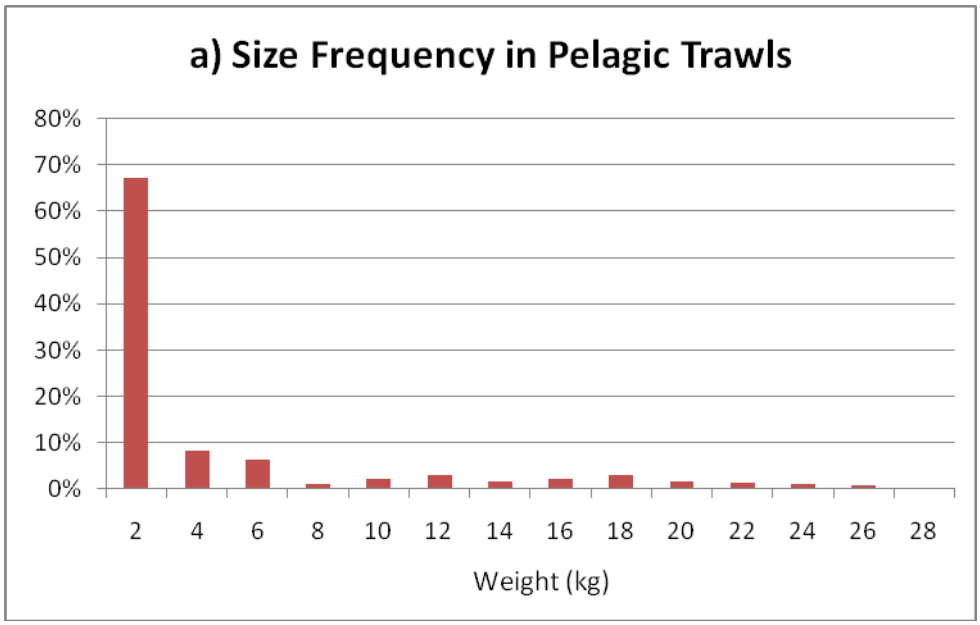


Figure 2. Size frequency of individual octopus (all species) from Bering Sea shelf bottom trawl surveys 2009 - 2011.



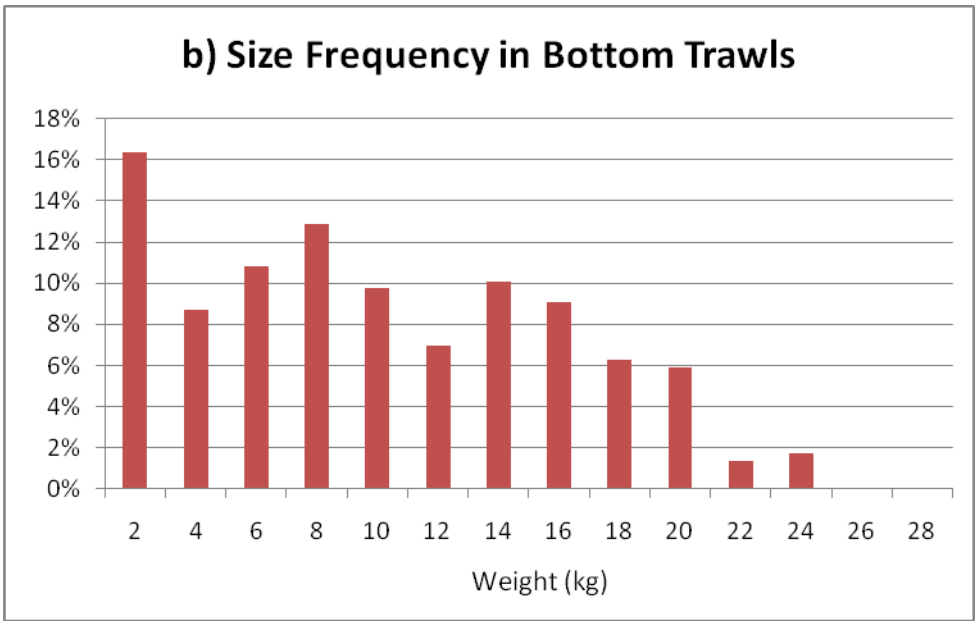
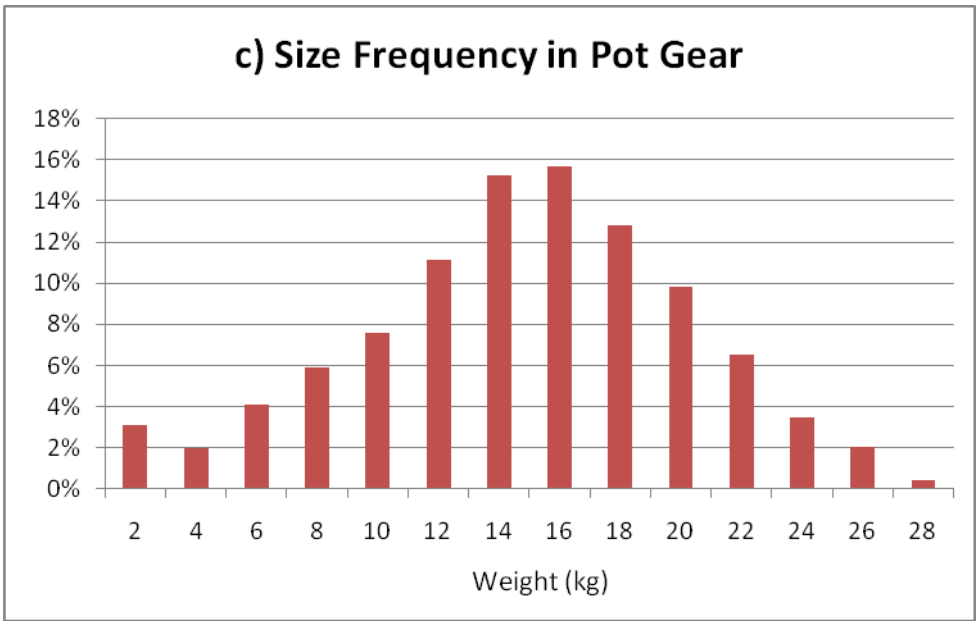


Figure 3. Size frequency of individual octopus from observer special project 2006-2011 by gear type: a) pelagic trawl, b) bottom trawl, c)pots, d) longline.



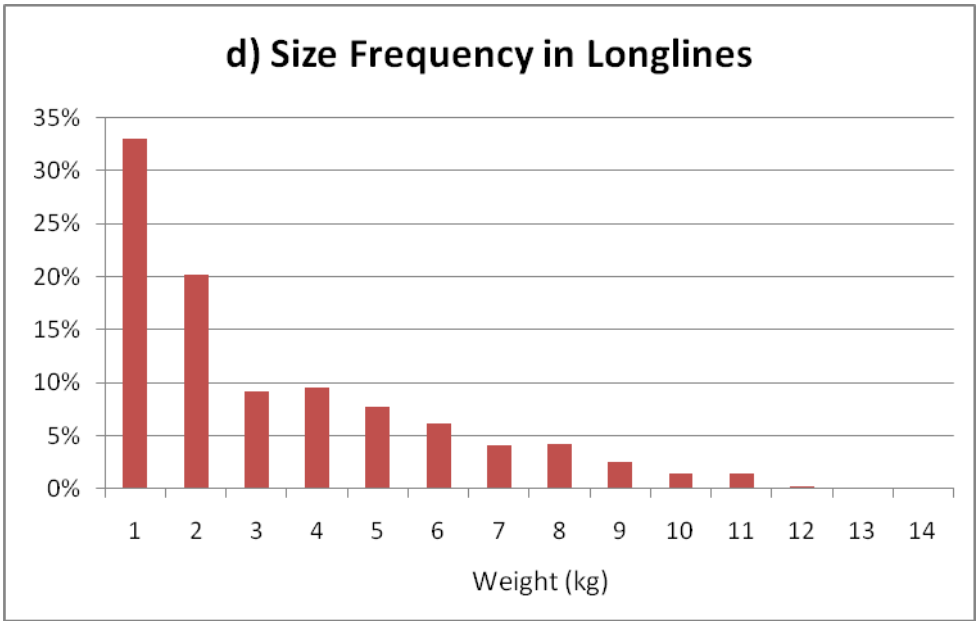


Figure 3. Continued.

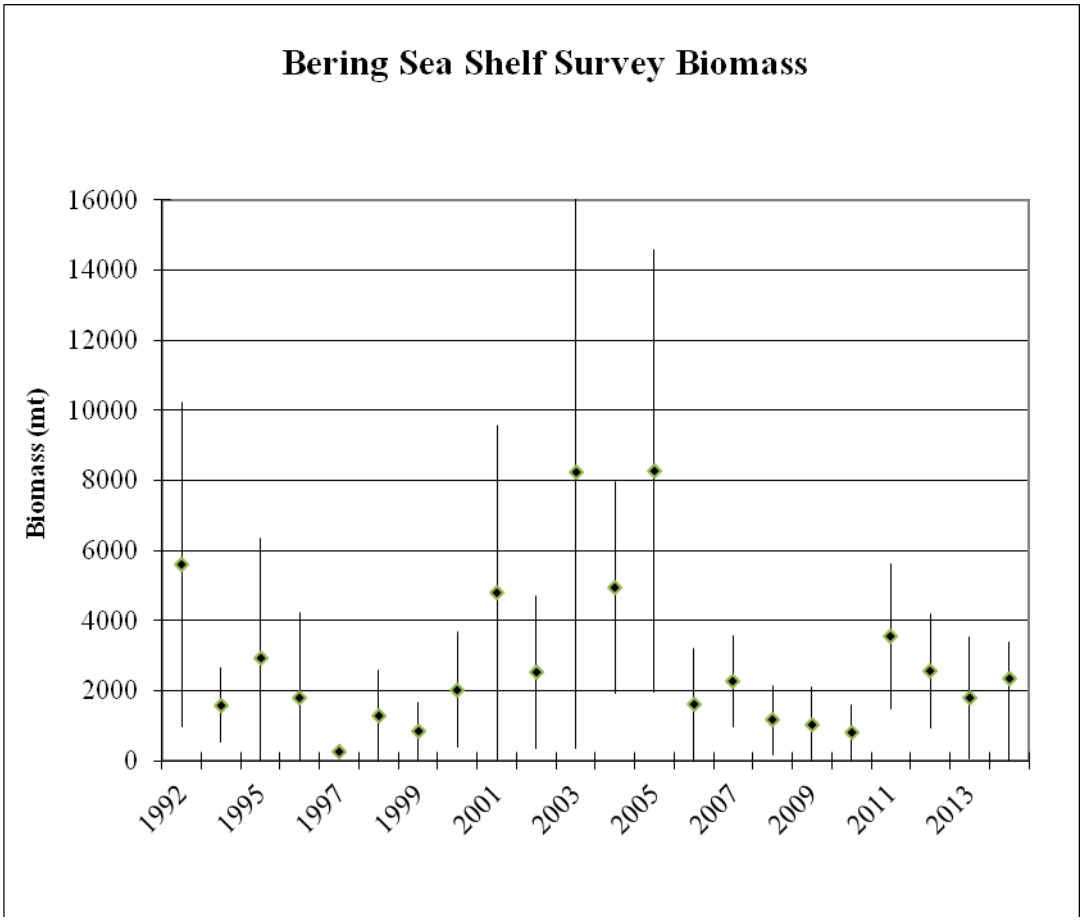
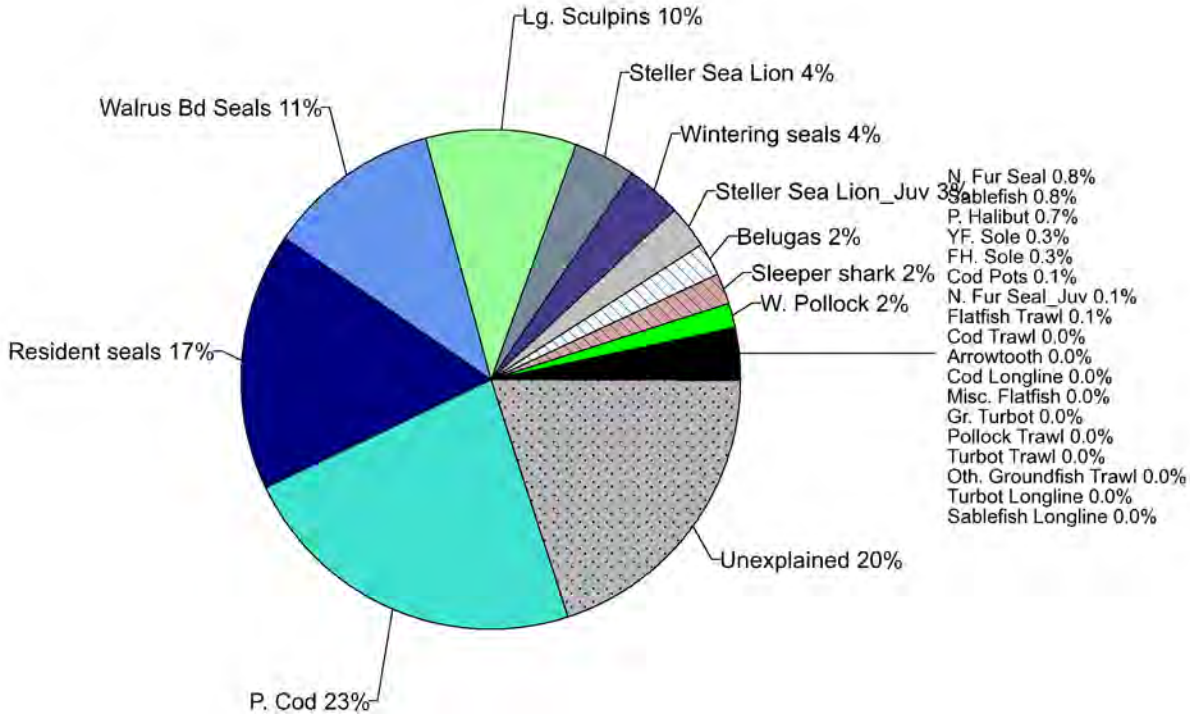


Figure 4. Biomass estimates of octopus (all species) from the Bering Sea shelf survey, with 95% confidence intervals shown.

a) Bering Sea Ecosystem



b) Aleutian Islands Ecosystem

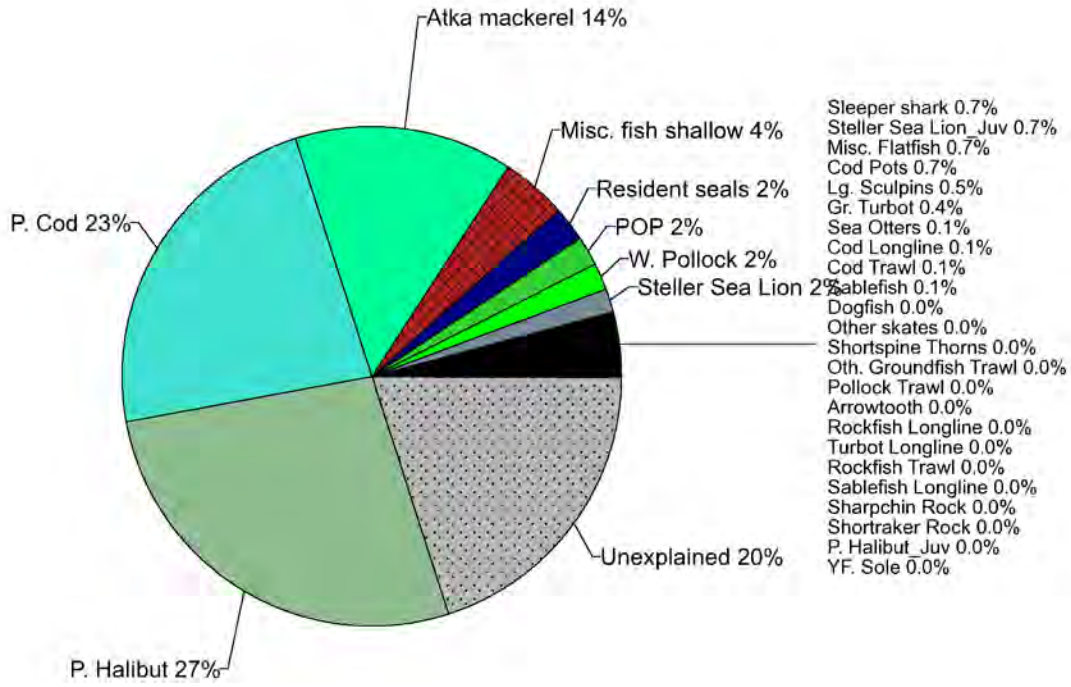


Figure 5. Ecopath model estimates of mortality sources of octopus in the BSAI.

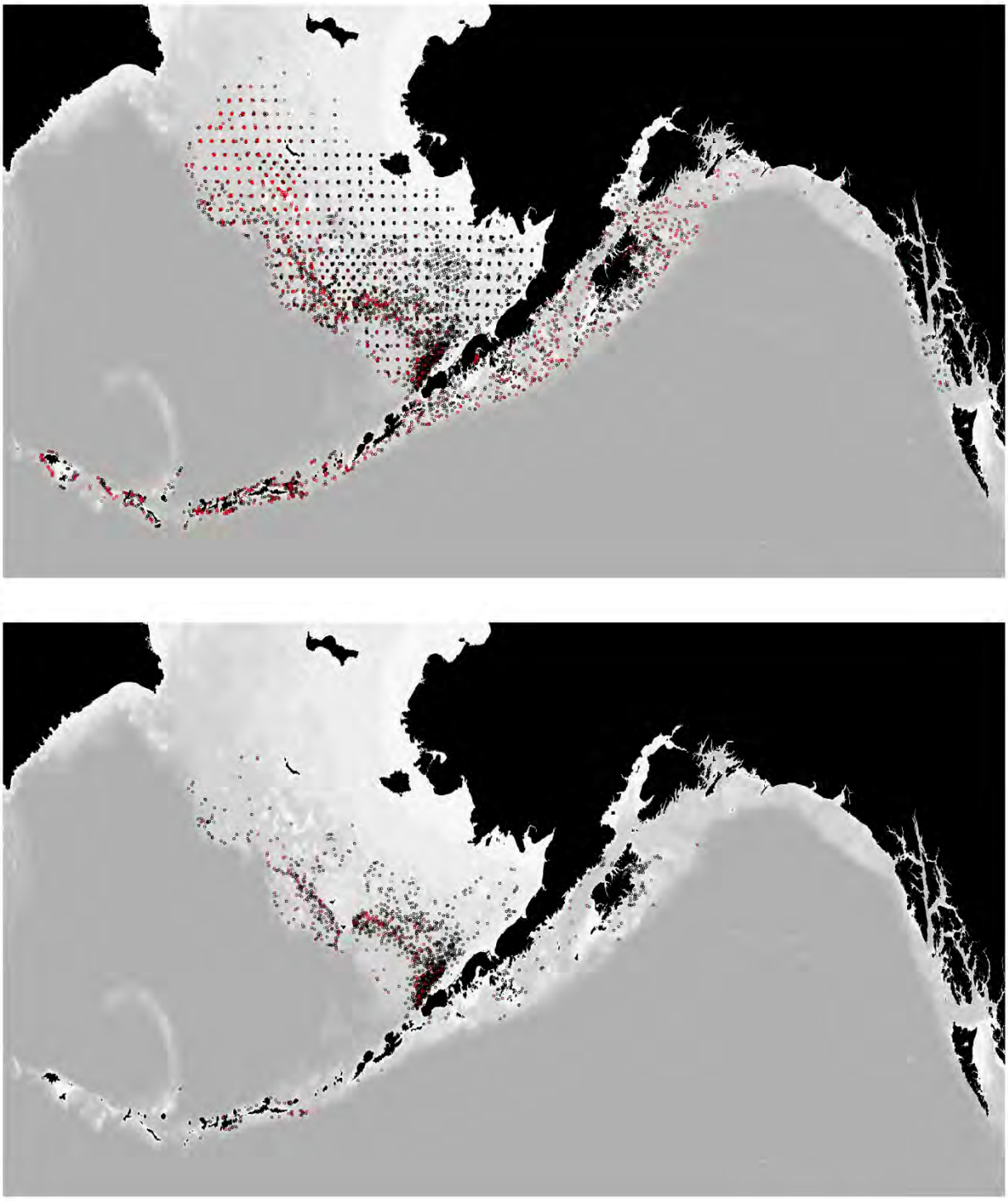


Figure 6. Locations of all sampled Pacific cod stomachs (black circles; N=62,393) and stomachs containing octopus (red circles), 1982-2011, for May-September (top panel) and October-April (bottom panel).

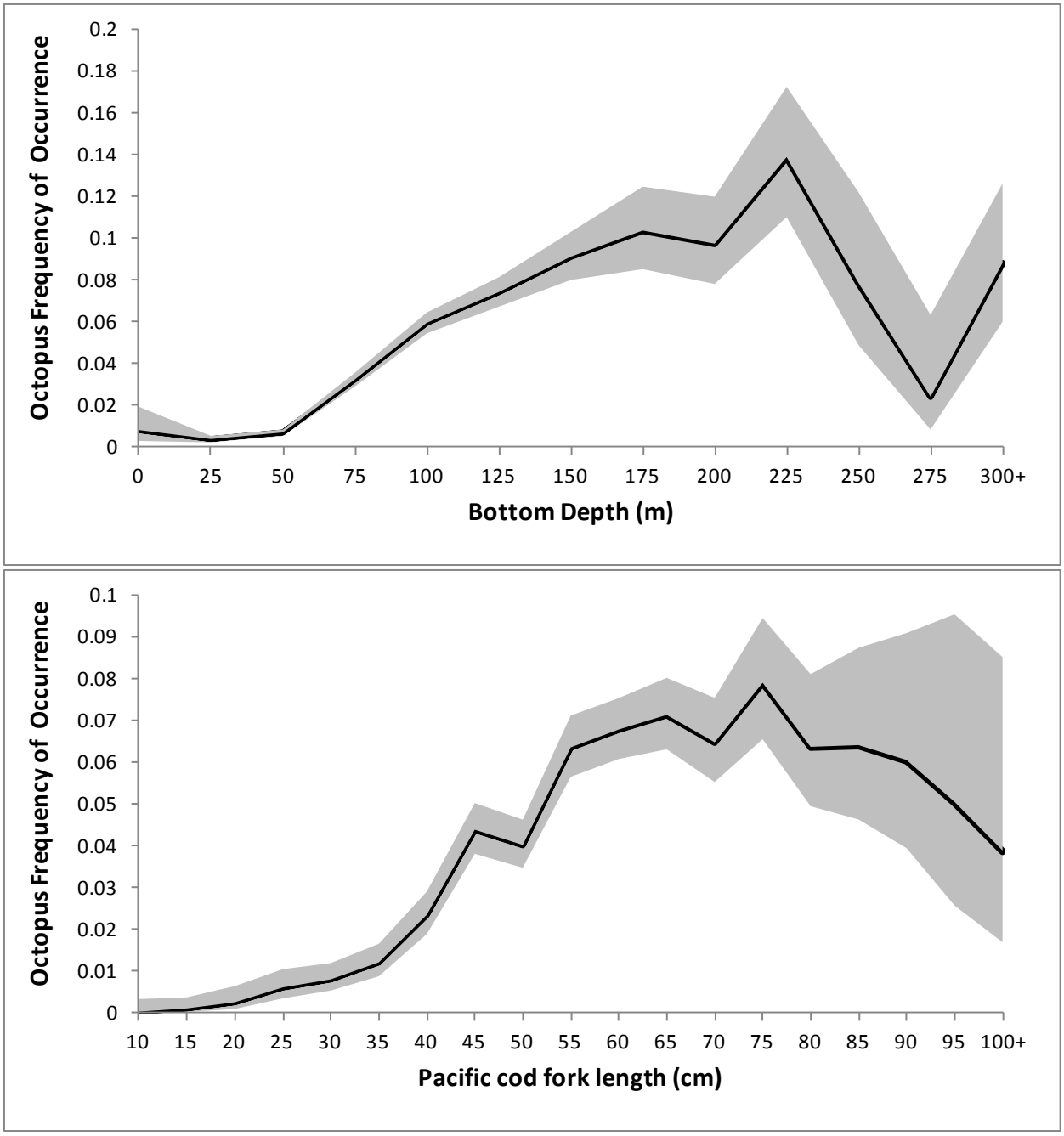


Figure 7. Frequency of occurrence of octopus in Pacific cod stomachs, all years, regions, and seasons, as a function of bottom depth (top panel) and Pacific cod fork length (bottom panel). Gray area shows the 95% confidence interval calculated from logit-transformed data (empirical logit transformation).

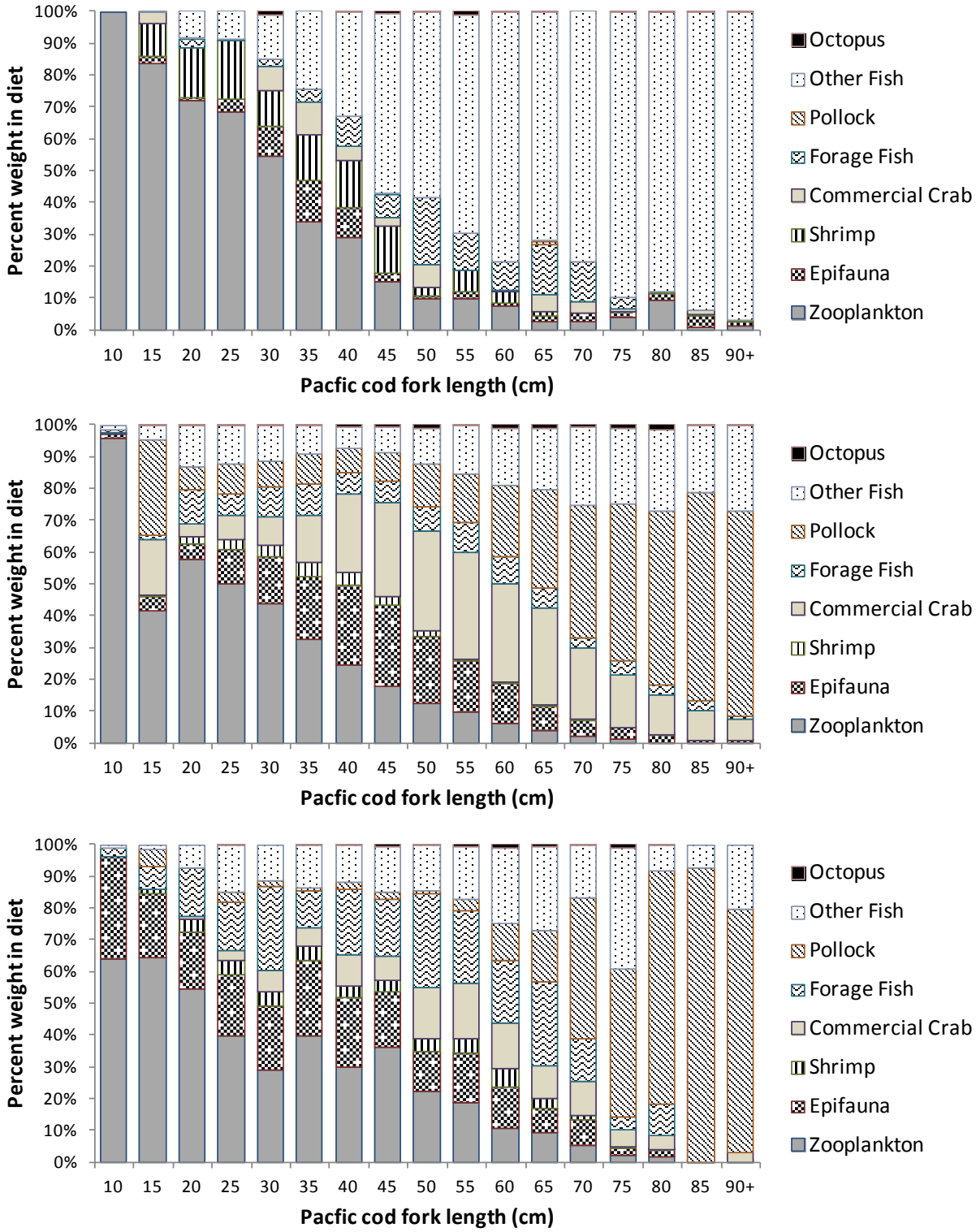


Figure 8. Percent diet by weight in Pacific cod stomachs sampled in water **<100m**, all years and seasons, for Aleutian Islands (top panel), Bering Sea (middle panel), and Gulf of Alaska (bottom panel).

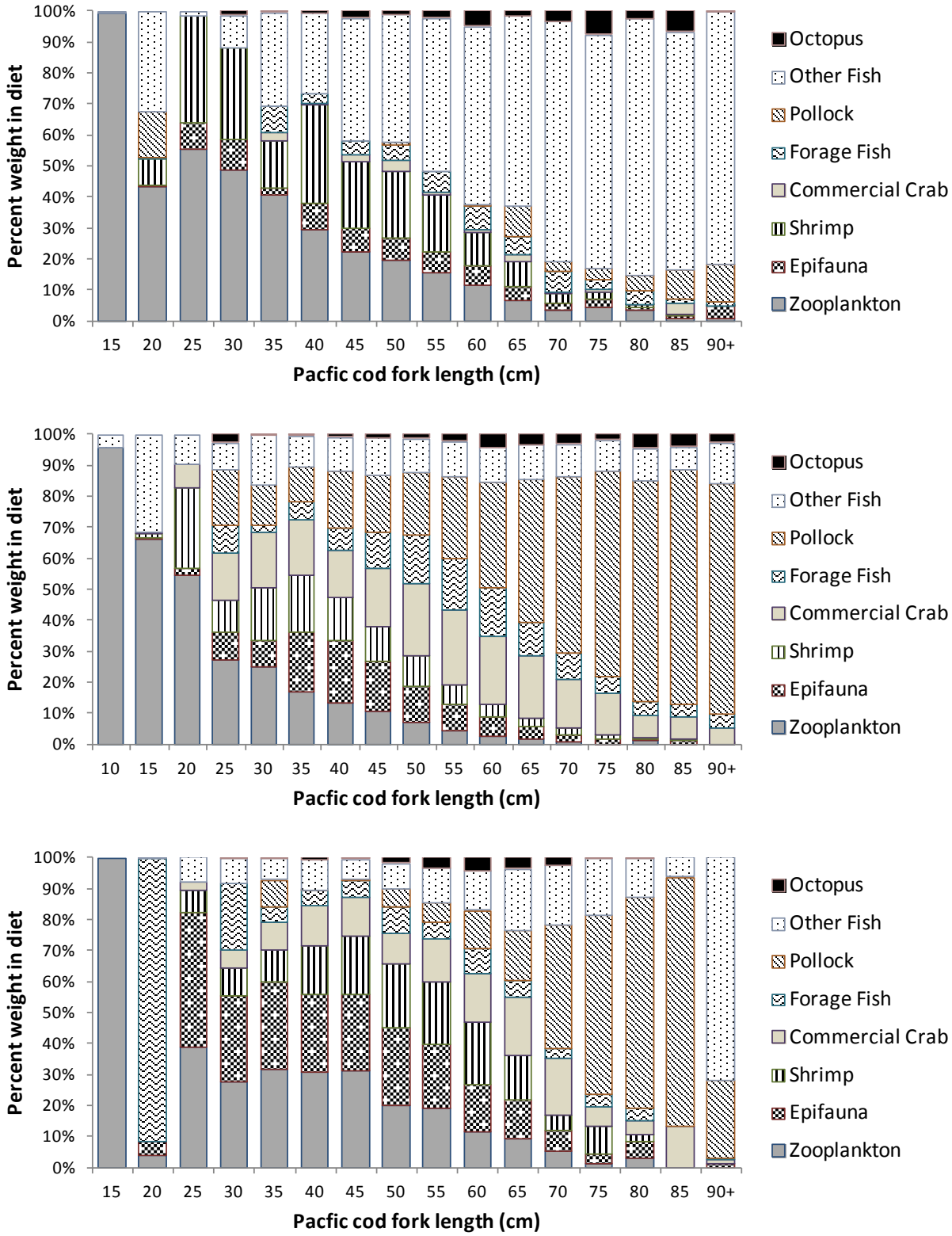


Figure 9. Percent diet by weight in Pacific cod stomachs sampled in water **≥100m**, all years and seasons, for Aleutian Islands (top panel), Bering Sea (middle panel), and Gulf of Alaska (bottom panel).

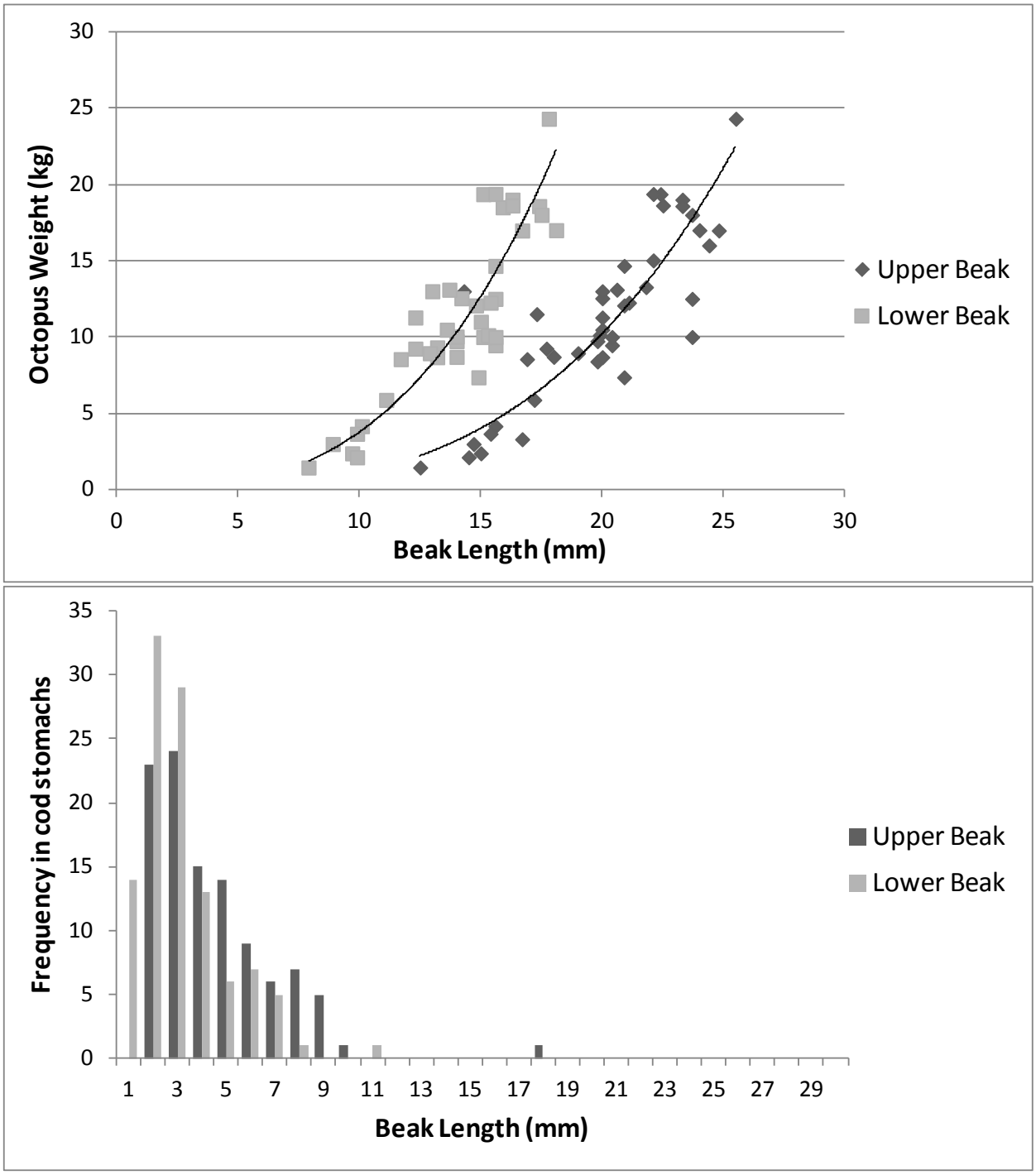


Figure10. (Top panel): Relationship between upper and lower beak hood length and Pacific octopus total weight, measured from fisheries-sampled octopus. (Bottom panel): Length frequency of upper and lower beaks sampled from Pacific cod stomachs.

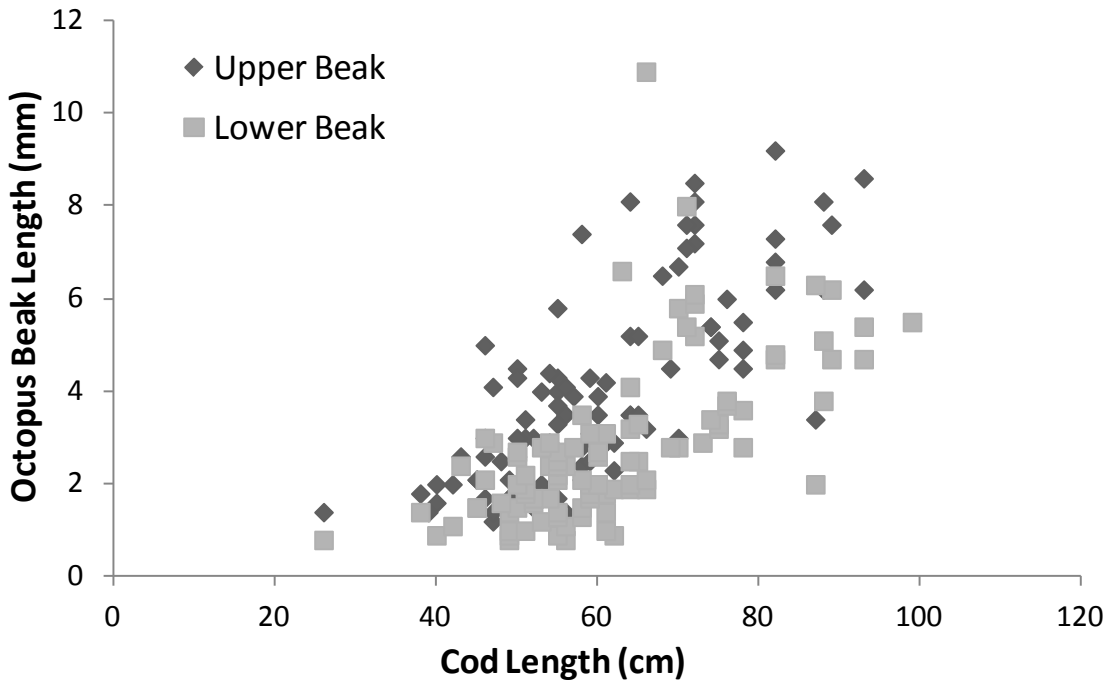


Figure 11. Beak hood lengths of octopus removed from Pacific cod stomachs as a function of cod fork length.

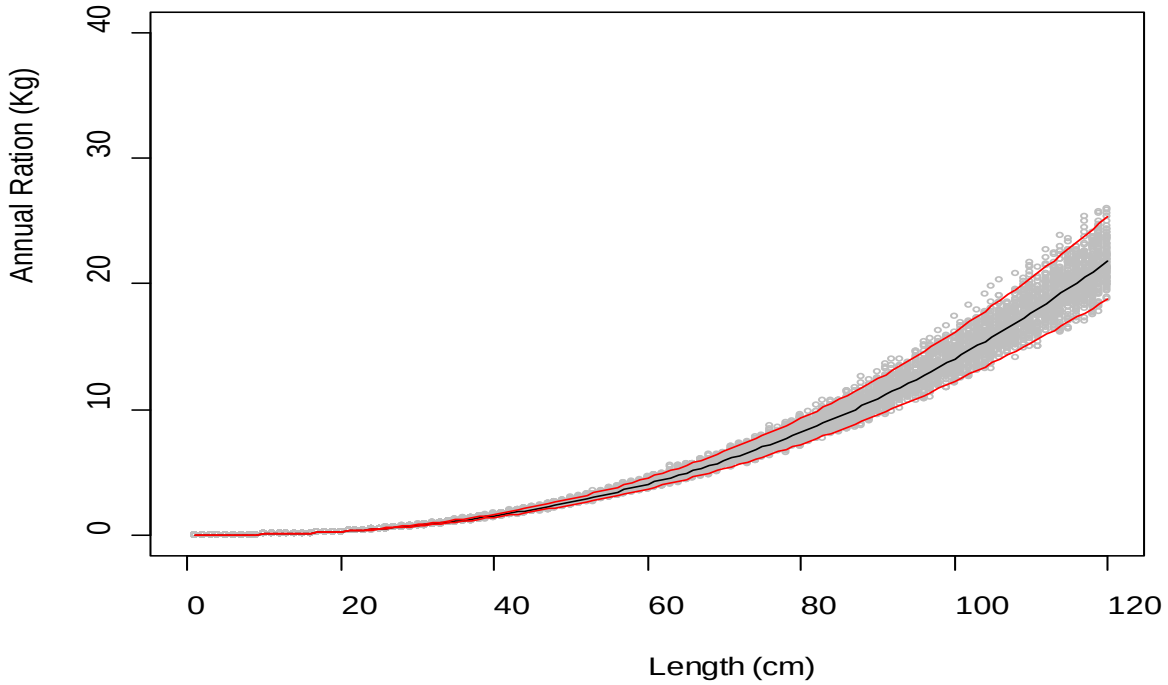


Figure12. Annual ration of Pacific cod as a function of fork length, as estimated from fit von Bertalanffy parameters. Points indicate MCMC posterior distribution for fit; black and red lines show estimate and 95% confidence intervals.

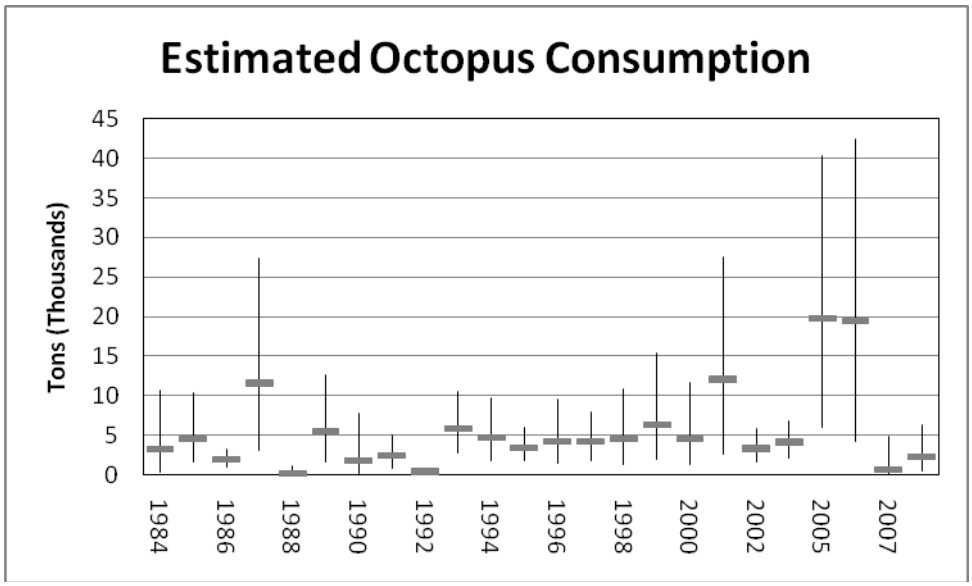


Figure13. Estimated consumption of octopus by Bering Sea Pacific cod, 1984-2008. Error bars show 95% confidence intervals of posterior distribution; solid bars are annual hyperbolic means.

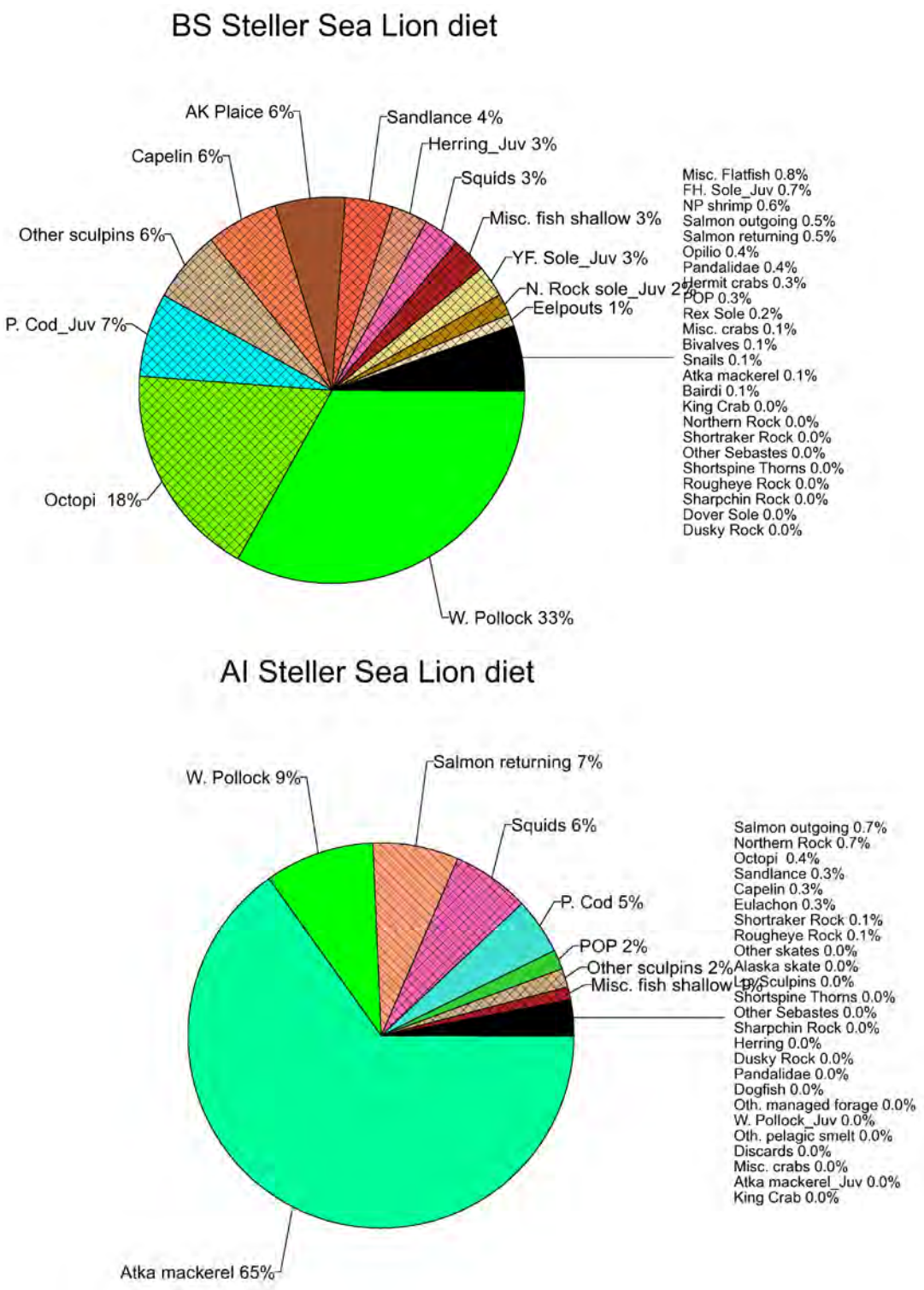


Figure 14. Literature-derived diets of Steller sea lions in the BS and AI.

Appendix 1. Summary of Octopus Research

Species Composition of the Catch

A NOAA Cooperative Research Program project was conducted in 2006 and 2007 by AFSC scientist Elaina Jorgensen. Processing plants buying octopus were visited in Dutch Harbor and Kodiak in October 2006 and February-March 2007. A total of 282 animals were examined at Harbor Crown Seafoods in Dutch Harbor and 102 animals at Alaska Pacific Seafoods in Kodiak. Species identification of octopus observed in plant deliveries confirmed that all individuals were *E. dofleini*. All animals delivered to the plants came from the Pacific cod pot fishery. Octopus in Dutch Harbor ranged from 4.5 to 27.7 kg gutted weight with an average gutted weight of 13.6 kg.

NPRB Projects 2009-2012

The North Pacific Research Board funded field studies in support of stock assessment for octopus, beginning in fall 2009. The studies were conducted by AFSC and UAF researchers in both the Gulf of Alaska near Kodiak and in the southeast Bering Sea near Dutch Harbor. The main focus of the 2009-2011 study was to increase knowledge of reproductive biology of *E. dofleini*, in particular to document the seasonality of mating and egg incubation in Alaskan waters. Specimens were collected from a variety of sources throughout the calendar year for dissection and examination of the gonads; a gonad maturity coding system was developed and samples collected for laboratory analysis of fecundity and weight at sexual maturity. In addition to the reproductive work, this project also included a pilot tagging study near Dutch Harbor and testing of habitat pot gear for use in octopus studies (Conners et al. 2012).

Octopus specimens for reproductive study were obtained from Kodiak waters during each season of the year from charter operations, the AFSC GOA and AI bottom trawl surveys, and from commercial cod pot fishermen. All octopus sampled were weighed, sexed, the mantle length was measured and the reproductive tract was removed and weighed. The weight and diameter of the gonad was measured and the condition of the reproductive tract was noted. For male specimens the presence and number of fully or partially formed spermatophores was noted. For female specimens the presence of visible eggs within the ovary was noted. For all specimens, all or part of the gonad was preserved. Thin sections of these tissues were embedded in paraffin, thin sectioned, and stained utilizing standard histological techniques. A three stage maturity classification system was derived for both male and female *E. dofleini* based on reproductive tract characteristics and the presence/absence of well developed eggs or spermatophores.

Enteroctopus dofleini samples collected during research in the Bering Sea were found to have size at 50% maturity values of 12.8 kg for females and 10.8 kg for males (Brewer and Norcross, in review). Results from this study indicate that *E. dofleini* are reproductively active in the fall with peak spawning occurring in the winter to early spring months. In the Gulf of Alaska, this species was found to mature between 10-20 kg with size at 50% maturity values of 13.7 kg (95% CI 12.5-15.5 kg) for females and 14.5 kg (95% CI = 12.5-16.3 kg) for males. Size at maturity was highly variable for this species, particularly for male octopus. *Enteroctopus dofleini* smaller than 10 kg tended to be immature but male and female mature members of this species in the size range between 10 – 20 kg were found to be immature, maturing, and mature. Fecundity for this species in the Gulf of Alaska was found to range from 41,600 to 239,000 with an average fecundity of 106,800 eggs/female. Fecundity was significantly and positively related to the weight of the female ($n = 33$, $P < 0.001$).

The pilot tagging study conducted in fall 2009-winter 2010 near Dutch Harbor was highly successful. Tagging studies target the local dynamics and seasonal movement of octopus, and may eventually allow estimation of parameters for Tier 5 management of the octopus species group. The results from initial tagging efforts have shown that the tagging method using Visual Implant Elastomers (VIE tags) is

feasible, and that the tags are readily visible in recaptured animals and have no associated tissue damage (Brewer and Norcross 2012). Based on these results, NPRB funded continued tagging effort through 2012. The goal of the extended effort is to collect enough tag recapture data to fit a Jolly-Seber or similar quantitative model that will allow estimation of natural mortality rates and local abundance of octopus in the study area. The results of this study have not yet been published.

Tagged octopus were weighed at each recapture and release to assess in-situ growth rates. Of the *E. dofleini* recaptured, change in weight for octopus appeared to be variable; no apparent pattern in weight change could be observed. When a larger data set has been collected, growth information from tagged octopus will be fitted to a von Bertalanffy growth curve. Parameter estimates from a fitted curve may be used to compare to literature values for other species and regions and in estimation of population growth for general production models.

As of October 2011, five seasons of tag and recapture efforts occurred 20km north of Unalaska Island in depths ranging from 50 to 200m. From October 2009 through October 2011, 1,730 *E. dofleini* were tagged and 243 recaptured. While most of the recaptures occurred within a few weeks after tagging, 32 octopus were recaptured between seasons after 60 days. Preliminary within-season abundance estimates give densities of 200-600 octopus per km^2 in the study area. If a density of 200 octopus/km^2 with an average weight of 15 kg were applied to the approximately 3,500 km^2 of shelf area around Unimak Pass, this would represent over 10,000 tons of octopus.

The initial NPRB study also included a vessel charter for testing and developing a specialized gear for octopus fishing that may eventually be useful for an index surveys of octopus abundance. The unbaited gear consists of small "habitat pots" that act as artificial den space for octopus. Similar gear is used in octopus fisheries in other parts of the world. A variety of pot designs and materials were tested for use in Alaska. An initial trial of habitat pot gear was conducted in spring and fall 2010, and more work was conducted during summer and fall 2011. Captured octopus ranged in size from smaller than 2 kg to over 20 kg. In all, a total of 319 octopus were captured in 1,901 pot lifts. In all trials, plywood box pots and scrap ATV tires captured octopus much more effectively than pots made of various plastic materials. Overall capture rates for boxes and tires was roughly 25%, but plastic pots had less than 10% catch rate. Capture rates varied between seasons, ranging from less than ten percent to over 50% occupancy (Conners et al, 2012). Results of this study indicate that longlined plywood box pots are an economical and feasible method for capturing octopus.

NMFS Cooperative Research Program Gear Study

In 2013, the NMFS Cooperative Research Program funded a small study to further develop the habitat pot gear. Three vessels obtained ADF&G Commissioner's permits for directed octopus fishing, under the agreement that they would share their fishing data with ADF&G and NMFS. These vessels were each provided with 200 of the plywood box pots that worked will in the initial field study, as well as associated longlines and tackle. One vessel, fishing commercial cod pots out of Dutch Harbor in winter 2014, set trial strings of octopus gear using a commercial pot hauler. Two smaller vessels fished near Kodiak in winter and fall 2014 using commercial longline reels. All vessels kept records of fishing locations, soak times, effort, and catch rate (numbers of pots fished and proportion of pots retrieved with octopus) as well as total catch. The vessel fishing near Dutch Harbor had very low catch rates, and actually saw more octopus in their cod pots than in the habitat pots. The Kodiak vessels have had varying catch rates, but report that both the plywood box pots and some plastic octopus pots purchased from Korea were successful at catching octopus. This project will be completed in early 2015, and a scientific publication covering both the NPRB and Cooperative Research gear studies is in preparation. The goals of this project are to refine fishing gear and techniques and to calculate an estimate of the variance of habitat pot catch data, so that the total effort and sample size needed for an index survey of octopus abundance can

be estimated. If there is sufficient industry interest, this project could be continued with a small experimental fishery. It is not clear at this time whether octopus catch rates would be high enough for a commercial directed fishery to be economically feasible.

Discard Mortality for Octopus

A number of studies have been directed at determining and estimating the mortality rate for octopus caught and discarded by commercial fisheries. Anecdotal evidence and occasional observation indicated that octopus are often in good condition when caught, and may often survive handling and discard. These observations suggested that octopus discard mortality could be expected to vary with gear type and octopus size. Mortality of small individuals and deep-water animals in trawl catch is probably high due to compression in the codend. Larger individuals may also have high trawl mortality if either towing or sorting times are long. Octopus caught with longline and pot gear are more likely to be handled and returned to the water quickly, thus improving the probability of survival. Octopuses have no swim bladder and are not affected by depth changes, and can survive out of water for brief periods. Large octopus caught in pots were very active during AFSC field studies and appeared to have a high survival rate. Observers report that octopus in longline hauls are often simply holding on to hooked bait or fish catch and are not hooked directly. At present, catch accounting for octopus uses the conservative assumption of 100% mortality for all octopus caught, whether retained or discarded. Studies have been undertaken to estimate the proportion of octopus that survive capture and discard from different fishing gears.

A special project by fisheries observers in 2006 and 2007 included a visual evaluation of the condition of the octopus when it was processed by the observer. In 2010 and 2011, the special project was modified so that observers recorded the condition of octopus at the point of discard from the vessel. The 2010-11 project included a three-stage viability coding (Excellent, Poor, or Dead) based on the color and mobility of octopus and the presence of visible wounds. Data from both projects are presented in Table 1.1. The table shows the number of observations and the proportion of observed octopus alive or dead for each gear type. These results provide partial data on the nature of discard mortality for octopus. In particular, the observed initial mortality rate for octopus caught in pot gear in 2006-2007 was less than one percent (two octopus out of 433, one coded as dead and the other as injured). In 2010-11, only 4 percent (30 out of 536) of the octopus caught in pot gear were in poor condition or dead at the point of discard. Immediate mortality rates in both time periods were roughly 20% for longline gear; observers report that most animals seen on longlines are not actually hooked but are holding on to bait or hooked fish. Bottom trawl mortality rates were variable at 58-74 %, variable conditions may be expected since this category includes several different target fisheries. Immediate mortality rates were highest for pelagic trawl gear, for which 85% of the observed octopus in both periods were dead.

In October of 2012, a brief field study was conducted by Reid Brewer of UAF. In this study, 15 *E. dofleini* captured as part of the Bering Sea pot cod fishery were fitted with video cameras and released. Go Pro HD video cameras were attached to each of the 15 *E. dofleini* and were retrieved using heavy duty fishing poles. The mean depth was 50.2 m with a range of 40.2 to 66.7m and the mean time to the sea floor was 5 min 32 seconds with a range of 2 min 3seconds to 9 min 50 seconds. Each of the 15 *E. dofleini* actively swam to depth and showed color and body positioning changes upon reaching the sea floor. Though this project does not determine the survival of *E. dofleini* beyond reaching the sea floor, Brewer and Norcross (2012) recaptured 243 tagged *E. dofleini* at least 24 hours after release. Together, these two studies also suggest that a large portion of discarded *E. dofleini* are making it to the sea floor and surviving capture and handling.

The NMFS Cooperative Research program funded a small field study of octopus discard mortality in winter 2013. This project was directed at measuring the short-term mortality of discarded octopus in

relation to condition coding. While many of the octopus in the observer study were rated in "Excellent" condition at discard, it is not known whether there is some delayed mortality due to handling stress or temperature changes during capture and discard. A small field project was conducted in January 2013 aboard the commercial pot vessel *Aleutian Mariner*. Small insulated seawater tanks were installed on the vessel during their winter cod pot season, and incidentally caught octopus were examined for condition at the normal point of discard from fishing operations. These octopus were then held in the onboard seawater tanks for at least 24 hours to look for delayed mortality or decline in condition. Some of the octopus were held and re-evaluated after longer time periods from 36-60 hours. All but one of the octopus were in excellent condition just after capture. None of the 36 octopus showed any overall decline in condition during holding. One octopus, in poor condition at capture, actually improved in condition during the first 24 hours, but then declined again to poor condition by 48 hours. Two octopus held in the air on deck were still in excellent condition after more than two hours.

A larger project, funded by NPRB, is being conducted at the AFSC Kodiak laboratory. In order to examine long term delayed discard mortality of giant Pacific octopus, octopus discards are obtained directly from commercial Pacific cod pot fishers and transported to the sea water facility at the Kodiak Laboratory. During the first fishing season in January and February 2014, 20 giant Pacific octopus were successfully collected for this project. There was one short term mortality that occurred while the octopus were still on board the vessel (before transport to the laboratory). In addition, there was one long term mortality that occurred at the laboratory that was attributed to a negative interaction with the fishing gear. This octopus died after 27 days at the laboratory and had wounds on six of eight legs, at least two with substantial damage to the underlying tissue. Preliminary results indicate a low level of short and long term mortality for octopus in good condition, with 90% of octopus surviving and in good health at the laboratory at least 24 days after capture. During the second fishing season in September and October 2014, an additional 24 octopus were brought to the laboratory. Of these octopus two died within seven days of arriving at the laboratory due to either injury or illness, one died due to equipment failure at the laboratory, 16 are currently being held to assess delayed discard mortality, and five were utilized to obtain additional condition information and to examine short-term delayed discard mortality. These octopus will be held for a period of at least 24 days after which time condition will be re-assessed. This project will continue with octopus collections during the fall 2014 and winter 2015 cod seasons.

Results of the studies to date suggest that a gear-specific discard mortality factor could be estimated for octopus, similar to approach currently used for Pacific halibut. If a discard mortality factor were included in catch accounting for octopus, the fraction of discarded octopus that are assumed to survive would not be counted toward the total "take" for the assemblage. Similar to the current practice used in Bering Sea crab assessments, the estimated catch for octopus would include all retained and dead animals, but only a percentage of those discarded alive. Estimated or assumed mortality rates would be assigned to each condition level, and combined with the observer data for a gear-specific estimate of the percentage mortality of discarded octopus. For example, if we assumed 75% survival for octopus discarded in excellent condition, then 96% * 75% = 72% of octopus discarded from pot vessels could be assumed to survive (mortality = 1- survival = 28%). Final study results could be combined with the observer data into overall gear-specific estimates of discard mortality for octopus.

Table 1.1. Results of observer program special project data on condition of octopus when observed (2006-2007) and at point of discard (2010-2011).

2006-2007	Observer Special Project Data Condition Reported for Observed Octopus			
Gear	**No. Alive**	**No. Dead**	**Total**	**Alive**
Bottom Trawl	32	43	75	42.7%
Pelagic Trawl	28	161	189	14.8%
Pots	431	2	433	99.5%
Longline	132	36	168	78.6%

2010-2011					
Gear	**Excellent**	**Poor**	**Dead**	**Total**	**%Excellent**
Bottom Trawl	16	11	35	62	25.8%
Pelagic Trawl	8	7	42	58	13.8%
Pots	506	14	16	536	94.4%
Longline	122	7	16	146	83.6%

Table 1.2. Results of 2013 field study of pot-caught octopus in the BS. Octopus condition was recorded at capture (0 hours, n = 36), after being held in flow-through seawater tanks for ≥24 hours, 25-36 hours, 37-48 hours, and 60 hours. The number of octopus removed from holding at each time is shown in parentheses. Percent downgraded refers to the percentage of octopus showing a downgrade from their condition at capture.

Holding time	**Condition code**			**Percent downgraded**
hours (n)	Excellent	Poor	Dead	
0	35	1	0	-
24 (20)	20	0	0	0
25-36 (5)	5	0	0	0
37-48 (10)	9	1	0	0
60 (1)	1	0	0	0

Appendix 2 —Supplemental catch data

In order to comply with the Annual Catch Limit (ACL) requirements, two new datasets have been generated to help estimate total catch and removals from NMFS stocks in Alaska. The first dataset, non-commercial removals, estimates total removals that do not occur during directed groundfish fishing activities. This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System estimates. Additional sources of significant removals are bottom trawl surveys and the International Pacific Halibut Commission longline survey. These removals are not substantial relative to the incidental catch from commercial fisheries. Total removals of octopus from activities other than directed fishery in 2013 was 2.9 tons.

Table 2.1 Total removals of octopus (mt) from activities not related to directed fishing in 2012 and 2013. Trawl survey sources are a combination of the NMFS echo-integration, small-mesh, GOA, AI, and BS Slope bottom trawl surveys, and occasional short-term research projects.

Source	2012	2013
Aleutian Island Bottom Trawl Survey	0.02	
Aleutian Islands Cooperative Acoustic Survey		
Annual Longline Survey	0.13	0.08
Bait for Crab Fishery	0.22	
Bering Sea Slope Survey	0.00	
Eastern Bering Sea Bottom Trawl Survey	0.01	
Golden King Crab Pot Survey		
Gulf of Alaska Bottom Trawl Survey		
IPHC Annual Longline Survey	0.64	2.41
Large-Mesh Trawl Survey	0.61	0.42
Pollock EFP 11-01	6.06	
Pribilof Islands Crab Survey		
Scallop Dredge Survey		0.02
Shelikof Acoustic Survey		
Small-Mesh Trawl Survey	0.02	0.01
Spot Shrimp Survey		
Subsistence Fishery		
Grand Total	7.71	2.93

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Assessment of the Grenadier Stock Complex in the Gulf of Alaska, Eastern Bering Sea, and Aleutian Islands

Cara Rodgveller and Pete Hulson
November 2014

Executive Summary

The Secretary of Commerce approved Amendments 100/91 on August 6, which added the grenadier complex into both FMPs as Ecosystem Components. Under this rule, they are not allowed to be targeted but there is an 8% Maximum Retainable Allowance (MRA) (Federal Register, Proposed Rules, Vol. 79, No. 93). The final rule will publish before the end of the year and so it may be effective for the start of the 2015 fishing year.

As an Ecosystem Component, a stock assessment is not required and there is no ABC or OFL. A full unofficial assessment report was prepared for grenadiers in even years since 2006, even though they were "nonspecified". For 2015, we are presenting an abbreviated SAFE report for the BSAI and GOA combined for the purpose of tracking trends in abundance. This content of future reports is still being evaluated since a SAFE report is not required. This report contains a time series of catch and abundance estimates and unofficial ABC and OFL values based on Tier 5 calculations. These values are not used for management or for determining if overfishing is occurring for Ecosystem Component species/complexes. There is no definition of overfishing for an Ecosystem Component.

Summary of Changes in Assessment Inputs

Changes in the input data: New data inputs include: 1) updated catch data for 2003-2014; 2) updated 2000-2014 Aleutian Island (AI) biomass from 1-1,000 m using the estimation method presented in the 2012 SAFE; 3) NMFS longline survey results for 2013 and 2014; 4) updated GOA biomass using a random effects model. There was no EBS slope trawl survey in 2014.

Changes in assessment methodology: This year we use a random effects model (a similar method, a Kalman filter, was presented in the 2012 SAFE report (Rodgveller et al. 2012)), that utilizes trawl survey data from 1984-2013 to estimate the exploitable biomass in 2013. Since there was no trawl survey in the GOA in 2014, the estimate for 2013 is used as the most recent value of exploitable biomass.

Summary of Results

For 2015, the maximum allowable ABC for the BSAI is 75,274 t and for the GOA is 30,691 t. This ABC is a 12% increase for the BSAI and a 12% decrease for the GOA. The corresponding reference values for grenadier are summarized in the following tables, with the recommended ABC and OFL values in bold. Overfishing is not occurring in either the BSAI or GOA.

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Gulf of Alaska Grenadiers

Quantity	As estimated or specified *last* year for[a]: 2014	2015	As estimated or recommended *this* year for: 2015	2016
M (natural mortality)	0.078	0.078	0.078	0.078
Specified/recommended Tier	5	5	5	5
Biomass (t)	597,884	597,884	524,624	524,624
F_{OFL} (F=M)	0.078	0.078	0.078	0.078
$maxF_{ABC}$ (maximum allowable = 0.75x F_{OFL})	0.0585	0.0585	0.0585	0.0585
F_{ABC}	0.0585	0.0585	0.0585	0.0585
OFL (t)	**46,635**	46,635	**40,921**	40,921
maxABC (t)	34,976	34,976	**30,691**	30,691
ABC (t)	**34,976**	34,976	**30,691**	30,691
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	No	n/a	No	n/a

[a]The values for biomass, OFL, and ABC in these two columns are based on Rodgveller and Hulson 2013. They are an average of the last three trawl surveys that sampled down to 1,000 m. The current values (for 2015 and 2016) are from the random effects model fit to survey biomass by region and depth strata.
These are unofficial ABC and OFL values since grenadier are an Ecosystem Component, which do not have ABCs or OFLs.

Bering Sea and Aleutian Islands Grenadiers

Quantity	As estimated or specified *last* year for[a]: 2014	2015	As estimated or recommended *this* year for: 2015	2016
M (natural mortality)	0.078	0.078	0.078	0.078
Specified/recommended Tier	5	5	5	5
Biomass (t)	1,152,284	1,152,284	1,286,734	1,286,734
F_{OFL} (F=M)	0.078	0.078	0.078	0.078
$maxF_{ABC}$ (maximum allowable = 0.75x F_{OFL})	0.0585	0.0585	0.0585	0.0585
F_{ABC}	0.0585	0.0585	0.0585	0.0585
OFL (t)	**89,878**	89,878	**100,365**	100,365
maxABC (t)	67,409	67,409	**75,274**	75,274
ABC (t)	**67,409**	67,409	**75,274**	75,274
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	No	n/a	No	n/a

[a]The values for biomass, OFL, and ABC in these two columns are based on Rodgveller and Hulson 2013.
These are unofficial ABC and OFL values since grenadier are an Ecosystem Component, which do not have ABCs or OFLs.

Tier 5 computations for giant grenadier OFL and ABC are summarized as follows (AI = Aleutian Islands, EBS = Eastern Bering Sea, GOA = Gulf of Alaska; biomass, OFL, and ABC are in mt) for 2015:

BSAI and GOA grenadiers

Area	Biomass	Natural mortality *M*	OFL definition	OFL	ABC definition	ABC
EBS	553,557	0.078	biom x *M*	43,177	OFL x 0.75	32,383
AI	733,177	0.078	biom x *M*	57,188	OFL x 0.75	42,891
BSAI total	1,286,734			100,365		75,274
GOA	524,624	0.078	biom x *M*	40,921	OFL x 0.75	30,691
Grand total	1,811,358			141,286		105,965

These are unofficial ABC and OFL values since grenadier are an Ecosystem Component, which do not have ABCs or OFLs.

The specifications in the GOA for 2015 differ from last year because a random effects model fit to the survey biomass was used as a proxy for the exploitable biomass in this year's assessment (following the recommendation of the Survey Averaging Working group). In the BSAI the ABC and OFL include the AI biomass estimated using the method presented in the 2012 SAFE report (Rodgveller et al. 2012). Further discussion of this method is below under SSC comments and under the Survey Data section. Catches are not approaching unofficial OFLs.

Summaries for Plan Team

Species	Year	BSAI Biomass	BSAI ABC	BSAI Catch[1]	GOA Biomass	GOA ABC	GOA Catch[1]	Total Catch[1]
grenadiers	2013	1,733,797	101,427	4,164	597,884	34,976	11,339	15,504
	2014	1,152,284	89,878	2,627	597,884	34,976	5,236	7,863
	2015	1,286,734	75,274		524,624	30,691		
	2016	1,286,734	75,274		524,624	30,691		

[1]Current as of October 7, 2014. Source: NMFS Alaska Regional Office Catch Accounting System via the Alaska Fisheries Information Network (AKFIN) database (http://www.akfin.org).

SSC and Plan Team Comments on Assessments in General

There were no comments on assessments in general that pertains to this assessment.

SSC and Plan Team Comments Specific to this Assessment

Here we report comments from the SSC in 2012 and 2013, since there was an executive summary in 2013. We also present comments from 2013 regarding the EA/RIR/IRFA on grenadier that pertain to

stock assessment. Responses to these comments and additions to the document were also made in the final EA/RIR/IRFA document (NMFS 2014.)

***"The authors introduced a new method for determining AI biomass and variance estimates. The SSC cautions that this is an uncertain extrapolation method. The catchability and size selection of longline surveys is known to differ from the trawl survey. This method assumes that the ratio between longline and trawl surveys in shallow water will be the same for the ratio of longline and trawl surveys in deep water. The SSC encourages the authors to verify whether this assumption is valid."* (SSC, 2012)**

The primary problem with using the AI trawl survey biomass estimates for giant grenadier is that the survey does not sample deeper than 500 m; where the majority of the giant grenadier population can be found. To account for the missing biomass from the trawl survey an expansion method is needed, for which we use the AFSC longline survey data, the only survey that samples deeper than 500 m in the AI.

The primary uncertainty associated with this method centers on the use of a ratio estimator between trawl survey biomass and longline survey RPWs. The ratio between trawl survey biomass and longline survey RPWs is assumed to be the same in shallow depths (1-500 m, for which we have trawl survey data) and deep depths (500-1000 m, for which we do not have trawl survey data), an assumption that must be made due to the available data. There may be uncertainty associated with extrapolating trawl survey biomass in this manner. Our opinion is that it is important to present estimates of deep-water biomass so that a better reflection of the potential grenadier biomass in the AI can be presented.

A comparison of the ratio of longline and trawl survey data in shallow- and deep-waters in the Gulf of Alaska is presented in an attempt to verify the assumption of constant catchability in each survey in shallow- and deep-water (See "Biomass estimation in the AI" under the "Trawl Surveys" section). Ratios between the two surveys in shallow- and deep-water were almost identical in the GOA, indicating that the assumption is valid.

The trends in RPWs and biomass were compared in the EBS and the GOA to determine if the two surveys are sampling the same population. Trends in the EBS tracked well, but trends in the GOA were not consistent among the two surveys (See "RPWs" under the "Longline surveys" section), so this did not validate nor contradict the effect of the differing selectivities of the two surveys.

***"In response to SSC comments, the authors included a Kalman filter model for estimating biomass. The Kalman filter estimates miss the most recent trawl biomass estimate in the GOA resulting in a substantially lower biomass estimate. For future assessments, the SSC encourages continued exploration of the Kalman filter method and we ask the authors to consider the recommendations in the Plan Team survey averaging work group* (SSC, Dec. 2012)."**

The survey averaging working group has recommended that for Tier 5 stocks authors should compare biomass estimates using random effects models to the standard calculations. We compared status quo to a Kalman filter in 2012 (Rodgveller et al. 2012). Here we use the random effects model to estimate GOA biomass for 2013. Approximately ½ of the grenadier biomass was in the deepest stratum (701-1,000 m) and this stratum was not sampled in 2011 or 2013. It is likely that it will not be sampled in 2015. The random effects model provides a method to incorporate all available trawl survey data since 1984. See the section titles "Biomass Estimation in the GOA" under the "Surveys" heading for details.

***"As a non-specified species complex the Plan Teams and the SSC are not required to provide harvest specifications for this species group. Given the potential that grenadier management may change in 2014, the SSC requests a full assessment next year."* (SSC, Dec. 2013)**

Because grenadiers were put into the FMPs as an Ecosystem Component in 2014, there are still no harvest specifications and no requirement to produce SAFE reports. Therefore, instead of presenting a full assessment, we are presenting an abbreviated assessment that contains a time series of catch and survey data and descriptions of new methodologies used for estimating biomass.

Comments on the EA/RIR/IRFA in 2013

"The SSC reviewed the document and concluded that it is very well done and ready for release for public review. *However, the SSC identified several areas where the document could be improved and requests that staff strive to make these improvements prior to release."* (SSC, Dec. 2013)

***"It would be useful to develop a food web for the slope regions as part of the ecosystem concerns chapter..."* (SSC, Dec. 2013)**

Little information is available on food web and habitat interactions between grenadiers and other groundfish. The information that is available indicates that in the Aleutian Islands, the diet of grenadiers is comprised mostly squid and bathypelagic fish (myctophids) (Yang 2003), whereas in the Gulf of Alaska, squid and pasiphaeid shrimp predominated as prey (Yang et al. 2006). Thus, other groundfish do not appear to compose the prey field of grenadiers.

***"The 2012 appendix revealed strong spatial partitioning of the sexes by depth. The SSC requests the author to estimate the sex ratio for survey biomass estimates in the assessment. The SSC requests that, if possible, the document should provide trawl and longline survey biomass estimates by sex and depth."* (SSC, Dec. 2013)**

In response to these comments, an appendix was added to the EA/RIR/IRFA with tables and figures that broke out catch, biomass, and RPWs by sex and depth (NMFS, 2013; see pages 77-82). We include a summary of that analysis as well as the data tables and figures presented in the EA/RIR/IRFA as an appendix to this SAFE report.

***"With respect to depth, the SSC requests that the document includes a short discussion of the potential uncertainty associated with the expansion method used to estimate grenadier biomass at deeper depths in the AI."* (SSC, Dec. 2013)**

See SSC comment from 2012 (above).

"The SSC also encourages the author to address comments and suggestions made by the non-target CIE review team if they are relevant to the grenadier appendix." (SSC, Dec. 2013)

See below.

Center of Independent Expect Review Comments

In May, 2013 there was a Center of Independent Expert (CIE) review of non-target assessments at the AFSC. Three reviewers participated and each produced a report without collaboration from NMFS or other reviewers. Here I will summarize the comments pertaining to grenadier. General comments about the tier system are excluded.

1) **The three CIE reviewers did not consider the estimates of absolute biomass to be reliable for grenadier, or for other reviewed species. The catchabilities of grenadier by the bottom trawl surveys is the EBS, AI, and GOA are unknown, but are currently assumed to be 1. One reviewer recommends using expert knowledge to estimate the availability, vulnerability, and density in trawlable and untrawlable grounds to explore converting the trawl survey data to absolute biomass.**

There is some evidence, based on diets and anecdotal evidence of higher catch rates when longline gear is held off off-bottom by rocky topography, that grenadier spend time off-bottom. If this is true, q is likely <1 for trawl gear. There have been no studies to estimate q for grenadier.

2) **There were concerns over the ratio that is used to extrapolate the relative population numbers and weights in the western AI from a ratio of western to eastern AI data from the 1980's.**

The western AI has not been sampled by the domestic NMFS longline survey. Data from Japanese surveys are used to extrapolate western AI abundance. This method is used for all species, including sablefish, since it is the only available data.

3) **The reviewers supported using models for estimating biomass, such as a Kalman filter or random effects model.**

This year we use a random effects model to estimate GOA biomass.

4) **A reviewer said that maximum age methods used for estimating natural mortality are acceptable, but recommended for swapping otoliths with other labs.**

The AFSC lab is the only lab that ages giant grenadier. A method was developed by Charles Hutchinson in the Age and Growth Laboratory for a previous age at maturity study (Rodgveller et al. 2010). Ages could not be validated using C14. This is likely because young fish are not in shallower waters (<200 m). Young fish are needed to confirm annuli at age 1-5; however, no young fish have been found in surveys or fisheries.

Introduction

Grenadiers (family Macrouridae) are deep-sea fishes related to hakes and cods that occur world-wide in all oceans. Also known as "rattails", they are especially abundant in waters of the continental slope, but some species are found at abyssal depths. At least seven species of grenadier are known to occur in Alaskan waters, but only three are commonly found at depths shallow enough to be encountered in commercial fishing operations or in fish surveys: giant grenadier (*Albatrossia pectoralis*), Pacific grenadier (*Coryphaenoides acrolepis*), and popeye grenadier (*Coryphaenoides cinereus*) (Mecklenburg et al. 2002). Of these, giant grenadier has the shallowest depth distribution and the largest apparent biomass, and hence is by far the most frequently caught grenadier in Alaska. Because of this importance, this report will emphasize giant grenadier, but it will also discuss the other two species.

Distribution: Giant grenadier range from Baja California, Mexico around the arc of the north Pacific Ocean to Japan, including the Bering Sea and the Sea of Okhotsk (Mecklenburg et al. 2002), and they are also found on seamounts in the Gulf of Alaska and on the Emperor Seamount chain in the North Pacific (Clausen 2008). In Alaska, they are especially abundant on the continental slope in waters >400 m depth.

These fish are the largest in size of the world's grenadier species (Iwamoto and Stein 1974); maximum weight of one individual in a Bering Sea trawl survey was 41.8 kg[1].

Speciation: Previous publications (Clausen 2006 and 2008) speculated that more than one species of giant grenadier may exist in Alaska because two morphs of the fish have been observed based primarily on the relative size of the eye to the head, as well as three very different patterns of otolith morphology. Tissue and otoliths samples were collected on the AFSC longline survey in 2013 for a more definitive analysis of speciation, stock structure, and otolith morphometrics.

Biology: There is some known biological information on adult giant grenadier, but data on larvae and juvenile grenadiers is nonexistent. The spawning period is thought to be protracted and may even extend throughout the year (Novikov 1970; Rodgveller et al. 2010). Two papers provide purported descriptions of larvae of giant grenadier in the North Pacific (Endo et al. 1993; Ambrose 1996), but Busby (2004) points out that these descriptions appear so different that they probably represent separate species. At any rate, no larvae have ever been collected in Alaska that correspond to either of these descriptions or to the description of a third form (Busby 2004) that is also giant grenadier-like[2]. Small, juvenile fish less than ~15-20 cm pre-anal fin length (PAFL) are virtually absent from bottom trawl catches (Novikov 1970; Ronholt et al. 1994; Hoff and Britt 2009, 2011), and juveniles may be pelagic in their distribution. (Because the long tapered tails of grenadiers are frequently broken off when the fish are caught, PAFL is the standard unit of length measurement for these fish. PAFL is defined to be the distance between the tip of the snout and the insertion of the first anal fin ray). Bottom trawl studies indicate that females and males have different depth distributions, with females inhabiting shallower depths than males. For example, both Novikov (1970) in Russian waters and Clausen (2008) in Alaskan waters found that nearly all fish <600 m depth were female, and the Novikov study was based on trawl sampling throughout the year. Presumably, some vertical migration of one or both sexes must occur for spawning purposes; Novikov (1970) speculates that females move to deeper water inhabited by males for spawning.

Ecology: The habitat and ecological relationships of giant grenadier are likewise little known and uncertain. Clearly, adults are often found in close association with the bottom, as evidenced by their large catches in bottom trawls and on longlines set on the bottom. However, based on a study of the food habits of giant grenadier off the U.S. west coast, Drazen et al. (2001) concluded that the fish feeds primarily in the water column. Most of the prey items found in the stomachs were meso- or bathypelagic squids and fish, and there was little evidence of benthic feeding. Smaller studies of giant grenadier food habits in the Aleutian Islands (Yang 2003) and Gulf of Alaska (Yang et al. 2006) showed similar results. In the Aleutian Islands, the diet comprised mostly squid and bathypelagic fish (myctophids), whereas in the Gulf of Alaska, squid and pasiphaeid shrimp predominated as prey. The hypothesis regarding the tendency of the fish to feed off bottom is supported by observations of sablefish longline fishermen, who report that their highest catches of giant grenadier often occur when the line has been inadvertently "clothes-lined" between two pinnacles, rather than set directly on the bottom[3]. Pacific sleeper sharks (*Somniosus pacificus)* and Baird's beaked whales (*Berardius bairdii*) have been documented as predators on giant grenadier (Orlov and Moiseev 1999; Walker et al. 2002). Sperm whales (*Physeter macrocephalus*) are another likely predator, as they are known to dive to depths inhabited by giant

[1] G. Hoff, National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115. Pers. comm. March 2005.
[2] M. Busby, National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115. Pers. comm. October 2006.
[3] D. Clausen, National Marine Fisheries Service, Alaska Fisheries Science, Auke Bay Laboratories, 17109 Point Lena Loop Rd., Juneau, AK 99801. Pers. observ. October 2004.

grenadier on the continental slope and have been observed in Alaska depredating on longline catches of giant grenadier[4].

Distribution of Pacific and popeye grenadier: Pacific grenadier have a geographic range nearly identical to that of giant grenadier, i.e., Baja California, Mexico to Japan. Popeye grenadier range from Oregon to Japan. Compared to giant grenadier, both species are much smaller and generally found in deeper water. They appear to be most abundant in waters >1,000 m, which is deeper than virtually all commercial fishing operations and fish surveys in Alaska. For example, in a recent experimental longline haul in the western Gulf of Alaska at a depth of 1400-1500 m, 56% of the hooks caught Pacific grenadier[5]. This indicates that at least in some locations in deep water, abundance of Pacific grenadier in Alaska can be extremely high. Few popeye grenadier are caught on longline gear, apparently because of the relatively small size of these fish, and most of the information on this species comes from trawling. Food studies off the U.S. West Coast indicate that Pacific grenadier are more benthic in their habitat than are giant grenadier, as the former species fed mostly on bottom organisms such as polychaetes, mysids, and crabs (Drazen et al. 2001).

Evidence of stock structure: Stock structure and migration patterns of giant grenadier in Alaska are unknown, as no genetics studies have been done (except for brief genetic investigation of the two morphs of this species that was previously mentioned), and the fish cannot be tagged because all individuals die due to barotrauma when brought to the surface. One study in Russian waters, however, used indirect evidence to conclude that seasonal feeding and spawning migrations occur of up "to several hundred miles" (Tuponogov 1997).

Natural mortality: In the 2014 assessment we continue to use the natural mortality estimate (*M*) of 0.078, calculated using Hoenig's (1983) longevity equation with a maximum age of 58 from a study of age at maturity for giant grenadier (Rodgveller et al. 2010). A discussion of the four methods employed by Rodgveller et al. (2010) and the reason for choosing Hoenig's (1983) method can be found in the 2010 grenadier SAFE (Clausen and Rodgveller 2010). Giant grenadier greater than 60 cm PAFL have been caught on the AFSC longline survey, whereas the greatest length in the age samples was 53 cm (Rodgveller et al. 2010). Therefore, it is probable that fish older than 58 exist. An older maximum age would result in a decrease in *M*. Because fish older than 58 years may exist, we suggest revisiting the determination of *M* for giant grenadier if more age samples become available in the future.

Fishery

Catch History

Catches since 1997 have been estimated for the eastern Bering Sea (EBS), Aleutian Islands (AI), and GOA based largely on data from the Alaska Fishery Science Center's Fishery Monitoring and Analysis program. The estimates for 1997-2002 were determined by simulating the catch estimation algorithm used for target species by the NMFS Alaska Regional Office in what was formerly called their "blend catch estimation system" (Gaichas 2002 and 2003). Although these estimates may not be as accurate as the official catch estimates determined for managed groundfish species, they are believed to be the best possible based on the data available. They do not appear unreasonable compared to the official catches of other species caught along with giant grenadier on the continental slope in Alaska, such as sablefish and

[4] C. Lunsford, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Point Lena Loop Rd., Juneau, AK 99801. Pers. comm. October 2006.
[5] D. M. Clausen and C. J. Rodgveller, 2010. Deep-water longline experimental survey for giant grenadier and sablefish in the western Gulf of Alaska, August 2008. National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Point Lena Loop Rd., Juneau, AK 99801. Unpubl. manuscr. 23p.

Greenland turbot. The estimates for 2003-2014 were computed by the NMFS Alaska Regional Office based on their Catch Accounting System, which replaced the "blend" system in 2003. All the data are presented as "grenadiers, all species combined".

In 2013 the observer program underwent restructuring. Implementation of this program is considered an improvement over the previous observer system and an analysis of the first year under the restructured program was presented at the June 2014 council meeting (Faunce et al. 2014). It is too early to determine if there are any changes in the time series due to this restructuring. More years of data are needed. There is now observer coverage of vessels <60 ft and of the IFQ Pacific halibut fleet. A description of changes in bycatch rate calculations and changes that occurred in CAS that relate to non-target species can be found in Tribuzio et al. (2014).

Overall, the estimate of total catch of grenadier in 2013 (15,504 mt) was almost the same as in 2012 (15,119 mt) (Table 1). Catch in 2013 was up 13% from the 2003-2012 average. Even though the great majority of grenadier catch occurs by Oct. 1, the catch estimate in 2014 is only 7,863 mt. For example, by Oct. of 2013 95% of the catch was taken. Thus we expect that the final catch estimate for 2014 will be much lower than average. It is possible that this is related to observer restructuring.

In the BSAI catch was down 21% (1,092 mt) from average in 2013 (Table 1). This was primarily in the Greenland turbot fishery in the BS and the Kamchatka flounder fishery in the AI (Table 2). In the GOA, grenadier catch was higher in 2013 than in previous years (2,890 mt above average; 34%; Table 1). The majority of this increase was in rockfish (461 mt; 84% above average), sablefish (1,476 mt; 22% above average) (Table 2), and the deep-water flatfish fisheries (1,063 mt; 581% above average) (Table 2). Surprisingly, the estimate of grenadier catch in the halibut target group was 47% below average in 2013; although, catch estimates in this target group have always been variable.

Survey Data

Trawl Surveys

Biomass estimation in GOA: The Plan Team Survey Averaging Plan Team working group and the SSC suggested that for tier 5 species authors should compare biomass estimates using a random effects model to standard calculations. For grenadier a Kalman filter model was presented in 2012 (Rodgveller et al. 2012). This year we used a random effects model to estimate exploitable biomass for unofficial ABCs and OFLs (Table 3). The only GOA trawl surveys that extended to 1,000 m include the surveys in 1984, 1987, 1999, 2005, 2007, and 2009. In 1990, 1993, 1996, and 2001 the trawl survey only sampled depths down to 500 m, and in 2003 and 2011 the trawl survey sampled depths up to 700 m. Due to the differences in the depth sampled among the various trawl surveys, and the distribution of giant grenadier biomass across depth strata, we applied the random effects model to biomass estimates for the 1-500 m, 501-700 m, and 701-1000 m depth strata by region separately. This resulted in three time series of biomass estimates: one for each depth stratum. The full time series of biomass estimates in the GOA from the random effects model were then obtained by summing the biomass estimates across the three depth strata (Figure 1). Biomass in the GOA, estimated using the random effects model, increased until 2005 and then decreased slowly and then increased in 2013 (Figure 1). Compared to status quo, biomass estimates from the random effects model are lower (Table 3) (ratios of random effects biomass/status quo biomass range from 0.76 to 0.97).

Biomass estimation in AI: The Aleutian Islands have presented a special problem for biomass estimation because no trawl surveys since 1986 have sampled waters deeper than 500 m, where most giant grenadier biomass is found. In previous SAFEs (Clausen 2006; Clausen and Rodgveller 2008, Clausen and

Rodgveller 2010) an AI biomass was estimated by using a combination of data from other areas and surveys: the GOA and EBS slope trawl surveys and the AFSC longline survey (Clausen and Rodgveller, 2010).

In 2012, a new method was used to estimate giant grenadier biomass that utilizes only AI survey data (Rodgveller et al. 2012; Appendix 1A and in the "survey data" section), and we continue to use this method. The AI trawl survey biomass estimates from the "shallow" depths, which are regularly sampled (1-500 m), and AI longline survey RPWs from "shallow" (200-500 m) and "deep" depths (501-1000 m) are used to estimate the total AI biomass using the following equation:

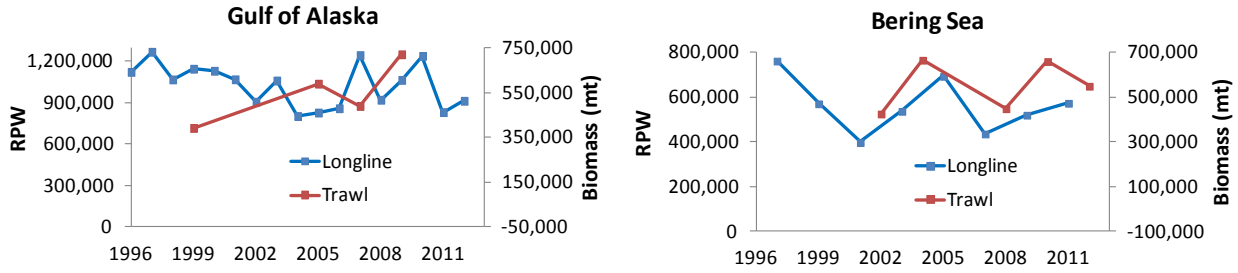
(1) $B_y = \bar{r}W_y$

where B_y is the total biomass in year y, $\bar{r}$ is the ratio of the sum of bottom trawl survey biomass estimates to the sum of longline RPWs in the shallow depth stratum for years when both surveys occurred (2000, 2002, 2004, 2006, 2010, 2012, 2014), and W_y is the total RPW in year y. $\bar{r}$ of "shallow" biomass to "shallow" RPWs for these years was 0.223. For those years when the AFSC longline survey occurs in the AI, an AI biomass estimate is now available (Table 4). Estimated biomass increased in 2014 by 53%. It is now similar to the estimated biomass in 2010.

When using this method, there is an assumption that the ratio between longline and trawl surveys in shallow water is the same as the ratio of longline and trawl surveys in deep water. In an attempt to validate this assumption, we examined the ratios of the two surveys in shallow- and deep-water in the GOA, where the trawl survey sampled down to 700 m in 2003 and 2011 and to 1,000 m in 1999, 2005, 2007, and 2009. In the GOA, the shallow ratio was nearly the same as the deep ratio (using the same method employed for calculating the AI shallow ratio), indicating that the assumption that the shallow- and deep-water ratios in the AI are similar is likely valid.

max depth	years	shallow ratio	deep ratio
700 m	2003,2011	0.60	0.62
1,000 m	1999,2005,2007,2009	0.52	0.51
all years		0.60	0.52

There is some evidence that trawl and longline survey abundance trends are similar. This may indicate that these surveys are sampling the same population and lend credence to the method we use to extrapolate AI biomass from longline survey data. Trawl and longline survey abundance trends can be compared in the GOA and EBS, since some trawl surveys sampled to at least 1,000 m in these areas. Longline and trawl surveys did not occur in the same years in the EBS (trawl survey was in even years and longline was in odd). The trends in the two surveys in the EBS tracked well. The trends in the GOA were not similar; however, there were not many trawl surveys in the GOA that sampled down to 1,000m within a short time frame (4 surveys over 10 years) vs. 5 years in the EBS.



Biomass in the EBS: There was no slope trawl survey in 2014. Biomass point estimates have ranged from 426-660 thousand mt between 2002 and 2012 (Table 4). Biomass was almost identical to the average in 2012 (550,266 mt), which was 17% lower than the estimate in 2010.

Longline Surveys

RPWs: RPWs of giant grenadier in the GOA had a general decreasing trend from 1999 through 2004, increased through 2007, and have been somewhat decreasing since then (Table 5). In 2014 the RPW in the GOA was 19% below average, which is well within the range of values in other years. RPWs in the Bering Sea have been increasing since 2007. In 2013 the biomass was 7% above average. The biomass of giant grenadier in the AI is larger than in other areas. This is because there is a large population estimated to be in the western Aleutians. This area is not currently sampled, but a ratio of eastern to western areas from previous surveys is used to extrapolate RPWs to these areas. In 2014, the AI RPW was 26% above average.

Analytic Approach

Modeling Approach

The tier 5 computations have been based only on giant grenadier because virtually none of the other species are caught in the commercial fishery or surveys. The exploitable biomass in the GOA was previously based on averaging the biomass estimates in the last three trawl surveys that extended to 1,000 m. The deepest stratum (701-1,000 m) was not sampled in 2011 or 2013, therefore, since 2009 the same estimate of biomass has been used for ABC/OFL calculations. This year we use a random effects model, presented in the 2012 SAFE report (Rodgveller et al. 2012), which utilizes trawl survey data from 1984-2013 to estimate the exploitable biomass in 2013 (see section above under Survey data, trawl surveys). Since there was no trawl survey in the GOA in 2014, the estimate for 2013 is used as the most recent value of exploitable biomass. To estimate exploitable biomass in the BS and AI, we continue to use an average of the three most recent trawl surveys with data available down to 1,000 m. For the BS that is 2008, 2010, and 2012. For the AI that is 2010, 2012, 2014. In the future we may use a random effects model in the Bering Sea to estimate biomass.

Parameter Estimates

Maximum Age: The most recent aging studies for giant grenadiers (Burton 1999 and Rodgveller et al. 2010) found the maximum age to be 56 and 58 years, respectively, based on specimens from the GOA. There have been no aging studies for Pacific grenadier in Alaska, but Andrews et al. (1999) found a maximum age of 73 years for this species off the U.S. west coast.

Natural mortality: In the 2014 assessment we continue to use the natural mortality estimate (M) of 0.078, calculated using Hoenig's (1983) longevity equation with a maximum age of 58 from a study of age at maturity for giant grenadier (Rodgveller et al. 2010).

Results

Harvest Recommendations

Parameters used: In the previous stock assessment for grenadiers (Rodgveller et al. 2013), the NPFMC's tier 5 approach for determining the OFL and ABC was recommended, and this approach was supported by both the GOA Groundfish Plan Team and the NPFMC's Scientific and Statistical Committee. We again use tier 5 unofficial ABC and OFL calculations.

Methods: Current biomass estimates in this assessment for giant grenadier in the EBS and GOA were calculated based on the average of the three most recent deep-water trawl surveys that sampled down to 1,000 or 1,200 m. In the EBS, these are now the 2008, 2010, and 2012 surveys. In the AI a method used in the 2012 SAFE was used to calculate biomass down to 1,000 m, even when trawl surveys sampled only to 500 m. Details are in Rodgveller et al. (2012). Estimates of AI biomass used for calculations of ABC and OFL are now based on 2010, 2012, and 2014.

The current GOA biomass was estimated using a random effects model (see section above under "Trawl Surveys"); therefore a single estimate is used as an estimate of exploitable biomass. This method is preferable to averaging the last three trawl surveys that sampled down to 1,000 m because trawl surveys have not extended this deep since 2009. The deepest stratum (700-1,000 m) will not likely be sampled in the near future.

The NPFMC's tier 5 definitions for OFL and ABC are: OFL = M x *Biomass*, where M is the estimated natural mortality rate, and ABC is $\leq$(0.75 x OFL). Based on our discussion above, tier 5 recommendations for OFL and ABC of grenadiers are listed below (biomass, OFL, ABC, and mean catch are in mt).

BSAI and GOA grenadiers

Area	Biomass	Natural mortality M	OFL definition	OFL	ABC definition	ABC
EBS	553,557	0.078	biom x M	43,177	OFL x 0.75	32,383
AI	733,177	0.078	biom x M	57,188	OFL x 0.75	42,891
BSAI total	1,286,734			100,365		75,274
GOA	524,624	0.078	biom x M	40,921	OFL x 0.75	30,691
Grand total	1,811,358			141,286		105,965

Gulf of Alaska Grenadiers

Quantity	As estimated or specified *last* year for[a]: 2014	2015	As estimated or recommended *this* year for: 2015	2016
M (natural mortality)	0.078	0.078	0.078	0.078
Specified/recommended Tier	5	5	5	5
Biomass (t)	597,884	597,884	524,624	524,624
F_{OFL} (F=M)	0.078	0.078	0.078	0.078
$maxF_{ABC}$ (maximum allowable = 0.75*x* F_{OFL})	0.0585	0.0585	0.0585	0.0585
F_{ABC}	0.0585	0.0585	0.0585	0.0585
OFL (t)	**46,635**	46,635	**40,921**	40,921
maxABC (t)	34,976	34,976	**30,691**	30,691
ABC (t)	**34,976**	34,976	**30,691**	30,691
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	No	n/a	No	n/a

[a]The values for biomass, OFL, and ABC in these two columns are based on Rodgveller and Hulson 2013. They are an average of the last three trawl surveys that sampled down to 1,000 m. The current values (for 2015 and 2016) are from the random effects model fit to survey biomass by region and depth strata.

Bering Sea and Aleutian Islands Grenadiers

Quantity	As estimated or specified *last* year for[a]: 2014	2015	As estimated or recommended *this* year for: 2015	2016
M (natural mortality)	0.078	0.078	0.078	0.078
Specified/recommended Tier	5	5	5	5
Biomass (t)	1,152,284	1,152,284	1,286,734	1,286,734
F_{OFL} (F=M)	0.078	0.078	0.078	0.078
$maxF_{ABC}$ (maximum allowable = 0.75*x* F_{OFL})	0.0585	0.0585	0.0585	0.0585
F_{ABC}	0.0585	0.0585	0.0585	0.0585
OFL (t)	**89,878**	89,878	**100,365**	100,365
maxABC (t)	67,409	67,409	**75,274**	75,274
ABC (t)	**67,409**	67,409	**75,274**	75,274
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	No	n/a	No	n/a

[a]The values for biomass, OFL, and ABC in these two columns are based on Rodgveller and Hulson 2013.

Not subject to over fishing: The recommended OFLs and ABCs in the above tables are much larger than the mean catches for grenadiers and also much larger than the catch in any single year, which indicates catches could increase without endangering the stocks. This is especially true for the EBS and AI, where the exploitation rate appears to be quite low.

Ecosystem Considerations

A determination of ecosystem considerations for grenadiers in Alaska is hampered by the extreme lack of biological and habitat information for these species and by limited knowledge in general on the deep slope environment inhabited by these fish.

Ecosystem Effects on the Stocks

Prey availability/abundance trends: The only food studies on grenadiers in the northeast Pacific have been on adults. One study of giant grenadier off the U.S. west coast concluded that the fish fed primarily off-bottom on bathy- and mesopelagic food items that included gonatid squids, viperfish, deep-sea smelts, and myctophids (Drazen et al. 2001). Smaller studies of giant grenadier food habits in Alaska showed generally similar results. In the Aleutian Islands, the diet comprised mostly squid and myctophids (Yang 2003), whereas in the Gulf of Alaska, squid and pasiphaeid shrimp predominated as prey (Yang et al. 2006). Research on these deep-sea prey organisms in Alaska has been virtually non-existent, so information on prey availability or possible variations in abundance of prey are unknown. Very few juvenile giant grenadier have ever been caught, so nothing is known about their food preferences.

In contrast to giant grenadier, a study of Pacific grenadier food habits off the U.S. west coast found a much higher consumption of benthic food items such as polychaetes, cumaceans, mysids, and juvenile Tanner crabs (*Chionoecetes* sp.), especially in smaller individuals (Drazen et al. 2001). Carrion also contributed to its diet, and larger individuals consumed some pelagic prey including squids, fish, and bathypelagic mysids.

Predator population trends: The only documented predators of giant grenadier are Pacific sleeper sharks (Orlov and Moiseev 1999) and Baird's beaked whales (Walker et al. 2002). According to Orlov's and Moiseev's study, giant grenadier was ranked third in relative importance as a food item in the diet of these sharks. Sperm whales are another potential predator, as they are known to dive to depths inhabited by giant grenadier on the slope and have been observed depredating on longline catches of giant grenadier[6]. Giant grenadier is a relatively large animal that is considered an apex predator in its environment on the deep slope (Drazen et al. 2001), so it may have relatively few predators as an adult. Predation on larval and juvenile giant grenadiers would likely have a much greater influence on the ultimate size of the adult population size, but information on predators of these earlier life stages is nil.

Changes in habitat quality: Little or no environmental information has been collected in Alaska for the deep slope habitat in which grenadiers live. This habitat is likely more stable oceanographically than shallower waters of the upper slope or continental shelf. Regime shifts on the continental shelf and slope in Alaska in recent decades have been well documented, but it is unknown if these shifts also extend to the deep slope. Regime shifts could have a pronounced effect on giant grenadier if their larvae or post-larvae inhabited upper portions of the water column. However, no larvae or post-larvae for this species have ever been collected in Alaska. The absence of larvae or post-larvae giant grenadier in larval surveys in Alaska, which have nearly all been conducted in upper parts of the water column, implies that larval giant grenadier may reside in deeper water, where they may be less affected by regime shifts since water temperatures in deep water tend to be more stable.

Fishery Effects on the Ecosystem

[6] C. Lunsford, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Point Lena Loop Rd., Juneau, AK 99801. Pers. comm. Oct 2012.

Because there has been virtually no directed fishing for grenadiers in Alaska, the reader is referred to the discussion on Fishery Effects in the sablefish SAFE report. The sablefish longline fishery is the main fishery that takes giant grenadier as bycatch, so the Fishery Effects section in the sablefish report is applicable to giant grenadier and is an indication of what the effects might be if a directed fishery for giant grenadier were to develop. It should be noted that because all grenadiers presently caught in the sablefish and Greenland turbot fisheries are discarded and do not survive, this constitutes a major input of dead organic material to the ecosystem that would not otherwise be there.

Data Gaps and Research Priorities

Research priorities

1) Because early life history information for giant grenadier is nil, studies are also needed to investigate where larvae and young juveniles reside.
2) Evaluation of the catchability of giant grenadier in the bottom trawl surveys, which would affect the accuracy of subsequent biomass estimates. Studies are needed on whether this fish is a completely benthic species or if individuals sometimes move off-bottom.
3) Validation of the AFSC REFM Division aging methodology for giant grenadier.
4) Further analysis and study of competition for hooks that may affect giant grenadier catch rates on the AFSC longline survey.
5) Continue a study to examine if the three different shapes of otoliths found in giant grenadier represent separate species or subpopulations. This is an ongoing cooperative project between the Marine Ecology and Stock Assessment program at Auke Bay Laboratories (ABL), REFM Age and Growth Lab, and the ABL genetics lab.

Current Research

Three otolith shapes were previously identified by Charles Hutchinson, AFSC Age and Growth Lab, in giant grenadier. A review of the literature revealed that this level of variability in otolith shape is extremely unusual for an individual fish species. These three otolith types may indicate that genetic subspecies or subpopulations exist for giant grenadier in Alaska that are not apparent based on the external morphology of the fish. Tagging studies are a traditional way to determine migration patterns and spatial stock structure for fish. However, these studies are not possible for giant grenadier because the fish do not survive the pressure difference when caught at depth and brought to the surface. Genetic and otolith microchemistry studies are an alternative means for determining patterns of stock structure.

In 2013, otolith and tissue samples were collected from giant grenadier in the eastern, central and western GOA and the EBS. Otoliths will be aged and photographed for morphometric measurements in 2015. Tissues are currently being analyzed by Scott Vulstek and Charles Guthrie, AFSC Auke Bay Laboratories genetics program. After genetic and morphometric data is collected, we will compare results from the two studies.

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Table 1.—Updated catch data (mt) for grenadiers, nearly all of which are thought to be giant grenadier, as of October 7, 2014 (NMFS Alaska Regional Office Catch Accounting System via the Alaska Fisheries Information Network (AKFIN) database, http://www.akfin.org). The estimates for 2003-2012 were computed by the NMFS Alaska Regional Office based on their Catch Accounting System, which replaced the "blend" system in 2003. Observer restructuring began in 2013 so the mean from 2003-2012 is presented for comparison to 2013 and 2014.

	Eastern Bering Sea	Aleutian Islands	Gulf of Alaska	Total
1997	2,964	2,887	12,029	17,881
1998	5,011	1,578	14,683	21,272
1999	4,505	2,883	11,388	18,776
2000	4,067	3,254	11,610	18,931
2001	2,294	1,460	9,685	13,439
2002	1,891	2,807	10,479	15,177
2003	2,641	3,036	10,843	16,520
2004	2,225	1,251	10,471	13,946
2005	2,633	1,795	6,606	11,034
2006	2,068	2,225	8,515	12,808
2007	1,645	1,817	9,629	13,091
2008	1,687	1,800	11,167	14,654
2009	2,983	3,681	6,696	13,360
2010	2,928	3,690	5,564	12,181
2011	4,333	2,578	7,437	14,349
2012	2,926	4,625	7,568	15,119
2013	1,629	2,535	11,339	15,504
2014	876	1,751	5,236	7,863
Mean 2003-2012	2,607	2,650	8,450	13,706

Table 2.—Estimated catch (mt) of grenadiers (all species combined) in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska, by target species/species group, 2003-2011. Arrow = arrowtooth flounder; DW flat = deep-water flatfish; GT = Greenland turbot; halibut = Pacific halibut; Kam = Kamchatka flounder; cod = Pacific cod; rex = rex sole; sable = sablefish; other sp. = other species combined (including yellowfin sole, rock sole, shallow-water flatfish, "other flatfish", flathead sole, and all other species). Source: Regional Office Catch Accounting System accessed through the Alaska Fisheries Information Network (AKFIN), October 7, 2014.

	Target species/species group									
Year	arrow	DW flat	GT	halibut	Kam	cod	rex	rockfish	sable	other
					Aleutian Islands					
2003			113	1,376		46		6	1,494	0
2004			14	414		13		60	748	1
2005			161	617		2		21	979	16
2006	341		328	172		121		154	1,109	0
2007	108		342	69		41		21	1,161	76
2008	397		67	229		26		59	746	276
2009	1,377		414			12		152	1,642	84
2010	1,674		210	44		259		168	1,127	206
2011	51		83	13	723	18		292	1,292	105
2012	264			113	2,56	55		38	1,167	428
2013	278		44	239	406	3		215	1,139	212
2014	254			63	295	23		218	842	56
					Eastern Bering Sea					
2003	38		1,452	355		240		9	370	164
2004	24		1,315	254		240		22	287	83
2005	11		1,977	143		333		32	108	31
2006	125		1,192	174		130		12	420	16
2007	2		1,073	89		179		17	215	70
2008	69		708	392		163		3	127	226
2009	243		1,823			212		6	692	8
2010	186		2,036	36		390		126	145	8
2011	807		1,799	7	241	1,13		17	316	5
2012	673		1,464	61	5	514		3	179	27
2013	272		533	321	12	274		47	166	4
2014	120		377	143	10	100		2	113	10

Table 2.—continued.

Year	Arrow	DW flat	GT	Halibut	Kam Fl	Cod	Rex	Rockfish	Sable	Other
					Target species/species group					
					Gulf of Alaska					
2003	27	474		710		5	325	613	8,464	223
2004	171	178		156		0	5	2,231	7,657	74
2005	103			488			4	212	5,743	56
2006	18			766		22	4	338	7,243	124
2007	90	20		530		79	5	198	8,702	5
2008	3			1,918		97	89	164	8,651	244
2009				1,430		79	102	227	4,816	43
2010	40	60		243		149	140	511	4,359	62
2011	114			172	723	69	229	529	6,208	116
2012	155			18	2,561	173	2	438	6,666	116
2013	161	1,246		338	406	169	4	1,008	8,327	87
2014	387			259	295	162	5	602	3,803	19

Table 3.—Biomass estimates for grenadier in the Gulf of Alaska using a random effects model. Estimates are for 1-1,000 m in all years. Left: estimates from using a random effects model. Center: estimates from NMFS trawl surveys that sampled down to 1,000 m. Right (status quo): biomass estimates used in SAFE reports for specifications of unofficial ABCs and OFLs since 2006. Biomass in 2006 was calculated as the average of the last two trawls surveys that sampled down to 1,000 m. Years after that the last three trawl surveys were averaged.

	Random Effects			Surveys down to 1,000 m			
Year	Biomass	U 95% CI	L 95% CI	Biomass	U 95% CI	L 95% CI	Status quo
1984	175,388	227,242	135,366	169,708	228,015	111,401	
1985	170,807	225,204	129,548				
1986	166,557	218,599	126,905				
1987	162,617	208,284	126,963	135,971	188,211	83,731	
1988	167,761	226,612	124,193				
1989	173,766	244,626	123,432				
1990	180,602	262,528	124,242				
1991	193,747	286,163	131,177				
1992	209,763	311,007	141,477				
1993	229,936	337,265	156,763				
1994	243,428	356,531	166,204				
1995	257,863	371,900	178,794				
1996	273,315	381,925	195,591				
1997	299,036	404,975	220,811				
1998	331,011	428,314	255,814				
1999	371,879	443,349	311,930	389,908	466,030	313,786	
2000	397,273	505,803	312,029				
2001	427,155	544,558	335,063				
2002	453,259	588,879	348,873				
2003	482,870	598,383	389,656				
2004	493,499	626,562	388,695				
2005	507,214	609,381	422,176	587,346	754,202	420,489	
2006	477,897	596,180	383,081				488,627
2007	463,065	568,252	377,349	487,987	629,173	346,802	488,414
2008	452,765	624,873	328,061				488,414
2009	455,461	749,608	276,738	718,320	1,484,296	0	597,884
2010	460,223	818,702	258,709				597,884
2011	473,685	898,965	249,595				597,884
2012	496,996	996,834	247,789				597,884
2013	524,624	1,099,917	250,229				597,884
2014	524,624	1,194,419	230,431				597,884

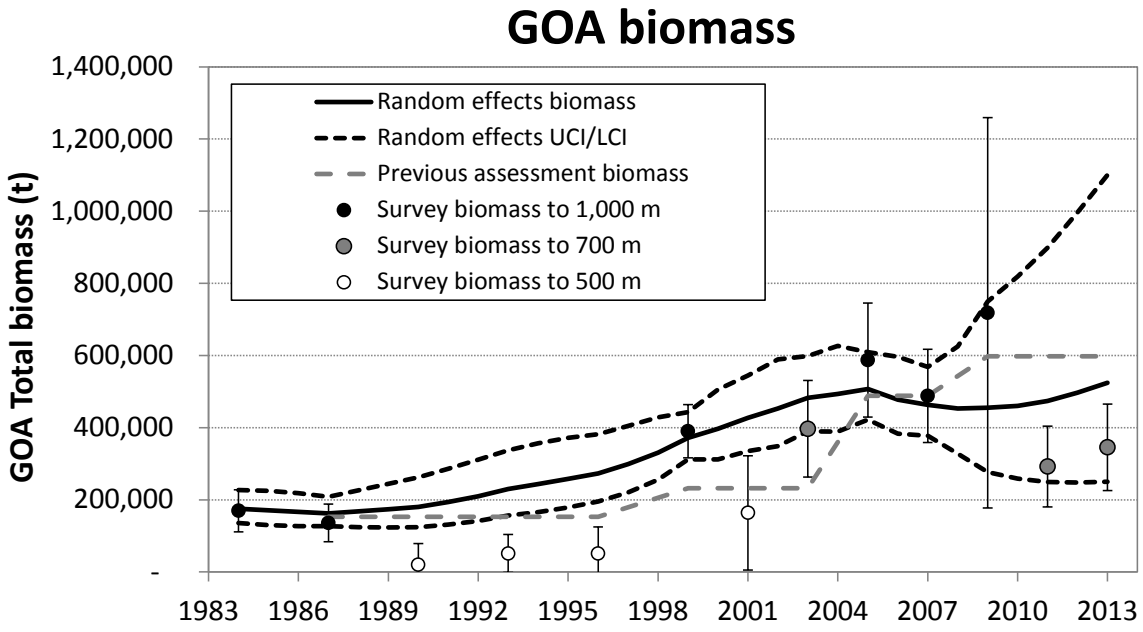
Table 4.—Biomass estimates (mt) and associated 95% confidence bounds (mt), variances, and coefficients of variation (cv) for giant grenadier in recent NMFS surveys in Alaska that sampled the upper continental slope. The Gulf of Alaska surveys included depths to 1,000 m, whereas the eastern Bering Sea slope surveys included depths to 1,200 m. Aleutian Islands biomass was estimated from trawl survey biomass estimates from 1-500 m and AFSC longline survey relative population weights from 200-1000m (see section titled "survey data").

			95% Conf. bounds			
Region	Year	Biomass	Lower	Upper	Variance	cv (%)
Aleutian Islands	2000	560,200	290,106	830,294	18,989,690,223	24.6
Aleutian Islands	2002	570,239	295,651	844,828	19,626,898,754	24.6
Aleutian Islands	2004	575,396	297,497	853,295	20,103,051,745	24.6
Aleutian Islands	2006	721,531	373,113	1,069,950	31,600,203,801	24.6
Aleutian Islands	2008	365,940	189,744	542,136	8,081,265,243	24.6
Aleutian Islands	2010	688,251	356,757	1,019,745	28,604,825,470	24.6
Aleutian Islands	2012	478,991	246,867	711,115	14,025,825,748	24.7
Aleutian Islands	2014	733,177	379,987	1,086,366	32,471,605,527	24.6
Eastern Bering Sea	2002	426,397	344,922	507,871	1,659,519,194	9.6
Eastern Bering Sea	2004	666,508	527,524	805,491	4,829,084,657	10.4
Eastern Bering Sea	2008	449,777	353,902	545,652	2,298,003,647	10.7
Eastern Bering Sea	2010	660,528	521,035	800,021	4,864,588,623	10.6
Eastern Bering Sea	2012	550,366	433,097	667,635	3,437,997,235	10.6

Table 5.—Giant grenadier relative population weight, by region, in AFSC longline surveys in Alaska, 1990-2014. Dashes indicate years that the eastern Bering Sea or Aleutian Islands were not sampled by the survey. Gulf of Alaska values include data only for the upper continental slope at depths 201-1,000 m and do not include continental shelf gullies sampled in the surveys. Note: relative population weight, although an index of biomass (weight), is a unit-less value. NA indicates that length data is not available for calculations of RPWs. AFSC longline survey database query, October 2014.

Year	Eastern Bering Sea	Aleutian Islands	Gulf of Alaska
1992	-	-	686,827
1993	-	-	1,041,508
1994	-	-	1,018,292
1995	-	-	1,264,245
1996	-	2,281,815	1,121,058
1997	762,639	-	1,266,800
1998	-	2,268,918	1,066,477
1999	571,852	-	1,277,141
2000	-	3,039,523	1,143,980
2001	398,950	-	1,067,335
2002	-	3,093,994	904,922
2003	538,190	-	1,058,570
2004	-	3,121,973	801,271
2005	694,456	-	826,495
2006	-	3,914,871	857,510
2007	437,268	-	1,242,833
2008	-	1,985,511	919,083
2009	521,179	-	1,063,104
2010	-	3,734,301	1,236,692
2011	574,349	-	829,476
2012	-	3,230,202	911,728
2013	605,727	-	896,776
2014	-	3,978,057	848,321
mean	567,179	3,151,928	1,012,140

Figure 1.—Biomass estimates of giant grenadier from NMFS bottom trawl surveys and from a random effects model that utilizes trawl survey biomass estimates from all years (with 95% confidence intervals). The estimates of exploitable biomass used in previous assessments are also presented. From 1987-1996 this was the average of the last two trawl surveys that extended down to 1,000 m. From 1999-2013, it was the average of the biomass from the most recent three surveys that sampled down to 1,000 m.



Appendix A. Giant grenadier depth distribution by sex in fisheries and surveys.

Method and Results

Catch

Observed grenadier catch, not estimated total catch, was split by sex using sex ratios from observer specimen data, i.e., fish that had their lengths taken from 2003-2013 (Table 1; Figure 1). This timeframe was chosen because catch estimates are available for grenadier since 2003. Length frequencies by sex, stratum, and FMP area were converted to weights using area (BS, AI, and GOA) and sex specific growth curves from AFSC trawl surveys. The percent males by weight were used to split the observed catch for the Bering Sea (BS), Aleutian Islands (AI), and the Gulf of Alaska (GOA) by stratum (Table 2). The same percentages were used for splitting BS and AI observed catch (Table 1).
Total estimated grenadier catch from the Catch Accounting System (CAS) was split by sex using sex ratios of weight from observer specimen data (Table 3), as described above, except a single proportion was used for all depth strata combined because catch is not available by depth from CAS. The percent male was 13% in the BSAI and 15% in the GOA.

AFSC Longline Survey

The AFSC longline survey stations are spaced systematically (~20-30 km apart) along the slope from the eastern Gulf of Alaska west to the Aleutian Islands and north into the eastern Bering Sea. At each station, depths from ~150-1000 m are sampled. Giant grenadier are caught in great numbers throughout the survey range, primarily in depths from 400-1,000 m. The Aleutian Islands are sampled in even years, the Bering Sea in odd years, and the Gulf of Alaska is sampled annually. Because the area that is sampled by the longline cannot be defined, an index of abundance in weight is calculated, called relative populating weight (RPW), but is not a measure of absolute biomass. The index is used for tracking trends in abundance.

Giant grenadier length frequencies are available since 2006. Length frequencies by sex, stratum, and area (AI, BS, GOA) were converted to weights using area and sex specific growth curves from AFSC trawl surveys. The percent males, by weight, for each depth strata and area were calculated (Table 4) and used to split the RPWs by sex and stratum (Table 5, Figure 2).

AFSC Gulf of Alaska Trawl Survey

The AFSC GOA trawl survey samples the continental shelf and slope where stations are randomly chosen within depth strata. Only surveys that sampled down to 1,000 m were included in this analysis (1999, 2005, 2007, and 2009); surveys in 1984 and 1987 were not included because survey methodology changed in 1996. In other years, surveys sampled down to only 500 or 700 m and are not reflective of the extent of grenadier distribution by sex.

Giant grenadier population length frequencies are available split by sex for each depth stratum. We converted these population length frequencies to weight (biomass) using sex specific growth curves from GOA trawl survey data (Table 6). The biomass split by sex, year, and strata, as well as the percent of giant grenadier biomass that is male, is presented in Table 6. For comparison to the longline survey and observed catch, the average biomass by sex and strata are shown in Figure 3. Bering Sea trawl survey biomass estimates spilt by sex are not currently available and will be examined in the future.

Discussion

The observed catch is primarily between depths of 201-400 m; however, this is not where the bulk of giant grenadier biomass is found (e.g., see figures 1 and 2 for AFSC longine and trawl survey data). Observer length data shows that the percent of the catch that is male, by weight, increases with depth in the GOA, but there is the opposite trend in the BSAI. Although, the decreasing trend in male abundance is not dramatic in the BSAI and sample sizes for several depths strata are small. Due to small sampled sizes, the apparent trend in the BSAI may not be representative of the true distribution of giant grenadier. There is a much greater proportion of male grenadier in the catch data compared to the longline survey. This could be partially explained by the diverse gear types in the fisheries that incidentally catch grenadier; however, a large proportion of the observed grenadier catch is from longline fisheries. The difference between the proportion of males in longline survey and fishery could also be attributed to seasonal variation in depth distribution. The longline survey takes place only in the summer, whereas fisheries take place nearly year round. More time is required to explore distribution differences in the fishery by season and we plan to examine this in the future.

The trawl survey had a greater proportion of males than the longline survey and the proportion of males increased with depth in all surveys. The sex proportions in the trawl survey were more similar to the fishery than the longline survey when all depths are considered; however, in the 1-500 depth stratum the trawl survey had a very low percentage of males (2-5%), whereas the majority of the fishery data was from 201-400 m and the percentage male was larger than 5% (12-16%).

In all data sources, including surveys and fisheries, the large majority of catch is females. Also, overall the proportion of male grenadier, by weight, increases with deeper depths. Taken together, this information indicates that our surveys and fisheries may not completely cover the range of grenadier distribution. However, it also indicates that a disproportionate harvest of females is occurring, and should continue to be monitored.

Although a portion of the male population may reside in depths deeper than surveys and fisheries, it is possible that there is not a 1:1 ratio of males to females. We have not aged males and, therefore, it is not known if the natural mortality rate is different between sexes for grenadiers. Given the sexual dimorphism in growth and differences in distribution by sex, it could be postulated that other life-history parameters, like natural mortality, may also vary by sex. For example, in some flatfish species there is sexual dimorphism in natural mortality, where males have a much higher rate than females (e.g., arrowtooth flounder, 0.2 for females and 0.35 for males). If this is true for grenadier, the sex ratio may not be 1:1. The number of females could be larger than the number of males. Even in a deep-water AFSC longline survey (down to 1,600 m in the WGOA), on average 24% were male by number. Also, because females were much larger at depths >1,000 m than depths <1,000 m, the weight ratio would likely be much less than 24%.

Table 1. Sum of observed giant grenadier catch in mt for males (M) and females (F) from 2003-2013.

	Aleutian Islands			Bering Sea			Gulf of Alaska		
Depth strata	AI	AI F	AI M	BS	BS F	BS M	GOA	GOA F	GOA M
1-100	31	27	5	441	383	58	69	59	10
101-200	802	701	106	1,280	1,113	166	1,891	1,607	284
201-300	10,183	8,855	1,328	5,300	4,610	692	8,849	7,522	1,327
301-400	6,338	5,512	828	8,457	7,355	1,104	8,726	7,415	1,309
401-500	265	230	34	788	684	104	671	570	101
501-600	4	4	0	8	6	0	20	16	1
601-700	0	0	0	2	2	0	4	4	0
701-800	0	0	0	0	0	0	3	3	0
801-900	0	0	0	0	0	0	1	1	0

Table 2. Percent of male giant grenadier in observed catch from 2003-2013 in numbers and weight. Weights were calculated from length frequencies by depth, sex, and area using sex specific growth curves from the AFSC trawl survey. The total sample size (n) for length frequencies is presented for each sex.

	BSAI		GOA	
Depth (m)	% male (numbers, weight)	n	% male (numbers, weight)	n
1-100		0	17%, 15%	6
101-200	25%, 22%	296	9%, 7%	690
201-300	19%, 16%	4,535	14%, 12%	6,623
301-400	17%, 14%	8,013	20%, 16%	11,986
401-500	23%, 17%	719	28%, 21%	1,603
501-600	20%, 13%	155	37%, 24%	123
601-700	11%, 6%	22	56%, 54%	18
701-800		0	20%, 12%	5

Table 3. Total estimated grenadier catch from 2003-2013 split by sex (mt). Observed lengths were converted to weights using area and sex specific growth curves and the percent male was calculated using these weights. The average proportion of males and females by weight in the catch was used to split catch.

Year	BS total	BS male	BS female	AI total	AI Male	AI Female	GOA total	GOA male	GOA female
2003	2,869	373	2,439	3,558	463	3,024	12,253	1,838	10,415
2004	2,223	289	1,890	1,251	163	1,063	11,989	1,798	10,191
2005	2,633	342	2,238	1,795	233	1,526	7,251	1,088	6,163
2006	2,067	269	1,757	2,195	285	1,866	8,429	1,264	7,165
2007	1,631	212	1,386	1,544	201	1,312	9,119	1,368	7,751
2008	2,820	367	2,397	2,525	328	2,146	11,333	1,700	9,633
2009	2,902	377	2,467	3,739	486	3,178	6,326	949	5,377
2010	2,799	364	2,379	3,553	462	3,020	5,419	813	4,606
2011	4,221	549	3,588	2,596	337	2,207	8,216	1,232	6,984
2012	2,276	296	1,935	4,383	570	3,726	7,206	1,081	6,125
2013	1,482	193	1,260	2,367	308	2,012	10,525	1,579	8,946
average	2,538	330	2,158	2,682	349	2,280	8,915	1,337	7,578

Table 4. Percent of fish that were male caught during the AFSC longline survey 2006-2013 in numbers and weight. Weights were calculated from length frequencies by depth, sex, and area using sex specific growth curves from the AFSC trawl survey. The total sample size (n) for length frequencies is presented for each sex.

	Aleutian Islands		Bering Sea		Gulf of Alaska	
Depth (m)	% male (numbers, weight)	n	% male (numbers, weight)	n	% male (numbers, weight)	n
101-200	0%, 0%	20	0%, 0%	9	0%, 0%	11
201-300	0%, 0%	312	0%, 0%	582	0.5%, 0.8%	2,098
301-400	0%, 0%	1,280	0%, 0%	1,559	1%, 0.5%	9,947
401-600	2%, 2%	2,912	0%, 0%	2,949	2%, 1%	19,527
601-800	6%, 5%	2,533	2%, 1%	3,038	5%, 3%	17,378
801-1000	20%, 15%	777	6%, 4%	1,015	9%, 6%	8,603
Total	5%, 4%	7,834	2%, 1%	9,255	4%, 3%	58,828

Table 5. Average AFCS longline survey Relative Population Weights split by sex and strata from 2006-2013.

Strata (m)	Aleutian Islands		Bering Sea		Gulf of Alaska	
	AI M	AI F	BS M	BS F	GOA M	GOA F
201-300	0	16,322	7	9,263	152	17,772
301-400	189	93,257	0	39,385	477	95,590
401-600	6,707	299,368	285	121,839	3,613	279,659
601-800	17,890	348,645	2,854	232,902	10,020	283,846
801-1000	37,164	218,898	6,692	148,634	17,131	271,927

Table 6. AFCS Gulf of Alaska trawl survey biomass estimates from recent years when the survey sampled down to 1,000 m (1999, 2005, 2007, 2009).

Depth strata (m)	Year	GOA M	GOA F	% male
1-500	1999	2,183	126,234	2%
1-500	2005	10,698	226,337	5%
1-500	2007	3,163	103,382	3%
1-500	2009	1,510	89,961	2%
501-700	1999	15,336	136,471	10%
501-700	2005	25,470	221,437	10%
501-700	2007	16,467	218,538	7%
501-700	2009	29,116	142,184	17%
701-1000	1999	28,466	81,219	26%
701-1000	2005	28,522	74,882	28%
701-1000	2007	46,574	99,862	32%
701-1000	2009	83,034	372,514	18%

Figure 1. Summed observed grenadier catch from 2003-2013, not total estimated catch, split by sex and depth strata.

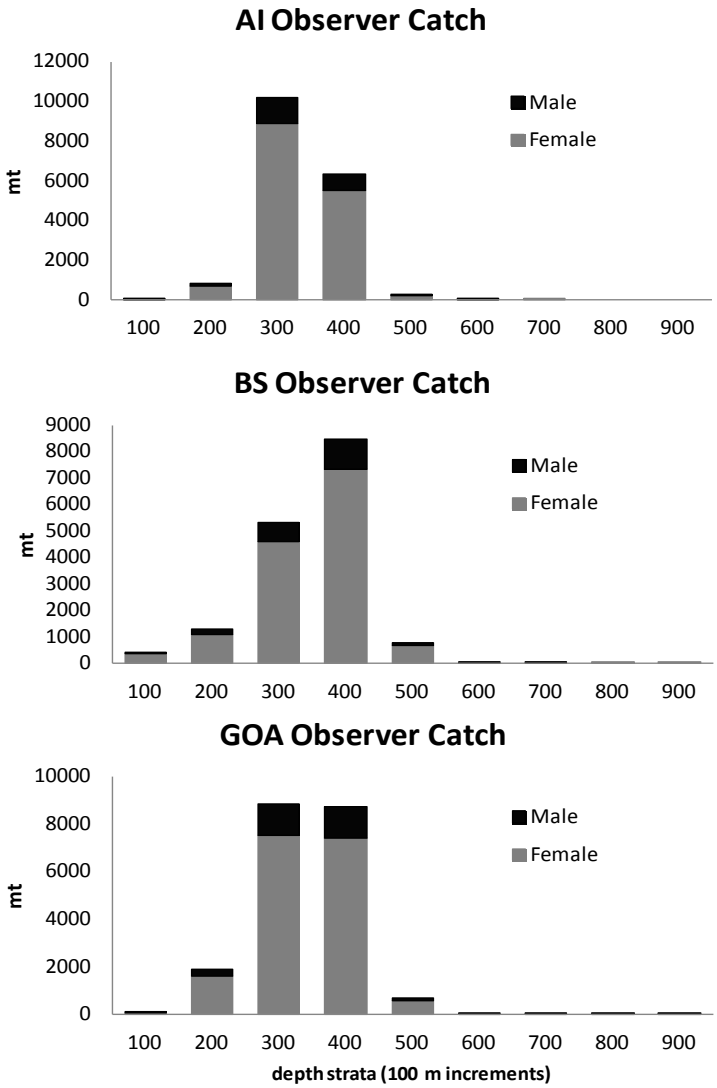


Figure 2. Average AFCS longline survey giant grenadier Relative Population Weights from 2006-2013 split by sex and depth stratum.

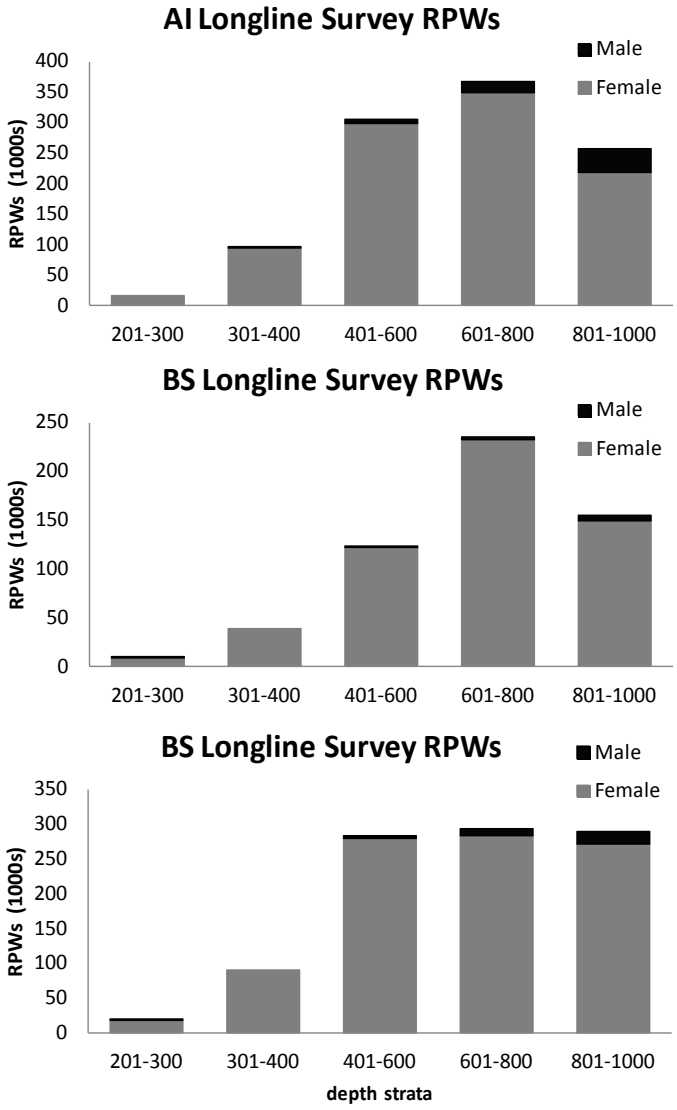
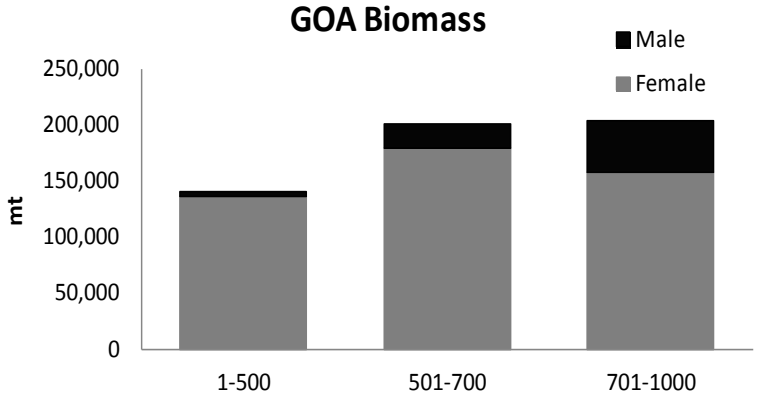


Figure 3. Average GOA AFCS trawl survey giant grenadier biomass estimates in 1999, 2005, 2007, and 2009 split by sex and strata (recent years when the survey sampled down to 1,000 m).



Appendix B

Tabbe 1B-1.—Research catch (mt) of grenadier (giant, popeye, and pacific grenadier, but primarily giant grenadier) in AFSC trawl and longline (LL) surveys and the International Pacific Halibut Commission (IPHC) longline survey. Only numbers are available from the IPHC survey through 2009; 2010 and 2011 catch in weight is available. 0s indicate that there was catch but it is <1 mt.

	BSAI					GOA					
Year	IPHC #s	IPHC wt	AFSC Trawl	AFSC LL	Total BSAI	IPHC #s	IPH C wt	AFSC Trawl	AFSC LL	Total GOA	Total
1979			33		33			0		0	33
1980			85		85			1		1	86
1981			66		66			3		3	69
1982			124		124			0		0	125
1983			136		136			0		0	136
1984								59		59	59
1985			165		165			9		9	174
1986			90		90			0		0	90
1987			0		0			42		42	42
1988			30		30						30
1989											
1990								3	128	131	131
1991			10		10				113	113	123
1992									117	117	117
1993								6	135	141	141
1994			6		6				134	134	140
1995									191	191	191
1996				38	38			8	173	181	219
1997	1,184		9	78	87	258			169	169	256
1998	556			59	59	681		12	141	153	212
1999	165		0	57	57	660		47	157	204	261
2000	774		118	88	206	621			160	160	366
2001	1,313			43	43	287		11	161	173	215
2002	987		23	81	104	942			129	129	233
2003	1,792		91	50	141	1,344		27	151	178	320
2004	2,111		196	78	274	1,110			109	109	383
2005	1,404			71	71	1,266		49	120	169	240
2006	941		20	76	96	919			112	112	208
2007	1,224			77	77	849		44	166	209	286
2008	1,331		123	47	170	755			120	120	290
2009	2,710			86	86	785		39	154	193	279
2010	2,451	9	156	66	231	1,265	6		164	170	401
2011	1,808	7		75	82	751	2	20	124	145	227
2012		5	135	43	177		2		132	132	310
*2013		5		83	88		2		132	134	222
*2014				73	73				127	127	200

*GOA trawl survey data is not available through the AKRO for grenadier for 2013 (accessed through AKFIN, October 2014). Only AFSC longline survey data is available for 2014.

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