Stock Assessment and Fishery Evaluation Report
for the
KING AND TANNER CRAB FISHERIES
of the
Bering Sea and Aleutian Islands Regions

2014 Final Crab SAFE

Compiled by

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of the Bering Sea and Aleutian Islands

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Fisheries of the Bering Sea and Aleutian Islands Regions

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Introduction

The annual stock assessment and fishery evaluation (SAFE) report is a requirement of the North Pacific Fishery Management Council's *Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs* (FMP), and a federal requirement [50 CFR Section 602.12(e)]. The SAFE report summarizes the current biological and economic status of fisheries, total allowable catch (TAC) or Guideline Harvest Level (GHL), and analytical information used for management decisions. Additional information on Bering Sea/Aleutian Islands (BSAI) king and Tanner crab is available on the National Marine Fisheries Service (NMFS) web page at http://www.fakr.noaa.gov and the Alaska Department of Fish and Game (ADF&G) Westward Region Shellfish web page at: http://www.cf.adfg.state.ak.us/region4/shellfsh/shelhom4.php.

This FMP applies to 10 crab stocks in the BSAI: 4 red king crab, *Paralithodes camtschaticus*, stocks (Bristol Bay, Pribilof Islands, Norton Sound and Adak), 2 blue king crab, *Paralithodes platypus,* stocks (Pribilof Islands and St Matthew Island), 2 golden (or brown) king crab, *Lithodes aequispinus,* stocks (Aleutian Islands and Pribilof Islands), southern Tanner crab *Chionoecetes bairdi* hereafter referred to as Tanner crab, and snow crab *Chionoecetes opilio*. All other crab stocks in the BSAI are exclusively managed by the State of Alaska (SOA).

The Crab Plan Team (CPT) annually assembles the SAFE report with contributions from ADF&G and the NMFS. This SAFE report is presented to the North Pacific Fishery Management Council (NPFMC) and is available to the public on the NPFMC web page at: http://fakr.noaa.gov/npfmc/membership/plan_teams/CRAB_team.htm. Under a process approved in 2008 for revised overfishing level (OFL) determinations, and annual catch limit (ACL) requirements in 2011, the CPT reviews three assessments in May to provide recommendations on OFL, acceptable biological catch (ABC) and stock status specifications for review by the NPFMC Science and Statistical Committee (SSC) in June. In September, the CPT reviews the remaining assessments and provides final OFL and ABC recommendations and stock status determinations. Additional information on the OFL and ABC determination process is contained in this report.

The CPT met from September 15-18, 2014 in Seattle, WA to review the final stock assessments as well as additional related issues, in order to provide the recommendations and status determinations contained in this SAFE report. This final 2014 Crab SAFE report contains all recommendations for all 10 stocks including those whose OFL and ABC were determined in June 2014. This SAFE report will be presented to the NPFMC in October for their annual review of the status of BSAI Crab stocks. Members of the team who participated in this review include the following: Bob Foy (Chair), Karla Bush (Vice-Chair), Wayne Donaldson, Heather Fitch, Brian Garber-Yonts, Ginny Eckert, Jason Gasper, Doug Pengilly André Punt, Buck Stockhausen, Martin Dorn, Shareef Siddeek, Jack Turnock and Diana Stram.

Stock Status Definitions

The FMP (incorporating all changes made following adoption of Amendment 24) contains the following stock status definitions:

Acceptable biological catch (ABC) is a level of annual catch of a stock that accounts for the scientific uncertainty in the estimate of OFL and any other specified scientific uncertainty and is set to prevent, with a greater than 50 percent probability, the OFL from being exceeded. The ABC is set below the OFL.

ABC Control Rule is the specified approach in the five-tier system for setting the maximum permissible ABC for each stock as a function of the scientific uncertainty in the estimate of OFL and any other specified scientific uncertainty.

Annual catch limit (ACL) is the level of annual catch of a stock that serves as the basis for invoking accountability measures. For EBS crab stocks, the ACL will be set at the ABC.

Total allowable catch (TAC) is the annual catch target for the directed fishery for a stock, set to prevent exceeding the ACL for that stock and in accordance with section 8.2.2 of the FMP.

Guideline harvest level (GHL) means the preseason estimated level of allowable fish harvest which will not jeopardize the sustained yield of the fish stocks. A GHL may be expressed as a range of allowable harvests for a species or species group of crab for each registration area, district, subdistrict, or section.

Maximum sustainable yield (MSY) is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions. MSY is estimated from the best information available.

F_{MSY} control rule means a harvest strategy which, if implemented, would be expected to result in a long-term average catch approximating MSY.

B_{MSY} stock size is the biomass that results from fishing at constant F_{MSY} and is the minimum standard for a rebuilding target when a rebuilding plan is required.

Maximum fishing mortality threshold (MFMT) is defined by the F_{OFL} control rule, and is expressed as the fishing mortality rate.

Minimum stock size threshold (MSST) is one half the B_{MSY} stock size.

Overfished is determined by comparing annual biomass estimates to the established MSST. For stocks where MSST (or proxies) are defined, if the biomass drops below the MSST (or proxy thereof) then the stock is considered to be overfished. For crab stocks, biomass for determining overfished status is estimated on February 15 of the current year and compared to the MSST established by the NPFMC in October of the previous year.

Overfishing is defined as any amount of catch in excess of the overfishing level (OFL). The OFL is calculated by applying abundance estimates to the F_{OFL} control rule which is annually estimated according the tier system (see Chapter 6.0 in the FMP).

Status Determination Criteria

The FMP defines the following status determination criteria and the process by which these are defined following adoption of amendment 24 and 38.

Status determination criteria for crab stocks are annually calculated using a five-tier system that accommodates varying levels of uncertainty of information. The five-tier system incorporates new scientific information and provides a mechanism to continually improve the status determination criteria as new information becomes available. Under the five-tier system, overfishing and overfished criteria and ABC levels are annually formulated. The ACL for each stock equals the ABC for that stock. Each crab stock is annually assessed to determine its status and whether (1) overfishing is occurring or the rate or level of fishing mortality for the stock is approaching overfishing, (2) the stock is overfished or the stock is approaching an overfished condition, and (3) the catch has exceeded the ACL.

For crab stocks, the OFL equals the maximum sustainable yield (MSY) and is derived through the annual assessment process, under the framework of the tier system. Overfishing is determined by comparing the OFL with the catch estimates for that crab fishing year. For the previous crab fishing year, NMFS will determine whether overfishing occurred by comparing the previous year's OFL with the catch from the previous crab fishing year. For the previous crab fishing year, NMFS will also determine whether the ACL was exceeded by comparing the ACL with the catch estimates for that crab fishing year. Catch includes all fishery removals, including retained catch and discard losses, for those stocks where non-target fishery removal data are available. Discard losses are determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the OFL and ACL will be set for and compared to the retained catch.

The NMFS will determine whether a stock is in an overfished condition by comparing annual biomass estimates to the established MSST. For stocks where MSST (or proxies) are defined, if the biomass drops below the MSST (or proxy thereof) then the stock is considered to be overfished. MSSTs or proxies are set for stocks in Tiers 1-4. For Tier 5 stocks, it is not possible to set an MSST because there are no reliable estimates of biomass.

If overfishing occurred or the stock is overfished, section 304(e)(3)(A) of the Magnuson-Stevens Act, as amended, requires the NPFMC to immediately end overfishing and rebuild affected stocks.

The Magnuson-Stevens Act requires that FMPs include accountability measures to prevent ACLs from being exceeded and to correct overages of the ACL if they do occur. Accountability measures to prevent TACs and GHLs from being exceeded have been used under this FMP for the management of the BSAI crab fisheries and will continue to be used to prevent ACLs from being exceeded. These include: individual fishing quotas and the measures to ensure that individual fishing quotas are not exceeded, measures to minimize crab bycatch in directed crab fisheries, and monitoring and catch accounting measures. Accountability measures in the harvest specification process include downward adjustments to the ACL and TAC in the fishing year after an ACL has been exceeded.

Annually, the NPFMC, SSC, and CPT will review (1) the stock assessment documents, (2) the OFLs and ABCs, and TACs or GHLs, (3) NMFS's determination of whether overfishing occurred in the previous crab fishing year, (4) NMFS's determination of whether any stocks are overfished and (5) NMFS's determination of whether catch exceeded the ACL in the previous crab fishing year.

Optimum yield is defined in Chapter 4 of the FMP. Information pertaining to economic, social and ecological factors relevant to the determination of optimum yield is provided in several sections of the FMP, including sections 7.2 (Management Objectives), Chapter 11, Appendix D (Biological and Environmental Characteristics of the Resource), and Appendix H (Community Profiles).

For each crab fishery, the optimum yield range is 0 to < OFL catch. For crab stocks, the OFL is the annualized MSY and is derived through the annual assessment process, under the framework of the tier system. Recognizing the relatively volatile reproductive potential of crab stocks, the cooperative management structure of the FMP, and the past practice of restricting or even prohibiting directed harvests of some stocks out of ecological considerations, this optimum yield range is intended to facilitate the achievement of the biological objectives and economic and social objectives of the FMP (see sections 7.2.1 and 7.2.2) under a variety of future biological and ecological conditions. It enables the SOA to determine the appropriate TAC levels below the OFL to prevent overfishing or address other biological concerns that may affect the reproductive potential of a stock but that are not reflected in the OFL itself. Under FMP section 8.2.2, the SOA establishes TACs at levels that maximize harvests, and associated economic and social benefits, when biological and ecological conditions warrant doing so.

Five-Tier System

The OFL and ABC for each stock are annually estimated for the upcoming crab fishing year using the five-tier system, detailed in Table 6-1 and 6-2. First, a stock is assigned to one of the five tiers based on the availability of information for that stock and model parameter choices are made. Tier assignments and model parameter choices are recommended through the CPT process to the SSC. The SSC recommends tier assignments, stock assessment and model structure, and parameter choices, including whether information is "reliable," for the assessment authors to use for calculating the proposed OFLs and ABCs based on the five-tier system.

For Tiers 1 through 4, once a stock is assigned to a tier, the determination of stock status level is based on recent survey data and assessment models, as available. The stock status level determines the equation used in calculating the F_{OFL}. Three levels of stock status are specified and denoted by “a,” “b,” and “c” (see Table 6-1). The F_{MSY} control rule reduces the F_{OFL} as biomass declines by stock status level. At stock status level “a,” current stock biomass exceeds the B_{MSY}. For stocks in status level “b,” current biomass is less than B_{MSY} but greater than a level specified as the “critical biomass threshold” (β).

In stock status level “c,” the ratio of current biomass to B_{MSY} (or a proxy for B_{MSY}) is below β. At stock status level “c,” directed fishing is prohibited and an F_{OFL} at or below F_{MSY} would be determined for all other sources of fishing mortality in the development of the rebuilding plan. The Council will develop a rebuilding plan once a stock level falls below the MSST.

For Tiers 1 through 3, the coefficient α is set at a default value of 0.1, and β set at a default value of 0.25, with the understanding that the SSC may recommend different values for a specific stock or stock complex as merited by the best available scientific information.

In Tier 4, a default value of natural mortality rate (M) or an M proxy, and a scalar, γ, are used in the calculation of the F_{OFL}.

In Tier 5, the OFL is specified in terms of an average catch value over an historical time period, unless the SSC recommends an alternative value based on the best available scientific information.

Second, the assessment author prepares the stock assessment and calculates the proposed OFLs by applying the F_{OFL} and using the most recent abundance estimates. The assessment authors calculate the proposed ABCs by applying the ABC control rule to the proposed OFL.

Stock assessment documents shall:

- use risk-neutral assumptions;
- specify how the probability distribution of the OFL used in the ABC control rule is calculated for each stock; and
- specify the factors influencing scientific uncertainty that are accounted for in calculation of the probability distribution of the OFL.

Second, the CPT annually reviews stock assessment documents, the most recent abundance estimates, the proposed OFLs and ABCs, and complies the SAFE. The CPT then makes recommendations to the SSC on the OFLs, ABCs, and any other issues related to the crab stocks.

Third, the SSC annually reviews the SAFE report, including the stock assessment documents, recommendations from the CPT, and the methods to address scientific uncertainty.

In reviewing the SAFE, the CPT and the SSC shall evaluate and make recommendations, as necessary, on:

- the assumptions made for stock assessment models and estimation of OFLs;
- the specifications of the probability distribution of the OFL;
- the methods to appropriately quantify uncertainty in the ABC control rule; and
- the factors influencing scientific uncertainty that the SOA has accounted for and will account for on an annual basis in TAC setting.

The SSC will then set the final OFLs and ABCs for the upcoming crab fishing year. The SSC may set an ABC lower than the result of the ABC control rule, but it must provide an explanation for setting the ABC less than the maximum ABC.

As an accountability measure, the total catch estimate used in the stock assessment will include any amount of harvest that may have exceeded the ACL in the previous fishing season. For stocks managed under Tiers 1 through 4, this would result in a lower maximum ABC in the subsequent year, all else being equal, because maximum ABC varies directly with biomass. For Tier 5 stocks, the information used to establish the ABC is insufficient to reliably estimate abundance or discern the existence or extent of biological consequences caused by an overage in the preceding year. Consequently, the subsequent year's maximum ABC will not automatically decrease. However, when the ACL for a Tier 5 stock has been exceeded, the SSC may decrease the ABC for the subsequent fishing season as an accountability measure.

<u>Tiers 1 through 3</u>

For Tiers 1 through 3, reliable estimates of B, B_{MSY}, and F_{MSY}, or their respective proxy values, are available. Tiers 1 and 2 are for stocks with a reliable estimate of the spawner/recruit relationship, thereby enabling the estimation of the limit reference points B_{MSY} and F_{MSY}.

- Tier 1 is for stocks with assessment models in which the probability density function (pdf) of F_{MSY} is estimated.
- Tier 2 is for stocks with assessment models in which a reliable point estimate, but not the pdf, of F_{MSY} is made.
- Tier 3 is for stocks where reliable estimates of the spawner/recruit relationship are not available, but proxies for F_{MSY} and B_{MSY} can be estimated.

For Tier 3 stocks, maturity and other essential life-history information are available to estimate proxy limit reference points. For Tier 3, a designation of the form "F_X" refers to the fishing mortality rate associated with an equilibrium level of fertilized egg production (or its proxy such as mature male biomass at mating) per recruit equal to X% of the equilibrium level in the absence of any fishing.

The OFL and ABC calculation accounts for all losses to the stock not attributable to natural mortality. The OFL and ACL are total catch limits comprised of three catch components: (1) non-directed fishery discard losses; (2) directed fishery discard losses; and (3) directed fishery retained catch. To determine the discard losses, the handling mortality rate is multiplied by bycatch discards in each fishery. Overfishing would occur if, in any year, the sum of all three catch components exceeds the OFL.

Tier 4

Tier 4 is for stocks where essential life-history, recruitment information, and understanding are insufficient to achieve Tier 3. Therefore, it is not possible to estimate the spawner-recruit relationship. However, there is sufficient information for simulation modeling that captures the essential population dynamics of the stock as well as the performance of the fisheries. The simulation modeling approach employed in the derivation of the annual OFLs captures the historical performance of the fisheries as seen in observer data from the early 1990s to present and thus borrows information from other stocks as necessary to estimate biological parameters such as γ.

In Tier 4, a default value of natural mortality rate (M) or an M proxy, and a scalar, γ, are used in the calculation of the F_{OFL}. Explicit to Tier 4 are reliable estimates of current survey biomass and the instantaneous M. The proxy B_{MSY} is the average biomass over a specified time period, with the understanding that the Council's Scientific and Statistical Committee may recommend a different value for a specific stock or stock complex as merited by the best available scientific information. A scalar, γ, is multiplied by M to estimate the F_{OFL} for stocks at status levels **"**a**"** and **"**b,**"** and γ is allowed to be less than or greater than unity. Use of the scalar γ is intended to allow adjustments in the overfishing definitions to account for differences in biomass measures. A default value of γ is set at 1.0, with the understanding that the Council's Scientific and Statistical Committee may recommend a different value for a specific stock or stock complex as merited by the best available scientific information.

If the information necessary to determine total catch OFLs and ACLs is available for a Tier 4 stock, then the OFL and ACL will be total catch limits comprised of three catch components: (1) non-directed fishery discard losses; (2) directed fishery discard losses; and (3) directed fishery retained catch. If the information necessary to determine total catch OFLs and ACLs is not available for a Tier 4 stock, then the OFL and ACL are determined for retained catch. In the future, as information improves, data would be available for some stocks to allow the formulation and use of selectivity curves for the discard fisheries (directed and non-directed losses) as well as the directed fishery (retained catch) in the models. The resulting OFL and ACL from this approach, therefore, would be the total catch OFL and ACL.

Tier 5

Tier 5 stocks have no reliable estimates of biomass and only historical catch data are available. For Tier 5 stocks, the OFL is set equal to the average catch from a time period determined to be representative of the production potential of the stock, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information. The ABC control rule sets the maximum ABC at less than or equal to 90 percent of the OFL and the ACL equals the ABC.

For Tier 5 stocks where only retained catch information is available, the OFL and ACL will be set for the retained catch portion only, with the corresponding limits applying to the retained catch only. For Tier 5 stocks where information on bycatch mortality is available, the OFL and ACL calculations could include discard losses, at which point the OFL and ACL would be applied to the retained catch plus the discard losses from directed and non-directed fisheries.

Figure 1. Overfishing control rule for Tiers 1 through 4. Directed fishing mortality is 0 below β.

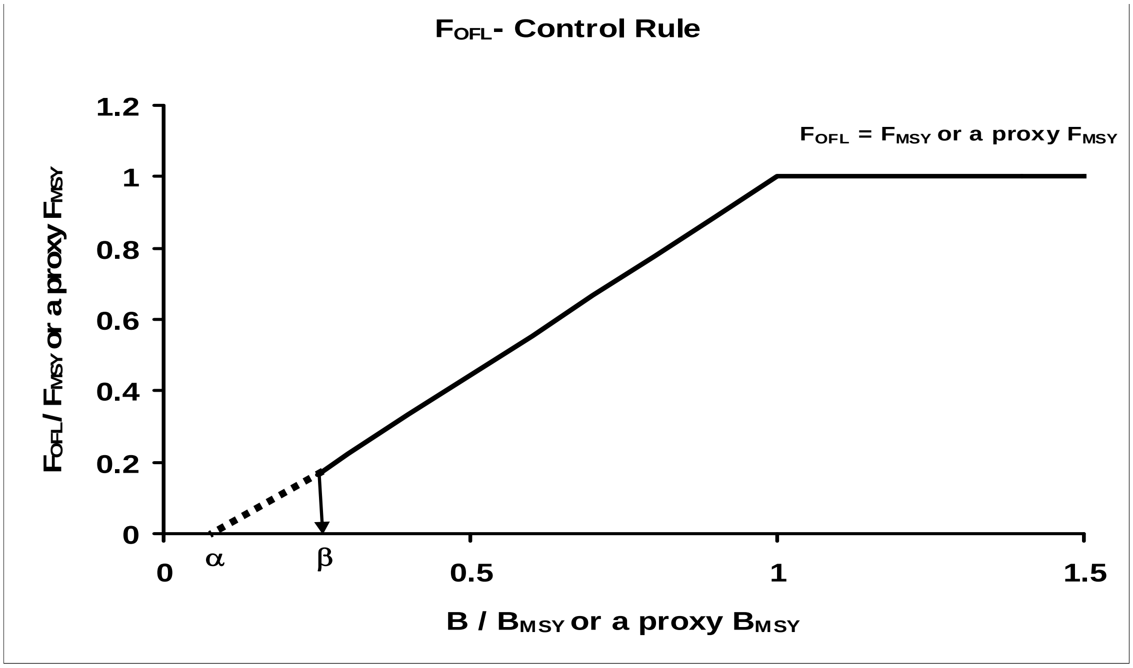

Table 1 Five-Tier System for setting overfishing limits (OFLs) and Acceptable Biological Catches (ABCs) for crab stocks. The tiers are listed in descending order of information availability. Table 2 contains a guide for understanding the five-tier system.

Information available	Tier	Stock status level	F_{OFL}	ABC control rule
B, B_{MSY}, F_{MSY}, and pdf of F_{MSY}	1	a. $\frac{B}{B_{msy}} > 1$	$F_{OFL} = \mu_A$ =arithmetic mean of the pdf	
		b. $\beta < \frac{B}{B_{msy}} \leq 1$	$F_{OFL} = \mu_A \frac{B/B_{msy} - \alpha}{1-\alpha}$	ABC≤(1-b_y) * OFL
		c. $\frac{B}{B_{msy}} \leq \beta$	*Directed fishery F = 0* $F_{OFL} \leq F_{MSY}$†	
B, B_{MSY}, F_{MSY}	2	a. $\frac{B}{B_{msy}} > 1$	$F_{OFL} = F_{msy}$	
		b. $\beta < \frac{B}{B_{msy}} \leq 1$	$F_{OFL} = F_{msy} \frac{B/B_{msy} - \alpha}{1-\alpha}$	ABC≤(1-b_y) * OFL
		c. $\frac{B}{B_{msy}} \leq \beta$	*Directed fishery F = 0* $F_{OFL} \leq F_{MSY}$†	
B, $F_{35\%}$*, $B_{35\%}$*	3	a. $\frac{B}{B_{35\%*}} > 1$	$F_{OFL} = F_{35\%}*$	
		b. $\beta < \frac{B}{B_{35\%}*} \leq 1$	$F_{OFL} = F^*_{35\%} \frac{\frac{B}{B^*_{35\%}} - \alpha}{1-\alpha}$	ABC≤(1-b_y) * OFL
		c. $\frac{B}{B_{35\%}*} \leq \beta$	*Directed fishery F = 0* $F_{OFL} \leq F_{MSY}$†	
B, M, $B_{msy^{prox}}$	4	a. $\frac{B}{B_{msy^{prox}}} > 1$	$F_{OFL} = \gamma M$	
		b. $\beta < \frac{B}{B_{msy^{prox}}} \leq 1$	$F_{OFL} = \gamma M \frac{B/B_{msy^{prox}} - \alpha}{1-\alpha}$	ABC≤(1-b_y) * OFL
		c. $\frac{B}{B_{msy^{prox}}} \leq \beta$	*Directed fishery F = 0* $F_{OFL} \leq F_{MSY}$†	
Stocks with no reliable estimates of biomass or M.	5		OFL = average catch from a time period to be determined, unless the SSC recommends an alternative value based on the best available scientific information.	ABC≤0.90 * OFL

*35% is the default value unless the SSC recommends a different value based on the best available scientific information.
† An $F_{OFL} \leq F_{MSY}$ will be determined in the development of the rebuilding plan for an overfished stock.

Table 2 A guide for understanding the five-tier system.

- F_{OFL} — the instantaneous fishing mortality (F) from the directed fishery that is used in the calculation of the overfishing limit (OFL). F_{OFL} is determined as a function of:
  - F_{MSY} — the instantaneous F that will produce MSY at the MSY-producing biomass
    - A proxy of F_{MSY} may be used; e.g., $F_{x\%}$, the instantaneous F that results in x% of the equilibrium spawning per recruit relative to the unfished value
  - B — a measure of the productive capacity of the stock, such as spawning biomass or fertilized egg production.
    - A proxy of B may be used; e.g., mature male biomass
  - B_{MSY} — the value of B at the MSY-producing level
    - A proxy of B_{MSY} may be used; e.g., mature male biomass at the MSY-producing level
  - β — a parameter with restriction that $0 \le \beta < 1$.
  - α — a parameter with restriction that $0 \le \alpha \le \beta$.
- The maximum value of F_{OFL} is F_{MSY}. $F_{OFL} = F_{MSY}$ when $B > B_{MSY}$.
- F_{OFL} decreases linearly from F_{MSY} to $F_{MSY}\cdot(\beta-\alpha)/(1-\alpha)$ as B decreases from B_{MSY} to $\beta\cdot B_{MSY}$
- When $B \le \beta\cdot B_{MSY}$, F = 0 for the directed fishery and $F_{OFL} \le F_{MSY}$ for the non-directed fisheries, which will be determined in the development of the rebuilding plan.
- The parameter, β, determines the threshold level of B at or below which directed fishing is prohibited.
- The parameter, α, determines the value of F_{OFL} when B decreases to $\beta\cdot B_{MSY}$ and the rate at which F_{OFL} decreases with decreasing values of B when $\beta\cdot B_{MSY} < B \le B_{MSY}$.
  - Larger values of α result in a smaller value of F_{OFL} when B decreases to $\beta\cdot B_{MSY}$.
  - Larger values of α result in F_{OFL} decreasing at a higher rate with decreasing values of B when $\beta\cdot B_{MSY} < B \le B_{MSY}$.
- The parameter, b_y, is the value for the annual buffer calculated from a P* of 0.49 and a probability distribution for the OFL that accounts for scientific uncertainty in the estimate of OFL.
- P* is the probability that the estimate of ABC, which is calculated from the estimate of OFL, exceeds the “true” OFL (noted as OFL’) (P(ABC>OFL’).

Crab Plan Team Recommendations

Table 3 lists the team’s recommendations for 2014/2015 on Tier assignments, model parameterizations, time periods for reference biomass estimation or appropriate catch averages, OFLs and ABCs. The team recommends three stocks be placed in Tier 3 (EBS snow crab, Bristol Bay red king crab and EBS Tanner crab), four stocks in Tier 4 (St. Matthew blue king crab, Pribilof Islands blue king crab, Pribilof Islands red king crab, and Norton Sound red king crab) and three stocks in Tier 5 (AI golden king crab, Pribilof Islands golden king crab, and Adak red king crab). Table 4 lists those stocks for which the team recommends an ABC less than the maximum permissible ABC for 2014/15. Stock status in relation to status determination criteria are evaluated in this report (Table 5). Status of stocks in relation to status determination criteria for stocks in Tiers 3 and 4 are shown in Figure 1. EBS Tanner crab is estimated to be above B_{MSY} for 2014/15 while snow crab, Bristol Bay red king crab, Pribilof Islands red king crab and Norton Sound red king crab are all estimated below B_{MSY}. Pribilof Islands blue king crab stock remains overfished and estimated to be well below its MSST.

The CPT has general recommendations for all assessments and specific comments related to individual assessments. All recommendations are for consideration for the 2015 assessments. The general comments are listed below while the comments related to individual assessments are contained within the summary of CPT deliberations and recommendations contained in the stock specific summary section. Additional details regarding recommendations are contained in the Crab Plan Team Report (September 2014 CPT Report).

General recommendations for all assessments

1. The team recommends that all assessment authors document assumptions and simulate data under those assumptions to test the ability of the model to estimate key parameters in an unbiased manner. These simulations would be used to demonstrate precision and bias in estimated model parameters.
2. The CPT recommends that weighting factors be expressed as sigmas or CVs or effective sample sizes. The team requests all authors to follow the Guidelines for SAFE preparation and to follow the Terms of Reference as listed therein as applicable by individual assessment for both content and diagnostics.
3. Authors should focus on displaying information on revised models as compared to last year’s model rather than focusing on aspects of the assessment that have not changed from the previous year.
4. The team recommends supporting the recruitment and survey average workgroup recommendations for crab assessments as well as groundfish
5. The current approach for fitting length-composition data accounts for sampling error but ignores the fact that selectivity among size classes is not constant within years; a small change in the selectivity on small animals could lead to a very large change in the catch of such animals (as may have happened for NSRKC). Authors are encouraged to develop approaches for accounting for this source of process error. This issue is generic to assessments of crab and groundfish stocks.
6. Authors are reminded that assessments should include the time series of stock estimates at the time of survey for at least the author's recommended model in that year.

By convention the CPT used the following conversions to include tables in both lb and t in the status status summary sections:

- million lb to 1000 t [/2.204624]
- 1000 t to million lb [/0.453592]

Stock Status Summaries

1 Eastern Bering Sea Snow crab

Fishery information relative to OFL setting

Total catch mortality in 2013/14 was 28,200 t (with discard mortality rates applied), while the retained catch in the directed fishery was 24,480 t. This is below the 2013/14 OFL of 78,100 t. Snow crab bycatch occurs in the directed fishery and to a lesser extent in the groundfish trawl fisheries. Estimates of trawl bycatch in recent years are less than 1% of the total snow crab catch. Prior to this year, estimates of stock status were above $B_{35\%}$ in the assessment since 2010/11. This year, MMB for 2014/15 (137,600 t) is 96% of the value for $B_{35\%}$ calculated in this assessment (142,900 t).

Data and assessment methodology

The stock assessment is based on a size- and sex-structured model in which crabs are categorized into immature, mature, new and old shell. The model is fitted to abundance and size frequency data from the NMFS trawl survey, total catch data from the directed fishery, bycatch data from the trawl fishery, and size frequency data for male retained catch in the directed fishery, and male and female bycatch in the directed fishery and trawl fishery. The model is also fitted to biomass estimates and size frequency data from the 20019 and 2010 BSFRF surveys and to growth increment data from Somerton. New data used in the model include biomass and length frequency data from the 2014 NMFS Eastern Bering Sea trawl survey, retained and discard catch and length size frequencies from the 2013/14 directed fishery, and discard catch and length frequency data from the groundfish fisheries.

Three growth models were considered in this assessment. The first growth model considered was the one used in the 2013 assessment, which modeled growth increment as a function of crab size using a single linear segment. A second model was based on a suggestion during the 2014 CIE review of the snow crab assessment that fits two linear segments to growth increment data using a smooth transition between the segments—with the result that the resulting function is differentiable at all points. The final model described growth increments using two linear segments and a fixed transition point; this model is not differentiable at the transition point from one segment to the other.

The assessment author presented nine model scenarios in this assessment. These scenarios included the 2013 assessment model with the old growth model, the two-segment "hockey stick"-type growth model, three models based on the smooth, 2-segment growth model but with different weights (1, 2 and 3) in the likelihood placed on fitting the growth data, and four other models (based on the smooth growth model with growth likelihood weight 2) that also incorporated different weights on likelihood penalties placed on fishing mortality rates in the final model estimation phase. Model estimates of biomass were relatively insensitive to these changes, as were the associated $F_{35\%}$'s and $B_{35\%}$'s (except for the model with the smallest penalty on fishing mortality rates). OFLs for the 2014/15 fishery were somewhat sensitive to individual model scenarios. The author's selected model (Model 2b) incorporated the CIE-suggested 2-segment growth model with the smooth transition with the moderate (2*x*) weighting in the likelihood to fit the growth data as his preferred model, and the CPT concurred with this recommendation. This model was selected because it used the smooth, 2-segment growth model and it fit the growth data much better than the similar model with the 1*x* weighting factor, while the fit was not substantially improved using model with the 3*x* factor on fitting the growth data.

Stock biomass and recruitment trends

Observed survey mature male biomass decreased from 167,400 t in 2011 to 120,800 t in 2012 and to 96,100 t in 2013. It increased to 156,900 t in 2014. Similarly, the observed survey mature female biomass also decreased from 2011 to 2013 (from 280,000 t in 2011, 220,600 t in 2012, and to 195,100 t in 2013) but increased in 2014 to 212,500 t. In contrast to the survey observations available at the time, the 2013 model had estimated that mature male biomass increased between 2012 and 2013, almost returning to the

2011 level. This was partly driven by a peak in 2009 in estimated recruitment that was not evident in the surveys for 2012 and 2013. The 2014 model also estimated a similar peak in recruitment, but delayed by a year (2010 rather than 2009), as well as an increasing trend in biomass (now supported by the survey results). The 2013 model-predicted mature male biomass at the time of the survey for 2013 was 1.5 times higher than the observed value. The 2014 model under-predicts mature male biomass at the time of the survey for 2014. Fits by the 2014 model to the size frequency data from the 2012 and 2013 surveys were poor; fitted size frequencies were lower than observed for females and higher than observed for males. The 2013 survey exhibited similar behavior. Fits to the 2014 data are somewhat improved, as the predicted recruitment event in 2010, apparently influenced a relatively high abundance of small (~50 mm CW) males observed in the 2010 survey propagates into the more fully-selected size classes in the survey.

Tier determination/Plan Team discussion and resulting OFL/ABC determination Status and catch specifications

The CPT recommends that the EBS snow crab is a Tier 3 stock so the OFL will be determined by the $F_{35\%}$ control rule. The proxy for B_{MSY} ($B_{35\%}$) is the mature male biomass at mating (142.9 thousand t) based on average recruitment over 1978 to 2014 present (1,351 million crab). Consequently, the minimum stock size threshold (MSST) is 71.5 thousand t. The CPT recommends that the ABC be less than maximum permissible ABC, and concurs with the authors' recommendation to use a default 10% buffer for setting the ABC.

Historical status and catch specifications for snow crab (thousand t).

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	73.7	196.6[A]	24.6	24.7	26.7	44.4	
2011/12	77.3	165.2[A]	40.3	40.5	44.7	73.5	66.2
2012/13	77.1	170.1[A]	30.1	30.1	32.4	67.8	61.0
2013/14	71.5	126.5[A]	24.5	24.5	28.1	78.1	70.3
2014/15		137.6[B]				69.0	62.1

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

Historical status and catch specifications for snow crab (millions of lb).

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	162.5	433.4[A]	54.2	54.5	58.9	97.9	
2011/12	170.4	364.2[A]	88.8	89.3	98.5	162.0	145.9
2012/13	170.0	375.0[A]	66.4	66.4	71.4	149.5	134.5
2013/14	157.6	279.0[A]	54.0	54.0	62.0	172.2	155.0
2014/15		303.4[B]				152.1	137.0

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

Additional Plan Team recommendations

The Plan Team recommended that the author explore the use of applying different penalty weights by time period to quantities related to fishing mortality. One specific suggestion was to eliminate the weights on average F and to put penalties on F deviations only in the "early" time period when data on discards is unavailable.

The Team also recommended the author consider whether the smallest crabs used to estimate growth increments could be molting more than once per year (contrary to the assumption used to incorporate the data in the model) and to explore the ramifications of this, if true, on the model.

2 Bristol Bay Red King Crab

Fishery information relative to OFL setting.

The commercial harvest of Bristol Bay red king crab (BBRKC) dates to the 1930s, initially prosecuted mostly by foreign fleets but shifting to a largely domestic fishery in the early 1970s. Retained catch peaked in 1980 at 129.9 million lb (58.9 thousand t), but harvests dropped sharply in the early 1980s, and population abundance has remained at relatively low levels over the last two decades compared to those seen in the 1970s. The fishery is managed for a total allowable catch (TAC) coupled with restrictions for sex (males only), a minimum size for legal retention (6.5-in carapace width; 135-mm carapace length is used a proxy for 6.5-in carapace width in the assessment), and season (no fishing during mating/molting periods). In addition to the retained catch that occurs during the commercial fishery, which is limited by the TAC, there is also retained catch that occurs in the ADF&G cost-recovery fishery.

The current SOA harvest strategy allows a maximum harvest rate of 15% of mature-sized (≥120 mm CL) males, but also incorporates a maximum harvest rate of 50% of legal males and a threshold of 8.4 million mature-sized (≥90 mm CL) females and 14.5 million lb (6.6 thousand t) of effective spawning biomass (ESB), to prosecute a fishery. Annual non-retained catch of female and sublegal male RKC during the fishery averaged less than 3.9 million lb (8.6 thousand t) since data collection began in 1990. Total catch (retained and bycatch mortality) increased from 16.9 million lb (7.6 thousand t) in 2005/06 to 23.4 million lb (10.6 thousand t) in 2007/08, but has decreased each season since then; retained catch in 2013/14 was 8.80 million lb (3.99 thousand t) and total catch was 10.05 million lb (4.56 thousand t).

Data and assessment methodology

The stock assessment model is based on a sex- and size-structured population dynamics model incorporating data from the NMFS eastern Bering Sea trawl survey, the Bering Sea Fisheries Research Foundation (BSFRF) trawl survey, landings of commercial catch, at-sea observers, and dockside samplers. In the model recommended by the CPT, annual stock abundance was estimated for male and female crabs ≥ 65-mm carapace length from 1975 to the time of the 2014 survey and mature male (males ≥120 mm CL) biomass was projected to 15 February 2015. Catch data (retained catch numbers, retained catch weight, and pot lifts by statistical area and landing date) from the directed fishery, which targets males ≥ 135 mm (6.5 in carapace length), were obtained from ADF&G fish tickets and reports, red king crab and Tanner crab fisheries bycatch data from the ADF&G observer database, and groundfish trawl bycatch data from the NMFS trawl observer database. NMFS trawl survey data was updated with the newly re-estimated time series provided by NMFS in 2014, Catch and bycatch data were updated with data from the 2013/14 crab fishery year; data on bycatch during groundfish fisheries during 2009/10−2012/13 were revised with data provided by NMFS in 2014 and data on bycatch during the Tanner crab fishery were revised with data provided by ADF&G in 2014.

Three alternative models were evaluated in the 2014: the accepted model for the 2013 assessment, which served as the base model (model scenario 4na); a variant of the base model that differed from the base model by estimating trawl survey catchability, Q, within the model (model scenario 4nb); and a variant of model scenario 4nb that estimates an additional mortality for males and females during 2006−2010. The author recommended model scenario 4nb for use in the 2014 stock assessment. After discussion, the CPT selected model scenario 4nb as its recommended model to proceed with status determination and OFL setting. Model scenario 4nb provides a slightly better fit than the base model (see Table 4 in the assessment) and reliably estimates survey catchability. Although the addition of an additional mortality parameter for 2006−2010 in model scenario 4n7 provided a better fit than either model scenarios 4na and

4nb, the CPT did not recommend 4n7 because there is presently no biological or environmental mechanism for invoking a higher natural mortality for that period.

Stock biomass and recruitment trends

Model (scenario 4nb) estimates of total survey biomass increased from 262.1 thousand t in 1975 to 310.0 thousand t in 1978, fell to 38.1 thousand t in 1985, generally increased to 94.9 thousand t in 2007, and subsequently declined to 76.3 thousand t in 2014. Estimated recruitment was high during the 1970s and early 1980s and has been generally low since 1985. The near-term outlook for this stock is a continued declining trend. Recruitment has been poor (less than the mean from 1984-2014) since 2006. The 2011 survey produced a high catch of juvenile males and females <65 mm CL in one survey tow but that catch did not track into the 2012−2014 surveys. The survey area-swept estimates for abundance and biomass in 2014 were surprisingly high, given the poor recruitment and the size distributions and area-swept estimates from recent previous surveys.

Tier determination/Plan Team discussion and resulting OFL and ABC determination

Bristol Bay red king crab is in Tier 3. The proxy of B_{MSY} ($B_{35\%}$) for a Tier 3 stock is based on mature male biomass at mating (MMB) and is computed as the average recruitment over some time period multiplied by the mature male biomass-per-recruit corresponding to $F_{35\%}$ less the mature male catch under an $F_{35\%}$ harvest strategy. Based on the author's discussion regarding an apparent reduction in stock productivity associated with the well-known 1976/77 climate regime shift in the EBS, the CPT continues to recommend computing average recruitment based on model recruitment using the time period 1984 (corresponding to fertilization in 1977) to the last year of the assessment. The estimated $B_{35\%}$ is 25.7 thousand t). MMB projected for 2014/15 is, at 24.7 thousand t, 96% of $B_{35\%}$. Consequently, the Tier 3 status level for the BBRKC stock in 2014/15 is b.

The team recommends that the OFL for 2014/15 be set according to model scenario 4nb, for which the calculated OFL is 6.82 thousand t (15.04 million lb). The team recommends that the ABC for 2014/15 be set below the maximum permissible ABC. The team recommends that a 10% buffer from the OFL be used to set the ABC at 6.14 thousand t (13.53 million lb).

MMB for 2013/14 is estimated to be above MSST (12.85 thousand t) 27.1 thousand t; hence the stock was not overfished in 2013/14. The total catch in 2013/14 (4.56 thousand t) was less than the 2013/14 OFL (7.96 thousand t); hence overfishing did not occur in 2013/14. The stock at 2014/15 time of mating is projected to be above the MSST and 96% of $B_{35\%}$ (see above); hence the stock is not projected to be in overfished condition in 2014/15.

Status and catch specifications (thousand t) for Bristol Bay red king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	13.63	32.64[A]	6.73	6.76	7.71	10.66	
2011/12	13.77	30.88[A]	3.55	3.61	4.09	8.80	7.92
2012/13	13.19	29.05[A]	3.56	3.62	3.90	7.96	7.17
2013/14	12.85	27.12[A]	3.90	3.99	4.56	7.07	6.36
2014/15		24.69[B]				6.82	6.14

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

Status and catch specifications (millions of lb) for Bristol Bay red king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	30.0	72.0 [A]	14.84	14.91	17.00	23.52	
2011/12	30.4	68.1 [A]	7.83	7.95	9.01	19.39	17.46
2012/13	29.1	64.0 [A]	7.85	7.98	8.59	17.55	15.80
2013/14	28.3	59.9 [A]	8.60	8.80	10.05	15.58	14.02
2014/15		54.4 [B]				15.04	13.53

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

Additional Plan Team comments

The model scenario 4nb that the CPT selected as its preferred model for status determination and OFL setting, was the result of a previous CPT request to the author to evaluate a model that estimates catchability for the NMFS trawl surveys as an alternative model to the 2013 model (i.e., the base model scenario 4na that was reviewed for this assessment).

The CPT noted that, at its May 2014 meeting, it asked that a model allowing for higher natural mortality during 2006−2010 not be brought for consideration as a 2014 stock assessment model. The SSC in June 2014, however, requested that such a model be investigated further for presentation in September 2014, if time permits. The author obliged with a presentation of model scenario 4n7. The CPT noted that model scenario 4n7 appears to result in improved model fits, but feels that this model scenario should not be used for stock assessment until a plausible mechanism for the estimated higher natural mortality during 2006−2010 has been identified.

3 Eastern Bering Sea Tanner crab

Fishery information relative to OFL setting.

Eastern Bering Sea (EBS) Tanner crabs are caught in a directed Tanner crab fishery, and as bycatch in the groundfish fisheries, scallop fisheries, the directed Tanner crab fishery (mainly as non-retained females and sublegal males), and other crab fisheries (notably, eastern Bering Sea snow crab and, to a lesser extent, Bristol Bay red king crab). A single OFL is set for Tanner crab in the EBS. Under the Crab Rationalization Program, ADF&G sets separate TACs for directed fisheries east and one west of 166° W longitude. NMFS declared this stock overfished in 1999 and the Council developed a rebuilding plan. Both fisheries were closed from 1997 to 2004 due to low abundance. In 2005/06, abundance increased to a level to support a fishery in the area west of 166° W. longitude. ADF&G opened both fisheries for the 2006/07 to 2008/09 crab fishing years, and to the area east of 166° W longitude only in 2009/10. In 2007, NMFS determined the stock was rebuilt because spawning biomass was above the proxy for B_{MSY} for two consecutive years. The mature male biomass was, however, estimated to be below the Minimum Stock Size Threshold (0.5B_{MSY}) in February 2010 (the assumed time of mating) based on trends in mature male biomass from the survey, and NMFS declared the stock overfished in September 2010. The directed fisheries were closed again in 2010/11 and 2011/12 crab fishery years, and remained closed in the 2012/13 crab fishery year. NMFS determined the stock was not overfished in 2012 based on a new assessment model with a revised estimate of B_{MSY}. The fishery was opened for the 2013/14 season with a Guideline Harvest Levels (GHLs) of 1,645,000 lb (746.2 t) for the area west of 166 deg. W and at 1,463,000 lb (663.6 t) for the area east of 166 deg. W.

Data and assessment methodology

A stock assessment model is used for the EBS Tanner crab. The SSC accepted the model for use in harvest specifications in 2012 and classified it as a Tier 3 stock. The current model structure, based on crab size, sex, shell condition, and maturity, is the same as in the 2013 assessment. The model uses available information on the magnitude and size-composition of: landings and discards by the directed fishery; bycatch in the Bristol Bay red king crab, EBS snow crab, and groundfish fisheries; and the NMFS trawl survey. The model includes prior distributions on parameters related to natural mortality and catchability, and penalties on changes in recruitment and in the proportion maturing. New input data were added for the 2014 assessment, and much of the previous data were recalculated and updated. In particular, retained size frequencies in the directed fishery were recalculated for 1990/91–2009/10 and updated for 2013/14. Effort data in the crab fisheries was recalculated for 1990/91–2012/13 to improve apportionment among fisheries and updated for 2013/14. The bycatch time series from crab fisheries' observer data were recalculated for 1992/93–2012/13, as were annual total at-sea size compositions. The time series of Tanner crab bycatch in the groundfish fisheries were recalculated for 2009/10–2012/13, updated to 2013/14, using SOA statistical reporting areas to expand groundfish observer data to unobserved catch. Bycatch size frequencies in the groundfish fisheries were recalculated for 1973/74–2012/13 based on the crab fishing year (July 1–June 30) rather than the groundfish year (Jan. 1–Dec. 1). Abundance, biomass and size frequency estimates from the 2014 NMFS EBS bottom trawl survey were also added to the assessment.

The major change to the assessment methodology this year is consideration of a handling mortality value of 0.321 in the crab fisheries vs. the default value of 0.500.

Stock biomass and recruitment trends

The MMB peaked in the mid-1970s and early 1990s; MMB at the time of mating was highest early in the modeled period (February 1972; 352.5 thousand t), with secondary peaks in February 1989 (70.6 thousand t) and February 2009 (71.6 thousand t). Estimated MMB subsequently declined. The MMB in February 2015 is estimated to be 63.8 thousand t compared to 53.1 thousand t in February 2014 based on the previous assessment. Recruitment is estimated to have peaked before 1974, the first year for which survey data are included in the assessment. Subsequent peaks in recruitment occurred during 1985 through 1987 and 2009 through 2010. Estimated recruitment fell dramatically in 2011 and 2012, but has increased over the past two years to 187.9 million males in 2014.

Tier determination/Plan Team discussion and resulting OFL and ABC determination

The team recommends the OFL for this stock be based on the Tier 3 control rule. Application of the Tier 3 control rule requires a set of years for defining R_{MSY}, the mean recruitment corresponding to B_{MSY} under prevailing environmental conditions. The CPT previously recommended that R_{MSY} be set to the mean recruitment from 1990 onwards based on an analysis of the relationship between log(R/MMB) and MMB that identified a change in this relationship in 1985 (1990 year of recruitment to the model). The SSC subsequently recommended that the years from 1982 onwards be used, corresponding to a change in 1977. This recommendation was based on various considerations, including the reliability of the earlier recruitment estimates, and the identification of the late 1970s as a period of rapid ecological change in the EBS.

The model scenario which incorporated the CPT's recommended discard mortality was unable to estimate selectivity during the 1997-2004 time period for male bycatch in the snow crab fishery (Model Alt1b). A new model based on a re-parameterization of selectivity in the snow crab fishery was developed by the author during the CPT meeting (Model Alt4b). This model successfully addressed the problem of estimating selectivity in the snow crab fishery and was the recommended model by the CPT. Results from the model scenario are presented in an appendix to the SAFE chapter.

Based on the estimated biomass at 15 February 2015, the stock is at Tier 3 level a. The F_{MSY} proxy ($F_{35\%}$) is 0.61 yr^{-1}, and the 2014/15 is F_{OFL}=0.61 yr^{-1} under the Tier 3 OFL Control Rule, which results in a total male and female catch of 31.48 thousand t. The team had previously recommended that the ABC be adjusted over three year period due to the major change in stock status, and concern about the stability of assessment model and the uncertainty of the OFL estimate. The NMFS bottom trawl survey showed an increase in male mature biomass and a decrease in female biomass in 2014, but the stock appears to be healthy. Therefore the team considered it appropriate to make the final step incremental to the ABC. However the CPT recommends a 20% buffer to account for model uncertainty and stock productivity uncertainty be applied to the OFL, to give an ABC = 25.18 thousand t.

Status and catch specifications (1000 t) for eastern Bering Sea Tanner crab.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2010/11	41.67	26.73[A]	0	0	0.87	1.45	
2011/12	11.40	58.59[A]	0	0	1.24	2.75	2.48
2012/13	16.77	59.35[A]	0	0	0.71	19.02	8.17
2013/14	16.98	72.70[A]	1.41	1.26	2.78	25.35	17.82
2014/15		63.8[B]				31.48	25.18

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

Status and catch specifications (million lb) for eastern Bering Sea Tanner crab.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2010/11	91.87	58.93 [A]	0.00	0.00	1.92	3.20	
2011/12	25.13	129.17 [A]	0.00	0.00	2.73	6.06	5.47
2012/13	36.97	130.84 [A]	0.00	0.00	1.57	41.93	18.01
2013/14	37.43	160.28[A]	3.12	2.78	6.13	55.89	39.29
2014/15		140.66 [B]				69.40	55.51

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

4 Pribilof Islands red king crab

Fishery information relative to OFL setting

The Pribilof Islands red king crab fishery began in 1973 as bycatch during the blue king crab fishery. The directed red king crab fishery opened with a specified GHL for the first time in September 1993. Beginning in 1995, combined Pribilof Islands red and blue king crab GHLs were established. Declines in crab abundance of both king crab stocks from 1996 to 1998 resulted in poor fishery performance during those seasons with annual harvest levels below the GHLs. The Pribilof red king crab fishery was closed from 1999 through 2013/14 due to uncertainty in estimated red king crab survey abundance and concerns for incidental catch and mortality of Pribilof blue king crab which was an overfished and severely depressed stock. Prior to the closure, the 1998/99 harvest was 246.9 t (0.544 million lb). The non-retained catches, with application of bycatch mortality rates, from pot and groundfish bycatch estimates of red king crab ranged from 1.2 t (0.003 million lb) to 192.1 t (0.424 million lb) during 1991/92 to 2012/14.

Data and assessment methodology

The 2014 assessment is based on trends in male mature biomass (MMB) at the time of mating inferred from NMFS bottom trawl survey from 1975-2014 and commercial catch and observer data from 1973/74 to 2013/14. The revised time-series of historical NMFS trawl survey abundance estimates were used in this assessment. The 2013/14 non-retained catch from all non-directed pot and groundfish fisheries were included in the SAFE report, incorporating the updated data set for observed groundfish fisheries which aggregates data on crab catch by species to the level of the respective stock area; prior to 2009, bycatch data are aggregated over all crab species by federal reporting area.

Two assessment methods were presented for evaluation: one calculated an annual index of MMB derived as the 3-yr running average centered on the current year MMB and weighted by the inverse variance; and a new integrated length-based assessment model which was reviewed by the CPT and SSC in the spring of 2014. While the 3-yr running average fit the survey data better than the integrated assessment model results, the integrated assessment incorporates additional data including length composition data and was seen as an improvement over the running average. The Crab Plan Team recommended using the biomass estimated derived from the integrated assessment model for setting the 2014/15 harvest specifications. Natural mortality was used as a proxy for F_{MSY} and a proxy for B_{MSY} was calculated by averaging MMB from the 1991/92 through the current season.

Stock biomass and recruitment trends

The stock exhibited widely varying mature male and female abundances during 1975-2014. Using the integrated assessment, the MMB estimated for 2014 was 2,239 t (4.94 million lb). Retained catches have not occurred since the 1998/99 season. Mature stock biomass (both males and females) increased in 2000/01 and has declined slightly in recent years. The estimated recruitment is very poor during recent years (2003 – present) and there does not seem to be a relationship between female mature biomass and recruitment at 4, 5, or 6 year lags, although this stock may not be well sampled by the NMFS survey. Non-directed discard losses in the pot fisheries decreased in recent years, and there are no discard losses in the current year. Bycatch losses resulting from the fixed gear groundfish fleet using the new dataset have ranged from 0.12 t (264 lb) in 2012/13 to 0.45 t (992 lb) in 2010/11, while losses resulting from discards in the groundfish trawl fleet ranged from 12,980 t (28.62 million lb) in 2012/13 to 1.05 t (0.002 million lb) in 2009/10.

Tier determination/Plan Team discussion and resulting OFL and ABC determination

The author recommended and the CPT agreed that this stock should remain in Tier 4 for stock status level determination. For 2014/15 the $B_{\text{MSY proxy}}$ = 2,754 t of $\text{MMB}_{\text{mating}}$ derived as the mean of 1991/92 to 2013/14. Male mature biomass at the time of mating for 2013/14 was estimated at 2.239 t. The $B/B_{\text{MSY Proxy}}$ =0.81 and F_{OFL}=0.18. $B/B_{\text{MSY Proxy}}$ is < 1, therefore the stock status level is *b*. For the 2014/15 fishery, the OFL was estimated at 320 t (0.71 million lb) of crab.

The maxABC, estimated using a p-star of 0.49, was 311 t (0.69 million lb). The author did not provide a recommendation to set the ABC below the maximum permissible. The CPT felt that additional uncertainty was warranted given the comparatively low amount of information available for Pribilof Island red king crab. Moving from a three-year weighted average calculation of MMB to an integrated assessment reduced the amount of uncertainty in this assessment. Therefore, the CPT recommended a 15% buffer (down from 20% the previous year) from the OFL be used to set the ABC at 272 t (0.60 million lb).

Status and catch specifications (t) of Pribilof Islands red king crab

Year	MSST	Biomass ($\text{MMB}_{\text{mating}}$)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	2,255	2,754^{A}	0	0	4.2	349	
2011/12	2,571	2,775^{A*}	0	0	5.4	393	307
2012/13	2,609	4,025^{A**}	0	0	13.1	569	455
2013/14	2,582	4,679^{A**}	0	0	2.25	903	718
2014/15	2,754	2,239^{B***}				320	272

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.
*2011/12 estimates based on 3 year running average
**estimates based on weighted 3 year running average using inverse variance
***estimates based on integrated length-based assessment

Status and catch specifications (million lb) of Pribilof Islands red king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	4.97	6.07^{A}	0	0	0.009	0.77	
2011/12	5.67	6.12^{A*}	0	0	0.011	0.87	0.68
2012/13	5.75	8.87^{A**}	0	0	0.029	1.25	1.00
2013/14	5.66	10.32^{A**}	0	0	0.005	1.99	1.58
2014/15	6.07	4.94^{B***}				0.71	0.60

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.
*2011/12 estimates based on 3 year running average
**estimates based on weighted 3 year running average using inverse variance
***estimates based on integrated length-based assessment

The stock was above MSST in 2013/14 and is hence not overfished. Overfishing did not occur during the 2013/14 fishing year.

5 Pribilof Islands blue king crab

Fishery information relative to OFL setting.

The Pribilof blue king crab fishery began in 1973, with peak landings of 11.0 million lb during the 1980/81 season. A steep decline in landings occurred after the 1980/81 season. Directed fishery harvest from 1984/85 until 1987/88 was annually less than 1.0 million lb with low CPUE. The fishery was closed from 1988/89 through 1994/95 fishing seasons. The fishery reopened from 1995/96 to 1998/99 seasons. Fishery harvests during this period ranged from 1.3 to 2.5 million lb. The fishery closed again for the 1999/00 season due to declining stock abundance and has remained closed through the 2013/14 season. The stock was declared overfished in 2002.

A revised rebuilding plan was submitted for review by the Secretary of Commerce in 2013 as NMFS determined that the stock was not rebuilding in a timely manner and would not meet the rebuilding horizon of 2014; the revised rebuilding plan is still under review. This rebuilding plan closes the Pribilof Island Habitat Conservation Zone to Pacific cod pot fishing, which comprises the highest historical rates of bycatch of this stock. This area is already closed to groundfish trawl fishing.

Data and assessment methodology

NMFS conducts an annual trawl survey to produce area-swept abundance estimates. The CPT has discussed the history of the fishery and the rapid decline in abundance. It is clear that the stock has collapsed, although the annual area-swept abundance estimates are imprecise.

The calculation of the 2014/15 survey biomass uses the stock area definition established in 2012/13 that includes an additional 20 nm strip east of the Pribilof District. MMB was estimated using a three-year running average centered on the current year weighted by the inverse variance of the area-swept estimate. Groundfish bycatch data for blue king crab from 2009/10 – 2013/14 used SOA statistical areas which provided greater resolution than previous data. The time series of the Pribilof Islands stock area utilizing SOA statistical areas resulted in significantly different estimates of blue king crab bycatch biomass in 2009/2010-2012/2013 than previously reported. In 2013/2014, using the new estimation method, 0.03 t of male and female blue king crab bycatch mortality were attributed to fixed gear (hook-and-line) and none to trawl gear. The targeted species in these fisheries were Pacific cod (99.2%), and yellowfin sole, flathead sole and sablefish each less than 1%.

Stock biomass and recruitment trends

The estimated mature-male biomass decreased to 225 t in 2013/14 from 579 t in 2012/13. The 2014/15 MMB at mating is projected to be 218 t, which is 5% of the proxy for B_{MSY}. The Pribilof blue king crab stock biomass continues to be low. From recent surveys there is no indication of recruitment.

Tier determination/Plan Team discussion and resulting OFL and ABC determination

This stock is recommended for placement into Tier 4. B_{MSY} was estimated using the time periods 1980/81 -1984/85 and 1990/91-1997/98. This range was chosen because it eliminates periods of extremely low abundance that may not be representative of the production potential of the stock. B_{MSY} is estimated at 4,022 t (8.82 million pounds).

Because the projected 2014/15 estimate of MMB is less than 25% B_{MSY}, the stock is in stock status c and the directed fishery F is 0. However, an F_{OFL} must be determined for the non-directed catch. Ideally this should be based on the rebuilding strategy. For this stock the F_{OFL} is based on average groundfish bycatch between 1999/00 and 2005/06. The recommended OFL for 2013/14 is 1.16 t (0.003 million lb).
The CPT recommended setting the ABC less than the maximum permissible by employing a 25% buffer

on the OFL. This recommendation was based upon continuing concerns with stock status and consistency with relative buffer levels for other stocks for which the OFL is based upon average catch.

Status and catch specifications (t) of Pribilof Islands blue king crab in recent years.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	2,105	286[A]	Closed	0	0.18	1.81	
2011/12	2,247	365[A]	Closed	0	0.36	1.16	1.04
2012/13	1,994	579[A]	Closed	0	0.61	1.16	1.04
2013/14	2,001	278 [A]	Closed	0	0.03	1.16	1.04
2014/15		218 [B]				1.16	0.87

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

Status and catch specifications (million lb) of Pribilof Islands blue king crab in recent years.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	4.64	0.63[A]	Closed	0	0.0004	0.004	
2011/12	4.95	0.80[A]	Closed	0	0.0008	0.003	0.002
2012/13	4.39	1.28[A]	Closed	0	0.0013	0.003	0.002
2013/14	4.41	0.61[A]	Closed	0	0.0001	0.003	0.002
2014/15		0.48 [B]				0.003	0.0019

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

The total catch for 2013/14 (0.03 t, 0.0001 million lb) was less than the 2013/14 OFL (1.16 t, 0.003 million lb) so overfishing did not occur during 2013/14. The 2014/15 projected MMB estimate of 218 t (0.48 million lb) is below the proxy for MSST (MMB/B_{MSY} = 0.05) so the stock continues to be in an overfished condition and failed to rebuild within the maximum required rebuilding time.

6 St. Matthew blue king crab

Fishery information relative to OFL setting

The fishery was prosecuted as a directed fishery from 1977 to 1998. Harvests peaked in 1983/84 when 9.454 million lb were landed by 164 vessels. Harvest was fairly stable from 1986/87 to 1990/91, averaging 1.252 million lb annually. Harvest increased to a mean catch of 3.297 million lb during the 1991/92 to 1998/99 seasons until the fishery was declared overfished and closed in 1999 when the stock size estimate was below the MSST. In November of 2000, Amendment 15 to the FMP was approved to implement a rebuilding plan for the St. Matthew Island blue king crab stock. The rebuilding plan included a harvest strategy established in regulation by the Alaska Board of Fisheries, an area closure to control bycatch, and gear modifications. In 2008/09 and 2009/10, the MMB was estimated to be above B_{MSY} for two years and the stock declared rebuilt in 2009.

The fishery re-opened in 2009/10 with a TAC of 1.167 million lb and 0.461 million lb of retained catch were harvested. The 2010/11 TAC was 1.600 million lb and the fishery reported a retained catch of 1.264 million lb. The 2011/12 harvest of 1.881 million lb represented 80% of 2.539 million lb TAC. In 2012/13, by contrast, harvesters landed 99% (1.616 million lb) of a reduced TAC of 1.630 million lb, though fishery efficiency, at about 10 crab per pot, was little changed from what it had been in each of the previous three years. The directed fishery was closed in 2013/14 due to declining trawl survey estimates of abundance and concerns about the health of the stock. Bycatch of non-retained blue king crab has been observed in the St. Matthew blue king crab fishery, the eastern Bering Sea snow crab fishery, and trawl and fixed-gear groundfish fisheries. Based on limited observer data, bycatch of sublegal male and female crabs in the directed blue king crab fishery off St. Matthew Island was relatively high when the fishery was prosecuted in the 1990s, and total bycatch (in terms of number of crabs captured) was often twice as high or higher than total catch of legal crabs.

Data and assessment methodology

A three-stage catch-survey analysis (CSA) is used to assess the male crab ≥90 mm CL. The three size categories are: 90–104 mm CL; 105–119 mm CL; and ≥120 mm CL. Males ≥ 105 are used as a proxy to identify mature males, and males ≥ 120 mm CL are used as a proxy to identify legal males. The CSA incorporates the following data: (1) commercial catch data from 1978/79 -1998/99, 2009/10- 2012/13; (2) annual trawl survey data from 1978 to 2014; (3) triennial pot survey data from 1995 to 2013; (4) bycatch data in the groundfish trawl and groundfish fixed-gear fisheries from 1991 to 2014; and (5) ADF&G crab-observer composition data for the years 1990/91–1998/99, 2009/10–2012/13. Trawl survey data are from summer trawl survey for stations within the St. Matthew Section. Trawl survey data provided estimates of density (number/nm^2) at each station for males in the three size categories. The pot survey data originate from the ADF&G triennial pot surveys that occurred during July and August in 1995, 1998, 2001, 2004, 2007, 2010 and 2013. The pot survey samples areas of high-relief habitat important to blue king crab (particularly females) that the NMFS trawl survey cannot sample. Data used are from only the 96 stations fished in common during each of the five pot survey years. The CPUE (catch per pot lift) indices from those 96 stations for the male categories listed above were used in the assessment.

Groundfish discard information for trawl and fixed gear is estimated from NMFS observer data. Bycatch composition data were not available so total biomass caught as bycatch was estimated by summing blue king crab biomass from federal reporting areas 524 and 521 according to gear type.

Stock biomass and recruitment trends

The 2014 assessment estimates that the stock is currently below the proxy for $B_{\mathrm{MSY},}$ as it was in the previous year. The MMB has fluctuated substantially over three periods, increasing during 1978 to 1981 of the first period from 7.6 million lb to 17.6 million lb, followed by a steady decrease to 2.9 million lb in

1985. The second period had a steady increase from 1986 to 13.3 million lb in 1997 followed by a rapid decline to 2.8 million lb in 1999. The third period starting in 2000 had a steady increase in all size classes and peaked at 14.77 million lb in 2010/2011 before declining to 6.29 million lb in 2012/2013.

Tier determination/Plan Team discussion and resulting OFL and ABC determination

The stock assessment examines four model configurations: 1) the base model used previously; 2) the base model with time-varying trawl-survey selectivity (Model S); 3) the base model with alternative stage-transition matrix (Model T); and 4) the base model with both modifications above (Model ST). These modifications were added to address concerns previously raised by the CPT and SSC. The author recommended use of the fourth model. Model comparisons suggest that the modified models fit the trawl-survey-index better than the base model and that the author-recommended model fits the trawl survey composition data better than the base model and two other formulations. The CPT expressed concerns with time varying selectivity, as no mechanism was identified to explain this variability and concerns were raised that it was fitting sampling error. Some plan team members regarded the selectivity patterns to be implausible, especially selectivities > 1 for the stage-2 crab. However, others commented that it could be possible given crab movement and the mismatch between survey-station location and crab distribution. As a result, the CPT selected the base model with an alternative stage-transition matrix (Model T) because the selectivities were reasonable (i.e. < 1 for stage-2 crab) unlike the previous base model. However, the CPT noted that this model still has poor fits to stage composition data and a retrospective pattern.

The CPT-recommended model uses the full assessment period (1978/79-2013/14) to define the proxy for B_{MSY} in terms of average estimated MMB_{mating} with gamma (γ)=1 and an instantaneous natural mortality 0.18^{-1} year. The MMB estimated for 2013/14 under the recommended model is 6.71 million lb (3,040 t) and the F_{MSY} proxy is taken equal to the assumed instantaneous natural mortality rate (0.18^{-1} year), resulting in a mature male biomass OFL of 0.940 million lb (426 t). The author recommended and the CPT concurred with a 20% buffer on the OFL for the ABC because of additional uncertainty in the model. This same approach was used last year. The ABC based on 20% buffer is 0.752 million lb (341 t).

Status and catch specifications (1000 t) of St. Matthew blue king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL*	ABC
2010/11	1.5	6.70[A]	0.73	0.57	0.64	1.04	
2011/12	1.5	5.03[A]	1.15	0.85	0.95	1.70	1.50
2012/13	1.8	2.85[A]	0.74	0.73	0.82	1.02	0.92
2013/14	1.5	3.04[A]	0	0	0.00027	0.56	0.45
2014/15	1.8	3.04 [B]				0.43	0.34

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.*Total male catch only

Status and catch specifications (millions lb) of St. Matthew blue king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL*	ABC
2010/11	3.4	14.77[A]	1.60	1.26	1.41	2.29	
2011/12	3.4	11.09[A]	2.54	1.88	2.10	3.31	3.40
2012/13	4.0	6.29[A]	1.63	1.62	1.81	2.24	2.02
2013/14	3.4	6.71[A]	0	0	0.0006	1.24	0.99
2014/15	3.9	6.71[B]				0.94	0.75

The total male catch for 2013/14 (0.00 million lb) was less than the 2013/14 OFL (1.24 million lb) so overfishing did not occur during 2013/14. Likewise, the 2013/14 MMB (6.71 million lb) is above the MSST (3.9 million lb) so the stock is not in an overfished condition.

Additional Plan Team recommendations

The CPT requested further investigation of the time-varying selectivity, including further explanation/investigation of plausible explanations. Research needs include better molting probability information for the two smaller stages (of the three used in the model).

7 Norton Sound Red King Crab

Fishery information relative to OFL setting

This stock supports three main fisheries: summer commercial, winter commercial, and winter subsistence. The summer commercial fishery, which accounts for the majority of the catch, reached a peak in the late 1970s at a little over 2.9 million pounds retained catch. Retained catches since 1982 have been below 0.5 million pounds, averaging 0.3 million pounds, including several low years in the 1990s. As the crab population rebounded, retained catches have increased somewhat to around 0.4 million pounds in recent years

Data and assessment methodology

Four types of surveys have occurred periodically during the last three decades: summer trawl, summer pot, winter pot, and preseason summer pot, but none of these surveys have been conducted every year. To improve abundance estimates, a male-only length-based model of male crab abundance was previously developed that combines multiple sources of data. A maximum likelihood approach was used to estimate abundance, recruitment, and selectivity and catchability of the commercial pot gear. The model has been updated with the following data: 1980–2012 winter pot survey, and 2013/2014 winter commercial and subsistence catches. In addition, the 1976–2011 trawl survey data were revised, but with no new years of data available (the next survey is scheduled for 2014). The current model assumes a constant $M=0.18yr^{-1}$, except for a fixed value of $0.648yr^{-1}$ for the largest length class. Logistic functions are used to describe fishery and survey selectivities, except for a dome-shaped function examined for the winter pot fishery.

The author summarized six model run alternatives, with the base model (Model 0) and alternatives originating from the 2014 modeling workshop. The CPT selected Model 2io as the recommended configuration based on: separate selectivities for NMFS and ADF&G trawl surveys; inclusion of winter survey data as a means of informing the winter fishery harvest,(although this had negligible impact on model results); and estimation of a growth matrix inside the model (separated for newshell and oldshell crab).

Stock biomass and recruitment trends

Mature male biomass was estimated to be at an historic low in 1982 following a crash from the peak biomass in 1977. The MMB then exhibited an upward trend from a recent low in 1997 to a peak in 2010, before declining in recent years. Estimated recruitment was weak during the late 1970s and high during the early 1980s, with a slight downward trend from 1983 to 1993. Estimated recruitment has been variable but with a slight increase in recent years.

Tier determination/Plan Team discussion and resulting OFL and ABC determination

The team recommended Tier 4, stock status b, for Norton Sound red king crab. For the recommended Model 2io, the author presented stock status information for retained catch. Model-based total catch estimates were provided, however, these estimates were model-generated from limited observer data and the team did not recommend their use in generating a total catch OFL. Thus the OFL and ABC are based on retained catch (only).

The estimated abundance and biomass in 2014 using model 2io are:
Mature male biomass: 3.71 million lb with a standard deviation of 0.64 million lb.

The $B_{MSY\ \mathrm{proxy}}$, calculated as the average of mature male biomass during 1980-2014, was $B_{MSY\ \mathrm{proxy}} = 4.19$

million lb. The $F_{MSY\ \mathrm{proxy}}$ is M =0.18 yr^{-1} and the F_{OFL}=0.157yr^{-1}, because the 2014 mature male biomass is less than $B_{MSY\ \mathrm{proxy}}$ with the CPT choosing the default of gamma =1.0, is.

The maximum permissible ABC would be 0.463 million lb, based on retained catch. The CPT recommended an ABC less than the maximum permissible due to concerns with model specification, lack of bycatch data as well as issues noted with the M employed for the largest length group. The CPT recommended an ABC = 90% of the OFL (10% buffer) of 0.417 million pounds.

Status and catch specifications (1000 t) of Norton Sound red king crab

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2010/11	0.71	2.47	0.18	0.19	0.22	0.33	
2011/12	0.71	2.13	0.16	0.18	0.20	0.30	0.27
2012/13	0.81	2.08	0.21	0.21	0.21	0.24	0.22
2013/14	0.93	2.16	0.23	0.16	0.16	0.26	0.24
2014/15	0.96	1.68	TBD	TBD	TBD	0.21	0.19

Status and catch specifications (million lb) of Norton Sound red king crab

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2010/11	1.56	5.44	0.40	0.42	0.46	0.73	
2011/12	1.56	4.70	0.36	0.40	0.43	0.66	0.59
2012/13	1.76	4.59	0.47	0.47	0.47	0.53	0.48
2013/14	2.06	5.00	0.50	0.35	0.35	0.58	0.52
2014/15	2.11	3.71	TBD	TBD	TBD	0.46	0.42

Total catch in 2013/14 did not exceed the OFL for this stock thus overfishing is not occurring. The stock biomass is above MSST; thus, the stock is not overfished.

Additional Plan Team recommendations

The CPT has the following recommends for the next assessment:

- construct a likelihood profile for M for all size classes vs. a single M for the largest size class and a separate M for the remaining classes;
- explore different weighting schemes for the tag data.

Due to the availability of survey and catch data, the assessment cannot be finalized for the September CPT cycle as planned. Thus the CPT recommends finalizing the assessment at a mid-year meeting (see CPT report for more details).

8 Aleutian Islands Golden King Crab

Fishery information relative to OFL setting

The directed fishery has been prosecuted annually since the 1981/82 season. Retained catch peaked in 1986/87 at 14.7 million lb and averaged 11.9 million lb over the 1985/86-1989/90 seasons. Average harvests dropped sharply from 1989/90 to 1990/91 to a level of 6.9 million lb for the period 1990/91–1995/96. Management based on a formally established GHL began with the 1996/97 season. The 5.9 million lb GHL established for the 1996/97 season, which was based on the previous five-year average catch, was subsequently reduced to 5.7 million lb beginning in 1998/99. The GHL (or TAC, since 2005/06) remained at 5.7 million lb for 2007/08, but was increased to 6.0 million lb for the 2008/09-2011/12 seasons, and to 6.3 million lb for the 2012/13 and 2013/2014 seasons. Average annual retained catch for the period 1996/97–2007/08 was 5.6 million lb, and 6.0 million lb for the period 2008/09-2012/13. The retained catch for 2012/13 was 6.3 million lb. This fishery is rationalized under the Crab Rationalization Program. The 2013/14 season ends by regulation on 15 May 2013.

Non-retained bycatch occurs mainly in the directed fishery, and to a minor extent in other crab fisheries. Bycatch also occurs in fixed-gear and trawl groundfish fisheries although that bycatch is low relative to the weight of bycatch in the directed fishery. Total annual non-retained catch of golden king crab during crab fisheries has decreased relative to the retained catch since the 1990s. It decreased from 13.8 million lb in 1990/91 (199% of the retained catch) to 9.1 million lb in 1996/97 (156% of the retained catch), and to 4.3 million lb in the 2004/05 season (78% of the retained catch). Bycatch in the post-rationalized fishery (2005/06-2012/13) has ranged from 2.5 million lb in 2005/06 (46% of the retained catch) to just over 3.0 million lb for 2007/08 (55% of the retained catch). Bycatch mortality has correspondingly decreased since 1996/97 both in absolute weight and relative to the retained catch weight. Estimated total mortality (retained catch plus bycatch in crab and groundfish fisheries) ranged from 5.8-9.4 million lb over 1995/96–2012/13. Estimated total mortality in 2012/13 was 6.9 million lb.

Data and assessment methodology

Available data used in the Tier 5 assessment are from ADF&G fish tickets (retained catch numbers, retained catch weight, and pot lifts by ADF&G statistical area and landing date), size-frequencies from samples of landed crabs, at-sea observations from pot lifts sampled during the fishery (date, location, soak time, catch composition, size, sex, and reproductive condition of crabs, etc.), and bycatch estimates from the groundfish fisheries. These data are available through the 2012/13 season; complete data from the 2013/14 fishery season, which ends on 15 May 2014, are not currently available. Most of the available data were obtained from the fishery which targets legal-size (≥6-inch CW) males and trends in the data can be affected by changes in both fishery practices and the stock. Data from triennial pot surveys (last performed in 2006) in the Yunaska-Amukta Island area of the Aleutian Islands, approximately 171° W longitude, and tag recoveries from crabs released during the triennial pot surveys are also available, but are not included in the Tier 5 assessment. The triennial survey is too limited in geographic scope and too infrequent to provide a reliable index of abundance for the Aleutian Islands area. A new survey as well as an assessment model are currently being developed for this stock.

Stock biomass and recruitment trends

Although a stock assessment is in development, it has not yet been accepted for use in management. There are consequently no estimates of stock biomass. Estimates of recruitment trends and current levels relative to virgin or historic levels are also not available.

Summary of major changes

Fishery data have been updated with the results for 2012/13: retained catch for the directed fishery and bycatch estimates for the directed fishery, non-directed crab fisheries, and groundfish fisheries.

Tier determination/Plan Team discussion and resulting OFL and ABC determination

The CPT recommends that this stock be managed as a Tier 5 stock in 2014/15. B_{MSY} and MSST are not estimated for this stock. Observer data on bycatch from the directed fishery and groundfish fisheries provides the estimate of total bycatch mortality. Bycatch data from the directed fishery for years after the 1990/91 season (excluding 1993/94 and 1994/95 seasons due to insufficient data) and from the groundfish fisheries since the 1993/94 season were used. There are no directed fishery observer data prior to the 1988/89 season and observer data are lacking or confidential for four seasons in at least one management area in the Aleutian Islands during 1988/89–1994/95.

This assessment author recommended using the same approach for determining the 2014/15 total catch OFL as was used to determine the 2013/14 total catch OFL. This approach uses data for 1985/86–1995/96 to estimate the mean retained catch in the crab fisheries, and bycatch data for 1990/91-95/96 to estimate the mean bycatch rate (0.363):

$$OFL_{2013/14} = (1+R_{90/91\text{-}95/96}) \bullet RET_{85/86\text{-}95/96} + BM_{GF,93/94\text{-}08/09} = 12{,}537{,}757 \text{ lb}$$

where,

- $R_{90/91\text{-}95/96}$ is the average of the annual ratios of bycatch mortality due to crab fisheries to retained catch in pounds over the period of the subscripted years, excluding 1993/94–1994/95 due to data confidentiality and lack of data,
- $RET_{85/86\text{-}95/96}$ is the average annual retained catch in the directed crab fishery over the period 1985/86-1995/96), and
- $BM_{GF,93/94\text{-}08/09}$ is the average of the annual estimates of bycatch mortality due to groundfish fisheries over the period 1993/94-2008/09.

The assessment author recommended a 25% buffer between the OFL and ABC, which is an increase over the 10% buffer used in recent years. The author noted that the time-period used to determine the OFL for Tier 5 stocks should be representative of a stock's productivity. In the past, the CPT has suggested various time ranges to compute the OFL, which suggests uncertainty regarding the time-period to represent productivity and the basis for setting the OFL. The assessment author noted that the ABC for the Tier 5 Adak red king crab stock is based on a 40% buffer, and three of the six FMP stocks that are surveyed by the EBS bottom trawl survey have buffers >10%. The CPT agreed that there is more uncertainty than is accommodated by a 10% buffer; however, the CPT agreed that uncertainty estimation issues should be more comprehensively addressed in the September CPT meeting and thus recommended the status quo 10% buffer for 2014/15 for this stock. The CPT recommended ABC is 11,283,981 lb.

Status and catch specifications (1000 t) of Aleutian Islands golden king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC
2010/11	N/A	N/A	2.72	2.71	2.98	5.02	N/A
2011/12	N/A	N/A	2.72	2.71	2.95	5.17	4.66
2012/13	N/A	N/A	2.85	2.84	3.12	5.69	5.12
2013/14	N/A	N/A	2.85	2.89	3.19	5.69	5.12
2014/15	N/A	N/A	2.85			5.69	4.26

a. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.

Status and catch specifications (million lb) of Aleutian Islands golden king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC
2010/11	N/A	N/A	5.99	5.97	6.56	11.06	N/A
2011/12	N/A	N/A	5.99	5.96	6.51	11.40	10.26
2012/13	N/A	N/A	6.29	6.27	6.87	12.54	11.28
2013/14	N/A	N/A	6.29	6.38	7.04	12.54	11.28
2014/15	N/A	N/A	6.29			12.53	9.40

a. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.

Overfishing did not occur during 2013/14 because the estimated total catch did not exceed the Tier 5 overfishing limit (OFL) of 12.54-million lb (5.69 thousand t). The total catch did not exceed the ABC established for 2013/14 (11.28-million lb, or 5.12 thousand t). The OFL and ABC values for 2014/15 in the table below are the values recommended by the SSC in June 2014. The 2014/15 TAC was established by ADF&G on 15 July 2014. The TACs for 2013/14 and 2014/15 in the table below do not include landings towards a cost-recovery fishing goal of $300,000 to cover costs of observer deployments in the fishery; the catch totals for 2013/14 do include the catch towards the 2013/14 cost-recovery fishery.

Additional Plan Team recommendations

The CPT reviewed progress on the assessment model for Aleutian Islands golden king crab. Detailed comments and recommendations for the model are contained in the CPT report. The team intends to further review this model at the January 2015 modeling workshop.

9 Pribilof District Golden King Crab

Fishery information relative to OFL setting

The Pribilof District fishery for male golden king crab developed in the 1982/83 season. The directed fishery mainly occurs in Pribilof Canyon of the continental slope. Peak directed harvest is 0.856-million lb (388 t) during the 1983/84 season by 50 vessels. Following the close of the 1983/84 season, since then, fishery participation has been sporadic and retained catches vary from 0 to 0.342-million lb (155 t). The current fishing season is based on a calendar year and the 2014 season is ongoing. The fishery is not rationalized and there is no SOA harvest strategy. A guideline harvest level (GHL) was first established for the fishery in 1999 at 0.200-million lb (91 t) and has been managed with a GHL of 0.150-million lb (68 t) since 2000. No directed fishery occurred during 2006–2009. One vessel landed catch in 2010, two vessels landed catch in 2011, and one vessel landed catch in each of 2012 and 2013. Catch and other fishery data from the directed fishery for those four years cannot be reported under the confidentiality requirements of the SOA. Non-retained bycatch occurs in the directed golden king crab fishery and can occur in the eastern Bering Sea snow crab fishery, Bering Sea grooved Tanner crab fishery, and Bering Sea groundfish fishery. Estimated total fishing mortality during 2001-2013 due to directed and non directed crab fisheries range from 0 to 0.160- million lb (73 t). Crab mortality in groundfish fisheries range from < 0.001 - million lb (< 1t) to 0.027-million lb (12 t) during 1991/92-2012/13.

Data and assessment methodology

Total golden king crab biomass has been estimated during the NMFS upper-continental-slope trawl surveys in 2002, 2004, 2008, 2010 and 2012. The survey scheduled for 2014 was cancelled, precluding a survey-based approach for establishing an OFL for 2015. The estimated total stock biomass for the entire slope survey area and the Pribilof Canyon have been estimated independently by the NMFS and ADFG. The estimates from the 2012 survey range 4.244 – 4.475 million lb (1925-2030 t) for the whole upper continental slope and 1.567 – 1.716 million lb (711 -778 t) for the Pribilof Canyon area.

There is no assessment model for this stock. Fish ticket and observer data are available (including retained catch numbers, retained catch weight, and pot lifts by statistical area and landing date), size-frequency data from samples of landed crabs, and pot lifts sampled during the fishery (including date, location, soak time, catch composition, size, sex, and reproductive condition of crabs, etc.), and from the groundfish fisheries. Much of the directed fishery data are confidential due to low number of participants.

Stock biomass and recruitment trends

Using the size-sex composition data from the slope surveys, the estimated mature male biomass in the entire survey area have increased slightly from 1.692 million lb (767 t) in 2010 to 1790 million lb (812 t) in 2012. However, estimated mature male biomass in the Pribilof canyon area has decreased markedly from 0.970 million lb (440 t) in 2010 to 0.565 million lb (256 t) in 2012.

Tier determination/Plan Team discussion and resulting OFL and ABC determination

The Team recommends this stock be managed under Tier 5 in 2015.

The assessment author presented only one alternative for establishing the OFL. The Team concurs with the author's recommendation for the 2015 OFL based on the same analysis as the 2014 OFL of 0.2 million lb and the maximum permissible ABC of 0.15 million lb. The ABC was derived by applying the Tier 5 control rule a 25% buffer of the OFL, ABC = 0.75 * OFL. The 2015 OFL calculation formula is the same as recommended by the SSC for 2012−2014:

$OFL_{2015} = (1+R_{2001–2010})*RET_{1993-1998} + BM_{NC,1994-1998} + BM_{GF,1992/93–1998/99}$

where,

- $R_{2001–2010}$ is the average of the estimated annual ratio of lb of bycatch mortality to lb of retained in the directed fishery during 2001–2010
- $RET_{1993-1998}$ is the average annual retained catch in the directed crab fishery during 1993–1998
- $BM_{NC,1994-1998}$ is the estimated average annual bycatch mortality in non-directed crab fisheries during 1994–1998
- $BM_{GF,1992/93–1998/99}$ is the estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99.

Status and catch specifications (t) of Pribilof District golden king crab

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2011	N/A	N/A	68	Conf.	Conf.	82	N/A
2012	N/A	N/A	68	Conf.	Conf.	91	82
2013	N/A	N/A	68	Conf.	Conf.	91	82
2014	N/A	N/A	68			91	82
2015	N/A	N/A				91	68

N/A = not available

Conf. = confidential

Status and catch specifications (millions lb) of Pribilof District golden king crab

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2011	N/A	N/A	0.15	Conf.	Conf.	0.18	N/A
2012	N/A	N/A	0.15	Conf.	Conf.	0.20	0.18
2013	N/A	N/A	0.15	Conf.	Conf.	0.20	0.18
2014	N/A	N/A	0.15			0.20	0.18
2015	N/A	N/A	0.15			0.20	0.15

N/A = not available

Conf. = confidential

10 Adak red king crab, Aleutian Islands

Fishery information relative to OFL and ABC setting

The domestic fishery has been prosecuted since 1960/61 and was opened every season through the 1995/96 season. Since 1995/96, the fishery was opened only in 1998/99, and from 2000/01-2003/04. Peak harvest occurred during the 1964/65 season with a retained catch of 21.19 million lb. During the early years of the fishery through the late 1970s, most or all of the retained catch was harvested in the area between 172° W longitude and 179° 15' W longitude. As the annual retained catch decreased into the mid-1970s and the early-1980s, a large portion of the retained catch came from the area west of 179° 15' W longitude.

Retained catch during the 10-year period, 1985/86 through 1994/95, averaged 0.94 million lb, but the retained catch during the 1995/96 season was low, only 0.04 million lb. There was an exploratory fishery with a low guideline harvest level (GHL) in 1998/99; three Commissioner's permit fisheries in limited areas during 2000/01 and 2002/03 to allow for ADF&G-Industry surveys, and two commercial fisheries with a GHL of 0.50 million lb during the 2002/03 and 2003/04 seasons. Most of the catch since the 1990/91 season was harvested in the Petrel Bank area (between 179° W longitude and 179° E longitude) and the last two commercial fishery seasons (2002/03 and 2003/04) were opened only in the Petrel Bank area. Retained catches in those two seasons were 0.51 million lb (2002/03) and 0.48 million lb (2003/04). The fishery has been closed since the end of the 2003/04 season.

Non-retained catch of red king crabs occurs in both the directed red king crab fishery (when prosecuted), in the Aleutian Islands golden king crab fishery, and in groundfish fisheries. Estimated bycatch mortality during the 1995/96-2012/13 seasons averaged 0.002 million lb in crab fisheries and 0.019 million lb in groundfish fisheries. Estimated annual total fishing mortality (in terms of total crab removal) during 1995/96-2012/13 averaged 0.091 million lb. The average retained catch during that period was 0.070 million lb. This fishery is rationalized under the Crab Rationalization Program only for the area west of 179° W longitude. Bycatch in 2012/13 was 196 lb in crab fisheries and 428 lb in groundfish fisheries (total catch 624 lb).

Data and assessment methodology

The 1960/61-2007/08 time series of retained catch (number and pounds of crabs), effort (vessels, landings and pot lifts), average weight and average carapace length of landed crabs, and catch-per-unit effort (number of crabs per pot lift) are available. Bycatch from crab fisheries during 1995/96-2012/13 and from groundfish fisheries during 1993/94-2012/13 are available. There is no assessment model for this stock. The standardized surveys of the Petrel Bank area conducted by ADF&G in 2006 and 2009 and the ADF&G-Industry Petrel Bank surveys conducted in 2001 have been too limited in geographic scope and too infrequent for reliable estimation of abundance for the entire western Aleutian Islands area.

Stock biomass and recruitment trends

Estimates of stock biomass are not available for this stock. Estimates of recruitment trends and current levels relative to virgin or historic levels are not available. The fishery has been closed since the end of 2003/04 season due to apparent poor recruitment. An ADF&G-Industry survey was conducted as a commissioner's permit fishery in the Adak-Atka-Amlia Islands area in November 2002 and provided no evidence of recruitment sufficient to support a commercial fishery. A pot survey conducted by ADF&G in the Petrel Bank area in 2006 provided no evidence of strong recruitment. A 2009 survey conducted by ADF&G in the Petrel Bank area encountered a smaller, ageing population with the catch of legal male crab occurring in a more limited area and at lower densities than were found in the 2006 survey and provided no expectations for recruitment. A test fishery conducted by a commercial vessel during October-December 2009 in the area west of Petrel Bank yielded only one legal male red king crab.

Tier determination/Plan Team discussion and resulting OFL and ABC determination

The CPT recommends that this stock be managed under Tier 5 for the 2014/15 season. The CPT concurs with the assessment author's recommendation of an OFL based on the 1995/96–2007/08 average total catch following the recommendation of the SSC in June 2010 to freeze the time period for computing the OFL at 1995/96–2007/08. The CPT recommends an OFL for 2014/15 of 0.12 million lb.

The Team continues to have concerns regarding the depleted status of this stock. Groundfish bycatch in recent years has accounted for the majority of the catch of this stock. The maximum permissible ABC is 0.11 million lb based on the Tier 5 control rule of a 10% buffer on the OFL.

The CPT recommends an ABC of 0.074 million lb for 2014/15, which is below the maximum permissible ABC (maxABC = 0.11 million lb). Industry has expressed interest in past years in an exploratory fishery around the Adak area based on anecdotal information that there may be legal crab available in this stock. Industry chose not to conduct a test fishery in 2012/13 and no such test fishery has been scheduled to date for 2014.

Status and catch specifications (1000 t) of Adak (WAI) red king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch[a]	Total Catch[a]	OFL	ABC
2010/11	N/A	N/A	Closed	0	2	54	N/A
2011/12	N/A	N/A	Closed	0	1	54	12
2012/13	N/A	N/A	Closed	0	<1	54	32
2013/14	N/A	N/A	Closed	0	<1	54	32
2014/15	N/A	N/A	Closed			54	32

Status and catch specifications (millions lb) of Adak (WAI) red king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch[a]	Total Catch[a]	OFL	ABC
2010/11	N/A	N/A	Closed	0	0.004	0.12	N/A
2011/12	N/A	N/A	Closed	0	0.002	0.12	0.03
2012/13	N/A	N/A	Closed	0	<0.001	0.12	0.07
2013/14	N/A	N/A	Closed	0	<0.001	0.12	0.07
2014/15	N/A	N/A	Closed			0.12	0.07

a Includes bycatch mortality of discarded bycatch.

Overfishing did not occur during 2013/14; the estimated total catch did not exceed the Tier 5 OFL of 0.12-million lb (56 t). The total catch did not exceed the ABC established for 2013/14 (0.7-million lb, or 34 t). The OFL and ABC values for 2014/15 in the tables below are the values recommended by the SSC in June 2014.

Additional Plan Team discussion

The plan team discussed the history of catch of the stock in continuing to recommend the status quo ABC. A State of Alaska Board of Fisheries meeting in March 2014 divided the area into two management districts: 1) west of 179 degrees W longitude and 2) 171 to 179 degrees W longitude. Pot limits were established at 10 pots per vessel in SOA waters and 15 pots in federal waters. The season open date was changed from October 15 to August 1 and federal waters would be closed when the GHL is less than 250,000 lb (113 t).

Figures and Tables

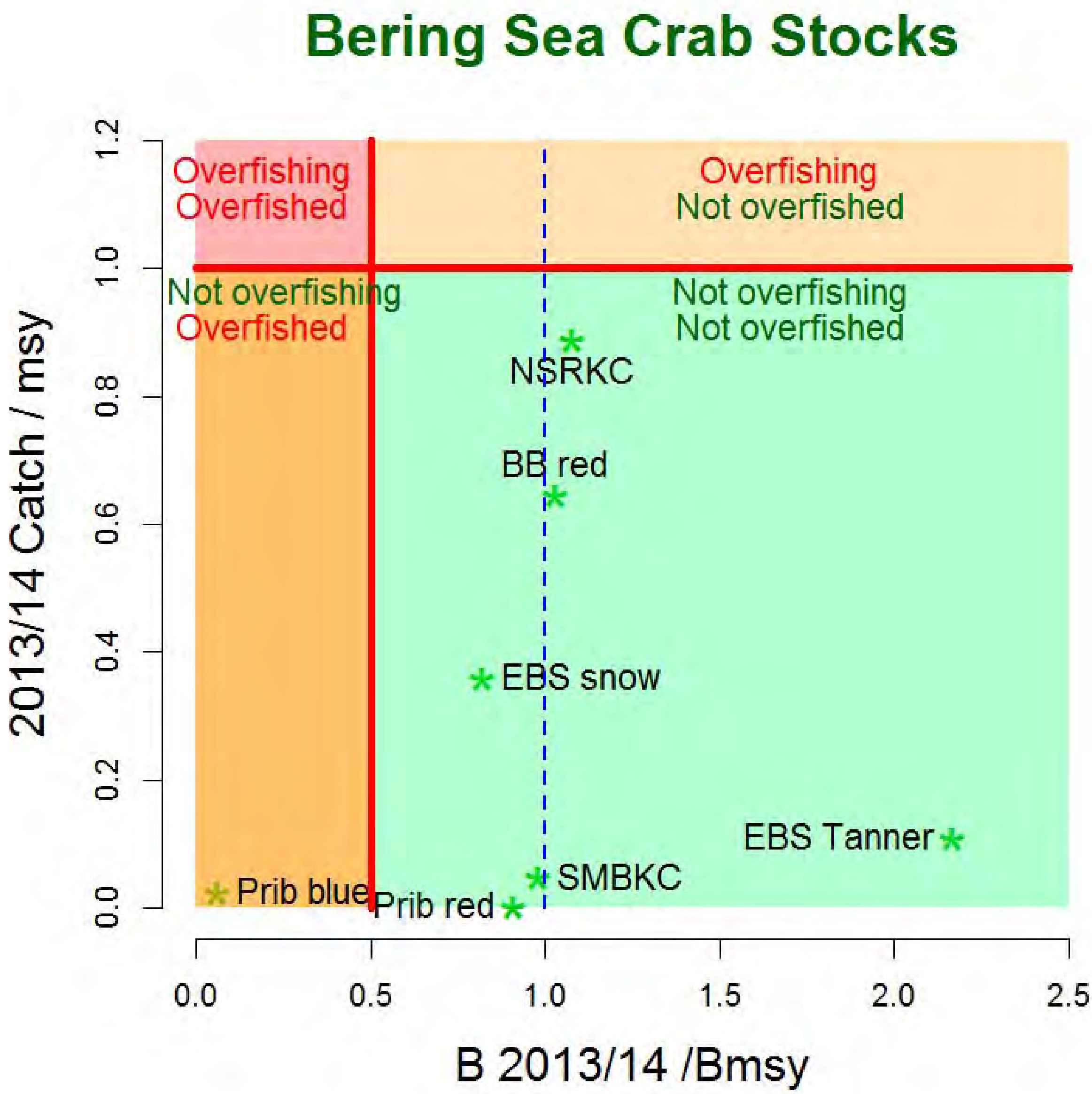

Figure 1. Status of 7 Bering Sea crab stocks in relation to status determination criteria (B_{MSY}, MSST, overfishing). Note that information is insufficient to assess Tier 5 stocks according to these criteria (WAIRKC, AIGKC, PIGKC).

Table 3 Crab Plan Team recommendations for September 2014 (stocks 1-7). Note that recommendations for stocks 7,9, 10 represent those final values recommended by the SSC in June 2014. Note diagonal fill indicates parameters are not applicable for that tier

Chapter	Stock	Tier	Status (a,b,c)	F_{OFL}	B_{MSY} or $B_{MSYproxy}$	Years[1] (biomass or catch)	2014/15[2 3] MMB	2014 MMB / MMB_{MSY}	γ	Mortality (M)	2014/15 OFL	2014/15 ABC	ABC buffer (%)
1	EBS snow crab	3	b	1.34	142.9	1979-current [recruitment]	137.6	0.96		0.23(females) 0.386 (imm) 0.2613 (mat males)	69.0	62.1	10%
2	BB red king crab	3	b	0.28	25.7	1984-current [recruitment]	24.69	0.96		0.18 default Estimated[4]	6.82	6.14	10%
3	EBS Tanner crab	3	a	0.61	29.82	1982-current [recruitment]	63.8	2.14		0.34 (females), 0.25 (mat male), 0.247 (imm males and females)	31.48	25.18	20%
4	Pribilof Islands red king crab	4	b	0.18	2.75	1991-current	2.24	0.81	1.0	0.18	0.32	0.27	15%
5	Pribilof Islands blue king crab	4	c	0	4.00	1980-1984 1990-1997	0.22	0.05	1.0	0.18	0.00116	0.00087	25%
6	St. Matthew Island blue king crab	4	b	0.18	7.78	1978-current	3.04	0.86	1.0	0.18	0.43 [total male catch]	0.34 [total male catch]	20%
7	Norton Sound red king crab	4	b	0.157	1.9	1980-current [model estimate]	1.68	0.88	1.0	0.18 0.68 (>123 mm)	0.21	0.19	10%
8	Aleutian Islands golden king crab	5				See intro chapter					5.69	4.26	25%
9	Pribilof Islands golden king crab	5				See intro chapter					0.09	0.07	25%
10	Adak red king crab	5				1995/96–2007/08					0.05	0.03	40%

1 For Tiers 3 and 4 where B_{MSY} or $B_{MSYproxy}$ is estimable, the years refer to the time period over which the estimate is made. For Tier 5 stocks it is the years upon which the catch average for OFL is obtained.
2 MMB as projected for 2/15/2015 at time of mating.
3 Model mature biomass on 7/1/2013.
4 Additional mortality males: two periods-1980-1985; 1968-1979 and 1986-2013. Females three periods: 1980-1984; 1976-1979; 1985 to 1993 and 1968-1975; 1994-2013. See assessment for mortality rates associated with these time periods.

Table 4 Maximum permissible ABCs for 2014/15 and Crab Plan Team recommended ABCs for those stocks where the Plan Team recommendation is below the maximum permissible ABC as defined by Amendment 38 to the Crab FMP. Note that the rationale is provided in the individual introduction chapters for recommending an ABC less than the maximum permissible for these stocks. Recommendations for Adak red king crab represent the final values recommended by the SSC in June 2014.

Stock	Tier	2014/15 *Max*ABC (1000 t)	2014/15 ABC (1000 t)
EBS Snow Crab	3a	68.8	62.1
Bristol Bay red king crab	3b	6.82	6.14
Tanner Crab	3a	31.43	25.18
Pribilof Islands red king crab	4b	0.311	0.027
Pribilof Islands blue king crab	4c	0.00116	0.00087
Saint Matthew blue king crab	4b	0.94	0.75
Aleutian Islands golden king crab	5	5.12	4.26
Pribilof Islands golden king crab [1]	5	0.08	0.07
Norton Sound red king crab	4b	0.21	0.19
Adak red king crab	5	0.05	0.03

1 for Pribilof Islands golden king crab this is for the 2015 calendar year instead of the 2014-2015 crab fishing year.

Table 5. Stock status in relation to status determination criteria 2013/14. (Note diagonal fill indicates parameters not applicable for this tier level).

Chapter	Stock	Tier	MSST	B_{MSY} or $B_{MSYproxy}$	2013/14[1] MMB	2013/14 MMB / MMB_{MSY}	2013/14 OFL 1000 t	2013/14 Total catch	Rebuilding Status
1	EBS snow crab	3	71.50	143.00	126.50	0.88	78.1	28.1	
2	BB red king crab	3	12.85	25.70	27.12	1.06	7.07	4.56	
3	EBS Tanner crab	3	16.98	33.96	72.70	2.14	25.35	2.78	
4	Pribilof Islands red king crab	4	2.58	5.16	4.68	0.91	0.90	0.0023	
5	Pribilof Islands blue king crab	4	2.00	4.00	0.28	0.07	0.00116	0.00003	overfished
6	St. Matthew Island blue king crab	4	1.55	3.1	3.04	0.98	0.56 [total male catch]	0.027 [total male catch]	
7	Norton Sound red king crab	4	1.0	2.0	2.16	1.08	0.18 [total male]	0.16	
8	Aleutian Islands golden king crab	5					5.69	3.19	
9	Pribilof Islands golden king crab	5					0.09	Conf.	
10	Adak red king crab	5					0.054	0.001	

1 MMB as estimated during this assessment for 2013/14 as of 2/15/2014.

Stock Assessment of eastern Bering Sea snow crab

Benjamin J. Turnock and Louis J. Rugolo
National Marine Fisheries Service
September 18, 2014

EXECUTIVE SUMMARY

1. Stock: species/area.

A size based model was developed for eastern Bering Sea snow crab (*Chionoecetes opilio*) to estimate population biomass and harvest levels.

2. Catches: trends and current levels

Catch trends historically followed survey abundance estimates of large males, as the survey estimates were the basis for calculating the GHL (Guideline Harvest Level for retained catch). A TAC is currently set (starting in 2009) by ADFG using the ADFG harvest strategy. Retained catches increased from about 3,040 t at the beginning of the directed fishery in 1973 to a peak of 149,110 t in 1991, declined thereafter, then increased to another peak of 110,410 t in 1998. Retained catch in the 1999/2000 fishery was reduced to 15,200 t due to the low abundance estimated by the 1999 survey. A harvest strategy (Zheng et al. 2002) was developed using a earlier generation simulation model that pre-dated the current stock assessment model. This early generation model has been used to set the GHL (TAC since 2009) since the 2000/01 fishery. Retained catch in the 2013/14 fishery decreased to 24,480 t from the 2012/13 fishery retained catch of 30,060 t. The total catch in the 2013/14 fishery was estimated at 28,200 t (30% mortality on directed discards) below the OFL of 78,100 t. Discard in the directed fishery was 12,090 t in 2013/14, an increase from 7,350 t (no mortality applied) in 2012/13.

Estimated discard mortality (mostly undersized males and old shell males) in the directed pot fishery has averaged about 31% (no mortality applied) of the retained catch biomass since 1992 when observers were first placed on crab vessels. Discards prior to 1992 were estimated based on fishery selectivities estimated for the period with observer data and the full selection fishing mortality estimated using the retained catch and retained fishery selectivities.

3. Stock Biomass:

Model estimates of total mature biomass of snow crab increased from the early 1980's to a peak in 1990 of about 1,005,600 t. The total mature biomass includes all sizes of mature females and morphometrically mature males. The stock was declared overfished in 1999 due to the survey estimate of total mature biomass (149,900 t) being below the minimum stock size threshold (MSST = 208,710 t). A rebuilding plan was implemented in 2000. Subsequently, the assessment model structure was changed and the currency for estimating B_{MSY} changed during the 10 year rebuilding period from total mature survey biomass to model estimated mature male biomass at mating (MMB). Using the current definitions for estimating B_{MSY}, MMB at mating was above B35% in 2010/11 and the stock was declared rebuilt in 2011. The total mature observed survey biomass in 2011 was 447,400 t which was also above the Bmsy(418,150 t) in place under the rebuilding plan implemented in 2000. The increase in total mature biomass was mainly due to a large increase in observed female mature biomass in 2011.

Observed survey mature male biomass decreased from 120,800 t in 2012 to 96,100 t in 2013, then increased to 156,900 t in 2014. Observed survey mature female biomass also decreased from 220,600 t in 2012 to 195,100 t in 2013, then increased to 212,500 t. The estimate of males greater than 101 mm decreased from 87.0 million in 2012 to 73.6 million in 2013, then increased to 138.5 million in 2014.

Base model estimates of mature male biomass at mating decreased from 129,700 t in 2011/12 to 109,100 t in 2012/13 then increased to 126,500 t in 2013/14 (89% of B35% (142,909 t)).

4. Recruitment

Recruitment was at or above average in 2004 and 2005 (lag 5 years) which has resulted in increasing biomass in the female mature stock and in 2014 in increasing male mature stock. Recruitment estimates in 2008 and 2009 were just above average.

5. Management

Historical status and catch specifications for snow crab (1000t).

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	73.7	196.6[A]	24.6	24.7	26.7	44.4	
2011/12	77.3	165.2[B]	40.3	40.5	44.7	73.5	66.2[E]
2012/13	77.1	170.1[C]	30.1	30.1	32.4	67.8	61.0[E]
2013/14	71.5	126.5[D]	24.5	24.5	28.1	78.1	70.3[E]
2014/15		137.6[D]				69.0	62.1[E]

Historical status and catch specifications for snow crab (millions of lb.).

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	162.5	433.4 [A]	54.2	54.5	58.9	97.9	
2011/12	170.4	364.2 [B]	88.8	89.3	98.5	162.0	145.8
2012/13	169.9	374.9 [C]	66.3	66.3	71.4	149.5	134.5
2013/14	157.7	279.0[D]	54.0	54.0	62.0	172.1	154.9
2014/15		303.5[D]				152.2	137.0

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2011
B– Calculated from the assessment reviewed by the Crab Plan Team in September 2012
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2013
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2014
E – 10% Buffer recommended by SSC

6. Basis for the OFL

The OFL for 2014/15 for the Base model was 69,000 t fishing at F_{OFL} = 1.34, a decrease from the 2013/14 OFL of 78,100 t. The MMB at mating projected for 2014/15 when fishing at the F35% control rule (OFL) was 96.3% of B35%.

7. Probability Density Function of the OFL

   The ABC (P*=.49) was estimated from the PDF of the OFL with a cv = 0.08 on beginning biomass estimated from the hessian. The projection model used to estimate the PDF is description is included in this assessment in a later section.

8. Basis for ABC

The ACL was estimated at 68,810 t using a p*=0.49. The total catch estimated at 90% of OFL (the ACL recommended by the SSC for 2013/14) was 62,100 t. The MMB projected for 2014/15 when fishing at 90% of the OFL catch was 100.3% of B35%. B35% for the Base model was estimated at 142,909 t and F35% was estimated at 1.40. MMB at mating for 2013/14 was estimated at 126,500 t above the estimated MMST of 71,455 t.

A. Summary of Major Changes

Changes to the Data

2014 Bering Sea survey biomass and length frequency data added to the model. 2013/14 directed fishery retained and discard catch and length frequencies for retained and discard catch were added to the model. Groundfish discard length frequency and discard catch from 2013/14 were added to the model.

Changes to the Assessment Methodology

The base model in the current assessment differs from the September 2013 base model in fitting a two part linear function with a smooth transition to the 2011 growth data, recommended in the 2014 CIE review (Cadigan 2014) and by the CPT and SSC. Nine model scenarios are presented in this assessment: 1) The September 2013 model (Model 0, one linear function fit to growth data), 2) two linear functions with a fixed intersection fit to growth data (Model 1), 3) Two linear functions with a smooth transition fit to growth data (Model 2a, Cardgan 2014), 4) same as 3 with factor of 2 times on growth likelihood (Model 2b, Base model for this assessment), 5) same as 3 with factor of 3 times on growth likelihood (Model 2c), 6) same as 3 with 0.5 weight on fishing penalties likelihood (Model 2d, weights relative to base model), 7) same as 3 with 0.25 weight on fishing penalties likelihood (Model 2e) 8) same as 3 with 0.1 weight on fishing penalties likelihood (Model 2f), 9) same as 3 with 0.001 weight on penalties on fishing mortality likelihood (Model 2g).

Model 2b was selected as the base model for this assessment because it uses the smooth transition for growth and the weight of 2 on the likelihood fits growth data much better than weight of 1, while a higher weight (3) does not improve the fit to growth data while degrading other fits.

Changes to Assessment Results
See above

CPT May 2014 Recommendations for next assessment:

*For the September 2014 stock assessment, the CPT would like to see Model 0 (*September 2013 base model*), Model 1 (*two linear lines with fixed intersection) *and Model 0 with Cadigan-recommended growth parameterization. If the model converges, then they would also like to see the model with fishing penalties removed.*

The model uses empirically-derived proportion mature data from the chela height measurements from 1989-2007 (new shell males only). For females, the actual proportion mature is used. The CPT would like to see further analyses of the existing data and evaluate how these data are used in the model. This topic could be considered at a future model/data workshop.

The CPT requested that the data used in the models for the September 2014 assessment be updated with the data set provided by Bob Foy (catch, bycatch, and survey data) to ensure use of the most up-to-date data.

Authors response

Model scenarios include all CPT recommended models. Survey data used in all the model scenarios are the most up-to-date data. No new analysis on male chela height data are presented in this assessment due to time constraints, new analysis is planned for May 2015.

SSC Recommendations June 2014:

***For the September assessment the SSC agrees with the CPT recommendations that Model 0 go forward along with a Model 1 scenario with an alternative parameterization of the growth model that is continuous and differentiable. The SSC has the following additional recommendations**:*

1) *Conduct additional sensitivity analyses on the penalties to constrain fishing mortality rate deviations and their impacts on biological reference points.*
2) *Investigate direct integration of the chela height data into the assessment model.*
3) *Explore time varying maturity options and potential environmental covariates as an explanation for the observed variability in male maturity-at-length.*

The SSC further requests detailed information on the new length-frequency information to be considered for use in the stock assessment model and details regarding the re-analysis of the landed-length composition data. Lastly, the SSC requests that the author provide a rationale for the various weightings used in the likelihood composition. Specifically, the SSC asks whether inverse variance weighting was used and how the effective sample size was determined for the length composition data.

Authors response

Model scenarios include all SSC recommended models, except no new analysis on male chela height data and time varying maturity are presented in this assessment. New analyses are planned for May 2015. Data weighting is not addressed in this assessment, this will be addressed in future assessments.

INTRODUCTION

Snow crab (*Chionoecetes opilio*) are distributed on the continental shelf of the Bering Sea, Chukchi Sea, and in the western Atlantic Ocean as far south as Maine. In the Bering Sea, snow crab are common at depths less than about 200 meters. The eastern Bering Sea population within U.S. waters is managed as a single stock; however, the distribution of the population may extend into Russian waters to an unknown degree.

FISHERY HISTORY

Snow crab were harvested in the Bering Sea by the Japanese from the 1960s until 1980 when the Magnuson Act prohibited foreign fishing. Retained catch in the domestic fishery increased in the late 1980's to a high of about 149,110 t in 1991, declined to 29,820 t in 1996, increased to 110,410 t in 1998 then declined to 15,200 t in the 1999/2000 fishery (Table 1, Figure 1). Due to low abundance and a reduced harvest rate, retained catches from 2000/01 to 2006/07 ranged from a low of about 10,860 t to 16,780 t. In the 2013/14 fishery retained catch was 24,480 t and total catch was estimated at 28,200 t (0.3 mortality for pot fishery discard and 0.8 mortality for groundfish discard). Total catch in 2011/12 to 42,000 t and in 2012/13 32,400 t.

Discard from the directed pot fishery was estimated from observer data since 1992 and ranged from 11% to 64% (average 33%) of the retained catch of male crab biomass (Table 1). Female discard catch is very low and not a significant source of mortality. In 1991/92 trawl discard was about 1,950 t (no mortality applied), increased to about 3,550 t in 1994/95, then declined and ranged between 900 t and 1,500 t until 1998/99. Trawl bycatch in 2012/13 and 2013/14 was 220 t and 120 t respectively. Discard of snow crab in groundfish fisheries from highest to lowest is the yellowfin sole trawl fishery, flathead sole trawl fishery, Pacific cod bottom trawl fishery, rock sole trawl fishery and the Pacific cod hook and line and pot fisheries.

Size frequency data and catch per pot have been collected by observers on snow crab fishery vessels since 1992. Observer coverage was 10% on catcher vessels larger than 125 ft (since 2001), and 100% coverage on catcher processors (since 1992).

The average size of retained crabs has remained fairly constant over time ranging between 105 mm and 118 mm, and most recently about 110 mm to 111 mm. The percent new shell animals in the catch has varied between 69% (2002 fishery) to 98% (1999), and was 87% for the 2005/6 fishery and 93% in the 2007/8 fishery. In the 2007/8 fishery 94% of the new shell males >101mm CW were retained, while 78% of the old shell males >101mm CW were retained. Only 3% of crab were retained between 78mm and 101 mm CW. The average weight of retained crab has varied between 0.5 kg (1983-1984) and 0.73 kg (1979), and 0.59 kg in the recent fisheries.

Several modifications to pot gear have been introduced to reduce bycatch mortality. In the 1978/79 season, pots used in the snow crab fishery first contained escape panels to prevent ghost fishing. Escape panels consisted of an opening with one-half the perimeter of the tunnel eye laced with untreated cotton twine. The size of the cotton laced panel to prevent ghost fishing was increased in 1991 to at least 18 inches in length. No escape mechanisms for undersized crab were required until the 1997 season when at least one-third of one vertical surface had to contain not less than 5 inches stretched mesh webbing or have no less than four circular rings of no less than 3 3/4 inches inside diameter. In the 2001 season the escapement for undersize crab was increased to at least eight escape rings of no less than 4 inches placed within one mesh measurement from the bottom of the pot, with four escape rings on each side of the two sides of a four-sided pot, or one-half of one side of the pot must have a side panel composed of not less than 5 1/4 inch stretched mesh webbing.

Harvest rates

The harvest rate used to set the GHL (Guideline Harvest Level of retained crab only) previous to 2000 was 58% of the number of male crab over 101 mm carapace width estimated from the survey. The minimum legal size limit for snow crab is 78 mm, however, the snow crab market generally accepts animals greater than 101 mm. In 2000, due to the decline in abundance and the declaration of the stock as overfished, the harvest rate for calculation of the GHL was reduced to 20% of male crab over 101 mm. After 2000, a rebuilding strategy was developed based on simulations by Zheng (2002).

The realized retained catch typically exceeded the GHL historically, resulting in exploitation rates for the retained catch on males >101mm ranging from about 10% to 80% (Figure 3). The exploitation rate for total catch divided by mature male biomass ranged from 6% to 46% and was 18% in 2013/14.

Prior to adoption of Amendment 24, B_{MSY} (921.6 million lbs (418,150 t)) was defined as the average total mature biomass (males and females) estimated from the survey for the years 1983 to 1997 (NPFMC 1998). MSST was defined as 50% of the B_{MSY} value (MSST=460 million lbs of total mature biomass (209,074 t)). The harvest strategy since 2000/1 used a retained crab harvest rate on the mature male biomass of 0.10 on levels of total mature biomass greater than ½ MSST (230 million lbs), increasing linearly to 0.225 when biomass is equal to or greater than B_{MSY} (921.6 million lbs) (Zheng et al. 2002). The GHL was actually set as the number of retained crab allowed in the harvest, calculated by dividing the GHL in lbs by the average weight of a male crab > 101 mm. If the GHL in numbers was greater than 58% of the estimated number of new shell crabs greater than 101 mm plus 25% of the old shell crab greater than 101 mm, the GHL is capped at 58%. If natural mortality is 0.2, then this actually results in a realized exploitation rate cap for the retained catch of 66% at the time of the fishery, occurring approximately 7 months after the survey (if survey Q=1). The fishing mortality rate that results from this harvest strategy depends on the relationship between mature male size numbers and male numbers greater than 101 mm.

DATA

Data Sources

Catch data and size frequencies of retained crab from the directed snow crab pot fishery from 1978 to the 2013/14 season were used in this analysis. Observers were placed on directed crab fishery vessels starting in 1990. Size frequency data on the total catch (retained plus discarded) in the directed crab fishery were available from 1992 to 2013/14. Total discarded catch was estimated from observer data from 1992 to 2013/14 (Table 1). The discarded male catch was estimated for 1978 to 1991 in the model using the estimated fishery selectivities based on the observer data for the period 1992 to 2013/14. The discard catch estimate was multiplied by the assumed mortality of discards from the pot fishery. The mortality of discarded crab was 30% in the Base model. This estimate differs from the current rebuilding harvest strategy used since 2001 to the present by ADFG to set the TAC, which assumes a discard mortality of 25% (Zheng, et al. 2002). The discards prior to 1992 may be underestimated due to the lack of escape mechanisms for undersized crab in the pots before 1997.

The following table contains the various data components used in the model,

Data component	Years
Retained male crab pot fishery size frequency by shell condition	1978/79-2013/14
Discarded male and female crab pot fishery size frequency	1992/3-2013/14
Trawl fishery bycatch size frequencies by sex	1991-2013/2014
Survey size frequencies by sex and shell condition	1978-2014
Retained catch estimates	1978/79-2013/14
Discard catch estimates from snow crab pot fishery	1992/93-2013/14 from observer data
Trawl bycatch estimates	1973-2013/14
Total survey biomass estimates and coefficients of variation	1978-2014
2009 study area biomass estimates and coefficients of variation and length frequencies for BSFRF and NMFS tows	2009
2010 study area biomass estimates and coefficients of variation and length frequencies for BSFRF and NMFS tows	2010

Survey Biomass

Abundance is estimated from the annual eastern Bering Sea (EBS) bottom trawl survey conducted by NMFS (see Rugolo et al. 2003 for design and methods). Since 1989, the survey has sampled stations farther north than previous years (61.2^{o} N previous to 1989). In 1982 the survey net was changed resulting in a change in catchability. Juvenile crabs tend to occupy more inshore northern regions (up to about 63^{o} N) and mature crabs deeper areas to the south of the juveniles (Zheng et al. 2001).

All survey data in this assessment use measured net widths instead of a fixed 50 ft net width used in the September 2009 snow crab assessment (variable net width data were shown for comparison in the September 2009 assessment). Snow crab assessments prior to and including September 2009 used survey biomass estimates for all crab based on an assumed 50 ft net width. In 2009, Chilton et al. (2009) provided new survey estimates based on measured net width. The average measured net width for all tows in the 2009 survey was 17.08 meters which is about 112% of 50ft (15.24 meters) (Chilton et al. 2009). The 2009 mature male survey biomass was 162,890 t using the fixed 50 ft net width and 141,300 t using the measured net width for each tow. The difference between the survey male mature biomass estimates calculated with the fixed 50 ft width and the measured net width is small in the early part of the time series, and then is an average ratio of 0.86 (range 0.81 to 0.90) from 1998 to 2009.

The total mature biomass (all sizes of morphometrically mature males and females) estimated from the survey declined to a low of 82,100 t in 1985, increased to a high of 809,600 t in 1991 (includes northern stations after 1989), then declined to 140,900 t in 1999, when the stock was declared overfished (Table 3 and Figure 4). The mature biomass increased in 2000 and 2001, mainly due to a few large catches of mature females. The survey estimate of total mature biomass increased from 245,000 t in 2009 to 447,400 t in 2011, declined to 291,200 t in 2013, then increased to 369,400 t in 2014.

Survey mature male biomass decreased from 167,400 t in 2011 to 96,100 t in 2013, then increased to 156,900 t in 2014. The observed survey estimate of males greater than 101 mm decreased from150.7 million in 2011 to 73.6 million in 2013, then increased to 138.9 million in 2014 (Table 3). Survey mature female biomass decreased from 280,000 t in 2011to 195,100 t in 2013, then increased to 212,500 t in 2014.

The term mature for male snow crab in this assessment means morphometrically mature. Morphometric maturity for males refers to a marked change in chelae size (thereafter termed "large claw"), after which males are assumed to be effective at mating. Males are functionally mature at smaller sizes than when they become morphometrically mature, although the contribution of these "small-clawed" males to annual reproductive output is negligible. The minimum legal size limit for the snow crab fishery is 78 mm, however the size for males that are generally accepted by the fishery is >101mm. The historical quotas were based on the survey abundance of large males (>101mm).

Survey Size Composition

Carapace width is measured on snow crab and shell condition noted in the survey and the fishery. Snow crab cannot be aged at present (except by radiometric aging of the shell since last molt) however, shell condition has been used as a proxy for age. Based on protocols adopted in the NMFS EBS trawl survey, shell condition class and presumptive age are as follows: soft shell (SC1) (less than three months from molting), new shell (SC2) (three months to less than one year from molting), old shell (SC3) (two years to three years from molting), very old shell (SC4) (three years to four years form molting), and very very old shell (SC5) (four years or longer from molting). Radiometric aging of shells from terminal molt male crabs (after the last molt of their lifetime) elucidated the relationship between shell condition and presumptive age, which will be discussed in a later section (Nevissi et al 1995).

Survey abundance by size for males and females indicate a moderate level of recruitment moving through the stock and resulting in the recent increase in abundance. (Figures 6 - 8). In 2009 small crab (<50mm) increased in abundance relative to 2008. The 2010 length frequency data showed high abundance in the 40 to 50 mm range. The recruitment progressed into the mature female abundance in 2011 and also can be seen in male abundance in the 50-65mm range in 2011(Figure 8a). However, in 2012 and 2013, the progress of the recruitment is not evident. Observed survey mature biomass for both males and females declined in 2013, which has resulted in estimated recent recruitments to be lower than in previous assessments. High numbers of small crab in the late 1970's survey data did not follow through the population to the mid-1980's. The high numbers of small crab in the late 1980's resulted in the high biomass levels of the early 1990's and subsequent high catches. Moderate increase in numbers can also be seen in the mid 1990's.

Spatial distribution of catch and survey abundance

The majority of the fishery catch occurs south of 58.5° N., even in years when ice cover did not restrict the fishery moving farther north. In past years, most of the fishery catch occurred in the southern portion of the snow crab range possibly due to ice cover and proximity to port and practical constraints of meeting delivery schedules. The directed fishery catch in 2012/13 is shown in Figure 11b showing some catch from east of the Pribilof Islands, however, the majority of catch is west and north of the Pribilof Islands.

CPUE of survey catch by tow for 2012 to 2014 are shown in Figures 12 through 25h. Immature female and small male (<78mm) distributions in 2013 and 2014 are farther south than in previous years with higher tows just north of the Pribilof Islands (Figures 20, 22, 25c and 25e). Legal males (>77mm) and large males (>101mm) are distributed farther south and east of the Pribilof Islands than in previous years (Figures 19, 21, 25b and 25d). Mature females with less than or equal to half clutch of eggs were mostly in the northern part of the survey area above 58 ° N (Figures 23 and 25h).

The difference between the summer survey distribution of large males and the fishery catch distribution indicates that survey catchability may be less than 1.0 and/or some movement occurs between the summer survey and the winter fishery. However, the exploitation rate on males south of 58.5° N latitude may exceed the target rate, possibly resulting in localized depletion of males from the southern part of their range. Snow crab larvae probably drift north and east after hatching in spring. Snow crab appear to move south and west as they age, however, no tagging studies have been conducted to fully characterize the ontogenetic or annual migration patterns of this stock. High exploitation rates in the southern area may have resulted in a northward shift in snow crab distribution. The last few years of survey data indicate a shift to the south in distribution of snow crab, which reverses the trends seen in early 2000's.

Ernst, et al. (2005) found the centroids of survey summer distributions have moved to the north over time (Figures 26 and 27). In the early 1980's the centroids of mature female distribution were near 58.5 ° N, in the 1990's the centroids were about 59.5 ° N. The centroids of old shell male distribution was south of 58 ° N in the early 1980's, moved north in the late 1980's and early 1990's then shifted back to the south in the late 1990's. The distribution of males>101 mm was about at 58 ° N in the early 1980's, then was farther north (58.5 to 59 ° N) in the late 1980's and early 1990's, went back south in 1996 and 1997 then has moved north with the centroid of the distribution in 2001 just north of 59 ° N.. The centroids of the catch are generally south of 58 ° N, except in 1987. The centroids of catch also moved north in the late 1980's and most of the 1990's. The centroids of the catch were about at 56.5 ° N in 1997 and 1998, then moved north to above 58.5 ° in 2002.

2009 and 2010 Study Area Data Additional survey data

Bering Sea Fisheries Research Foundation (BSFRF) conducted a survey of 108 tows in 27 survey stations (10,827 sq nm, hereafter referred to as the "study area") in the Bering Sea in summer 2009(Figure 28, see Somerton et al 2010 for more details). The abundance estimated by the BSFRF survey in the study area was 66.9 million male crab >=100 mm compared to 36.7

million for the NMFS tows (Table 4). The NMFS abundance of females >=50mm (121.5 million) was greater than the BSFRF abundance estimate in the study area (113.6 million) (Table 4).

The abundance of male crab in the entire Bering Sea survey for 2009 was greatest in the 30 – 60mm size range (Figures 29 and 30). The abundance of crab in the 35 to 60mm size range for the BSFRF net in the study area was very low compared to the abundance of the same size range for the NMFS entire Bering Sea survey. The differences in abundance by size for the NMFS entire Bering Sea survey and the BSFRF study area are due to availability of crab in the study area as well as capture probability. While the abundance of larger male crab for the NMFS net in the study area is less than for the BSFRF, the abundance of females >45 mm is greater for the NMFS net than the BSFRF (Figure 29). This difference may be due to different towing locations for the two nets within the study area, or to higher catchability of females possibly due to aggregation behavior. The ratio of abundance of the NMFS net and BSFRF net in the study area are quite different for males and females (Figure 31). The ratio of abundance indicates a catchability for mature females (mainly 45 – 65 mm) that is greater than 1.0 for the NMFS net.

The largest tows for small (<78mm) male crab in the entire Bering Sea area were north of the study area near St. Matthew Island (Figure 12 and 20). Some higher tows for large males (>=100mm) and for mature females occurred in the study area as well as outside the study areas (Figures 5-18 and 22-24). These distributions indicate that availability of crab of different sizes and sex varies spatial throughout the Bering Sea. The numbers by length and mature biomass by sex for the BSFRF tows and the NMFS tows within the study area were added to the model as an additional survey.

The 2009 estimated snow crab abundance by length in the study area had very low numbers of both male and female crab in the 35 mm to 70 mm range than observed in the Bering sea wide survey(Figures 29 and 30). The ratio of abundance (NMFS/BSFRF) by length for 2009 was 0.2 at about 45 mm increasing gradually to 0.4 at 95mm then increasing steeply to 0.9 to 1.25 above 115 mm (Figure 31). The mean size of crab retained by the fishery is about 110 mm, with minimum size retained about 102mm. Ratios of abundance for female crab were above 1.0 from 45mm to 60mm then declined to 0.5 to 0.8 above 60mm to 80mm. There were very few female crab above 80mm in the population.

The 2010 study area covered a larger portion of the distribution of snow crab than the 2009 study area. The abundance by length for the 2010 study area is very different from the 2009 data, with higher abundance in 2010 of small crab (Figure 32). The expanded estimate (expanded to the study area) of male abundance from BSFRF data is higher than the Bering Sea wide abundance for length from 50mm to about 110mm. Female abundance shows a similar relationship (Figure 33). The ratio of male abundance by length (NMFS/BSFRF) in 2010 increased to 0.6 at 40mm then decreased to about 0.2 at 65-70mm then increased and ranged between 0.3 and 0.4 up to about 112mm (Figure 34). The ratios increased from 0.4 at 112 to about 0.7 at 122mm then to 1.55 at 132mm. The ratio of female abundance by length in 2010 was 0.6 at about 45mm and declined to 0.4 at about 67mm then declined below 0.1 above about 77mm.

Several processes influence net performance. Somerton et al. accounted for area swept, sediment type, depth and crab size. They did not correct for the probability of encountering crab. The 2010 study area data have a number of paired tows where BSFRF caught no crab (within a particular size bin) or where NMFS caught no crab. This creates problems with simply taking the ratio of catches since a number of ratios will be infinity (dividing by 0). This occurs because the paired tows although near in space were not fishing on the same density of crab. In addition, the BSFRF tow covered about 10% of the area of the NMFS tow, due to the narrower net width and the 5 minute tow duration compared to the 30 minute NMFS tow duration. In order to analyze this data, first the ratio of the NMFS density (numbers per nm^2) to the sum of the density of NMFS and BSFRF were calculated (Figure 35 males and Figure 38 females). These values range from 0 to 1.0. The simple mean of these values was estimated by length bin and then transformed to estimate mean catchability by length bin (Figure 39 males Figure 40 females). A value of 0.5 for the ratio of NMFS to sum of density is equivalent to a catchability of 1.0 and 0.33 is catchability of 0.5. The size of the catch for each observation is plotted in Figure 36 (same data as Figure 35).

The BSFRF study provides a rich data set to evaluate net performance. In this survey the sample is the paired tows and the goal would be to evaluate net performance over a wide range of densities, sediment types and depths. Somerton et al. (February 2011 Modeling Workshop) used catch to weight observations for estimation of the selectivity curve. This assumes that trawl performance is influenced by local density of crab (an untested assumption). No weighting of the observations assumes that there is no relationship between catch and the selectivity of crab. If selectivity changes depending on whether catches are high or low, then further study and analysis is needed. Further analysis needs to be done on whether data should be weighted in the initial estimation of the selectivity curve. The unweighted mean values by length bin are higher than the values estimated by Somerton et al.. Somerton weights again by survey abundance and adjusts for depth and sediment type in a separate step in the analysis to estimate a Bering Sea wide survey selectivity. Simulation studies are needed to determine the influence of weighting (whether bias is introduced) and whether the distributional assumptions and likelihood equations used in the analysis of the paired tow data are correct and unbiased.

The overall distribution of the ratio of NMFS density to the sum of the densities is skewed with about 140 - 0.0 values and 110 - 1.0 values (Figure 41). The percentage of observations where NMFS caught crab and no crab were caught by the BSFRF tow increases by size bin for male crab (Figures 41 through 46).

Catches of male crab decrease with size simply because they are lower in abundance in the population. At sizes of male crab greater than about 90 mm the fraction of observations where the ratio of NMFS density to the sum of densities was 1.0 and 1 crab was caught in the net was about 10% to 30%. In other, words the majority of the tows involved more than 1 crab caught.

The mean values of the ratio of NMFS density to the sum of densities for female crab transformed to catchability increase from less than 0.1 at 25mm to about 0.5 at 55mm then decrease slightly above 70mm (Figures 38 and 40).

Weight - Size

The weight (kg) – size (mm) relationship was estimated from survey data, where weight = a* size^b. Juvenile female a= 0.00000253, b=2.56472. Mature female a=0.000675 b=2.943352, and males, a= 0.00000023, b=3.12948 (Figure 47).

Maturity

Maturity for females was determined by visual examination during the survey and used to determine the fraction of females mature by size for each year. Female maturity was determined by the shape of the abdomen, by the presence of brooded eggs or egg remnants. The average fraction mature for female snow crab is shown in Figure 48b, although this curve is not used in the model.

Morphometric maturity for males is determined by chela height measurements, which are available starting from the 1989 survey (Otto 1998). The number of males with chela height measurements has varied between about 3,000 and 7,000 per year. In this report a mature male refers to a morphometrically mature male.

One maturity curve for males was estimated using the average fraction mature based on chela height data and applied to all years of survey data to estimate mature survey numbers (Figure 48c). The separation of mature and immature males by chela height at small widths may not be adequately refined given the current measurement to the nearest millimeter. Chela height measured to the nearest tenth of a millimeter (by Canadian researchers on North Atlantic snow crab) shows a clear break in chela height at small and large widths and shows fewer mature animals at small widths than the Bering Sea data measured to the nearest millimeter. Measurements taken in 2004-2005 on Bering Sea snow crab chela to the nearest tenth of a millimeter show a similar break in chela height to the Canadian data (Rugolo et al. 2005).

The probability of a new shell crab maturing was estimated in the model at a smooth function to move crab from immature to mature (Figure 48). The probability of maturing was estimated to match the observed fraction mature for all mature males and females observed in the survey data. The probability of maturing by size for female crab was about 50% at about 48 mm and increased to 100% at 60mm (Figure 49). The probability of maturing for male crab was about 15% to 20% at 60 mm to 90mm and increased sharply to 50% at about 98mm, and 100% at 108 mm.

Natural Mortality

Natural mortality is a critical variable in population dynamic modeling, and may have a large influence on derived optimal harvest rates. Natural mortality rates estimated in a population dynamics model may have high uncertainty and may be correlated with other parameters, and therefore are usually fixed. The ability to estimate natural mortality in a population dynamics model depends on how the true value varies over time as well as other factors (Fu and Quinn 2000, Schnute and Richards 1995).

Nevissi, et al. (1995) used radiometric techniques to estimate shell age from last molt (Table 7). The total sample size was 21 male crabs (a combination of Tanner and snow crab) from a collection of 105 male crabs from various hauls in the 1992 and 1993 NMFS Bering Sea survey. Fishing mortality rates before and during the time period when these crab were collected were relatively high, and therefore maximum age would represent Z (total mortality) rather than M. Representative samples for the 5 shell condition categories were collected that made up the 105 samples. The oldest looking crab within shell conditions 4 and 5 were selected from the total sample of SC4 and SC5 crabs to radiometrically age (Orensanz, pers comm.). Shell condition 5 crab (SC5 = very, very old shell) had a maximum age of 6.85 years (s.d. 0.58, 95% CI approximately 5.69 to 8.01 years). The average age of 6 crabs with SC4 (very old shell) and SC5, was 4.95 years. The range of ages was 2.70 to 6.85 years for those same crabs. Given the small sample size, this maximum age may not represent the 1.5% percentile of the population that is approximately equivalent to Hoenig's method (1983). Maximum life span defined for a virgin stock is reasonably expected to be longer than these observed maximum ages from exploited populations. Radiometric ages estimated by Nevissi, et al. (1995) may be underestimated by several years, due to the continued exchange of material in crab shells even after shells have hardened (Craig Kastelle, pers. comm., Alaska Fisheries Science Center, Seattle, WA).

Tag recovery evidence from eastern Canada reveal observed maximum ages in exploited populations of 17-19 years (Nevissi, et al. 1995, Sainte-Marie 2002). A maximum time at large of 11 years for tag returns of terminally molted mature male snow crab in the North Atlantic has been recorded since tagging started about 1993 (Fonseca, et al. 2008). Fonseca, et al. (2008) estimated a maximum age of 7.8 years post terminal molt using data on dactal wear.

We reasoned that in a virgin population of snow crab, longevity would be at least 20 years. Hence, we used 20 years as a proxy for longevity and assumed that this age would represent the upper 99^{th} percentile of the distribution of ages in an unexploited population if observable. Under negative exponential depletion, the 99^{th} percentile corresponding to age 20 of an unexploited population corresponds to a natural mortality rate of 0.23. Using Hoenig's (1983) method an M=0.23 corresponds to a maximum age of 18 years (Table 8). M=0.23 was used for all female crab in the model. Male natural mortality estimated in the model with a prior constraint of mean M=0.23 with a se = 0.054 estimated from using the 95% CI of +-1.7 years on maximum age estimates from dactal wear and tag return analysis in Fonseca, et al. (2008).

Molting probability

Female and male snow crab have a terminal molt to maturity. Many papers have dealt with the question of terminal molt for Atlantic Ocean mature male snow crab (e.g., Dawe, et al. 1991). A laboratory study of morphometrically mature male Tanner crab, which were also believed to have a terminal molt, found all crabs molted after two years (Paul and Paul 1995). Bering Sea male snow crab appear to have a terminal molt based on data on hormone levels (Tamone et al. 2005) and findings from molt stage analysis via setagenesis. The models presented here assume a terminal molt for both males and females.

Male Tanner and snow crabs that do not molt (old shell) may be important in reproduction. Paul et al. (1995) found that old shell mature male Tanner crab out-competed new shell crab of the same size in breeding in a laboratory study. Recently molted males did not breed even with no competition and may not breed until after about 100 days from molting (Paul et al. 1995). Sainte-Marie et al. (2002) states that only old shell males take part in mating for North Atlantic snow crab. If molting precludes males from breeding for a three month period, then males that are new shell at the time of the survey (June to July), would have molted during the preceding spring (March to April), and would not have participated in mating. The fishery targets new shell males, resulting in those animals that molted to maturity and to a size acceptable to the fishery of being removed from the population before the chance to mate. Animals that molt to maturity at a size smaller than what is acceptable to the fishery may be subjected to fishery mortality from being caught and discarded before they have a chance to mate. However, new shell males will be a mixture of crab less than 1 year from terminal molt and 1+ years from terminal molt due to the inaccuracy of shell condition as a measure of shell age.

Crabs in their first few years of life may molt more than once per year, however, the smallest crabs included in the model are probably 3 or 4 years old and would be expected to molt annually. The growth transition matrix was applied to animals that grow, resulting in new shell animals. Those animals that don't grow become old shell animals. Animals that are classified as new shell in the survey are assumed to have molted during the last year. The assumption is that shell condition (new and old) is an accurate measure of whether animals have molted during the previous year. The relationship between shell condition and time from last molt needs to be investigated further.

Mating ratio and reproductive success

Full clutches of unfertilized eggs may be extruded and appear normal to visual examination, and may be retained for several weeks or months by snow crab. Resorption of eggs may occur if not all eggs are extruded resulting in less than a full clutch. Female snow crab at the time of the survey may have a full clutch of eggs that are unfertilized, resulting in overestimation of reproductive potential. Male snow crab are sperm conservers, using less than 4% of their sperm at each mating. Females also will mate with more than one male. The amount of stored sperm and clutch fullness varies with sex ratio (Sainte-Marie 2002). If mating with only one male is inadequate to fertilize a full clutch, then females will need to mate with more than one male, necessitating a sex ratio closer to 1:1 in the mature population, than if one male is assumed to be able to adequately fertilize multiple females.

The fraction barren females and clutch fullness observed in the survey increased in the early 1990's then decreased in the mid- 1990's then increased again in the late 1990's (Figures 49 and 50). The highest levels of barren females coincides with the peaks in catch and exploitation rates that occurred in 1992 and 1993 fishery seasons and the 1998 and 1999 fishery seasons. While the biomass of mature females was high in the early 1990's, the rate of production from the stock may have been reduced due to the spatial distribution of the catch and the resulting sex ratio in areas of highest reproductive potential. The percentage of barren females was low in 2006, increased in 2007, then declined in 2008 and 2009 to below 1 percent for new and old shell females and about 17% for very old females. Clutch fullness for new shell females declined slightly in 2009 relative to 2008, however, on average is about 70% compared to about 80% before 1997. Clutch fullness for old and very old shell females was high in 2006, declined in 2007, then was higher in 2009 (about 78% old shell and 60% very old).

The fraction of barren females in the 2003 and 2004 survey south of 58.5 ^{o} N latitude was generally higher than north of 58.5 ^{o} N latitude (Figures 51 and 52). In 2004 the fraction barren females south of 58.5 ^{o} N latitude was greater for all shell conditions. In 2003, the fraction barren was greater for new shell and very very old shell south of 58.5 ^{o} N latitude.

Laboratory analysis of female snow crab collected in waters colder than 1.5 ^{o} C from the Bering Sea have been determined to be biennial spawners in the Bering Sea. Future recruitment may be affected by the fraction of biennial spawning females in the population as well as the estimated fecundity of females, which may depend on water temperature.

An index of reproductive potential for crab stocks needs to be defined that includes spawning biomass, fecundity, fertilization rates and frequency of spawning. In most animals, spawning biomass is a sufficient index of reproductive potential because it addresses size related impacts on fecundity, and because the fertilization rates and frequency of spawning are relatively constant over time. This is not the case for snow crab.

The centroids of the cold pool (<2.0 ^{o} C) were estimated from the summer survey data for 1982 to 2006 (Figure 53). The centroid is the average latitude and average longitude. In the 1980's the cold pool was farther south(about 58 to 59 ^{o} N latitude) except for 1987 when the centroid shifted to north of 60 ^{o} N latitude. The cold pool moved north from about 58 ^{o} N latitude in 1999 to about 60.5 ^{o} N latitude in 2003. The cold pool was farthest south in 1989, 1999 and 1982 and farthest north in 1987, 1998, 2002 and 2003. In 2005 the cold pool was north, then in 2006 back to the south. The last three years (2007, 2008 and 2009) have all been cold years.

The clutch fullness and fraction of unmated females however, does not account for the fraction of females that may have unfertilized eggs. The fraction of barren females observed in the survey may not be an accurate measure of fertilization success because females may retain unfertilized eggs for months after extrusion. To examine this hypothesis, RACE personnel sampled mature females from the Bering Sea in winter and held them in tanks until their eggs hatched in March of the same year. All females then extruded a new clutch of eggs in the absence of males. All eggs were retained until the crabs were sacrificed near the end of August. Approximately 20% of the females had full clutches of unfertilized eggs. The unfertilized eggs could not be distinguished from fertilized eggs by visual inspection at the time they were sacrificed. Indices of fertilized females based on the visual inspection method of assessing clutch fullness and percent unmated females may overestimate fertilized females and not an accurate index of reproductive success.

McMullen and Yoshihara (1969) examined female red king crab around Kodiak Island in 1968 and found high percentages of females without eggs in areas of most intense fishing (up to 72%). Females that did not extrude eggs and mate were found to resorb their eggs in the ovaries over a period of several months. One trawl haul captured 651 post-molt females and nine male red king crab during the period April to May 1968. Seventy-six percent of the 651 females were not carrying eggs. Ten females were collected that were carrying eggs and had firm post-molt shells. The eggs were sampled 8 and 10 days after capture and were examined microscopically. All eggs examined were found to be infertile. This indicates that all ten females had extruded and held egg clutches without mating. Eggs of females sampled in October of 1968 appear to have been all fertile from a table of results in McMullen and Yoshihara(1969), however the results are not discussed in the text, so this is unclear. This may mean that extruded eggs that are unfertilized are lost between May and October.

ANALYTIC APPROACH

Model Structure

The model structure was developed following Fournier and Archibald's (1982) methods, with many similarities to Methot (1990). The model was implemented using automatic differentiation software developed as a set of libraries under C++ (ADModel Builder). ADModel Builder can estimate a large number of parameters in a non-linear model using automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries. This software provides the derivative calculations needed for finding the objective function via a quasi-Newton function minimization routine (e.g., Press et al. 1992). The model implementation language (ADModel Builder) gives simple and rapid access to these routines and provides the ability to estimate the variance-covariance matrix for all parameters of interest.

The model estimates the abundance by length bin and sex in the first year (1978) as parameters rather than estimating the recruitments previous to 1978. This results in 44 estimated parameters.

Recruitment is determined from the estimated mean recruitment, the yearly recruitment deviations and a gamma function that describes the proportion of recruits by length bin,

$$N_{t,1} = pr_l \, e^{R_0^l + \tau_t}$$

where,

R_0^l Log Mean recruitment

pr_l Proportion of recruits for each length bin

τ_t Recruitment deviations by year.

Recruitment is estimated equal for males and females in the model.

Crab were distributed into 5mm CW bins based on a pre-molt to post-molt transition matrix. For immature crab, the number of crabs in length bin *l* in year *t-1* that remain immature in year *t* is given by,

$$N^{s}_{t,l} = (1-\phi^{s}_{l}) \sum_{l=l_1}^{l'} \psi^{s}_{l',l} \; e^{-Z^{s}_{l'}} N^{s}_{t-1,l'}$$

$\psi^{s}_{l',l}$	growth transition matrix by sex, pre-molt and post-molt length bins which defined the fraction of crab of sex *s* and pre-molt length bin *l'*, that moved to length bin *l* after molting,
$N^{s}_{t,l}$	abundance of immature crab in year *t*, sex *s* and length bin *l*,
$N^{s}_{t-1,l'}$	abundance of immature crab in year *t-1*, sex s and length bin *l'*,
$Z^{s}_{l'}$	total instantaneous mortality by sex *s* and length bin *l'*,
ϕ^{s}_{l}	fraction of immature crab that became mature for sex *s* and length bin *l*,
l'	pre-molt length bin,
l	post-molt length bin.

Growth

Very little information exists on growth for Bering Sea snow crab. A growth study was conducted in 2011 (Somerton 2013) that added new information that was used in the Base model of the current assessment. Tagging experiments were conducted on snow crab in 1980 with recoveries occurring in the Tanner crab (*Chionoecetes bairdi*) fishery in 1980 to 1982 (Mcbride 1982). All tagged crabs were males greater than 80mm CW and which were released in late May of 1980. Forty-nine tagged crabs were recovered in the Tanner crab fishery in the spring of 1981 of which only 5 had increased in carapace width. It is not known if the tags inhibited molting or resulted in mortality during molting, or the extent of tag retention. One crab was recovered after 15 days in the 1980 fishery, which apparently grew from 108 mm to 123 mm carapace width. One crab was recovered in 1982 after almost 2 years at sea that increased from 97 to 107 mm.

In the 2012 assessment and previous to 2012, growth data from 14 male crabs collected in March of 2003 that molted soon after being captured were used to estimate a linear function between premolt and postmolt width (Lou Rugolo unpublished data, Figure 54). The crabs were measured when shells were still soft because all died after molting, so measurements are probably underestimates of postmolt width (Rugolo, pers. com.). Growth appears to be greater than growth of some North Atlantic snow crab stocks (Sainte-Marie 1995). Growth from the 1980 tagging of snow crab was not used due to uncertainty about the effect of tagging on growth. Previous to the 2011 growth data collection that was used in the Base model and scenario 1, there were no growth measurements for Bering Sea snow crab females. North Atlantic growth data indicate growth is slightly less for females than males.

Somerton's (2013) estimates of growth for Bering sea snow crab combined several data sets as well as female and male data. The best model determined by Somerton(2013) included the following data :

1. Transit study; 14 crab
2. Cooperative seasonality study (Rugolo); 6 crab
3. Dutch harbor holding study; 9 crab
4. NMFS Kodiak holding study held less than 30 days; 6 crab

Total sample size was 35 crab. Somerton(2013) excluded data from the NMFS Kodiak holding study where crab were held more than 30 days and also for the ADF&G Kodiak holding study where crab were collected during the summer survey and held until molting the next spring because growth was significantly lower than the above four data sets.

Some data points were excluded from 1, 2 and 3 above (35 is the final sample size). Females molting to maturity were excluded from all data sets, since the molt increment is usually smaller. Crab missing more than two limbs were excluded due to other studies showing lower growth. Crab from Rugolo's seasonal study were excluded that were measured less than 3 days after molting due to difficulty in measuring soft crab accurately. Somerton fit each data set starting with (1) above and testing the next data set for significant difference. Two linear models were fit that joined at 36.1 mm (males and females combined, Figure 55),

For < =36.1mm
Postmolt = -4.0 + 1.46 * Premolt

>= 36.1 mm
Postmolt = 6.59 + 1.17 * Premolt

The postmolt size is 48.8 mm at premolt size of 36.1 mm.

The September 2013 model fit the growth data by sex reported by Somerton (2013) within the assessment model by adding a sum of squared deviations likelihood component. Sample sizes were 17 for males and 18 for females. One linear function for each sex was estimated resulting in four parameters (an intercept and slope by sex) (Figures 54b and 54c),

$$\text{Width}_{t+1,\,s} = a_s + b_s * \text{width}_{t,\,s}$$

where s is sex and t is width interval.

The two line growth model estimates two linear segments similar to Somerton (2013), except by sex with the intersection of the lines fixed at 36.1 mm (premolt) and 48.8 mm (postmolt). This results in four parameters total (two parameters estimated per sex). The parameters of the intersection point are not estimable in the assessment model due the equation being nondifferentiable.

Premolt < 36.1mm

$$\text{Postmolt}_s = a1_s + \text{Premolt}_s * (48.8 - a1_s)/36.1$$

Premolt > 36.1mm

$Postmolt_s = a2_s + Premolt_s * (48.8 - a2_s)/36.1$

Where $a1_s$ and $a2_s$ are estimated parameters by sex.

Likelihood equations were added for the sum of squares fit with the new growth data by sex,

$$0.5\sum(g_i - \hat{g}_i)^2$$

Where g_i is post-molt size from growth data (Somerton 2013) and $\hat{g}_i$ is predicted post-molt size.

The base model in the current assessment has growth modeled as two linear segments with a smooth transition recommended by the 2014 CIE review (Cadigan 2014),

$$f_i(x) = a_i + b_i\, x, \qquad i = 1,2\,,$$

$$a_2 = a_1 + (b_1 - b_2)\delta$$

$$f(x) = f_1(x)\left\{1 - \varphi\left(\frac{x-\delta}{s}\right)\right\} + f_2(x)\left\{\varphi\left(\frac{x-\delta}{s}\right)\right\}$$

Where φ is the cumulative distribution function for a standard normal random variable. δ constrains the breakpoint, and s is a scale parameter determining how smooth the transition is between equation segments. The cumd_norm function was used in ADMB for the cumulative normal distribution. Separate parameters were estimated for male and female crab, except one s parameter was estimated for both sexes. This results in 4 estimated parameters per sex plus the s parameter, for a total of 9 estimated parameters.

Crab were assigned to 5mm width bins using a two-parameter gamma distribution with mean equal to the growth increment by sex and length bin and a beta parameter (which determines the variance),

$$\psi^{s}_{l',l} = \int_{l-2.5}^{l+2.5} gamma(l/\alpha_{s,l'}, \beta_s)$$

where,

$\alpha_{s,l'}$ expected growth interval for sex s and size l' divided by the shape parameter β,

$\psi^{s}_{l',l}$ growth transition matrix for sex, s and length bin l' (pre-molt size), and post-molt size l.

The Gamma distribution was,

$$gamma(l / \alpha_{s,l}, \beta_s) = \frac{l^{\alpha_{s,l}-1} e^{-\frac{l}{\beta_s}}}{\beta^{\alpha_{s,l}} \Gamma(\alpha_{s,l})}$$

where l is the length bin, β for both males and females was set equal to 0.75, which was estimated from growth data on Bering Sea Tanner and King crab due to the small amount of growth data available for snow crab. The distribution was truncated at postmolt sizes greater 40mm above the premolt size due to problems in estimation of very small values in the growth transition matrix, and that crab would not be expected to have a larger molt increment than 40mm. There was no difference in the results of the model with the truncated growth matrix and without.

The probability of an immature crab becoming mature by size is applied to the post-molt size. Crab that mature and reach their terminal molt in year t then are mature new shell during their first year of maturity. The abundance of newly mature crab ($\Omega^s_{t,l}$) in year t is given by,

$$\Omega^s_{t,l} = \phi^s_l \sum_{L=l_1}^{l'} \psi^s_{l',l} \, e^{-Z^s_{l'}} N^s_{t-1,l'}$$

Crab that were mature SC2 in year *t-1* no longer molt and move to old shell mature crab (SC3+) in year t ($\Lambda^s_{t,l}$). Crab that are SC3+ in year *t-1* remained old shell mature for the rest of their lifespan. The total old shell mature abundance ($\Lambda^s_{t,l}$) in year t is the sum of old shell mature crab in year *t-1* plus previously new shell (SC2) mature crabs in year *t-1*,

$$\Lambda^s_{t,l} = e^{-Z^{s,old}_l} \Lambda^s_{t-1,l} + e^{-Z^{s,new}_l} \Omega^s_{t-1,l}$$

The fishery is prosecuted in early winter prior to growth in the spring. Crab that molted in year *t-1* remain as SC2 until after the spring molting season. Crab that molted to maturity in year *t-1* are SC2 through the fishery until the spring molting season after which they become old shell mature (SC3).

Mature male biomass (MMB) was calculated as the sum of all mature males at the time of mating multiplied by respective weight at length.

$$B_t = \sum_{L=1}^{lbins} (\Lambda^{males}_{tm,l} + \Omega^{males}_{tm,l}) W^{males}_l$$

tm	nominal time of mating after the fishery and before molting,
lbins	number of length bins in the model,
$\Lambda^{males}_{tm,l}$	abundance of mature old shell males at time of mating in length bin l,
$\Omega^{males}_{tm,l}$	abundance of mature new shell males at the time of mating in length bin l,

W_l mean weight of a male crab in length bin l.

Catch of male snow crab was estimated as a pulse fishery 0.62 yr after the beginning of the assessment year (July 1),

$$catch = \sum_{l} (1 - e^{-(F * Sel_l + Ftrawl * TrawlSel_l)}) w_l N_l \, e^{-M * .62}$$

F	Full selection fishing mortality determined from the control rule using biomass including implementation error
$Sel_{,l}$	Fishery selectivity for length bin l for male crab
Ftrawl	Fishing mortality for trawl bycatch fixed at 0.01 (average F)
$TrawlSel_l$	Trawl bycatch fishery selectivity by length bin l
W_l	weight by length bin l
N_l	Numbers by length for length bin l
M	Natural Mortality

Selectivity

The selectivity curve total catch, female discard and groundfish bycatch were estimated as two-parameter ascending logistic curves (Figure 56 and 67).

$$S_l = \frac{1}{1 + e^{-a \ (l - b \ )}}$$

The probability of retaining crabs by size with combined shell condition was estimated as an ascending logistic function. The selectivities for the retained catch were estimated by multiplying a two parameter logistic retention curve by the selectivities for the total catch.

$$S_{ret,l} = \frac{1}{1 + e^{-a(l-b)}} \frac{1}{1 + e^{-c_{ret}(l - d_{ret})}}$$

The selectivities for the survey were estimated with three-parameter (Q, L95% and L50%), ascending logistic functions (Survey selectivities in Figure 57).

$$\text{Selectivity}_l = \frac{Q}{1 + e^{\left\{ \frac{-\ln(19)(l - l_{50\%})}{(l_{95\%} - l_{50\%})} \right\}}}$$

Separate survey selectivities were estimated for the period 1978 to 1981, 1982 to 1988, and 1989 to the present. Survey selectivities were estimated separately for males and females in the 1989 to present period. The maximum selectivity(Q) for each time period was estimated in the model for the Base Model. The separate selectivities were used due to the change in catchability in 1982 from the survey net change, and the addition of more survey stations to the north of the survey area after 1988. Survey selectivities have been estimated for Bering Sea snow crab from underbag trawl experiments (Somerton and Otto 1999). A bag underneath the regular trawl was used to catch animals that escaped under the footrope of the regular trawl, and was assumed to have selectivity equal to 1.0 for all sizes. The selectivity was estimated to be 50% at about 74 mm, 0.73 at 102 mm, and reached about 0.88 at the maximum size in the model of 135 mm.

Likelihood Equations

Weighting values (λ) for each likelihood equation are shown in Table 11.

Catch biomass is assumed to have a normal distribution,

$$\lambda \sum_{t=1}^{T} \left[C_{t,\,fishery,obs} - C_{t,\,fishery.pred} \right]^2$$

There are separate likelihood components for the retained and total catch.

The robust multinomial likelihood is used for length frequencies from the survey and the catch (retained and total) for the fraction of animals by sex in each 5mm length interval. The number of samples measured in each year is used to weight the likelihood. However, since thousands of crab are measured each year, the sample size was set at 200.

$$Length\,Likelihood = -\sum_{t=1}^{T}\sum_{l=1}^{L} nsamp_t * p_{t,l} \log(\hat{p}_{t,l} + o) - Offset$$

$$Offset = \sum_{t=1}^{T}\sum_{l=1}^{L} nsamp_t * p_{t,l} \log(p_{t,l})$$

Where, T is the number of years, $p_{t,l}$ is the proportion in length bin *l*, an *o* is fixed at 0.001.

An additional length likelihood weight (2) is added to the first year survey length composition fit to facilitate the estimation of the initial abundance parameters. A smoothness constraint is also added to the numbers at length by sex in the first year,

$$\sum_{S=1}^{2} \sum_{l=1}^{L} (\textit{first differences}(N_{1978,s,l}))^2$$

The survey biomass (including biomass in the 2009 and 2010 study areas) assumes a lognormal distribution with the inverse of the standard deviation of the log(biomass) in each year used as a weight,

The survey biomass assumes a lognormal distribution with the inverse of the standard deviation of the log(biomass) in each year used as a weight,

$$\lambda \sum_{t=1}^{ts} \left[\frac{\log(SB_t) - \log(\hat{SB}_t)}{sqrt(2) * s.d.(\log(SB_t))} \right]^2$$

$$s.d.(\log(SB_t)) = sqrt(\log((cv(SB_t))^2 + 1))$$

Recruitment deviations likelihood equation is,

$$\lambda \sum_{s=1}^{2} \sum_{t=1}^{T} \tau_{s,t}^2$$

Smooth constraint on probability of maturing by sex and length

$$\sum_{S=1}^{2} \sum_{l=1}^{L} (\textit{first differences}(\textit{first differences}(PM_{s,l}))^2$$

Where $PM_{s,l}$ is a vector of parameters that define the probability of molting.

Penalties on Fishing mortalities.

Penalty on average F for males (λ = 2 in last phases),

$$\lambda \sum_{t=1}^{T} (F_t - 1.15)^2$$

Fishing mortality deviations for males($\lambda = 0.1$),

$$\lambda \sum_{t=1}^{T} \varepsilon_t^2$$

Female bycatch fishing mortality penalty ($\lambda = 1.0$).

$$\lambda \sum_{t=1}^{T} (\varepsilon_{female,t})^2$$

Trawl bycatch fishing mortality penalty ($\lambda = 1.0$).

$$\lambda \sum_{t=1}^{T} (\varepsilon_{trawl,t})^2$$

Male natural mortality, when estimated in the model uses a penalty which assumes a normal distribution. A 95% CI of +/- 1.7 yrs translates to a 95% CI in M of about +-0.025 using an exponential model, which is a CV= 0.054.

$$0.5\left(\frac{M-0.23}{0.0125}\right)^2$$

No penalty was used when immature M was estimate.

Likelihood equations were added for the sum of squares fit for the Base model with the new growth data by sex and a linear model by sex, where post-molt CW = a + b Premolt CW. ($\lambda = 2.0$ Base model)

$$\lambda\ 0.5\sum(g_i - \hat{g}_i)^2$$

Where g_i is post-molt size from growth data (Somerton 2013) and $g^\wedge_i$ is predicted post-molt size from a linear model with intercept and slope parameters.

There were a total of 320 parameters estimated in the Base model (Table 10) for the 37 years of data (1978-2014). The 105 fishing mortality parameters (one set for the male catch, one set for the female discard catch, and one set for the trawl fishery bycatch) estimated in the model were constrained so that the estimated catch fit the observed catch closely. There were 37 recruitment parameters estimated in the model, one for the mean recruitment, 36 for each year from 1979 to 2014 (male and female recruitment were fixed to be equal). There were 8 fishery selectivity parameters that did not change over time. Survey selectivity was estimated for three different periods resulting in 9 parameters for males and 9 parameters for females. There were 6 survey selectivity parameters estimated for the study area for BSFRF female logistic availability curves for 2009 and 2010. 22 parameters for each year (2009 and 2010) for male crab were estimated for the smooth availability curve for the BSFRF net. Two parameters for natural mortality and 9 growth parameters were also estimated in the Base model. The September 2013 model and the two line growth model estimated 4 growth parameters.

Molting probabilities for mature males and females were fixed at 0, i.e., growth ceases at maturity which is consistent with the terminal molt paradigm (Rugolo et al. 2005 and Tamone et al. 2005). Molting probabilities were fixed at 1.0 for immature females and males. The intercept and slope of the linear growth function of postmolt relative to premolt size were estimated in the model (3 parameters, Table 10). A gamma distribution was used in the growth transition matrix with the beta parameters fixed at 0.75 for male and females.

The model separates crabs into mature, immature, new shell and old shell, and male and female for the population dynamics. The model estimate of survey mature biomass is fit to the observed survey mature biomass time series by sex. The model fits the size frequencies of the survey by immature and mature separately for each sex. The probability of immature crab maturing was estimated in the model using 22 parameters for each sex with a second difference smooth constraint (44 total parameters). The model fits the size frequencies for the pot fishery catch by new and old shell and by sex.

Crabs 25 mm CW (carapace width) and larger were included in the model, divided into 22 size bins of 5 mm each, from 25-29 mm to a plus group at 130-135mm. In this report the term size as well as length will be considered synonymous with CW. Recruits were distributed in the first few size bins using a two parameter gamma distribution with the alpha parameter of the distribution fixed at 11.5 and the beta parameter fixed at 4.0. Seventy parameters were estimated for the initial population size composition of new and old shell males and females in 1978. No spawner-recruit relationship was used in the population dynamics part of the model. Recruitments for each year were estimated in the model to fit the data.

The NMFS trawl survey occurs in summer each year, generally in June-July. In the model, the time of the survey is considered to be the start of the year (July), rather than January. The modern directed snow crab pot fishery has occurred generally in the winter months (January to February) over a short period of time. In contrast, in the early years the fishery occurred over a longer time period. The mean time of the fishery was estimated from the weighted distribution of catch by day for each year. The fishing mortality was applied all at once at the mean time for that year. Natural mortality is applied to the population from the time the survey occurs until the fishery occurs, then catch is removed. After the fishery occurs, growth and recruitment take place (in spring), with the remainder of the natural mortality through the end of the year as defined above.

Discard mortality

Discard mortality was 30% for all model scenarios as recommended by the CPT and the SSC 2013. The fishery for snow crabs occurs in winter when low temperatures and wind may result in freezing of crabs on deck before they are returned to the sea. Short term mortality may occur due to exposure, which has been demonstrated in laboratory experiments by Zhou and Kruse (1998) and Shirley (1998), where 100% mortality occurred under temperature and wind conditions that may occur in the fishery. Even if damage did not result in short term mortality, immature crabs that are discarded may experience mortality during molting some time later in their life.

Model Scenarios

The model structure of the Base model in this assessment is the same as the base model in the September 2013 assessment except for the formulation of the growth function.
The base model in the current assessment fits a two part linear function with a smooth transition recommended in the 2014 CIE review (Cadigan 2014). Nine model scenarios are presented in this assessment: 1) The September 2013 model (Model 0, one linear function fit to growth data), 2) two linear functions with a fixed intersection fit to growth data (Model 1), 3) Two linear functions with a smooth transition fit to growth data (Model 2a, Cardgan 2014), 4) same as 3 with factor of 2 times on growth likelihood (Model 2b, Base model for this assessment), 5) same as 3 with factor of 3 times on growth likelihood (Model 2c), 6) same as 3 with 0.5 weight on fishing penalties likelihood (Model 2d, weights relative to base model), 7) same as 3 with 0.25 weight on fishing penalties likelihood (Model 2e) 8) same as 3 with 0.1 weight on fishing penalties likelihood (Model 2f), 9) same as 3 with 0.001 weight on penalties on fishing mortality likelihood (Model 2g).

Model 2b was selected as the base model for this assessment because it uses the smooth transition for growth and the weight of 2 on the likelihood fits growth data much better than weight of 1, while a higher weight (3) does not provide much better fit to growth data.

The CPT and SSC in 2010 and 2011 recommended the use of the BSFRF 2009 and 2010 survey data as an additional survey in the assessment model to inform estimates of survey selectivity.

The current models and the September 2013 assessment estimated natural mortality for immature crab (male and female as 1 parameter), mature male crab and growth parameters for male and female crab. Survey selectivities for the BSFRF and NMFS data in the study area are also estimated separately for males and females.

Following the recommendation of the CPT and SSC in 2011, abundance estimates by length as well as survey biomass for the study area for the BSFRF tows and the NMFS tows were included in the September 2011, 2012 stock assessment models and the current assessment as an additional survey. Likelihood equations were added to the model for fits to the length frequency by sex for the BSFRF tows in the study area and the NMFS tows in the study area. A likelihood equation was also added for fit to the mature biomass by sex in the study area for the BSFRF tows and NMFS tows separately.

The formulation used in this assessment (and since the September 2011) was recommended by the February 2011 Crab Modeling Workshop,

$$\widetilde{C}_l^s = N_l\, Q_{BSFRF}^s A_l S_l Q_{NMFS}^n$$

$\widetilde{C}_l^s =$ numbers by length for NMFS in study area

A_l = a smooth function of availability in the study area for the BSFRF net

S_l = 2 parameter logistic function for the entire Bering Sea for the NMFS net

Q_{BSFRF}^s = Q for study area (s) for the BSFRF net

Q_{NMFS}^n = Q for the entire Bering Sea NMFS net

N_l = population abundance by length

All Bering Sea male survey selectivity was estimated as a 3 parameter logistic function,

$$\text{Selectivity}_l = \frac{Q}{1 + e^{\left\{\frac{-\ln(19)(l - l_{50\%})}{(l_{95\%} - l_{50\%})}\right\}}}$$

The BSFRF availability was estimated as a smooth function (22 parameters, 1 parameter for each length bin(22),

$$A_l = \exp(p_l); \qquad p_l \le 0.$$

A second difference constraint was added to the likelihood with a weight of 5.0,

$$5.0 \sum_{l=1}^{L} (\textit{first differences}(\textit{first differences}(p_l)))^2 \; .$$

The maximum survey selectivity (Q) estimated for the entire Bering Sea area in Somerton et al. 2010 was estimated at 0.76 at 140 mm. The maximum size bin in the model is 130-135, which for the Somerton curve has a maximum selectivity of 0.75.

Projection Model Structure

The projection model was used to estimate the OFL, ABC and future biomass values. Variability in recruitment, as well as implementation error, was simulated with temporal autocorrelation. Recruitment was generated from a Beverton-Holt stock-recruitment model,

$$R_t = \frac{0.8\, h\, R_0\, B_t}{0.2\ spr_{F=0}\ R_0(1-h)+(h-0.2)B_t}\ e^{\varepsilon_t - \sigma_R^2/2}$$

$spr_{F=0}$ — mature male biomass per recruit fishing at F=0. $B_0 = spr_{F=0}\ R_0$,
B_t — mature male biomass at time t,
h — steepness of the stock-recruitment curve defined as the fraction of R_0 at 20% of B_0,
R_0 — recruitment when fishing at F=0,
σ_R^2 — variance for recruitment deviations, estimated at 0.74 from the assessment model.

The temporal autocorrelation error (ε_t) was estimated as,

$$\varepsilon_t = \rho_R \varepsilon_{t-1} + \sqrt{1+\rho_R^2}\ \ \eta_t \qquad where\ \eta_t \sim N(0;\sigma_R^2) \tag{2}$$

ρ_R — temporal autocorrelation coefficient for recruitment, set at 0.6.

Recruitment variability and autocorrelation were estimated using recruitment estimates from the stock assessment model. Steepness (h) and R_0 were estimated by setting Bmsy and Fmsy equal to B35% and F35% using a Beverton and Holt spawner recruit curve.

Implementation error was modeled as a lognormal autocorrelated error on the mature male biomass used to determine the fishing mortality rate in the harvest control rule,

$$B_t^{'} = B_t\, e^{\phi_t - \sigma_I^2/2}\ ;\quad \phi_t = \rho_I \phi_{t-1} + \sqrt{1+\rho_I^2}\ \ \varphi_t \qquad where\ \varphi_t \sim N(0;\sigma_I^2)$$

$B_t^{'}$ — mature male biomass in year t with implementation error input to the harvest control rule,
B_t — mature male biomass in year t,
ρ_I — temporal autocorrelation for implementation error, set at 0.6 (estimated from the recruitment time series),
σ_I — standard deviation of φ which determines the magnitude of the implementation error.

Implementation error was set at a fixed value (e.g., 0.2) plus the s.d. on log scale from the assessment model for mature male biomass. Implementation error in mature male biomass resulted in fishing mortality values applied to the population that were either higher or lower than the values without implementation error. The autocorrelation was assumed to be the same value as that estimated for recruitment. Implementation autocorrelation was used to more closely approximate the process of estimating a biomass time series from within a stock assessment model. The variability in biomass of the simulated population resulted from the variability in recruitment and variability in full selection F arising from implementation error on biomass. The population dynamics equations were identical to those presented for the assessment model in the model structure section of this assessment.

RESULTS

The Base model estimated immature M at 0.367 and mature male M at 0.270 (Table 13).

The model estimated total mature biomass increased from about 384,400 t in 1978 to the peak biomass of 1,006,800 t in 1990 for the Base model (Table 6). Table 6a contains model predicted survey biomass and numbers. Model estimated total mature biomass declined after 1997 to about 372,400 t in 2003. Total mature biomass increased from 484,300 t in 2013 to 556,000 t in 2014 (Table 6 and Figure 4). The model results are informed by the population dynamics structure, including natural mortality, the growth and selectivity parameters and the fishery catches. The low observed survey abundance in the mid-1980's were followed by an abrupt increase in the survey abundance of crab in 1987, which followed through the population and resulted in the highest catches recorded in the early 1990's.

Average model estimated discard catch mortality for 1978 to 2012 was about 9.1% of the retained catch (with 30% mortality applied). The average observed discards from 1992 to 2012 was 8.4% of the retained catch (30% mortality applied) (Tables 1 and 2, and Figure 58). Estimates of observed discard mortality ranged from 2.5% of the retained catch to 19.2% of the retained catch (30% discard mortality). The percent observed discard has increased from 7.3% in 2012/13 to 14.8% in 2013/4 possibly due to recruitment.

Parameter estimates are listed in Table 10. The model fit to the total directed male catch, groundfish bycatch, male discard catch and female discard catch are shown in Figures 58, 59, 60, and 61 respectively.

Mature male and female biomass show similar trends (Table 3 and Table 6, Figures 62 and 64). Model estimates of mature male biomass increased from about 168,000 t to 178,000 t in the period 2002 to 2006, to 250,700 t in 2009, declined to 166,100 t in 2012, then increased to 236,100 t in 2014. Observed survey mature male biomass declined from 120,800 t in 2012 and 96,100 t in 2013, then increased to 156,900 t in 2014. Mature female biomass observed from the survey increased from 86,400 t in 2008 to 280,000 t in 2011 then declined to 195,100 t in 2012, then increased to 212,500 t in 2014. Model estimates of mature female biomass have an increasing trend from 187,300 t in 2009 to 287,100 t in 2014.

Fishery selectivities and retention curves were estimated using ascending logistic curves (Figures 56 and 66). Selectivities for trawl bycatch were estimated as ascending logistic curves (Figure 67). Plots of model fits to the survey size frequency data are presented in Figures 68 and 70 by sex for shell conditions combined with residual plots in Figures 69 and 71. A summary of the fit across all years for male and female length frequency data indicates a very good fit overall (Figure 72). The model is not fit to crab by shell condition due to the inaccuracy of shell condition as a measure of shell age. Tagging results presented earlier indicate that the number of animals that are more than one year from molting may be underestimated by using shell condition as a proxy for shell age. However, an accurate measure of shell age is needed to improve the estimation of the composition of the catch that is extracted from the stock.

Differences between the observed and predicted survey length frequencies could be a result of spatial differences in growth due to temperature, or size at maturity. These would need to be investigated using a spatial model. Changing growth or maturity over time simply to fit the length frequency data was not recommended by the 2008 CIE reviewers. There also could be changes in survey catchability by area or between years that could contribute to any lack of fit to the observed survey length frequency data.

The September 2013 assessment survey Q for the 1989 to present period was estimated at 0.55 for male crab (Turnock and Rugolo 2013). The Base model estimate for survey Q was 0.61. The maximum survey selectivity estimated using the 2009 study area by Somerton (2010) was 0.76 at 140 mm for male crab (Figure 90). The survey selectivity curves estimated for the base model are shown in Figure 57. Immature M was estimated at 0.366 (2013 assessment 0.386) and mature male M 0.270 (2013 assessment 0.261). Mature female M was fixed at 0.23.

The estimated number of males > 101mm generally follows the observed survey abundance estimates (Figure 73). Observed survey Males >101mm declined from 150.7 million crab in 2011 to 73.2 million in 2013 then increased to 138.5 million in 2014 (Table 3). Model estimates of large males show a decreasing trend from 233.0 million in 2009 to 109.9 million in 2012, then an increase to 183.0 million in 2014.

Several periods of above average recruitment were estimated by the model in 1979-1981, 1983, 1987-1988, 1998-99, and 2004-2005 (fertilization year, Figure 74). Recruits are 25mm to about 40 mm and may be about 4 years from hatching, 5 years from fertilization (Figure 75, although age is approximated). Lower than average recruitments were estimated from 1989 to 1997, 2000 to 2003, 2006-2007. The 1998-1999 and 2004 and 2005 year classes appear to be near or above average recruitment and have resulted in an increase in biomass in recent years. Recruitment through the male stock can be seen in the abundance by length (Figure 8a).

The size at 50% selected for the pot fishery for total catch (retained plus discarded) was 106.2 mm for males (shell condition combined, Figure 56). The size at 50% selected for the retained catch was about 106 mm. The fishery generally targets and retains new shell animals > 101mm with clean hard shells and all legs intact. The fits to the fishery size frequencies are in Figures 76 through 81. Fits to the trawl fishery bycatch size frequency data are in Figures 82 through 84.

Fishing mortality rates ranged from 0.15 to 2.6 (Figure 85 and Table 6). Fishing mortality rates ranged from 0.57 to 2.59, for the 1986/87 to 1998/99 fishery seasons. For the period after the snow crab stock was declared overfished (1999/2000 to 20010/11), full selection fishing mortality ranged from 0.18 to 0.58. Fishing mortality rate increased from 0.32 in 2010/11 to 0.94 in 2012/13 then declined to 0.73 in 2013/14.

Base Model estimates of mature male biomass at mating decreased from 189,300 t in 2009/10 to 109,200 t in 2012/13 then increased to 126,500 t in 2013/14 (89% of B35% (142,909 t), Table 6 and Figure 86). Estimates of MMB at mating in recent years are lower for the Base model than the 2013 assessment due to higher survey Q and changes in B35% and F35% from different growth estimates (Figure 103). Estimates of MMB at mating were lower for lower weights on fishing mortality penalties (Figure 87).

Likelihood values for all 9 model scenarios are shown in Table 13. Total likelihood values are not comparable between scenarios due to different numbers of parameters, weights on likelihood components (growth and fishing mortality penalties) and model structure (growth equations). Model 2b fits survey length data better than lower or higher weights on growth likelihood (models 2a and 2c). Survey biomass fit is best for model 2a relative to 2b and 2c. Length data are fit better with lower weight on fishing mortality penalties. Fit to survey biomass decreases with decreasing weight on fishing mortality penalties.

When weights on fishing mortality penalties are reduced, estimates of discard mortality and fishing mortality in early years increase to levels that are not plausible (Figures 107 and 108). In years where there are not data on discards the model is fitting retained catch to estimate Fs and uses the selectivity curves for total and retained crab to estimate catches. The model can still fit the retained catch with an F of 20 (where selectivity is close to 1.0) however, estimates much higher discard (where selectivities are less than 1).

The estimated growth for the base model (2b, weight 2 on growth likelihood) and the models with weight 1 (2a) and weight 3 (2c) on the growth likelihood are shown in Figures 54b to 54e. The estimated growth transition matrix for males and females are shown in Figures 105 and 106.

Survey selectivity curves estimated for the Base model are shown in Figures 90 to 97. Base Model fits to the length frequency in the 2009 and 2010 study areas are shown in Figure 98. Base Model fits to the mature biomass in the 2009 and 2010 study areas are shown in Figures 99 and 100.

The history of fishing mortality and MMB at mating with the F35% control rule for the Base model estimates the 2013/14 F to be below the overfishing level and MMB at mating at 89% of B35% (Figure 101).

Fishing mortality estimates and estimated male discard in the directed fishery were higher with lower weights on the fishing mortality penalties (Figures 107 and 108). With a weight of 0.001 relative to the base model F was about 19.9 in 1982 and 1983 and discard catch very high.

B35% decreased and F35% increased with decreasing weight on F penalties (Table 14). Survey Q increased, mature male biomass decreased and OFL declined with decreasing weight on F penalties.

Harvest Strategy and Projected Catch

Rebuilding Harvest Strategy

A rebuilding harvest strategy was developed and adopted in December 2000 in Amendment 14 and first applied in the 2000/01 fishing season (NPFMC 2000). Harvest strategy simulations are reported by Zheng et al. (2002) based on a model with structure and parameter values different than the model presented here. The harvest strategy by Zheng et al. (2002) was developed for use with survey biomass estimates. Prior to the passage of Amendment 24, Bmsy was defined as the average total mature survey biomass for 1983 to 1997. MSST was defined as ½ Bmsy. The harvest strategy consists of a threshold for opening the fishery (104,508 t (230.4 million lbs) of total mature biomass (TMB), 0.25*Bmsy), a minimum GHL of 6,804 t (15 million lbs) for opening the fishery, and rules for computing the GHL. This strategy without the minimum constraint is currently used by ADFG for setting the TAC.

This exploitation rate is based on total survey mature biomass (TMB) which decreases below maximum E when TMB < average 1983-97 TMB calculated from the survey.

$$E=\begin{cases} Bycatch\ only, Directed\ E=0, & if\ \dfrac{TMB}{averageTMB}<0.25 \\ \dfrac{0.225*\left[\dfrac{TMB}{averageTMB}-\alpha\right]}{(1-\alpha)} & if\ 0.25<\dfrac{TMB}{averageTMB}<1 \\ 0.225 & if\ TMB\ \geq\ averageTMB \end{cases} \quad (13)$$

Where, α = -0.35 and averageTMB = 418,030 t (921.6 million lbs).

The maximum target for the retained catch is determined by using E as a multiplier on survey mature male biomass (MMB),

Retained Catch = E * MMB.

There is a 58% maximum harvest rate on exploited legal male abundance. Exploited legal male abundance is defined as the estimated abundance of all new shell males >=102 mm CW plus a percentage of the estimated abundance of old shell males >= 102 mm CW. The percentage to be used is determined using fishery selectivities for old shell males.

Overfishing Control Rule

Amendment 24 to the FMP introduced revised the definitions for overfishing. The information provided in this assessment is sufficient to estimate overfishing based on Tier 3b. The overfishing control rule for tier 3b is based on spawning biomass per recruit reference points (NPFMC 2007) (Figure 101).

$$F = \begin{cases} Bycatch\ only,\ Directed\ F = 0,\ if\ \dfrac{B_t}{B_{REF}} \le \beta \\[2em] \dfrac{F_{REF}\left[\dfrac{B_t}{B_{REF}} - \alpha\right]}{(1-\alpha)} \qquad if\ \beta < \dfrac{B_t}{B_{REF}} < 1 \\[2em] F_{REF} \qquad if\ B_t \ge B_{REF} \end{cases} \qquad (12)$$

B_t mature male biomass at time of mating in year t,

B_{REF} mature male biomass at time of mating resulting from fishing at F_{REF},

F_{REF} F_{MSY} or the fishing mortality that reduces mature male biomass at the time of mating-per-recruit to x% of its unfished level,

α fraction of B_{REF} where the harvest control rule intersects the x-axis if extended below β,

β fraction of B_{REF} below which directed fishing mortality is 0.

B35% was estimated using average recruitment from1978 to 2013 and mature male biomass per recruit fishing at F35%.

The natural log of recruits/MMB at mating (5 yr lag for recruitment) indicates productivity of the Bering sea snow crab stock is currently not different from earlier levels (Figure 102).

Biomass and catch projections based on $F_{REF} = F_{35\%}$ and $B_{REF} = B_{35\%}$ were used to estimate the catch OFL and the ABC (Tables 9a and 9b). The OFL was estimated as the median of the distribution of OFLs from the stochastic projection model described earlier. The OFL for the Base model in 2014/15 was estimated at 69,000 t total catch (60,300 t retained catch). The previous year's OFL (2013/14) was 78,100 t of total catch (69,100 t retained catch). The average catch from 1978/79 to 1998/99 was 70,348 t, and was 19,975 t during the rebuilding period 1999/2000 to 2010/11.

The ABC was estimated at 68,810 t, based on a probability of overfishing of 49% from the projection model with a cv= 0.08 on 2013/14 biomass estimated from the Hessian matrix by the ADMB software and the median of the projected distribution of catch fishing at F35% as the estimate of OFL (Table 9a and Table 14). The SSC in 2013 recommended an ACL of 90% of the OFL (70,290 t) for the 2013/14 fishing season. 90% of the 2014/15 Base Model OFL is 62,100 t of total catch.

F35% in the September 2013 assessment was estimated at 1.58 and B35% at 154,170 t. F35% for the Base model was 1.40 and B35% 142,909 t. The MMB at mating projected for 2013/14 when fishing at the F35% control rule (OFL) was 100.2% of B35% from the base model in the September 2013 assessment. The MMB at mating projected for 2014/15 when fishing at the F35% control rule (OFL) was 96.3% of B35%. Reference points for scenarios and key parameters for the 9 scenarios are shown in Table 14.

The total catch, including all bycatch of both sexes, using the control rule is estimated by the following equation,

$$catch = \sum_{s} \sum_{l} (1 - e^{-(F^{*}Sel_{s,l} + F_{trawl}{}^{*}Sel_{Trawl,l})}) w_{s,l} N_{s,l}\, e^{-M_s{}^{*}.62}$$

Where $N_{S,l}$ is the current year numbers at length(l) and sex at the time of the survey estimated from the population dynamics model, M_s is natural mortality by sex, 0.625 is the time elapsed (in years) from when the survey occurs to the fishery, F is the value estimated from the harvest control rule using the current year mature male biomass projected forward to the time of mating time (Feb. 15), and $w_{s,l}$ is weight at length by sex. $Sel_{s,l}$ are the fishery selectivities by length and sex for the total catch (retained plus discard) estimated from the population dynamics model (Figure 56).

Projections were run for the Base model fishing at the F35% control rule and fishing at a catch of 90% of the OFL (the SSC recommended ACL method in 2011/12 to 2013/14). Steepness of the Beverton and Holt spawner recruit curve used in projections was estimated at 0.74 and R_0 at 1.69 billion crab, by equating F35% with Fmsy and B35% with Bmsy.

Median MMB at mating was projected to increase in 2014/15 based on projections from the September 2013 assessment (Turnock and Rugolo 2013). Projections using the Base model, estimate MMB at mating to increase over the next 5 years from 96.3% of B35% in 2014/15 to 125.9% in 2019/20 (Tables 9a and 9b). Fishing at 90% of the OFL also results in increasing MMB over the next several years from about 100% of B35% in 2014/15 to 135% of B35% in 2019/20.

Conservation concerns

- Estimation of natural mortality in the model at values higher than estimates based on current knowledge of snow crab age could be risk prone. Aging methods need to be developed to improve estimation of natural mortality.
- Exploitation rates in the southern portion of the range of snow crab may have been higher than target rates, possibly contributing to the shift in distribution to less productive waters in the north.

Data Gaps and Research Needs

Research is needed to improve our knowledge of snow crab life history and population dynamics to reduce uncertainty in the estimation of current stock size, stock status and optimum harvest rates.

Tagging programs need to be initiated to estimate longevity and migrations. Studies and analyses are needed to estimate natural mortality.

A method of verifying shell age is needed for all crab species. A study was conducted using lipofuscin to age crabs, however verification of the method is needed. Radiometric aging of shells of mature crabs is costly and time consuming. Aging methods will provide information to assess the accuracy of assumed ages from assigned shell conditions (i.e. new, old, very old, etc), which have not been verified, except with the 21 radiometric ages reported here from Orensanz (unpub data).

Techniques for determining which males are effective at mating and how many females they can successfully mate with in a mating season are needed to estimate population dynamics and optimum harvest rates. At the present time it is assumed that when males reach morphometric maturity they stop growing and they are effective at mating. Field studies are needed to determine how morphometric maturity corresponds to male effectiveness in mating. In addition the uncertainty associated with the determination of morphometric maturity (the measurement of chelae height and the discriminate analysis to separate crabs into mature and immature) needs to be analyzed and incorporated into the determination of the maturity by length for male snow crab.

Female opilio in waters less than 1.5 ^{o} C and colder have been determined to be biennial spawners in the Bering Sea. Future recruitment may be affected by the fraction of biennial spawning females in the population as well as the estimated fecundity of females, which may depend on water temperature.

A female reproductive index needs to be developed that incorporates males, mating ratios, fecundity, sperm reserves, biennial spawning and spatial aspects.

Analysis needs to be conducted to determine a method of accounting for the spatial distribution of the catch and abundance in computing quotas.

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Table 1. Catch (1,000 t) for the snow crab pot fishery and groundfish trawl bycatch. Retained catch for 1973 to 1981 contain Japanese directed fishing. Observed discarded catch is the total estimate of discards before applying mortality. Discards from 1992 to 2011/12 were estimated from observer data. Total catch discard mortality applied.

Year fishery occurred	Retained catch (1000 t)	Observed Discard male catch (no mort. applied) (1000 t)	Observed Retained + discard male catch(no mort. Applied) (1000 t)	Year of trawl bycatch	Observed trawl bycatch(no mort. Applied) (1000 t)	Total catch (1000 t) 0.3 mort.applied directed fishery 0.8 mort. Applied GF	GHL(1980-2007) or TAC (2008 to present)(retained catch only) (1000 t)	OFL (2008/9 first year of total catch OFL) (1000 t)
1973/74	3.04			1973	13.63			
1974/75	2.28			1974	18.87			
1975/76	3.74			1975	7.3			
1976/77	4.56			1976	3.16			
1977/78	7.39			1977	2.14			
1978/79	23.72			1978	2.46			
1979/80	34.04			1979	1.98			
1980/81	30.37			1980	1.44		17.9-41.3	
1981/82	13.32			1981	0.6		7.3-10.0	
1982/83	11.85			1982	0.24		7.17	
1983/84	12.17			1983	0.31		22.23	
1984/85	29.95			1984	0.33		44.46	
1985/86	44.46			1985	0.29		25.86	
1986/87	46.24			1986	1.23		25.59	
1987/88	61.41			1987	0		50.23	
1988/89	67.81			1988	0.44		59.89	
1989/90	73.42			1989	0.51		63.43	
1990/91	149.11			1990	0.39		142.92	
1991/92	143.06	43.65	186.71	1991	1.95	157.7	151.09	
1992/93	104.71	56.65	161.37	1992	1.84	123.2	94.01	
1993/94	67.96	17.66	85.62	1993	1.81	74.7	48	
1994/95	34.14	13.36	47.5	1994	3.55	41.0	25.27	
1995/96	29.82	19.1	48.92	1995	1.35	36.6	23	
1996/97	54.24	24.68	78.92	1996	0.93	62.4	53.09	
1997/98	110.41	19.05	129.46	1997	1.5	117.3	102.5	
1998/99	88.02	15.5	103.52	1998	1.02	93.5	84.48	
1999/00	15.2	1.72	16.92	1999	0.61	16.2	12.93	
2000/01	11.46	2.06	13.52	2000	0.53	12.5	12.39	
2001/02	14.85	6.27	21.12	2001	0.39	17.0	13.97	
2002/03	12.84	4.51	17.35	2002	0.23	14.4	11.62	
2003/04	10.86	1.9	12.77	2003	0.76	12.0	9.44	
2004/05	11.29	1.69	12.98	2004	0.96	12.6	9.48	
2005/06	16.78	4.52	21.3	2005	0.37	18.4	16.74	
2006/07	16.5	5.9	22.39	2006	0.84	18.9	16.42	
2007/08	28.6	8.42	37.02	2007	0.44	31.5	28.58	
2008/09	26.56	6.86	33.42	2008	0.3	28.9	26.59	35.07
2009/10	21.82	4.09	25.91	2009/10	0.66	23.6	21.8	33.1
2010/11	24.67	2.05	26.72	2010/11	0.18	25.4	24.62	44.4
2011/12	40.3	5.21	45.51	2011/12	0.17	42.0	40.3	73.5
2012/13	30.06	7.35	37.41	2012/13	0.22	32.4	30.06	67.8
2013/14	24.48	12.09	36.57	2013/14	0.12	28.2	24.48	78.1

Table 2. Base model estimates of catch (1,000 t) for Bering Sea snow crab. Model estimates of pot fishery discards include 30% mortality and groundfish discard 80% mortality.

Year	Model estimate of male retained (1000 t)	Model estimate of male discard(30% mort) (1000 t)	Model estimate Discard female catch (1000 t)	Model estimate groundfish bycatch(0.8 mort., 1000 t)	Model estimate total directed male catch (1000 t)	Model estimate total catch (1000 t)
1978/79	23.8	1.7	0	3.8	25.5	29.3
1979/80	34.1	1.9	0	3	36	39.1
1980/81	30.5	4.3	0	2.1	34.7	36.9
1981/82	13.4	4.5	0	0.7	17.9	18.6
1982/83	11.9	2.2	0	0.2	14.1	14.4
1983/84	12.2	0.9	0	0.4	13.1	13.5
1984/85	30	1.5	0	0.4	31.6	32
1985/86	44.5	2.1	0	0.4	46.6	47
1986/87	46.3	2.7	0.1	1.8	49	50.9
1987/88	61.5	6.8	0.1	0.2	68.3	68.6
1988/89	67.9	10.3	0.1	0.6	78.2	78.9
1989/90	73.6	10.4	0.1	0.7	83.9	84.7
1990/91	149.4	18.7	0.1	0.6	168.1	168.8
1991/92	143.3	20.5	0.1	1.9	163.8	165.8
1992/93	105	16.8	0.2	1.7	121.7	123.7
1993/94	67.9	6	0.1	1.7	73.9	75.8
1994/95	34.2	3.9	0.1	3.5	38.2	41.8
1995/96	29.9	5.9	0.1	1.2	35.7	37
1996/97	54.6	6.4	0.1	0.8	60.9	61.9
1997/98	114.5	6.9	0	1.4	121.4	122.8
1998/99	88.3	4.9	0	0.9	93.2	94.1
1999/00	15.1	0.8	0	0.5	15.9	16.4
2000/01	11.5	0.6	0	0.3	12.1	12.5
2001/02	15	1.1	0	0.2	16.1	16.3
2002/03	12.9	1.1	0	0.2	14.1	14.3
2003/04	10.9	0.7	0	0.5	11.6	12.1
2004/05	11.3	0.6	0	0.8	11.9	12.6
2005/06	16.9	0.9	0	0.2	17.8	18.1
2006/07	16.6	1.4	0	0.6	18	18.6
2007/08	28.6	2.7	0	0.3	31.4	31.7
2008/09	26.6	2	0	0.2	28.6	28.9
2009/10	21.8	1.1	0	0.5	22.9	23.5
2010/11	24.6	1.1	0	0.2	25.7	26
2011/12	40.5	1.9	0.3	0.2	42.4	42.8
2012/13	30.1	2.9	0	0.2	32.9	33.2
2013/14	25	3.6	0.1	0.2	28.6	28.8

Table 3. Observed survey female, male and total spawning biomass(1000t) and numbers of males > 101mm (millions of crab).

Year	Observed survey female mature biomass	CV female mature biomass	Observed survey male mature biomass	CV male mature biomass	Observed survey total mature biomass	Observed number of males > 101mm (millions)
1978/79	153.0	0.2	193.1	0.12	346.2	163.4
1979/80	323.7	0.2	240.3	0.12	564.1	169.1
1980/81	364.9	0.2	193.8	0.12	558.7	133.9
1981/82	195.9	0.2	107.7	0.12	303.6	40.7
1982/83	213.3	0.2	173.1	0.12	386.4	60.9
1983/84	125.4	0.2	146.0	0.12	271.5	65.2
1984/85	70.4	0.4	161.2	0.24	231.5	139.9
1985/86	12.5	0.4	69.6	0.24	82.1	71.5
1986/87	47.7	0.4	87.3	0.24	135.1	77.1
1987/88	294.7	0.2	192.1	0.12	486.8	130.5
1988/89	276.9	0.125	251.6	0.12	528.5	170.2
1989/90	427.3	0.32	299.1	0.095	726.4	162.4
1990/91	312.1	0.185	442.4	0.105	754.5	389.6
1991/92	379.2	0.19	430.5	0.145	809.6	418.8
1992/93	242.4	0.2	238.5	0.12	480.9	232.5
1993/94	237.3	0.2	178.3	0.12	415.6	124.4
1994/95	216.8	0.16	163.6	0.15	380.4	71.2
1995/96	257.0	0.115	209.5	0.105	466.5	63.0
1996/97	161.7	0.145	281.7	0.09	443.4	154.8
1997/98	157.5	0.195	319.9	0.09	477.4	280.2
1998/99	124.3	0.255	201.1	0.12	325.4	208.4
1999/00	51.4	0.195	89.5	0.10	140.9	82.1
2000/01	152.4	0.435	88.9	0.14	241.3	65.7
2001/02	131.4	0.28	129.2	0.185	260.6	67.6
2002/03	50.5	0.295	90.2	0.195	140.8	63.1
2003/04	74.2	0.285	73.0	0.20	147.3	52.3
2004/05	84.5	0.28	75.8	0.16	160.3	56.0
2005/06	158.2	0.17	119.5	0.16	277.7	61.5
2006/07	109.6	0.17	134.5	0.18	244.2	118.7
2007/08	121.4	0.26	147.3	0.15	268.7	124.1
2008/09	86.4	0.22	121.6	0.10	208.0	97.7
2009/10	103.8	0.22	141.3	0.12	245.0	125.9
2010/11	145.1	0.156	157.3	0.142	302.4	137.6
2011/12	280.0	0.178	167.4	0.120	447.4	150.7
2012/13	220.6	0.198	120.8	0.143	341.4	87.0
2013/14	195.1	0.185	96.1	0.125	291.2	73.6
2014/15	212.5	0.207	156.9	0.192	369.4	138.5

Table 4. Abundance estimates of females and males by size groups for the BSFRF net in the 2009 and 2010 study areas, the NMFS net in the study area, and the NMFS survey of the entire Bering Sea. Mature abundance uses the maturity curve.

		Females			Males	
	>25mm	>50mm	mature	>25mm	Mature	>100
2009 BSFRF Study	585.3	113.6	129.4	422.9	200.9	66.9
2009 NMFS Study	150.2	121.5	120.5	119.2	76.9	36.7
2009 NMFS Bering Sea	1773.5	828.7	1,143.9	1,225.0	463.8	147.2
2010 BSFRF Study	6372.1	2328.9	3459.4	3344.8	877.7	186.9
2010 NMFS Study	2509.2	919.0	1102.6	1318.9	402.8	68.8

Table 5. Observed male and female mature biomass for the 2009 and 2010 study areas.

Mature Biomass (1000 t) 2009 and 2010 Study areas.

	BSFRF		NMFS	
	Female	Male	Female	Male
2009 Obs	12.2	68.4	11.9	32.3
2009 Pred	12.6	54.4	10.3	41.0
2010 Obs	279.0	193.3	91.5	77.7
2010 Pred	203.9	176.3	163.3	132.7

Table 6. Base model estimates of population biomass (1000t), population numbers, male, female and total mature biomass(1000t) and number of males greater than 101 mm in millions. Recruits enter the population at the beginning of the survey year after molting occurs. * Numbers by length estimated in the first year, so recruitment estimates start in second year.

Year	Biomass (1000t 25mm+)	numbers (million crabs 25mm+)	Female mature biomass(1000t)	Male mature biomass(1 000t)	Total mature biomass (1000t)	Number of males >101mm (millions)	Recruit-ment (millions, 25 mm to 50 mm)	Male mature biomass at mating time(Feb of survey year+1) (1000t)	Full selection fishing mortality	Exp.rate of total male catch on mature male biomass
1978/79	605.2	11521.6	189.2	197.2	386.4	143.3	1608.8	141.7	0.45	0.15
1979/80	685.1	11418.7	254.2	177.5	431.7	120.8	1421.9	112.3	0.81	0.24
1980/81	762.4	11062.1	372.5	133.3	505.8	63.8	968.4	78.5	2.21	0.31
1981/82	793.8	10036.6	393.9	124.1	517.9	34.8	319.2	90.2	1.57	0.17
1982/83	803.4	8070.4	374.8	180.2	555	93.1	1301.8	140.4	0.4	0.09
1983/84	828.1	8670	330.2	273.9	604.1	226.1	2068.6	218.9	0.15	0.06
1984/85	873.8	10577.9	309.6	321.1	630.7	298.6	2669	240.6	0.28	0.12
1985/86	944.8	13054	331.2	311	642.3	289.5	4743.8	217.2	0.46	0.18
1986/87	1130.3	18924.3	383.2	275.8	659	227.7	763.4	184.4	0.65	0.21
1987/88	1223.6	15084.6	498.4	270.8	769.2	184.8	4501.8	166	1.33	0.3
1988/89	1403.6	20019.2	515.3	303.9	819.2	189	178.8	188.3	1.53	0.3
1989/90	1434.3	14785.6	570.8	372.3	943.1	246.5	580.7	241.1	1.14	0.27
1990/91	1378.8	12044.8	545.5	460.2	1005.6	355.9	713.8	239.5	2.01	0.43
1991/92	1171.5	10239.1	469.2	417.5	886.7	302.9	6601.7	206.5	2.59	0.46
1992/93	1222.7	20659.9	405.7	344.7	750.4	233.4	1429.3	184.8	2.29	0.42
1993/94	1251.1	17511.6	528.5	302.7	831.3	204.7	978.2	185.4	1.33	0.29
1994/95	1257.9	14688.5	585.5	264	849.5	126.5	250.9	185.2	0.95	0.17
1995/96	1230.5	11388.2	542.4	298.6	841	134.6	135	221.5	0.75	0.14
1996/97	1168.2	8825.6	462.7	426.1	888.8	313.8	193.3	305.8	0.57	0.17
1997/98	1019.6	7044.5	379.8	506.8	886.6	469.7	867.6	312	0.84	0.28
1998/99	793.8	6972.4	310.9	387.4	698.2	340	1012.5	236.1	0.9	0.28
1999/00	642.1	7154.4	276.2	259.4	535.6	198.9	319.1	203.1	0.21	0.07
2000/01	579.9	5955.7	265.4	211	476.4	155	298.6	165.9	0.21	0.07
2001/02	527.5	5070.5	241.8	179.1	420.9	121.9	672.9	135.6	0.36	0.11
2002/03	496.8	5163.5	210.3	168.5	378.8	116.1	1340.4	129	0.33	0.1
2003/04	512.9	6524.2	193.4	176.8	370.2	141.1	1997.3	138	0.22	0.08
2004/05	581.5	8764.7	206	177.8	383.7	150.9	654	138	0.21	0.08
2005/06	620.6	7647.1	248.6	170.1	418.7	134	845	126.2	0.37	0.12
2006/07	647.7	7302.3	258.1	174.2	432.3	124	172	129.9	0.4	0.12

Table 6 Cont.. Base model estimates of population biomass (1000t), population numbers, male, female and total mature biomass(1000t) and number of males greater than 101 mm in millions. Recruits enter the population at the beginning of the survey year after molting occurs. * Numbers by length estimated in the first year, so recruitment estimates start in second year.

Year	Biomass (1000t 25mm+)	numbers (million crabs 25mm+)	Female mature biomass(1000t)	Male mature biomass(1 000t)	Total mature biomass (1000t)	Number of males >101mm (millions)	Recruit-ment (millions, 25 mm to 50 mm)	Male mature biomas s at mating time(Fe b of survey year+1) (1000t)	Full selec tion fishin g morta lity	Exp.rat e of total male catch on mature male biomas s
2007/08	639.7	5725.7	248.7	206.2	454.9	155.7	192.5	145.3	0.59	0.18
2008/09	592.2	4645.7	220.9	239.4	460.3	204.5	1367.2	175.4	0.39	0.14
2009/10	574.7	6220.8	187.3	250.7	438.1	233	2353.1	189.3	0.26	0.11
2010/11	627.1	9251.2	192.8	231.9	424.7	218.6	808.9	170.7	0.32	0.13
2011/12	655.5	8265.3	247.2	202.9	450.1	178.7	1197	129.7	0.75	0.25
2012/13	674.1	8399.2	267.8	166.1	433.9	109.9	1609.6	109.1	0.99	0.23
2013/14	732.5	9348.5	270.8	179.5	450.3	110	1527	126.5	0.79	0.19
2014/15	804.1	9851.7	287.1	236.1	523.2	183	NA	NA	NA	NA

Table 6a. Base model predicted survey values for female, male and total mature biomass and numbers of males > 101mm (millions of crab).

	Predicted Female survey mature Biomass:	Predicted Male survey mature Biomass:	Predicted total survey mature Biomass:	model Predicted survey males>101 (millions)
1978	147.2	196.7	343.9	143.3
1979	191.1	176.3	367.4	120.8
1980	284.8	131.3	416.1	63.8
1981	304.3	121.6	425.8	34.8
1982	169.1	113.1	282.1	60.7
1983	149.5	174.3	323.8	147.2
1984	139.8	205.2	345.1	194.5
1985	149.1	198.4	347.4	188.6
1986	172.3	174.5	346.8	148.3
1987	223.5	169.5	393.0	120.4
1988	233.3	190.1	423.4	123.1
1989	309.1	226.4	535.5	151.4
1990	295.7	280.5	576.2	218.7
1991	254.4	254.6	509.0	186.1
1992	220.0	210.1	430.1	143.4
1993	286.0	183.8	469.9	125.8
1994	317.3	159.8	477.1	77.7
1995	294.1	181.2	475.3	82.7
1996	250.9	259.9	510.8	192.8
1997	206.0	309.9	515.9	288.6
1998	168.6	236.8	405.4	208.9
1999	149.7	158.4	308.1	122.2
2000	143.8	128.6	272.4	95.2
2001	131.1	109.1	240.2	74.9
2002	114.0	102.7	216.8	71.3
2003	104.8	107.9	212.8	86.7
2004	111.6	108.4	220.0	92.7
2005	134.6	103.5	238.1	82.3
2006	139.9	106.0	245.9	76.2
2007	134.8	125.7	260.5	95.6
2008	119.8	146.2	266.0	125.6
2009	101.6	153.3	254.9	143.2
2010	104.4	141.7	246.2	134.3
2011	133.8	123.6	257.5	109.8
2012	145.1	100.9	246.0	67.5
2013	146.7	109.2	255.9	67.6
2014	155.6	143.9	299.4	112.4

Table 7. Radiometric ages for male crabs for shell conditions 1 through 5. Data from Orensanz (unpub).

				Radiometric age	
Shell Condition	description	sample size	Mean	minimum	maximum
1	soft	6	0.15	0.05	0.25
2	new	6	0.69	0.33	1.07
3	old	3	1.02	0.92	1.1
4	very old	3	5.31	4.43	6.6
5	very very old	3	4.59	2.7	6.85

Table 8. Natural mortality estimates for Hoenig (1983), the 5% rule and the 1% rule, given the oldest observed age.

	Natural Mortality		
oldest observed age	Hoenig (1983) empirical	5% rule	1% Rule
10	0.42	0.3	0.46
15	0.28	0.2	0.30
17	0.25	0.18	0.27
20	0.21	0.15	0.23

Tables 9a-b. Projections using a multiplier on the F35% control rule for 2014/15 to 2024/25 fishery seasons. Median total catch (ABC_{tot} 1000 t), median retained catch (C_{dir} 1000 t), Percent mature male biomass at time of mating relative to B35. Values in parentheses are 90% CI. F is full selection fishing mortality. Base model $B_{35\%}$ = 142,909 t. $F_{35\%}$ = 1.40.

a) 100%OFL Base Model, 100% $F_{35\%}$ B35% = 142,909 t F35%=1.40

Year	**ABC_{tot} (1000t)**	**C_{dir} (1000t)**	**Percent MMB/ $B_{35\%}$**	**Full Selection Fishing Mortality**
2014/15	69(57.2,81.8)	60.3(50,71.3)	96.3(87.9,109.6)	1.34
2015/16	68.2(45.3,87)	60.5(40.7,76.3)	98.8(84.5,116.1)	1.32
2016/17	58.2(39.4,74.8)	49.7(34.6,64.2)	99(83,118.9)	1.32
2017/18	62.6(40.8,79.5)	52.6(35.4,67)	106.8(86.8,134)	1.34
2018/19	70.9(46.7,94.2)	60.2(41.6,77)	116.6(87.3,169.2)	1.33
2019/20	78.7(45.7,142.8)	67.4(40.6,117.8)	125.9(81.8,224.5)	1.33
2020/21	84.7(35.2,210.5)	73.7(30.6,179.5)	127.8(74.5,276.2)	1.32
2021/22	82(25.1,213.7)	71.1(21.9,189.7)	126.7(67.8,288.2)	1.29
2022/23	74.1(21.9,207.5)	64(19.2,181.9)	120.3(63.6,294.4)	1.29
2023/24	66.9(19.8,205.1)	57.2(16.7,178.3)	117.5(63.8,292)	1.27
2024/25	68.3(18.8,198.7)	57.3(15.9,171.2)	118.5(61.4,297.9)	1.28

b) 90% Catch at FOFL Base Model, B35% = 142,909 t. $F_{35\%}$ = 1.40.

Year	**ABC_{tot} (1000t)**	**C_{dir} (1000t)**	**Percent MMB/ $B_{35\%}$**	**Full Selection Fishing Mortality**
2014/15	62.1(51.3,71.5)	54.4(45.1,62.7)	100.3(91.3,115.6)	1.15
2015/16	64.8(42.6,81.8)	58(38.5,72.6)	105.5(90.9,123.1)	1.12
2016/17	56.2(37.5,70.9)	48.8(33.4,61.5)	105.7(89.1,126.3)	1.12
2017/18	58.8(38.9,75.3)	50.6(34.1,63.8)	113.8(93.6,142.2)	1.12
2018/19	66.3(44.9,87.9)	57.3(40.1,73.4)	124.8(94.4,178.8)	1.11
2019/20	73.8(44.6,131.9)	64(40,111.6)	135.2(88.5,239.9)	1.11
2020/21	79.9(34.6,191.3)	70.1(30.6,170.4)	138(80,297.7)	1.1
2021/22	77.6(24.7,200.4)	68.6(21.8,178.7)	137.4(72,316.3)	1.08
2022/23	72.5(21.7,195)	63.1(18.7,173.1)	131.1(67.8,325.3)	1.08
2023/24	64.9(19.5,195.1)	56.1(16.8,171.1)	127.8(68.1,321.1)	1.06
2024/25	66.5(18.4,187.1)	56.8(15.9,165)	129(66.4,327.6)	1.07

Table 10 cont. Base Model Parameters values for the base model, excluding recruitments, probability of maturing and fishing mortality parameters.

Parameter	Value	S.D. for estimated parameters	Estimated(Y/N)	Bounded (bounds)
Natural Mortality immature females and males	0.37	0.02	Y	0.05,0.46
Natural Mortality mature females	0.23		N	
Natural Mortality mature males	0.27	0.01	Y	0.05,0.46
Female intercept (a1) growth	-4.69	2.88	Y	0,10
Female slope(b1) growth	1.51	0.12	Y	
Female slope(b2) growth	1.07	0.02	Y	1,1.3
female delta	31.01	2.49	Y	
Male intercept(a1) growth	-29.82	10.86	Y	
Male slope (b1) growth	1.17	0.01	Y	
Male slope (b2) growth	2.54	0.47	Y	
male delta	25.58	1.13	Y	
female and male s (scale parameter smooth)	5.56	1.34	Y	
Alpha for gamma distribution of recruits	11.50		N	
Beta for gamma distribution of recruits	4.00		N	
Beta for gamma distribution female growth	0.75		N	
Beta for gamma distribution male growth	0.75		N	
Fishery selectivity total males slope	0.18	0.00	Y	0.1,0.5
Fishery selectivity total males length at 50%	106.23	0.12	Y	55,148
Fishery selectivity retention curve males slope	0.41	0.02	Y	0.05,0.5
Fishery selectivity retention curve males length at 50%	96.00	0.16	Y	85,120
Fishery discard selectivity female slope	0.32	0.01	Y	0.1,0.7
Fishery discard selectivity female length at 50%	66.70		N	
Trawl Fishery selectivity slope	0.10	0.00	Y	0.01,.3
Trawl Fishery selectivity length at 50%	95.91	1.49	Y	30,120
Survey Q 1978-1981 male	1.00	0.00	Y	0.2,1.0
Survey 1978-1981 length at 95% of Q male	60.15	2.88	Y	30,150
Survey 1978-1981 length at 50% of Q male	42.11	1.42	Y	0,150
Survey Q 1978-1981 Female	0.89	0.05	Y	0.04,2.0
Survey 1978-1981 length at 95% of Q female	60.15		Set equal to Male	
Survey 1978-1981 length at 50% of Q female	42.11		Set equal to Male	
Survey Q 1982-1988 male	0.65	0.05	Y	0.2,1.0
Survey 1982-1988 length at 95% of Q male	70.91	5.47	Y	50,160
Survey 1982-1988 length at 50% of Q male	43.29	2.10	Y	0,80
Survey Q 1982-1988 female	0.58		Y	0.04,2.0
Survey 1982-1988 length at 95% of Q female	70.91		Set equal to Male	50,160
Survey 1982-1988 length at 50% of Q female	43.29		Set equal to Male	0,80

Parameter	Value	S.D. for estimated parameters	Estimated(Y/N)	Bounded (bounds)
Survey Q 1989-present male	0.61	0.03	Y	0.2,1.0
Survey 1989-present, length at 95% of Q male	57.48	2.98	Y	40,200
Survey 1989-present length at 50% of Q male	38.34	1.11	Y	20,90
Female Survey Q 1989-present	0.55	0.03	Y	0.04,2.0
Female Survey 1989-present, length at 95% of Q	46.15	1.34	Y	40,150
Female Survey 1989-present length at 50% of Q	34.55	0.64	Y	0,90
Male BSFRF 2009 Study area Q (availability)	0.38	0.10	Y	0.1,1.0
Female BSFRF 2009 Study area Q (availability)	0.14		Y	0.01,1.0
Female BSFRF 2009 Study area length at 95% of Q	60.00	0.00	Y	50,120
Female BSFRF 2009 Study are length at 50% of Q	51.79	0.57	Y	-50.0,60.0
male BSFRF 2010 Study area Q (availability)	1.00	0.00	Y	0.2,1.0
Female BSFRF 2010 Study area Q (availability)	1.07	0.12	Y	0.5,2.0
Female BSFRF 2010 Study area length at 95% of Q	25		N	
Female BSFRF 2010 Study are length at 50% of Q	25		N	

Table 11. Weighting factors for likelihood equations.

Likelihood component	Weighting factor	Equivalent CV, SD or sample size
Retained catch	10	SD=0.22
Retained catch length comp	1	Sample size 200
Total catch	10	SD=0.22
Total catch length comp	1	Sample size 200
Female pot catch	10	SD=0.22
Female pot fishery length comp	0.2	Sample size 200
Trawl catch	10	SD=0.22
Trawl catch length comp	0.25	Sample size 200
Survey biomass	survey cv by year	See cv table
Survey length comp	1	Sample size 200
Recruitment deviations	1	CV=0.7
Fishing mortality average	1	SD=0.70
Fishing mortality deviations	0.1	CV=2.2
Initial length comp smoothness	1	SD=0.7

Table 12. Base Model estimated recruitments (male) and mature male biomass at mating with standard deviations. Recruits enter the population at the beginning of the survey year.

Survey year	Recruit (male,millions)	S.D.	MMB at mating (1000 tons)	S.D.
1978/79			141.67	11.40
1979/80	1,608.80	361.50	112.30	7.34
1980/81	1,421.90	326.54	78.46	5.50
1981/82	968.43	251.85	90.24	5.85
1982/83	319.16	140.67	140.45	9.71
1983/84	1,301.80	247.80	218.91	15.43
1984/85	2,068.60	360.59	240.62	18.01
1985/86	2,669.00	435.21	217.25	17.27
1986/87	4,743.80	574.48	184.40	14.64
1987/88	763.38	272.79	166.02	12.18
1988/89	4,501.80	460.56	188.28	12.27
1989/90	178.79	75.56	241.15	13.53
1990/91	580.74	105.34	239.52	12.76
1991/92	713.79	156.77	206.50	11.10
1992/93	6,601.70	669.06	184.80	10.62
1993/94	1,429.30	280.96	185.41	10.99
1994/95	978.25	158.46	185.22	11.82
1995/96	250.92	79.94	221.50	14.44
1996/97	135.00	48.64	305.78	18.59
1997/98	193.27	68.65	312.00	19.27
1998/99	867.64	154.68	236.06	16.82
1999/00	1,012.40	176.37	203.12	14.20
2000/01	319.14	89.37	165.92	11.90
2001/02	298.61	86.85	135.57	10.37
2002/03	672.86	134.56	128.98	9.82
2003/04	1,340.40	221.41	137.95	9.85
2004/05	1,997.30	266.46	138.01	9.49
2005/06	654.00	163.44	126.24	8.93
2006/07	845.03	141.51	129.90	9.08
2007/08	172.01	58.45	145.29	10.31
2008/09	192.50	52.57	175.40	11.57
2009/10	1,367.20	184.57	189.34	11.08
2010/11	2,353.00	363.01	170.73	9.51
2011/12	808.89	229.65	129.75	8.55
2012/13	1,197.10	274.26	109.11	9.27
2013/14	1,609.60	354.66	126.55	12.63
2014/15	1,527.00	446.73		

Table 13. Likelihood values for base model and other 9 model scenarios.

Likelihood Component	Model 0	Model 1	Model 2a	Model 2b Base Model	Model 2c	Model 2d	Model 2e	Model 2f	Model 2g
Scenario	13-Sep	Two line growth	grwt 1	grwt 2	grwt 3	0.5 fpen	.25 fpen	.1 fpen	.001 fpen
Discard mortality	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Recruitment	34.24	33.26	34.45	33.85	33.98	34.06	34.47	34.93	35.99
Initial numbers old shell males small length bins	2.20	2.22	2.17	2.22	2.23	2.32	2.29	2.33	2.55
ret fishery length	352.48	347.03	351.76	355.11	356.75	350.81	347.81	343.76	325.45
total fish length	778.00	778.78	775.80	777.80	779.67	775.99	774.87	772.88	769.94
female fish length	213.85	219.54	218.82	214.58	214.28	215.05	213.83	213.72	213.67
survey length	3773.97	3787.75	3785.73	3778.39	3792.45	3786.20	3771.44	3770.69	3773.23
trawl length	269.85	272.42	288.74	272.80	273.86	270.81	268.46	267.14	265.91
2009 BSFRF length	-83.50	-83.31	-85.49	-83.20	-83.36	-83.27	-83.49	-83.67	-84.16
2009 NMFS study area length	-70.97	-70.81	-71.53	-70.60	-70.35	-70.55	-70.50	-70.41	-70.30
M prior	5.84	11.38	17.64	10.59	10.44	10.42	9.97	9.57	9.10
maturity smooth	51.98	65.23	57.00	56.03	58.62	54.99	52.50	50.82	47.37
growth males	43.75	32.06	28.43	43.29	44.89	43.96	43.98	45.92	50.10
growth females	52.42	20.28	32.09	47.79	49.90	47.45	50.34	51.05	52.87
2009 BSFRF biomass	0.17	0.14	0.16	0.17	0.18	0.19	0.20	0.22	0.25
2009 NMFS study area biomass	0.08	0.05	0.07	0.08	0.08	0.09	0.11	0.13	0.16
retained catch	3.76	3.80	3.84	3.65	3.81	3.70	3.78	3.84	3.96
discard catch	139.92	148.72	131.35	135.85	144.40	136.16	137.75	135.89	129.81
trawl catch	9.46	9.67	9.76	9.82	9.81	7.92	7.07	4.69	0.93
female discard catch	5.93	5.76	5.99	5.83	5.76	4.85	3.30	2.75	2.47
survey biomass	183.11	181.97	173.87	181.52	181.94	181.19	183.50	183.65	187.62
F penalty	80.06	80.66	77.22	80.17	80.04	49.12	32.16	20.25	2.31
2010 BSFRF Biomass	2.29	1.85	2.62	2.18	2.27	2.28	2.35	2.53	2.84
2010 NMFS Biomass	1.24	0.84	0.90	1.29	1.21	1.41	1.58	1.80	2.18
initial numbers fit	506.67	559.26	503.58	507.99	508.32	525.33	508.07	507.83	509.78
2010 BSFRF length	-54.05	-52.84	-50.60	-55.49	-53.84	-55.64	-56.04	-56.26	-57.02
2010 NMFS length	-66.92	-63.75	-63.46	-65.85	-64.31	-65.83	-65.75	-65.58	-65.48
male survey selectivity smooth constraint	3.79	4.03	4.34	3.70	3.83	3.66	3.62	3.56	3.44
init nos smooth constraint	39.66	34.19	38.30	39.45	39.63	35.58	40.06	40.29	42.40
Total	6279.29	6330.20	6273.55	6289.02	6326.49	6268.26	6217.74	6194.32	6157.38

Table 13. Differences in Likelihood values for 9 model scenarios relative to Base model (negative values are better fits than Base Model).

Likelihood Component	Model 0	Model 1	Model 2a	Model 2b Base Model	Model 2c	Model 2d	Model 2e	Model 2f	Model 2g
Scenario	13-Sep	Two line growth	grwt 1	grwt 2	grwt 3	0.5 fpen	.25 fpen	.1 fpen	.001 fpen
Discard mortality	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Recruitment	0.39	-0.59	0.60	0.00	0.13	0.21	0.62	1.08	2.13
Initial numbers old shell males small length bins	-0.02	0.00	-0.05	0.00	0.01	0.10	0.07	0.11	0.33
ret fishery length	-2.63	-8.09	-3.35	0.00	1.63	-4.30	-7.31	-11.36	-29.66
total fish length	0.20	0.99	-2.00	0.00	1.87	-1.81	-2.93	-4.92	-7.86
female fish length	-0.73	4.96	4.24	0.00	-0.30	0.47	-0.75	-0.86	-0.91
survey length	-4.42	9.36	7.34	0.00	14.06	7.81	-6.95	-7.70	-5.16
trawl length	-2.94	-0.38	15.94	0.00	1.06	-1.99	-4.34	-5.66	-6.89
2009 BSFRF length	-0.30	-0.10	-2.29	0.00	-0.16	-0.06	-0.29	-0.47	-0.95
2009 NMFS study area length	-0.36	-0.20	-0.93	0.00	0.25	0.05	0.11	0.19	0.31
M prior	-4.75	0.78	7.04	0.00	-0.15	-0.17	-0.62	-1.02	-1.50
maturity smooth	-4.06	9.20	0.97	0.00	2.59	-1.04	-3.53	-5.21	-8.66
growth males	0.46	-11.23	-14.86	0.00	1.60	0.67	0.69	2.63	6.81
growth females	4.63	-27.51	-15.70	0.00	2.11	-0.34	2.55	3.26	5.08
2009 BSFRF biomass	-0.01	-0.03	-0.01	0.00	0.00	0.01	0.02	0.04	0.08
2009 NMFS study area biomass	-0.01	-0.03	-0.02	0.00	0.00	0.01	0.02	0.04	0.08
retained catch	0.11	0.14	0.19	0.00	0.15	0.04	0.13	0.19	0.31
discard catch	4.07	12.87	-4.51	0.00	8.55	0.30	1.89	0.04	-6.04
trawl catch	-0.36	-0.15	-0.06	0.00	-0.01	-1.90	-2.76	-5.13	-8.89
female discard catch	0.10	-0.07	0.16	0.00	-0.07	-0.98	-2.53	-3.08	-3.37
survey biomass	1.59	0.46	-7.65	0.00	0.42	-0.33	1.98	2.13	6.10
F penalty	-0.10	0.50	-2.95	0.00	-0.12	-31.05	-48.01	-59.91	-77.86
2010 BSFRF Biomass	0.12	-0.32	0.44	0.00	0.09	0.10	0.17	0.36	0.67
2010 NMFS Biomass	-0.04	-0.44	-0.39	0.00	-0.08	0.13	0.30	0.51	0.90
initial numbers fit	-1.32	51.27	-4.41	0.00	0.33	17.34	0.08	-0.16	1.80
2010 BSFRF length	1.43	2.64	4.89	0.00	1.65	-0.15	-0.55	-0.78	-1.54
2010 NMFS length	-1.07	2.10	2.39	0.00	1.54	0.02	0.10	0.27	0.37
male survey selectivity smooth constraint	0.09	0.33	0.64	0.00	0.13	-0.04	-0.09	-0.14	-0.26
init nos smooth constraint	0.21	-5.26	-1.15	0.00	0.18	-3.87	0.61	0.84	2.95
Total	-9.73	41.18	-15.48	0.00	37.47	-20.76	-71.28	-94.71	-131.64

Table 14. Reference values for 9 model scenarios.

Model	0	1	2a	2b	2c	2d	2e	2f	2g
	Sept 2013 model	Two line model	Model gr wt 1	Base Model Gr wt 2	Model gr wt 3	0.5 F penalty	0.25 F penalty	0.1 F penalty	0.001 F penalty
B35%	141.9	148.9	141.3	142.9	143.7	141.3	139.7	137.3	134.1
F35%	1.5	1.6	1.5	1.4	1.4	1.5	1.5	1.6	2.0
OFL 2014/15	67.1	81.2	83.6	69.0	70.6	66.9	63.6	59.3	52.7
ABC(p*=.49) 2014/15	66.9	80.9	83.3	68.8	70.3	66.6	63.4	59.1	52.6
ABC(90%OFL) 2014/15	60.4	73.1	75.2	62.1	63.5	60.2	57.2	53.4	47.4
Percent MMB/B35% 2013/14	94.7	99.9	99.9	96.3	97.3	95.4	93.4	91.7	87.8
Survey Q 1989-present	0.61	0.57	0.59	0.61	0.61	0.63	0.64	0.65	0.68
M mature males	0.27	0.27	0.28	0.27	0.27	0.27	0.27	0.27	0.27

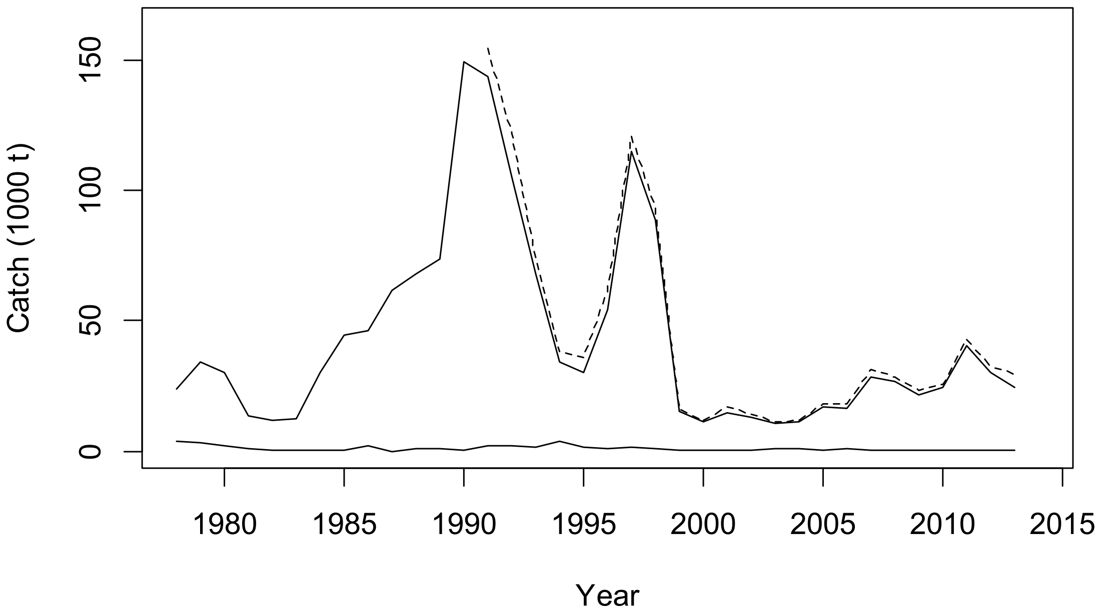


Figure 1. Catch (1000 t) from the directed snow crab pot fishery and groundfish trawl bycatch. Total catch (dashed line) is retained catch(solid line) plus discarded catch after 30% discard mortality was applied. Trawl bycatch (lower solid line) is male and female bycatch from groundfish trawl fisheries with 80% mortality applied.

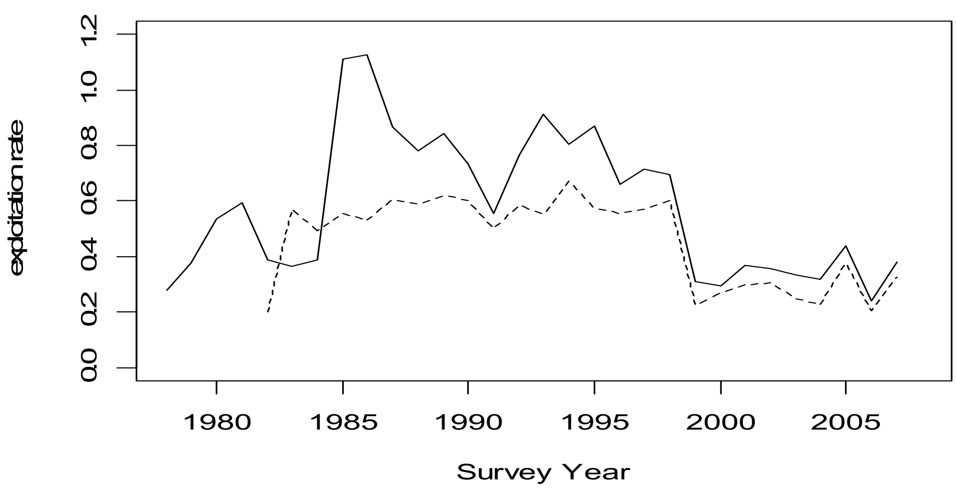


Figure 2. Exploitation rate estimated as the preseason GHL divided by the survey estimate of large male biomass (>101 mm) at the time the survey occurs (dotted line). The solid line is the retained catch divided by the survey estimate of large male biomass at the time the fishery occurs. Year is the survey year.

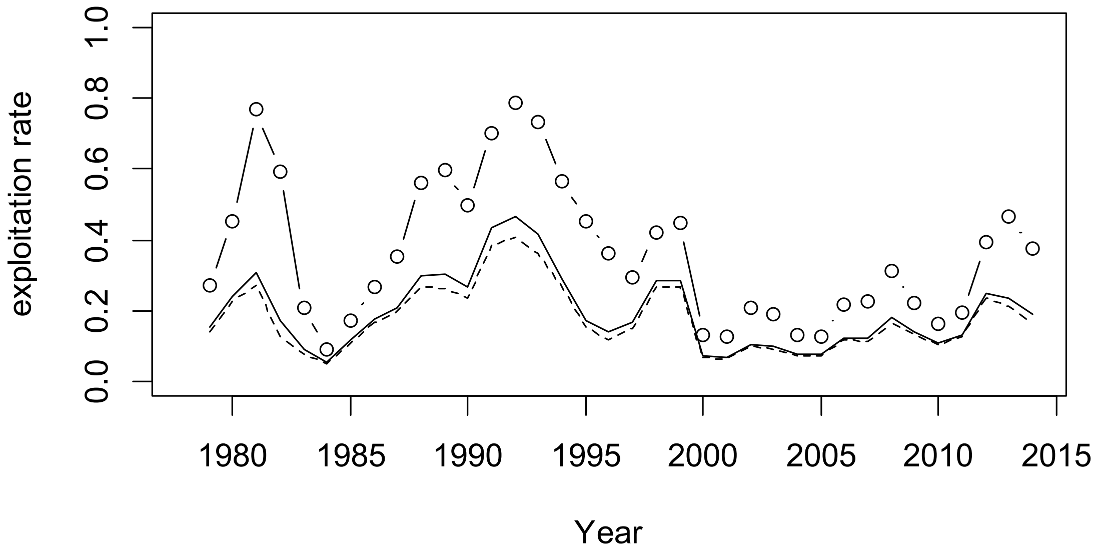


Figure 3. Base Model. Exploitation fraction estimated as the catch biomass (total or retained) divided by the mature male biomass from the model at the time of the fishery (solid line is total and dotted line is retained). The exploitation rate for total catch divided by the male biomass greater than 101 mm is the solid line with dots. Year is the year of the fishery.

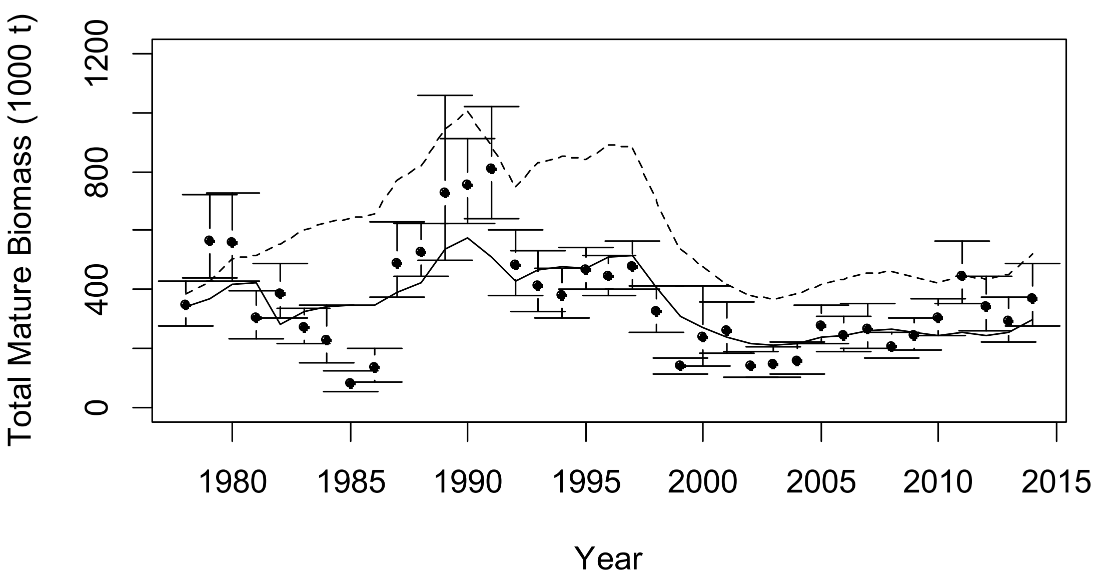


Figure 4. Population total mature biomass (millions of pounds, solid line), model estimate of survey

mature biomass (dotted line) and observed survey mature biomass with approximate lognormal 95% confidence intervals.

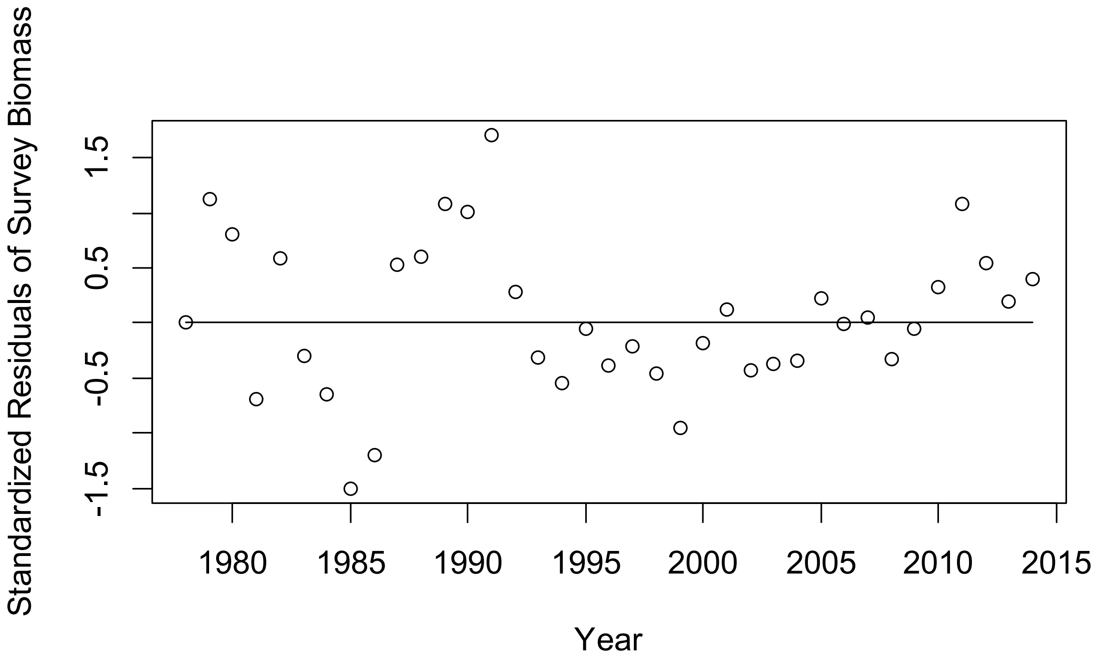


Figure 5. Standardized residuals for model fit to total mature biomass from Figure 4.

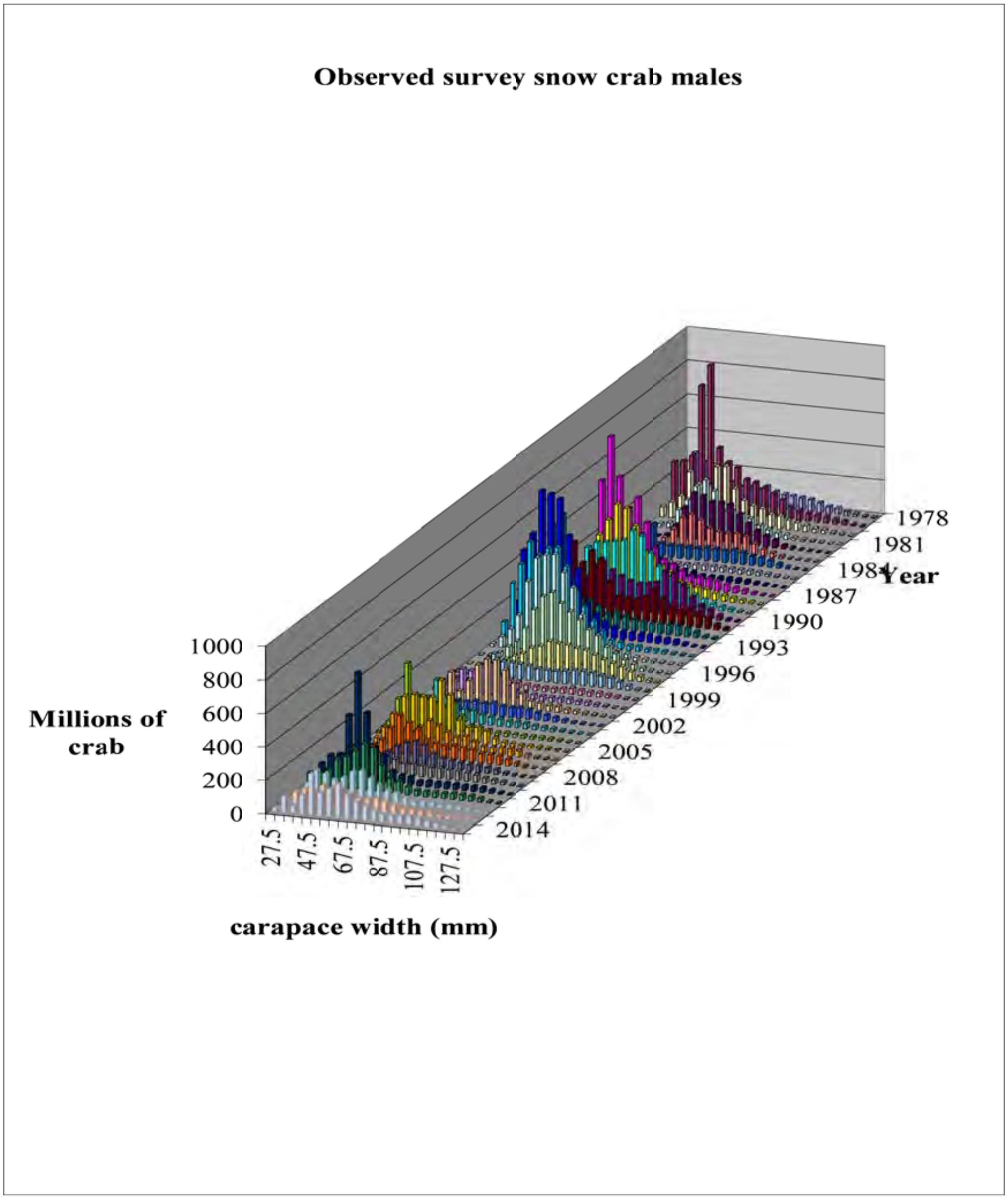


Figure 6. Observed survey numbers (millions of crab) by carapace width and year for male snow crab.

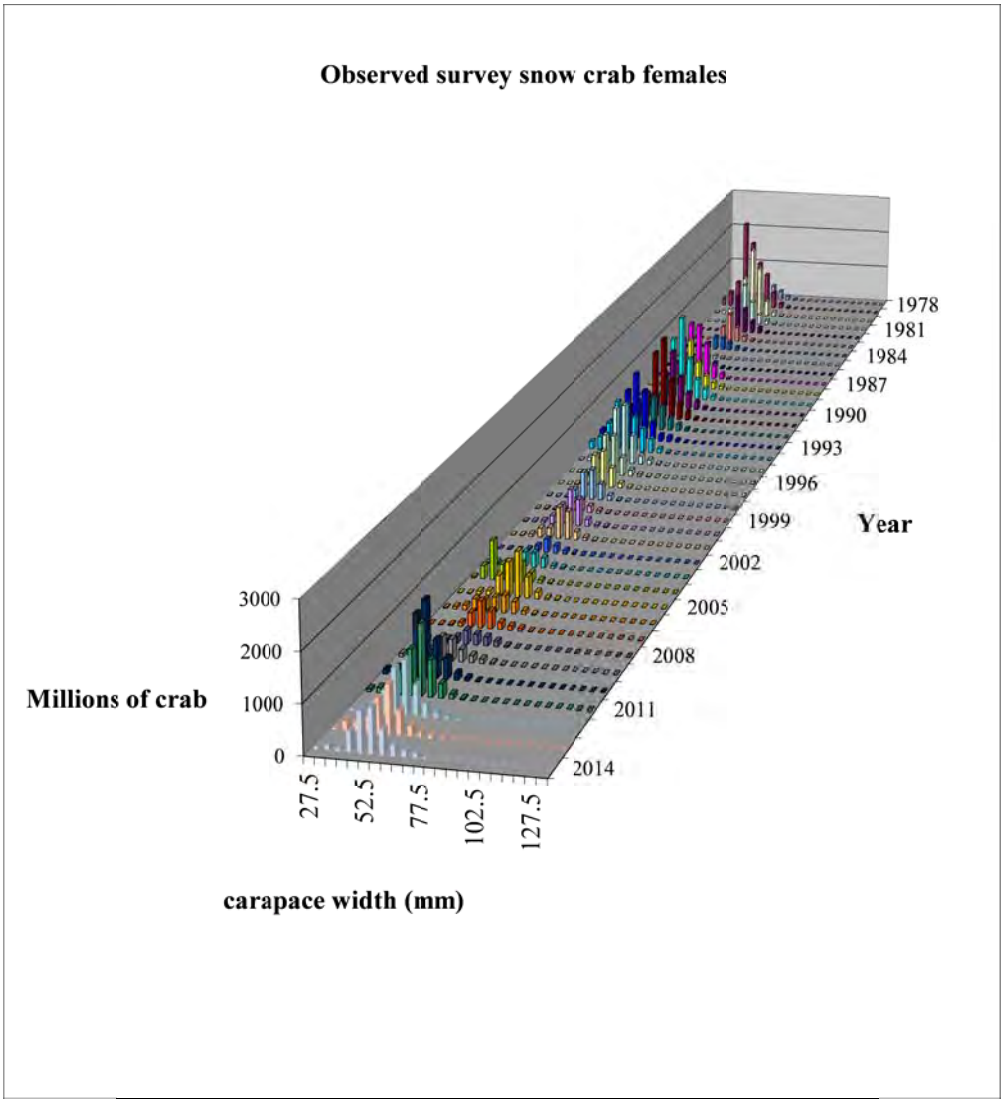


Figure 7. Observed survey numbers (millions of crab) by carapace width and year for female snow crab.

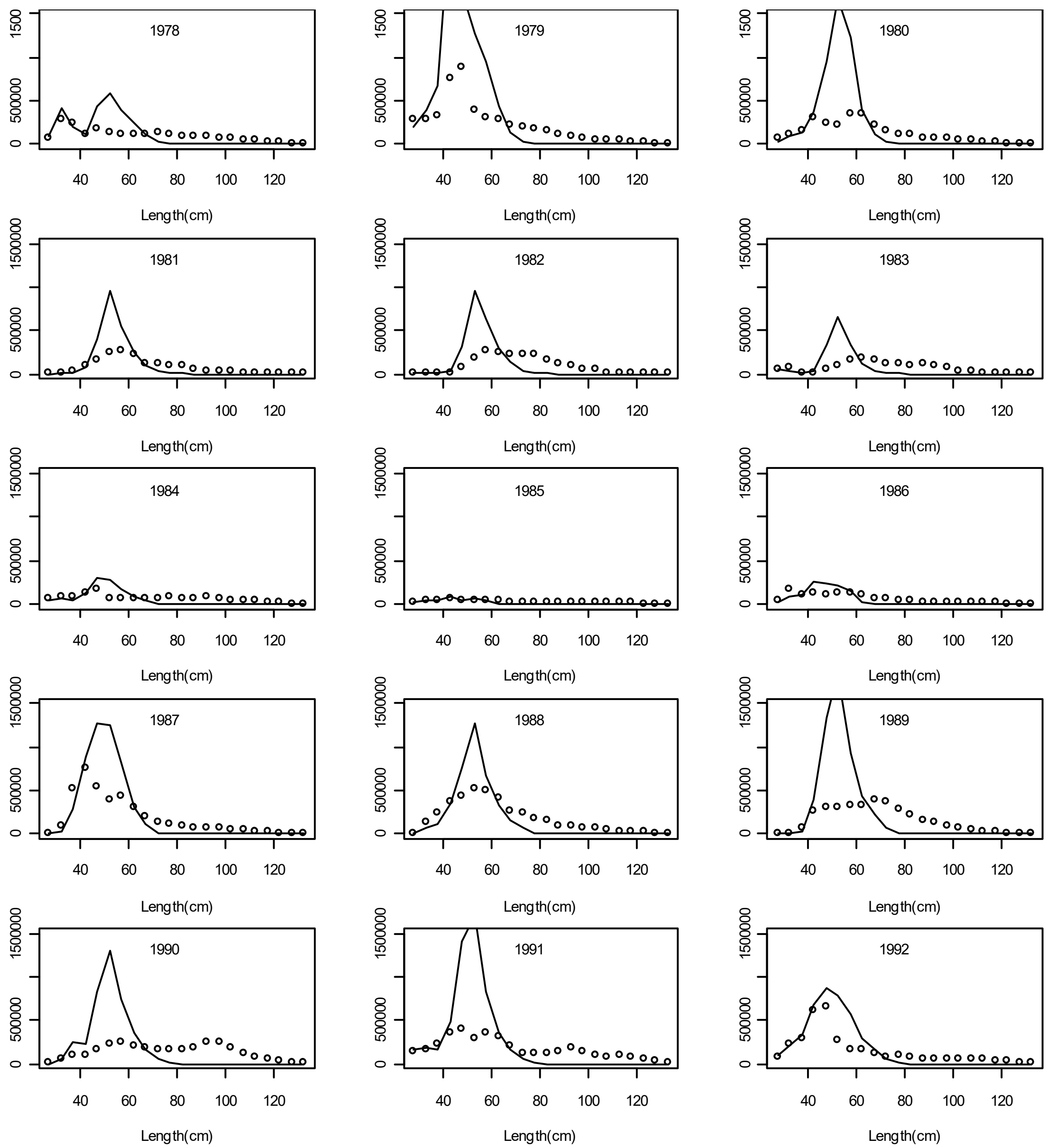


Figure 8. Observed survey numbers 1978 to 1992 by length, males circles, females solid line.

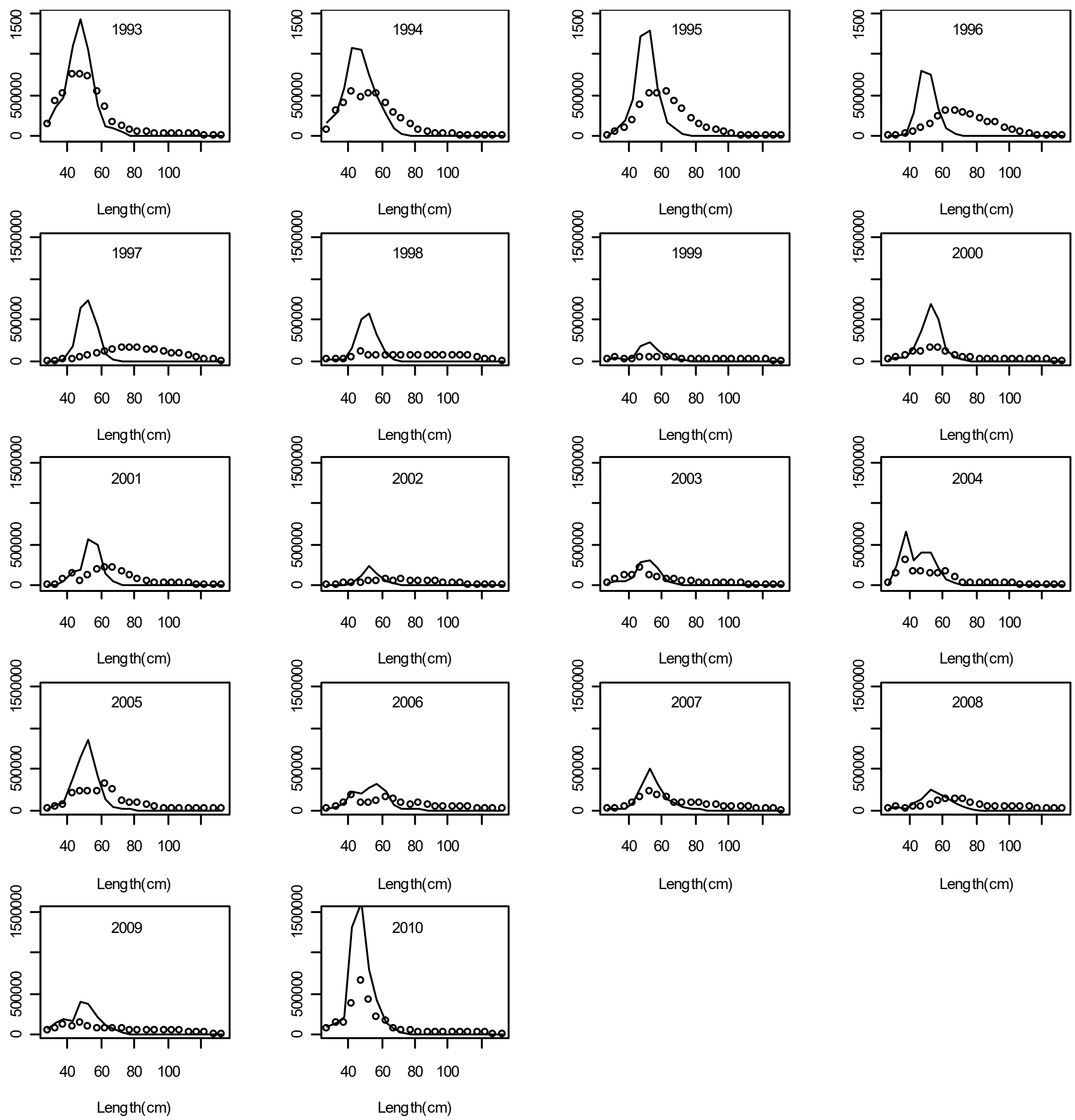


Figure 8 continued. Observed survey numbers 1993 to 2010 by length, males circles, females solid line.

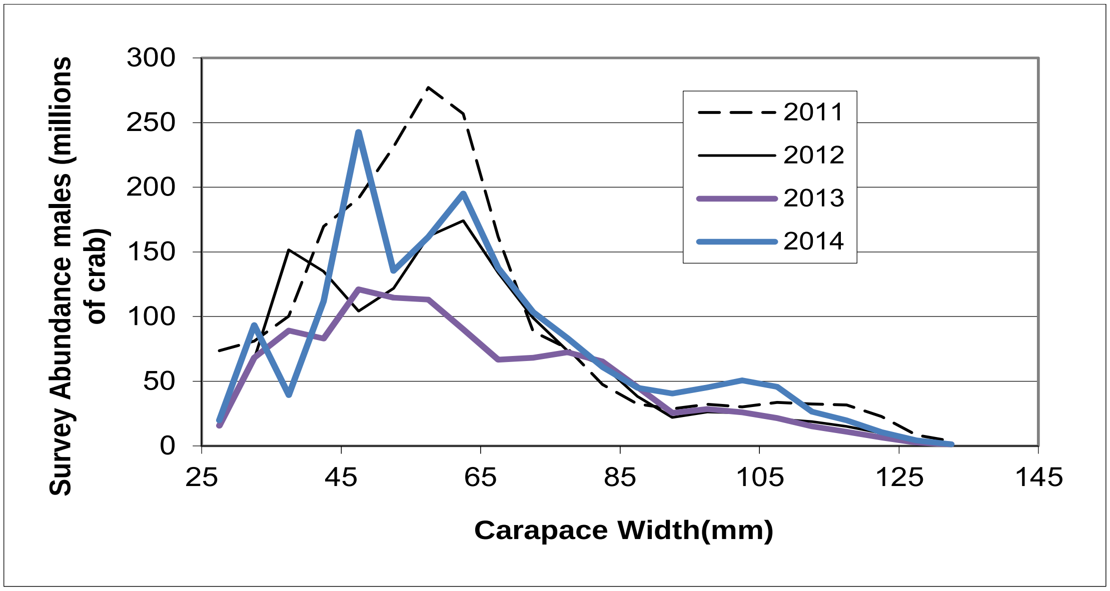


Figure 8a. Survey male abundance by length for 2011 to 2014.

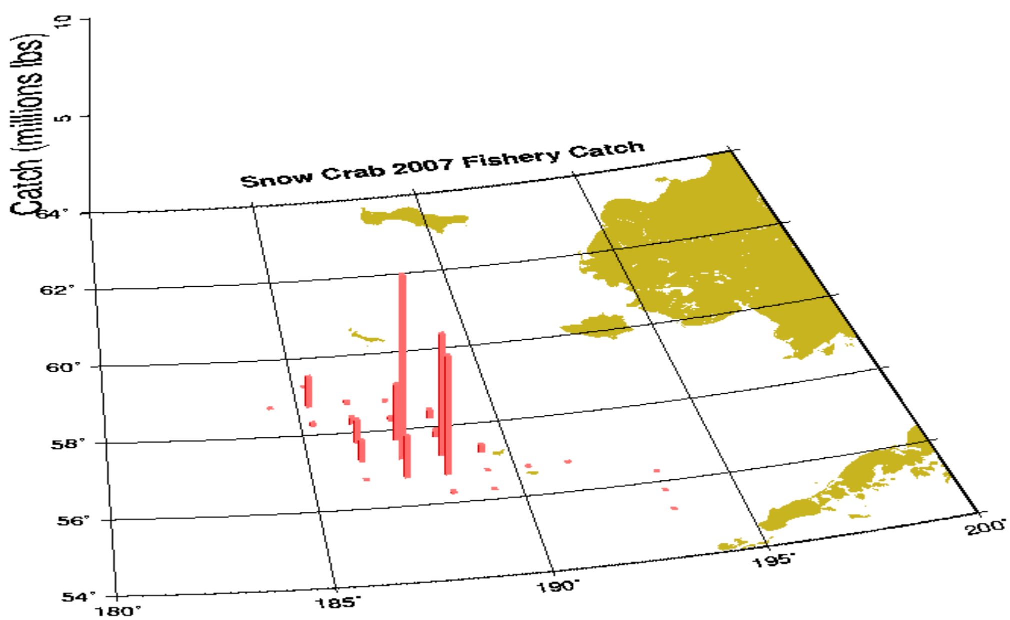


Figure 9. 2006/07 snow crab pot fishery retained catch(million lbs) by statistical area. Longitude increases from west to east (190 degrees = 170 degrees W longitude). Areas are 1 degree longitude by 0.5 degree latitude.

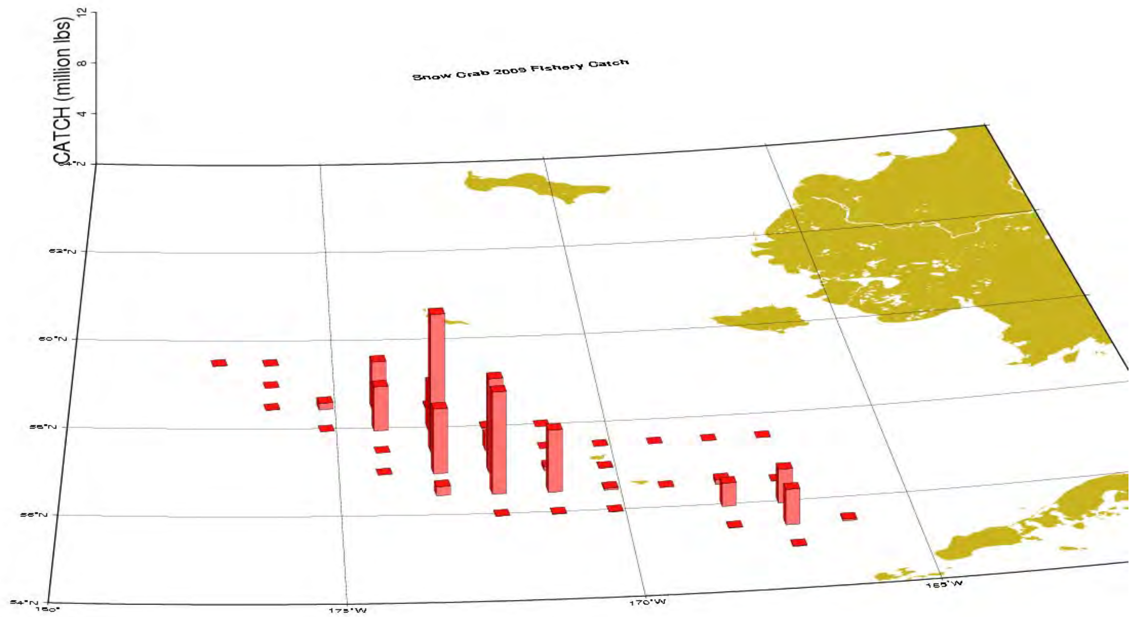


Figure 10. 2008/09 snow crab pot fishery retained catch(million lbs) by statistical area. Statistical areas are 1 degree longitude by 0.5 degree latitude.

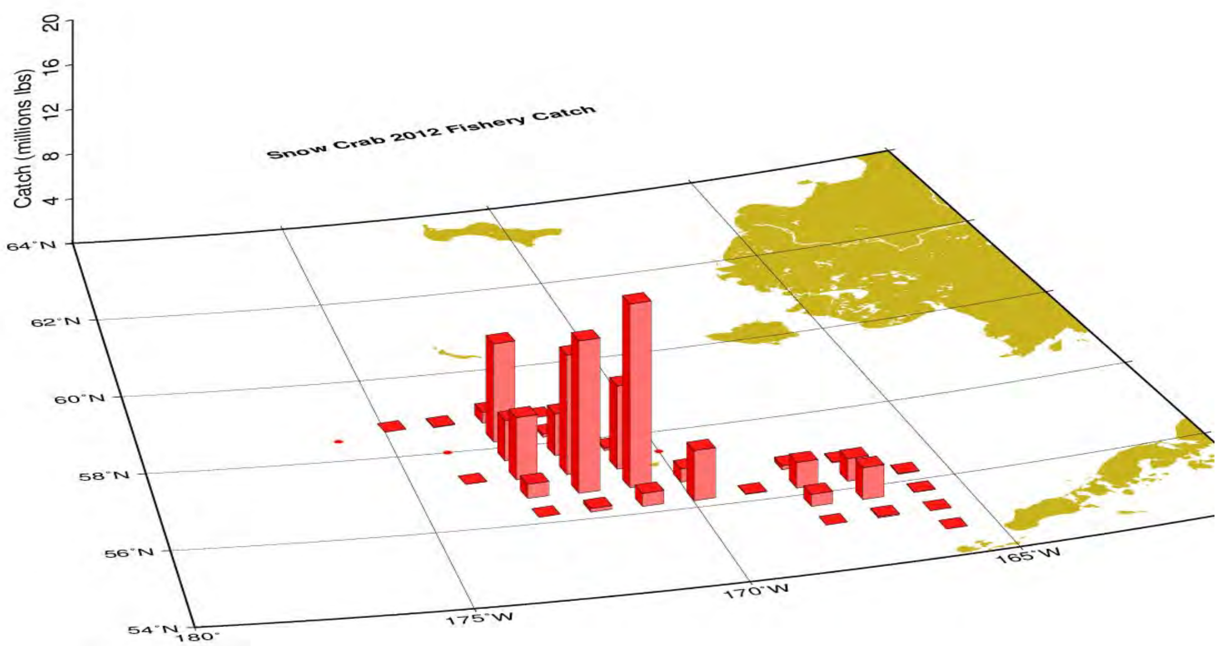


Figure 11. 2011/12 snow crab pot fishery retained catch(million lbs) by statistical area. Statistical areas are 1 degree longitude by 0.5 degree latitude.

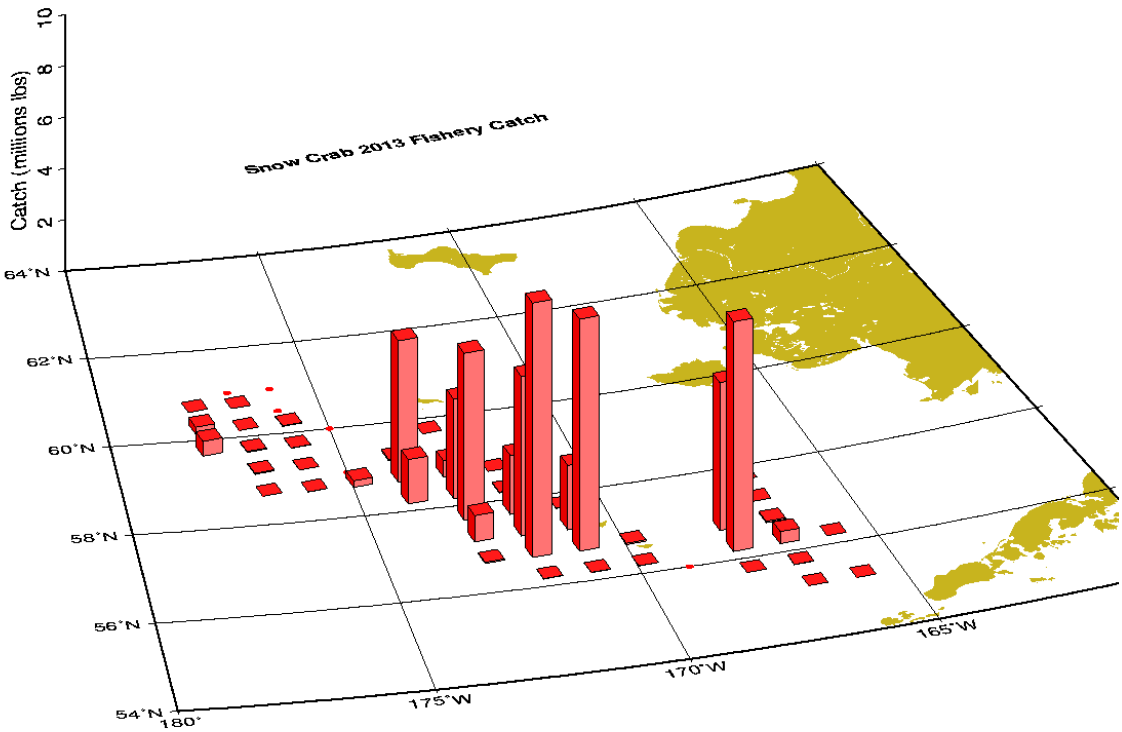


Figure 11b. 2012/13 snow crab pot fishery retained catch(million lbs) by statistical area. Statistical areas are 1 degree longitude by 0.5 degree latitude.

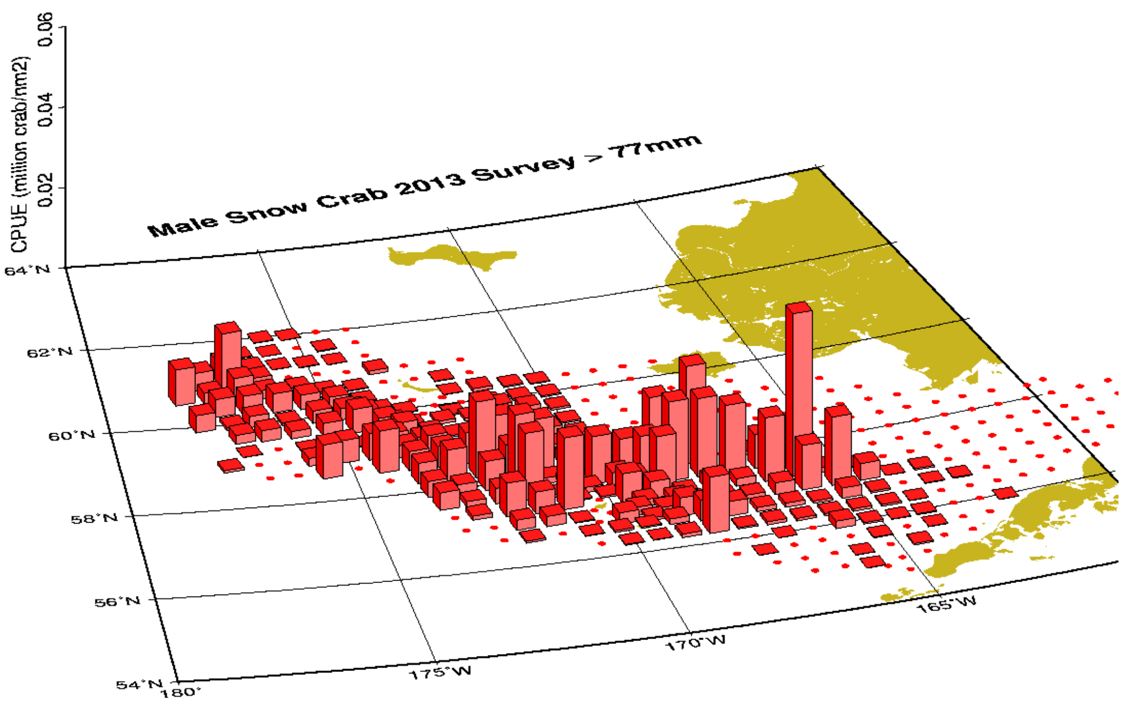


Figure 12. 2013 Survey CPUE (million crab per nm2) of males > 77mm by tow. Filled circles are tows with 0 cpue.

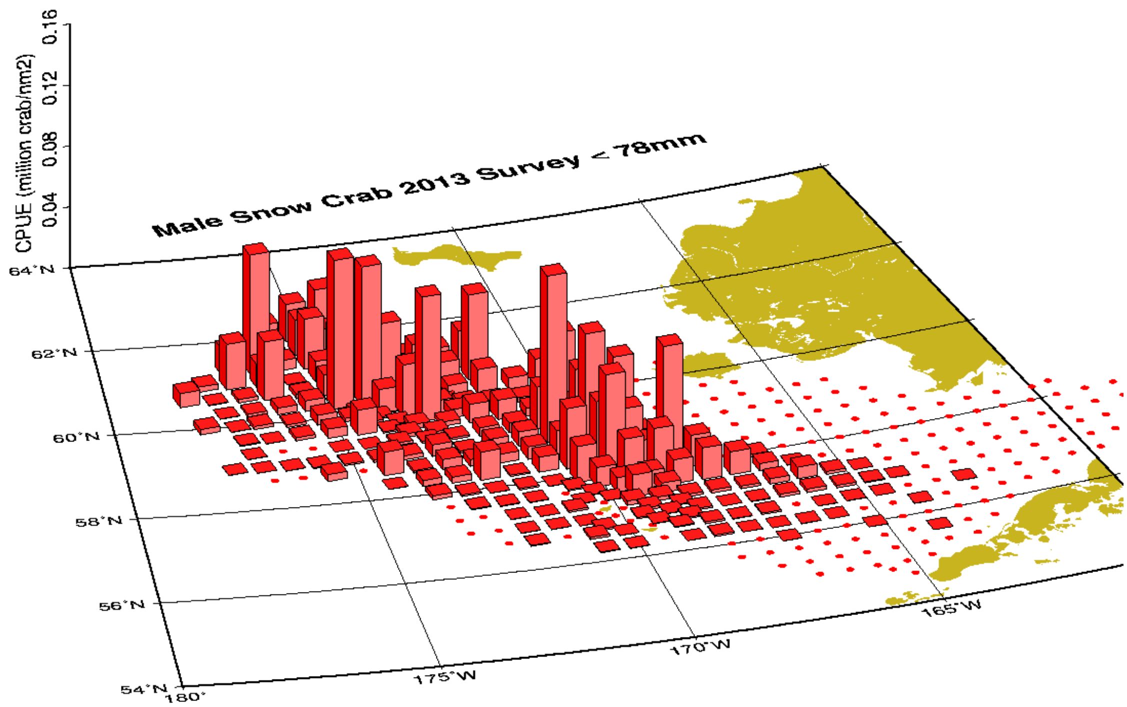


Figure 13. 2013 Survey CPUE (million crab per nm2) of males < 78mm by tow. Filled circles are tows with 0 cpue.

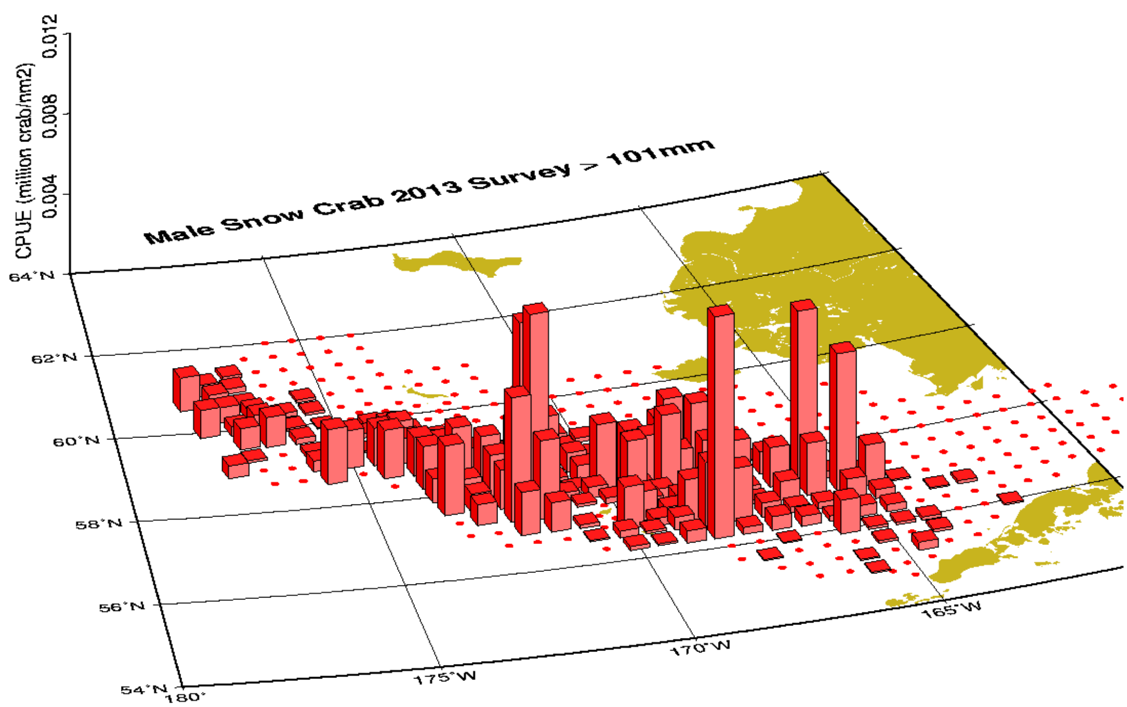


Figure 14. 2013 Survey CPUE (million crab per nm2) of males > 101mm by tow. Filled circles are tows with 0 cpue.

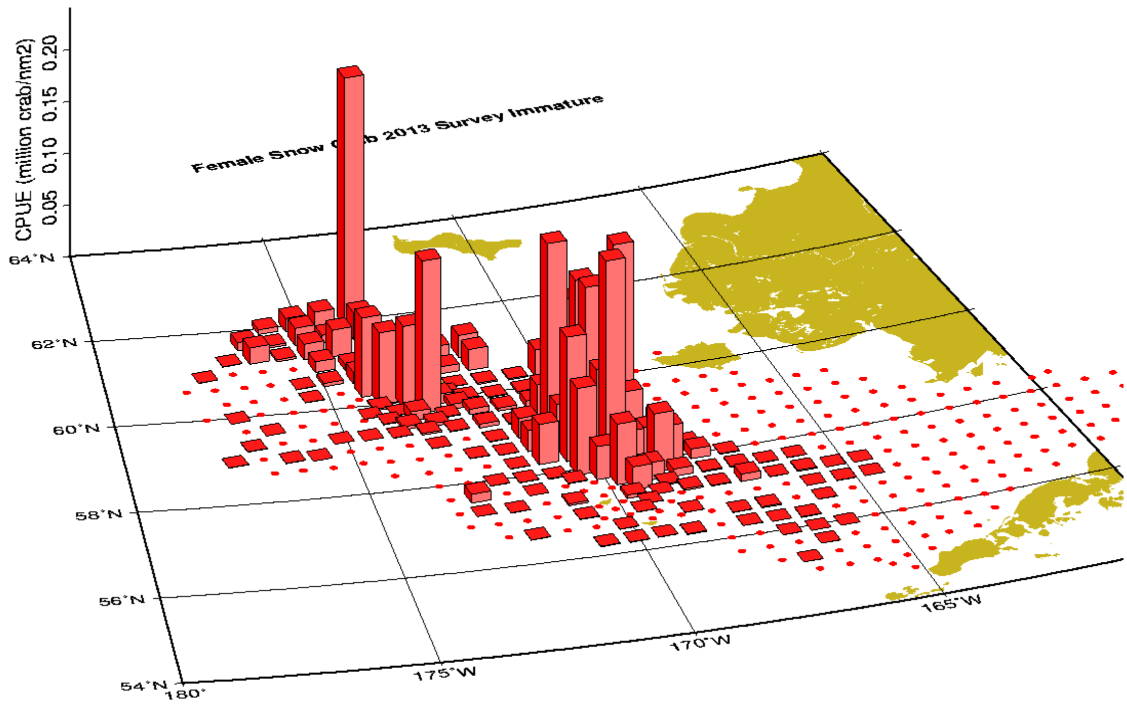


Figure 15. 2013 Survey CPUE (million crab per nm2) of immature females by tow. Filled circles are tows with 0 cpue.

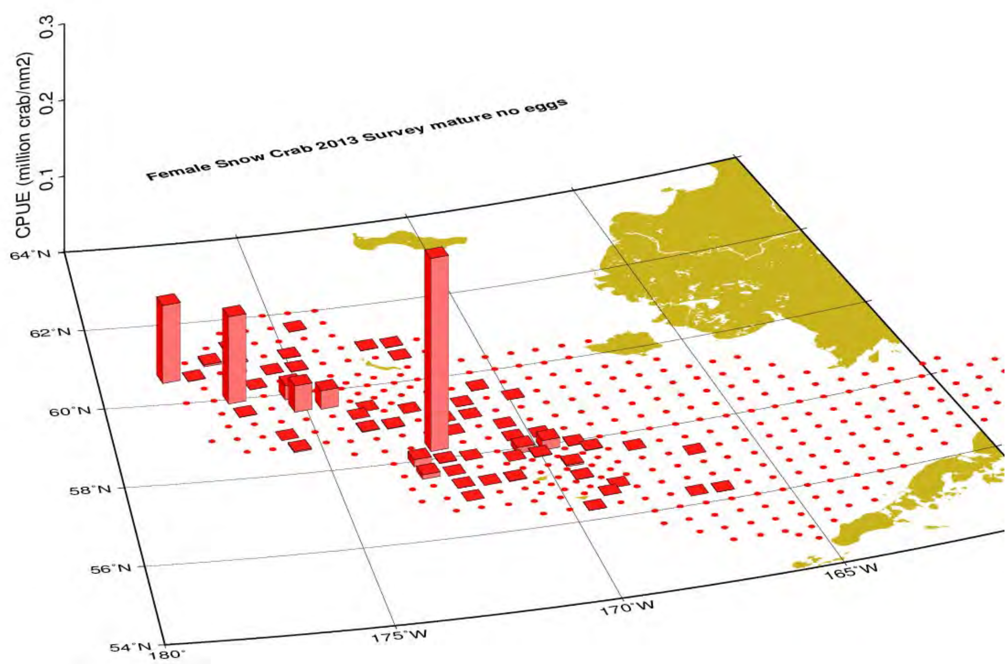


Figure 16. 2013 Survey CPUE (million crab per nm2) of mature females with no eggs by tow. Filled circles are tows with 0 cpue.Figure 25g. 2013 Survey CPUE (million crab per nm2) of mature females with eggs by tow. Filled circles are tows with 0 cpue.

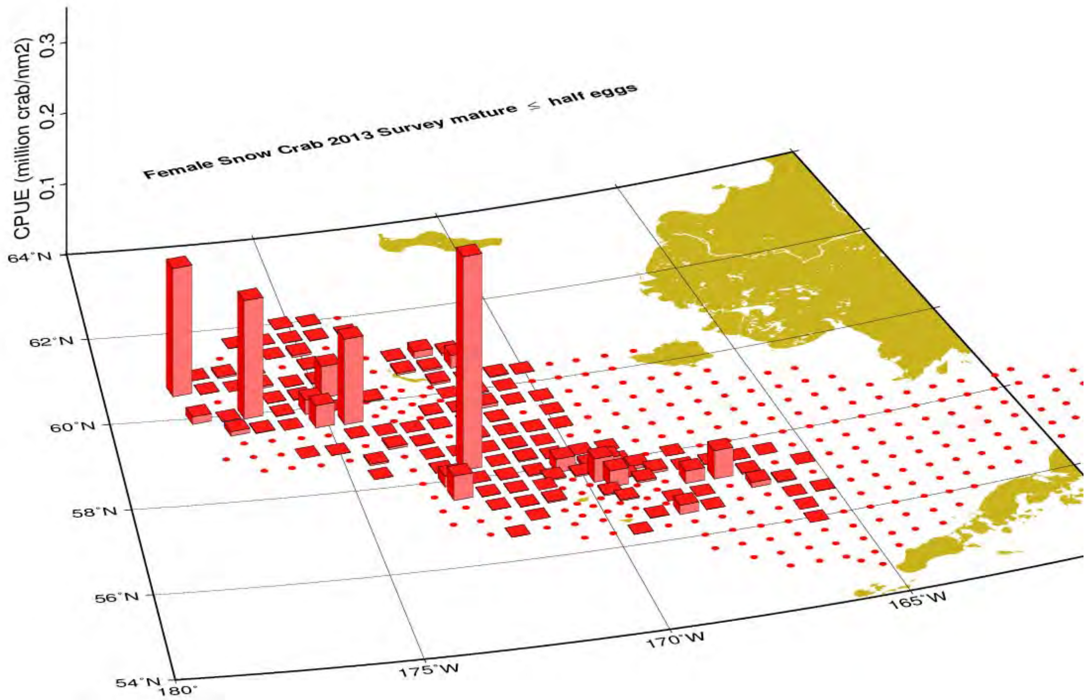


Figure 17. 2013 Survey CPUE (million crab per nm2) of mature females with <= half clutch of eggs by tow. Filled circles are tows with 0 cpue.

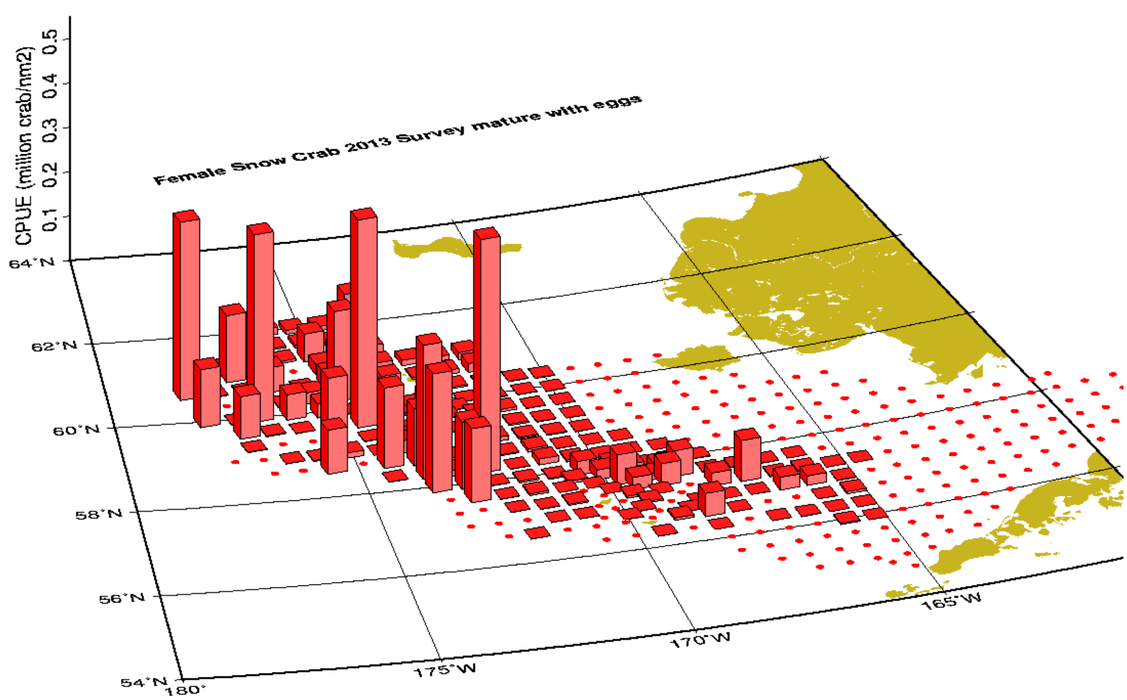


Figure 18. 2013 Survey CPUE (million crab per nm2) of mature females with eggs by tow. Filled circles are tows with 0 cpue.

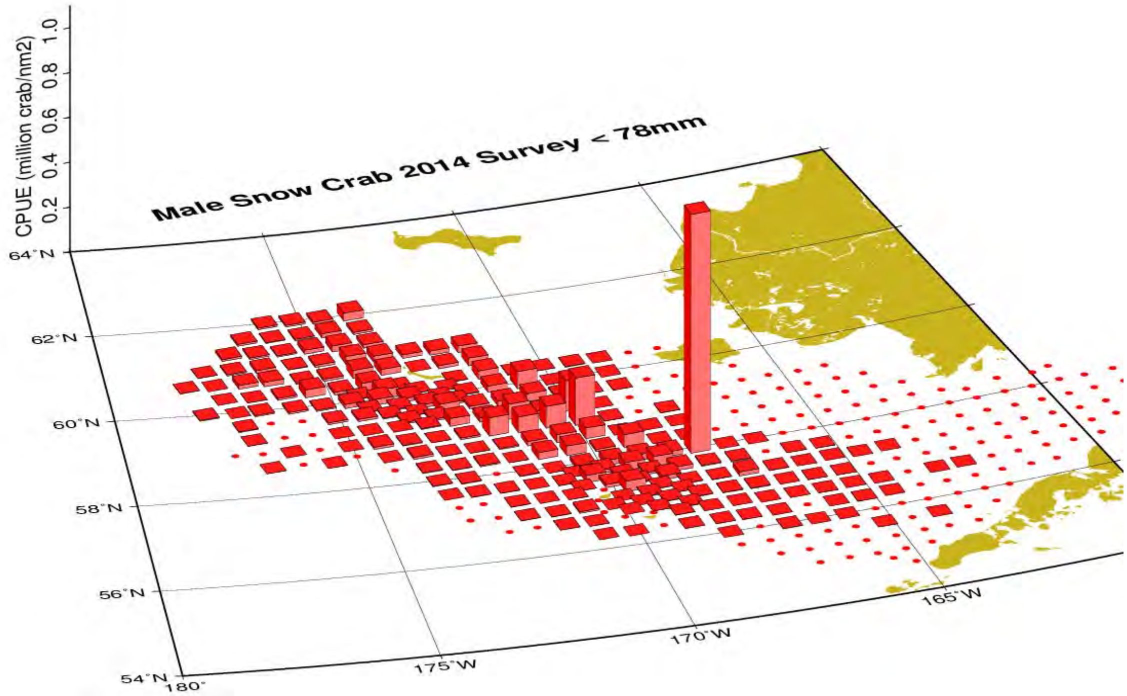


Figure 19. 2014 Survey CPUE (million crab per nm2) of males < 78mm by tow. Filled circles are tows with 0 cpue.

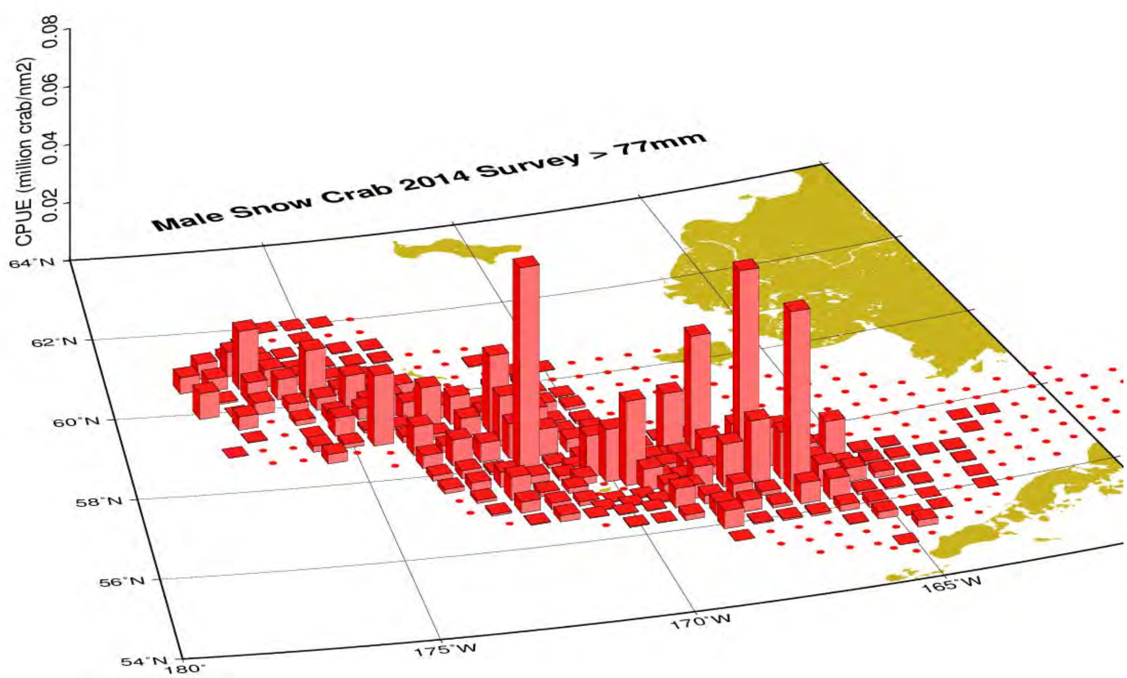


Figure 20. 2014 Survey CPUE (million crab per nm2) of males > 77mm by tow. Filled circles are tows with 0 cpue.

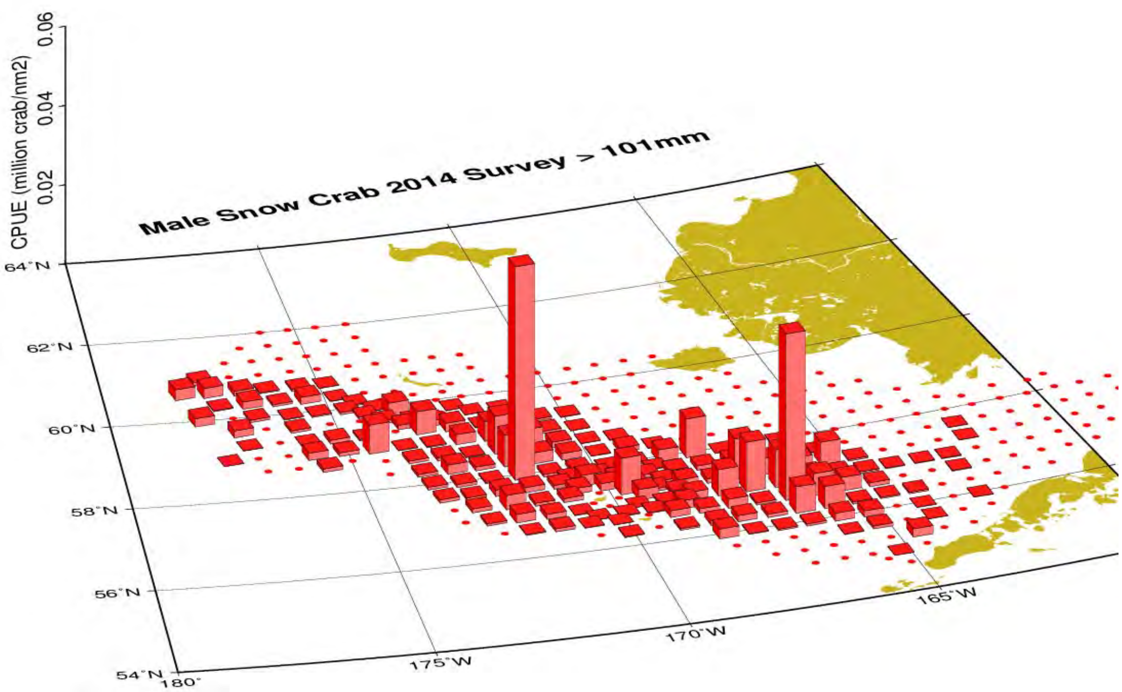


Figure 21. 2014 Survey CPUE (million crab per nm2) of males > 101mm by tow. Filled circles are tows with 0 cpue.

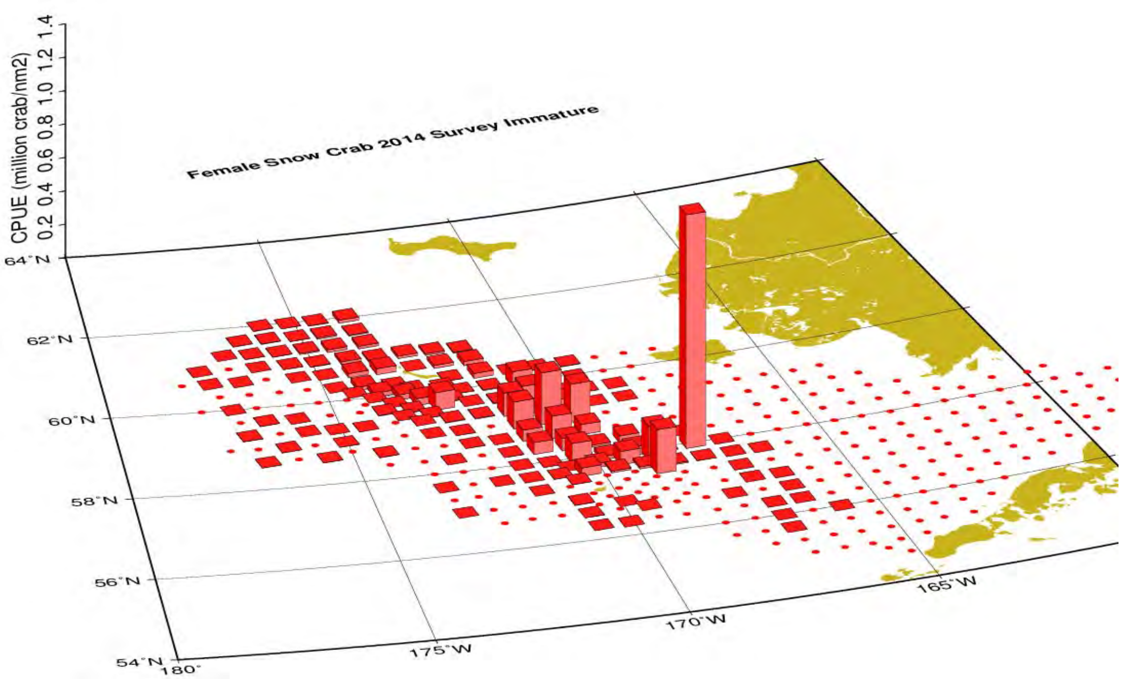


Figure 22. 2014 Survey CPUE (million crab per nm2) of immature females by tow. Filled circles are tows with 0 cpue.

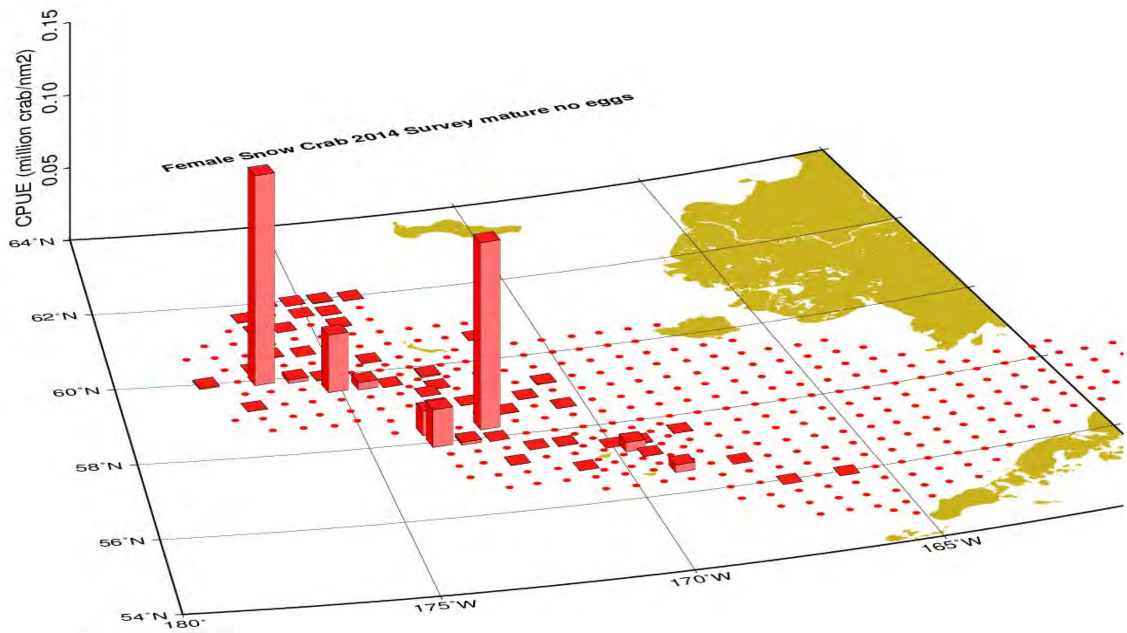


Figure 23. 2014 Survey CPUE (million crab per nm2) of mature females with no eggs by tow. Filled circles are tows with 0 cpue.

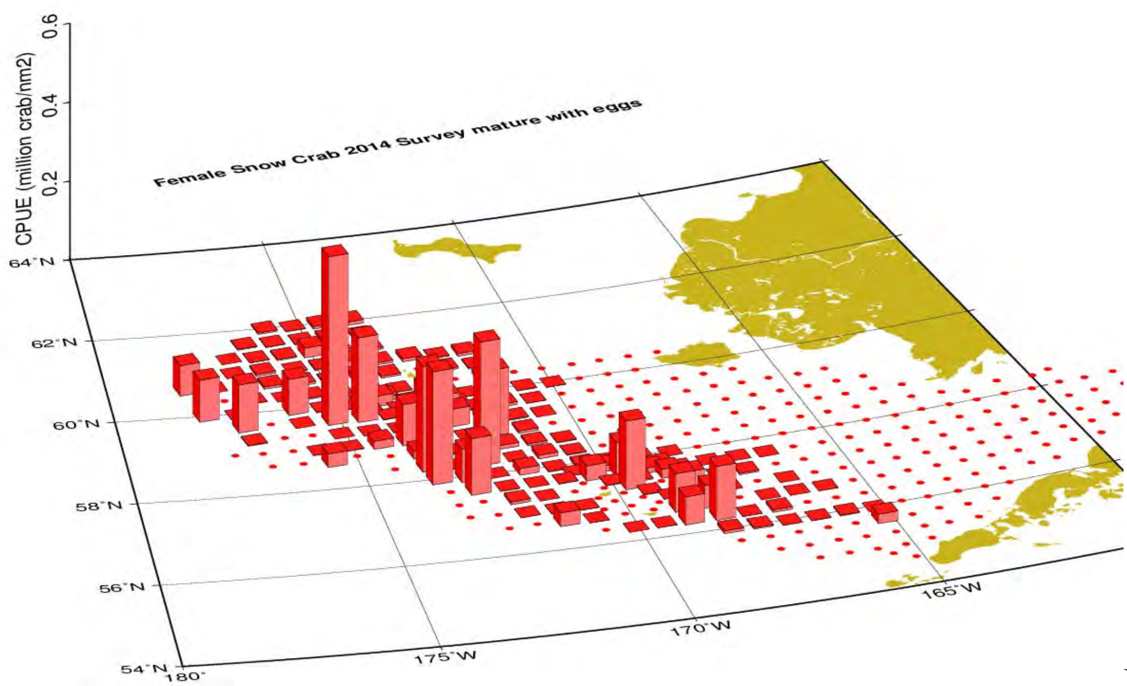


Figure 24. 2014 Survey CPUE (million crab per nm2) of mature females with eggs (all clutch sizes) by tow. Filled circles are tows with 0 cpue.

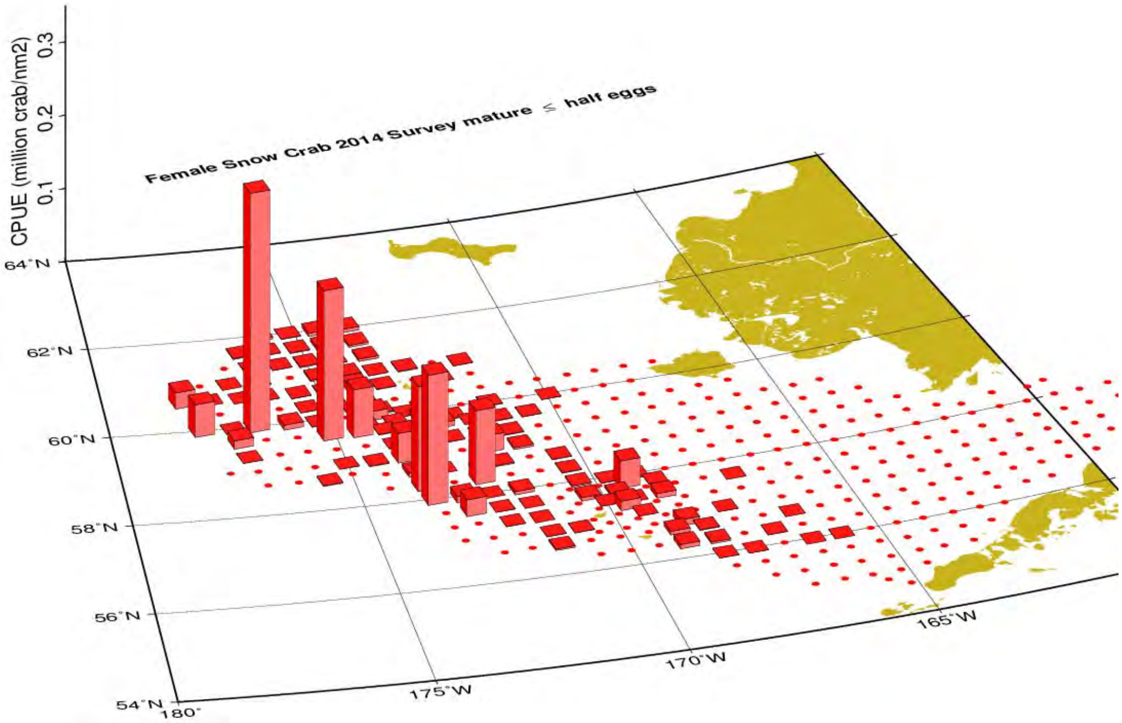


Figure 25. 2014 Survey CPUE (million crab per nm2) of mature females with <= half clutch of eggs by tow. Filled circles are tows with 0 cpue.

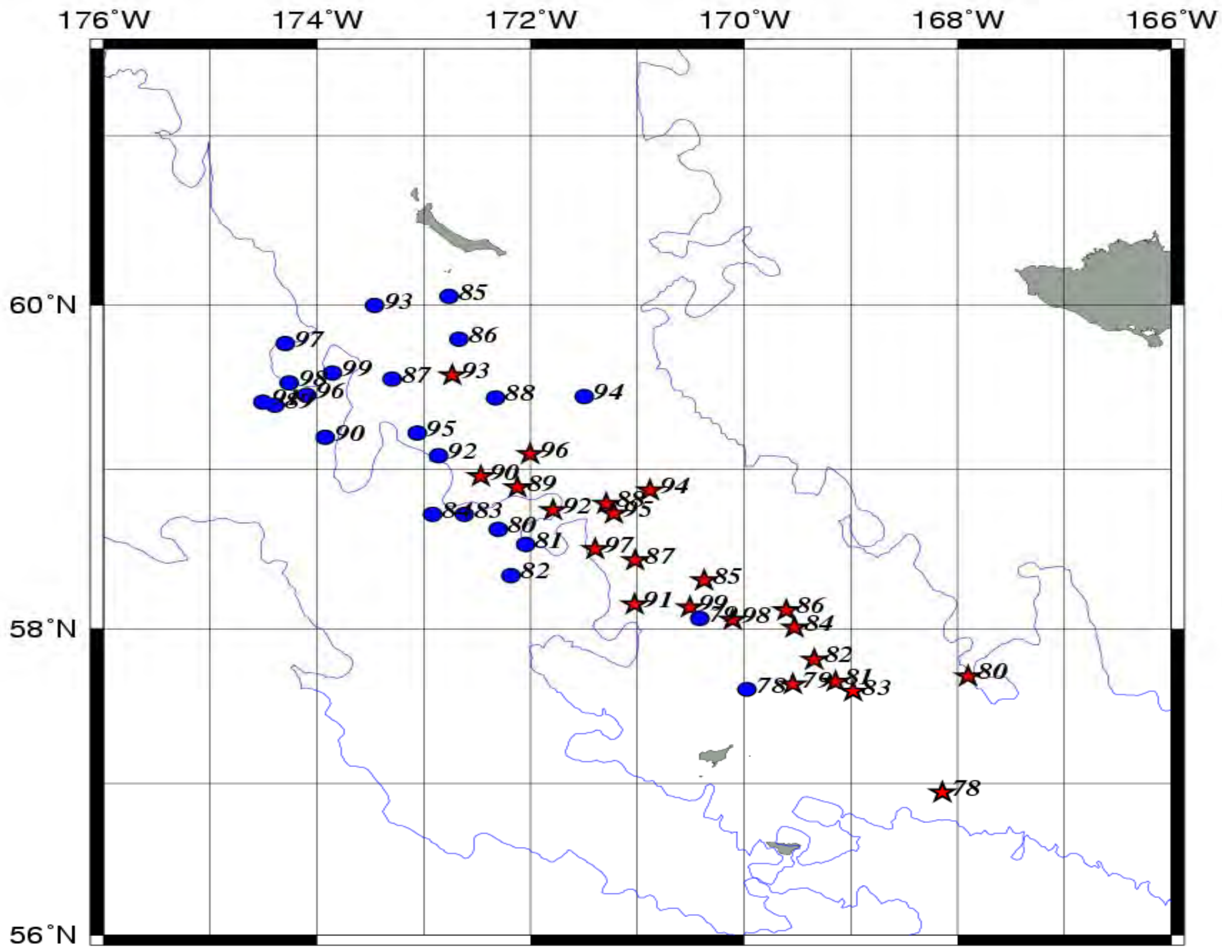


Figure 26. Centroids of abundance of mature female snow crabs (shell condition 2+) in blue circles and mature males (shell condition 3+) in red stars (Ernst, et al. 2005).

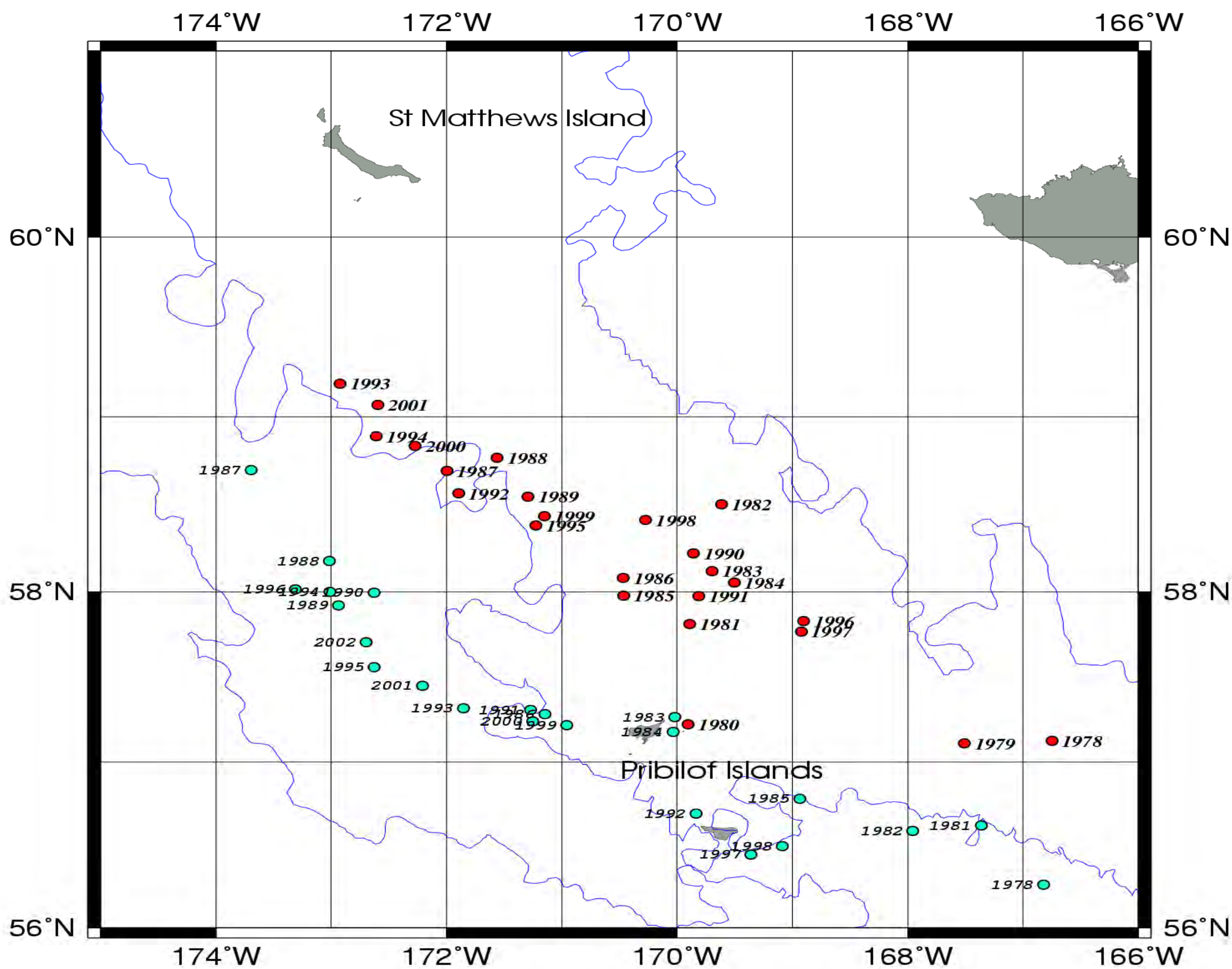


Figure 27. Centroids abundance (numbers) of snow crab males > 101 mm from the summer NMFS trawl survey (red) and from the winter fishery (blue-green) (Ernst, et al. 2005).

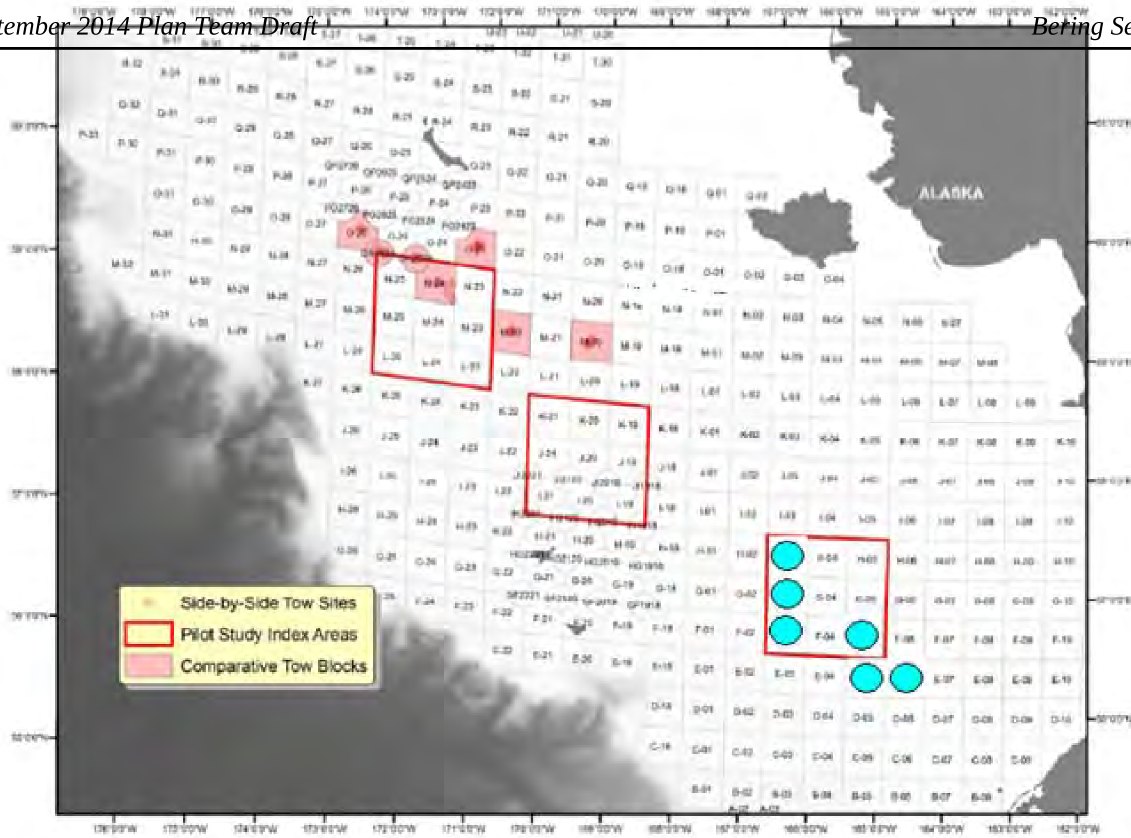


Figure 28. Location of the side-by-side trawling areas (shown with pink shading) and the 3 BSFRF survey areas encompassing the 27 NMFS survey blocks (shown with a red line). Location of the 1998 auxiliary bag experiment sampling areas are the blue circles.

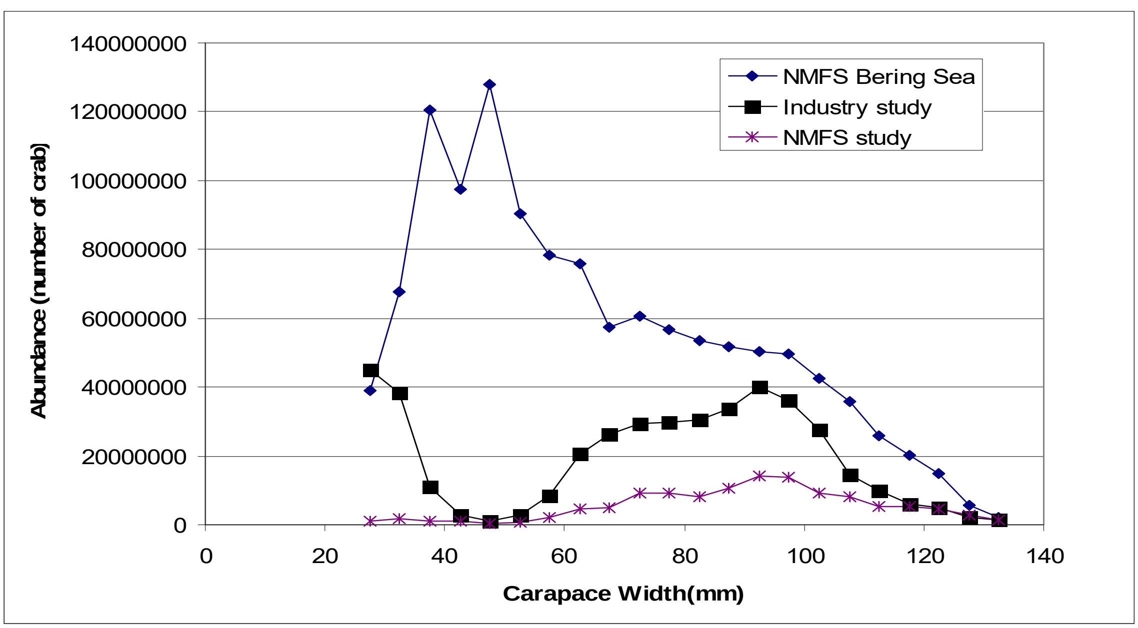


Figure 29. Abundance estimates of male snow crab by 5 mm carapace width(>=25mm) for the NMFS survey of the entire Bering Sea survey area (NMFS Bering Sea), the BSFRF net in the study area (108 tows) and the NMFS survey in the 2009 study area.

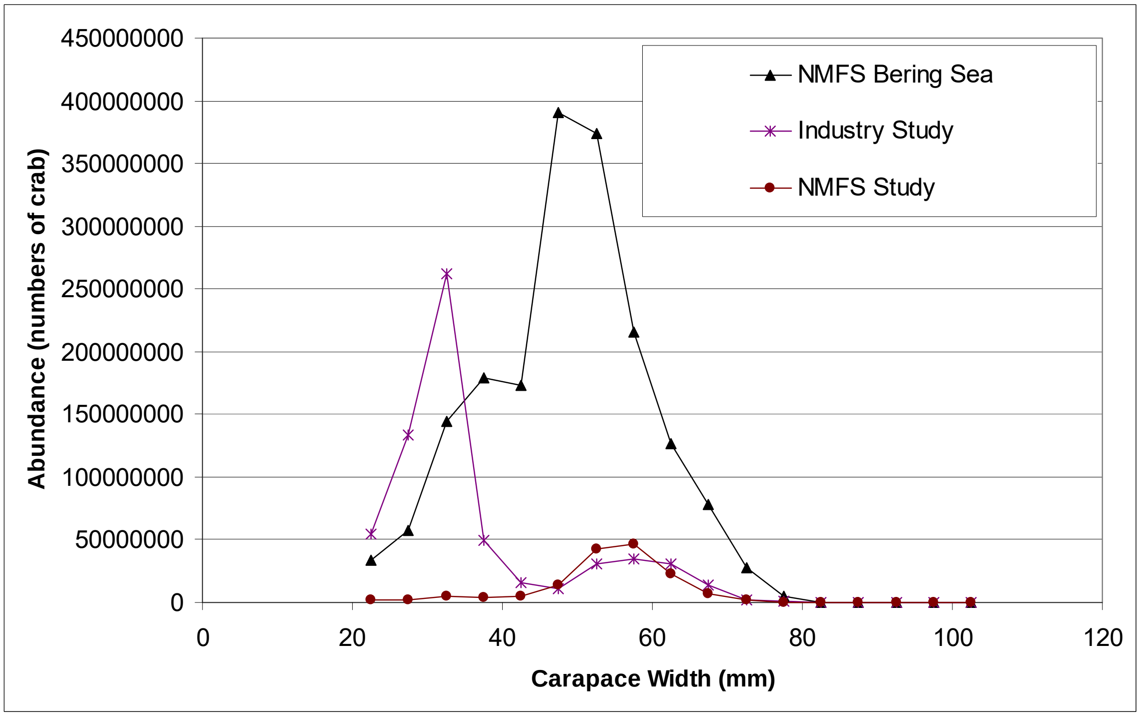


Figure 30. Abundance estimates of female snow crab by 5 mm carapace width for the NMFS survey of the entire Bering Sea survey area (NMFS Bering Sea), the BSFRF net in the study area (108 tows) and the NMFS survey in the 2009 study area.

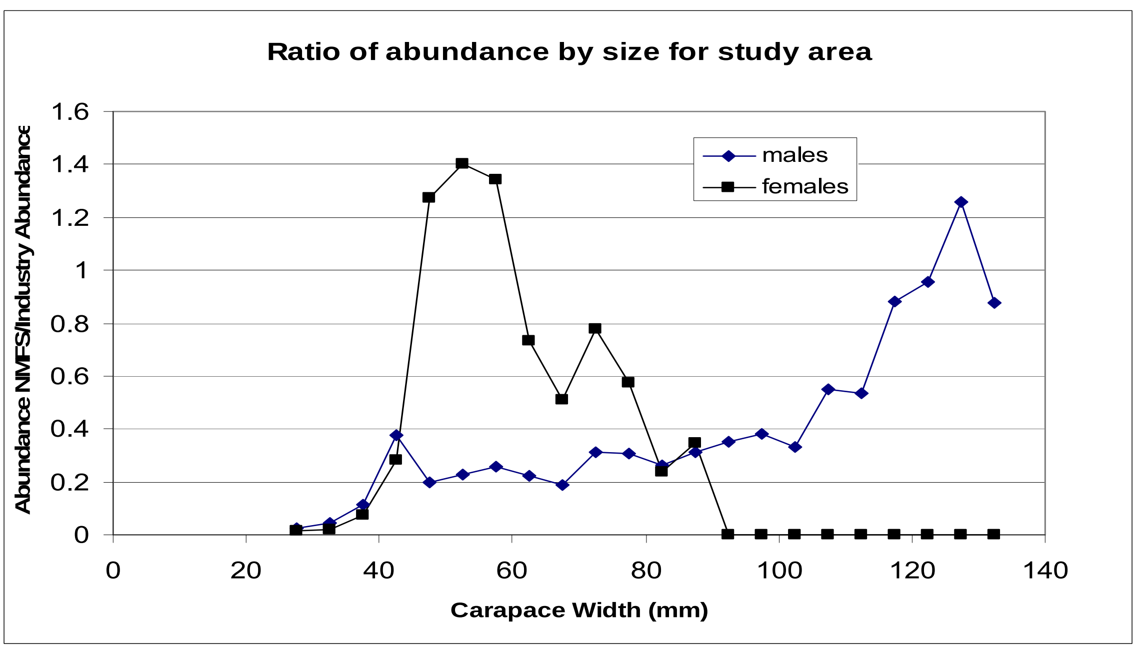


Figure 31. Ratio of abundance in the 2009 study area from the NMFS net to the BSFRF net for male and female crab.

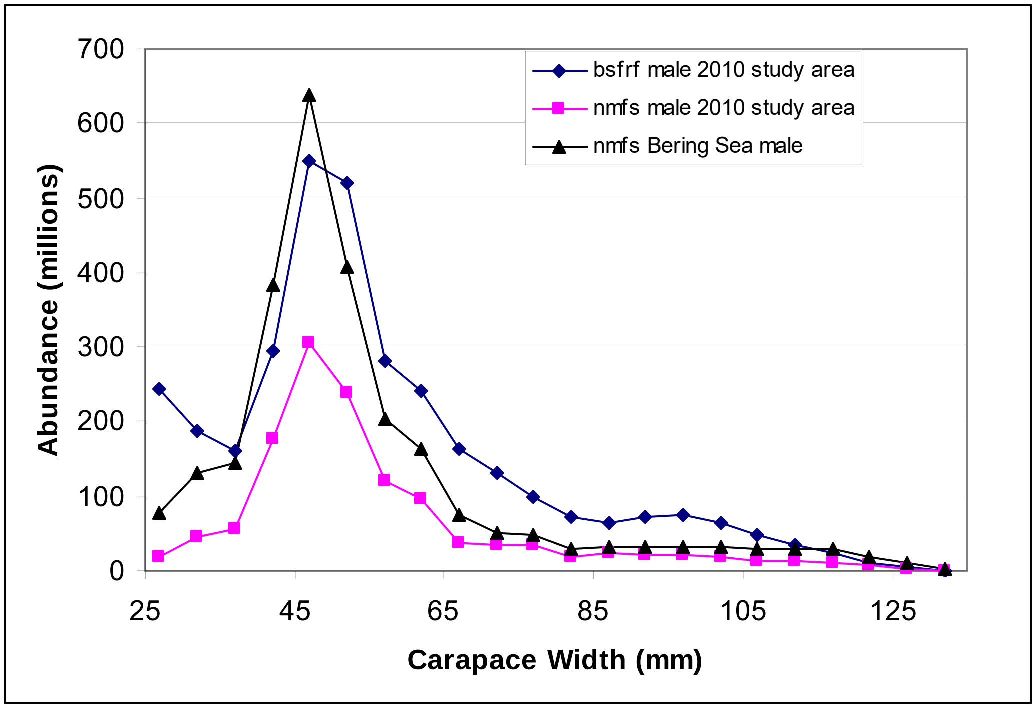


Figure 32. 2010 study area Male abundance.

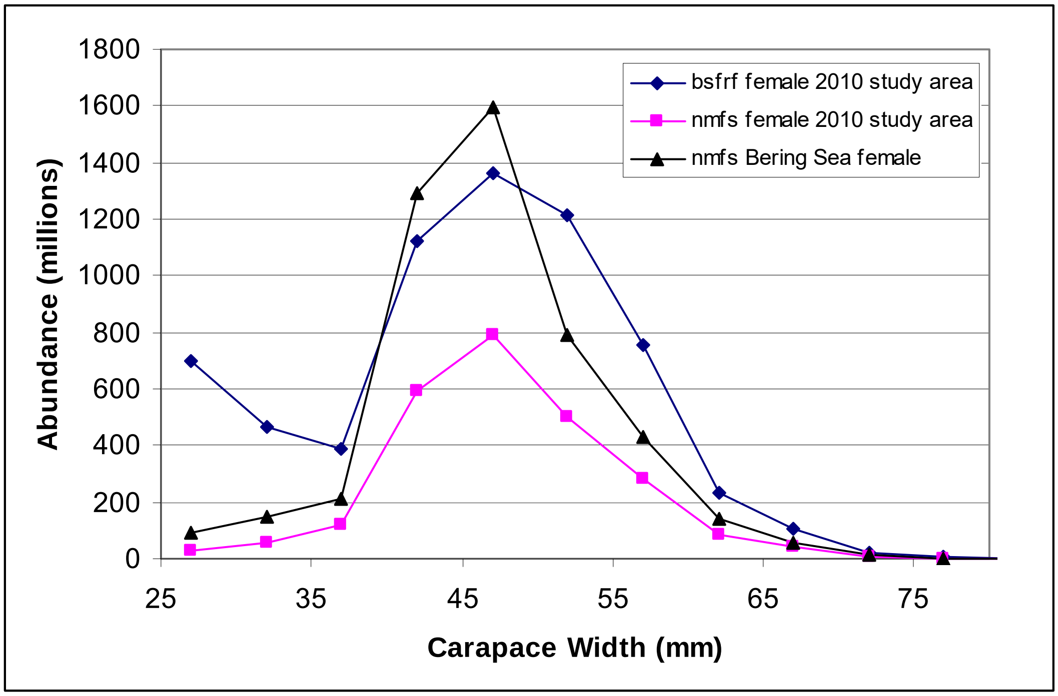


Figure 33. 2010 study area Female abundance.

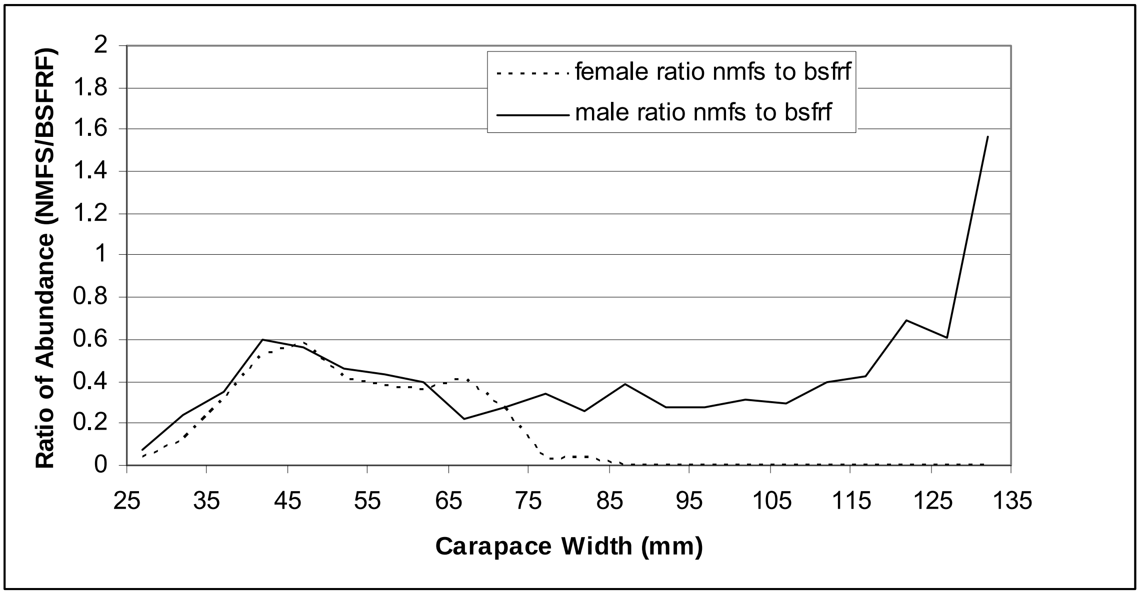


Figure 34. 2010 study area ratio of abundance

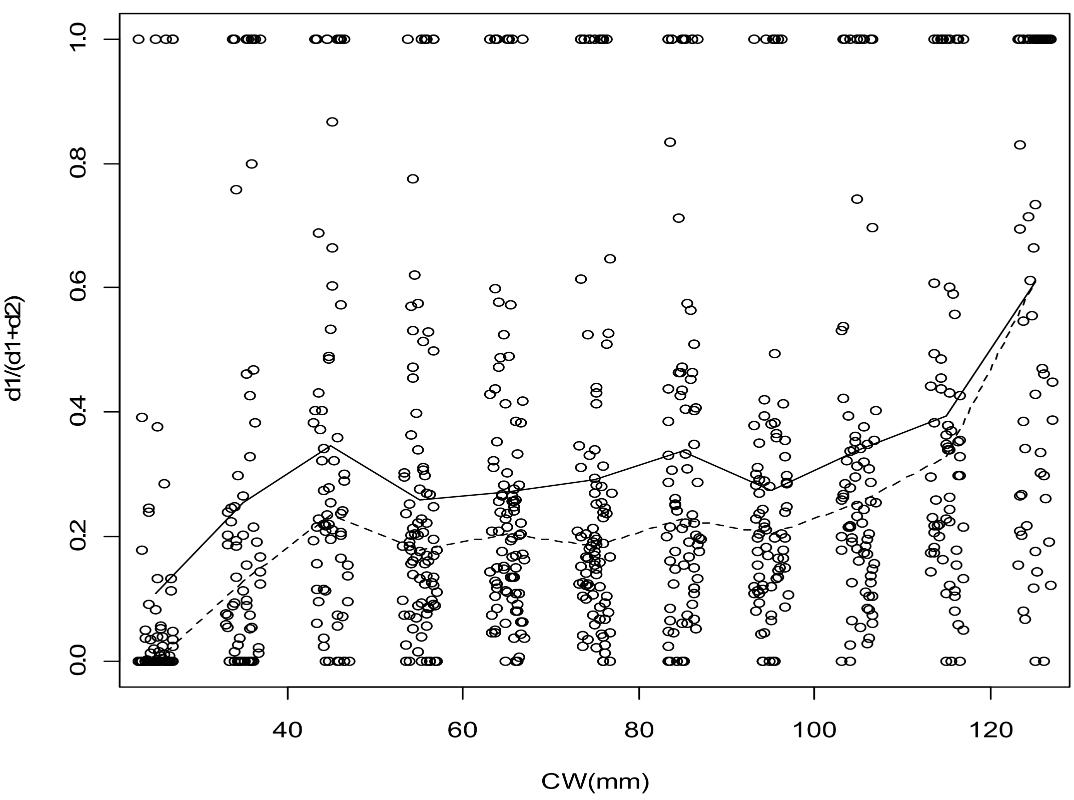


Figure 35. Male crab. Density (catch/nm2) of NMFS tow (d1) divided by sum of density (d2 is density of BSFRF tow). Solid line is unweighted mean, dotted line median of each length bin. A value of 0.5 is equal density (d1=d2). Length values are jittered to show multiple 1.0 and 0.0 data.

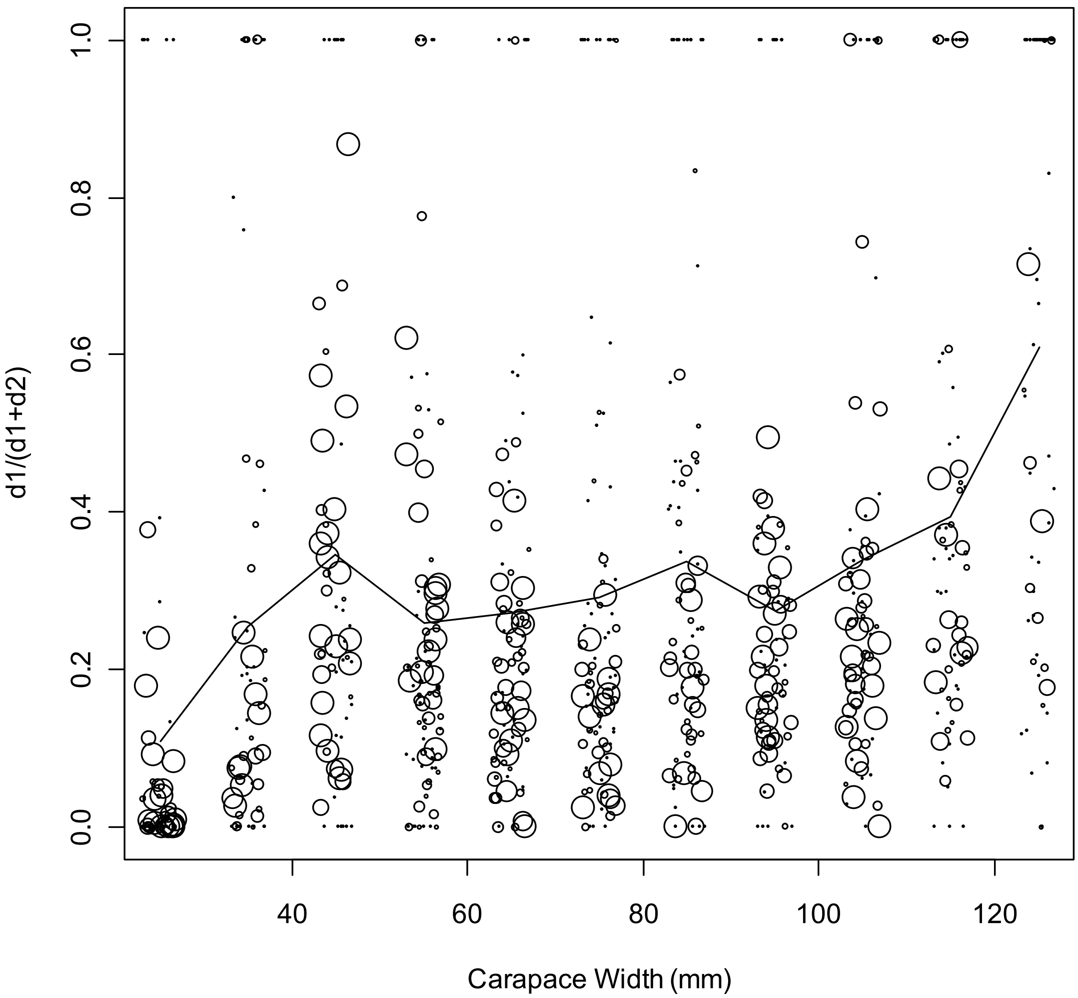


Figure 36. Density of NMFS tow (d1) divided by the sum of the density of the NMFS tow (d1) and the Industry tow (d2). The radius of the circle at each point is proportional to the sum of the catch in numbers where the Industry numbers are adjusted by the ratio of the NMFS area swept to the Industry area swept. The line is the unweighted mean values of d1/(d1+d2) in each size bin.

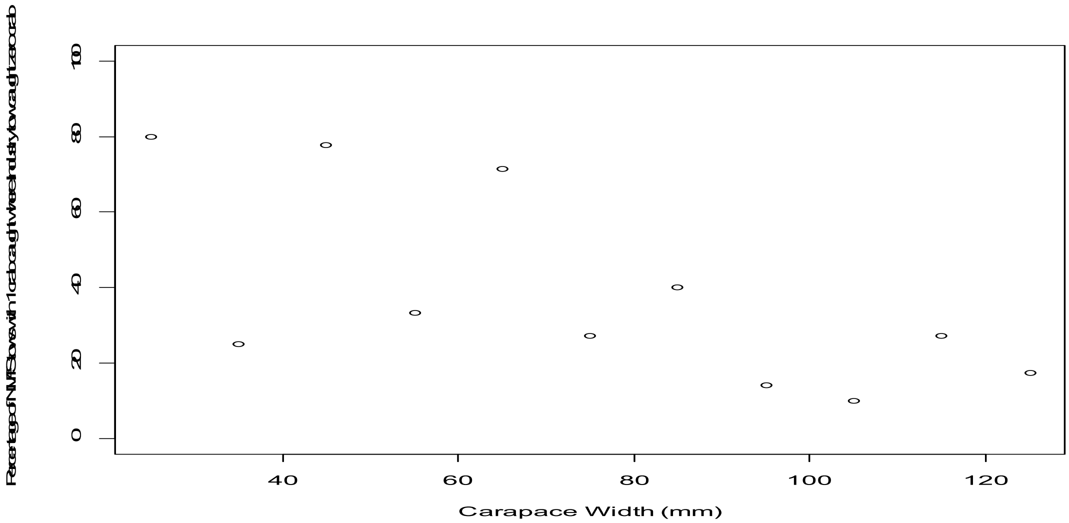


Figure 37. Percentage of paired tows where BSFRF caught no crab and NMFS caught only 1 crab.

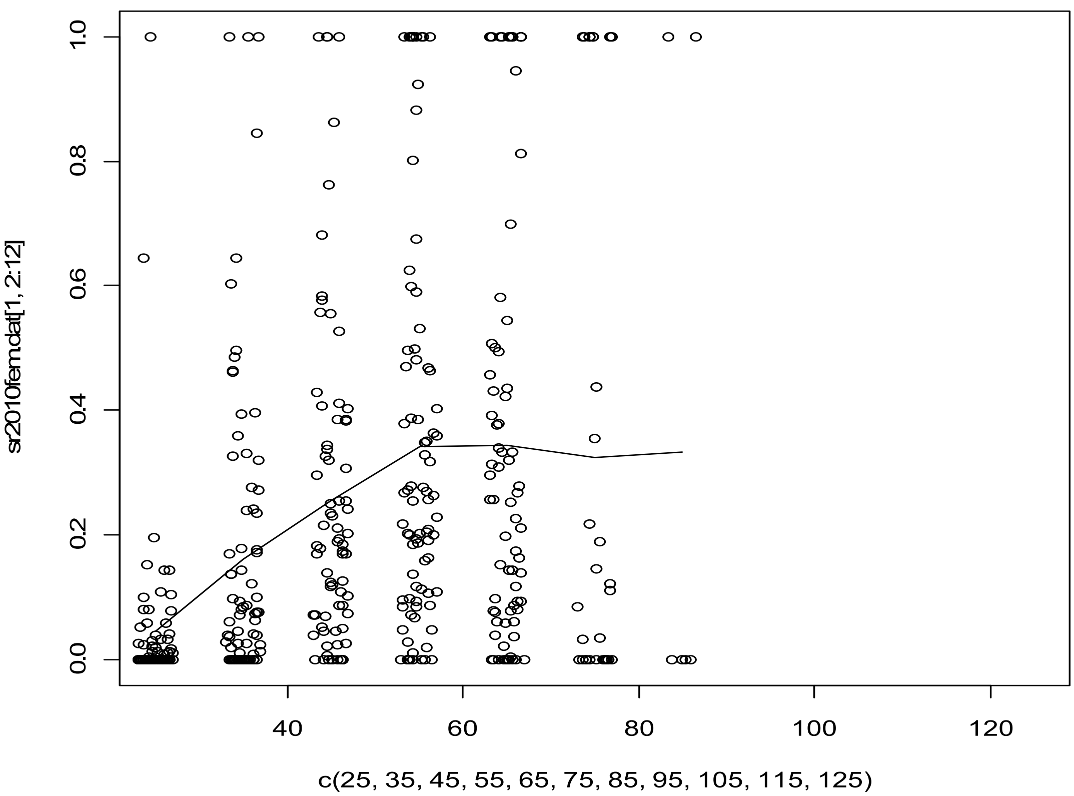


Figure 38. Female d1/(d1+d2) with mean. Density (catch/nm2) of NMFS tow (d1) divided by sum of density (d2 is density of BSFRF tow). Solid line is mean, dotted line median of each length bin. A value of 0.5 is equal density (d1=d2). Length values are jittered to show multiple 1.0 and 0.0 data.

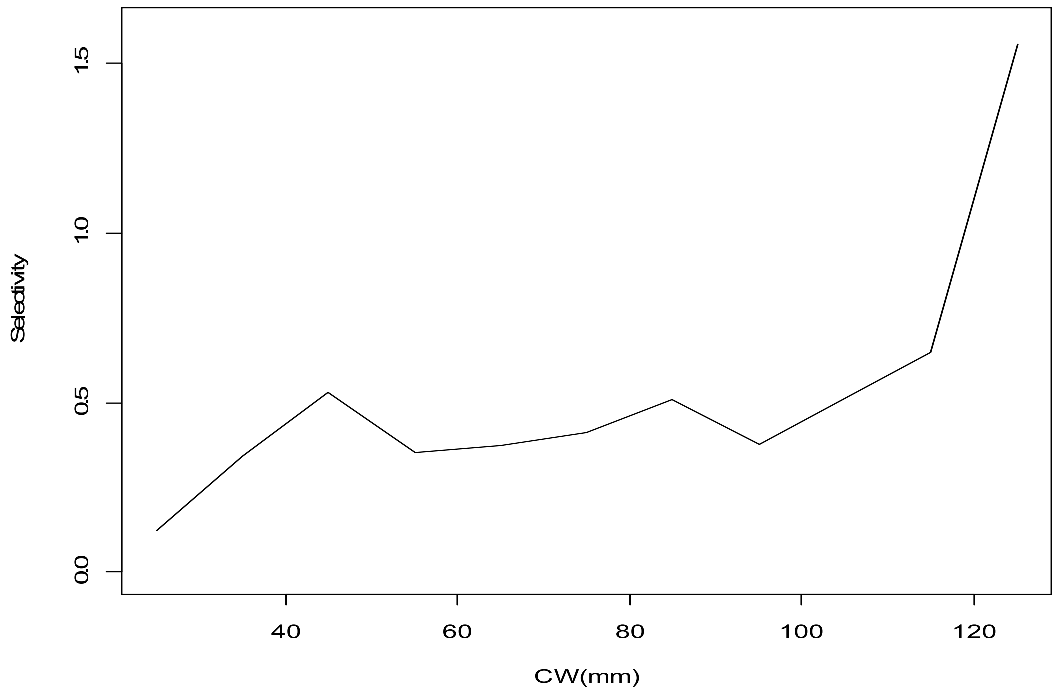


Figure 39. Mean from Figure 9 translated to selectivity (selectivity = p/(1-p), where p= d1/(d1+d2)).

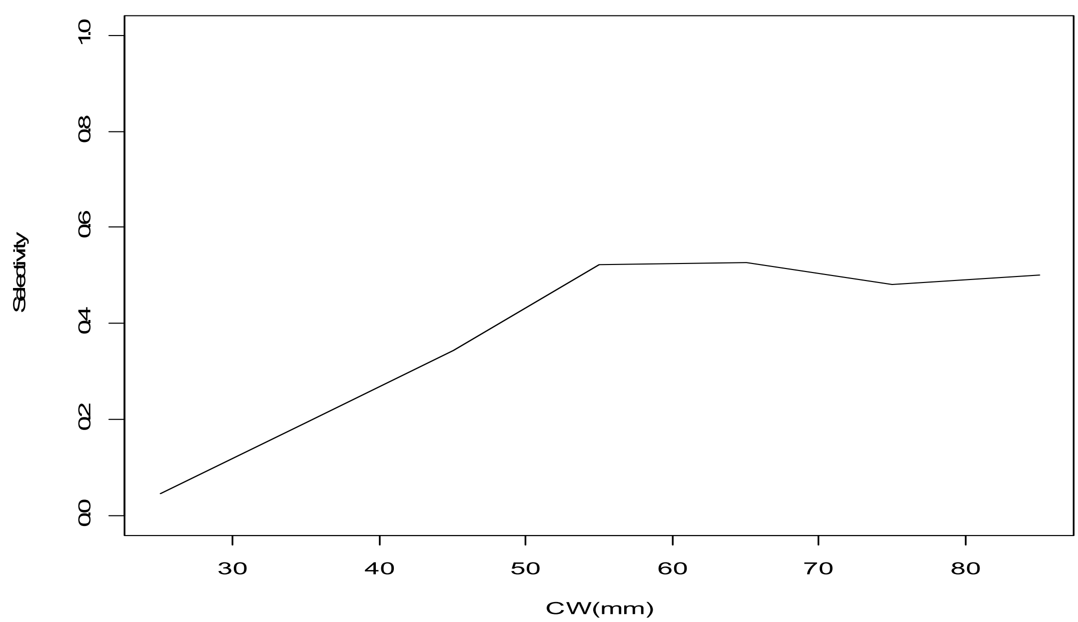


Figure 40. Mean from Figure 38, female crab translated to selectivity (selectivity = p/(1-p), where p= d1/(d1+d2))

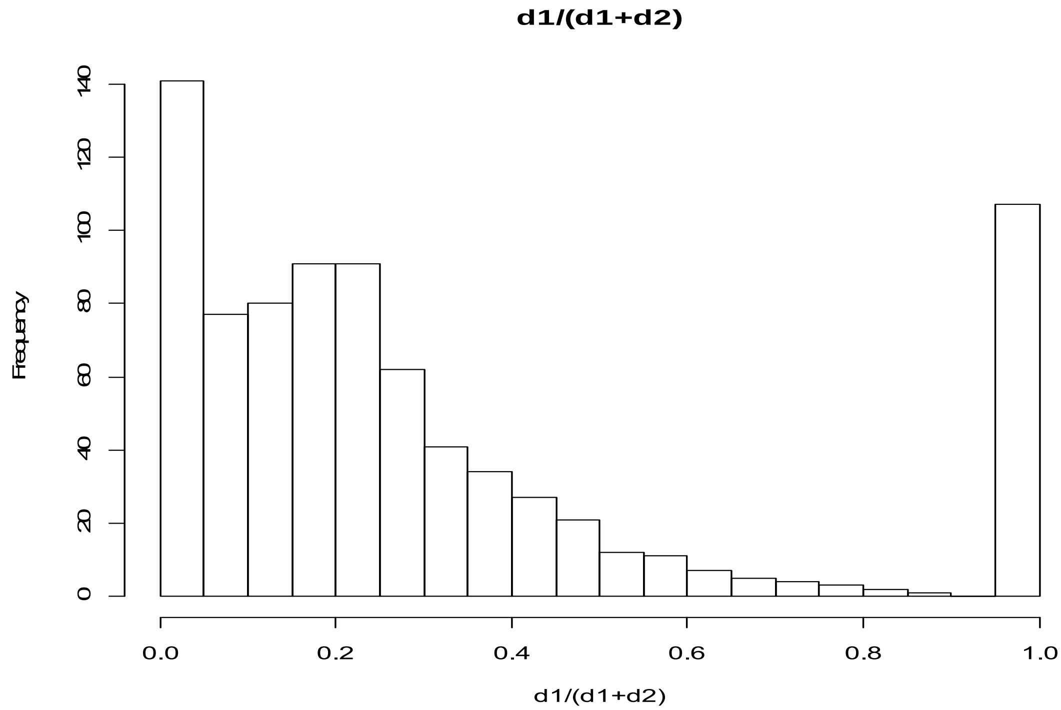


Figure 41. Histogram of d1/(d1+d2) over all sizes and tows. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

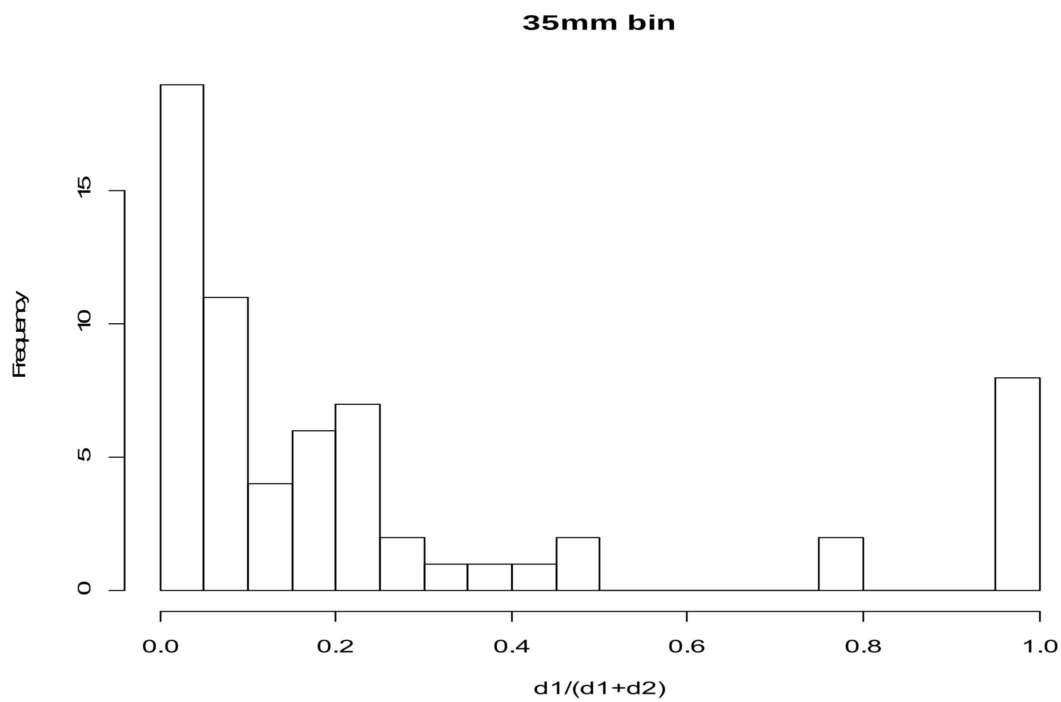


Figure 42. Histogram of d1/(d1+d2) for the 30 to 40 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

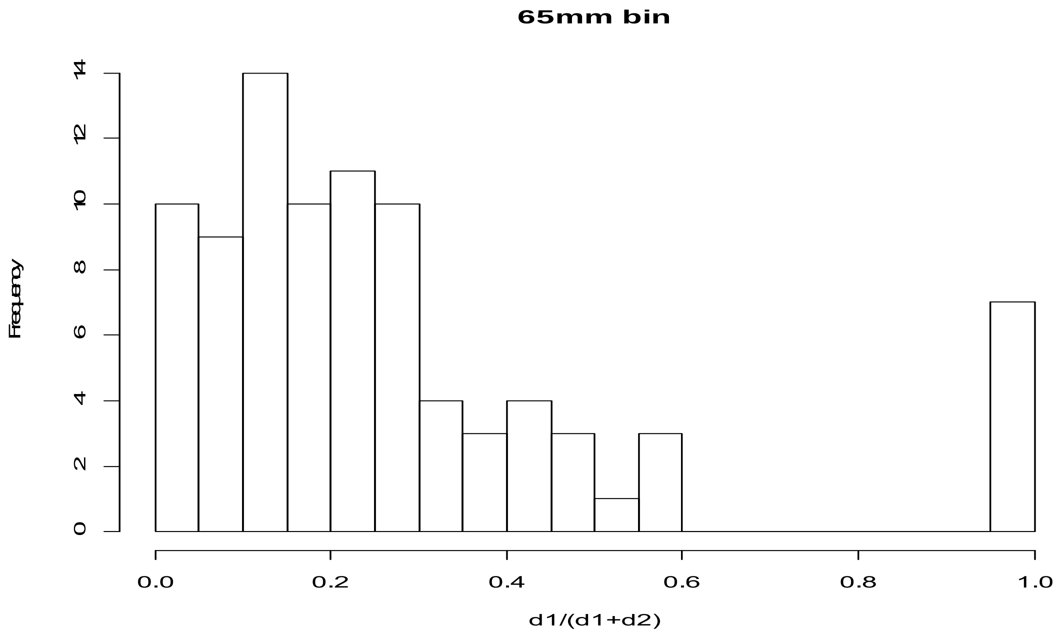


Figure 43. Histogram of d1/(d1+d2) for the 60 to 70 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

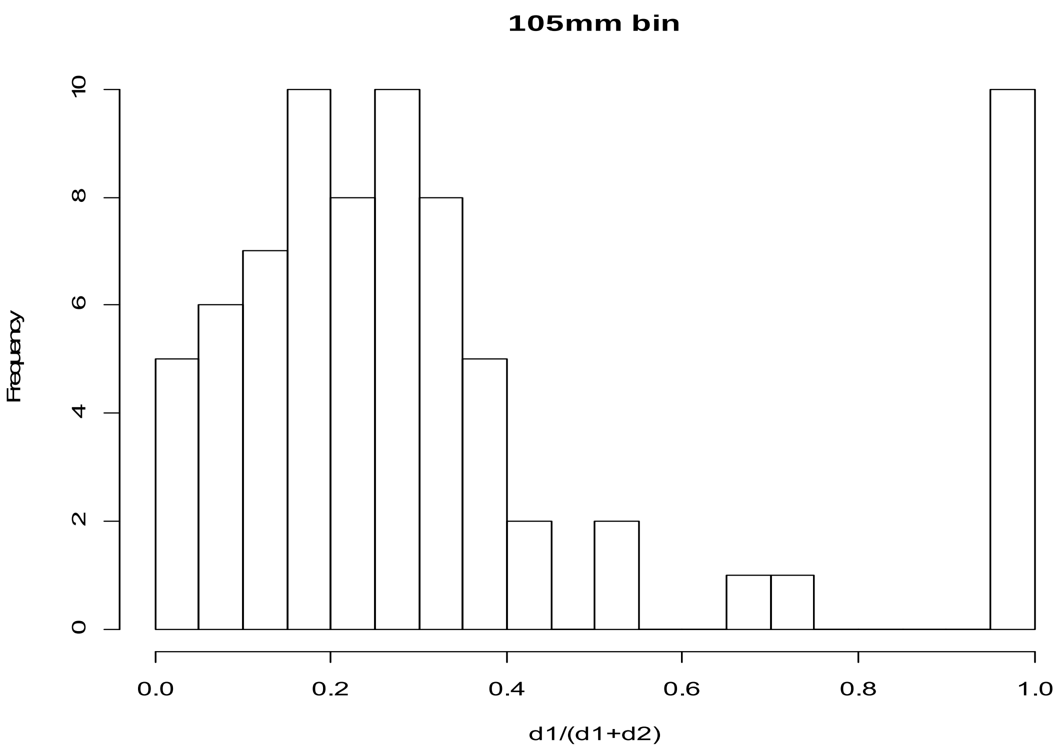


Figure 44. Histogram of d1/(d1+d2) for the 100 to 110 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

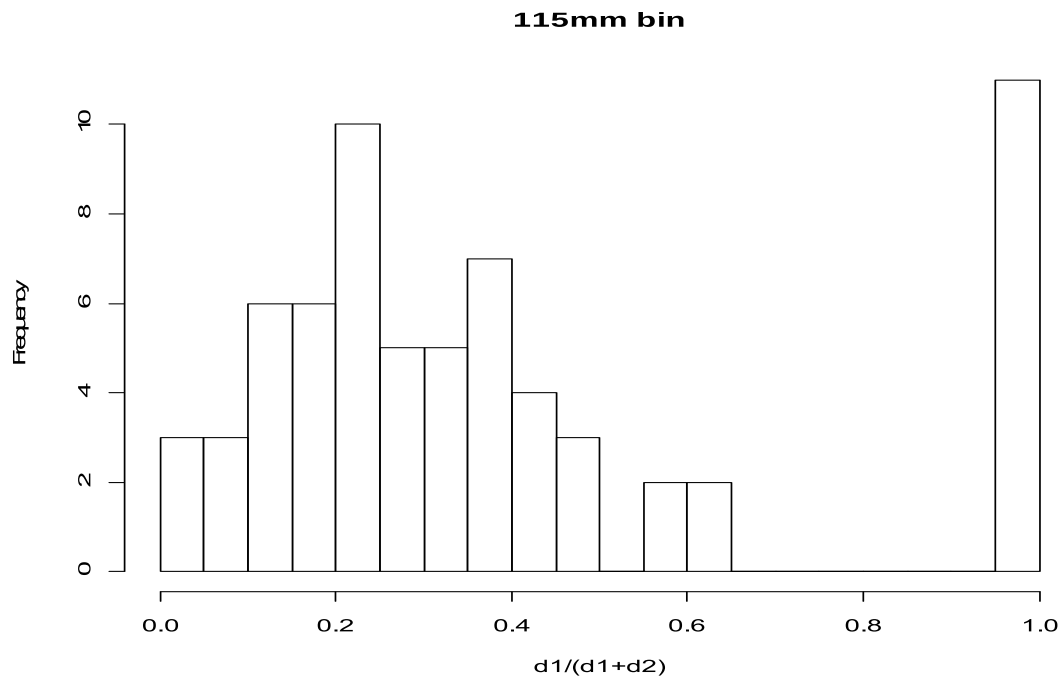


Figure 45. Histogram of d1/(d1+d2) for the 100 to 120 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

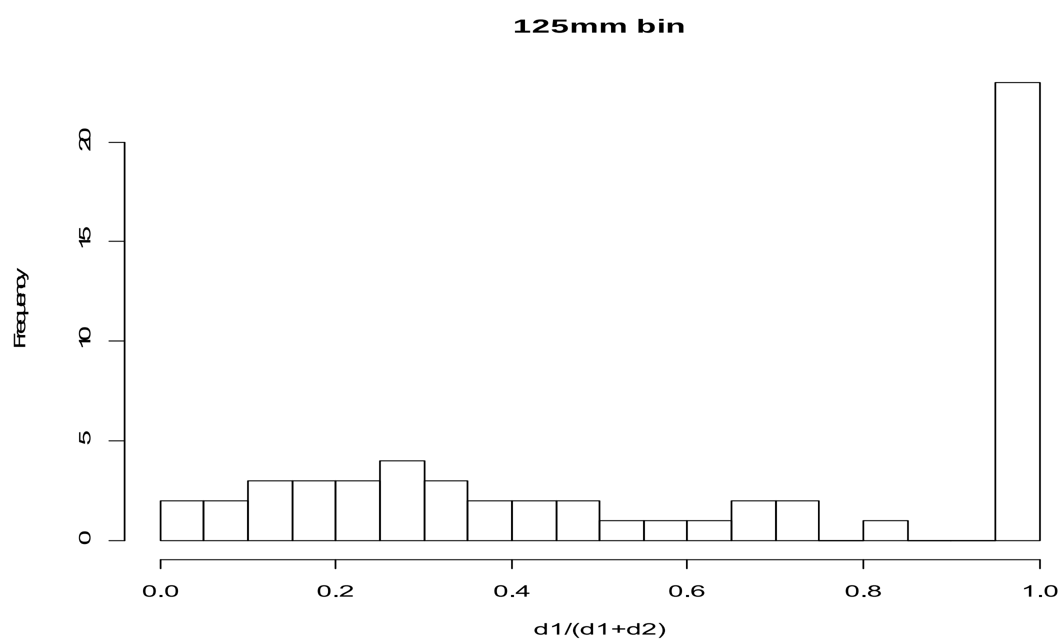


Figure 46. Histogram of d1/(d1+d2) for the 120+mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

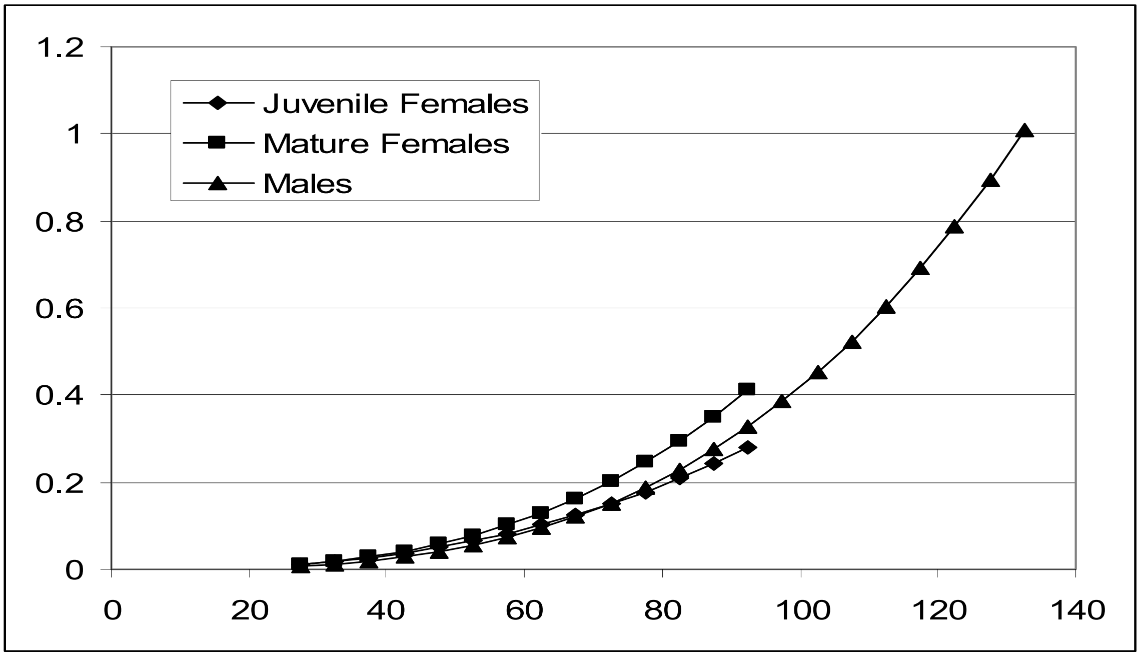


Figure 47. Weight (kg) – size (mm) relationship for male, juvenile female and mature female snow crab.

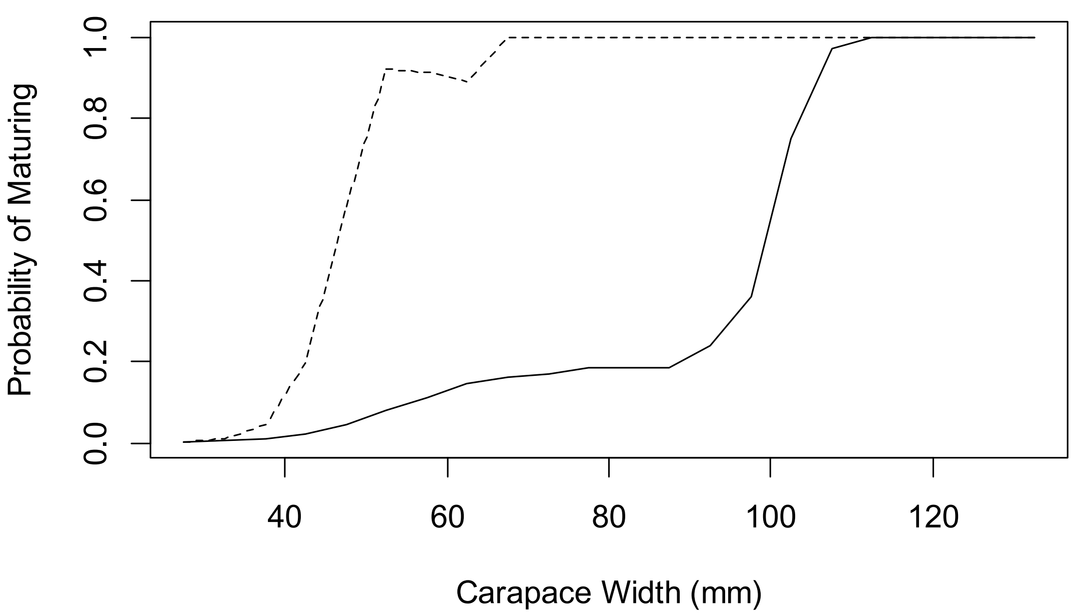


Figure 48. Probability of maturing by size estimated in the model for male(solid line) and female (dashed line) snow crab (not the average fraction mature.

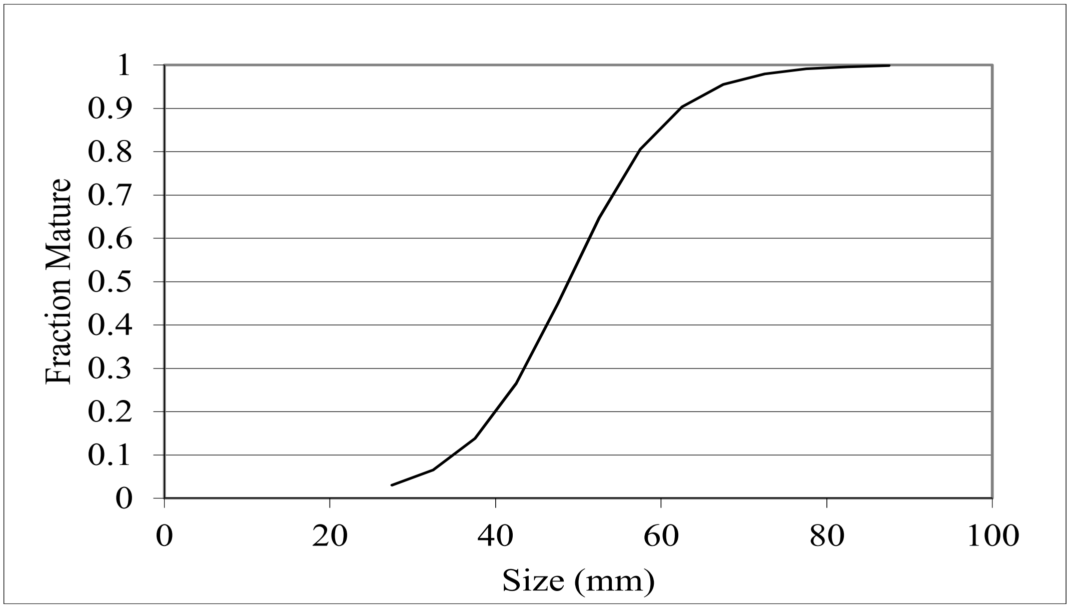


Figure 48b. Logistic fit to fraction mature for female snow crab (not used in model).

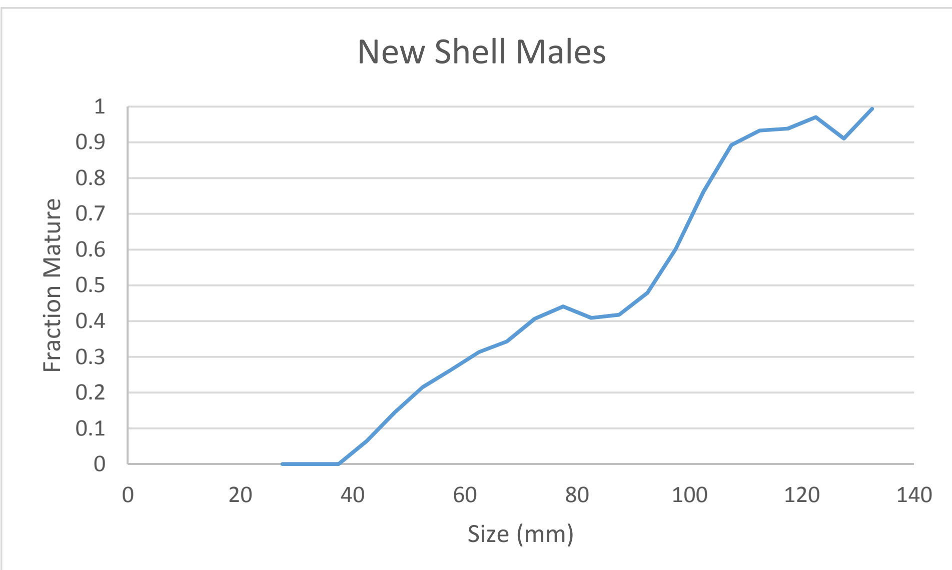


Figure 48c. Average fraction mature for new shell males from chela height data 1989-2007.

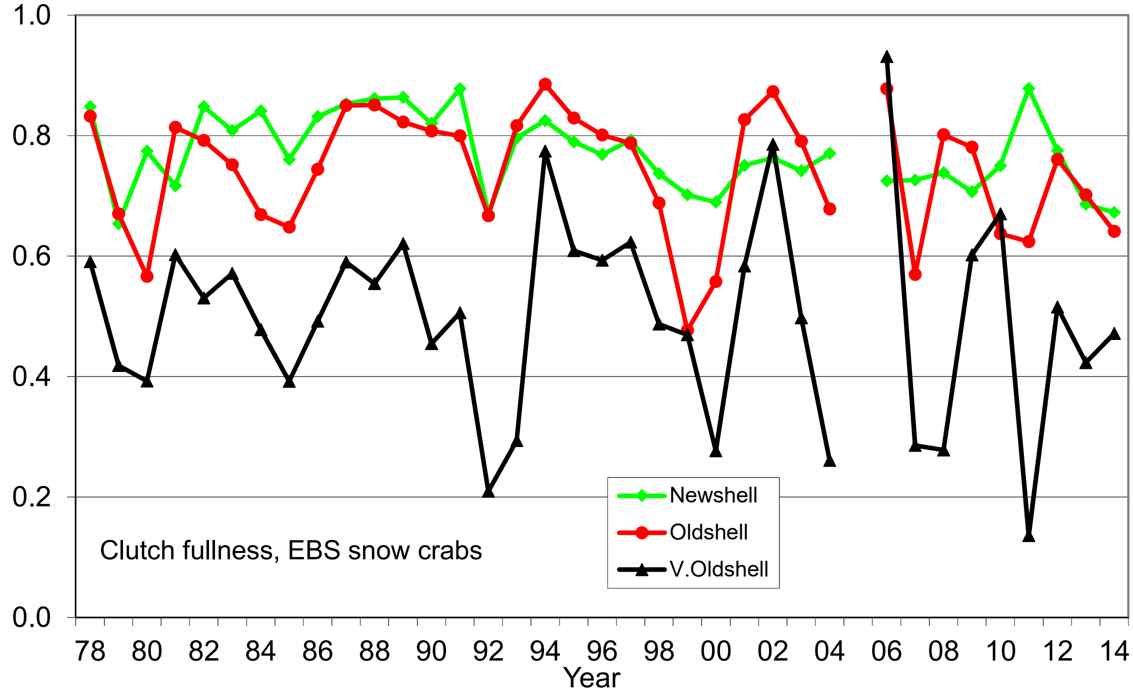


Figure 49. Clutch fullness for Bering Sea snow crab survey data by shell condition for 1978 to 2014.

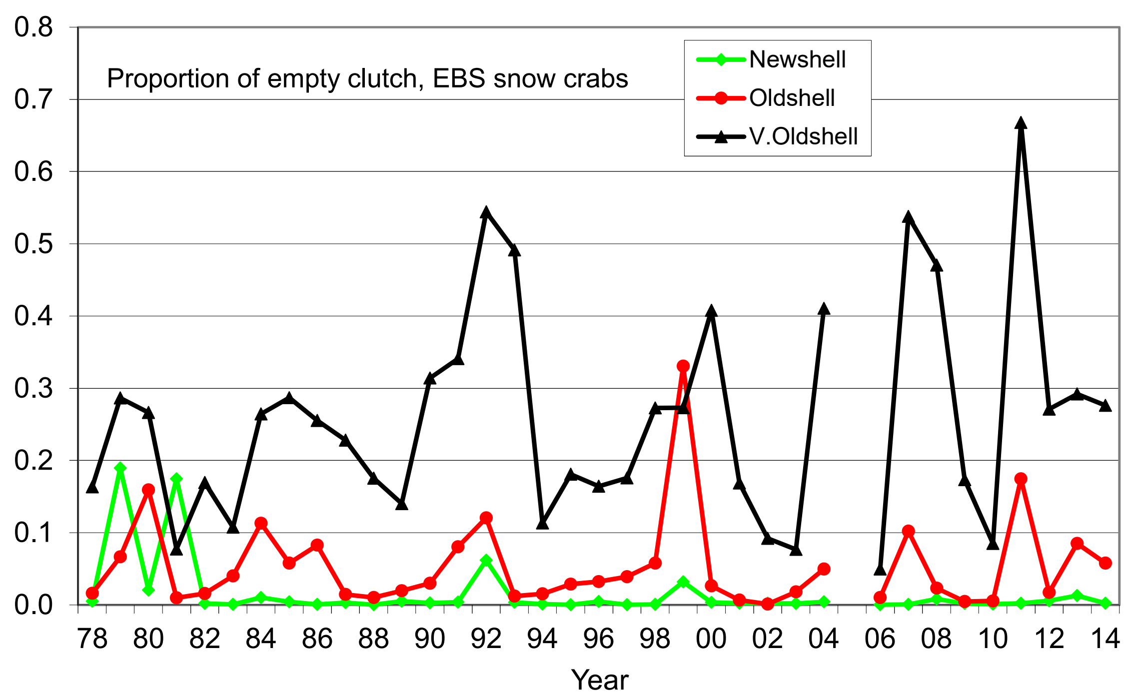


Figure 50. Proportion of barren females by shell condition from survey data 1978 to 2014.

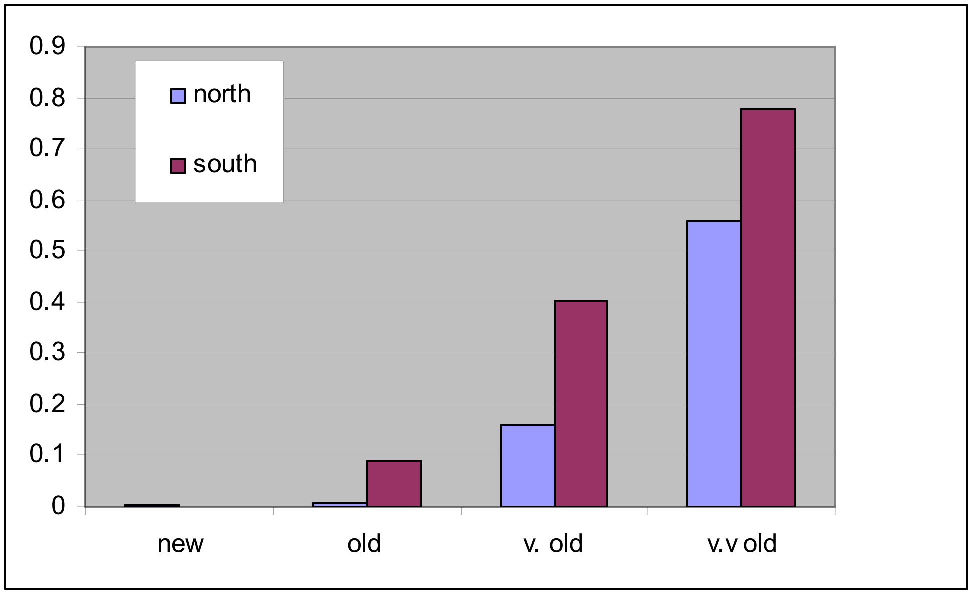


Figure 51. Fraction of barren females in the 2004 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N.

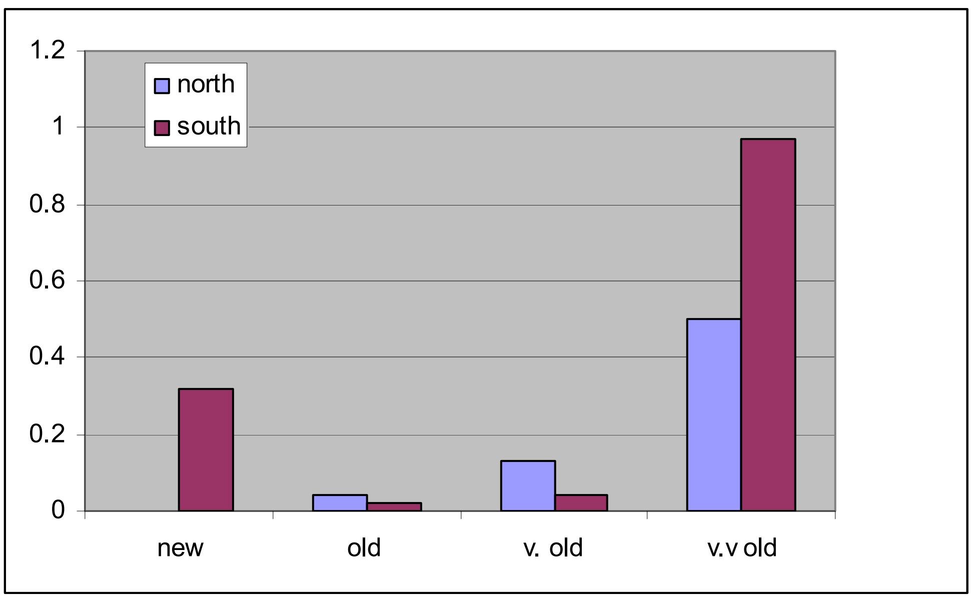


Figure 52. Fraction of barren females in the 2003 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N. The number of new shell mature females south of 58.5 deg N was very small in 2003.

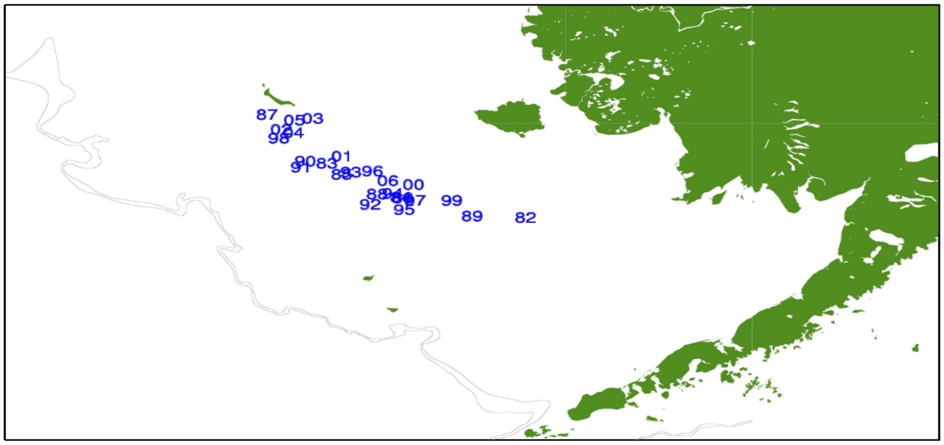


Figure 53. Centroids of cold pool (<2.0 deg C) from 1982 to 2006. Centroids are average latitude and longitude.

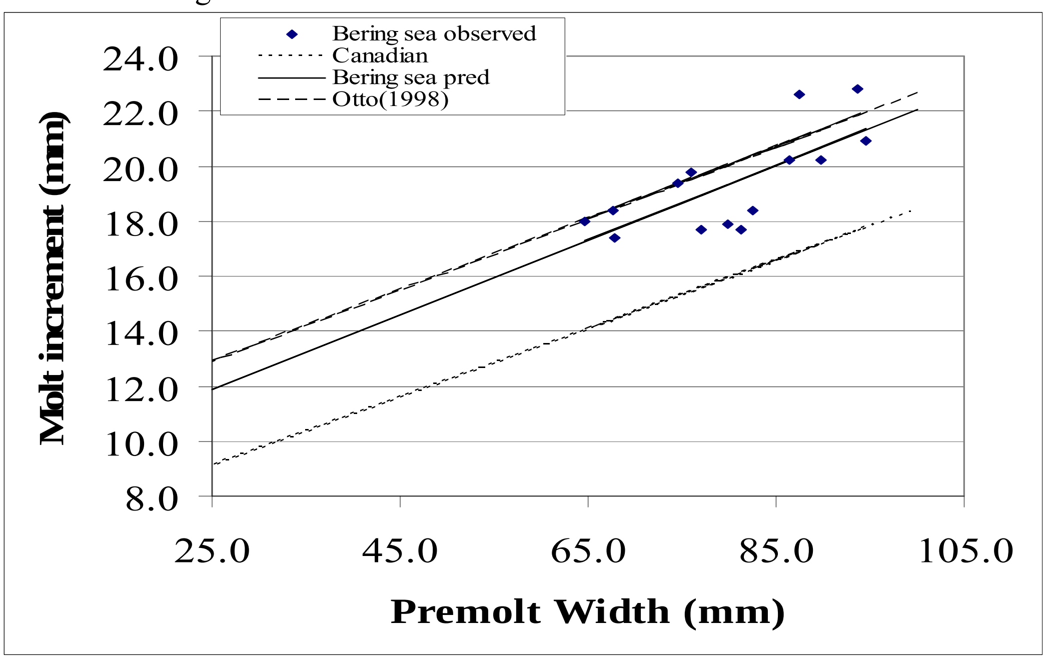
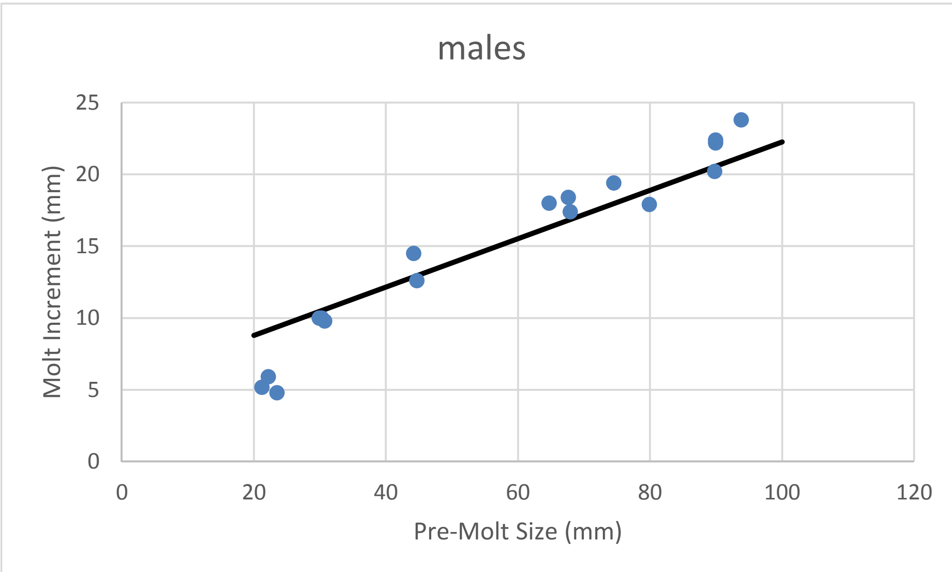


Figure 54. Growth increment as a function of premolt size for male snow crab. Points labeled Bering Sea observed are observed growth increments from Rugolo (unpub data). The line labeled Bering Sea pred is the predicted line from the Bering Sea observed growth, which was used as a prior for the growth parameters estimated in Scenarios 3 and 4. The line labeled Canadian is estimated from Atlantic snow crab (Sainte-Marie data). The line labeled Otto(1998) was estimated from tagging data from Atlantic snow crab less than 67 mm, from a different area from Sainte-Marie data.



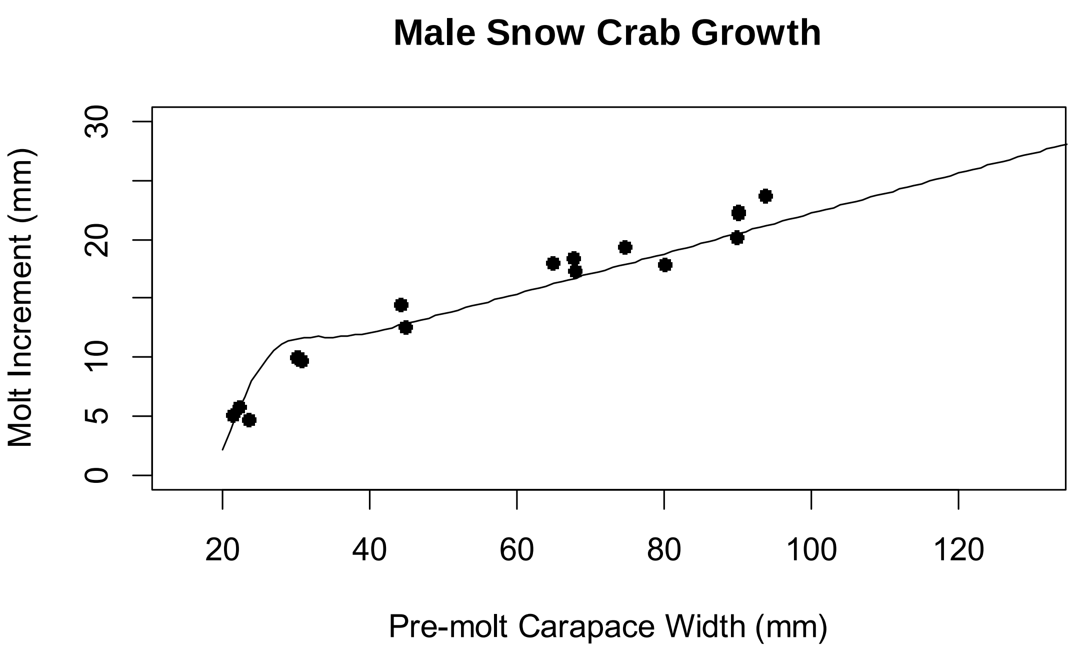


Figure 54b. Male growth data from 2011 growth study with estimated linear growth function (top panel last year's assessment - September 2013 assessment base model) and using the Cadigan method (Base model this assessment – Model 2b).

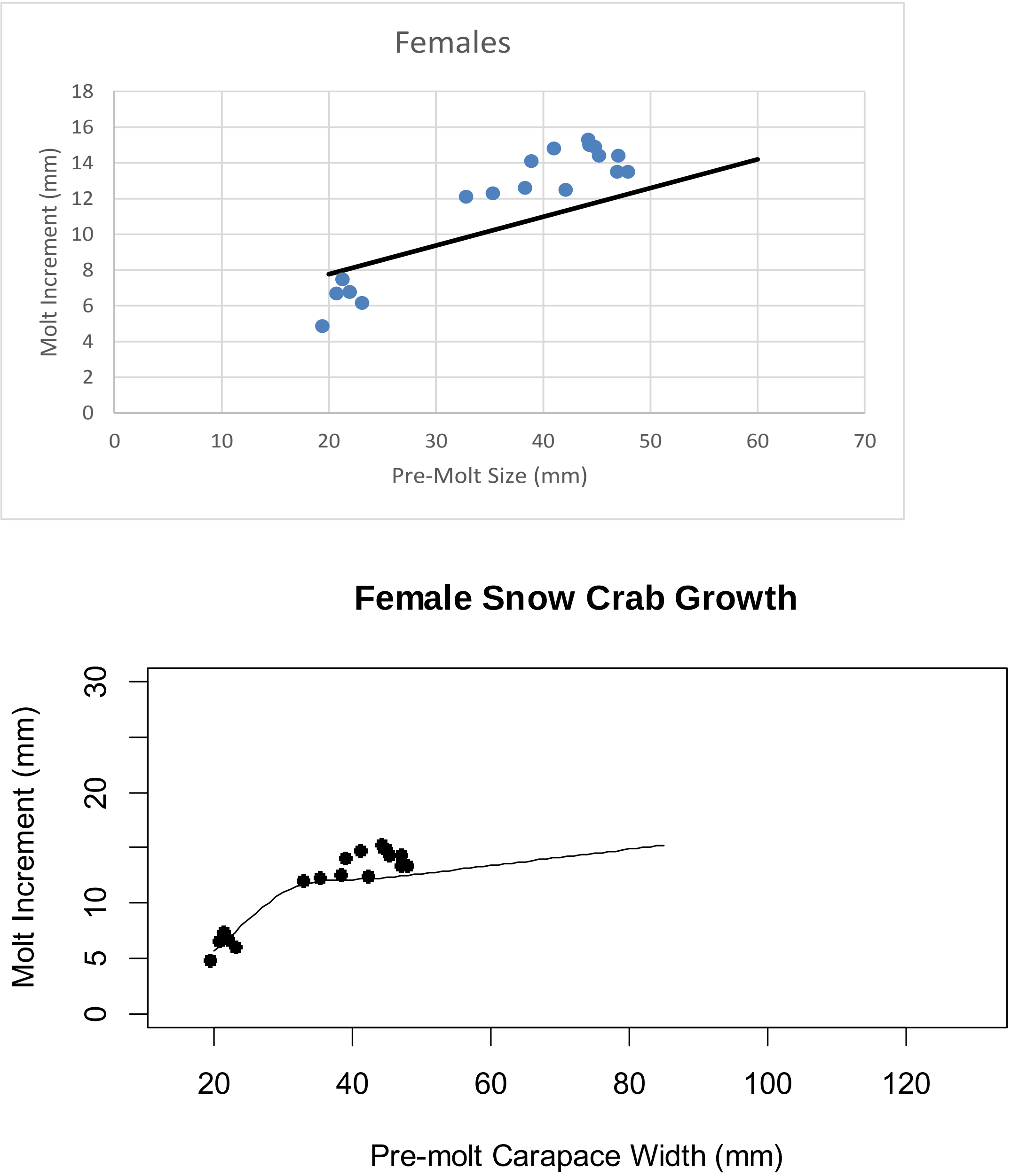


Figure 54c. Female growth data from 2011 growth study with estimated linear growth function (top panel last year's assessment - September 2013 assessment base model) and using the Cadigan method (Base model this assessment, model 2b).

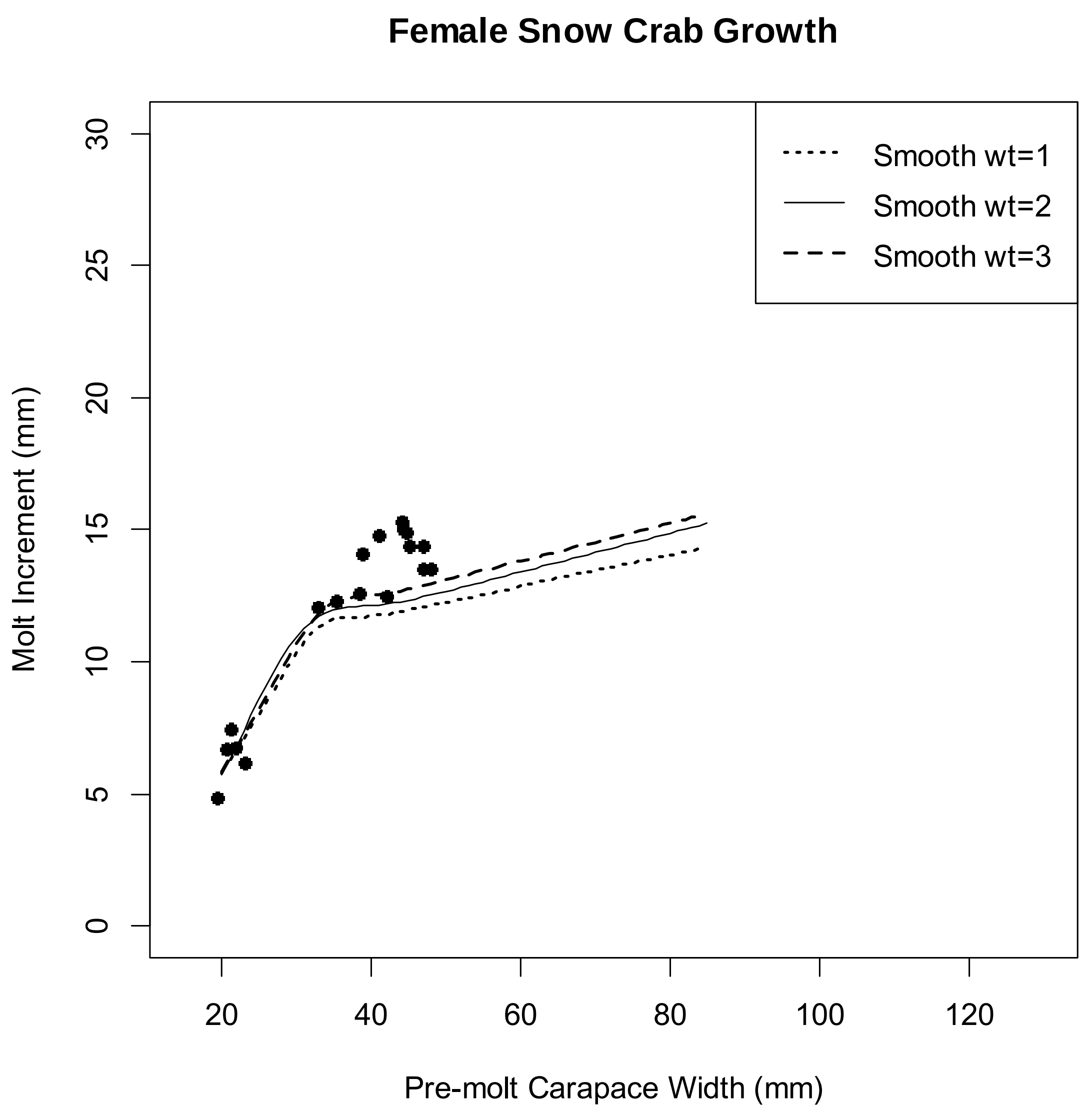


Figure 54d. Estimated female growth for cardigan smooth with weights 1, 2 and 3 on growth likelihood(2a, 2b and 2c model scenarios).

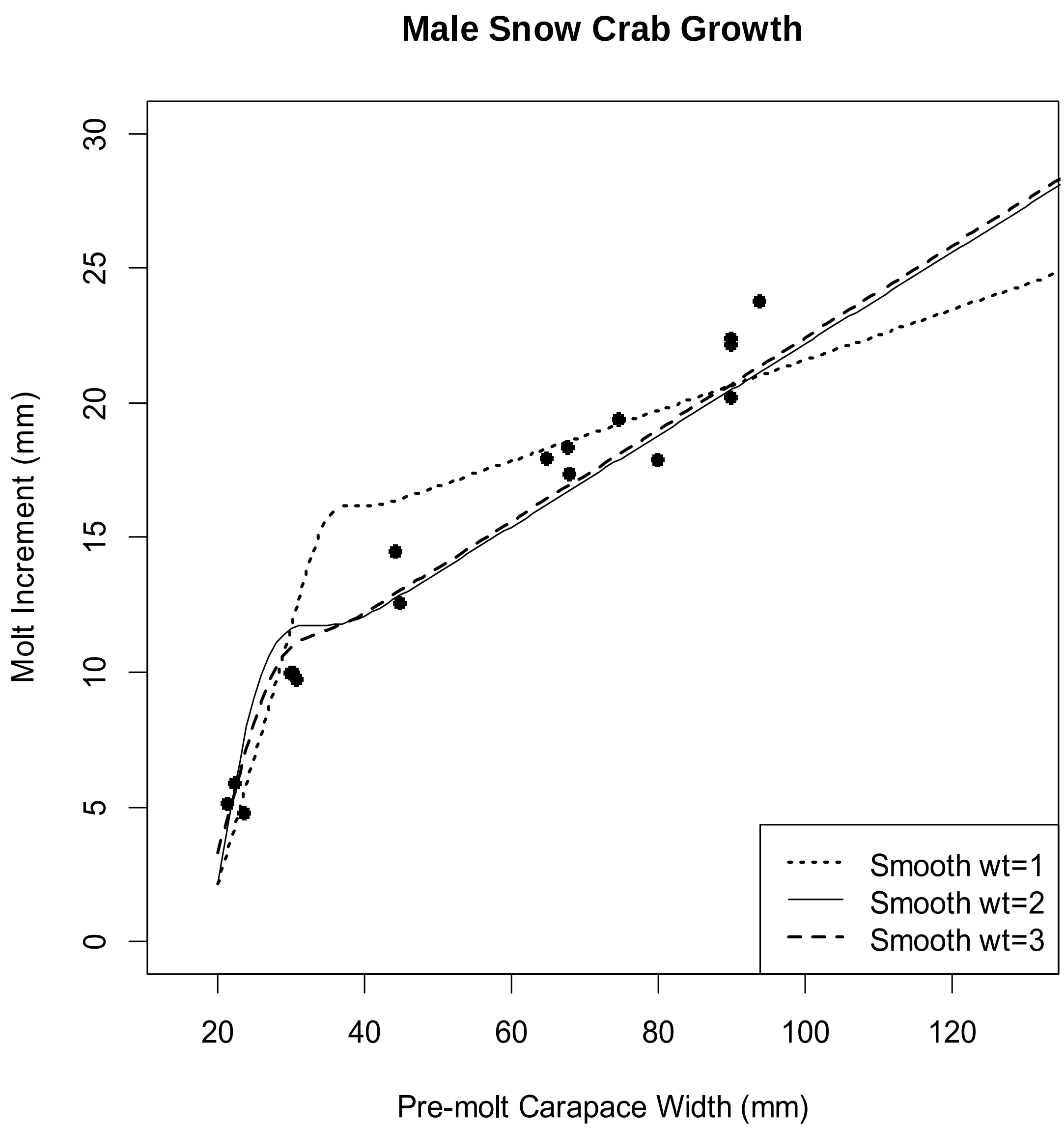


Figure 54e. Estimated male growth for cardigan smooth with weights 1, 2 and 3 on growth likelihood (2a, 2b and 2c model scenarios).

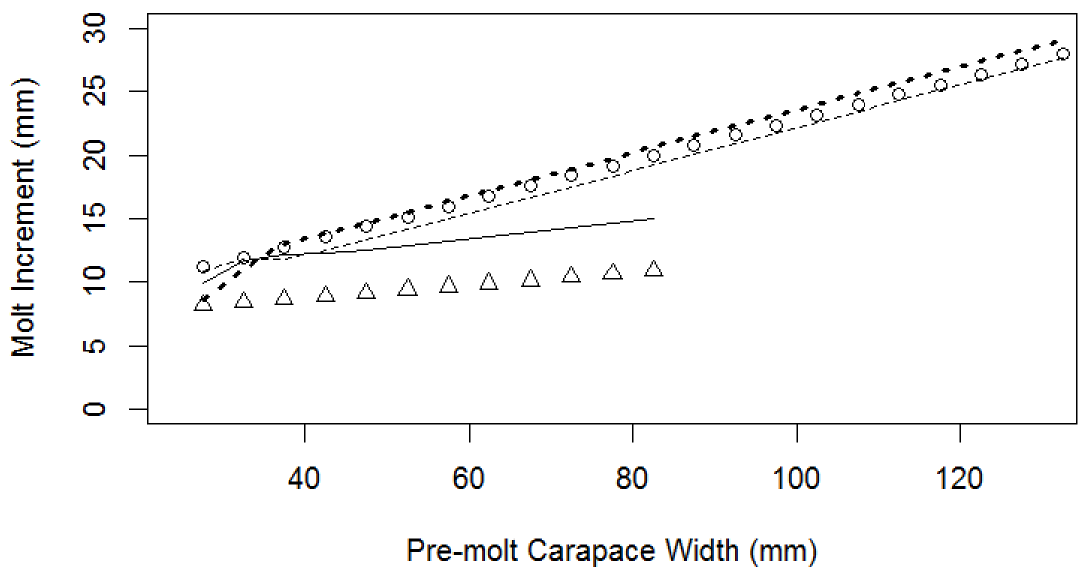


Figure 55. Growth(mm) for male(dotted line) and female snow crab (solid line) estimated from the base model. The priors for the growth curve used in models before September 2013 are circles (males) and triangle (females). Heavy dotted line is the growth curve estimated by Somerton for males and females from the 2011 growth study (Somerton 2012).

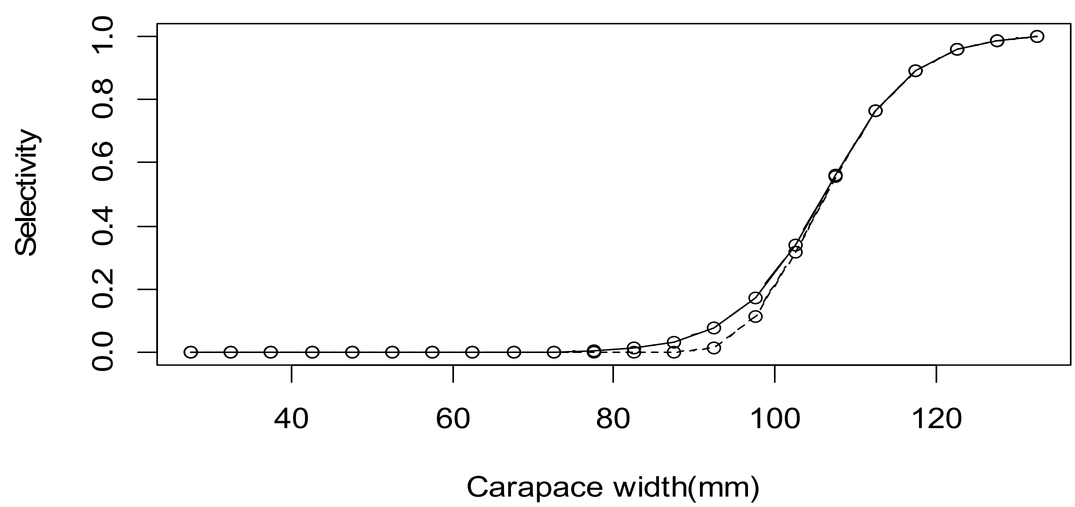


Figure 56. Base Model. Selectivity curve for total catch (discard plus retained, solid line) and retained catch (dotted line) for combined shell condition male snow crab.

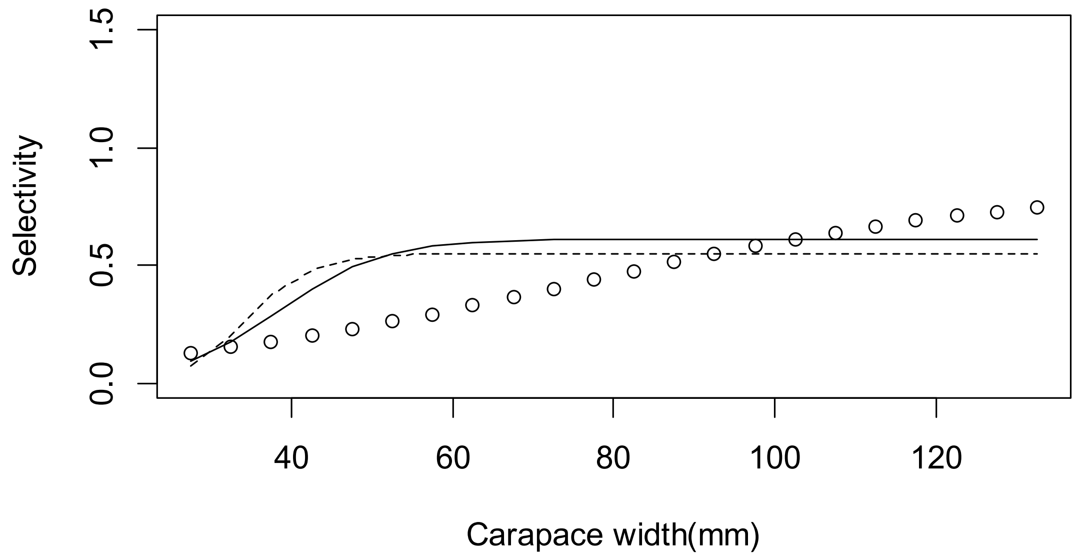


Figure 57. Base Model. Survey selectivity curves for female (dotted lines) and male snow crab (solid lines) estimated by the model for 1989 to present. Survey selectivities estimated by Somerton from 2009 study area data (2010) are the circles.

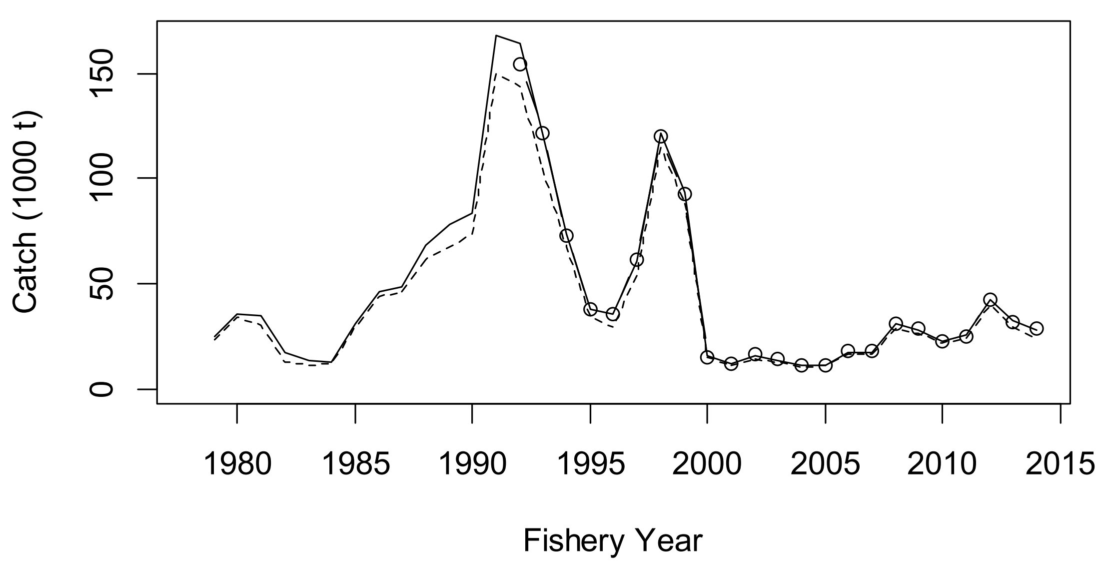


Figure 58. Base Model. Estimated total catch(discard + retained) (solid line), observed total catch (solid line with circles) (assuming 30% mortality of discarded crab) and observed retained catch (dotted line).

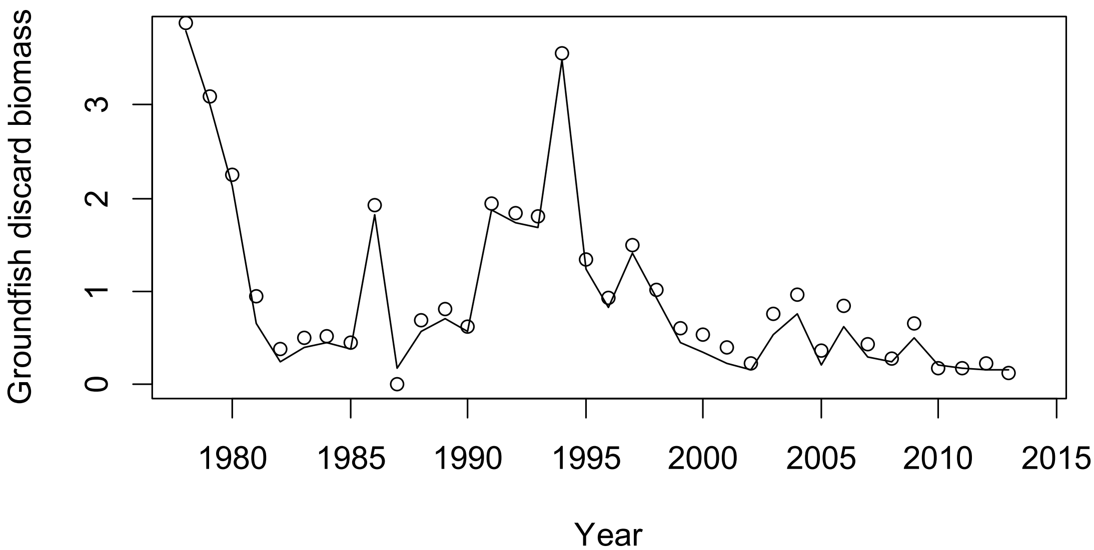


Figure 59. Base Model. Model fit to groundfish bycatch. Circles are observed catch, line is model estimate.

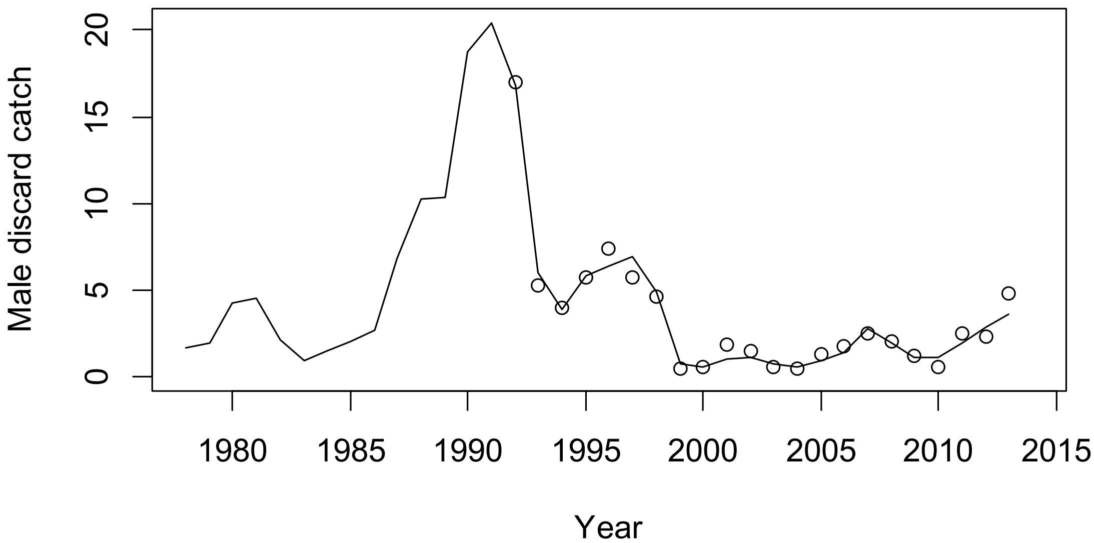


Figure 60. Base Model. Model fit to male directed discard catch for 1992/93 to present and model estimated male discard catch from 1978 to 1991.

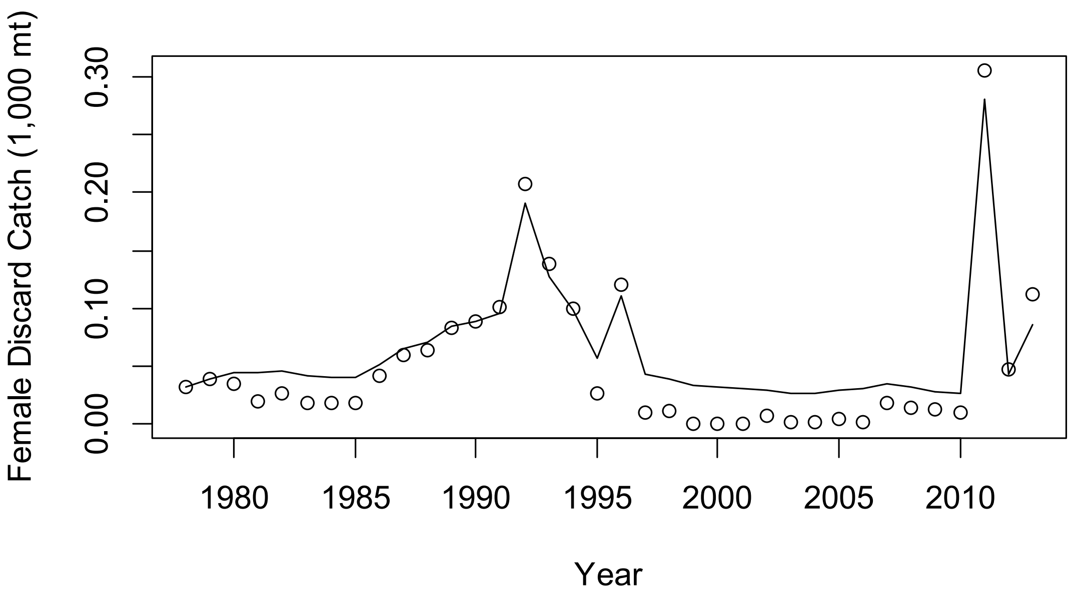


Figure 61. Base Model. Model fit to female discard bycatch in the directed fishery from 1992/93 to present and model estimates of discard from 1978 to 1991.

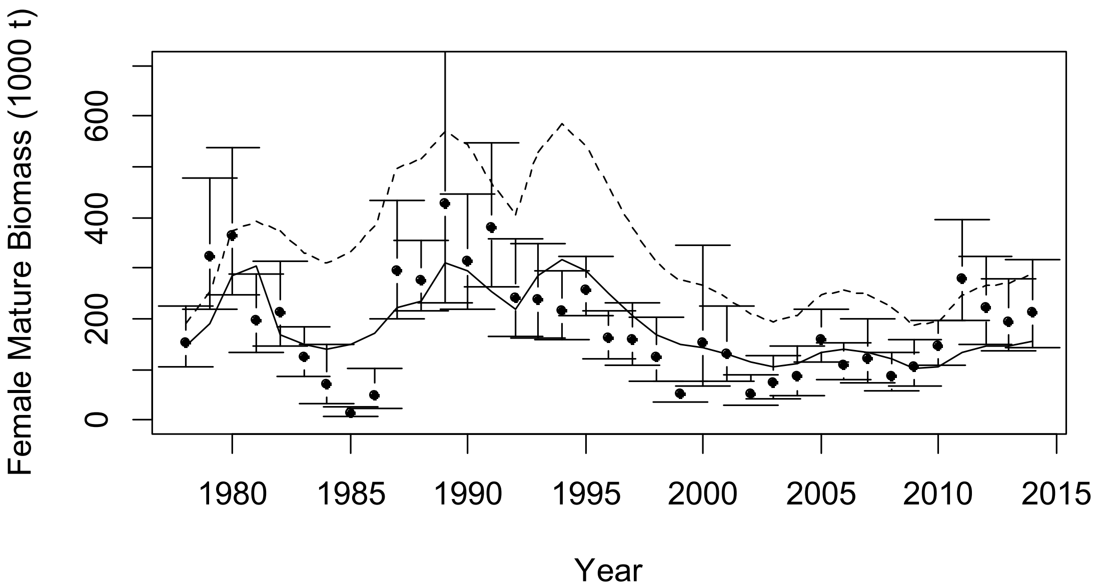


Figure 62. Base Model. Population female mature biomass (1000 t, dotted line), model estimate of survey female mature biomass (solid line) and observed survey female mature biomass with approximate lognormal 95% confidence intervals.

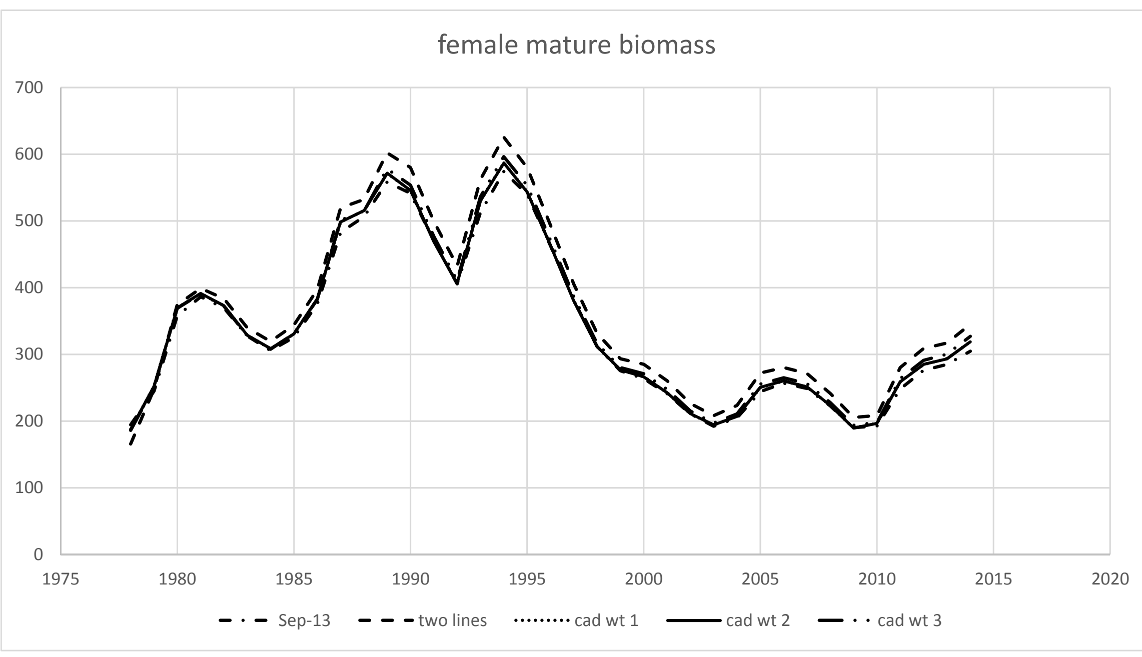


Figure 63. Population female mature biomass for the Base model (2b) and scenarios 0, 1, 2a and 2c.

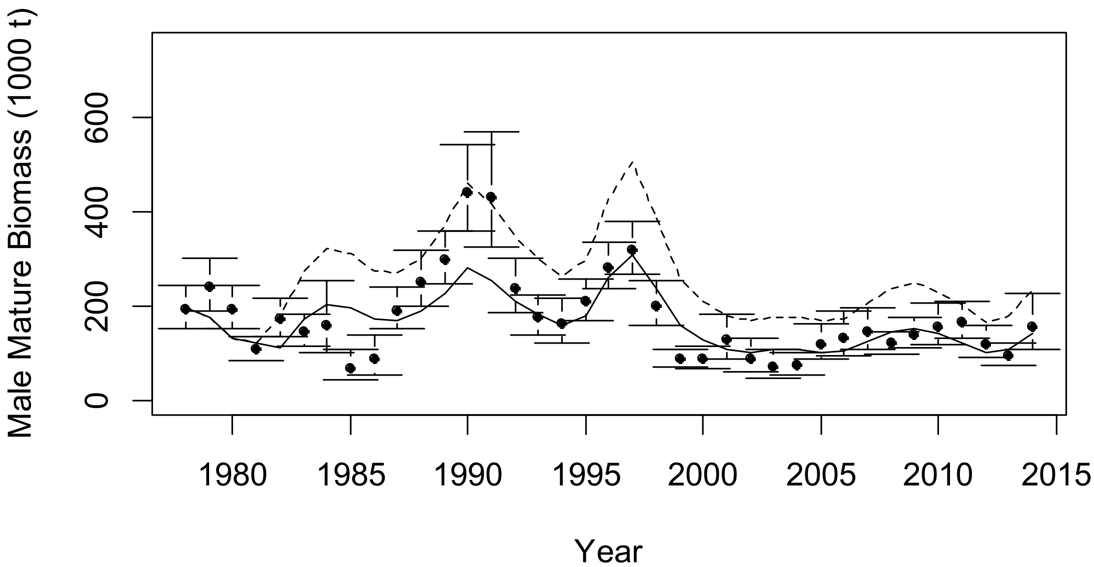


Figure 64. Base Model. Population male mature biomass (1000 t, dotted line), model estimate of survey male mature biomass (solid line) and observed survey male mature biomass with approximate lognormal 95% confidence intervals.

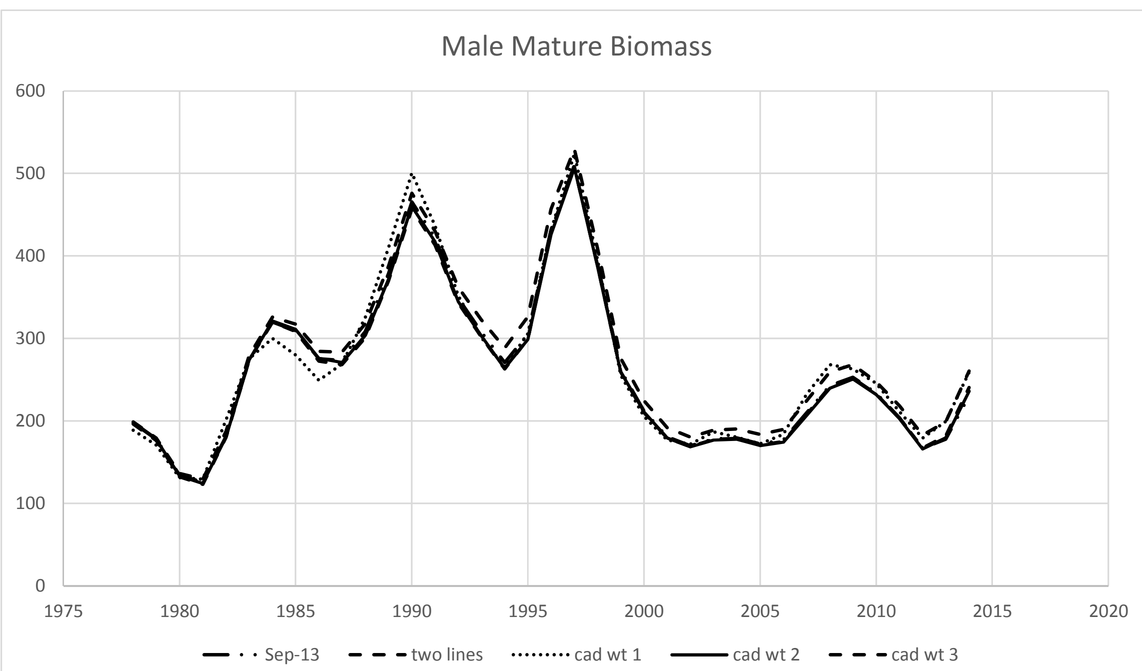


Figure 65. Population male mature biomass for the Base model (2b) and scenarios 0, 1, 2a and 2c.

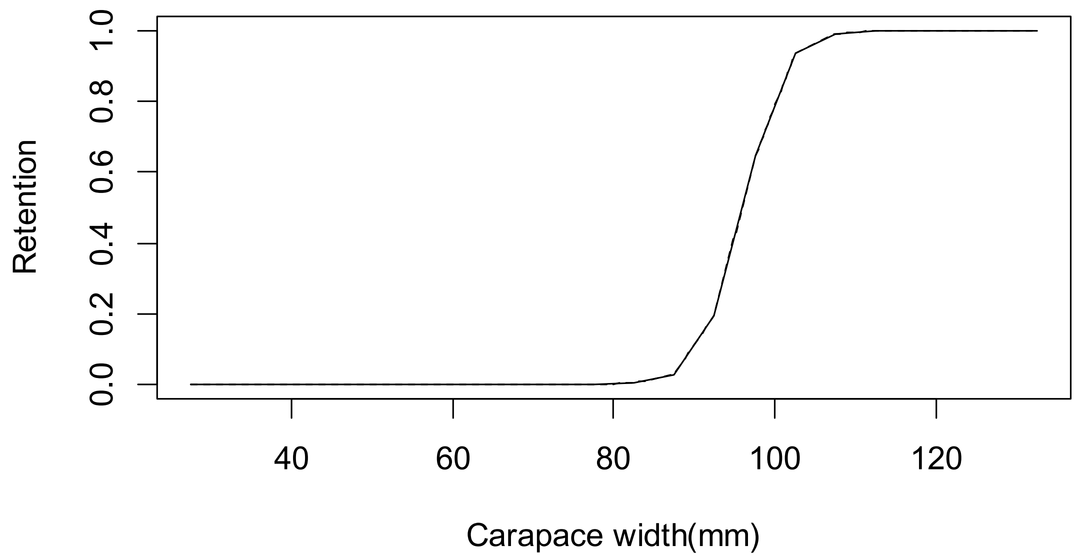


Figure 66. Base Model. Model estimated fraction of the total catch that is retained by size for male snow crab combined shell condition.

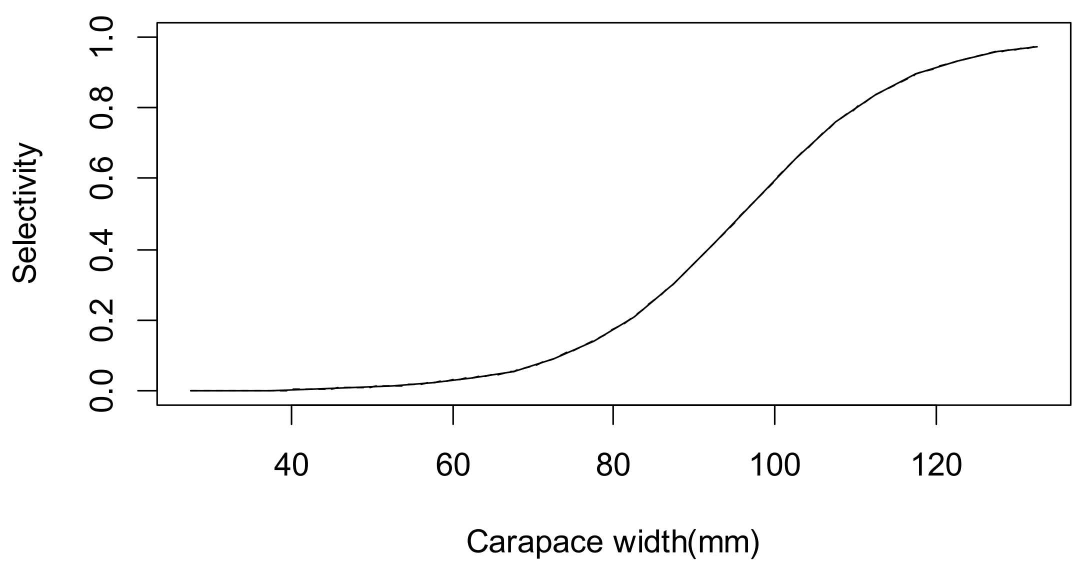


Figure 67. Base Model. Selectivity curve estimated by the model for bycatch in the groundfish trawl fishery for females and males.

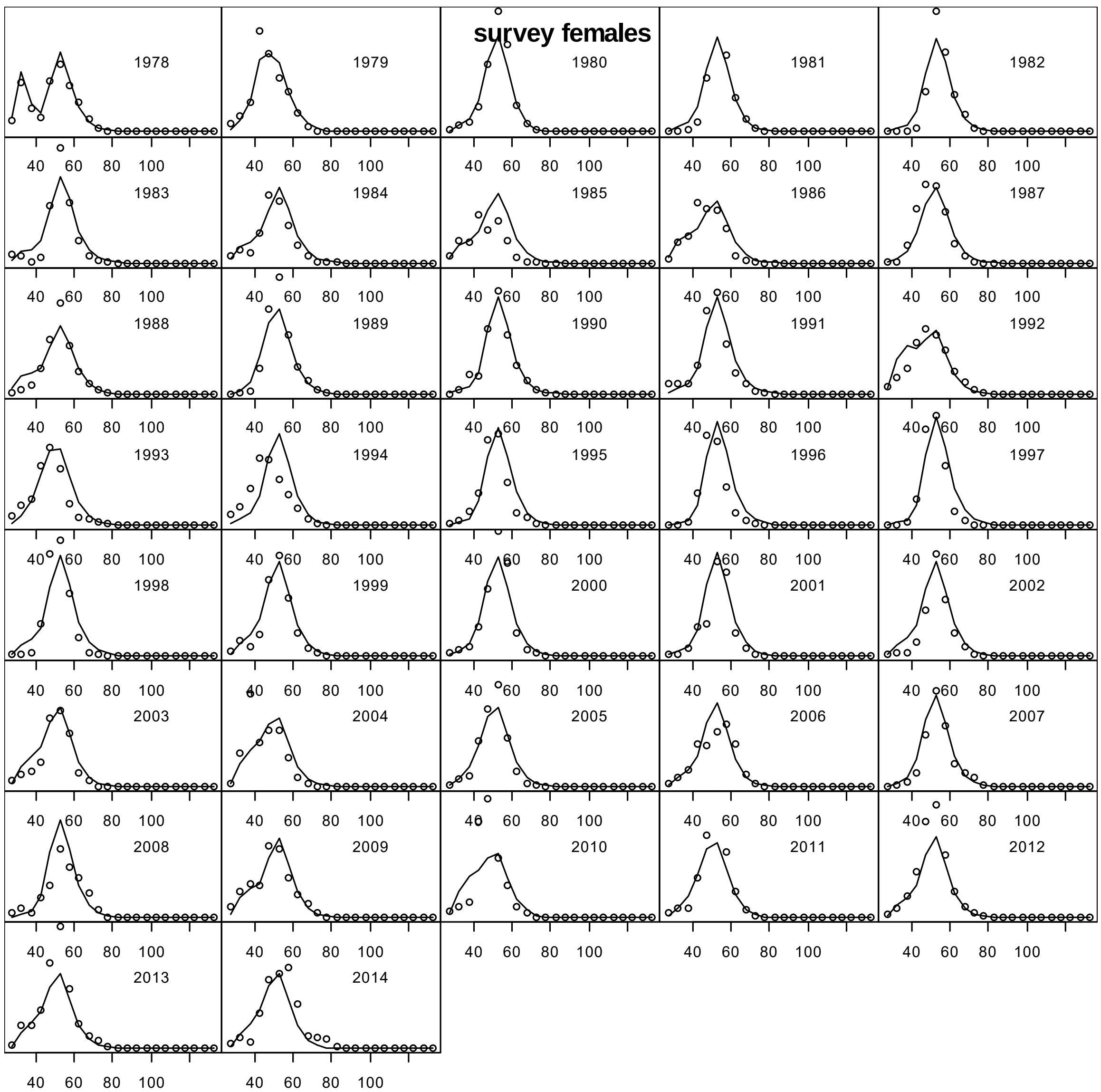


Figure 68. Base Model. Model fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

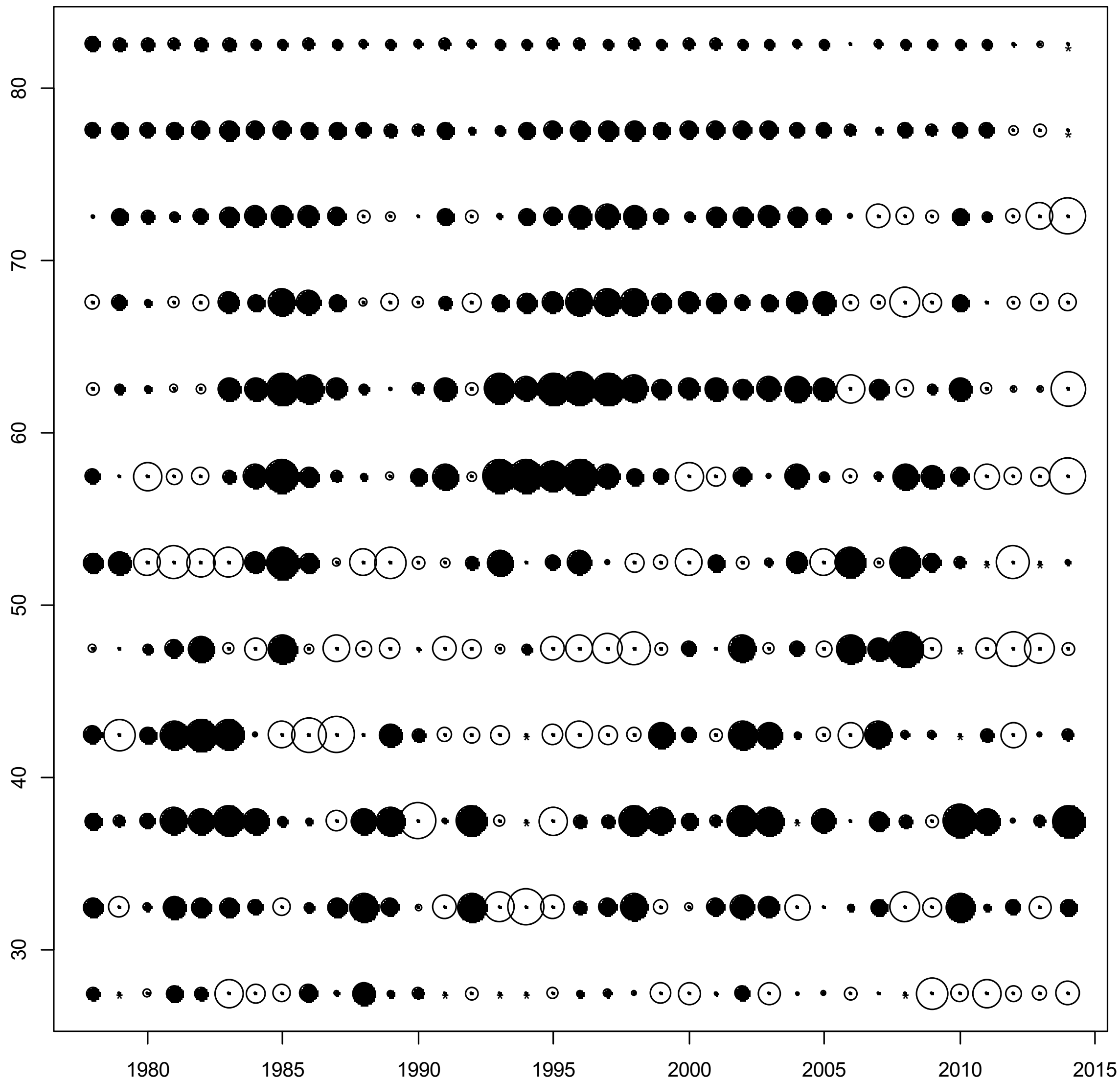


Figure 69. Base Model. Residuals of fit to survey female size frequency. Filled circles are negative residuals.

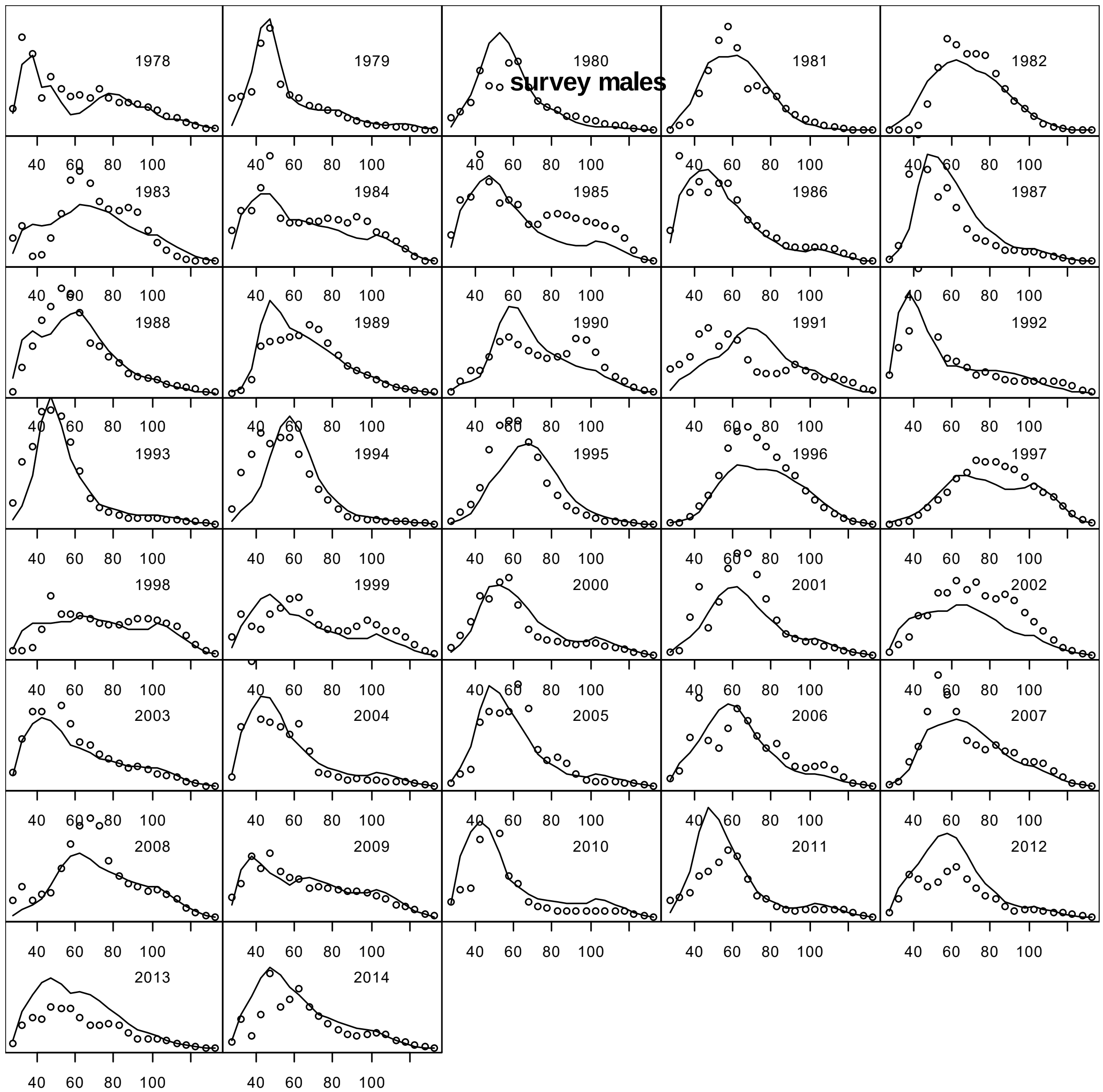


Figure 70. Base Model. Model fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

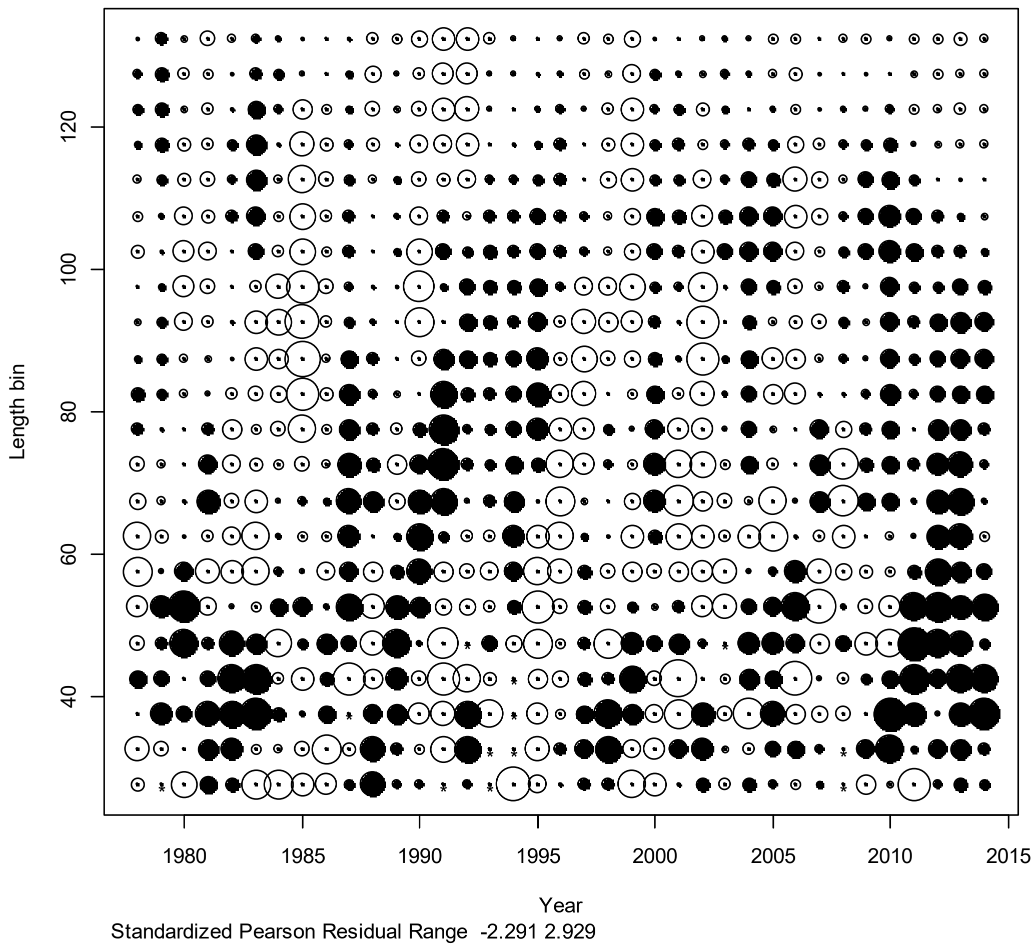


Figure 71. Base Model. Residuals for fit to survey male size frequency. Filled circles are negative residuals (predicted higher than observed).

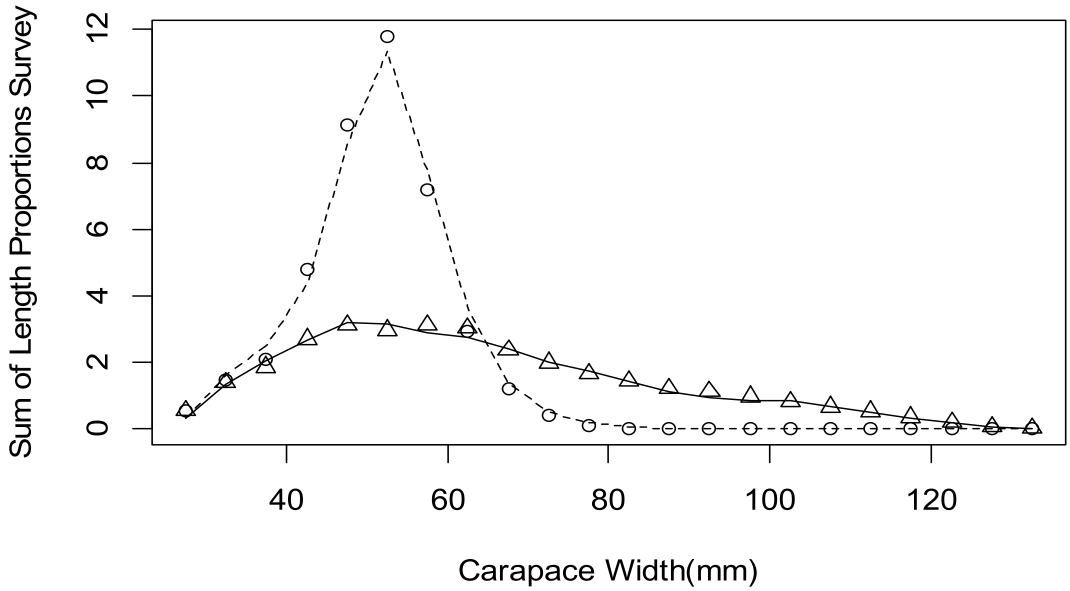


Figure 72. Base Model. Summary over years of fit to survey length frequency data by sex. Dotted line is fit for females, circles are observed. Solid line is fit for males, triangles are observed.

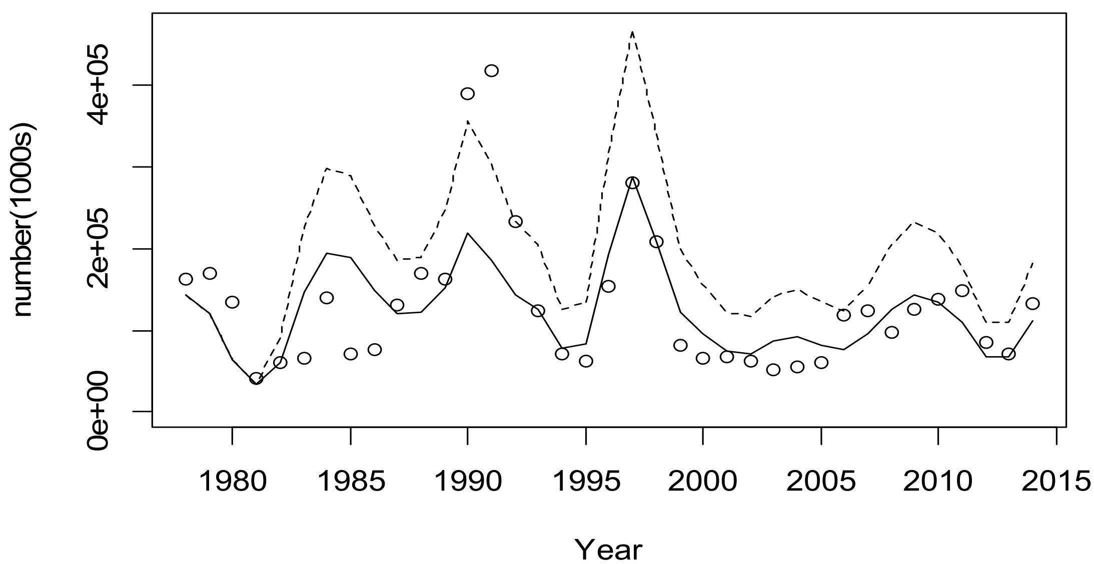


Figure 73. Base Model. Observed survey numbers of males >101mm (circles), model estimates of the population number of males >101mm(solid line) and model estimates of survey numbers of males >101 mm (dotted line).

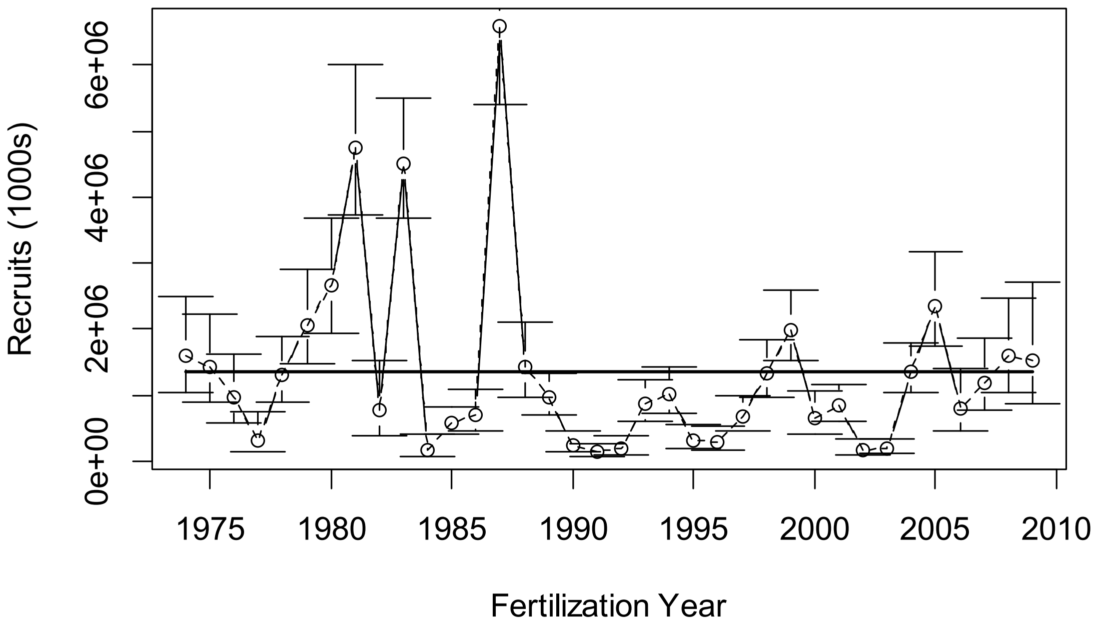


Figure 74. Base Model. Recruitment to the model for crab 25 mm to 50 mm. Total recruitment is 2 times recruitment in the plot. Male and female recruitment fixed to be equal. Solid horizontal line is average recruitment. Error bars are 95% C.I.

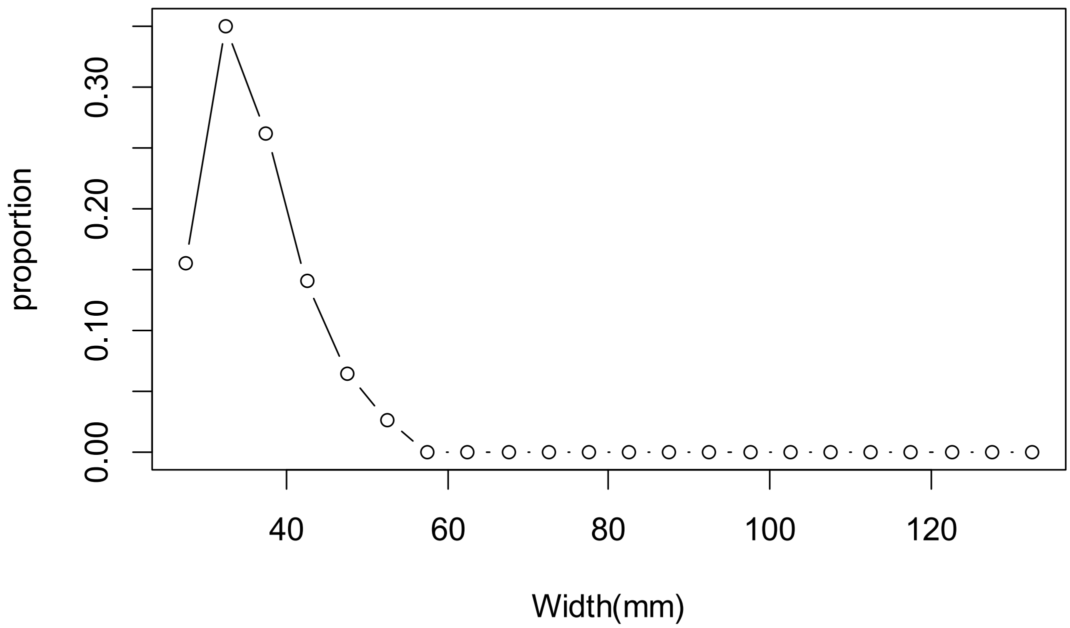


Figure 75. Base Model. Distribution of recruits to length bins estimated by the model.

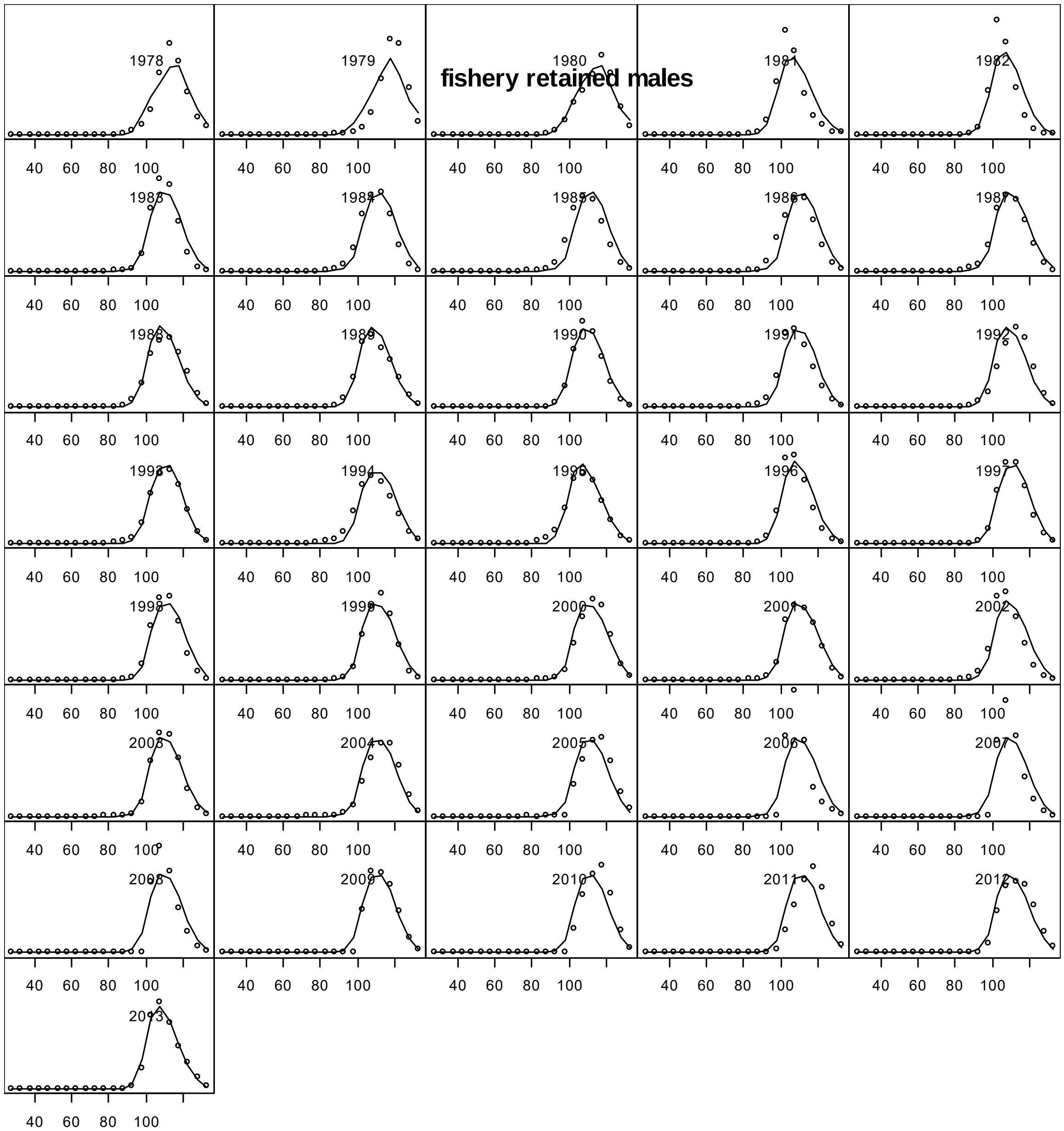


Figure 76. Base Model. Model fit to the retained male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

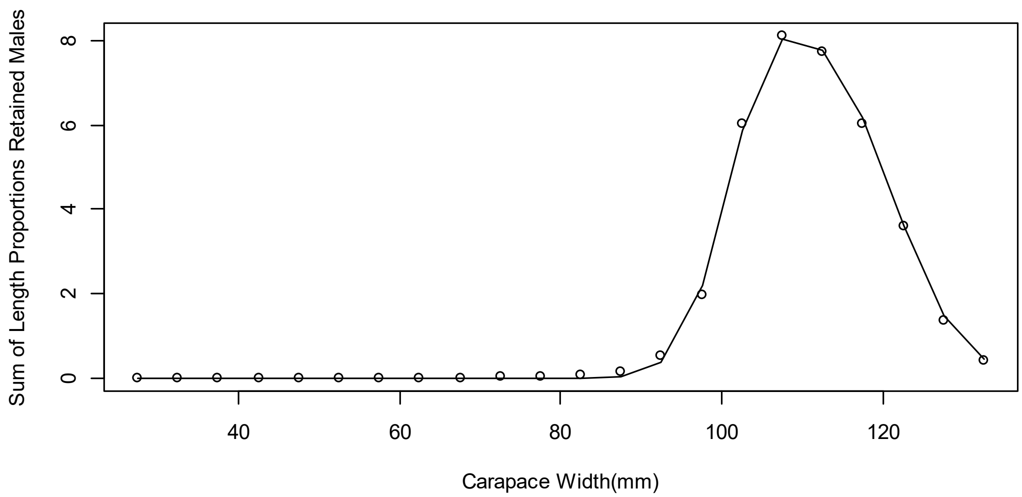


Figure 77. Base Model. Summary fit to retained male length.

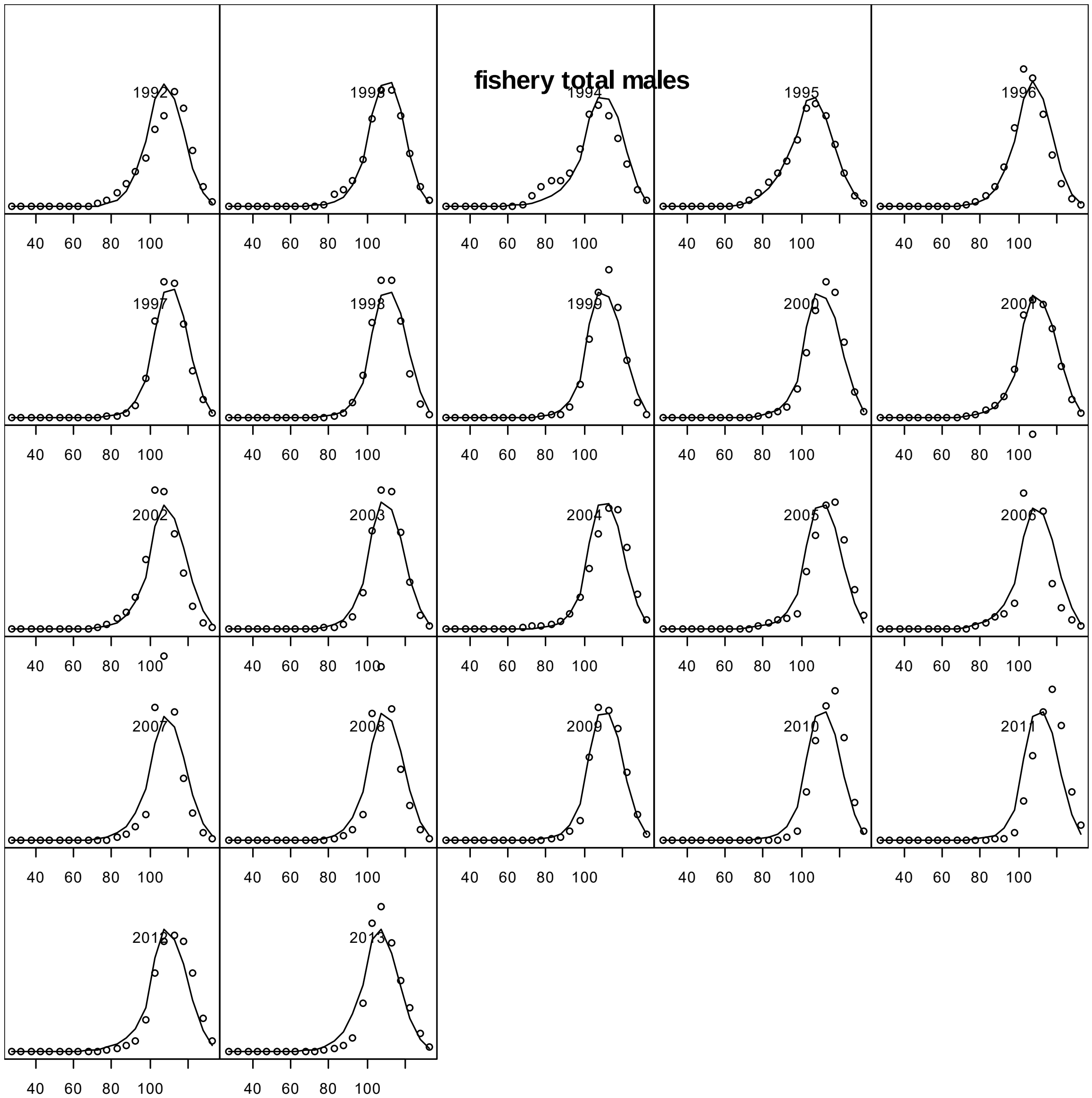


Figure 78. Base Model. Model fit to the total (discard plus retained) male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

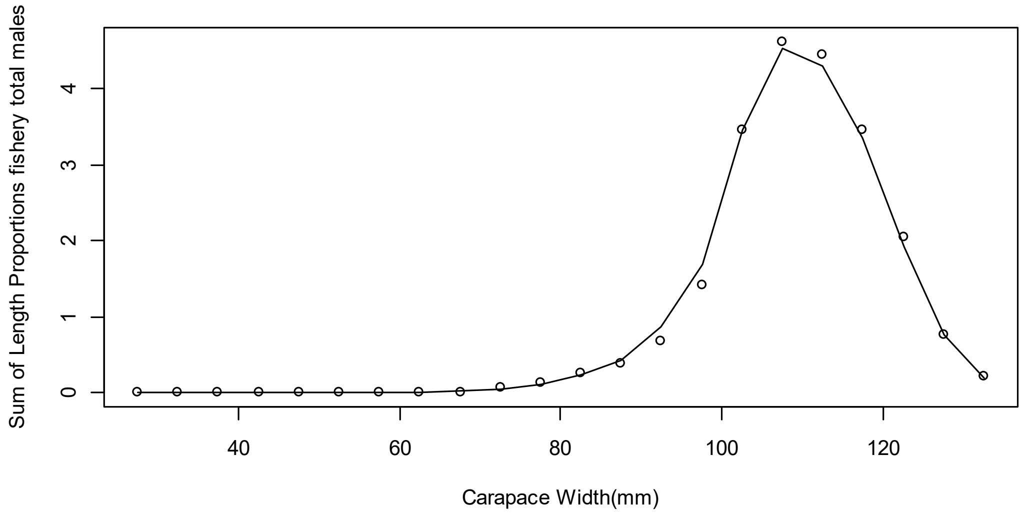


Figure 79. Base Model. Summary fit to total length frequency male catch.

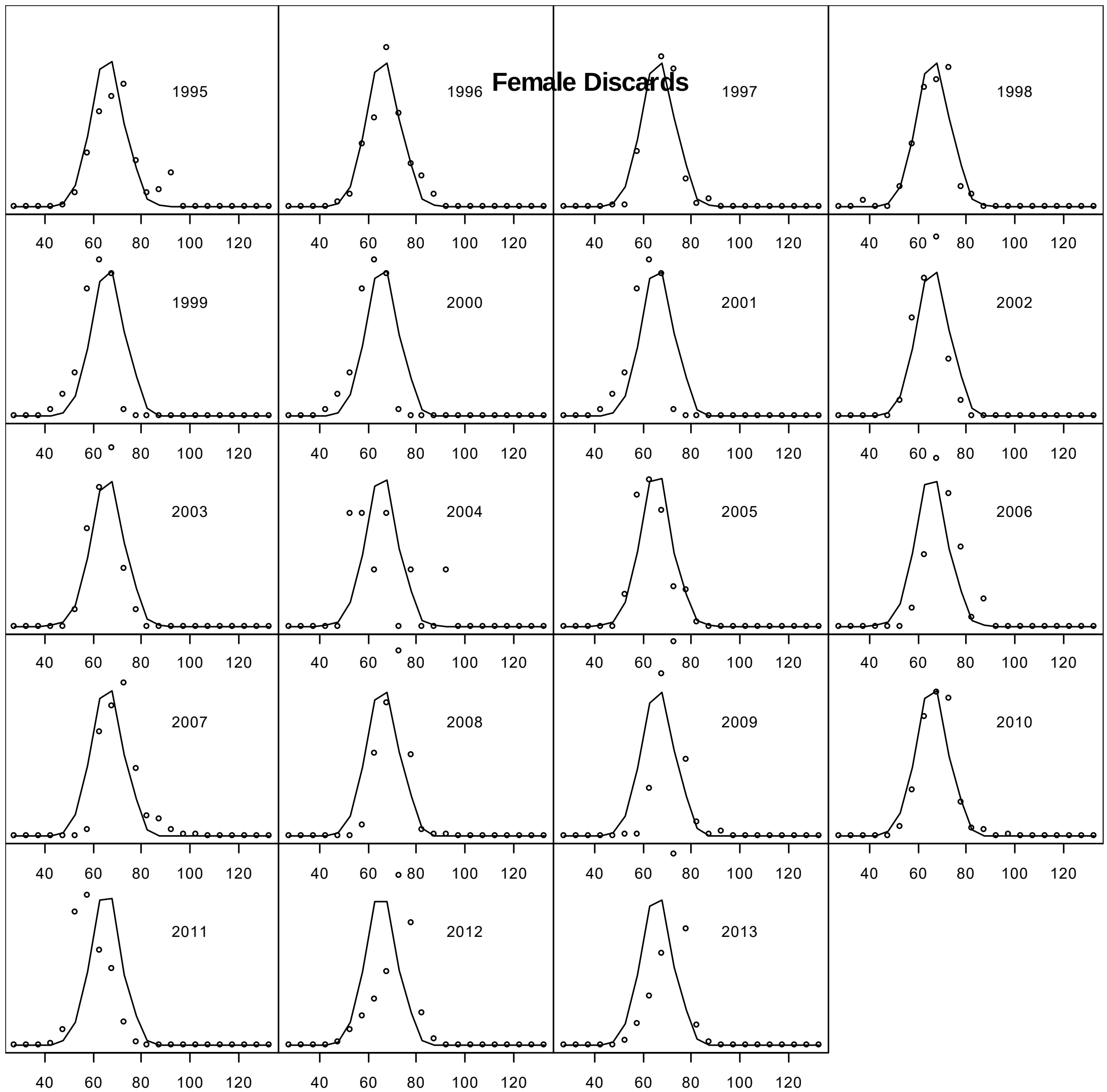


Figure 80. Base Model. Model fit to the discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

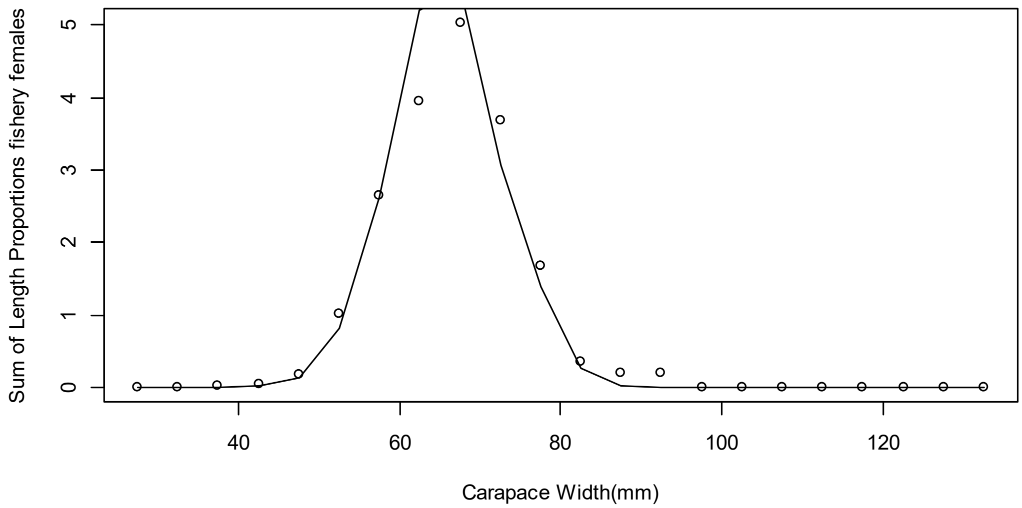


Figure 81. Base Model. Summary fit to directed fishery female discards.

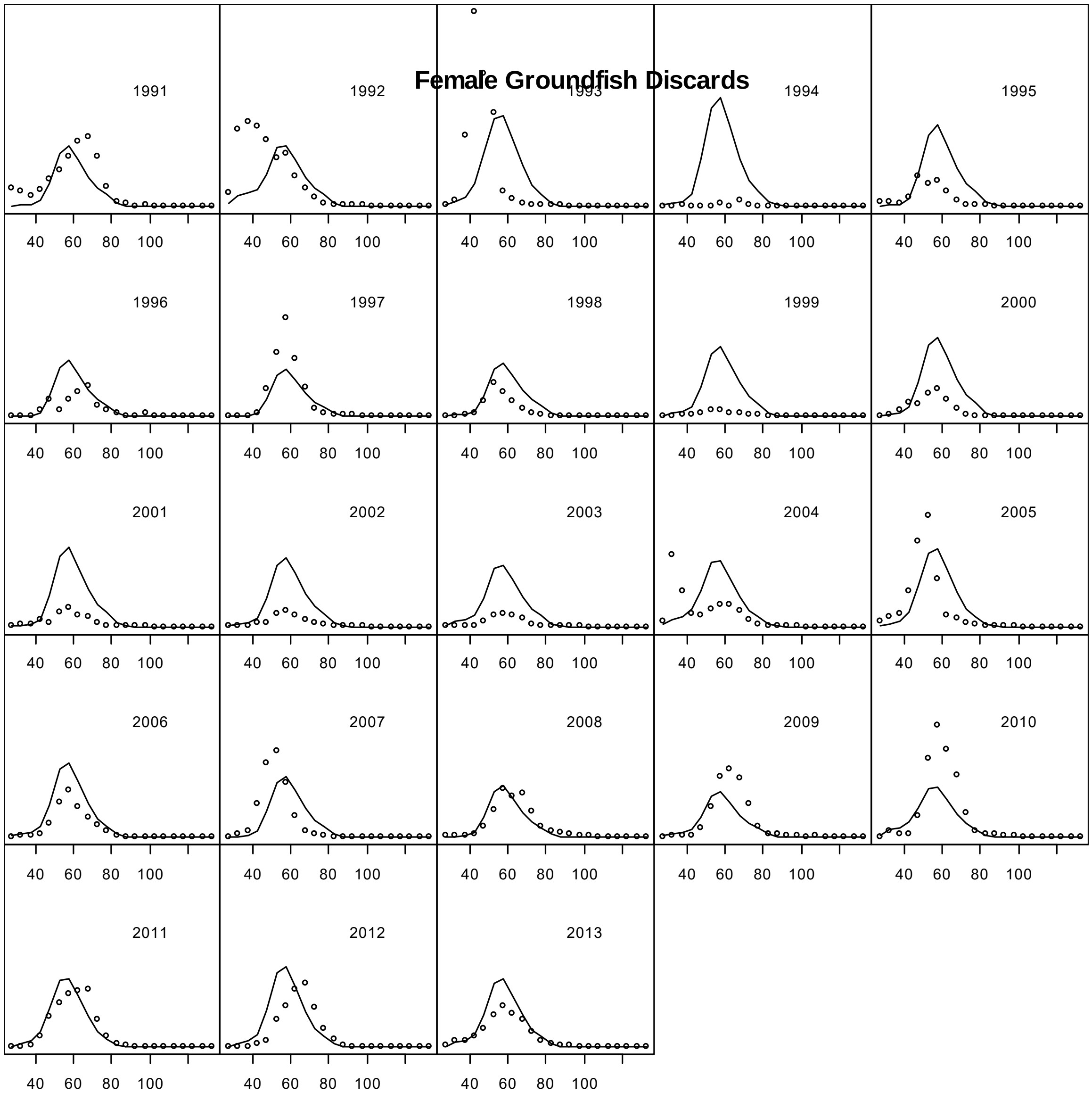


Figure 82. Base Model. Model fit to the groundfish trawl discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

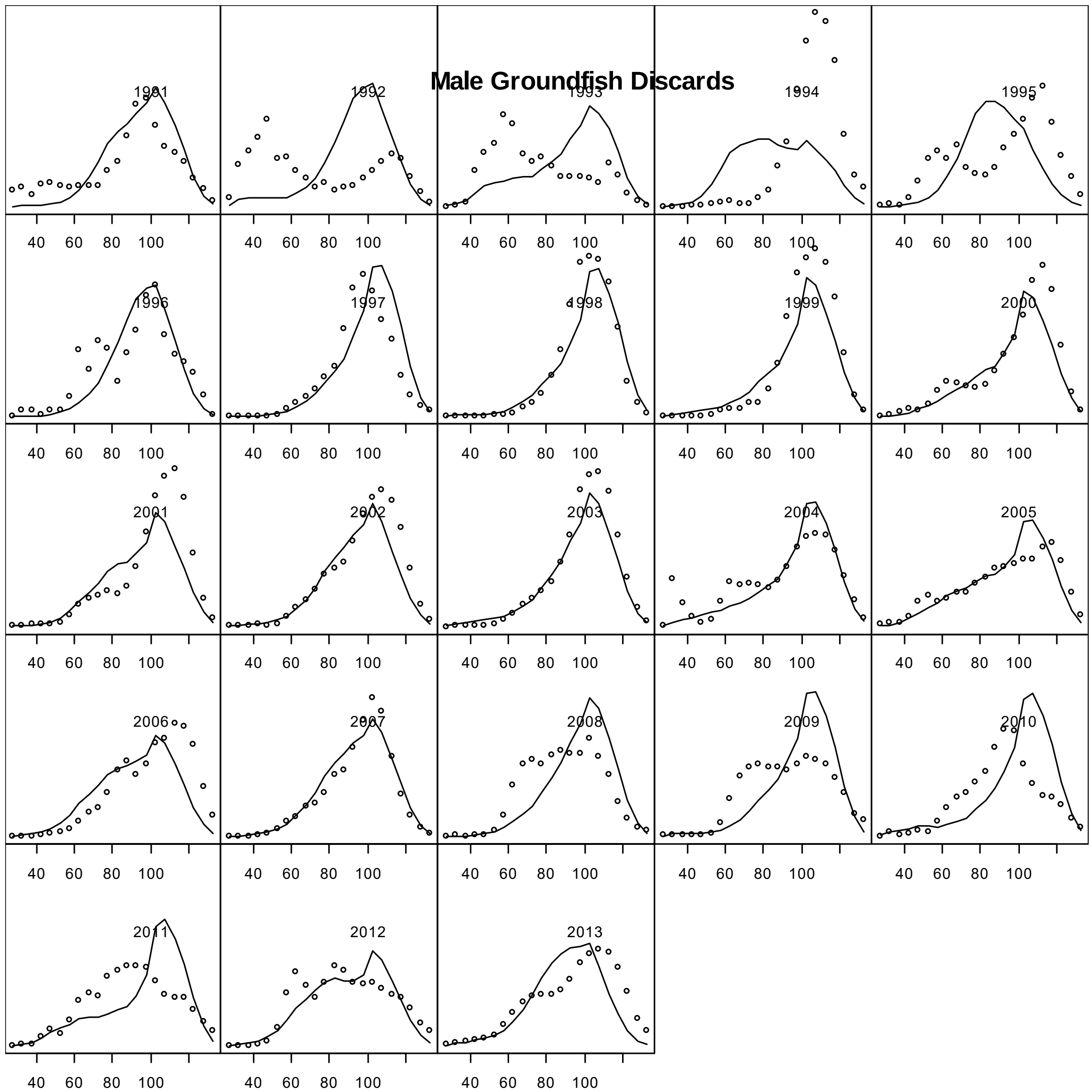


Figure 83. Base Model. Model fit to the groundfish trawl discard male size frequency data. Solid line is the model fit. Circles are observed data.

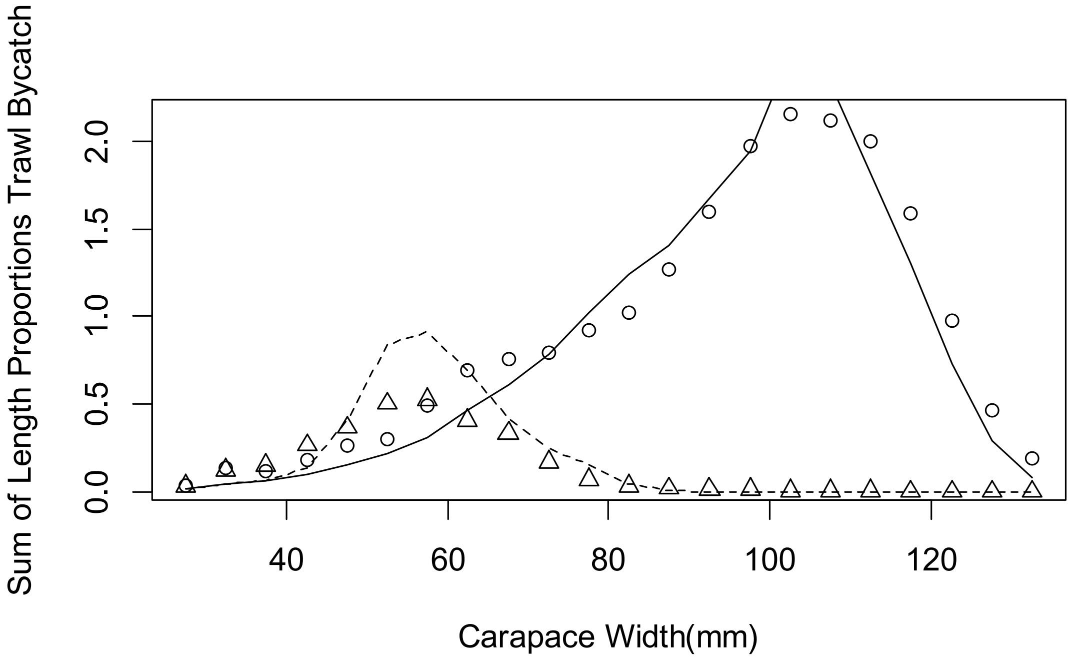


Figure 84. Base Model. Summary fit to groundfish length frequency.

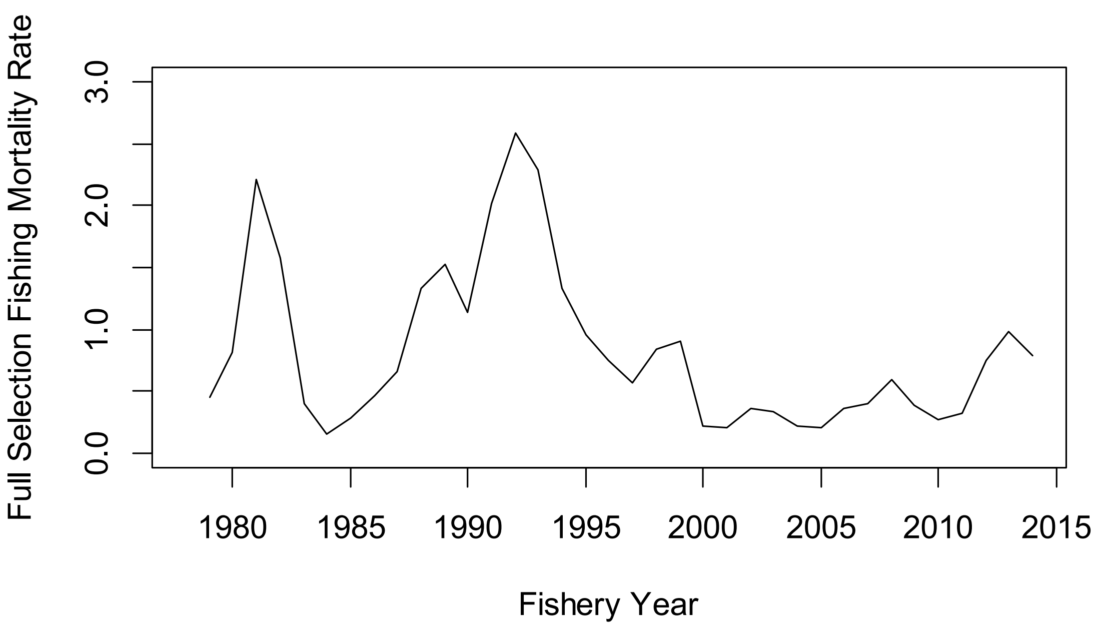


Figure 85. Base Model. Full selection fishing mortality estimated in the model from 1978/79 to present.

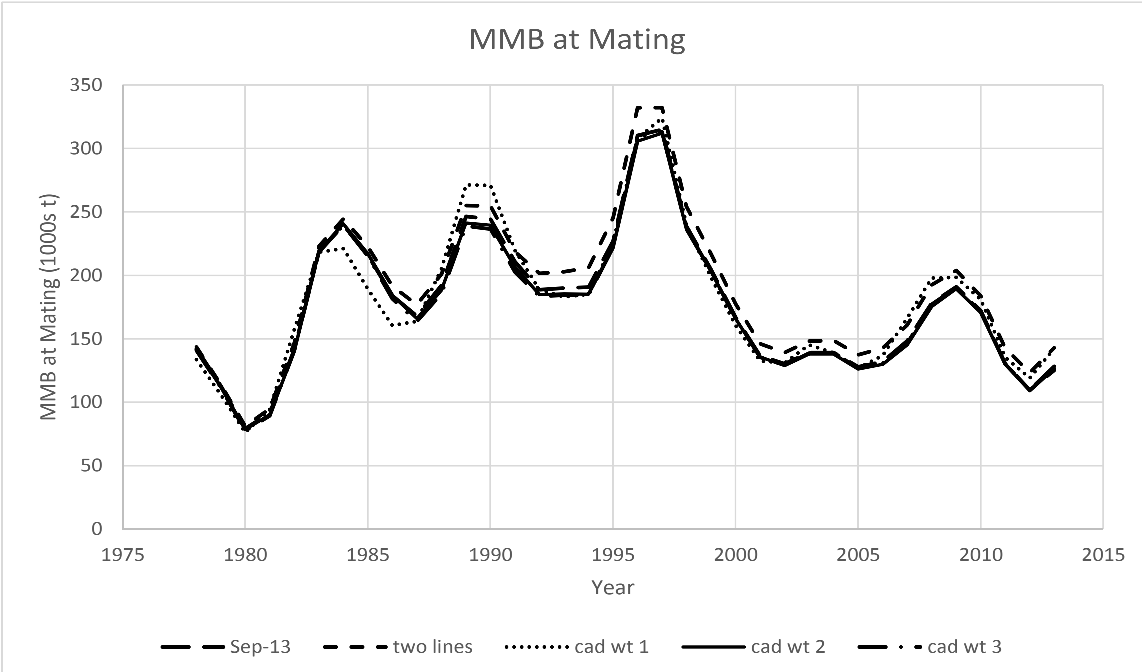


Figure 86. Mature male biomass at mating for the Base model (2b) and scenarios 0, 1, 2a and 2c.

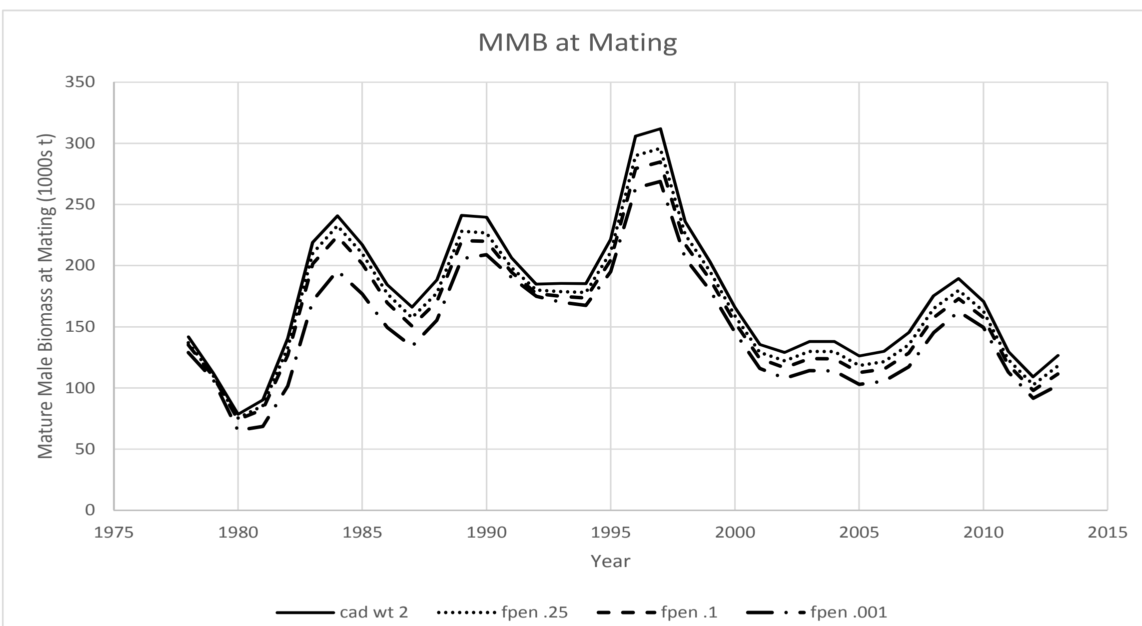


Figure 87. Mature male biomass at mating for the Base model (2b) and scenarios 2e, 2f and 2g.

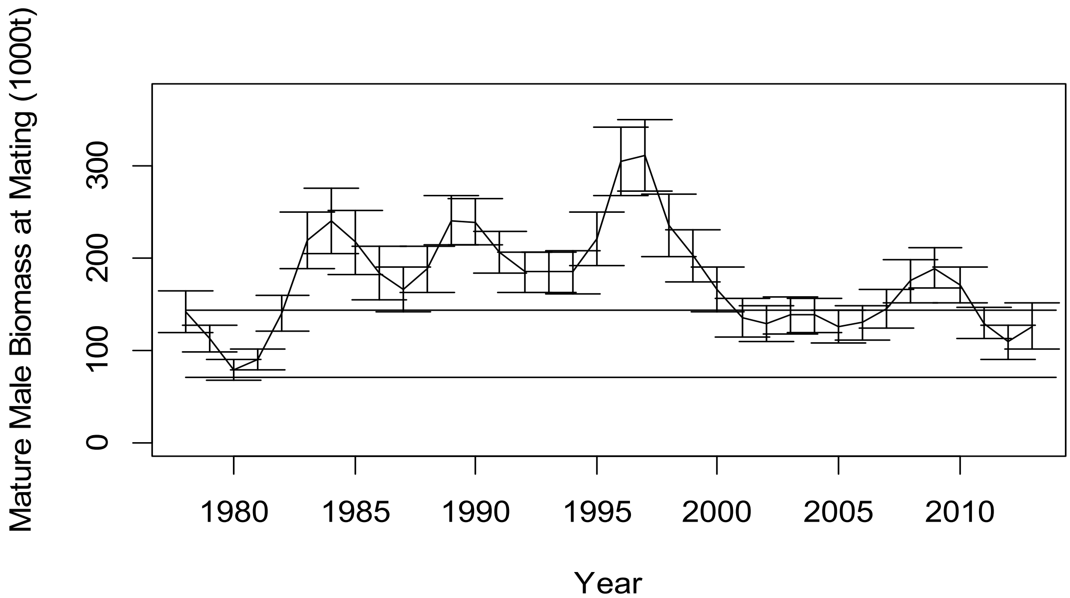


Figure 88. Base Model. Mature Male Biomass at mating with 95% confidence intervals. Top horizontal line is B35%, lower line is ½ B35%.

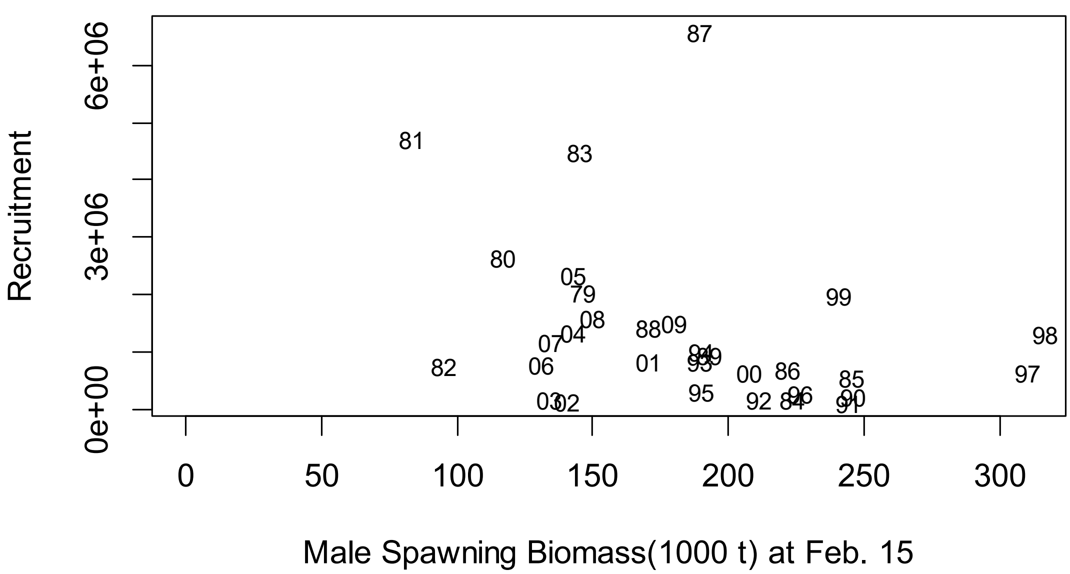


Figure 89. Base Model. Spawner recruit estimates using male mature biomass at time of mating (1000t). Numbers are fertilization year assuming a lag of 5 years. Recruitment is half total recruits in thousands of crab.

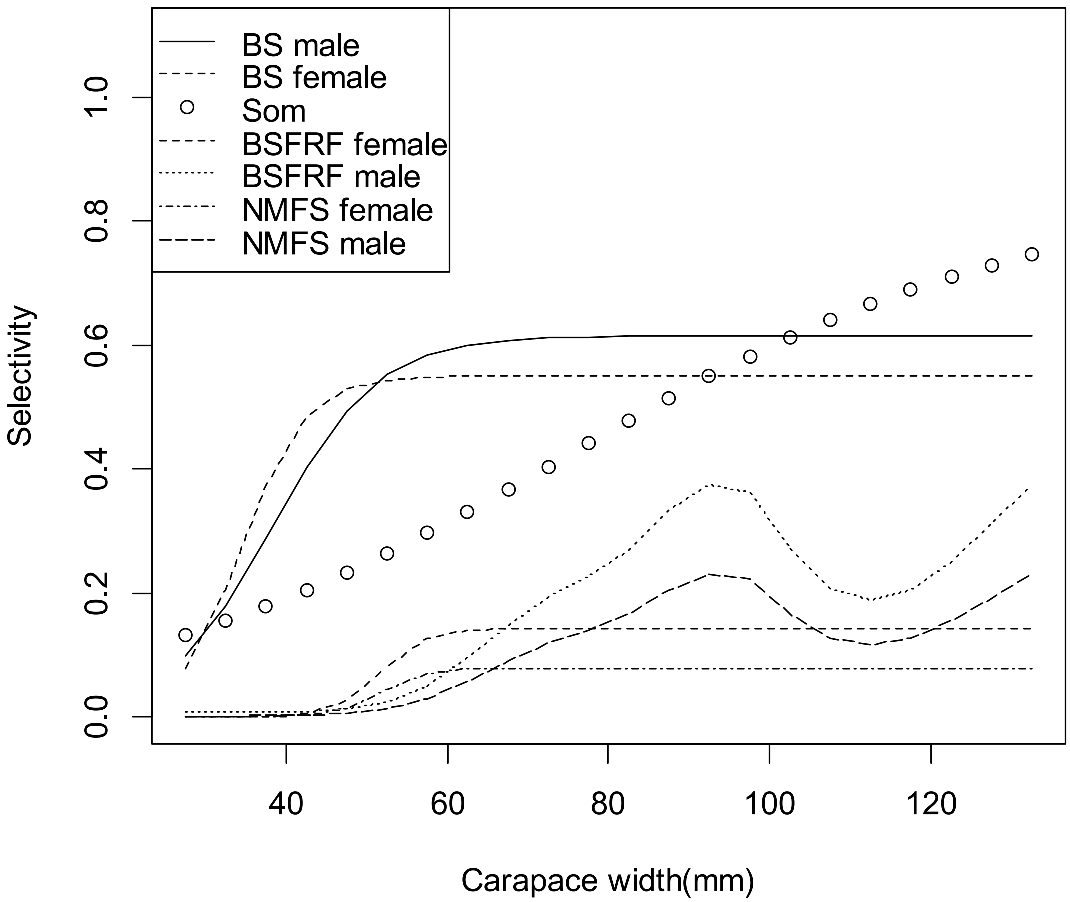


Figure 90. Base Model. Survey selectivity curves entire Bering Sea survey for female (upper dashed line) and male snow crab (solid lines) estimated by the model for 1989 to present. Survey selectivities estimated by Somerton(2010) from 2009 study area data are the circles. Lower lines are survey selectivities in the study area for BSFRF male and female crab and NMFS male and female crab.

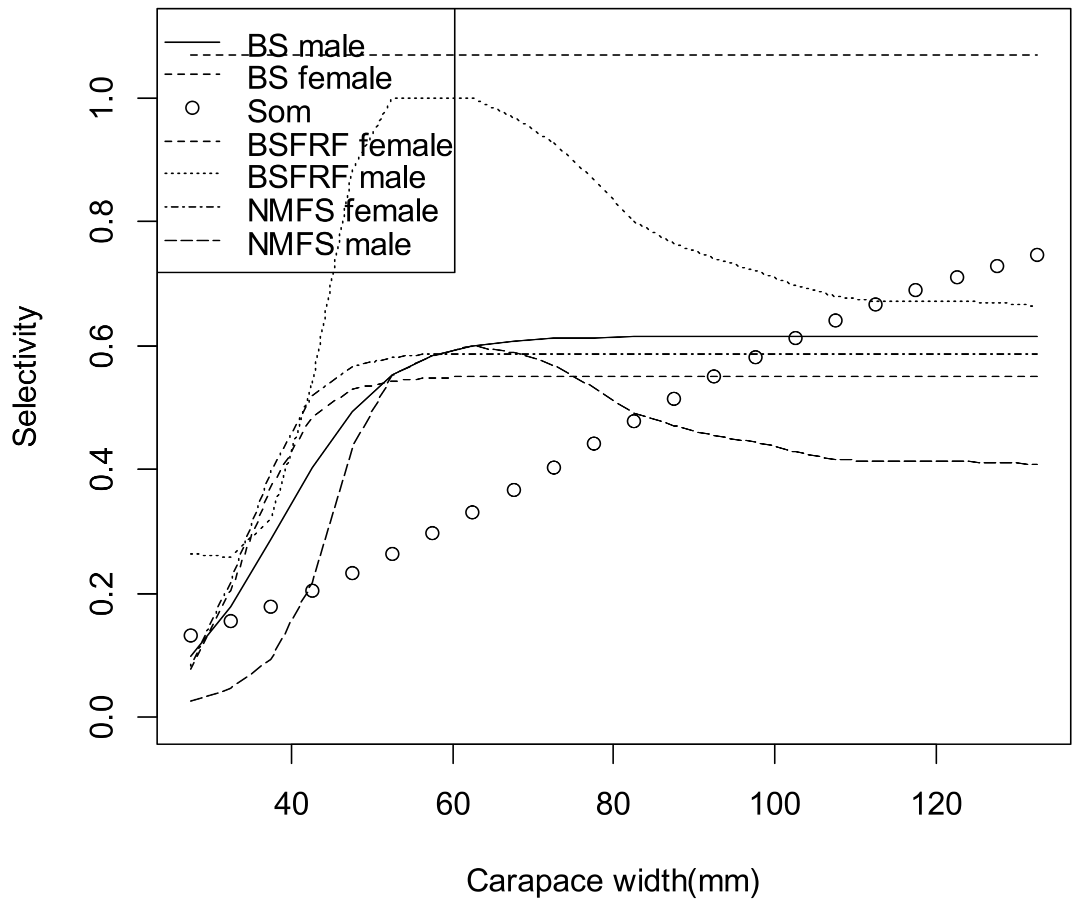


Figure 91. Base Model. 2010 study area survey availability curve (BSFRF) and selectivity curves (NMFS). BSFRF female is 1.0 all sizes (need to extend y axis). BS are survey selectivity curves for the entire Bering Sea. Som is the selectivity curve estimated by Somerton from the 2009 study area data.

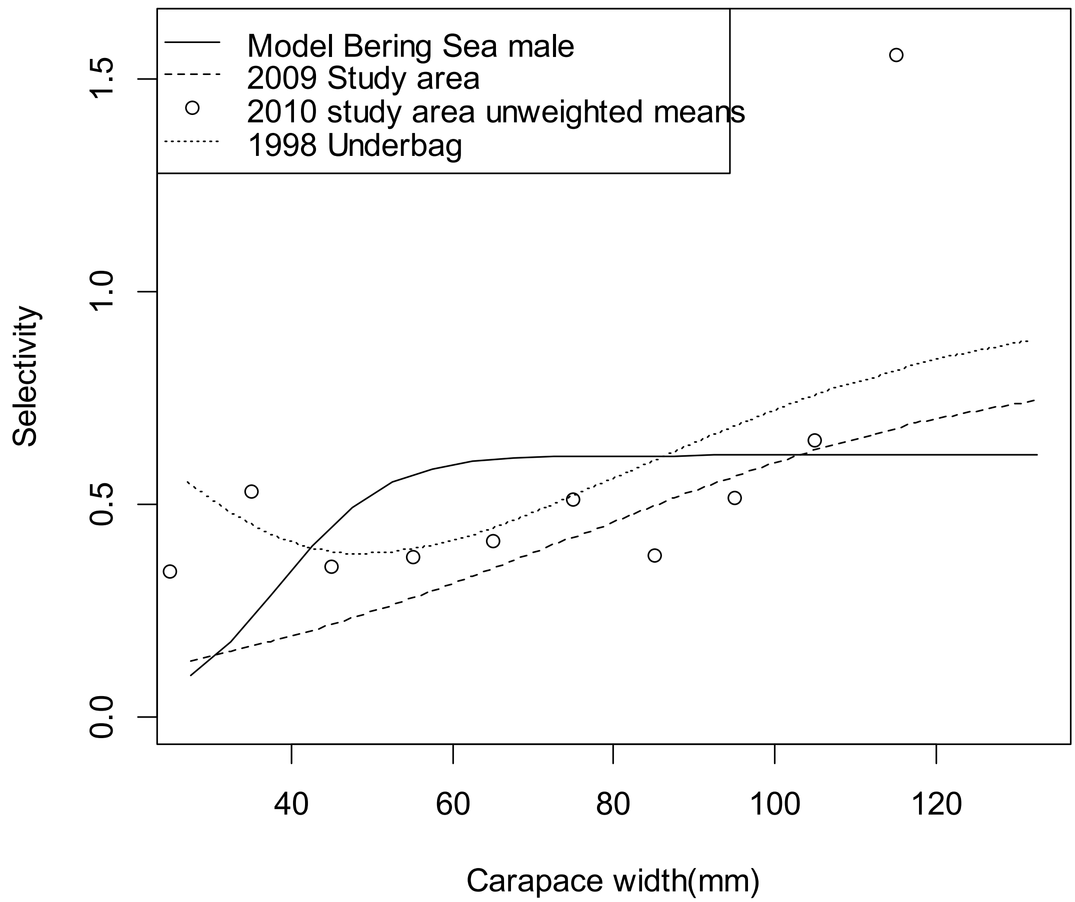


Figure 92. Base Model. Survey selectivity for male crab 1989- present (Model Bering Sea male), with selectivity curves estimated outside the model. 2009 study area is the curve estimated by Somerton from the 2009 study area data.

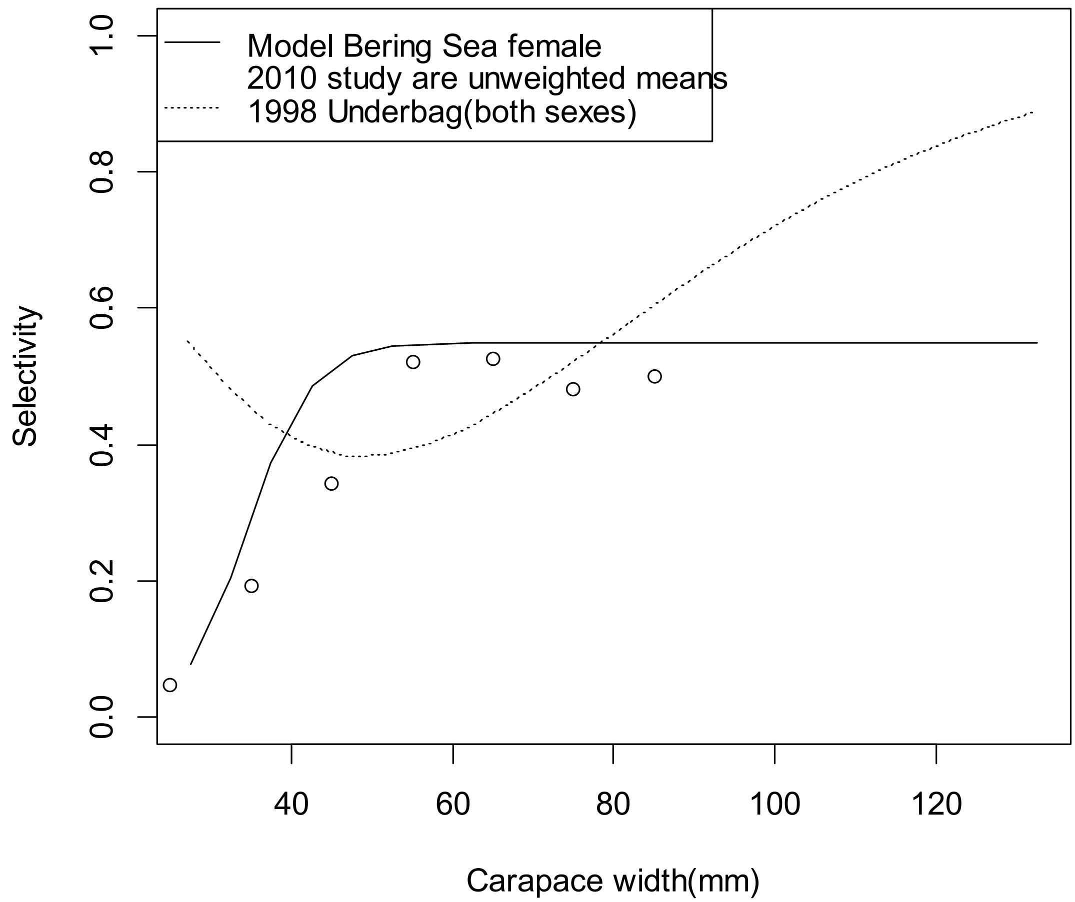


Figure 93. Base Model. Survey selectivity for female crab 1989- present (Model Bering Sea female).

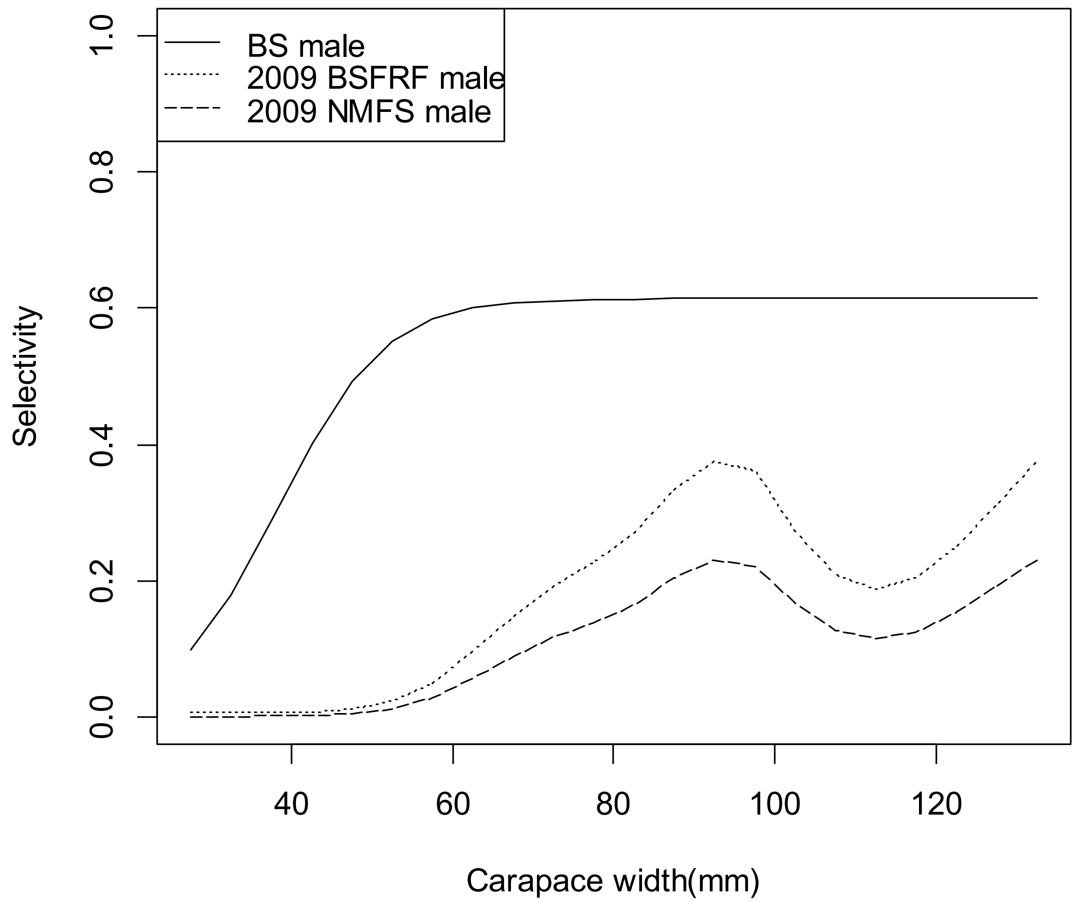


Figure 94. Base Model. Survey selectivity curves for male crab in the entire Bering sea 1989-present (BS male), 2009 study area BSFRF male and 2009 study area NMFS male.

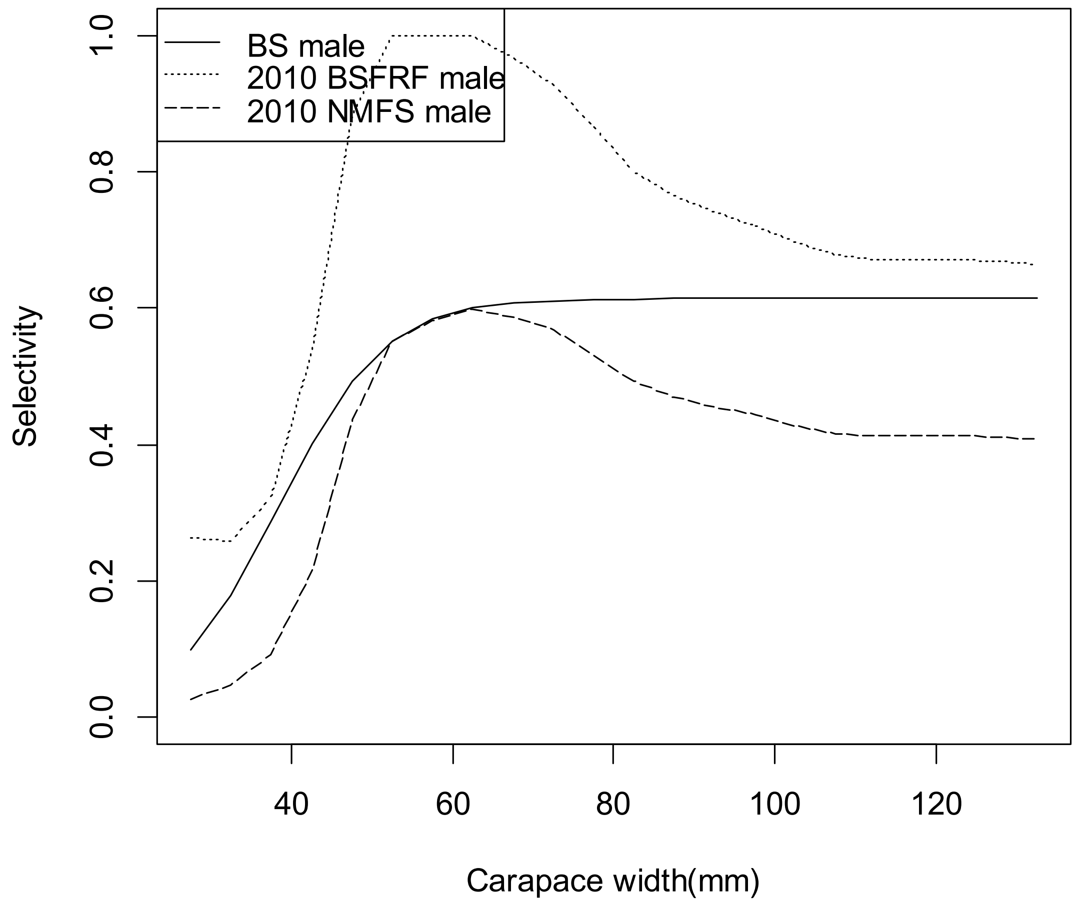


Figure 95. Base Model. Survey selectivity curves for male crab in the entire Bering sea 1989-present (BS male), 2010 study area BSFRF male and 2010 study area NMFS male.

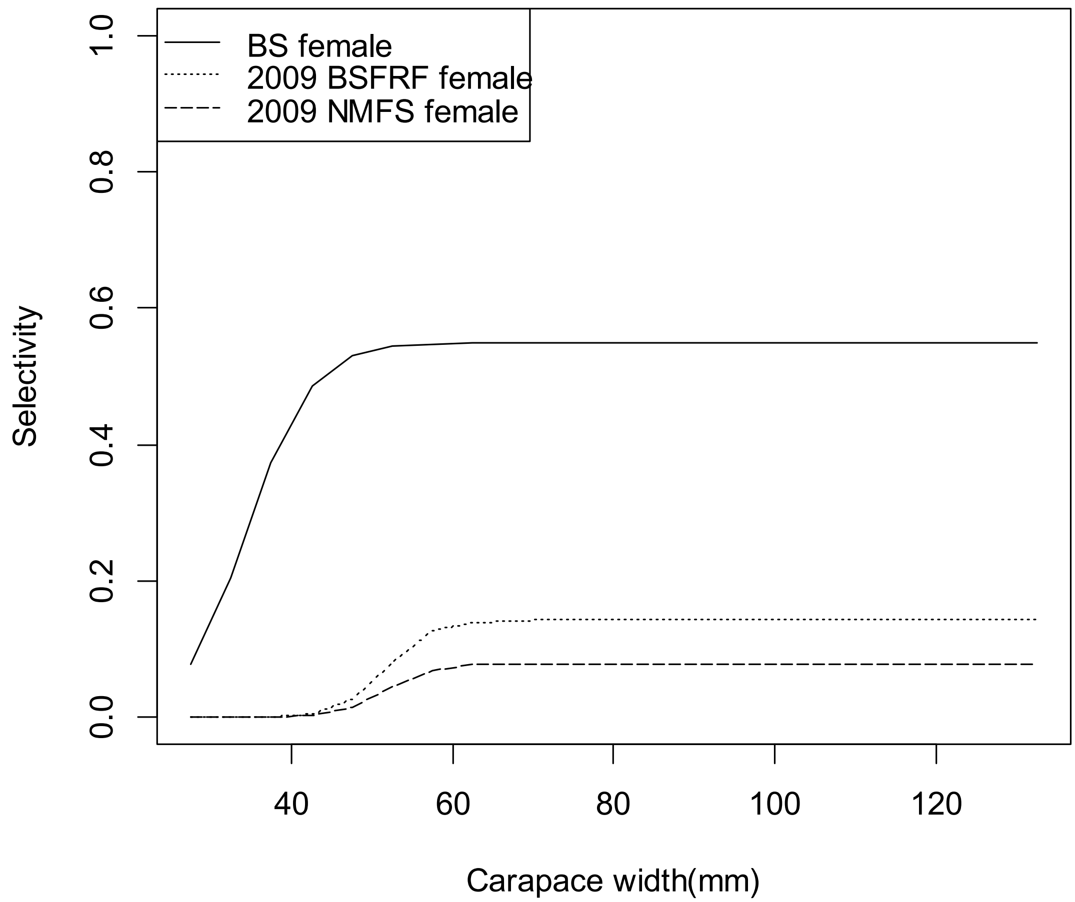


Figure 96. Base Model. Survey selectivity curves for female crab in the entire Bering sea 1989-present (BS female), 2009 study area BSFRF female and 2009 study area NMFS female.

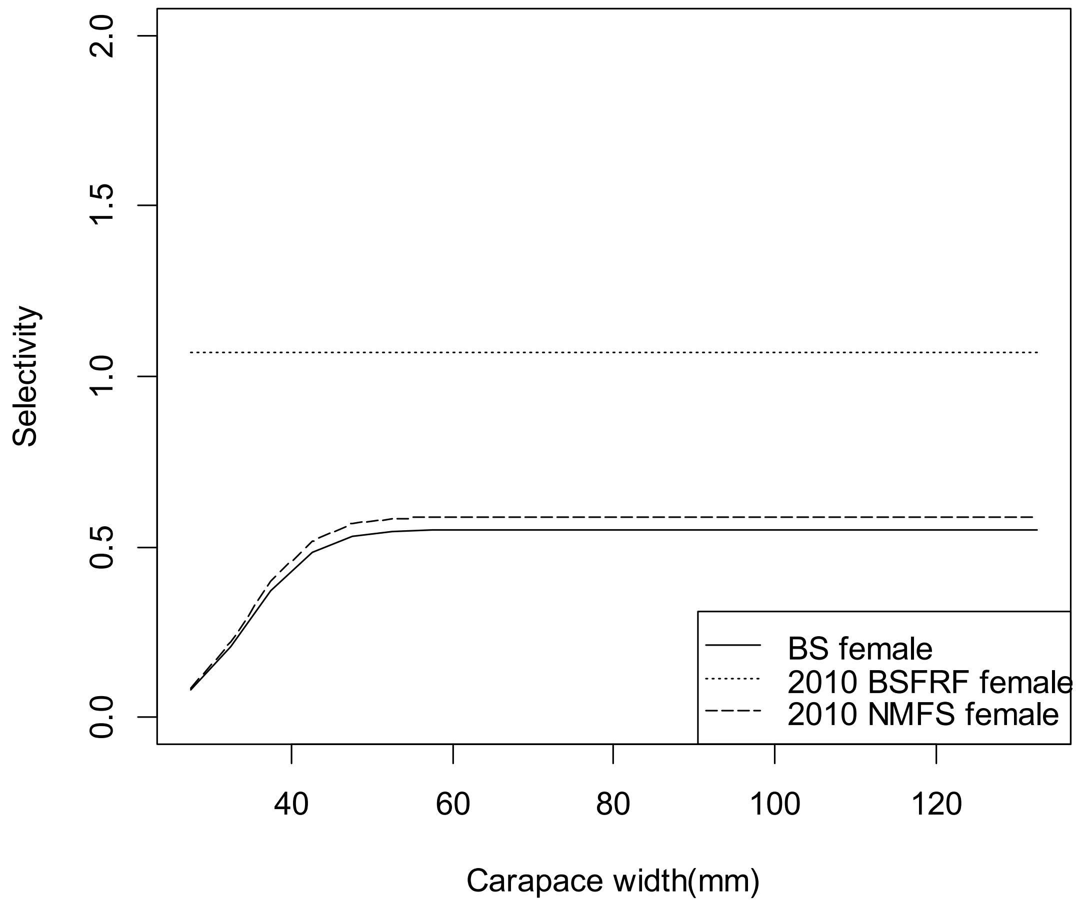


Figure 97. Base Model. Survey selectivity curves for female crab in the entire Bering sea 1989-present (BS female), 2010 study area BSFRF female and 2010 study area NMFS female.

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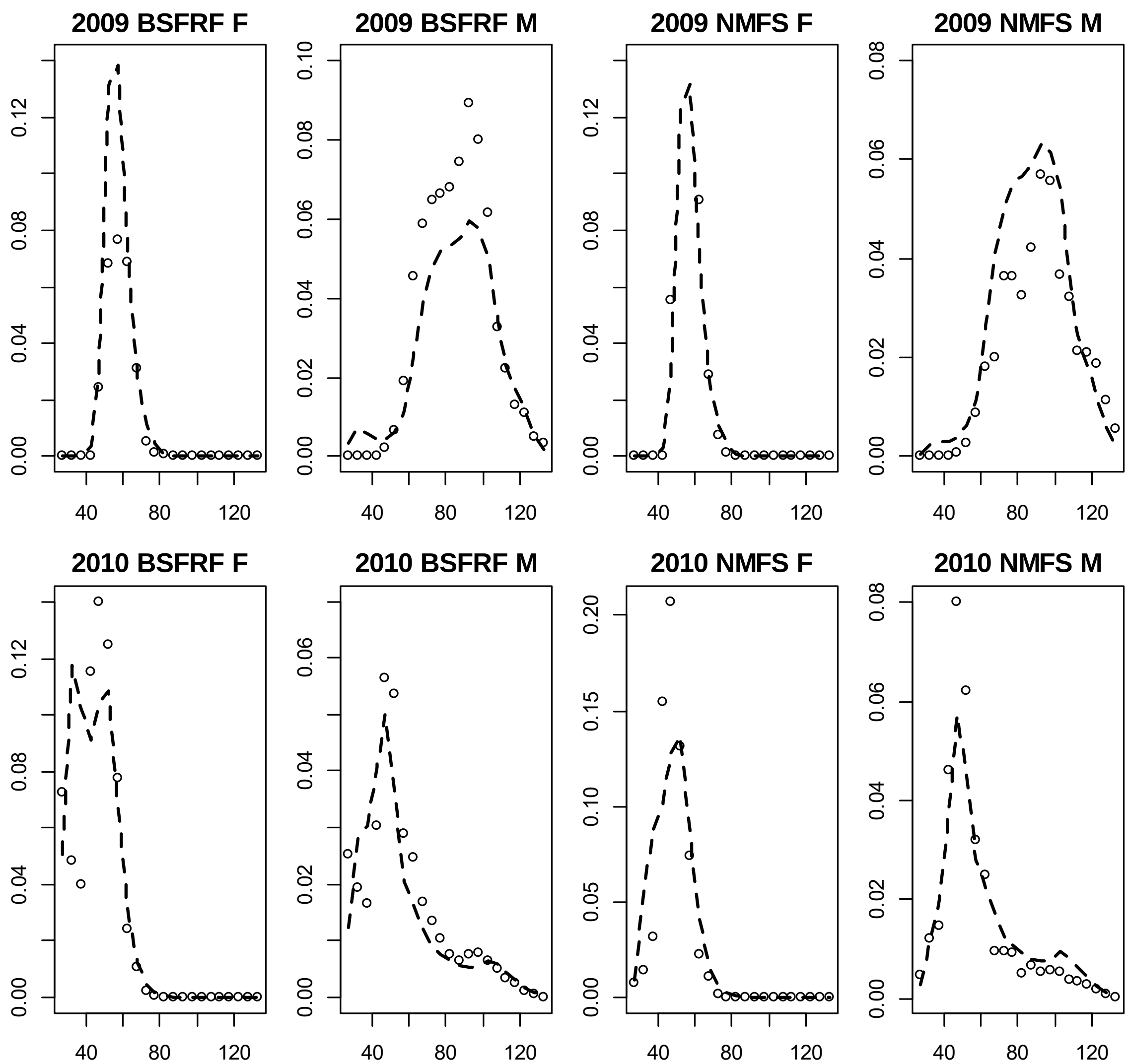

Figure 98. Base Model. Model fit to length frequency for BSFRF and NMFS females and males in the study area.

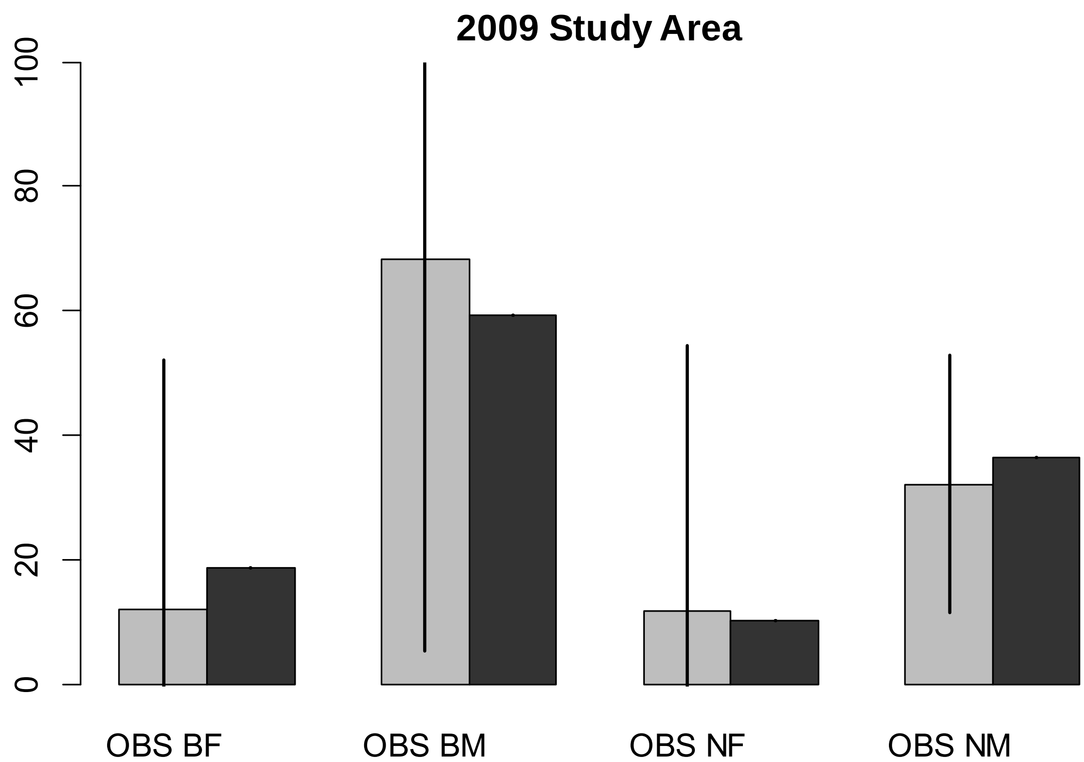

Figure 99. Base Model. Fits to 2009 study area mature biomass by sex for BSFRF and NMFS data.

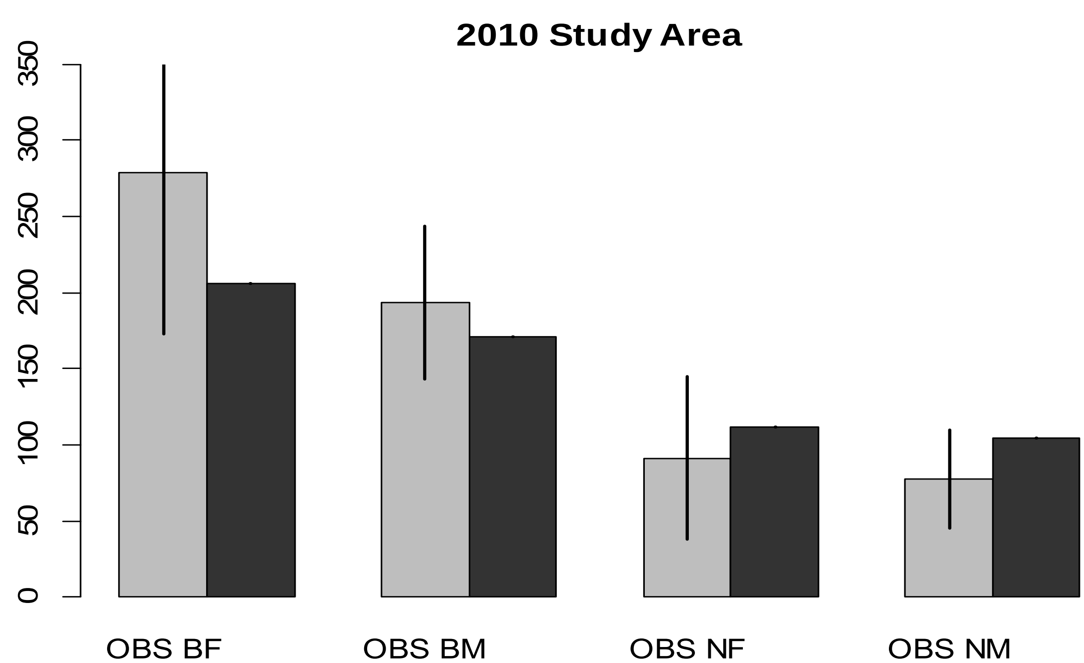

Figure 100. Base Model. Fits to 2010 study area mature biomass by sex for BSFRF and NMFS data.

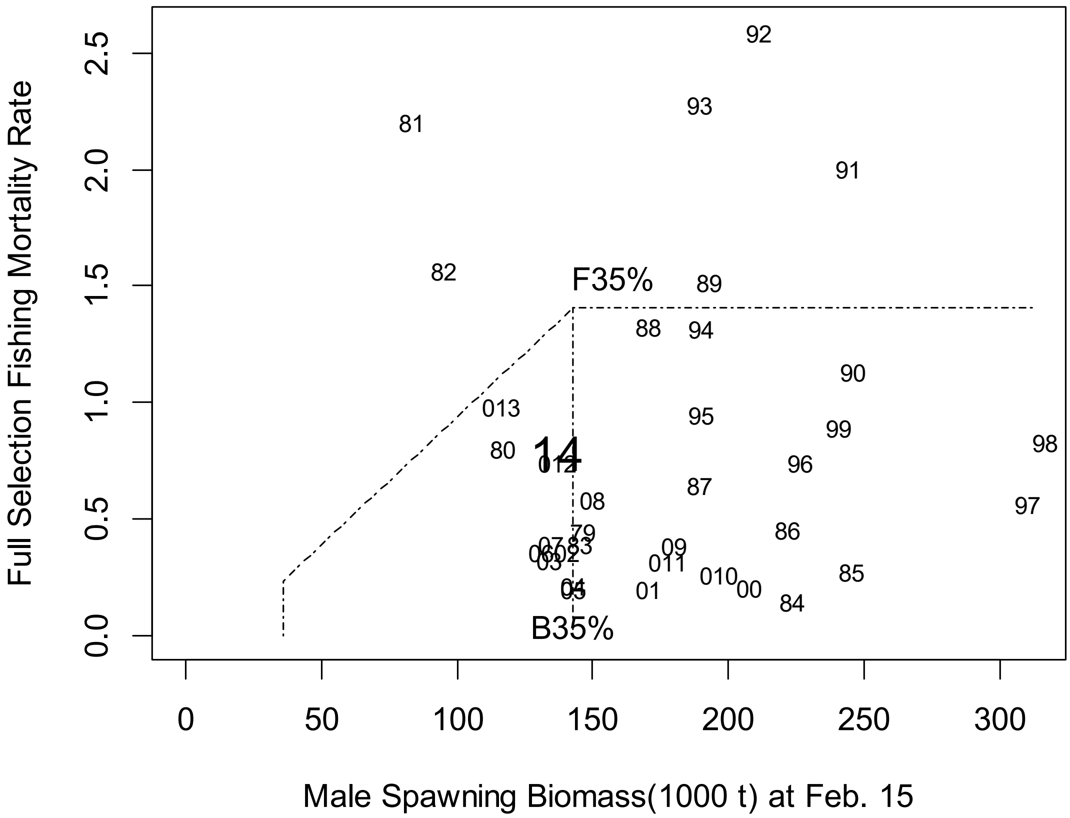

Figure 101. Base Model. Fishing mortality estimated from fishing years 1979 to 20013/14 (labeled 14 in the plot). The OFL control rule (F35%) is shown for comparison. The vertical line is B35%, estimated from the product of spawning biomass per recruit fishing at F35% and mean recruitment from the stock assessment model.

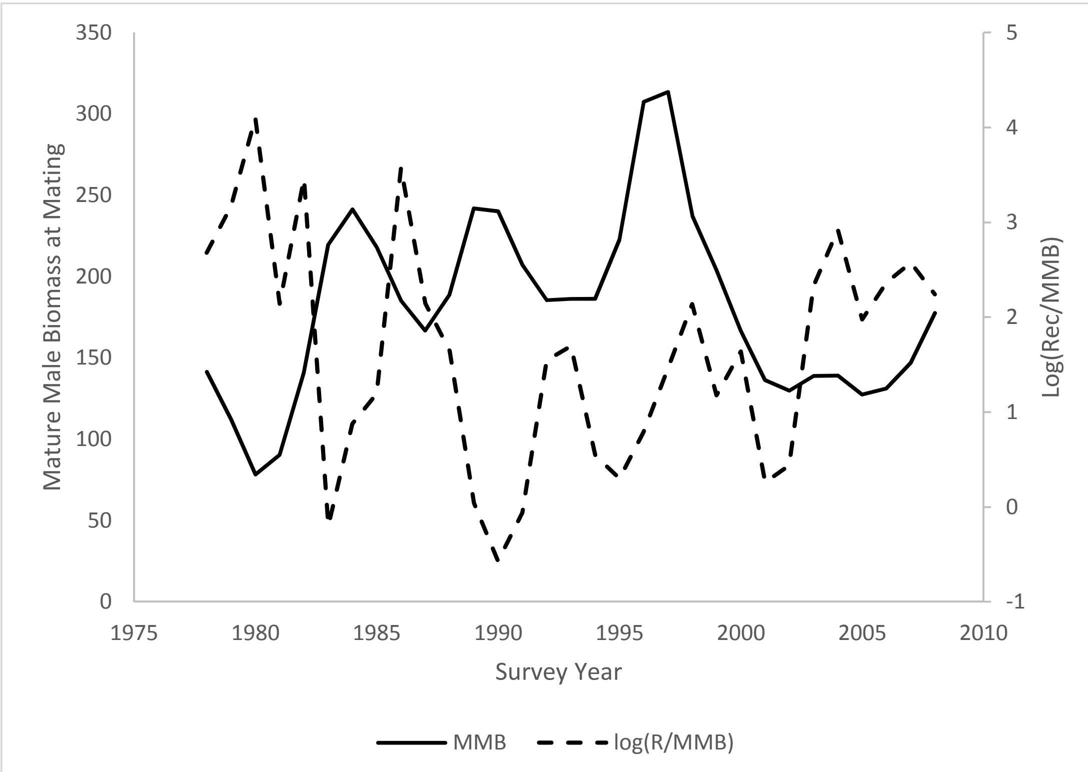

Figure 102. Log of recruits/MMB at mating with a 5 yr lag for recruitment and mature male biomass at mating.

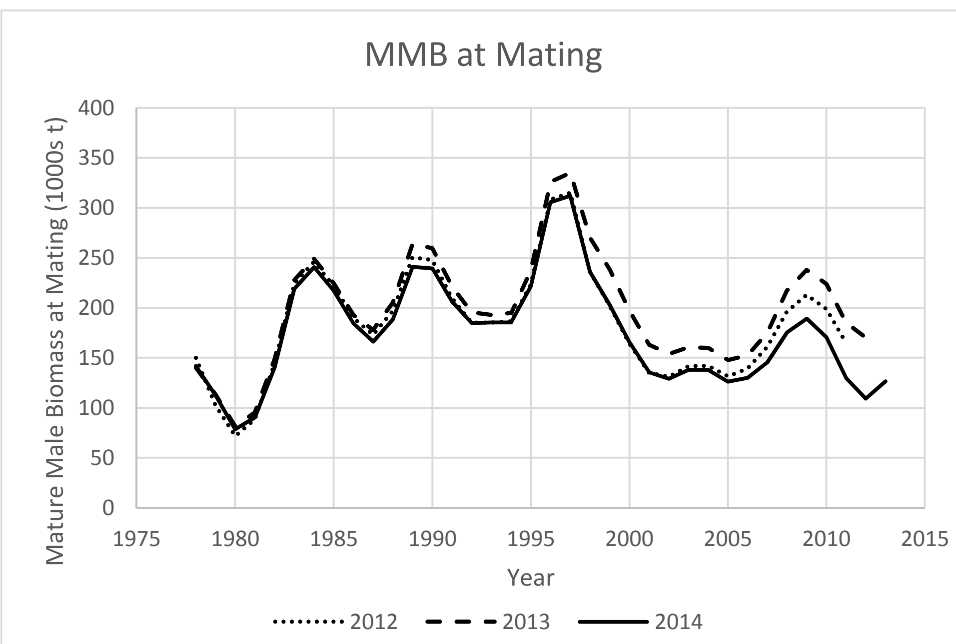

Figure 103. MMB at mating from the 2012 and 2013 assessments, and the Base model (2014).

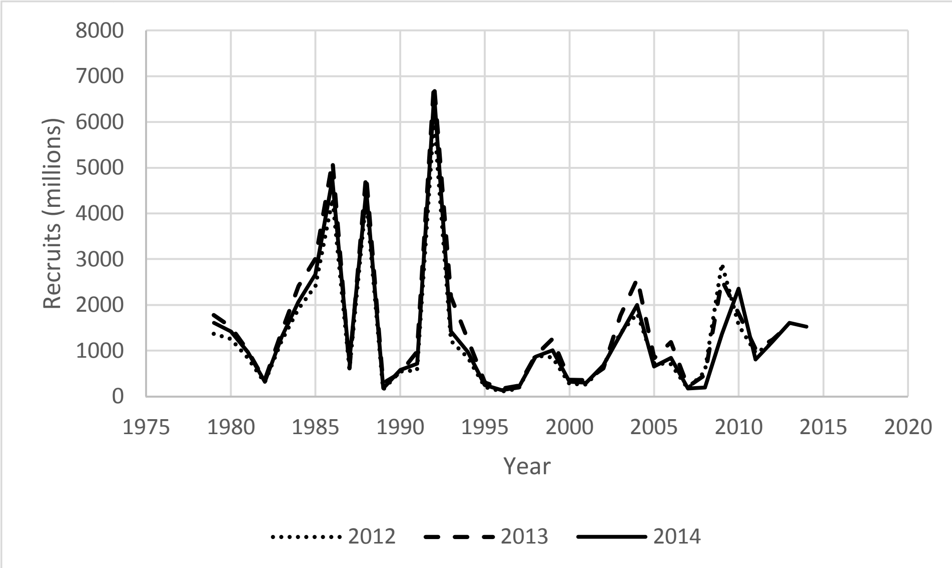

Figure 104. Recruitment estimates from the 2012 and 2013 assessments, and the Base model (2014).

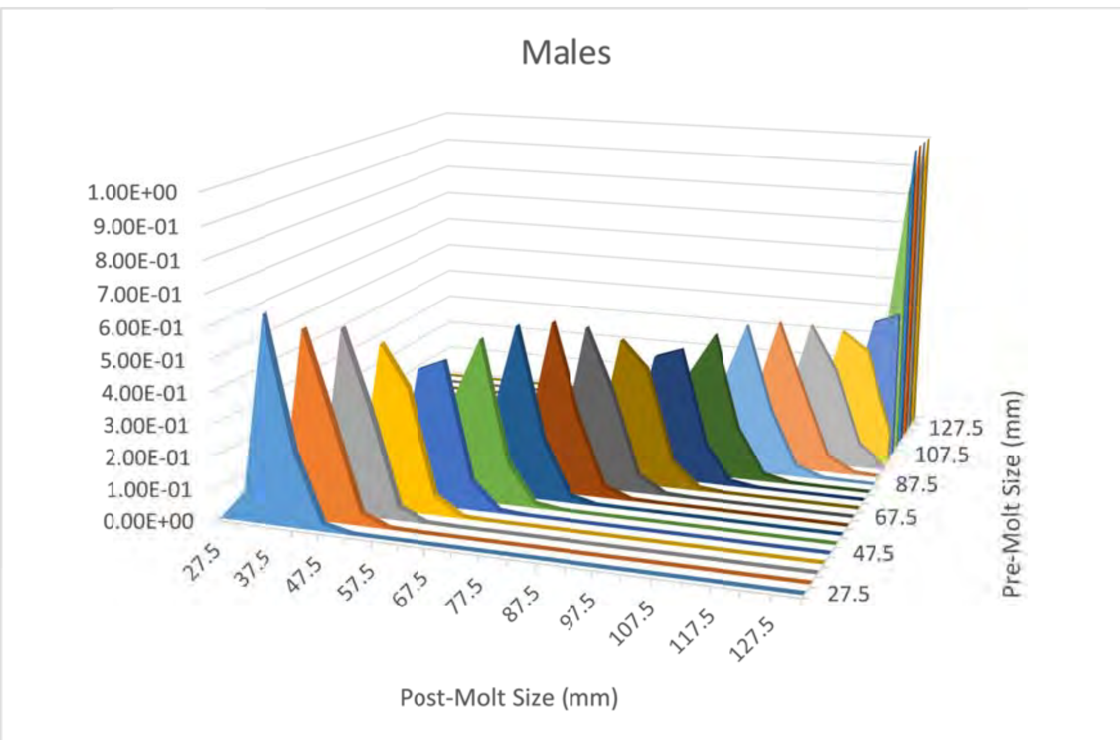

Figure 105. Male growth matrix for the Base model.

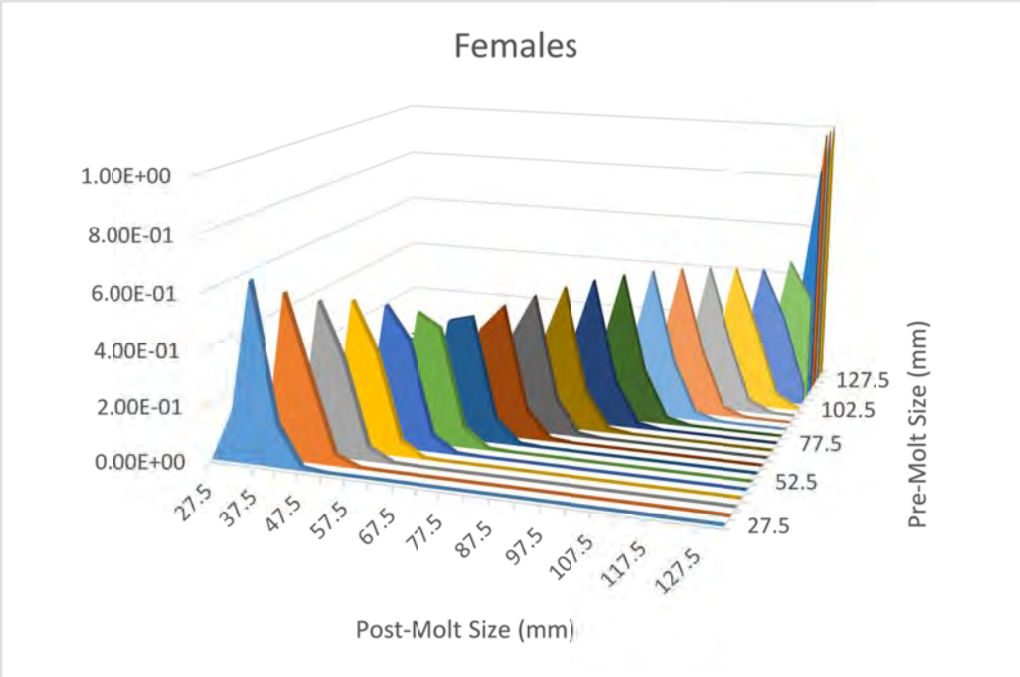

Figure 106. Female growth matrix for the Base model.

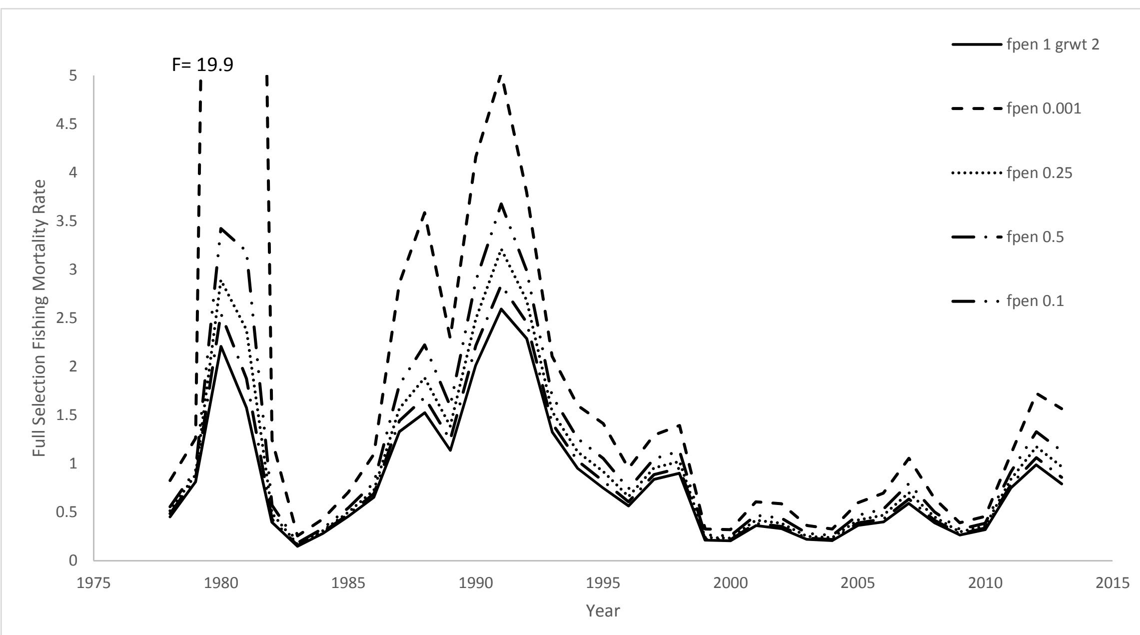

Figure 107. Full selection fishing mortality rate for models 2b (base model), 2d, 2e, 2f and 2g.

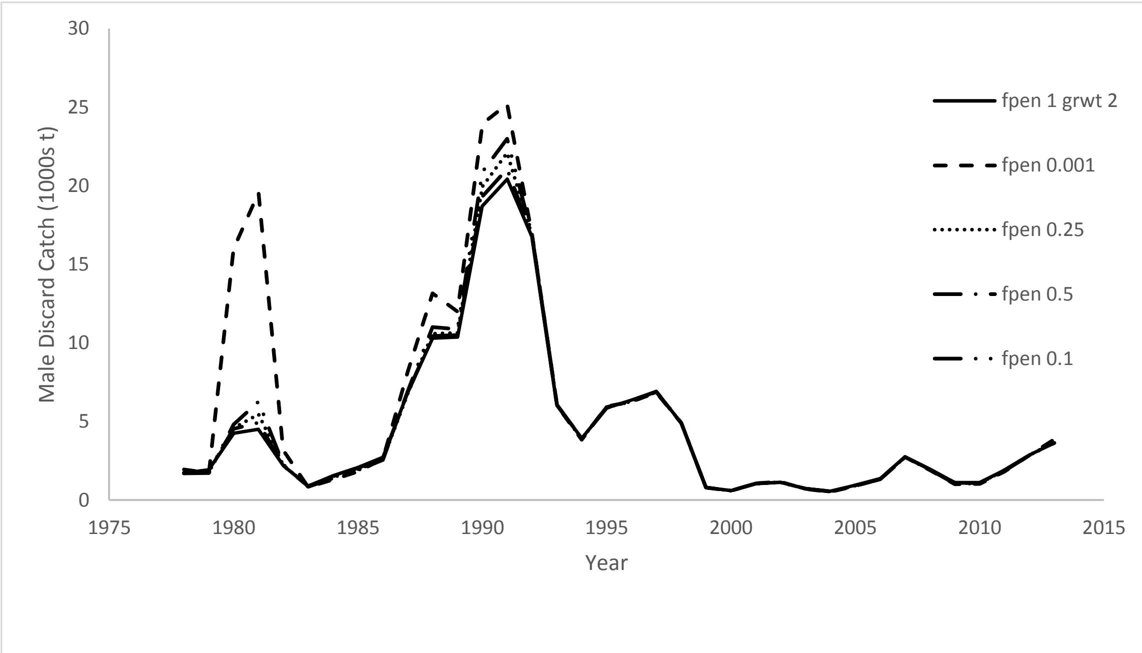

Figure 108. Male discard catch estimates from models 2b (base model), 2d, 2e, 2f and 2g.

Appendix A

Minutes of Crab Plan Team May 2013 on Handling Mortality

Dan Urban (AFSC – Kodiak) provided a presentation on application of the "reflex action mortality predictor" (RAMP) method to estimating handling mortality of discarded crab in the commercial BSAI crab fisheries.

Urban reviewed information on the short and long term handling mortality of discarded crab relevant to crab stock assessment and development of fishery management measures, with an emphasis on EBS snow crab. Estimates of bycatch biomass during the fishery are multiplied by the handling mortality rate and that product is added to the retained catch biomass to estimate total fishery mortality. Hence, assumptions about handling mortality will affect the time series of estimates of total fishery mortality used in stock assessment models, the determination of annual OFLs, and annual total-catch accounting.

In the EBS snow crab fishery, the discarded catch of snow crab is about 1/3 of the catch of retained crab; the discarded snow crab are mainly males smaller than the size preferred by processors (4 inches carapace width). The EBS snow crab assessment model has been using 0.5 as the handling mortality rate for snow crab discarded during the directed fishery. Urban noted that there is high uncertainty on this value; consensus of the CPT discussion during the presentation was that, rather than being directly estimated from data, the 0.5 value was largely based on balancing the concerns that handling mortality could be close to 100% versus an assumption closer to 0% based on an inferred low retained-crab deadloss rate (~2%).

Urban reviewed the sources of short term handling mortality for discards during crab fisheries, which include trauma at dumping and sorting of the catch, on-deck anoxia, and temperature stress on deck.

Temperature stress and freezing is a particular concern for the winter snow crab fishery, which is often conducted during sub-freezing temperatures that are known from laboratory studies to induce mortality in snow crab (e.g., Shirley and Warrenchuck) and to freeze eyestalks (ongoing project). On-deck sorting and discarding may induce short-term mortality, long-term mortality, and long-term reductions in reproductive potential. Short-term mortality can be directly studied and estimated; estimation of longterm effects is more difficult. Long-term effects could include: increased risk to predation, decreased ability to feed or mate, and increased mortality during molting. Laboratory studies have confirmed that increased mortality of molting Tanner crab after exposure to sub-freezing temperatures and freezing of eye stalks could be reasonably assumed to have long-term effects on survival and reproduction.

The RAMP approach provides a means to estimate short-term (< 2 weeks) mortality due to discarding by scoring a suite of reflex responses of crab captured during fisheries prior to their being discarded.

Previous studies by Allan Stoner allow short-term mortality rates to be predicted from the RAMP reflex response scores. With RAMP scores recorded from uninjured snow crab caught on 22 vessels during 2009/10 season, the predicted handling mortality of discards varied from 1.4% to 32% among vessels; overall RAMP-predicted mortality of discards using the data from all vessels was 5.9%.

Additional studies on commercial fishing vessels were conducted on one vessel during the 2010/11 snow crab season and on four vessels during the 2011/12 season. The RAMP-predicted handling mortality from the 2010/11
study was 4.6% and from the 2011/12 study was 4.5%.
The predicted handling mortality was negatively correlated with back-deck temperature on the vessel during the time that RAMP-scoring occurred, such that temperature can be used to predict handling mortality; e.g., predicted mortality was approximately 35% at -14° C and <10% at temperatures ≥ -6° C.
Directly obtaining back-deck temperatures on all vessels throughout the season is not feasible. Urban therefore used the temperatures recorded at the St. Paul airport as a proxy for on-deck temperatures to extend the results to all vessels fishing. Most of the temperatures recorded at the St. Paul airport during the 2009/10 season were at levels associated with low RAMP-predicted mortality. Urban estimated the average per-season handling mortality rate during the 1990/91–2010/11 seasons to be 4%, with the highest estimate for any single season to be 8% (during the early 1990s) using the historical St. Paul airport temperatures to estimate the freezing-related handling mortality. Urban provided ADF&G's estimates of injury rates of snow crab captured during the fishery. Those estimates of injury rates (from data collected by observers during the 1997/98 and 1998/99 seasons) are approximately 10% (it should be noted that data on injury rates observed during the 2009/10–2011/12 seasons in conjunction with the
RAMP study were lower). Urban suggested that the injury rates could be used to predict short-term mortality due to factors other than temperature.
Urban acknowledged that a determination of the true handling mortality rate is difficult, particularly when considering the long-term mortality. Nonetheless, he felt that evidence from the RAMP studies and the observed injury rates suggest that the 0.5 currently assumed for handling mortality in the snow crab assessment and for determining the OFL is too high. Urban proposed three options for handling mortality rates for use in the snow crab assessment: status quo (handling mortality rate = 0.5, a conservative approach); a constant in the range of 0.15–0.20 (based on adding the highest or average estimate of
RAMP-predicted mortality and the highest observed injury rate); or using the historic St. Paul airport temperatures and applying the temperature-mortality relationship to obtain an annual handling mortality rate.
Urban concluded his presentation with a summary of the attempts to develop a RAMP-based method to estimate handling mortality for red and golden king crab. Those attempts were not successful and suggested that the RAMP approach may have no useful application to king crab. Red king crab mortality showed no relationship with reflex-response scores, whereas experimenters had a difficult time inducing the golden king crab subjects to die. Urban noted that one observation from this study was that golden king crab appear to be more hardy than red king crab. As an example, clipping the leg of a golden king crab caused only 3% mortality; significant mortality (80%) required complete severing of the leg.
The CPT discussed how to apply the findings presented for use in the snow crab stock assessment. The
CPT was reminded that estimates used in the stock assessment should be unbiased and that conservation concerns due to uncertainty should enter in the consideration of the ABC. Much of the initial CPT discussion focused on the uncertainty related to long-term handling mortality and on the effects due to discarding itself (as opposed to the injuries suffered when brought on deck). The CPT felt that the weight of evidence is that 0.5 is too high, but struggled with reconciling the

results presented by Urban with the uncertainty associated with other, long-term effects to survival, growth, and reproduction (e.g., predation, displacement, affects to hormone regulation, additional stresses during molting, etc). Some voiced concerns that, given those uncertainties, the CPT may be placing more weight on the results of recent studies than is warranted. With regard to some of the concerns, it was noted that most of the discards are males > 3 inches carapace width, which Urban noted may have low risk of predation relative to smaller crab. In addition, although the long-term effects will be much higher for crab that will molt, data collected on chela heights of males captured during the fishery suggest that most of the discarded males have already completed their terminal molt.

Discussion provided four options to consider for a total handling mortality rate for snow crab:

1. 0.2, derived by summing the highest estimate due to freezing (0.08) with the highest estimate of injury rates (0.12); i.e., one of the options that Urban presented
2. 0.25, derived as a balance between the extremes of 0.0 and 0.5; the argument for this was that it was consistent with the approach to obtain the currently-used 0.5, which was derived as a balance between the two extremes of 0.0 and 1.0
3. 0.3, derived by taking the "base" of 20% handling mortality that is applied to king crab stocks and adding the highest estimate of freezing-related handling mortality (0.08) and rounding up to the nearest 0.1.
4. 0.3, derived by summing the highest estimate due to freezing (0.08) with the highest estimate of injury rates (0.12) to capture the short-term mortality and multiplying that sum by 1.5 to provide an estimate that includes long-term mortality. Since there is no information on long-term mortality, the CPT agreed that the best first-order estimate of the long-term mortality is 50% of the short-term mortality.

The consensus of the CPT was that the best current estimate of handling mortality of snow crab was 0.3, based on the argument of the last bullet (above). The CPT requested that the next snow crab assessment use 0.3 as handling mortality for all pot fisheries (crab and fish) in the base run and 0.5 as an alternative scenario (there was some discussion as to whether 0.3 or 0.5 should be the base, but if 0.3 is chosen it should be the base run so that the new handling mortality is included in the remaining alternative runs).
The 0.5 run should be included so that the effects on OFL, stock status, etc., can be evaluated. The CPT recommended that the 0.3 handling mortality not be applied to Tanner crab, neither as bycatch in the snow crab fishery or in the directed Tanner crab fishery; i.e., the recommended handling mortality for Tanner crab remains at 0.5 until sufficient data suggests otherwise. Stoner's work suggests that Tanner crab may suffer higher handling mortality than snow crab, but no data were presented at this meeting for
Tanner crab similar to what were presented for snow crab. The CPT recommended that a sensitivity analysis on handling mortality be done in the Tanner crab assessment to provide impetus for research on
Tanner handling mortality during the snow crab fishery because Tanner bycatch mortality during snow crab fishery has a large effect on the Tanner crab stock assessment, OFL setting, and available TAC.
Discussion turned to the results that Urban presented on king crabs, for which the RAMP approach appears to be not useful. Currently, the Bristol Bay red king crab and the golden king

crab assessments assume that handling mortality is 0.2. Although on-deck injury rates for king crab during the red and golden king crab fisheries have been estimated using data collected by ADF&G during the late 1990s, no new data was presented on king crab handling mortality at the meeting. The CPT discussed the apparently greater “hardiness” of golden king crab relative to red king crab and some members of the public suggested that this observation could justify reducing the handling mortality used for golden king crab to less than 0.2. The CPT was unable to recommend a change to the golden king crab handling mortality on the basis of what was presented during the meeting and recommended that it stay at the status quo 0.2 until some data providing estimates of the handling mortality rate are presented. It was noted that both the golden king crab stocks (Aleutian Islands and Pribilof Islands) are currently managed as Tier 5 stocks, for which the assumed handling mortality rates have no impact on the retained-catch portion of the OFL or of the ABC; handling mortality would become an important consideration if the golden king crab stocks become managed under Tier 4.
The CPT emphasizes that handling mortality remains a priority research objective for king crab species and Tanner crab.

BRISTOL BAY RED KING CRAB STOCK ASSESSMENT IN FALL 2014

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Executive Summary

1. Stock: red king crab (RKC), *Paralithodes camtschaticus,* in Bristol Bay, Alaska.
2. Catches: The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lbs (58,943 t). The catch declined dramatically in the early 1980s and remained at low levels during the last three decades. Catches during recent years until 2010/11 were among the high catches in last 15 years. The retained catch in 2013/14 was about 7 million lbs (3,154 t) less than it was in 2009/10. The magnitude of bycatch from groundfish trawl fisheries has been stable and small relative to stock abundance during the last 10 years.
3. Stock biomass: Estimated mature biomass increased dramatically in the mid 1970s and decreased precipitously in the early 1980s. Estimated mature crab abundance has increased during the last 25 years with mature females being 3.4 times more abundant in 2009 than in 1985 and mature males being 2.3 times more abundant in 2009 than in 1985. Estimated mature abundance has steadily declined since 2009.
4. Recruitment: Estimated recruitment was high during 1970s and early 1980s and has generally been low since 1985 (1979 year class). During 1984-2014, only in 1984, 1995, 2002 and 2005 was estimated recruitment above the historical average for 1969-2014. Estimated recruitment was extremely low during the last 8 years.
5. Management performance:

Status and catch specifications (1000 t) (scenario 4nb):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	13.63[A]	32.64[A]	6.73	6.76	7.71	10.66	N/A
2011/12	13.77[B]	30.88[B]	3.55	3.61	4.09	8.80	7.92
2012/13	13.19[C]	29.05[C]	3.56	3.62	3.90	7.96	7.17
2013/14	12.85[D]	27.12[D]	3.90	3.99	4.56	7.07	6.36
2014/15		24.69[D]				6.82	6.14

The stock was above MSST in 2013/14 and is hence not overfished. Overfishing did not occur.

Status and catch specifications (million lbs):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	30.0[A]	72.0[A]	14.84	14.91	17.00	23.52	N/A
2011/12	30.4[B]	68.1[B]	7.83	7.95	9.01	19.39	17.46
2012/13	29.1[C]	64.0[C]	7.85	7.98	8.59	17.55	15.80
2013/14	28.3[D]	59.9[D]	8.60	8.80	10.05	15.58	14.02
2014/15		54.4[D]				15.04	13.53

Notes:
A – Calculated from the assessment reviewed by the Crab Plan Team in September 2011
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2012
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2013
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2014

6. Basis for the OFL: All table values are in 1000 t (Scenario 4nb).

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2010/11	3a	28.4	37.7	1.33	0.32	1995-2010	0.18
2011/12	3a	27.3	29.8	1.09	0.32	1984-2011	0.18
2012/13	3b	27.5	26.3	0.96	0.31	1984-2012	0.18
2013/14	3b	26.4	25.0	0.95	0.27	1984-2013	0.18
2014/15	3b	25.7	24.7	0.96	0.28	1984-2014	0.18

Basis for the OFL: All table values are in million lbs.

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2010/11	3a	62.7	83.1	1.33	0.32	1995-2010	0.18
2011/12	3a	60.1	65.6	1.09	0.32	1984-2011	0.18
2012/13	3b	60.7	58.0	0.96	0.31	1984-2012	0.18
2013/14	3b	58.2	55.0	0.95	0.27	1984-2013	0.18
2014/15	3b	56.7	54.4	0.96	0.28	1984-2014	0.18

A. Summary of Major Changes

1. Change to management of the fishery: None.

2. Changes to the input data:

a. Newly re-estimated trawl survey results provided by NMFS in 2014 were used.

b. Catch and bycatch data were updated with 2014 data.

c. Trawl bycatch length frequency data during 1986-2012 and trawl bycatch abundance data during 2009-2012 were revised based on the new data provided by NMFS in 2014.

d. Tanner crab fishery bycatch length frequency and abundance data were revised based on the revised data provided by ADF&G in 2014.

3. Changes to the assessment methodology:

Three model scenarios are evaluated in this report (See Section E.3.a for details):

Scenarios 4na and 4nb: the same as scenarios 4na and 4nb in the SAFE report in May 2014. Scenario 4na is the same as scenario 4 used to set OFL in 2013. Scenario 4nb differs with scenario 4na by estimating trawl survey catchability within the model.

Scenario 4n7: the same as scenario 4nb7 in the SAFE report in May 2014. Scenario 4n7 is the same as scenario 4nb except it estimates one additional natural mortality parameter for both males and females during 2006-2010.

4. Changes to assessment results:

The time series of area-swept abundance estimates provided by NMFS in August 2014 are very similar to those provided in April 2014. The area-swept abundance estimates from the survey in 2014 are higher than expected and are not consistent with the results from the previous several years.

Model estimated relative survey biomasses are very similar between scenarios 4na and 4nb and differ with those of 4n7. Increasing natural mortality from 0.18 to 0.27 during 2006-2010 under scenario 4n7 provided a better fit of trawl survey data during recent years, resulting in a much lower OFL. Scenario 4nb is recommended for overfishing determination this year. The full results for scenarios 4na and 4nb are presented in this report.

B. Responses to SSC and CPT Comments

1. Responses to the most recent two sets of SSC and CPT comments on assessments in general:

None.

2. Responses to the most recent two sets of SSC and CPT comments specific to this assessment:

Response to CPT Comments (from September 2013)

"Estimate catchability for the NMFS surveys while fixing it to 1 for the BSFRF surveys."

Scenarios 4nb and 4n7 estimate Q for the NMFS survey.

"Explore the implications in the new base model (Scenario 4) of an additional period of higher natural mortality in the mid-2000s as suggested by the Scenario 7 model results."

Scenario 4n7 estimates an additional natural mortality during 2006-2010, which results in statistically better fits to the data.

Response to CPT Comments (from May 2014)

"1. Drop Scenarios 4 and 4b because these use the old data."

Done.

"2. Move forward with Scenarios 4na, 4nb for September 2014."
Done.

"3. Although it appears to result in improved model fits, drop Scenario 4nb7 from consideration until a mechanism for the estimated higher M can be established; this scenario can be presented for reconsideration once a plausible mechanism has been identified."

SSC asked to continue 4nb7, which has been changed to 4n7. So scenario 4n7 is still in the SAFE report for September 2014.

"4. Add the number of estimated parameters to tables that compare values for likelihood components from different Scenarios so that the degree of improved fit can be more easily evaluated. Also, express the values of log-likelihood components between the base and alternative models as differences (e.g., base less alternative), rather than reporting the actual values because it is the differences in log-likelihood values that are informative."

Done.

Response to SSC Comments specific to this assessment (from October 2013)

"1. Shifts in the center of distribution of BBRKC can be a function of depletion of the stock, the crab closure area, shifts in larval drift, habitat selection, or fishing. The interpretation of which of these potential causes contributes to selection of a time period should be investigated."

We investigated this issue and summarized the results in Appendix C. Our conclusion is that changes in spatial distribution of the blood stock abundance over time were caused by environmental conditions, not by fishing.

"2. We suggest that the authors work with flatfish authors to come up with a consistent approach to treatment of biomass outside of the survey area."

The flatfish authors used a linear regression model to fill in the missing survey data. We feel that this approach does not apply to Bristol Bay red king crab. The area that is not surveyed for Bristol Bay red king crab is the shallow, nearshore area, where some juvenile red king crab may be found during the normal survey times. Presently, there are no surveys that can completely cover the area. Two recent nearshore surveys in 2011 and 2012, limited in spatial extent, found some red king crab in the unsurveyed area, but those surveys did not cover the untrawlable area. The abundance estimates of red king crab from those surveys varied greatly and are too limited to be useful for use for filling-in of any missing data. The current Bristol Bay red king crab model accounts for crab outside the survey area through the survey selectivity. The survey selectivity and catchability in the model includes both capture probability (gear selectivity) and availability to the survey. In the future, if we can find a way to completely survey this area, we will examine approaches to be better to deal with the availability problem.

"3. Further study of maturity is needed."

Currently, we use a step curve to model changes in female size-at-maturity over time (see Figure A3). It would be better to fit the data with a continuous curve over time. However, the reason for modeling the change is to improve estimation of growth increment per molt. There are very little growth increment data for females in the eastern Bering Sea. Limited availability of growth increment data is the main reason for using a simple step curve. In the future, we may examine the growth increment data from Kodiak female red king crab to see whether we can use them to construct growth functions for Bristol Bay female red king crab. Once we have better growth functions, we can improve methods of estimating variation in female size-at-maturity over time. Female biomass is not used for overfishing determination.

Although size at sexual maturity for Bristol Bay red king crab males has been estimated (Paul et al. 1991), there are no data for estimating size of functional maturity collected in the natural environment. Based on the data of size of Kodiak red king crab males in mating pairs (see Figure A4) and the larger size-at-maturity of Kodiak red king crab females than of Bristol Bay red king crab females (Pengilly et al. 2002), the functional maturity sizes were estimated for Bristol Bay red king crab males. Sizes of males that can successfully mate with females in laboratory are much smaller than the estimated 120+ mm functional maturity sizes used here.

"4. The SSC suggests a re-evaluation of predation pressure on BBRKC."

We would like to get some more detailed guidance from the SSC on how to investigate this issue. The main problem we have is that the diet data currently collected by NMFS do not reflect the predation of Bristol Bay red king crab by groundfish due to the timing (primarily summer) and spatial distribution of data collection. There is also a lack of information on groundfish abundance in the shallow, nearshore waters where small juvenile red king crab likely occur. At the CIE meeting in 2010 on Bristol Bay red king crab, a model was presented by a NMFS scientist to show how many juvenile king crab were consumed by groundfish. However, the juvenile king crab discussed were mainly St. Matthews blue king crab as very few small Bristol Bay juvenile red king crab were present in the diet data.

SSC has provided some suggestions for future study on groundfish predation in October 2014. We will work on this issue in the future.

"5. The Plan Team should investigate the impact of dropping hotspots as per CIE review."

The CPT has addressed this issue.

"6. The Plan Team should investigate the impact of corner stations for hotspots as per CIE review."

The CPT has addressed this issue.

"7. The Plan Team should investigate the impact of re-tows as per CIE review."

The CPT has discussed these issues and made some decisions on use of the re-tow data. NMFS is working on a new time series of survey area-swept estimates to deal with the hotspot issue. Any in-depth studies would be helpful.

Response to SSC Comments specific to this assessment (from June 2014)

"The SSC concurs with the PT recommendations, except that it would like Model 4nb7 or similar models to be investigated further for September 2014, if time permits. Similar models include the random walk model investigated in June 2013 or a model that uses environmental (e.g., SST) or biological (e.g., Pacific cod abundance) covariates. These models may provide insights into processes influencing natural mortality rates. The SSC agrees with the CPT that new procedures would be needed to accommodate estimation of biological reference points under assumptions of

time varying M. A critical issue is to consider what "equilibrium" means under time varying M (especially when M is increasing in the most recent time period)."

Scenario 4nb7, renamed as 4n7, is included in the September 2014 assessment. A scenario with random walk may be added in May assessments in the future.

"The SSC found that the nomenclature for models was confusing and recommends that a more straightforward system be used. Also, the SSC encourages authors to continue to investigate whether recruitment is related to environmental or biological variables."

Simple scenario names will be used in next May assessments. In this September 2014 report, we still used the names similar to those in May 2014 for continuity. Scenario 4nb7 was shortened as 4n7.

Recruitment dynamics is the top priority for our research. We will continue to investigate factors that impact recruitment strength.

C. Introduction

1. Species

Red king crab (RKC), *Paralithodes camtschaticus*, in Bristol Bay, Alaska**.**

2. General distribution

Red king crab inhabit intertidal waters to depths >200 m of the North Pacific Ocean from British Columbia, Canada, to the Bering Sea, and south to Hokkaido, Japan. RKC are found in several areas of the Aleutian Islands and eastern Bering Sea.

3. Stock Structure

The State of Alaska divides the Aleutian Islands and eastern Bering Sea into three management registration areas to manage RKC fisheries: Aleutian Islands, Bristol Bay, and Bering Sea (Alaska Department of Fish and Game, ADF&G, 2012). The Bristol Bay area includes all waters north of the latitude of Cape Sarichef (54°36' N lat.), east of 168°00' W long., and south of the latitude of Cape Newenham (58°39' N lat.) and the fishery for red king crab in this area is managed separately from fisheries for red king crab outside of this area; i.e., the red king crab in the Bristol Bay area are assumed to be a separate stock from red king crab outside of this area. This report summarizes the stock assessment results for the Bristol Bay RKC stock.

4. Life History

Red king crab have a complex life history. Fecundity is a function of female size, ranging from several tens of thousands to a few hundreds of thousands (Haynes 1968, Swiney et al. 2012). The eggs are extruded by females and fertilized in the spring and are held by females for about 11 months (Powell and Nickerson 1965). Fertilized eggs are hatched in spring, most during the

April to June period (Weber 1967). Primiparous females are bred a few weeks earlier in the season than multiparous females.

Larval duration and juvenile crab growth depend on temperature (Stevens 1990; Stevens and Swiney 2007). Male and female RKC mature at 5–12 years old, depending on stock and temperature (Loher et al. 2001, Stevens 1990) and may live >20 years (Matsuura and Takeshita 1990). Males and females attain a maximum size of 227 and 195 mm carapace length (CL), respectively (Powell and Nickerson 1965). Female maturity is evaluated by the size at which females are observed to carry egg clutches. Male maturity can be defined by multiple criteria including spermataphore production and size, chelae vs. carapace allometry, and participation in mating *in situ.* (reviewed by Webb 2014). For management purposes, females >89 mm CL and males >119 mm CL are assumed to be mature for Bristol Bay RKC. Juvenile RKC molt multiple times per year until age 3 or 4; thereafter, molting continues annually in females for life and in males until maturity. Male molting frequency declines after attaining functional maturity.

5. Fishery

The RKC stock in Bristol Bay, Alaska, supports one of the most valuable fisheries in the United States. A review of the history of the Bristol Bay red king crab fishery is provided in Fitch et al. (2012) and Otto (1989). The Japanese fleet started the fishery in the early 1930s, stopped fishing from 1940 to 1952, and resumed the fishery from 1953 until 1974. The Russian fleet fished for RKC from 1959 through 1971. The Japanese fleet employed primarily tanglenets with a very small proportion of catch from trawls and pots. The Russian fleet used only tanglenets. United States trawlers started to fish for Bristol Bay RKC in 1947, but their effort and catch declined in the 1950s. The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lbs (58,943 t), worth an estimated $115.3 million ex-vessel value. The catch declined dramatically in the early 1980s and has continued at low levels during the last two decades (Table 1). After the stock collapse in the early 1980s, the Bristol Bay RKC fishery took place during a short period in the fall (usually lasting about a week) with the catch quota based on the stock assessment conducted the previous summer (Zheng and Kruse 2002). Beginning with the 2005/2006 season, new regulations associated with fishery rationalization resulted in an increase in the duration of the fishing season (October 15 to January 15). With the implementation of crab rationalization, historical guideline harvest levels (GHL) were changed to a total allowable catch (TAC). Before rationalization, the implementation errors were quite high for some years and total actual catch from 1980 to 2007 was about 6% less than the sum of GHL/TAC over that period.

6. Fisheries Management

King and Tanner crab stocks in the Bering Sea and Aleutian Islands are managed by the State of Alaska through a federal king and Tanner crab fishery management plan (FMP). Under the FMP, management measures are divided into three categories: (1) fixed in the FMP, (2) frame worked in the FMP, and (3) discretion of the State of Alaska. The State of Alaska is responsible for determining and establishing the GHL/TAC under the framework in the FMP.

Harvest strategies for the Bristol Bay RKC fishery have changed over time. Two major management objectives for the fishery are to maintain a healthy stock that ensures reproductive viability and to provide for sustained levels of harvest over the long term (ADF&G 2012). In attempting to meet these objectives, the GHL/TAC is coupled with size-sex-season restrictions. Only males≥6.5-in carapace width (equivalent to 135-mm carapace length, CL) may be harvested and no fishing is allowed during molting and mating periods (ADF&G 2012). Specification of TAC is based on a harvest rate strategy. Before 1990, harvest rates on legal males were based on population size, abundance of prerecruits to the fishery, and postrecruit abundance, and rates varied from less than 20% to 60% (Schmidt and Pengilly 1990). In 1990, the harvest strategy was modified, and a 20% mature male harvest rate was applied to the abundance of mature-sized (≥120-mm CL) males with a maximum 60% harvest rate cap of legal (≥135-mm CL) males (Pengilly and Schmidt 1995). In addition, a minimum threshold of 8.4 million mature-sized females (≥90-mm CL) was added to existing management measures to avoid recruitment overfishing (Pengilly and Schmidt 1995). Based on a new assessment model and research findings (Zheng et al. 1995a, 1995b, 1997a, 1997b), the Alaska Board of Fisheries adopted a new harvest strategy in 1996. That strategy had two mature male harvest rates: 10% when effective spawning biomass (ESB) is between 14.5 and 55.0 million lbs and 15% when ESB is at or above 55.0 million lbs (Zheng et al. 1996). The maximum harvest rate cap of legal males was changed from 60% to 50%. An additional threshold of 14.5 million lbs of ESB was also added. In 1997, a minimum threshold of 4.0 million lbs was established as the minimum GHL for opening the fishery and maintaining fishery manageability when the stock abundance is low. The Board modified the current harvest strategy by adding a mature harvest rate of 12.5% when the ESB is between 34.75 and 55.0 million lbs in 2003 and eliminated the minimum GHL threshold in 2012. The current harvest strategy is illustrated in Figure 1.

D. Data

1. Summary of New Information

New data for the September 2014 assessment include commercial catch and bycatch in 2013/2014, the 2014 summer trawl survey, and updated summer trawl survey data from 1975 to 2014. The revised (2013) NMFS length-weight relationships are used. Trawl bycatch length frequency data during 1986-2012 and trawl bycatch abundance data during 2009-2012 were revised based on the new data provided by NMFS in 2014. Tanner crab fishery bycatch length frequency and abundance data were revised based on the revised data provided by ADF&G in 2014.

2. Catch Data

Data on landings of Bristol Bay RKC by length and year and catch per unit effort were obtained from annual reports of the International North Pacific Fisheries Commission from 1960 to 1973 (Hoopes et al. 1972; Jackson 1974; Phinney 1975) and from the ADF&G from 1974 to 2012. Bycatch data are available starting from 1990 and were obtained from the ADF&G observer database and reports (Gaeuman 2013). Sample sizes for catch by length and shell condition are summarized in Table 2. Relatively large samples were taken from the retained catch each year. Sample sizes for trawl bycatch were the annual sums of length frequency samples in the National Marine Fisheries Service (NMFS) database.

(i). Catch Biomass

Retained catch and estimated bycatch biomasses are summarized in Table 1 and illustrated in Figure 2. Retained catch and estimated bycatch from the directed fishery include the general, open-access fishery (prior to rationalization) or the individual fishery quota (IFQ) fishery (after rationalization) as well as the Community Development Quota (CDQ) fishery and the ADF&G cost-recovery harvest. Starting in 1973, the fishery generally occurred during the late summer and fall. Before 1973, a small portion of retained catch in some years was caught from April to June. Because most crab bycatch from the groundfish trawl fisheries occurred during the spring, the years in Table 1 are one year less than those from the NMFS trawl bycatch database to approximate the annual bycatch for reporting years defined as June 1 to May 31; e.g., year 2002 in Table 1 corresponds to what is reported for year 2003 in the NMFS database. Catch biomass is shown in Figure 2. Bycatch data for the cost-recovery fishery before 2006 were not available. In this report, pot fisheries includes both the directed fishery and RKC bycatch in the Tanner crabpot fisheryfor crab and trawl fisheries are groundfish trawl fisheries.

(ii). Catch Size Composition

Retained catch by length and shell condition and bycatch by length, shell condition, and sex were obtained for stock assessments. From 1960 to 1966, only retained catch length compositions from the Japanese fishery were available. Retained catches from the Russian and U.S. fisheries were assumed to have the same length compositions as the Japanese fishery during this period. From 1967 to 1969, the length compositions from the Russian fishery were assumed to be the same as those from the Japanese and U.S. fisheries. After 1969, foreign catch declined sharply and only length compositions from the U.S. fishery were used to distribute catch by length.

(iii). Catch per Unit Effort

Catch per unit effort (CPUE) is defined as the number of retained crab per tan (a unit fishing effort for tanglenets) for the Japanese and Russian tanglenet fisheries and the number of retained crab per potlift for the U.S. fishery (Table 3). Soak time, while an important factor influencing CPUE, is difficult to standardize. Furthermore, complete historical soak time data from the U.S. fishery are not available. Based on the approach of Balsiger (1974), all fishing effort from Japan, Russia, and U.S. were standardized to the Japanese tanglenet from 1960 to 1971, and the CPUE was standardized as crab per tan. Except for the peak-to-crash years of late 1970s and early 1980s the correspondence between U.S. fishery CPUE and area-swept survey abundance is poor (Figure 3). Due to the difficulty in estimating commercial fishing catchability and crabavailability to the NMFS annual trawl survey data, commercial CPUE data were not used in the model.

3. NMFS Survey Data

The NMFS has performed annual trawl surveys of the eastern Bering Sea since 1968. Two vessels, each towing an eastern otter trawl with an 83 ft headrope and a 112 ft footrope, conduct this multispecies, crab-groundfish survey during the summer. Stations are sampled in the center of a systematic 20 X 20 nm grid overlaid in an area of ≈140,000 nm^2. Since 1972 the trawl survey has covered the full stock distribution except in nearshore waters. The survey in Bristol Bay occurs primarily during late May and June. Tow-by-tow trawl survey data for Bristol Bay RKC during 1975-2014 were provided by NMFS.

Abundance estimates by sex, carapace length, and shell condition were derived from survey data using an area-swept approach (Figures 4 and 5). Spatial distributions of crab from the standard trawl surveys during recent years are shown in Appendix B. Until the late 1980s, NMFS used a post-stratification approach, but subsequently treated Bristol Bay as a single stratum; the estimates shown in Figures 4 and 5 were made without post-stratification. If multiple tows were made for a single station in a given year, the average of the abundances from all tows within that station was used as the estimate of abundance for that station. If more than one tow was conducted in a station because of high RKC abundance (i.e., the station is a "hot spot"), NMFS regards the station as a separate stratum. A "hot spot" was not surveyed with multiple tows during the early years. Two such "hot spots" affected the survey abundance estimates greatly: station H13 in 1984 (mostly juvenile crab 75-90 mm CL) and station F06 in 1991 (mostly newshell legal males). The tow at station F06 was discarded in the older NMFS abundance estimates (Stevens et al. 1991). In this study, all tow data were used. NMFS re-estimated the historic area-swept by tow using variable versus fixed net width and re-estimated area-swept abundance in 2008, using all tow data and standardized the survey time series estimates in 2014. We used the new area-swept estimates provided by NMFS in 2014.

In addition to standard surveys, NMFS also conducted some surveys after the standard surveys to assess mature female abundance. In addition to the standard survey conducted in early June (late May to early June in 1999 and 2000), a portion of the distribution of Bristol Bay RKC was re-surveyed in 1999, 2000, and 2006-2012. Resurveys performed in late July, about six weeks after the standard survey, included 31 stations (1999), 23 stations (2000), 31 stations (2006, 1 bad tow and 30 valid tows), 32 stations (2007-2009), 23 stations (2010) and 20 stations (2011 and 2012) with high female density. The resurveys were necessary because a high proportion of mature females had not yet molted or mated when sampled by the standard survey. Differences in area-swept estimates of abundance between the standard surveys and resurveys of these same stations are attributed to survey measurement errors or to seasonal changes in distribution between survey and resurvey. More large females were observed in the resurveys than during the standard surveys in 1999 and 2000 because most mature females had not molted prior to the standard surveys. As in 2006, area-swept estimates of males >89 mm CL, mature males, and legal males within the 32 resurvey stations in 2007 were not significantly different between the standard survey and resurvey (P=0.74, 0.74 and 0.95) based on paired t-tests of sample means. However, similar to 2006, area-swept estimates of mature females within the 32 resurvey stations in 2007 were significantly different between the standard survey and resurvey (P=0.03) based on the t-test. Resurvey stations were close to shore during 2010-2012 and mature and legal male abundance estimates were lower for the re-tow than the standard survey. Following the CPT recommendation, we used the standard survey data for male abundance estimates and only the resurvey data, plus the standard survey data outside the resurveyed stations, to assess female abundance during these resurvey years.

4. Bering Sea Fisheries Research Foundation Survey Data

The BSFRF conducted trawl surveys for Bristol Bay red king crab in 2007 and 2008 with a small-mesh trawl net and 5-minute tows. The surveys occurred at similar times with the NMFS standard surveys and covered about 97% of the Bristol Bay area. Few Bristol Bay red king crab were outside of the BSFRF survey area. Because of small mesh size, the BSFRF surveys were expected to catch nearly all red king crab within the swept area. Crab abundances of different size groups were estimated by the kriging method. Mature male abundances were estimated to be 22.331 in 2007 and 19.747 million in 2008 with associated CVs of 0.0634 and 0.0765.

E. Analytic Approach

1. History of Modeling Approaches

To reduce annual measurement errors associated with abundance estimates derived from the area-swept method, the ADF&G developed a length-based analysis (LBA) in 1994 that incorporates multiple years of data and multiple data sources in the estimation procedure (Zheng et al. 1995a). Annual abundance estimates of the Bristol Bay RKC stock from the LBA have been used to manage the directed crab fishery and to set crab bycatch limits in the groundfish fisheries since 1995 (Figure 1). An alternative LBA (research model) was developed in 2004 to include small size groups for federal overfishing limits. The crab abundance declined sharply during the early 1980s. The LBA estimated natural mortality for different periods of years, whereas the research model estimated additional mortality beyond a basic constant natural mortality during 1976-1993. In this report, we present only the research model that was fit to the data from 1975 to 2014.

2. Model Description

The original LBA model was described in detail by Zheng et al. (1995a, 1995b) and Zheng and Kruse (2002). The model combines multiple sources of survey, catch, and bycatch data using a maximum likelihood approach to estimate abundance, recruitment, selectivities, catches, and bycatch of the commercial pot fisheries and groundfish trawl fisheries. A full model description is provided in Appendix A.

a-f. See appendix A.

g. Critical assumptions of the model:

i. The base natural mortality is constant over shell condition and length and was estimated assuming a maximum age of 25 and applying the 1% rule (Zheng 2005).

ii. Survey and fisheries selectivities are a function of length and were constant over shell condition. Selectivities are a function of sex except for trawl bycatch selectivities, which are the same for both sexes. Two different survey selectivities were estimated: (1) 1975-1981 and (2) 1982-2014 based on modifications to the trawl gear used in the assessment survey.

iii. Growth is a function of length and is assumed to not change over time for males. For females, growth-per-molt increments as a function of length were estimated for three periods (1975-1982, 1983-1993, and 1994-2014) based on sizes at maturity. Once mature, female red king crab grow with a much smaller growth increment per molt.

iv. Molting probabilities are an inverse logistic function of length for males. Females molt annually.

v. Annual fishing seasons for the directed fishery are short.

vi. Survey catchability (Q) was estimated to be 0.896, based on a trawl experiment by Weinberg et al. (2004) with a standard deviation of 0.025. Q was assumed to be constant over time. Some scenarios estimate Q in the model.

vii. Males mature at sizes ≥120 mm CL. For convenience, female abundance was summarized at sizes ≥90 mm CL as an index of mature females.

viii. For summer trawl survey data, shell ages of newshell crab were 12 months or less, and shell ages of oldshell and very oldshell crab were more than 12 months.

ix. Measurement errors were assumed to be normally distributed for length compositions and were log-normally distributed for biomasses.

h. Changes to the above since previous assessment: see Section A.3. Changes to the assessment methodology.

i. Outline of methods used to validate the code used to implement the model and whether the code is available: The code is available.

3. Model Selection and Evaluation

a. Alternative model configurations:

Several scenarios were compared for this report:

Scenario 4na: base scenario. Scenario 4na includes:

(1) Basic $M = 0.18$, with an additional mortality level during 1980-1984 for males and two additional mortality levels (one for 1980-1984 and the other for 1976-1979 and 1985-1993) for females.

(2) Including BSFRF survey data in 2007 and 2008.

(3) Assuming survey catchability to be 0.896 for all other years.

(4) Two levels of molting probabilities for males: one before 1980 and one after 1979, based on survey shell condition data. Each level has two parameters.

(5) Estimating effective sample size from observed sample sizes. Effective sample sizes are estimated as min(0.5*observed-size, N) for trawl surveys and min(0.1* observed-size, N) for catch and bycatch, where N is the maximum sample size (200 for trawl surveys, 100 for males from the pot fishery and 50 for females from pot fishery and both males and females from the trawl fisheries. The effective sample sizes that were used are plotted against the implied effective sample sizes in Figures 6 and 7, where the implied effective sample sizes are estimated as follows:

$$n_y = \sum_l \hat{P}_{y,l}(1-\hat{P}_{y,l}) / \sum_l (P_{y,l} - \hat{P}_{y,l})^2$$

where $\hat{P}_{y,l}$ and $P_{y,l}$ are estimated and observed size compositions in year y and length group l, respectively.

(6) Standard survey data for males and retow data for females.

(7) Estimating initial year length compositions.

Scenario 4nb: the same as scenario 4 except estimating trawl survey catchability.

Scenario 4n7: the same as scenario 4nb except estimating one additional natural mortality parameter for both males and females during 2006-2010.

Only the full results for scenarios 4na and 4nb are presented in this report. Each figure or table is indicated with a scenario.

b. Progression of results: See the new results at the beginning of the report.

c. Evidence of search for balance between realistic and simpler models: NA.

d. Convergence status/criteria: ADMB default convergence criteria.

e. Sample sizes for length composition data. Estimated sample sizes and effective sample sizes are summarized in tables.

f. Credible parameter estimates: All estimated parameters seem to be credible.

g. Model selection criteria. The likelihood values were used to select among alternatives that could be legitimately compared by that criterion.

h. Residual analysis. Residual plots are illustrated in figures.

i. Model evaluation is provided under Results, below.

4. Results

a. Effective sample sizes and weighting factors.

i. The effective sample sizes are:

(1) Trawl surveys: 200 for males and females except for females: 184 in 1986, 180 in 1992 and 133 in 1994.
(2) Retained catch: 100.
(3) Pot male discard: 100 except 87 in 1990 and 23 in 1996.
(4) Pot female discard: 50 except 38 in 1991, 1 in 1996, 4 in 1999, and 30 in 2002.
(5) Trawl bycatch: 50 for males and females except for males 44 in 1988, 21 in 1991 and 1992, 33 in 1994, 10 in 1995, and for females 28 in 1986 and 1988, 19 in 1989, 40 in 1991, 11 in 1992, 25 in 1994, 5 in 1995, 48 in 1997.
(6) Tanner fishery bycatch: 50 for males and females except for males 28 in 1992, 23 in 1993 and 22 in 2013, and for females 27 in 1993.
(7) BSFRF survey: 200 for the BSFRF survey males and females.

For scenario 4na, effective sample sizes are illustrated in Figures 6 and 7.

ii. Weights are assumed to be 500 for retained catch biomass, and 100 for all bycatch biomasses, 2 for recruitment variation, and 10 for recruitment sex ratio.

iii. Initial trawl survey catchability is estimated to be 0.896 with a standard deviation of 0.025 (CV about 0.03) based on the double-bag experiment results.

b. Tables of estimates.

i. Parameter estimates for scenarios 4na and 4nb are summarized in Tables 4 and 5.

ii. Abundance and biomass time series are provided in Table 6 for scenarios 4na and 4nb.

iii. Recruitment time series for scenarios 4na and 4nb are provided in Table 6.

iv. Time series of catch biomass is provided in Table 1.

Negative log-likelihood values and parameter estimates are summarized in Tables 4 and 5, respectively. Length-specific fishing mortality is equal to selectivity-at-length times the full fishing mortality. Estimated full pot fishing mortalities for females and full fishing mortalities for trawl bycatch were very low due to low bycatch as well as handling mortality rates less than 1.0. Estimated recruits varied greatly from year to year (Table 6). Estimated low selectivities for male pot bycatch, relative to the retained catch, reflected the 20% handling mortality rate (Figure 8). Both selectivities were applied to the same level of full fishing mortality. Estimated selectivities for female pot bycatch were close to 1.0 for all mature females, and the estimated full fishing mortalities for female pot bycatch were lower than for male retained catch and bycatch (Table 5).

c. Graphs of estimates.

i. Selectivities and molting probabilities by length are provided in Figures 8 and 9 for scenarios 4na and 4nb.

One of the most important results is estimated trawl survey selectivity/catchability (Figure 8). Survey selectivity affects not only the fitting of the data but also the absolute abundance estimates. Estimated survey selectivities in Figure 8 are generally smaller than the capture probabilities in Figure A1 because survey selectivities include capture probabilities and crab availability. NMFS survey catchability was estimated to be 0.896 from the trawl experiment, which is higher than that estimated from the BSFRF surveys (0.854). The reliability of estimated survey selectivities will greatly affect the application of the model to fisheries management. Under- or overestimates of survey selectivities will cause a systematic upward or downward bias of abundance estimates. Information about crab availability to the survey area at survey times will help estimate the survey selectivities.

For scenarios 4na and 4nb, estimated molting probabilities during 1975-2014 (Figure 9) were generally lower than those estimated from the 1954-1961 and 1966-1969 tagging data (Balsiger 1974). Lower molting probabilities mean more oldshell crab, possibly due to changes in molting probabilities over time or shell aging errors. Overestimates or underestimates of oldshell crab will result in lower or higher estimates of male molting probabilities.

ii. Estimated total survey biomass and mature male and female abundances are plotted in Figure 10.

Estimated survey biomass, mature male and female abundances are similar between scenarios 4na and 4nb (Figure 10a,b).

Although the model did not fit the mature crab abundance directly, trends in the mature abundance estimates agree well with observed survey values except in 2014 (Figure 10b). Estimated mature crab abundance increased dramatically in the mid 1970s then decreased precipitously in the early 1980s. Estimated mature crab abundance has increased during the last 27 years with mature females being 3.4

times more abundant in 2009 than in 1985 and mature males being 2.3 times more abundant in 2009 than in 1985 (Figure 10b). Model estimates of mature abundances have declined since the late 2000s.

The fit to BSFRF survey data and estimated survey selectivities are illustrated in Figures 10c-e.

iii. Estimated recruitment time series are plotted in Figure 11 for scenarios 4na and 4nb.

iv. Estimated fishing mortaltiy rates are plotted against mature male biomass in Figure 12 for scenarios 4na and 4nb.

The average of estimated male recruits from 1984 to 2014 (Figure 11) and mature male biomass per recruit were used to estimate $B_{35\%}$. Alternative periods of 1976-present and 1976-1983 were compared in our report. The full fishing mortalities for the directed pot fishery at the time of fishing were plotted against mature male biomass on Feb. 15 (Figure 12). Estimated fishing mortalities in most years before the current harvest strategy was adopted in 1996 were above $F_{35\%}$ (Figure 12). Under the current harvest strategy, estimated fishing mortalities were at or above the $F_{35\%}$ limits in 1998, 2005, 2007-2009 for scenario 4na and 1998, 2003, 2005-2010 for scenario 4nb but below the $F_{35\%}$ limits in the other post-1995 years. The estimated higher survey catchability with scenario 4nb results in relatively higher fishing mortalities than those with scenario 4na.

For scenario 4na, estimated full pot fishing mortalities ranged from 0.00 to 1.52 during 1975-2013, with estimated values over 0.40 during 1975-1981, 1986, and 2008 (Table 5, Figure 12). For scenario 4nb, estimated full pot fishing mortalities ranged from 0.00 to 1.58 during 1975-2013, with estimated values over 0.40 during 1975-1981, 1986-1987, 1993, and 2007-2008 (Table 5, Figure 12). Estimated fishing mortalities for pot female bycatch and trawl bycatch were generally less than 0.06.

v. Estimated mature male biomass and recruitment are plotted to illustrate their relationships with scenarios 4na and 4nb (Figure 13a). Annual stock productivities are illustrated in Figure 13b.

Stock productivity (recruitment/mature male biomass) was generally lower during the last 20 years (Figure 13c).

Egg clutch data collected during summer surveys may provide information about mature female reproductive conditions. Although egg clutch data are subject to rating errors as well as sampling errors, data trends over time may be useful. Proportions of empty clutches for newshell mature females >89 mm CL were high in some years before 1990, but have been low since 1990 (Figure 14). The highest proportion of empty clutches (0.2) was in 1986, and primarily involved soft shell females (shell condition 1). Clutch fullness fluctuated annually around average levels during two periods: before 1991 and after 1990 (Figure 14). The average clutch fullness was close for these two periods (Figure 14).

d. Graphic evaluation of the fit to the data.

i. Observed vs. estimated catches are plotted in Figure 15.

ii. Model fits to total survey biomass are shown in Figure 10 with a standardized residual plot in Figure 16.

iii. Model fits to catch and survey proportions by length are illustrated in Figures 17-24 and residual bubble plots are shown in Figures 25-27.

The model (scenarios 4na and 4nb) fit the fishery biomass data well and the survey biomass reasonably well (Figures 10 and 15). Because the model estimates annual fishing mortality for directed pot male catch, undirected pot male bycatch, pot female bycatch, and trawl bycatch, the deviations of observed and predicted (estimated) fishery biomass are mainly due to size composition differences.

The model also fit the length composition data well (Figures 17-24). It is surprising that the model fit the length proportions of the pot male bycatch well with two simple linear selectivity functions (Figure 21). We explored a logistic selectivity function, but due to the long left tail of the pot male bycatch selectivity, the logistic selectivity function did not fit the data well.

Modal progressions are tracked well in the trawl survey data, particularly beginning in the mid-1990s (Figures 17 and 19). Cohorts first seen in the trawl survey data in 1975, 1986, 1990, 1995, 1999, 2002 and 2005 can be tracked over time. Some cohorts can be tracked over time in the pot bycatch as well (Figure 21), but the bycatch data did not track the cohorts as well as the survey data. Groundfish trawl bycatch data provide little information to track modal progression (Figures 23 and 24).

Standardized residuals of total survey biomass and proportions of length are plotted to examine their patterns. Residuals were calculated as observed minus predicted and standardized by the estimated standard deviation. Standardized residuals of total survey biomass did not show any consistent patterns (Figure 16). Standardized residuals of proportions of survey males appear to be random over length and year (Figures 25 and 26). There is an interesting pattern for residuals of proportions of survey females. Residuals were generally negative for large-sized mature females during 1975-1987 (Figure 27). Changes in growth over time or increased mortality may cause this pattern. The inadequacy of the model can be corrected by adding parameters to address these factors. Further study for female growth and availability for survey gears due to different molting times may be needed.

e. Retrospective and historic analyses.

Two kinds of retrospective analyses were conducted for this report: (1) the 2014 model (scenario 4nb) hindcast results and (2) historical results. The 2014 model results are based on sequentially excluding one-year of data to evaluate the current model performance with fewer data. The historical results are the trajectories of biomass and abundance from previous assessments that capture both new data and changes in methodology over time. Treating the 2014 estimates as the baseline values, we can also evaluate how well the model had done in the past.

i. Retrospective analysis (retrospective bias in base model or models).

The performance of the 2014 model includes sequentially excluding one-year of data. The model with scenario 4nb performed reasonably well during 2008-2013 with a lower terminal year estimates in 2012 and 2013 and higher estimates during 2008-2010 (Figure 28).

ii. Historic analysis (plot of actual estimates from current and previous assessments).

The model first fit the data from 1985 to 2004 in the terminal year of 2004. Thus, 10 historical assessment results are available for comparison with the 2014 assessment model results (Figure 29). The main differences of the 2004 model were weighting factors and effective sample sizes for the likelihood functions. In 2004, the weighting factors were 1000 for survey biomass, 2000 for retained catch biomass and 200 for bycatch biomasses. The effective sample sizes were set to be 200 for all proportion data but weighting factors of 5, 2, and 1 were also applied to retained catch proportions, survey proportions and bycatch proportions. Estimates of time series of abundance in 2004 were generally higher than those estimated after 2004 (Figure 29).

In 2005, to improve the fit for retained catch data, the weight for retained catch biomass was increased to 3000 and the weight for retained catch proportions was increased to 6. All other weights were not changed. In 2006, all weights were re-configured. No weights were used for proportion data, and instead, effective sample sizes were set to 500 for retained catch, 200 for survey data, and 100 for bycatch data. Weights for biomasses were changed to 800 for retained catch, 300 for survey and 50 for bycatch. The weights in 2007 were the same as 2006. Generally, estimates of time series of abundance in 2005 were slightly lower than in 2006 and 2007, and there were few differences between estimates in 2006 and 2007 (Figure 29).

In 2008, estimated coefficients of variation for survey biomass were used to compute likelihood values as suggested by the CPT in 2007. Thus, weights were re-configured to: 500 for retained catch biomass, 50 for survey biomass, and 20 for bycatch biomasses. Effective sample size was lowered to 400 for the retained catch data. These changes were necessary for the estimation to converge and for a relatively good balanced fit to both biomasses and proportion data. Also, sizes at 50% selectivities for all fisheries data were allowed to change annually, subject to a random walk pattern, for all assessments before 2008. The 2008 model does not allow annual changes in any fishery selectivities. Except for higher estimates of abundance during the late 1980s and early 1990s, estimates of time series of abundance in 2008 were generally close to those in 2006 and 2007 (Figure 29).

During 2009-2013, the model was extended to the data through 1968. No weight factors were used for the NMFS survey biomass during 2009-2013 assessments. Since 2013, the model has fitted the data only back to 1975 for consistence of trawl survey data. Two levels of molting probabilities over time were used, shell conditions for males were combined, and length composition data of the BSFRF survey were used as well. In 2014, the trawl survey time series were re-estimated and a trawl survey catchability was estimated for some scenarios.

Overall, both historical results (historic analysis) and the 2014 model results (retrospective analysis) performed reasonably well. No great overestimates or underestimates occurred as was observed in assessments for Pacific halibut (*Hippoglossus stenolepis*) (Parma 1993) and some eastern Bering Sea groundfish stocks (Zheng and Kruse 2002, Ianelli et al. 2003). Since the most recent model was not used to set TAC or overfishing limits until 2009, historical implications for management from the stock assessment errors cannot be evaluated at the current time. However, management implications of the ADF&G stock assessment model were evaluated by Zheng and Kruse (2002).

f. Uncertainty and sensitivity analyses

i. Estimated standard deviations of parameters are summarized in Table 5 for scenarios 4na and 4nb. Estimated standard deviations of mature male biomass are listed in Table 6.

ii. Probabilities for trawl survey catchability *Q* are illustrated in Figure 30 for scenarios 4nb and 4n7 using the mcmc approach; estimated *Q*s are generally less than 1.0. Probabilities for mature male biomass and OFL in 2014 are illustrated in Figure 31 for scenario 4na, 4nb and 4n7 using the mcmc appproach. The confidence intervals are quite narrow.

iii. Sensitivity analysis for handling mortality rate was reported in the SAFE report in May 2010. The baseline handling mortality rate for the directed pot fishery was set at 0.2. A 50% reduction and 100% increase resulted in 0.1 and 0.4 as alternatives. Overall, a higher handling mortality rate resulted in slightly higher estimates of mature abundance, and a lower rate resulted in a minor reduction of estimated mature abundance. Differences of estimated legal abundance and mature male biomass were small among these handling mortality rates.

iv. Sensitivity of weights. Sensitivity of weights was examined in the SAFE report in May 2010. Weights to biomasses (trawl survey biomass, retained catch biomass, and bycatch biomasses) were reduced to 50% or increased to 200% to examine their sensitivity to abundance estimates. Weights to the penalty terms (recruitment variation and sex ratio) were also reduced or increased. Overall, estimated biomasses were very close under different weights except during the mid-1970s. The variation of estimated biomasses in the mid-1970s was mainly caused by the changes in estimates of additional mortalities in the early 1980s.

g. Comparison of alternative model scenarios

These comparisons, based on the data through 2010, were reported in the SAFE report in May 2011. Estimating length proportions in the initial year (scenario 1a) results in a better fit of survey length compositions at an expense of 36 more parameters than scenario 1. Abundance and biomass estimates with scenario 1a are similar between scenarios. Using only standard survey data (scenario 1b) results in a poorer fit of survey length compositions and biomass than scenarios using both standard and re-tow data (scenarios 1, 1a, and 1c) and has the lowest likelihood value. Although the likelihood value is higher for using both standard survey and re-tow data for males (scenario 1) than using only standard survey for males (scenario 1c), estimated abundances and biomasses are almost identical. The higher likelihood value for scenario 1 over scenario 1c is due to trawl bycatch length compositions.

In this report (September 2014), three scenarios are compared. Model estimated relative survey biomasses are very similar between scenarios 4na and 4nb and differ with those of 4n7. Increasing natural mortality from 0.18 to 0.27 during 2006-2010 under scenario 4n7 provided a better fit of trawl survey data during recent years, resulting in a much lower OFL.

F. Calculation of the OFL and ABC

1. Bristol Bay RKC is currently placed in Tier 3b (NPFMC 2007).
2. For Tier 3 stocks, estimated biological reference points include $B_{35\%}$ and $F_{35\%}$. Estimated model parameters were used to conduct mature male biomass-per-recruit analysis.
3. Specification of the OFL:

   The Tier 3 can be expressed by the following control rule:

$$\text{a)}\quad \frac{B}{B^*} > 1 \qquad\qquad F_{OFL} = F^*$$

$$\text{b)}\quad \beta < \frac{B}{B^*} \le 1 \qquad\qquad F_{OFL} = F^*\left(\frac{B/B^* - \alpha}{1-\alpha}\right) \tag{1}$$

$$\text{c)}\quad \frac{B}{B^*} \le \beta \qquad\qquad \text{directed fishery } F = 0 \text{ and } F_{OFL} \le F^*$$

   Where

   B = a measure of the productive capacity of the stock such as spawning biomass or fertilized egg production. A proxy of B, MMB estimated at the time of primiparous female mating (February 15) is used as a default in the development of the control rule.

   F^* = $F_{35\%}$, a proxy of F_{MSY}, which is a full selection instantaneous F that will produce MSY at the MSY producing biomass,

   B^* = $B_{35\%}$, a proxy of B_{MSY}, which is the value of biomass at the MSY producing level,

   β = a parameter with restriction that $0 \le \beta < 1$. A default value of 0.25 is used.

   α = a parameter with restriction that $0 \le \alpha \le \beta$. A default value of 0.1 is used.

   Because trawl bycatch fishing mortality was not related to pot fishing mortality, average trawl bycatch fishing mortality during 2004 to 2013 was used for the per recruit analysis as well as for projections in the next section. Pot female bycatch fishing mortality was set equal to pot male fishing mortality times 0.02, an intermediate level during 1990-2013. Some discards of legal males occurred since the IFQ fishery started in 2005, but the discard rates were much lower during 2007-2013 than in 2005 after the fishing industry minimized discards of legal males. Thus, the average of retained selectivities and discard male selectivities during 2012-2013 were used to represent current trends for per recruit analysis and projections. Average molting probabilities during 2004-2013 were used for per recruit analysis and projections.

Average recruitments during three periods were used to estimate $B_{35\%}$: 1976-1983, 1976-2013, and 1984-2013 (Figure 11). Estimated $B_{35\%}$ is compared with historical mature male biomass in Figure 13a. We recommend using the average recruitment during 1984-present, corresponding to the 1976/77 regime shift. Note that recruitment period 1984-present has been used since 2011 to set the overfishing limits. Several factors support our recommendation. First, estimated recruitment was lower after 1983 than before 1984, which corresponded to brood years 1978 and later, after the 1976/77 regime shift. Second, high recruitments during the late 1960s and 1970s generally occurred when the spawning stock was primarily located in the southern Bristol Bay, whereas the current spawning stock is mainly in the middle of Bristol Bay. The current flows favor larvae hatched in the southern Bristol Bay (see the section on Ecosystem Considerations for SAFE reports in 2008 and 2009). Finally, stock productivity (recruitment/mature male biomass) was higher before the 1976/1977 regime shift.

If we believe that the productivity differences and differences of other population characteristics before 1978 were caused by fishing, not by the regime shift, then we should use the recruitment from 1976-1983 (corresponding to brood years before 1978) as the baseline to estimate B35%. If we believe that the regime shift during 1976/77 caused the productivity differences, then we should select the recruitments from period 1984-2014 as the baseline.

The control rule is used for stock status determination. If total catch exceeds OFL estimated at B, then "overfishing" occurs. If B equals or declines below 0.5 B_{MSY} (i.e., MSST), the stock is "overfished." If B equals or declines below β*B_{MSY} or β*a proxy B_{MSY}, then the stock productivity is severely depleted and the fishery is closed.

The estimated probability distribution of MMB in 2014 is illustrated in Figure 30. The normal approximation is used to estimate the 49th percentile for the OFL in 2014 (Figure 31). Based the SSC suggestion in 2011, ABC = 0.9*OFL is used to estimate ABC.

Status and catch specifications (1000 t) (scenario 4nb):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	13.63^{A}	32.64^{A}	6.73	6.76	7.71	10.66	N/A
2011/12	13.77^{B}	30.88^{B}	3.55	3.61	4.09	8.80	7.92
2012/13	13.19^{C}	29.05^{C}	3.56	3.62	3.90	7.96	7.17
2013/14	12.85^{D}	27.12^{D}	3.90	3.99	4.56	7.07	6.36
2014/15		24.69^{D}				6.82	6.14

The stock was above MSST in 2013/14 and is hence not overfished. Overfishing did not occur.

Status and catch specifications (million lbs):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	30.0[A]	72.0[A]	14.84	14.91	17.00	23.52	N/A
2011/12	30.4[B]	68.1[B]	7.83	7.95	9.01	19.39	17.46
2012/13	29.1[C]	64.0[C]	7.85	7.98	8.59	17.55	15.80
2013/14	28.3[D]	59.9[D]	8.60	8.80	10.05	15.58	14.02
2014/15		54.4[D]				15.04	13.53

Notes:

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2011
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2012
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2013
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2014

4. Based on the $B_{35\%}$ estimated from the average male recruitment during 1984-2014, the biological reference points and OFL were estimated as follows:

	Scenario 4na		Scenario 4nb		Scenario 4n7	
	1000t	Million lbs	1000t	Million lbs	1000t	Million lbs
$B_{35\%}$	26.313	58.010	25.703	56.665	27.953	61.627
$F_{35\%}$	0.29		0.29		0.29	
MMB_{2014}	25.735	56.736	24.687	54.443	20.407	44.990
OFL_{2014}	7.289	16.070	6.820	15.036	3.982	8.779
ABC_{2014}	6.560	14.463	6.138	13.532	3.584	7.901

5. Based on the 10% buffer rule used last year, ABC = 0.9*OFL. If P*=49% is used, the ABC would be higher.

G. Rebuilding Analyses

NA.

H. Data Gaps and Research Priorities

1. The following data gaps exist for this stock:
   a. Information about changes in natural mortality in the early 1980s;
   b. Un-observed trawl bycatch in the early 1980s;
   c. Natural mortality;
   d. Crab availability to the trawl surveys;
   e. Juvenile crab abundance;
   f. Female growth per molt as a function of size and maturity;
   g. Changes in male molting probability over time.

2. Research priorities:
    a. Estimating natural mortality;
    b. Estimating crab availability to the trawl surveys;
    c. Surveying juvenile crab abundance in nearshore;
    d. Studying environmental factors that affect the survival rates from larvae to recruitment.

I. Projections and Future Outlook

1. Projections

Future population projections primarily depend on future recruitment, but crab recruitment is difficult to predict. Therefore, annual recruitment for the projections was a random selection from estimated recruitments during 1984-2014. Besides recruitment, the other major uncertainty for the projections is estimated abundance in 2014. The 2014 abundance was randomly selected from the estimated normal distribution of the assessment model output for each replicate. Three scenarios of fishing mortality for the directed pot fishery were used in the projections:

(1) No directed fishery. This was used as a base projection.

(2) $F_{40\%}$. This fishing mortality creates a buffer between the limits and target levels.

(3) $F_{35\%}$. This is the maximum fishing mortality allowed under the current overfishing definitions.

Each scenario was replicated 1000 times and projections made over 10 years beginning in 2014 (Table 7).

As expected, projected mature male biomasses are much higher without the directed fishing mortality than under the other scenarios. At the end of 10 years, projected mature male biomass is above $B_{35\%}$ for all scenarios (Table 7; Figure 32). Projected retained catch for the $F_{35\%}$ scenario is higher than those for the $F_{40\%}$ scenario (Table 7, Figure 33). Due to the poor recruitment during recent years, the projected biomass and retained catch are expected to decline during the next few years.

2. Near Future Outlook

The near future outlook for the Bristol Bay RKC stock is a declining trend. The three recent above-average year classes (hatching years 1990, 1994, and 1997) had entered the legal population by 2006 (Figure 34). Most individuals from the 1997 year class will continue to gain weight to offset loss of the legal biomass to fishing and natural mortalities. The above-average year class (hatching year 2000) with lengths centered around 87.5 mm CL for both males and females in 2006 and with lengths centered around 112.5-117.5 mm CL for males and around 107.5 mm CL for females in 2008 has largely entered the mature male population in 2009 and the legal population by this year (Figure 34). No strong cohorts have been observed in the survey data after this cohort through 2010 (Figure 34). There was a huge tow of juvenile crab of size 45-55 mm in 2011, but these juveniles were not observed during 2012-2014 surveys. This singe tow is unlikely to be an indicator for a strong cohort. The high survey abundance of large males and mature females in 2014 cannot be explained by the survey data during the previous years (Figure 34). Due to lack of recruitment, mature and legal crab should continue to decline next year. Current crab abundance is still low relative to the late 1970s, and without favorable environmental conditions, recovery to the high levels of the late 1970s is unlikely.

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Table 1. Bristol Bay red king crab annual catch and bycatch mortality biomass (t) from June 1 to May 31. A handling mortality rate of 20% for the directed pot, 25% for the Tanner fishery, and 80% for trawl was assumed to estimate bycatch mortality biomass.

Year	Retained Catch				Pot Bycatch		Trawl Bycatch	Tanner Fishery Bycatch	Total Catch
	U.S.	Cost-Recovery	Foreign	Total	Males	Females			
1953	1331.3		4705.6	6036.9					6036.9
1954	1149.9		3720.4	4870.2					4870.2
1955	1029.2		3712.7	4741.9					4741.9
1956	973.4		3572.9	4546.4					4546.4
1957	339.7		3718.1	4057.8					4057.8
1958	3.2		3541.6	3544.8					3544.8
1959	0.0		6062.3	6062.3					6062.3
1960	272.2		12200.7	12472.9					12472.9
1961	193.7		20226.6	20420.3					20420.3
1962	30.8		24618.7	24649.6					24649.6
1963	296.2		24930.8	25227.0					25227.0
1964	373.3		26385.5	26758.8					26758.8
1965	648.2		18730.6	19378.8					19378.8
1966	452.2		19212.4	19664.6					19664.6
1967	1407.0		15257.0	16664.1					16664.1
1968	3939.9		12459.7	16399.6					16399.6
1969	4718.7		6524.0	11242.7					11242.7
1970	3882.3		5889.4	9771.7					9771.7
1971	5872.2		2782.3	8654.5					8654.5
1972	9863.4		2141.0	12004.3					12004.3
1973	12207.8		103.4	12311.2					12311.2
1974	19171.7		215.9	19387.6					19387.6
1975	23281.2		0	23281.2					23281.2
1976	28993.6		0	28993.6			682.8		29676.4
1977	31736.9		0	31736.9			1249.9		32986.8
1978	39743.0		0	39743.0			1320.6		41063.6
1979	48910.0		0	48910.0			1331.9		50241.9
1980	58943.6		0	58943.6			1036.5		59980.1
1981	15236.8		0	15236.8			219.4		15456.2
1982	1361.3		0	1361.3			574.9		1936.2
1983	0.0		0	0.0			420.4		420.4
1984	1897.1		0	1897.1			1094.0		2991.1
1985	1893.8		0	1893.8			390.1		2283.8
1986	5168.2		0	5168.2			200.6		5368.8
1987	5574.2		0	5574.2			186.4		5760.7
1988	3351.1		0	3351.1			597.8		3948.9
1989	4656.0		0	4656.0			174.1		4830.1
1990	9236.2	36.6	0	9272.8	526.9	651.5	247.6		10698.7
1991	7791.8	93.4	0	7885.1	407.8	75.0	316.0	1401.8	10085.7
1992	3648.2	33.6	0	3681.8	552.0	418.5	335.4	244.4	5232.2
1993	6635.4	24.1	0	6659.6	763.2	637.1	426.6	54.6	8541.0
1994	0.0	42.3	0	42.3	3.8	1.9	88.9	10.8	147.8
1995	0.0	36.4	0	36.4	3.3	1.6	194.2	0.0	235.5
1996	3812.7	49.0	0	3861.7	164.6	1.0	106.5	0.0	4133.9
1997	3971.9	70.2	0	4042.1	244.7	19.6	73.4	0.0	4379.8
1998	6693.8	85.4	0	6779.2	959.7	864.9	159.8	0.0	8763.7
1999	5293.5	84.3	0	5377.9	314.2	8.8	201.6	0.0	5902.4
2000	3698.8	39.1	0	3737.9	360.8	40.5	100.4	0.0	4239.5
2001	3811.5	54.6	0	3866.2	417.9	173.5	164.6	0.0	4622.1
2002	4340.9	43.6	0	4384.5	442.7	7.3	155.1	0.0	4989.6

2003	7120.0	15.3	0	7135.3	918.9	430.4	172.3	0.0	8656.9
2004	6915.2	91.4	0	7006.7	345.5	187.0	119.6	0.0	7658.8
2005	8305.0	94.7	0	8399.7	1359.5	498.3	155.2	0.0	10412.8
2006	7005.3	137.9	0	7143.2	563.8	37.0	116.7	3.8	7864.4
2007	9237.9	66.1	0	9303.9	1001.3	186.1	138.5	1.8	10631.6
2008	9216.1	0.0	0	9216.1	1165.5	148.4	159.5	4.0	10693.5
2009	7226.9	45.5	0	7272.5	888.1	85.2	103.7	1.6	8351.2
2010	6728.5	33.0	0	6761.5	797.5	122.6	89.0	0.0	7770.7
2011	3553.3	53.8	0	3607.1	395.0	24.0	69.2	0.0	4095.3
2012	3560.6	61.1	0	3621.7	205.2	12.3	62.2	0.0	3901.4
2013	3901.1	89.9	0	3991.0	310.6	99.8	126.8	28.5	4556.6

Table 2. Annual sample sizes (>64 mm CL) for catch by length and shell condition for retained catch and bycatch of Bristol Bay red king crab.

Year	Trawl Survey		Retained Catch	Pot Bycatch		Trawl Bycatch		Tanner Fishery Bycatch	
	Males	Females		Males	Females	Males	Females	Males	Females
1968	3,684	2,165	18,044						
1969	6,144	4,992	22,812						
1970	1,546	1,216	3,394						
1971			10,340						
1972	1,106	767	15,046						
1973	1,783	1,888	11,848						
1974	2,505	1,800	27,067						
1975	2,943	2,139	29,570						
1976	4,724	2,956	26,450			2,327	676		
1977	3,636	4,178	32,596			14,014	689		
1978	4,132	3,948	27,529			8,983	1,456		
1979	5,807	4,663	27,900			7,228	2,821		
1980	2,412	1,387	34,747			47,463	39,689		
1981	3,478	4,097	18,029			42,172	49,634		
1982	2,063	2,051	11,466			84,240	47,229		
1983	1,524	944	0			204,464	104,910		
1984	2,679	1,942	4,404			357,981	147,134		
1985	792	415	4,582			169,767	30,693		
1986	1,962	367	5,773			1,199	284		
1987	1,168	1,018	4,230			723	927		
1988	1,834	546	9,833			437	275		
1989	1,257	550	32,858			3,147	194		
1990	858	603	7,218	873	699	761	1,570		
1991	1,378	491	36,820	1,801	375	208	396	885	2,198
1992	513	360	23,552	3,248	2,389	214	107	280	685
1993	1,009	534	32,777	5,803	5,942			232	265
1994	443	266	0	0	0	330	247		
1995	2,154	1,718	0	0	0	103	35		
1996	835	816	8,896	230	11	1,025	968		
1997	1,282	707	15,747	4,102	906	1,202	483		
1998	1,097	1,150	16,131	11,079	9,130	1,627	915		
1999	764	540	17,666	1,048	36	2,154	858		
2000	731	1,225	14,091	8,970	1,486	994	671		
2001	611	743	12,854	9,102	4,567	4,393	2,521		
2002	1,032	896	15,932	9,943	302	3,372	1,464		
2003	1,669	1,311	16,212	17,998	10,327	1,568	1,057		
2004	2,871	1,599	20,038	8,258	4,112	1,689	1,506		
2005	1,283	1,682	21,938	55,019	26,775	1,815	1,872		
2006	1,171	2,672	18,027	32,252	3,980	1,481	1,983		
2007	1,219	2,499	22,387	59,769	12,661	1,011	1,097		
2008	1,221	3,352	14,567	49,315	8,488	1,867	1,039		
2009	830	1,857	16,708	52,359	6,041	1,482	870		
2010	705	1,633	20,137	36,654	6,868	734	876		
2011	525	994	10,706	20,629	1,920	600	1,094		
2012	580	707	8,956	7,206	561	1,577	1,770		
2013	633	560	10,197	13,828	6,048	4,681	4,174	218	596
2014	1,106	1,255							

Table 3. Annual retained catch (million crab) and catch per unit effort of the Bristol Bay red king crab fishery.

Year	Japanese Tanglenet		Russian Tanglenet		U.S. Pot/Trawl		Standardized
	Catch	Crab/tan	Catch	Crab/tan	Catch	Crab/Potlift	Crab/tan
1960	1.949	15.2	1.995	10.4	0.088		15.8
1961	3.031	11.8	3.441	8.9	0.062		12.9
1962	4.951	11.3	3.019	7.2	0.010		11.3
1963	5.476	8.5	3.019	5.6	0.101		8.6
1964	5.895	9.2	2.800	4.6	0.123		8.5
1965	4.216	9.3	2.226	3.6	0.223		7.7
1966	4.206	9.4	2.560	4.1	0.140	52	8.1
1967	3.764	8.3	1.592	2.4	0.397	37	6.3
1968	3.853	7.5	0.549	2.3	1.278	27	7.8
1969	2.073	7.2	0.369	1.5	1.749	18	5.6
1970	2.080	7.3	0.320	1.4	1.683	17	5.6
1971	0.886	6.7	0.265	1.3	2.405	20	5.8
1972	0.874	6.7			3.994	19	
1973	0.228				4.826	25	
1974	0.476				7.710	36	
1975					8.745	43	
1976					10.603	33	
1977					11.733	26	
1978					14.746	36	
1979					16.809	53	
1980					20.845	37	
1981					5.308	10	
1982					0.541	4	
1983					0.000		
1984					0.794	7	
1985					0.796	9	
1986					2.100	12	
1987					2.122	10	
1988					1.236	8	
1989					1.685	8	
1990					3.130	12	
1991					2.661	12	
1992					1.208	6	
1993					2.270	9	
1994					0.015		
1995					0.014		
1996					1.264	16	
1997					1.338	15	
1998					2.238	15	
1999					1.923	12	
2000					1.272	12	
2001					1.287	19	
2002					1.484	20	
2003					2.510	18	
2004					2.272	23	
2005					2.763	30	
2006					2.477	31	
2007					3.154	28	
2008					3.064	22	
2009					2.553	21	
2010					2.410	18	
2011					1.298	28	
2012					1.176	30	
2013					1.272	27	

Table 4(4na). Summary of statistics for the model (Scenario 4na).

Parameter counts

Fixed growth parameters	9
Fixed recruitment parameters	2
Fixed length-weight relationship parameters	6
Fixed mortality parameters	4
Fixed survey catchability parameter	2
Fixed high grading parameters	9
Total number of fixed parameters	32
Free growth parameters	6
Initial abundance (1975)	1
Recruitment-distribution parameters	2
Mean recruitment parameters	1
Male recruitment deviations	40
Female recruitment deviations	40
Natural and fishing mortality parameters	4
Pot male fishing mortality deviations	41
Bycatch mortality from the Tanner crab fishery	8
Pot female bycatch fishing mortality deviations	26
Trawl bycatch fishing mortality deviations	40
Initial (1975) length compositions	35
Free selectivity parameters	22
Total number of free parameters	266
Total number of fixed and free parameters	298

Negative log likelihood components (see table 4)

Length compositions---retained catch
Length compositions---pot male discard
Length compositions---pot female discard
Length compositions---survey
Length compositions---trawl discard
Length compositions---Tanner crab discards
Pot discard male biomass
Retained catch biomass
Pot discard female biomass
Trawl discard
Survey biomass
Recruitment variation
Others
Total

Table 4(4nb). Summary of statistics for the model (Scenario 4nb).

Parameter counts

Fixed growth parameters	9
Fixed recruitment parameters	2
Fixed length-weight relationship parameters	6
Fixed mortality parameters	4
Fixed survey catchability parameter	1
Fixed high grading parameters	9
Total number of fixed parameters	31
Free survey catchability parameter	1
Free growth parameters	6
Initial abundance (1975)	1
Recruitment-distribution parameters	2
Mean recruitment parameters	1
Male recruitment deviations	40
Female recruitment deviations	40
Natural and fishing mortality parameters	4
Pot male fishing mortality deviations	41
Bycatch mortality from the Tanner crab fishery	8
Pot female bycatch fishing mortality deviations	26
Trawl bycatch fishing mortality deviations	40
Initial (1975) length compositions	35
Free selectivity parameters	22
Total number of free parameters	267
Total number of fixed and free parameters	298

Negative log likelihood components (see table 4)

Length compositions---retained catch
Length compositions---pot male discard
Length compositions---pot female discard
Length compositions---survey
Length compositions---trawl discard
Length compositions---Tanner crab discards
Pot discard male biomass
Retained catch biomass
Pot discard female biomass
Trawl discard
Survey biomass
Recruitment variation
Others
Total

Table 4. Negative log likelihood components for scenario 4na and differences in negative log-likelihood components among model scenarios.

	Scenario			
Negative log likelihood	4na	4nb-4na	4n7-4na	4n7-4nb
R-variation	78.08	-0.06	2.48	2.54
Length-like-retained	-948.94	-0.54	-2.90	-2.36
Length-like-discmale	-953.65	0.38	1.38	1.00
Length-like-discfemale	-2250.44	-0.67	2.26	2.93
Length-like-survey	-44871.50	-2.20	-12.30	-10.10
Length-like-disctrawl	-1967.16	1.03	2.17	1.14
Length-like-discTanner	-330.52	-0.27	-1.87	-1.60
Length-like-bsfrfsurvey	-237.28	-0.02	-1.71	-1.69
Catchbio_retained	46.35	0.29	-2.46	-2.74
Catchbio_discmale	210.62	-0.35	-6.11	-5.76
Catchbio-discfemale	0.14	0.00	0.03	0.03
Catchbio-disctrawl	0.86	0.00	-0.02	-0.02
Biomass-trawl survey	87.67	-2.31	-4.25	-1.95
Biomass-bsfrfsurvey	-5.42	1.00	2.00	1.00
Others	21.50	1.12	-1.40	-2.52
Total	-51119.70	-2.60	-22.70	-20.10
Free parameters	266	1	2	1

Table 5(4na). Summary of model parameter estimates (scenario 4na) for Bristol Bay red king crab. Estimated values and standard deviations (SD). All values are on a log scale. Male recruit is exp(mean+males), and female recruit is exp(mean+males+females).

	Recruits				F for Directed Pot Fishery				F for Trawl	
Year	Females	SD	Males	SD	Males	SD	Females	SD	Estimate	SD
Mean	15.935	0.021	15.935	0.021	-2.010	0.032	0.011	0.001	-5.245	0.060
Limits↑	13,18		13,18		-4.0,0.0		.001,0.1		-8.5,-1.0	
Limits↓	-15,15		-15,15		-15,2.43		-6.0,3.5		-10,10	
1975					1.121	0.100				
1976	-0.411	0.309	0.766	0.131	1.142	0.070			0.177	0.107
1977	0.732	0.133	0.681	0.095	1.170	0.060			0.708	0.105
1978	0.598	0.112	0.908	0.078	1.403	0.053			0.701	0.104
1979	0.311	0.111	1.068	0.075	1.660	0.047			0.727	0.104
1980	0.319	0.105	1.271	0.074	2.425	0.013			0.755	0.104
1981	0.461	0.117	0.634	0.093	2.425	0.007			0.321	0.104
1982	-0.095	0.049	2.246	0.044	0.536	0.046			2.044	0.105
1983	0.033	0.073	1.376	0.050	-10.185	0.674			1.928	0.105
1984	0.419	0.062	1.250	0.045	0.949	0.056			2.906	0.104
1985	0.182	0.158	-0.560	0.102	1.023	0.063			1.833	0.105
1986	0.478	0.058	0.645	0.045	1.477	0.059			0.757	0.104
1987	-0.091	0.137	-0.255	0.072	1.085	0.054			0.445	0.103
1988	0.373	0.166	-1.010	0.108	0.186	0.049			1.427	0.102
1989	0.050	0.149	-0.739	0.083	0.317	0.046			0.025	0.102
1990	-0.068	0.068	0.334	0.045	0.928	0.042	2.092	0.102	0.317	0.102
1991	-0.116	0.095	-0.119	0.054	0.905	0.044	-0.048	0.102	0.652	0.103
1992	-0.455	0.367	-1.787	0.159	0.390	0.046	2.242	0.102	0.826	0.103
1993	-0.266	0.099	-0.347	0.055	1.038	0.047	2.121	0.103	1.087	0.102
1994	-0.174	0.397	-2.109	0.185	-4.100	0.047	1.485	0.130	-0.377	0.104
1995	0.035	0.039	1.200	0.035	-4.434	0.044	1.603	0.134	0.255	0.102
1996	-0.681	0.239	-0.565	0.104	0.115	0.042	-3.621	0.152	-0.453	0.103
1997	-0.772	0.369	-1.349	0.150	0.227	0.042	-0.964	0.103	-0.832	0.103
1998	-0.232	0.119	-0.226	0.067	0.927	0.043	2.109	0.101	-0.101	0.102
1999	0.079	0.058	0.644	0.041	0.484	0.042	-2.024	0.106	0.124	0.102
2000	-0.108	0.139	-0.309	0.079	0.112	0.041	-0.237	0.102	-0.632	0.102
2001	0.792	0.168	-0.934	0.131	0.133	0.041	1.124	0.101	-0.187	0.102
2002	0.265	0.055	1.003	0.042	0.236	0.041	-2.205	0.107	-0.286	0.101
2003	-0.026	0.208	-0.496	0.123	0.751	0.041	1.196	0.101	-0.227	0.101
2004	-0.031	0.140	0.053	0.083	0.609	0.041	0.408	0.101	-0.574	0.102
2005	0.352	0.060	0.955	0.046	1.033	0.042	0.927	0.101	-0.342	0.101
2006	-0.578	0.161	0.270	0.069	0.758	0.042	-1.500	0.102	-0.626	0.102
2007	-0.354	0.149	-0.111	0.078	1.088	0.043	-0.280	0.101	-0.507	0.102
2008	0.134	0.162	-0.712	0.106	1.179	0.046	-0.587	0.102	-0.370	0.103
2009	0.211	0.142	-0.664	0.096	0.888	0.049	-0.818	0.103	-0.812	0.104
2010	-0.037	0.106	-0.115	0.068	0.753	0.051	-0.281	0.103	-0.994	0.105
2011	0.031	0.110	-0.117	0.073	0.077	0.053	-1.204	0.105	-1.237	0.106
2012	-0.109	0.141	-0.309	0.085	-0.027	0.056	-1.741	0.107	-1.355	0.107
2013	-0.551	0.207	-0.517	0.105	0.153	0.060	0.202	0.105	-0.637	0.107
2014	-0.700	0.467	-1.953	0.238						

Table 5(4na) (continued). Summary of model parameter estimates for Bristol Bay red king crab (scenario 4na). Estimated values and standard deviations. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

				Initial Length Composition 1975			
Parameter	Value	SD	Limits	Length	Value	SD	Limits
Mm80-84	0.465	0.016	0.184, 1.00	68	1.231	0.094	-5, 5
Mf80-84	0.815	0.020	0.276, 1.50	73	1.260	0.087	-5, 5
Mf76-79,85-93	0.080	0.006	0.0, 0.108	78	0.480	0.110	-5, 5
log_betal, females	0.181	0.055	-0.67, 1.32	83	0.456	0.096	-5, 5
log_betal, males	0.511	0.084	-0.67, 1.32	88	0.414	0.089	-5, 5
log_betar, females	-0.726	0.062	-1.14, 0.50	93	0.107	0.101	-5, 5
log_betar, males	-0.658	0.047	-1.14, 0.50	98	0.133	0.099	-5, 5
Bsfrf_CV	0.064	0.065	0.00, 0.40	103	-0.098	0.114	-5, 5
moltp_slope, 75-79	0.133	0.023	0.01, 0.168	108	-0.040	0.113	-5, 5
moltp_slope, 80-14	0.099	0.004	0.01, 0.168	113	0.074	0.112	-5, 5
log_moltp_L50, 75-79	4.967	0.013	4.47, 5.52	118	-0.075	0.129	-5, 5
log_moltp_L50, 80-14	4.944	0.003	4.47, 5.52	123	-0.088	0.138	-5, 5
log_N75	20.044	0.031	15.0, 21.00	128	-0.073	0.147	-5, 5
log_avg_L50_ret	4.921	0.002	4.78, 5.05	133	-0.124	0.160	-5, 5
ret_fish_slope	0.530	0.032	0.05, 0.70	138	-0.214	0.145	-5, 5
pot disc.males, φ	-0.332	0.014	-0.40, 0.00	143	-0.315	0.146	-5, 5
pot disc.males, κ	0.004	0.000	0.0, 0.005	148	-0.470	0.156	-5, 5
pot disc.males, γ	-0.015	0.001	-0.025, 0.0	153	-0.828	0.190	-5, 5
pot disc.fema., slope	0.242	0.069	0.05, 0.69	158	-1.321	0.256	-5, 5
log_pot disc.fema., L50	4.424	0.019	4.24, 4.61	163	-1.357	0.272	-5, 5
trawl disc slope	0.061	0.003	0.01, 0.20	68	1.669	0.096	-5, 5
log_trawl disc L50	4.973	0.032	4.40, 5.20	73	1.598	0.094	-5, 5
log_srv_L50, m, bsfrf	4.391	0.042	3.59, 5.49	78	1.412	0.094	-5, 5
srv_slope, f, bsfrf	0.015	0.006	0.01, 0.435	83	1.164	0.097	-5, 5
log_srv_L50, f, bsfrf	5.100	0.461	4.09, 5.54	88	1.155	0.088	-5, 5
log_srv_L50, m, 75-81	4.324	0.010	4.09, 5.54	93	0.765	0.100	-5, 5
srv_slope, f, 75-81	0.067	0.004	0.01, 0.33	98	0.481	0.115	-5, 5
log_srv_L50, f, 75-81	4.445	0.018	4.09, 4.70	103	0.399	0.117	-5, 5
log_srv_L50, m, 82-14	4.472	0.007	4.09, 5.10	108	0.203	0.129	-5, 5
srv_slope, f, 82-14	0.062	0.002	0.01, 0.30	113	0.028	0.144	-5, 5
log_srv_L50, f, 82-14	4.513	0.011	4.09, 4.90	118	-0.509	0.213	-5, 5
TC_slope, females	0.365	0.140	0.02, 0.40	123	-0.693	0.258	-5, 5
log_TC_L50, females	4.542	0.015	4.24, 4.90	128	-1.110	0.382	-5, 5
TC_slope, males	0.258	0.115	0.05, 0.90	133	-1.904	0.778	-5, 5
log_TC_L50, males	4.584	0.021	4.25, 5.14	138	-2.324	1.230	-5, 5
log_TC_F, males, 91	-4.165	0.082	-10.0, 1.00	143	NA	NA	
log_TC_F, males, 92	-6.134	0.083	-10.0, 1.00				
log_TC_F, males, 93	-6.863	0.085	-10.0, 1.00				
log_TC_F, males, 13	-8.253	0.095	-10.0, 1.00				
log_TC_F, females, 91	-2.891	0.084	-10.0, 1.00				
log_TC_F, females, 92	-4.552	0.084	-10.0, 1.00				
log_TC_F, females, 93	-6.452	0.085	-10.0, 1.00				
log_TC_F, females, 13	-7.726	0.083	-10.0, 1.00				

Table 5(4nb). Summary of model parameter estimates (scenario 4nb) for Bristol Bay red king crab. Estimated values and standard deviations. All values are on a log scale. Male recruit is exp(mean+males), and female recruit is exp(mean+males+females).

Year	Recruits				F for Directed Pot Fishery				F for Trawl	
	Females	SD	Males	SD	Males	SD	Females	SD	Estimate	SD
Mean	15.910	0.024	15.910	0.024	-1.970	0.042	0.011	0.001	-5.205	0.064
Limits↑	13,18		13,18		-4.0,0.0		.001,0.1		-8.5,-1.0	
Limits↓	-15,15		-15,15		-15,2.43		-6.0,3.5		-10,10	
1975					1.095	0.102				
1976	-0.387	0.302	0.769	0.133	1.111	0.072			0.154	0.107
1977	0.725	0.133	0.688	0.096	1.137	0.063			0.683	0.105
1978	0.598	0.112	0.907	0.078	1.369	0.057			0.677	0.104
1979	0.311	0.111	1.062	0.075	1.626	0.053			0.704	0.104
1980	0.315	0.106	1.265	0.074	2.405	0.050			0.734	0.104
1981	0.461	0.117	0.624	0.094	2.425	0.007			0.315	0.104
1982	-0.099	0.049	2.244	0.044	0.551	0.047			2.053	0.106
1983	0.028	0.073	1.376	0.050	-10.21	0.709			1.934	0.105
1984	0.414	0.062	1.254	0.045	0.951	0.057			2.908	0.104
1985	0.186	0.157	-0.561	0.103	1.028	0.064			1.834	0.105
1986	0.473	0.058	0.649	0.045	1.479	0.059			0.755	0.104
1987	-0.092	0.136	-0.253	0.072	1.085	0.055			0.444	0.104
1988	0.371	0.166	-1.009	0.108	0.182	0.049			1.425	0.102
1989	0.049	0.148	-0.738	0.083	0.311	0.047			0.021	0.102
1990	-0.071	0.068	0.333	0.045	0.927	0.043	2.101	0.102	0.313	0.102
1991	-0.122	0.095	-0.123	0.055	0.912	0.045	-0.046	0.102	0.653	0.103
1992	-0.427	0.357	-1.790	0.159	0.401	0.046	2.243	0.102	0.834	0.103
1993	-0.278	0.099	-0.347	0.055	1.055	0.048	2.118	0.103	1.097	0.103
1994	-0.134	0.387	-2.124	0.187	-4.085	0.048	1.484	0.130	-0.360	0.104
1995	0.027	0.039	1.197	0.035	-4.429	0.045	1.611	0.135	0.264	0.103
1996	-0.681	0.235	-0.559	0.104	0.119	0.043	-3.612	0.152	-0.450	0.103
1997	-0.759	0.361	-1.347	0.150	0.232	0.043	-0.959	0.104	-0.828	0.103
1998	-0.244	0.119	-0.222	0.067	0.935	0.044	2.109	0.101	-0.097	0.102
1999	0.068	0.058	0.648	0.041	0.491	0.043	-2.023	0.106	0.130	0.102
2000	-0.118	0.139	-0.303	0.079	0.116	0.043	-0.233	0.102	-0.629	0.102
2001	0.788	0.168	-0.935	0.132	0.135	0.042	1.128	0.101	-0.185	0.102
2002	0.252	0.056	1.008	0.042	0.238	0.042	-2.201	0.107	-0.284	0.101
2003	-0.023	0.208	-0.501	0.124	0.751	0.042	1.202	0.101	-0.226	0.101
2004	-0.043	0.140	0.056	0.083	0.610	0.042	0.413	0.101	-0.573	0.102
2005	0.345	0.061	0.952	0.047	1.037	0.043	0.928	0.101	-0.341	0.101
2006	-0.582	0.160	0.271	0.069	0.762	0.043	-1.498	0.103	-0.624	0.102
2007	-0.366	0.148	-0.107	0.077	1.094	0.044	-0.280	0.101	-0.506	0.102
2008	0.124	0.161	-0.708	0.106	1.191	0.047	-0.595	0.102	-0.367	0.103
2009	0.206	0.142	-0.663	0.096	0.903	0.050	-0.828	0.103	-0.806	0.104
2010	-0.040	0.106	-0.116	0.068	0.767	0.053	-0.291	0.103	-0.988	0.105
2011	0.025	0.110	-0.117	0.073	0.090	0.055	-1.213	0.105	-1.230	0.106
2012	-0.112	0.140	-0.308	0.085	-0.015	0.057	-1.749	0.107	-1.349	0.107
2013	-0.548	0.206	-0.516	0.105	0.165	0.061	0.193	0.105	-0.631	0.107
2014	-0.641	0.458	-1.960	0.239						

Table 5(4nb) (continued). Summary of model parameter estimates for Bristol Bay red king crab (scenario 4nb). Estimated values and standard deviations. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

				Initial Length Composition 1975			
Parameter	Value	SD	Limits	Length	Value	SD	Limits
Mm80-84	0.466	0.016	0.184, 1.0	68	1.235	0.095	-5, 5
Mf80-84	0.816	0.020	0.276, 1.5	73	1.266	0.087	-5, 5
Mf76-79,85-93	0.082	0.006	0.0, 0.108	78	0.485	0.111	-5, 5
log_betal, females	0.177	0.055	-0.67, 1.32	83	0.461	0.097	-5, 5
log_betal, males	0.523	0.084	-0.67, 1.32	88	0.421	0.090	-5, 5
log_betar, females	-0.724	0.062	-1.14, 0.5	93	0.115	0.102	-5, 5
log_betar, males	-0.652	0.047	-1.14, 0.5	98	0.141	0.099	-5, 5
Bsfrf_CV	0.941	0.021	0.00, 0.40	103	-0.089	0.114	-5, 5
moltp_slope, 75-78	0.135	0.025	0.01, 0.207	108	-0.032	0.113	-5, 5
moltp_slope, 79-14	0.100	0.004	0.01, 0.207	113	0.083	0.112	-5, 5
log_moltp_L50, 75-78	4.969	0.014	4.47, 5.62	118	-0.066	0.129	-5, 5
log_moltp_L50, 79-14	4.948	0.004	4.47, 5.62	123	-0.081	0.138	-5, 5
log_N75	20.028	0.033	15.0, 21.0	128	-0.065	0.147	-5, 5
log_avg_L50_ret	4.921	0.002	4.78, 5.05	133	-0.120	0.161	-5, 5
ret_fish_slope	0.529	0.032	0.05, 0.70	138	-0.210	0.146	-5, 5
pot disc.males, φ	-0.328	0.014	-0.40, 0.00	143	-0.310	0.147	-5, 5
pot disc.males, κ	0.004	0.000	0.0, 0.005	148	-0.465	0.157	-5, 5
pot disc.males, γ	-0.015	0.001	-0.025, 0.0	153	-0.824	0.192	-5, 5
pot disc.fema., slope	0.240	0.068	0.05, 0.69	158	-1.319	0.258	-5, 5
log_pot disc.fema., L50	4.424	0.019	4.24, 4.61	163	-1.354	0.273	-5, 5
trawl disc slope	0.061	0.003	0.01, 0.20	68	1.661	0.096	-5, 5
log_trawl disc L50	4.974	0.032	4.40, 5.20	73	1.592	0.095	-5, 5
log_srv_L50, m, bsfrf	4.393	0.042	3.59, 5.49	78	1.408	0.094	-5, 5
srv_slope, f, bsfrf	0.015	0.007	0.01, 0.435	83	1.161	0.097	-5, 5
log_srv_L50, f, bsfrf	5.083	0.460	4.09, 5.54	88	1.153	0.088	-5, 5
log_srv_L50, m, 75-81	4.324	0.010	4.09, 5.54	93	0.764	0.101	-5, 5
srv_slope, f, 75-81	0.066	0.004	0.01, 0.33	98	0.480	0.115	-5, 5
log_srv_L50, f, 75-81	4.443	0.018	4.09, 4.70	103	0.398	0.117	-5, 5
log_srv_L50, m, 82-14	4.478	0.008	4.09, 5.10	108	0.203	0.130	-5, 5
srv_slope, f, 82-14	0.062	0.002	0.01, 0.30	113	0.026	0.145	-5, 5
log_srv_L50, f, 82-14	4.517	0.011	4.09, 4.90	118	-0.512	0.215	-5, 5
TC_slope, females	0.365	0.139	0.02, 0.40	123	-0.698	0.261	-5, 5
log_TC_L50, females	4.543	0.015	4.24, 4.90	128	-1.119	0.387	-5, 5
TC_slope, males	0.253	0.111	0.05, 0.90	133	-1.922	0.795	-5, 5
log_TC_L50, males	4.586	0.022	4.25, 5.14	138	-2.354	1.271	-5, 5
log_TC_F, males, 91	-4.116	0.086	-10.0, 1.00	143	NA	NA	
log_TC_F, males, 92	-6.083	0.088	-10.0, 1.00				
log_TC_F, males, 93	-6.807	0.090	-10.0, 1.00	Q	0.941	0.021	0.6, 1.2
log_TC_F, males, 13	-8.202	0.098	-10.0, 1.00				
log_TC_F, females, 91	-2.848	0.086	-10.0, 1.00				
log_TC_F, females, 92	-4.508	0.086	-10.0, 1.00				
log_TC_F, females, 93	-6.407	0.088	-10.0, 1.00				
log_TC_F, females, 13	-7.693	0.084	-10.0, 1.00				

Table 6(4na). Annual abundance estimates (million crab), mature male biomass (MMB, 1000 t), and total survey biomass estimates (1000 t) for red king crab in Bristol Bay estimated by length-based analysis (scenario 4) from 1975-2014. Mature male biomass for year *t* is on Feb. 15, year *t*+1. Size measurements are mm CL.

Year (t)	Males				Females	Total Recruits	Total Survey Biomass	
	Mature (>119 mm)	Legal (>134mm)	MMB (>119 mm)	SD MMB	Mature (>89 mm)		Model Est. (>64 mm)	Area-Swept (>64 mm)
1975	55.180	29.449	81.839	5.183	88.778		252.621	219.637
1976	59.609	35.213	89.398	4.362	121.394	29.784	288.969	301.454
1977	61.159	37.082	91.434	3.660	150.091	50.657	299.154	380.351
1978	69.367	37.996	96.141	3.035	143.319	58.201	292.503	349.437
1979	67.278	40.826	84.571	2.553	127.045	57.263	270.391	264.248
1980	48.360	34.593	25.740	0.935	115.531	70.522	234.150	244.793
1981	15.235	8.764	9.006	0.399	49.894	40.607	96.831	122.499
1982	7.677	3.331	8.638	0.360	23.193	150.183	53.768	141.610
1983	6.724	3.172	8.831	0.348	15.130	67.045	46.902	49.322
1984	6.486	3.118	6.783	0.341	15.459	73.233	46.034	134.594
1985	8.378	2.653	11.865	0.509	13.289	10.462	37.683	34.281
1986	13.429	5.376	17.617	0.743	19.269	41.461	49.474	47.804
1987	16.335	7.655	23.754	0.899	23.171	12.337	56.017	68.935
1988	16.826	9.803	29.138	0.979	28.266	7.432	60.004	54.056
1989	18.348	11.411	32.731	1.016	26.099	8.157	62.935	61.499
1990	18.546	12.422	30.546	1.021	22.565	22.506	62.843	56.730
1991	15.020	11.166	25.367	0.991	20.514	13.971	57.261	87.499
1992	11.868	8.964	23.062	0.942	20.378	2.278	51.502	37.410
1993	12.436	8.088	20.463	0.908	18.371	10.395	49.705	53.898
1994	12.238	7.466	25.892	0.922	15.240	1.860	44.164	32.099
1995	12.635	9.262	28.525	0.892	14.836	56.251	50.203	38.116
1996	12.624	9.837	26.408	0.844	19.975	7.126	57.484	44.323
1997	11.776	8.876	24.369	0.802	29.380	3.160	61.987	84.653
1998	16.057	8.497	26.566	0.852	27.439	11.904	65.161	84.554
1999	17.666	10.079	31.029	0.933	24.066	33.007	64.825	60.878
2000	15.704	11.452	30.814	0.925	26.540	11.602	67.005	68.429
2001	14.649	10.947	29.598	0.890	31.006	10.496	69.811	52.801
2002	16.407	10.451	31.594	0.888	30.819	52.294	74.232	69.273
2003	17.204	11.330	30.410	0.884	36.339	10.007	79.062	96.781
2004	15.273	10.816	28.171	0.852	44.052	17.283	81.036	96.230
2005	17.371	10.176	28.066	0.861	42.509	52.408	85.949	106.558
2006	17.581	10.577	29.864	0.909	46.499	17.029	88.980	94.914
2007	17.046	11.091	27.069	0.934	53.741	12.678	93.928	103.801
2008	18.572	10.282	28.092	1.062	50.365	8.755	93.596	111.996
2009	19.445	10.996	31.346	1.255	45.651	9.584	90.386	91.784
2010	18.351	12.008	31.286	1.394	41.622	14.577	86.961	78.432
2011	15.823	11.572	31.338	1.462	38.922	15.041	82.548	64.555
2012	14.333	11.085	30.003	1.487	37.680	11.597	80.960	60.801
2013	13.939	10.297	28.669	1.537	36.437	7.829	79.151	61.954
2014	14.014	9.807	25.735	1.291	33.795	1.767	75.670	119.620

Table 6(4nb). Annual abundance estimates (million crab), mature male biomass (MMB, 1000 t), and total survey biomass estimates (1000 t) for red king crab in Bristol Bay estimated by length-based analysis (scenario 4nb) from 1975-2014. Mature male biomass for year *t* is on Feb. 15, year *t*+1. Size measurements are mm CL.

Year (t)	Males				Females	Total Recruits	Trawl Survey Biomass	
	Mature (>119 mm)	Legal (>134 mm)	MMB (>119 mm)	SD MMB	Mature (>89 mm)		Model Est. (>64 mm)	Area-Swept
1975	54.578	29.101	80.680	5.522	87.096		262.081	219.637
1976	58.974	34.876	88.280	4.639	119.084	29.443	299.722	301.454
1977	60.479	36.735	90.312	3.865	146.958	49.546	309.978	380.351
1978	68.517	37.619	94.854	3.195	140.055	56.689	302.629	349.437
1979	66.356	40.385	83.245	2.662	123.888	55.590	279.160	264.248
1980	47.562	34.142	24.826	0.992	112.376	68.209	240.906	244.793
1981	14.798	8.527	8.487	0.467	48.355	39.193	98.759	122.499
1982	7.364	3.179	8.200	0.424	22.398	146.074	54.088	141.610
1983	6.455	3.041	8.456	0.398	14.595	65.238	47.165	49.322
1984	6.256	3.006	6.472	0.374	14.940	71.520	46.437	134.594
1985	8.104	2.555	11.388	0.559	12.865	10.221	38.059	34.281
1986	13.009	5.210	16.878	0.823	18.676	40.484	50.082	47.804
1987	15.798	7.403	22.775	1.011	22.461	12.070	56.678	68.935
1988	16.249	9.472	28.020	1.110	27.399	7.254	60.705	54.056
1989	17.742	11.032	31.515	1.161	25.273	7.967	63.754	61.499
1990	17.938	12.014	29.266	1.176	21.822	21.899	63.656	56.730
1991	14.447	10.744	24.087	1.148	19.801	13.550	57.759	87.499
1992	11.332	8.543	21.824	1.096	19.630	2.243	51.686	37.410
1993	11.893	7.685	19.229	1.066	17.664	10.089	49.836	53.898
1994	11.678	7.072	24.608	1.091	14.622	1.822	44.120	32.099
1995	12.098	8.862	27.271	1.059	14.251	54.545	50.377	38.116
1996	12.119	9.444	25.210	1.004	19.240	6.998	57.839	44.323
1997	11.298	8.497	23.223	0.956	28.350	3.104	62.397	84.653
1998	15.472	8.133	25.292	1.030	26.498	11.610	65.694	84.554
1999	17.017	9.680	29.627	1.129	23.230	32.164	65.324	60.878
2000	15.088	11.016	29.432	1.117	25.645	11.330	67.559	68.429
2001	14.074	10.502	28.273	1.073	29.991	10.209	70.464	52.801
2002	15.826	10.024	30.268	1.069	29.822	50.923	75.011	69.273
2003	16.626	10.917	29.107	1.056	35.181	9.733	79.957	96.781
2004	14.726	10.414	26.923	1.014	42.652	16.826	81.927	96.230
2005	16.789	9.782	26.791	1.023	41.158	50.796	86.913	106.558
2006	16.975	10.179	28.541	1.070	44.998	16.597	89.880	94.914
2007	16.429	10.677	25.729	1.090	52.003	12.364	94.881	103.801
2008	17.867	9.846	26.607	1.224	48.736	8.537	94.469	111.996
2009	18.665	10.510	29.694	1.418	44.176	9.331	91.145	91.784
2010	17.571	11.471	29.580	1.544	40.285	14.184	87.649	78.432
2011	15.095	11.014	29.674	1.591	37.683	14.637	83.116	64.555
2012	13.669	10.545	28.424	1.595	36.494	11.310	81.554	60.801
2013	13.311	9.792	27.155	1.627	35.305	7.649	79.777	61.954
2014	13.404	9.332	24.687	1.346	32.759	1.748	76.295	119.620

Table 7(4na). Comparison of projected mature male biomass (1000 t) on Feb. 15, retained catch (1000 t), their 95% limits, and mean fishing mortality with no directed fishery, $F_{40\%}$, and $F_{35\%}$ harvest strategy with $F_{35\%}$ constraint during 2014-2023. Parameter estimates with scenario 4na are used for the projection.

Year	MMB	95% LCI	95% UCI	Catch	95% LCI	95% UCI
			No Directed Fishery			
2014	32.277	29.102	35.275	0.000	0.000	0.000
2015	35.395	31.913	38.683	0.000	0.000	0.000
2016	37.237	33.574	40.697	0.000	0.000	0.000
2017	37.190	33.609	40.819	0.000	0.000	0.000
2018	38.523	33.262	48.164	0.000	0.000	0.000
2019	42.274	33.115	60.929	0.000	0.000	0.000
2020	46.687	33.483	72.619	0.000	0.000	0.000
2021	50.822	33.812	79.445	0.000	0.000	0.000
2022	54.590	34.784	84.734	0.000	0.000	0.000
2023	57.922	35.810	89.371	0.000	0.000	0.000
			$F_{40\%}$			
2014	26.715	24.400	29.126	5.622	4.753	6.216
2015	25.282	23.370	27.343	5.042	4.261	5.734
2016	23.666	22.056	25.317	4.471	3.839	5.171
2017	21.400	20.052	22.802	3.765	3.283	4.312
2018	21.198	18.106	28.707	3.387	2.722	4.584
2019	23.354	17.131	36.977	3.575	2.306	5.723
2020	25.766	16.880	43.965	4.130	2.155	7.271
2021	27.543	17.054	46.884	4.701	2.137	8.622
2022	28.796	17.740	47.492	5.132	2.233	9.267
2023	29.634	18.022	48.971	5.430	2.418	9.413
			$F_{35\%}$			
2014	25.805	23.700	28.009	6.540	5.459	7.341
2015	23.995	22.309	25.680	5.483	4.673	6.358
2016	22.244	20.831	23.607	4.715	4.094	5.353
2017	19.979	18.785	21.198	3.905	3.439	4.398
2018	19.791	16.861	26.827	3.517	2.806	5.020
2019	21.863	15.918	34.793	3.781	2.351	6.298
2020	24.083	15.765	40.899	4.434	2.214	8.043
2021	25.619	15.978	43.535	5.057	2.203	9.456
2022	26.629	16.674	43.578	5.506	2.328	10.113
2023	27.260	16.807	44.628	5.790	2.538	10.231

Table 7(4nb). Comparison of projected mature male biomass (1000 t) on Feb. 15, retained catch (1000 t), their 95% limits, and mean fishing mortality with no directed fishery, $F_{40\%}$, and $F_{35\%}$ harvest strategy with $F_{35\%}$ constraint during 2014-2023. Parameter estimates with scenario 4nb are used for the projection.

Year	MMB	95% LCI	95% UCI	Catch	95% LCI	95% UCI
			No Directed Fishery			
2014	30.801	27.672	33.757	0.000	0.000	0.000
2015	33.972	30.520	37.231	0.000	0.000	0.000
2016	35.883	32.237	39.326	0.000	0.000	0.000
2017	35.930	32.360	39.554	0.000	0.000	0.000
2018	37.314	32.094	46.758	0.000	0.000	0.000
2019	41.061	32.066	59.383	0.000	0.000	0.000
2020	45.455	32.473	70.820	0.000	0.000	0.000
2021	49.572	32.852	77.604	0.000	0.000	0.000
2022	53.321	33.860	82.818	0.000	0.000	0.000
2023	56.632	34.915	87.299	0.000	0.000	0.000
			$F_{40\%}$			
2014	25.559	23.316	27.893	5.299	4.403	5.927
2015	24.392	22.516	26.361	4.793	4.031	5.515
2016	22.954	21.356	24.557	4.302	3.681	4.973
2017	20.817	19.476	22.201	3.652	3.172	4.187
2018	20.668	17.629	28.019	3.302	2.639	4.483
2019	22.816	16.692	36.168	3.500	2.244	5.618
2020	25.206	16.495	42.950	4.058	2.108	7.148
2021	26.964	16.659	45.810	4.628	2.092	8.479
2022	28.201	17.340	46.571	5.056	2.190	9.154
2023	29.027	17.619	47.882	5.349	2.377	9.270
			$F_{35\%}$			
2014	24.731	22.662	26.828	6.134	5.063	7.000
2015	23.192	21.512	24.829	5.222	4.429	6.055
2016	21.603	20.186	22.947	4.552	3.933	5.175
2017	19.455	18.257	20.669	3.797	3.329	4.283
2018	19.310	16.410	26.239	3.435	2.730	4.919
2019	21.369	15.529	33.960	3.707	2.298	6.198
2020	23.565	15.381	40.111	4.360	2.168	7.925
2021	25.082	15.618	42.559	4.982	2.161	9.347
2022	26.076	16.300	42.739	5.427	2.288	9.951
2023	26.696	16.442	43.681	5.707	2.491	10.061

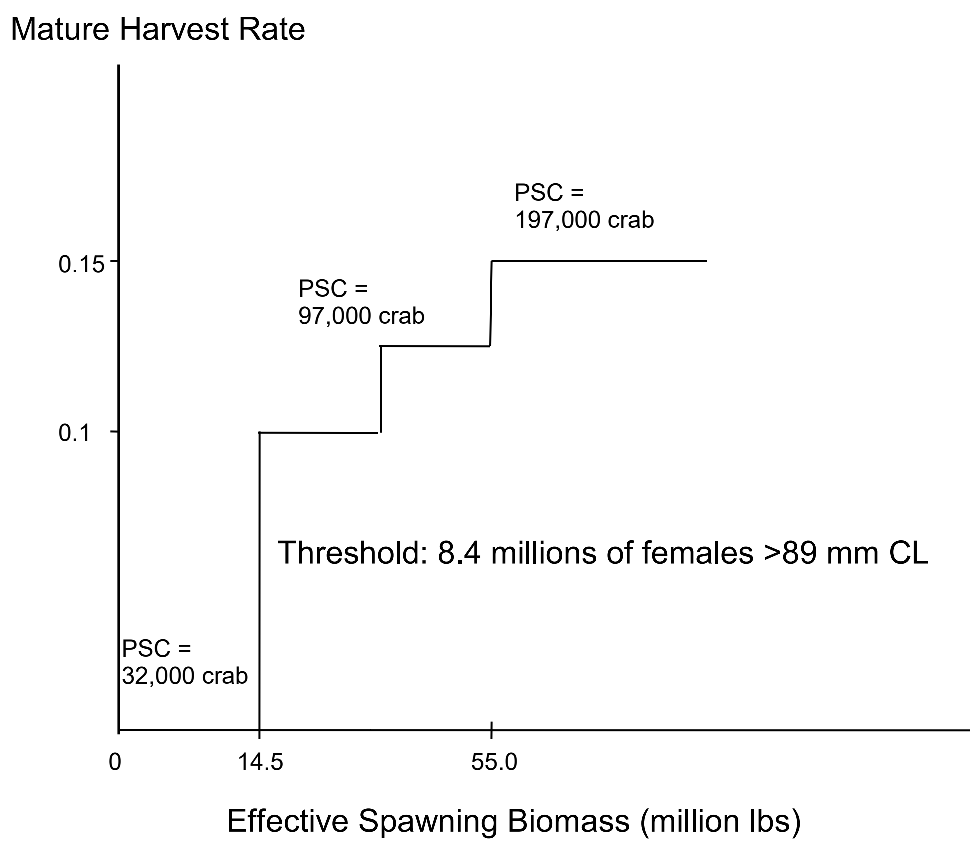

Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and annual prohibited species catch (PSC) limits (numbers of crab) of Bristol Bay red king crab in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates of effective spawning biomass (ESB), whereas PSC limits apply to previous-year ESB.

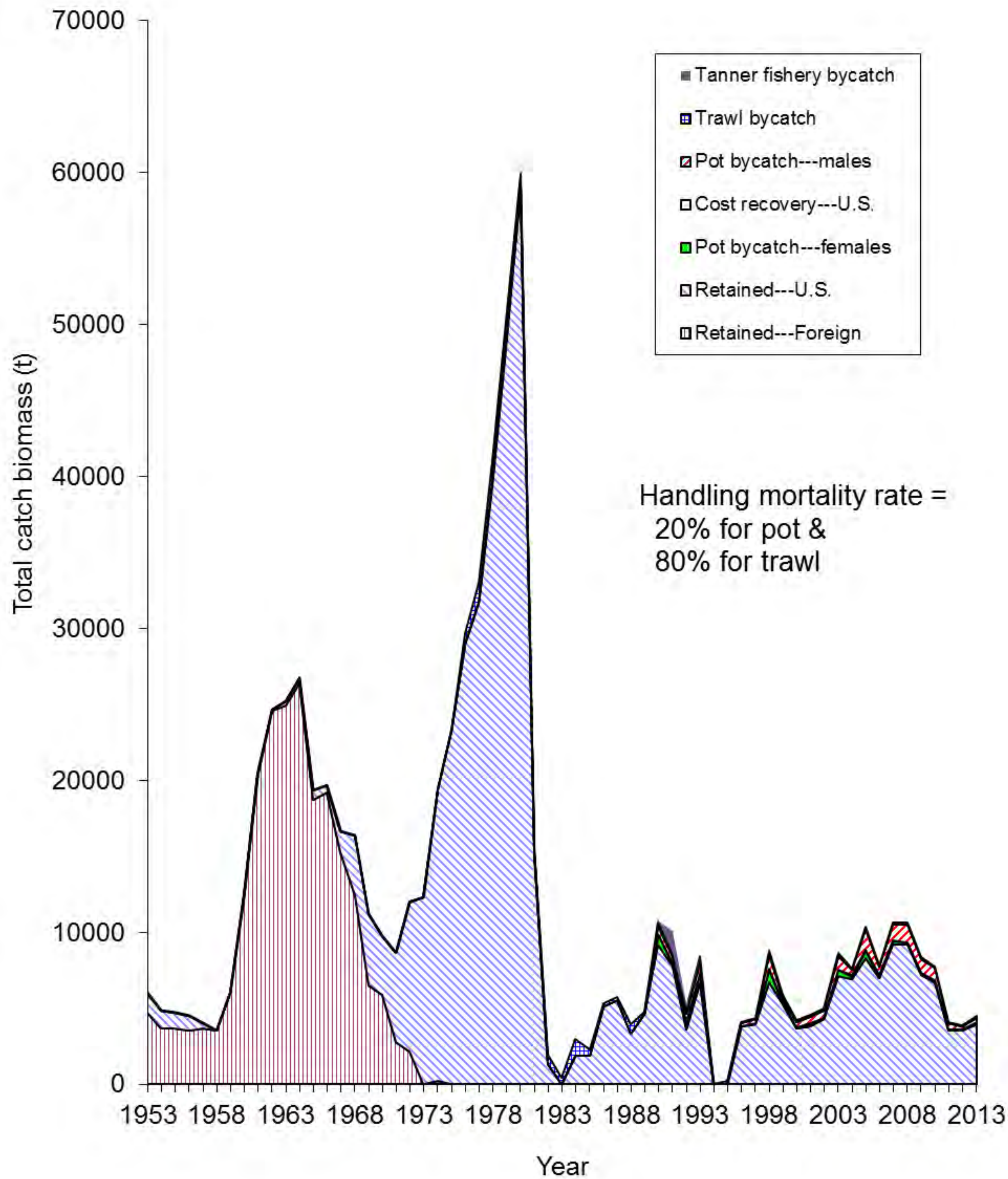

Figure 2. Retained catch biomass and bycatch mortality biomass (t) for Bristol Bay red king crab from 1953 to 2013. Handling mortality rates were assumed to be 0.2 for the directed pot fishery 0.25 for the Tanner crab fishery and 0.8 for the trawl fisheries.

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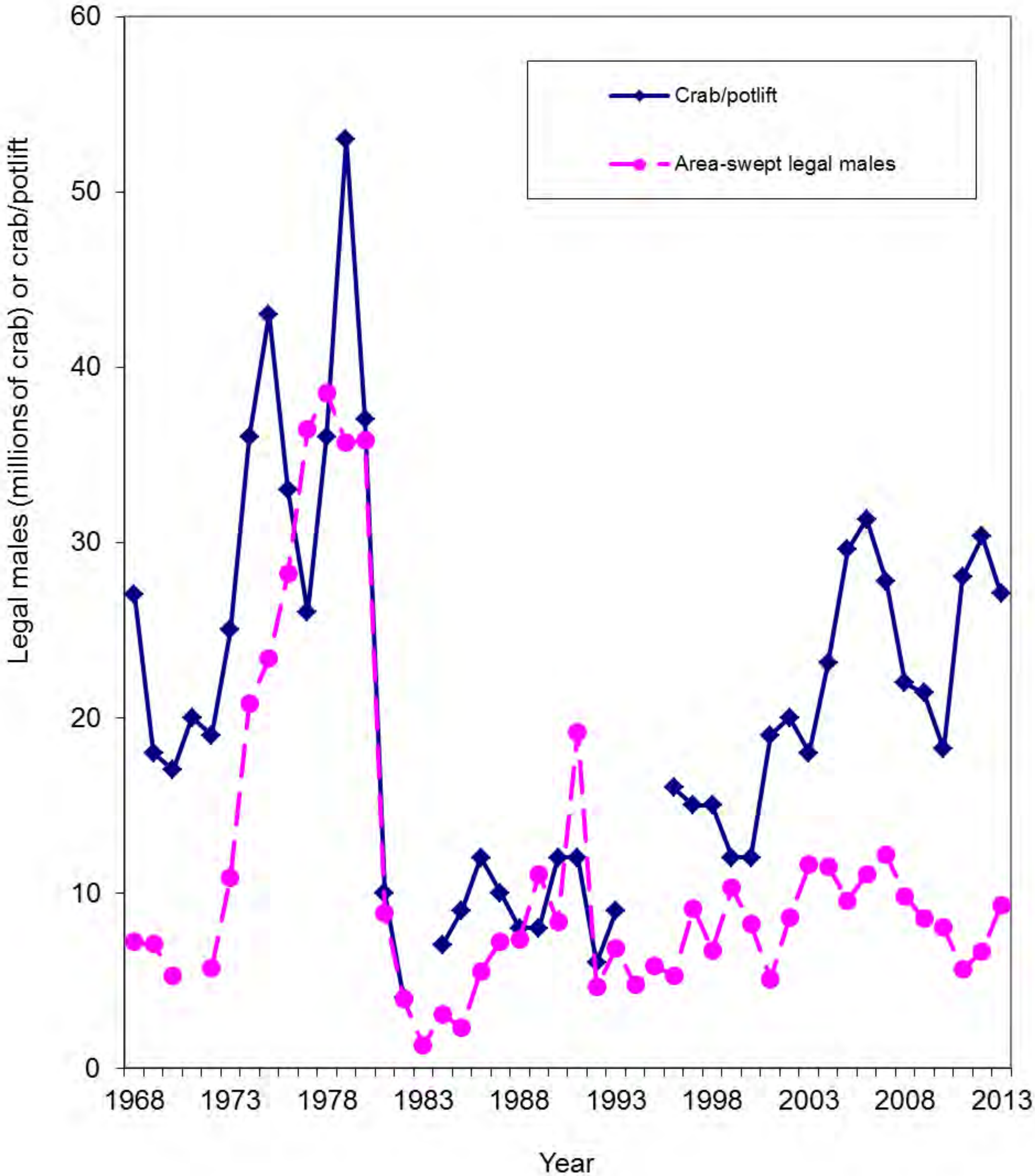

Figure 3. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2013.

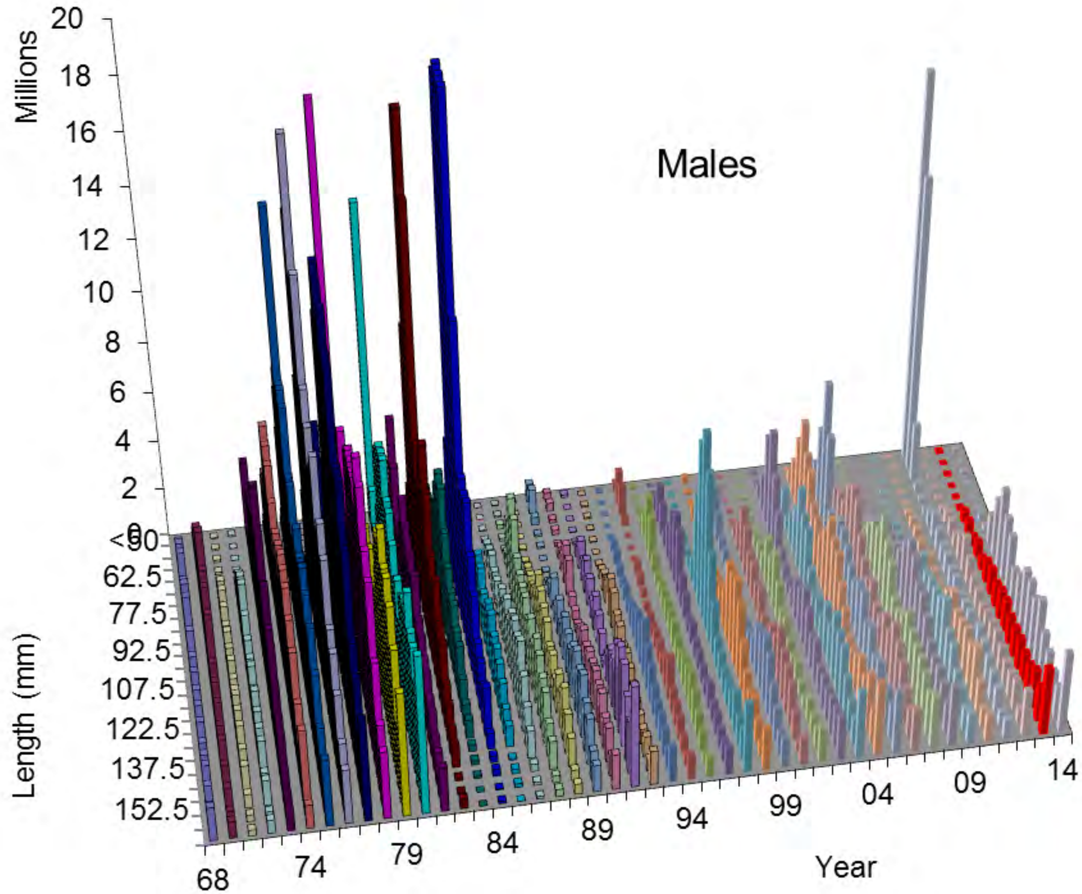

Figure 4. Survey abundances by 5-mm carapace length bin for male Bristol Bay red king crab from 1968 to 2014.

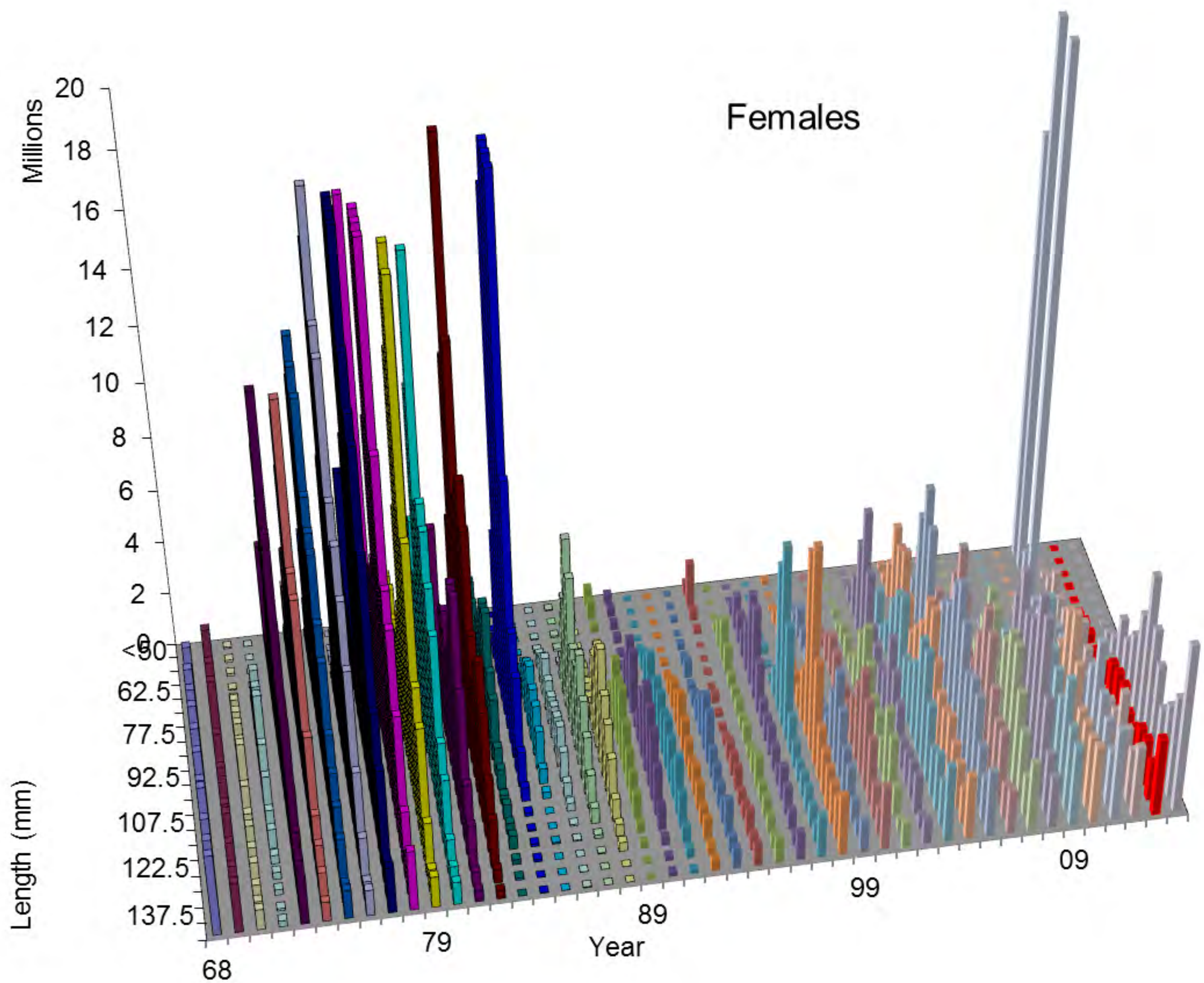

Figure 5. Survey abundances by 5 mm carapace length bin for female Bristol Bay red king crab from 1968 to 2014.

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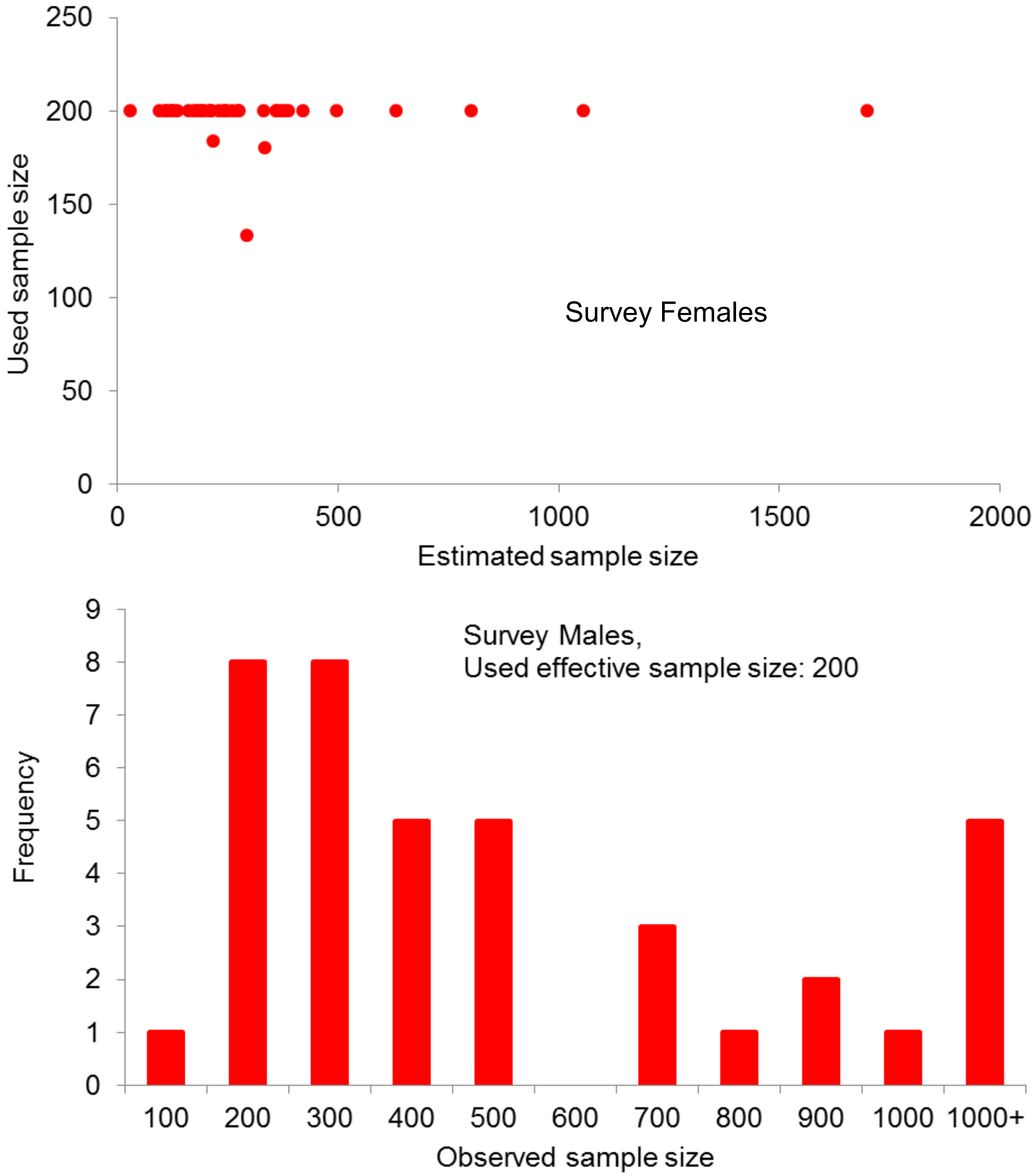

Figure 6. Relationship between implied effective sample sizes (section 3(a)(5)(i)) and used effective sample sizes (see effective sample sizes for scenario 4na) for length/sex composition data with scenario 4na: trawl survey data.

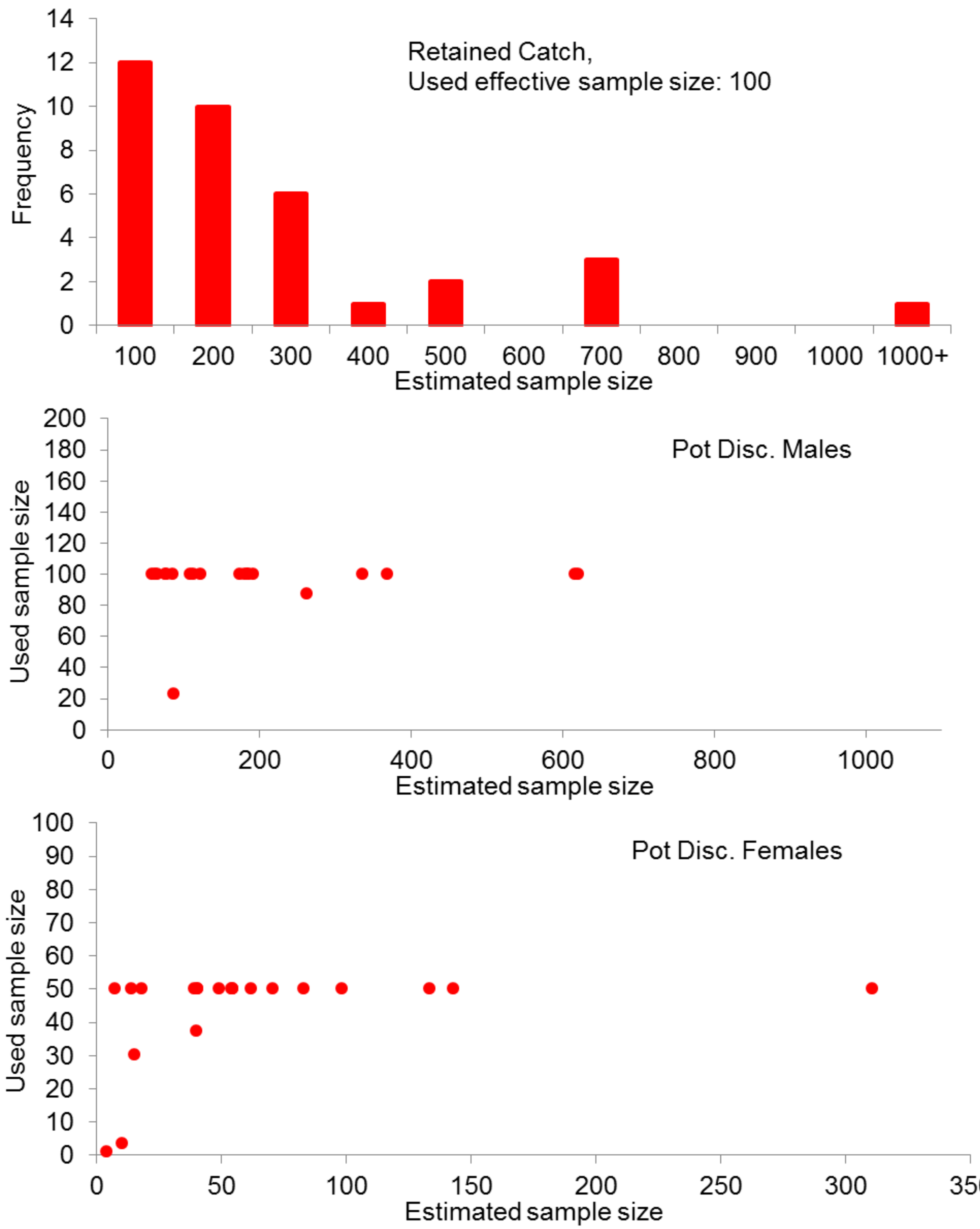

Figure 7. Relationship between implied effective sample sizes (section 3(a)(5)(i)) and used effective sample sizes (see effective sample sizes for scenario 4na) for length/sex composition data with scenario 4na: directed pot fishery data.

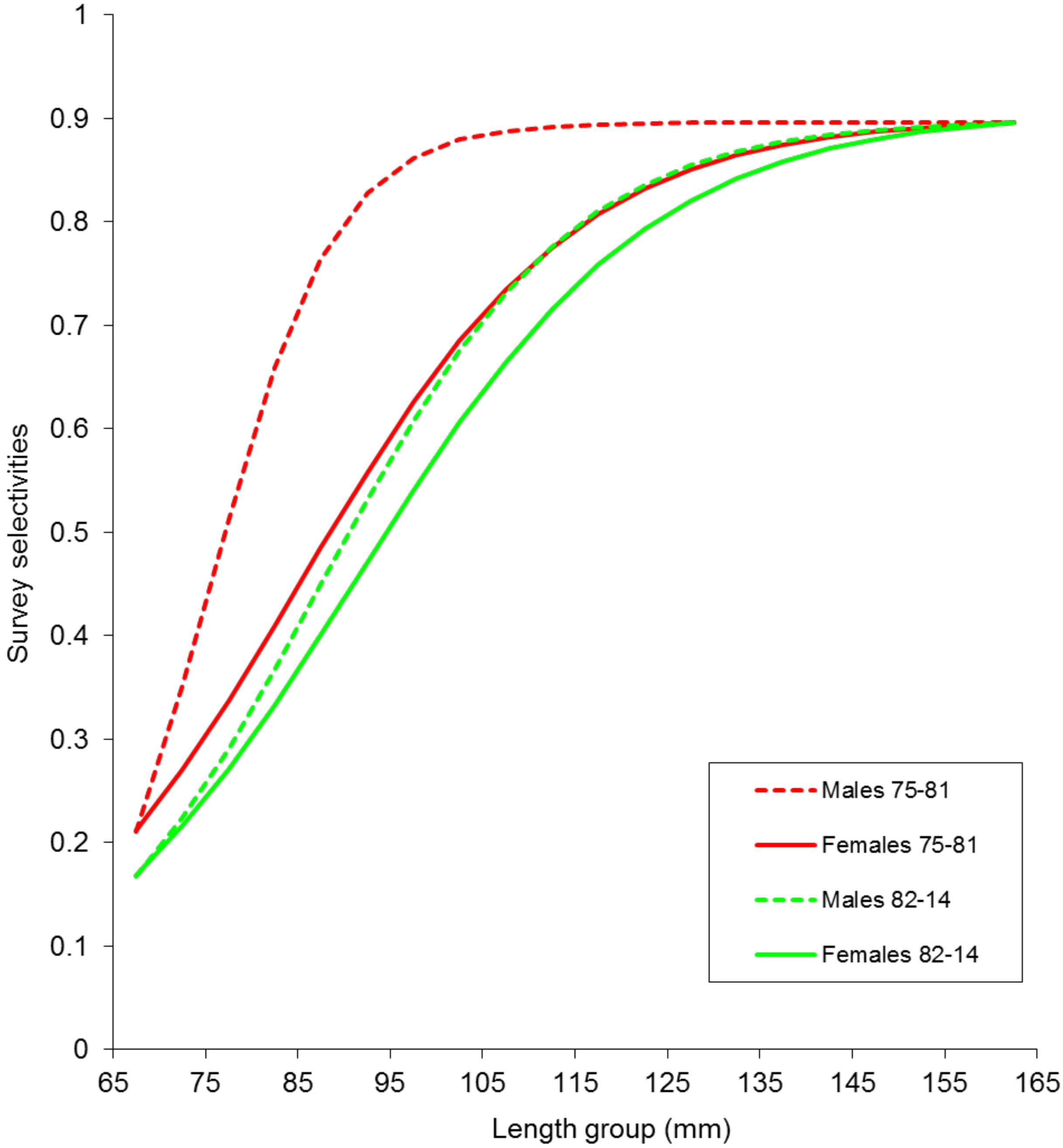

Figure 8a(4na). Estimated trawl survey selectivities/catchability under scenario 4na. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

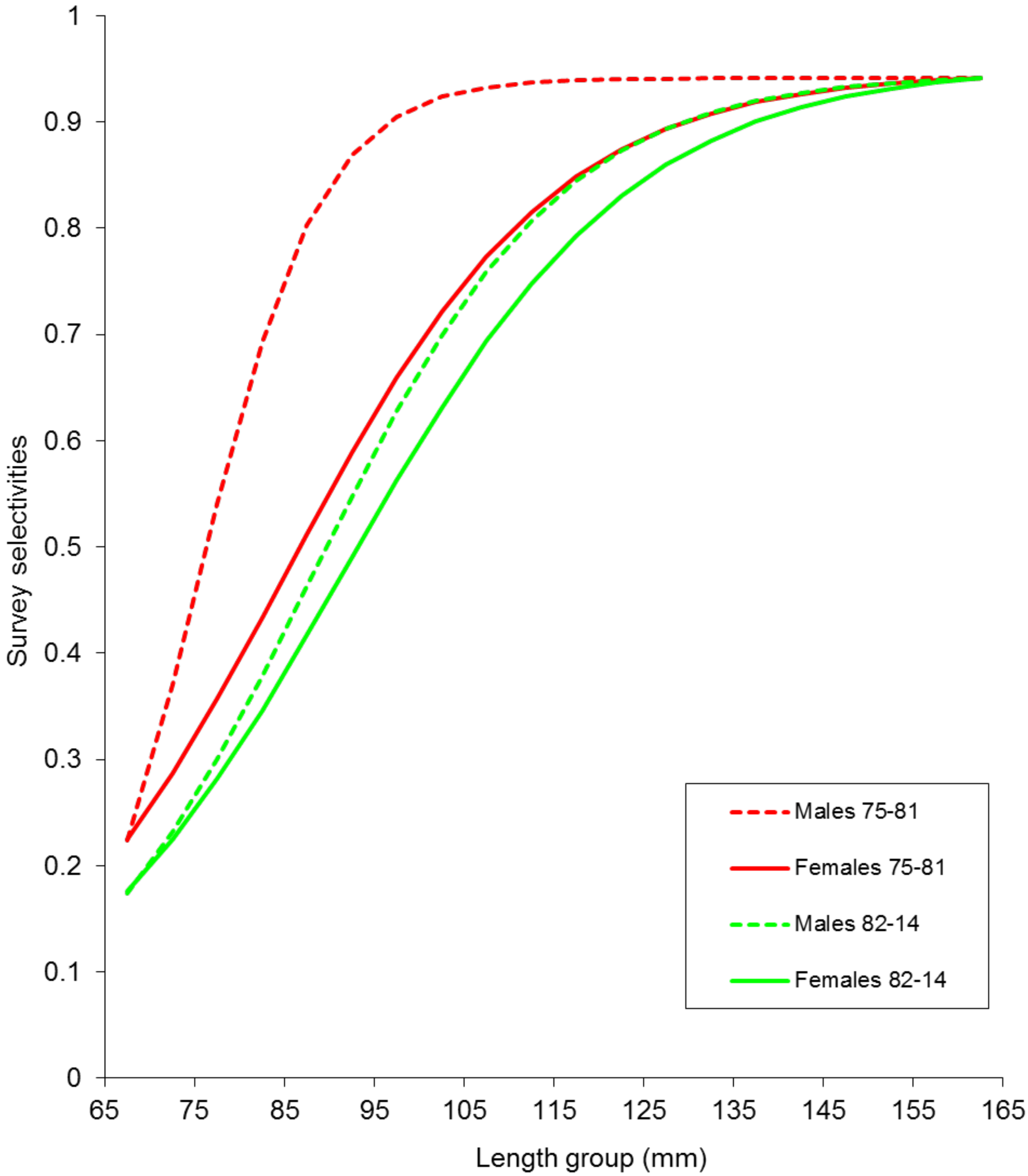

Figure 8a(4nb). Estimated trawl survey selectivities/catchability under scenario 4nb. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

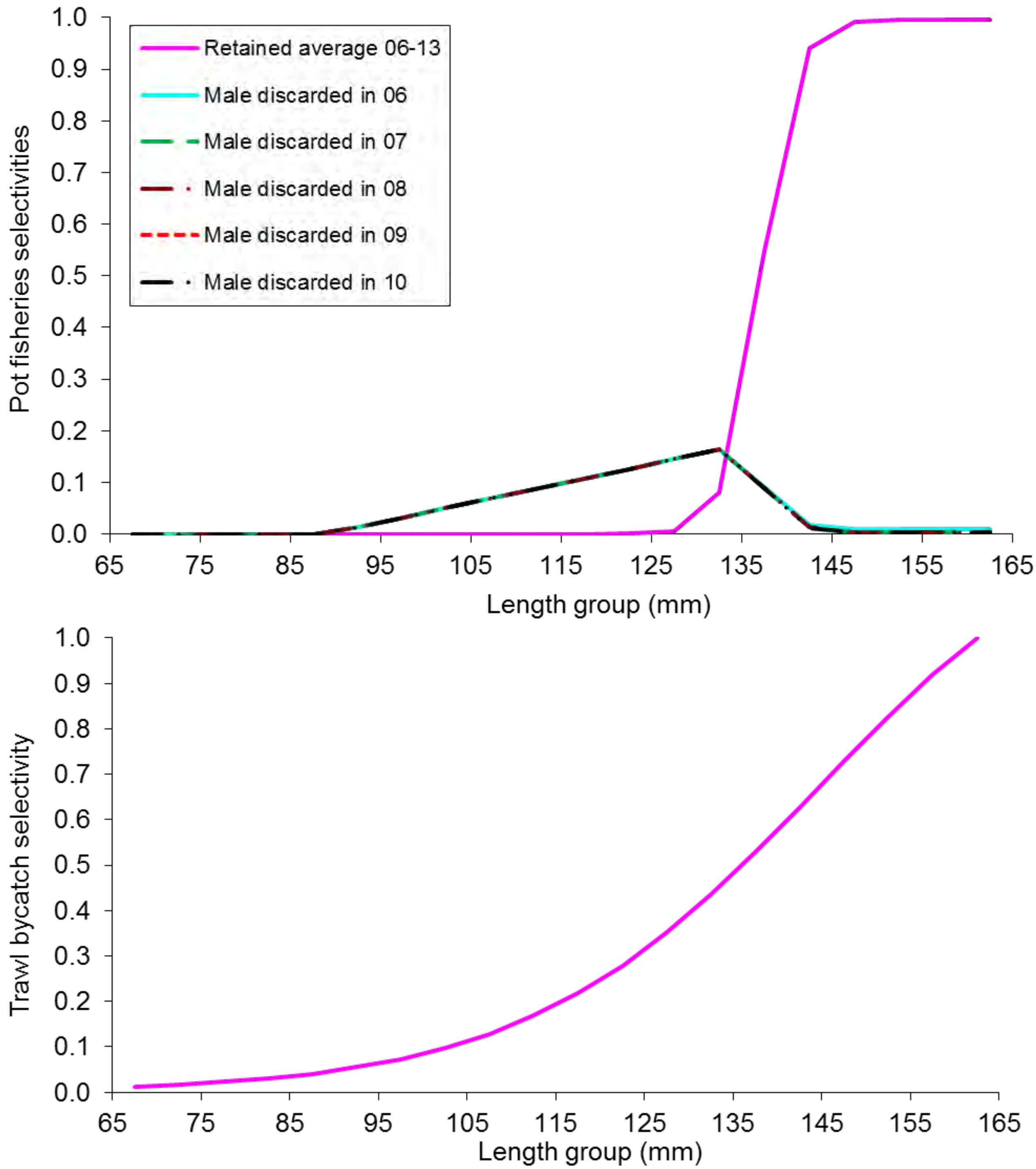

Figure 8b. Estimated pot fishery selectivities and groundfish trawl bycatch selectivities under scenario 4na. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

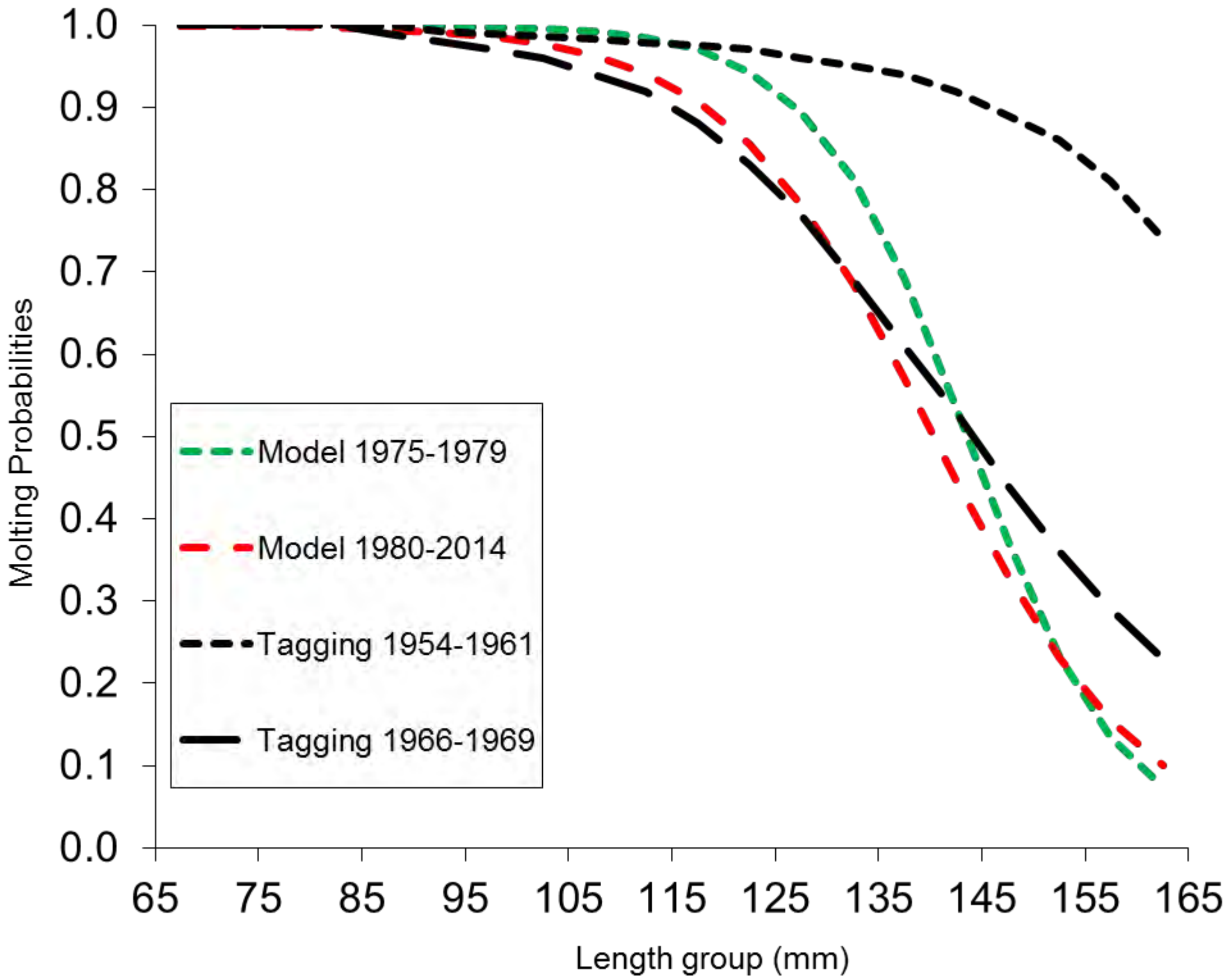

Figure 9(4na). Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-2014 were estimated with a length-based model with a pot handling mortality rate of 0.2 under scenario 4na.

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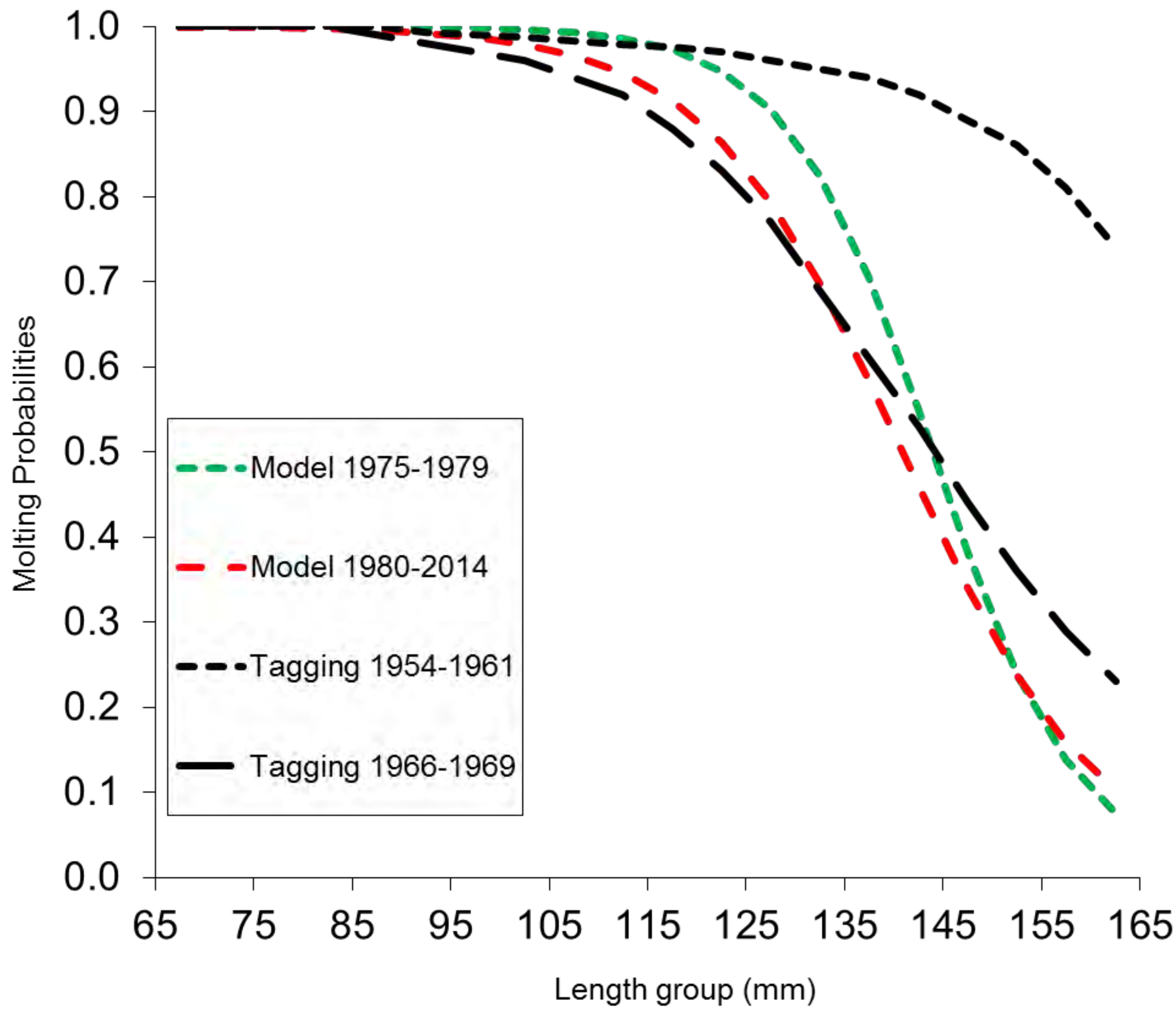


Figure 9(4nb). Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-2014 were estimated with a length-based model with pot handling mortality rate of 0.2 under scenario 4nb.

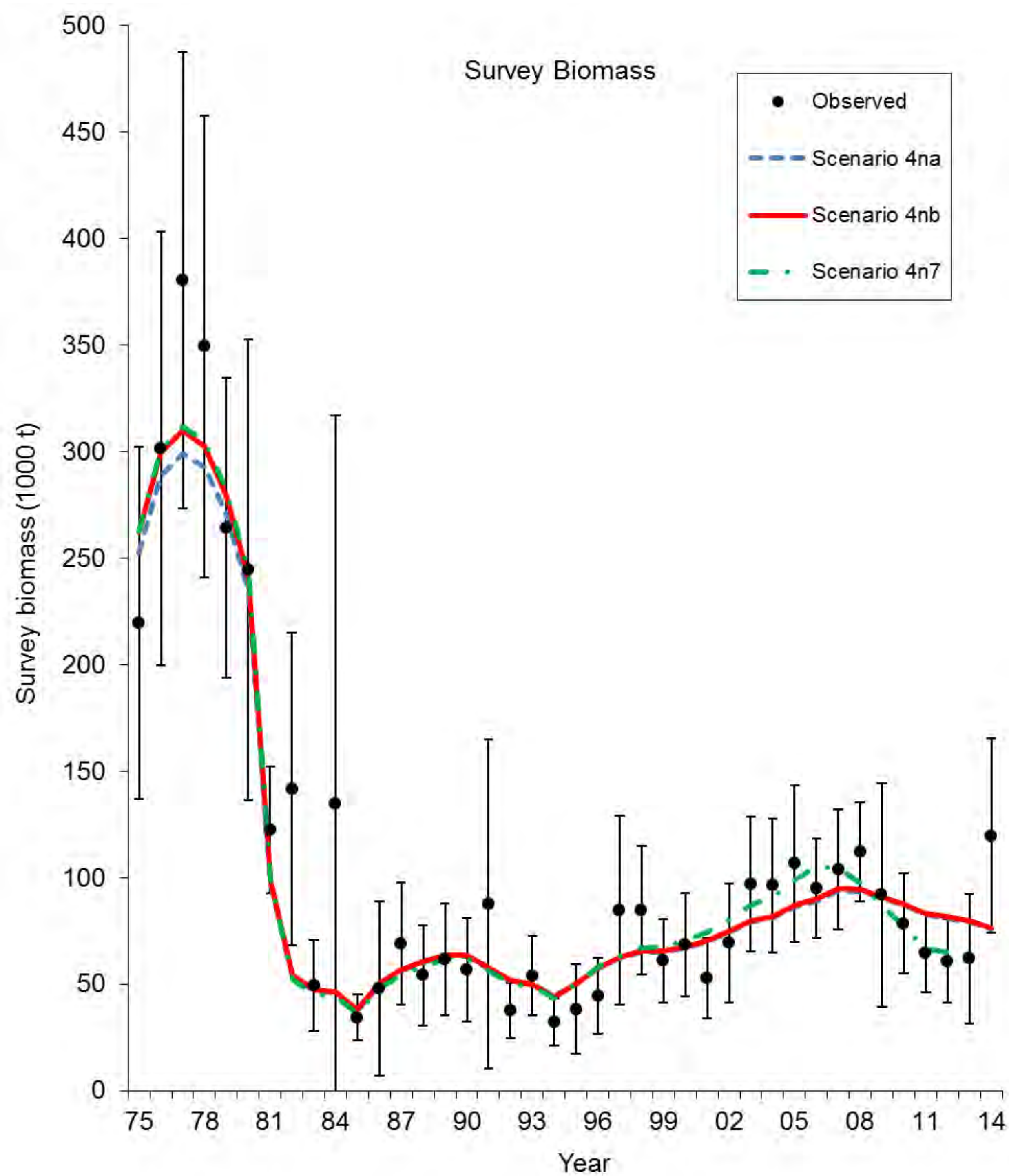
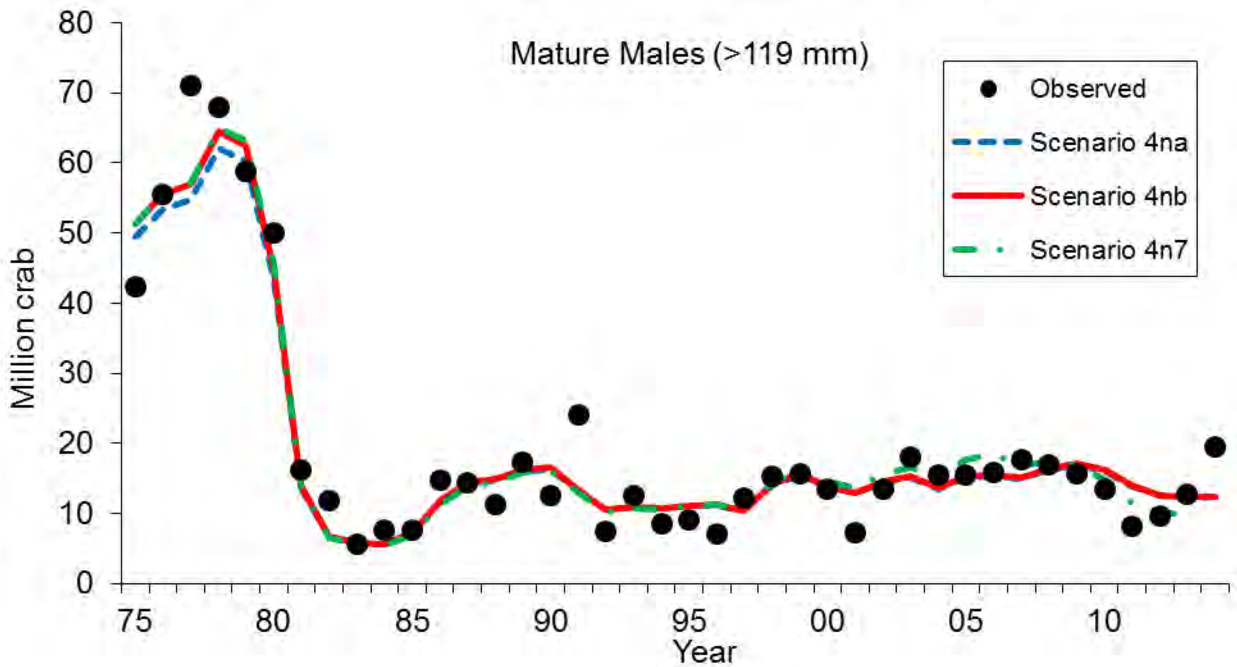


Figure 10a. Comparisons of area-swept estimates of total survey biomass and model prediction for model estimates in 2014 under scenarios 4na, 4nb and 4n7. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively. The error bars are plus and minus 2 standard deviations.



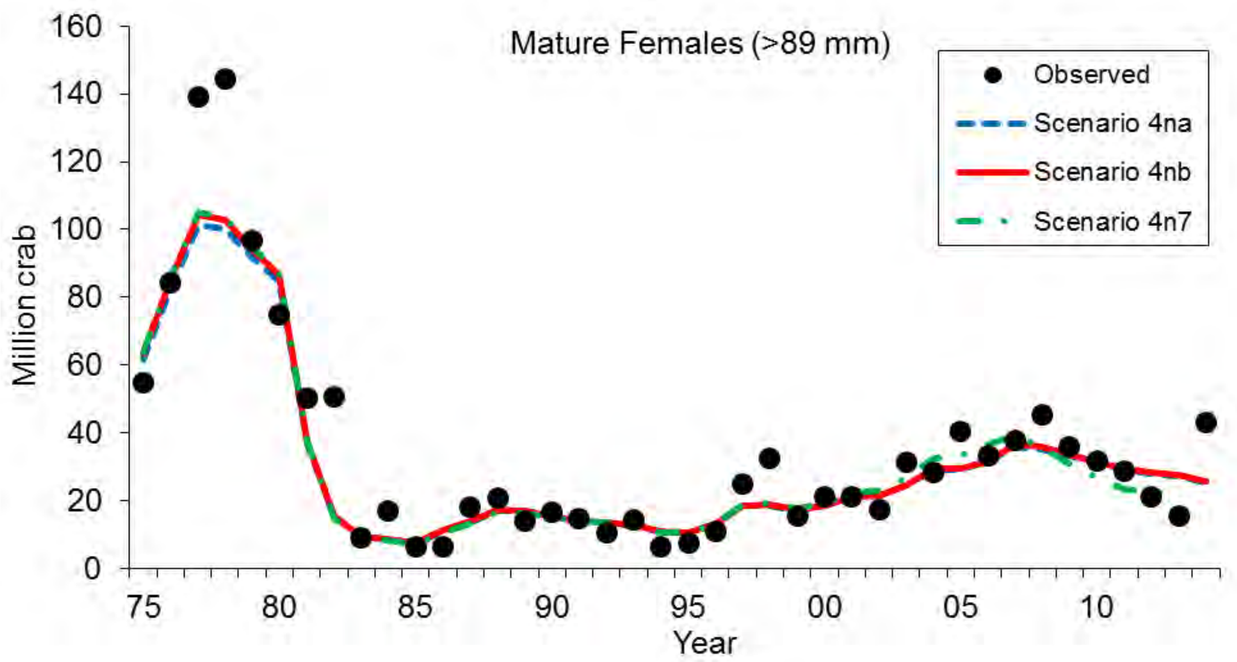


Figure 10b. Comparisons of area-swept estimates of mature male (>119 mm) and female (>89 mm) abundance and model prediction for model estimates in 2014 under scenarios 4na, 4nb and 4n7. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

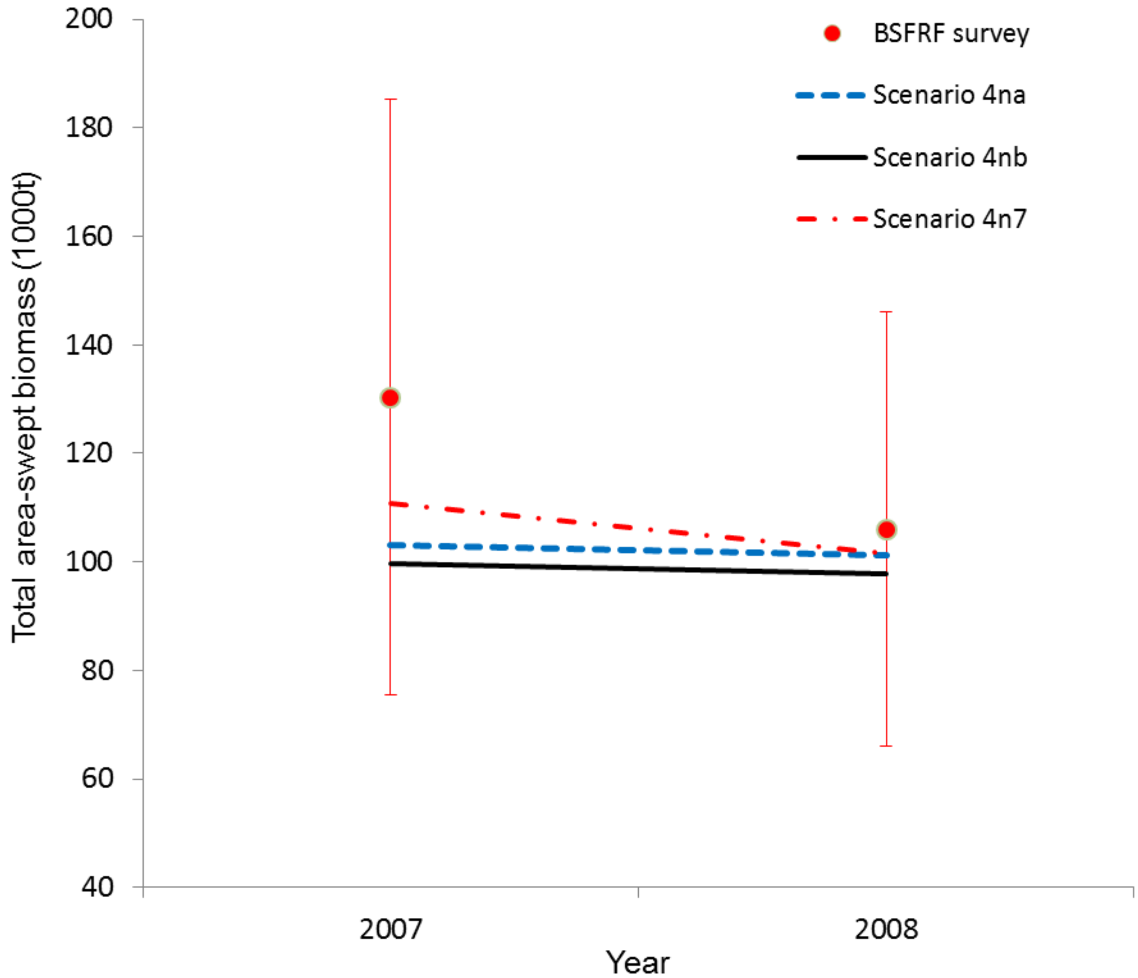


Figure 10c. Comparisons of total survey biomass estimates by the BSFRF survey and the model for model estimates in 2014 (scenarios 4na, 4nb and 4n7). The error bars are plus and minus 2 standard deviations.

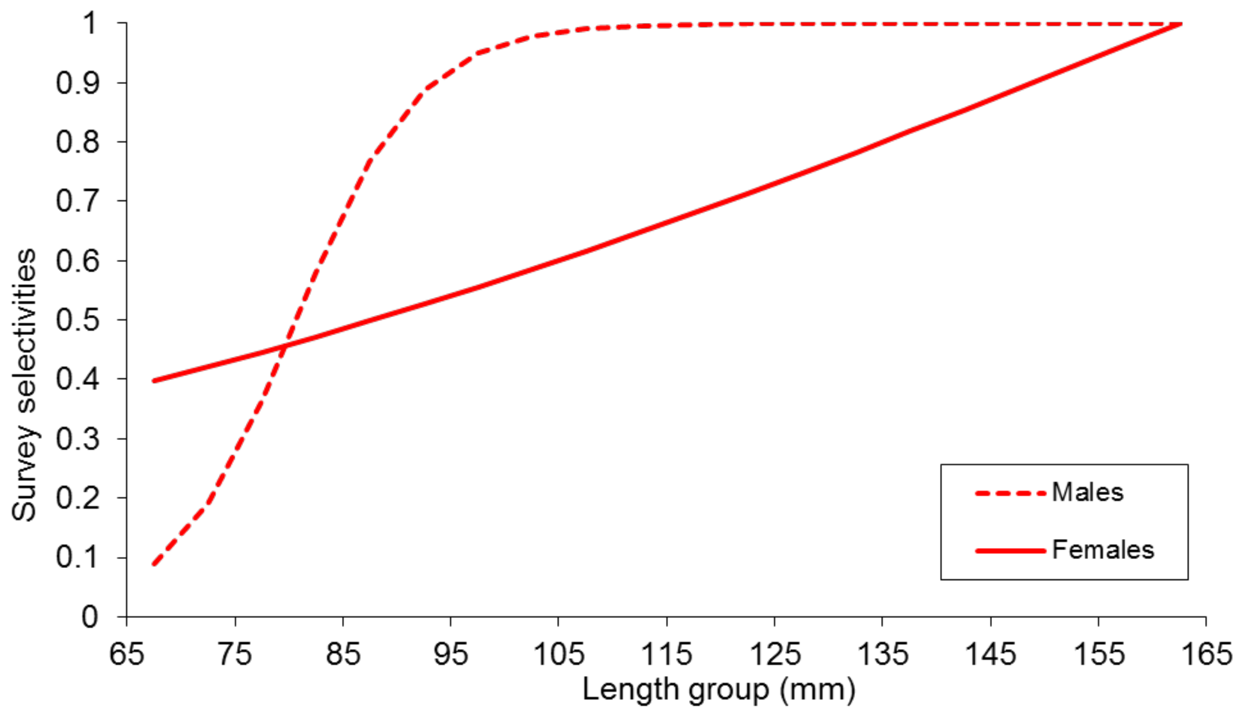


Figure 10d(4na). Estimated BSFRF survey selectivities with scenario 4na. The catchability is assumed to be 1.0.

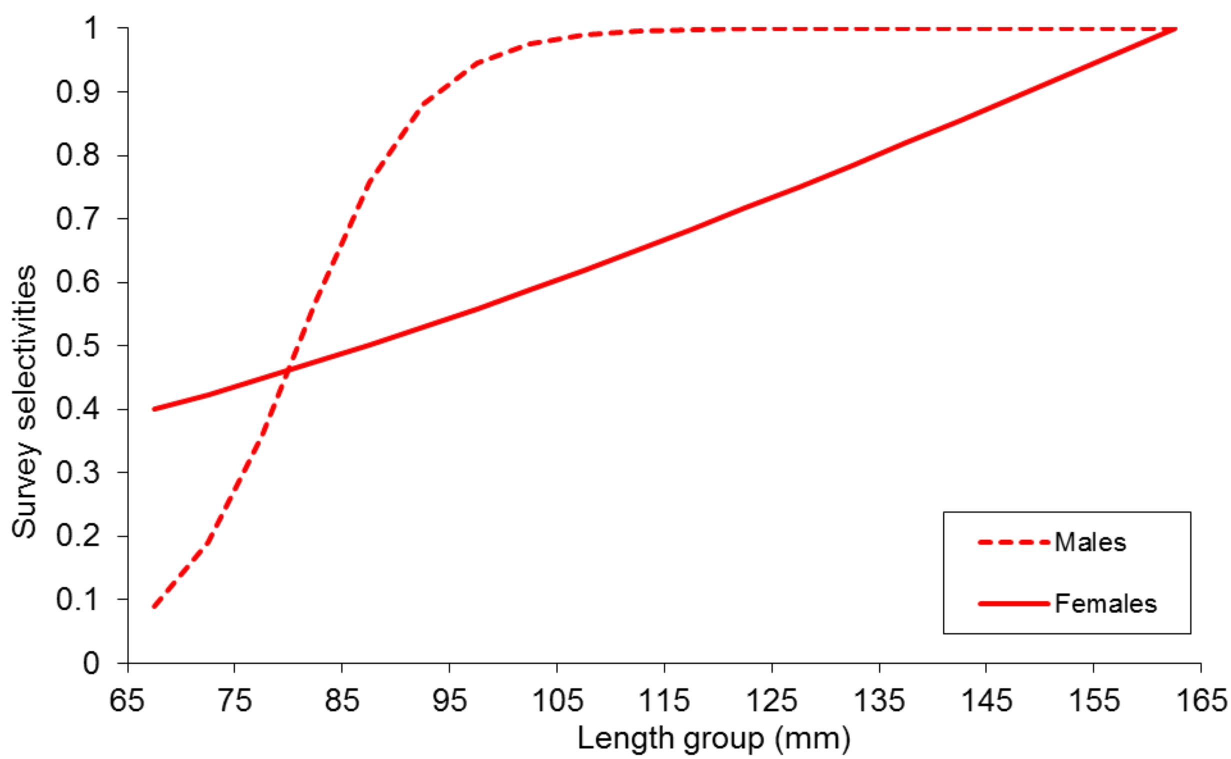


Figure 10d(4nb). Estimated BSFRF survey selectivities with scenario 4nb. The catchability is assumed to be 1.0.

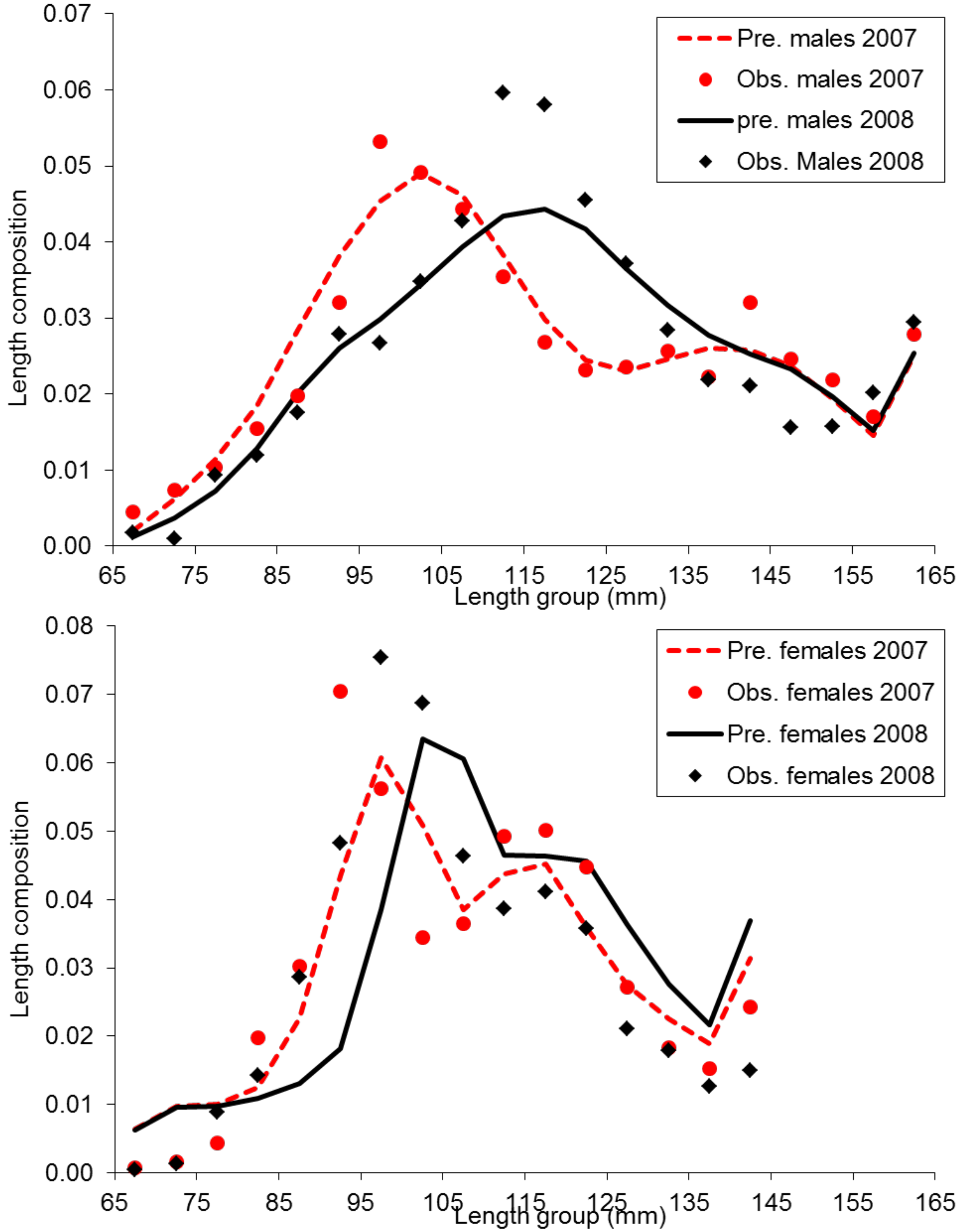


Figure 10e(4na). Comparisons of length compositions by the BSFRF survey and the model estimates in 2007 and 2008 with scenario 4na.

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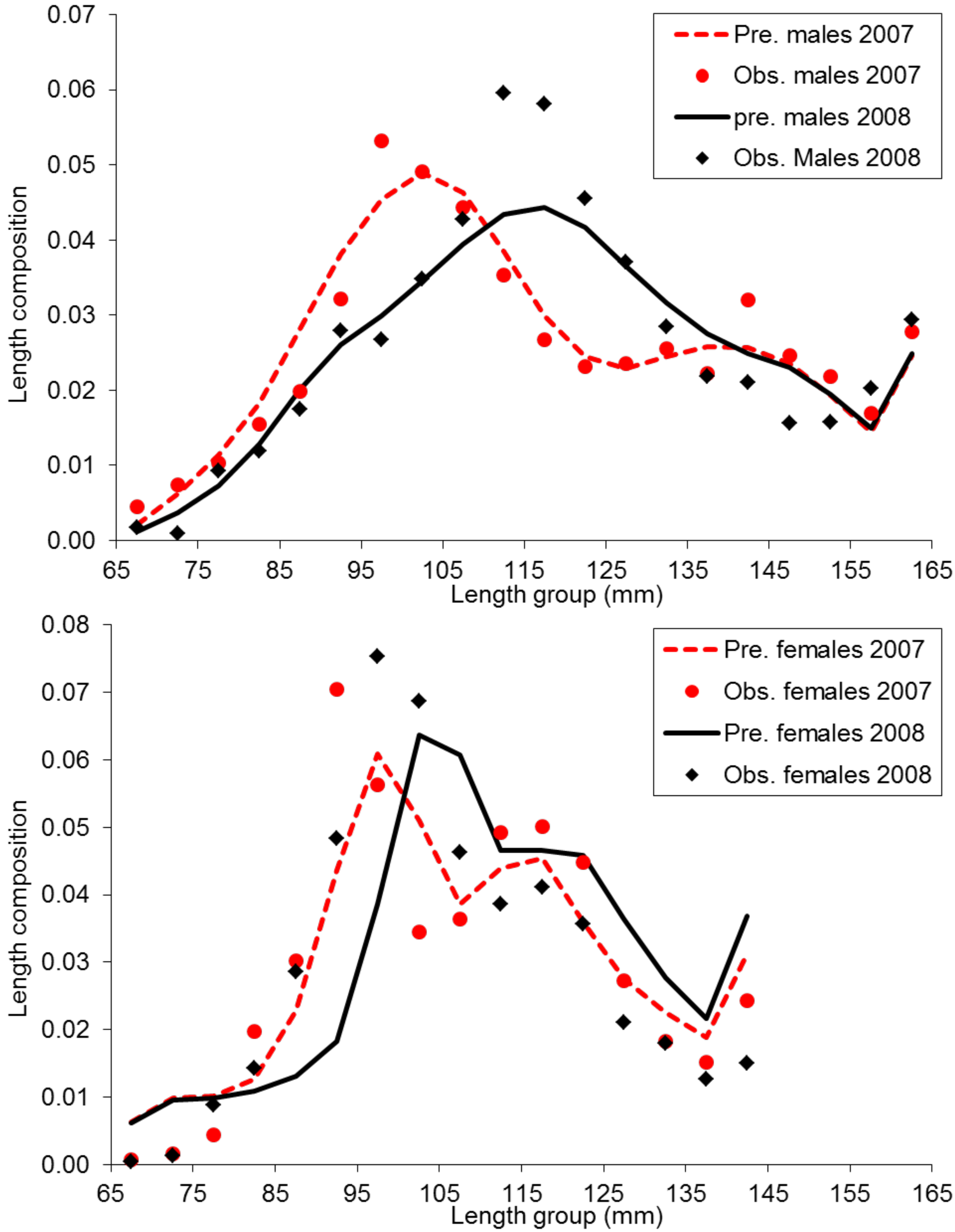

Figure 10e(4nb). Comparisons of length compositions by the BSFRF survey and the model estimates in 2007 and 2008 with scenario 4nb.

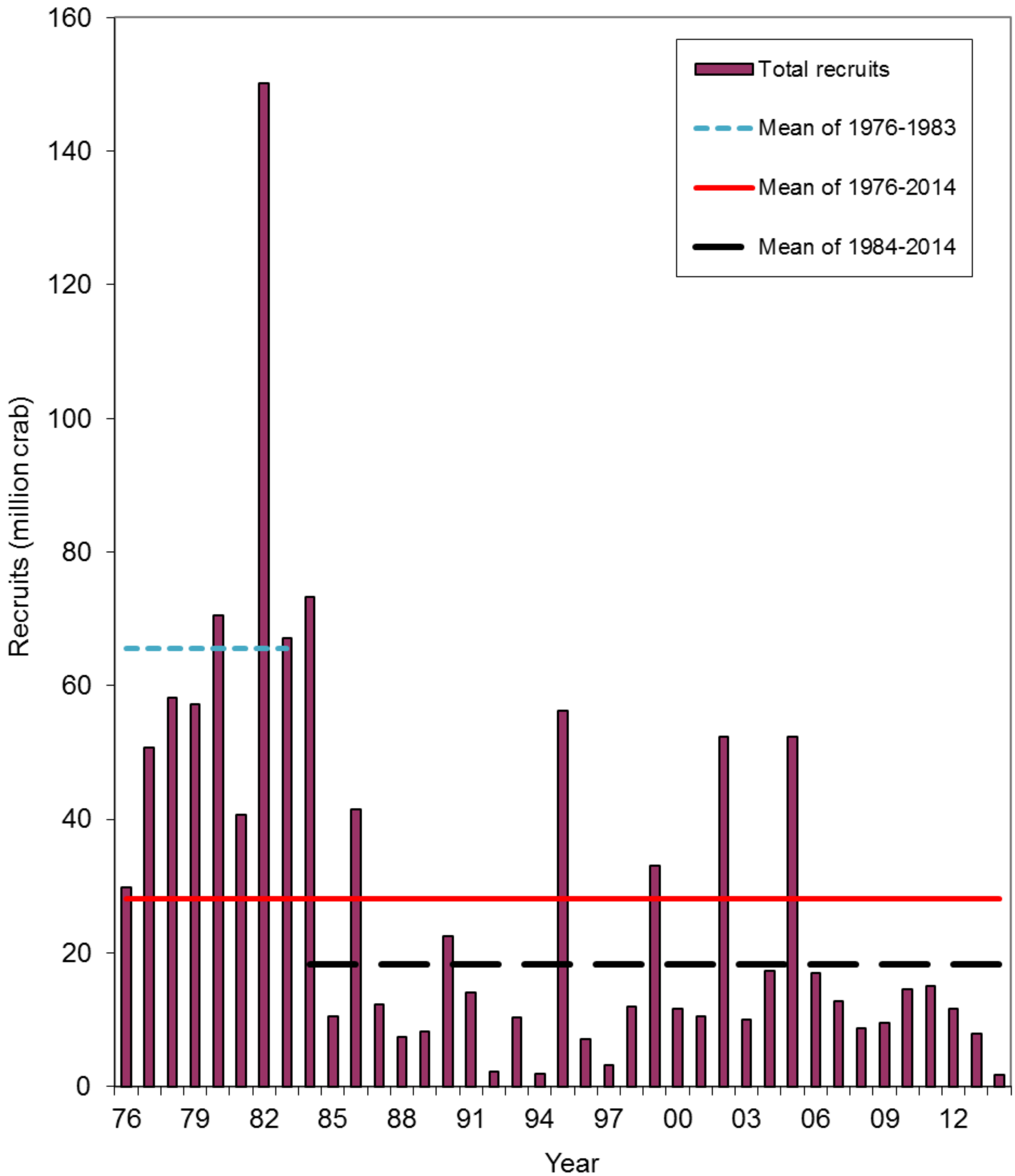

Figure 11(4na). Estimated recruitment time series during 1976-2014 (occurred year) with scenario 4na. Mean male recruits during 1984-2014 was used to estimate $B_{35\%}$.

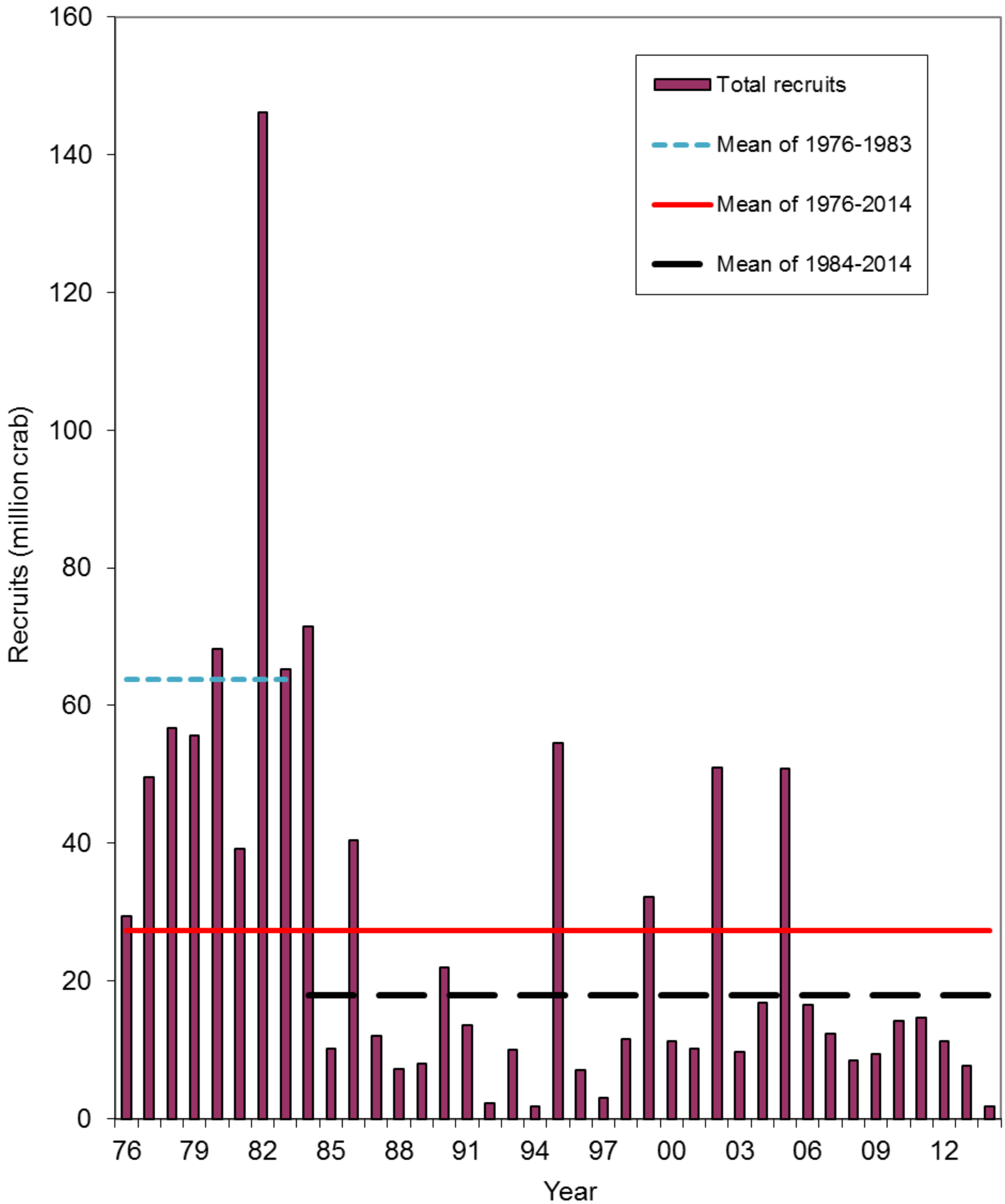

Figure 11(4nb). Estimated recruitment time series during 1976-2014 (occurred year) with scenario 4nb. Mean male recruits during 1984-2014 was used to estimate $B_{35\%}$.

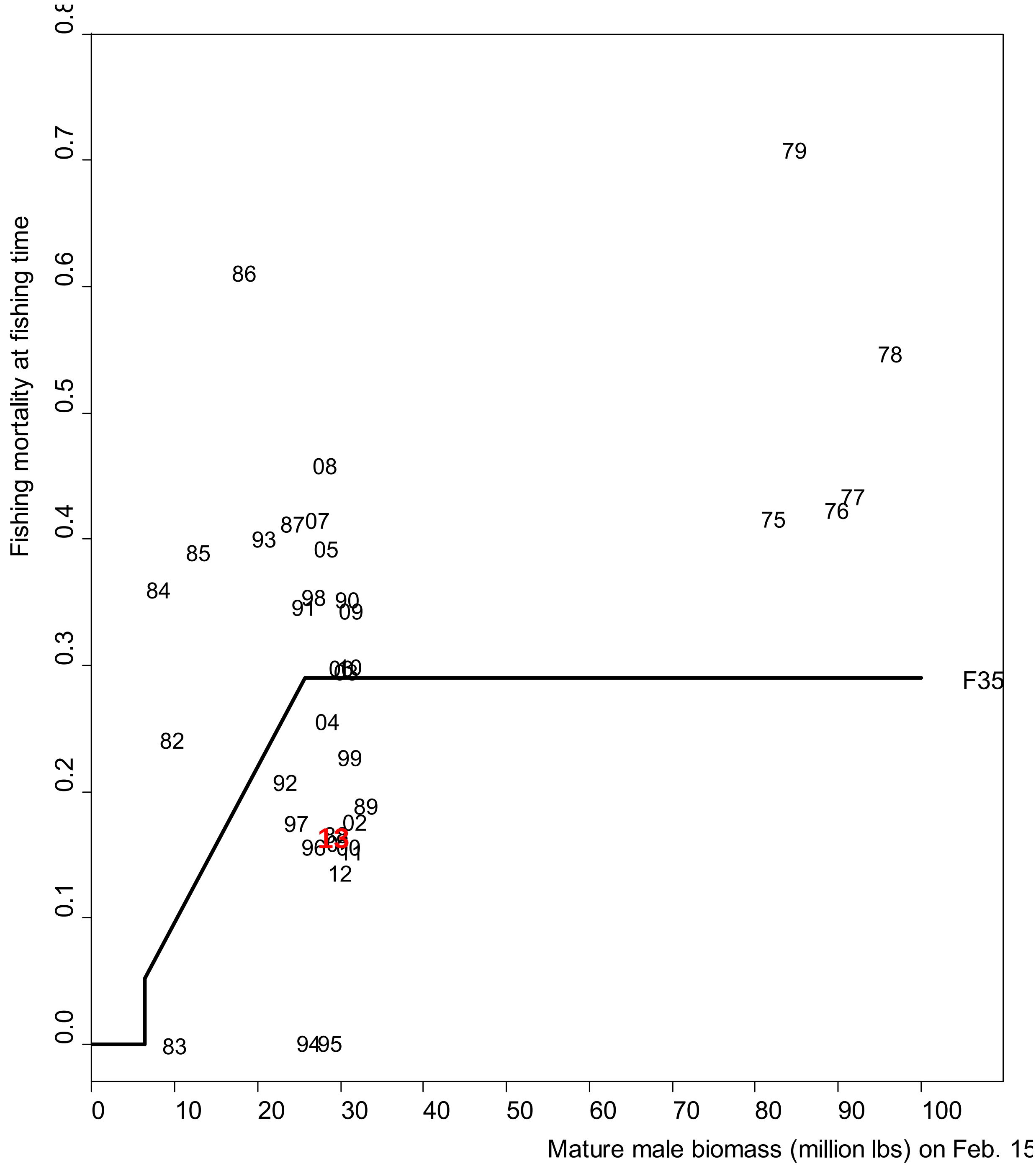

Figure 12(4na). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2013 under scenario 4na. Average of recruitment from 1984 to 2014 was used to estimate B_{MSY}. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

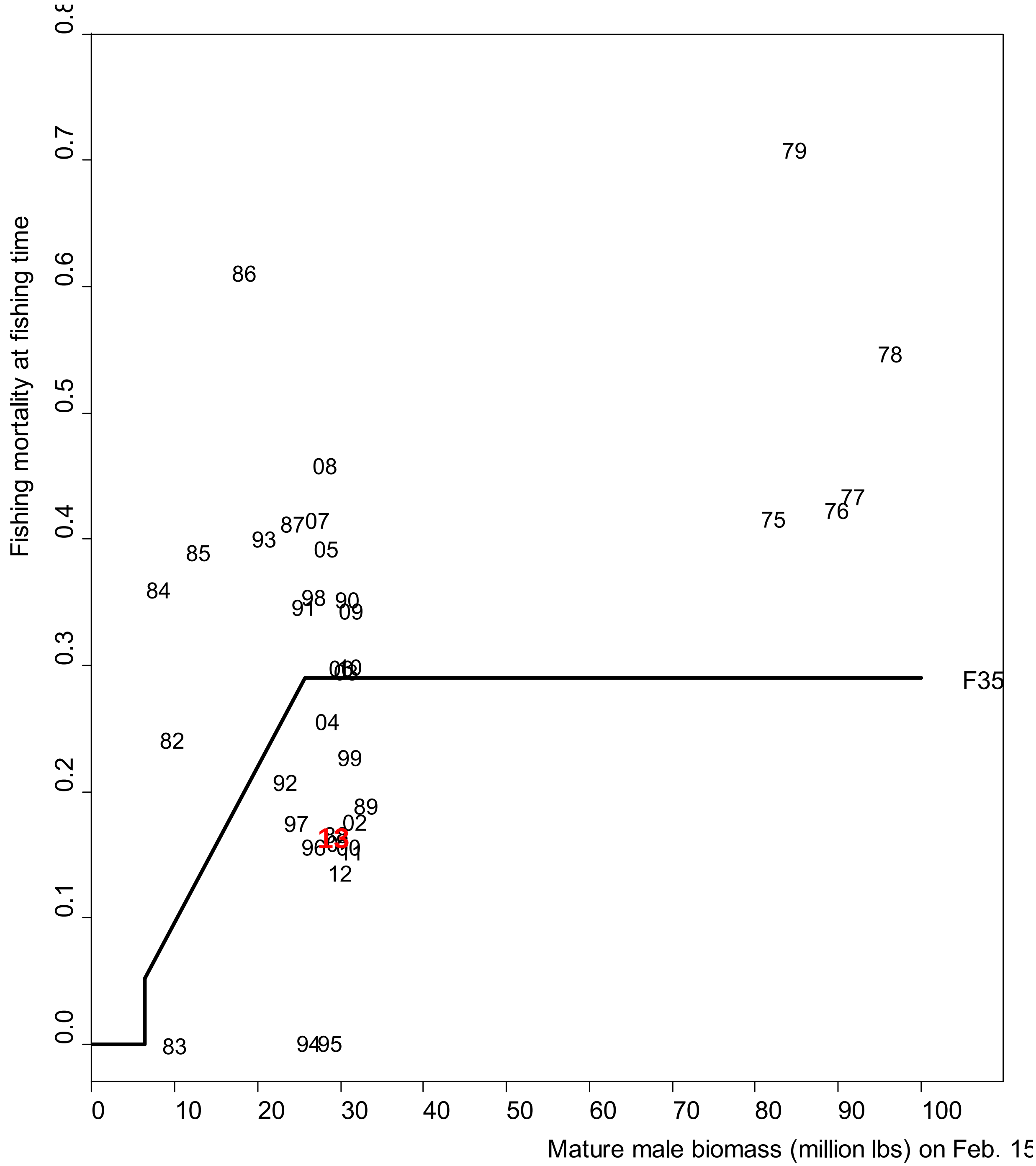

Figure 12(4nb). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2013 under scenario 4nb. Average of recruitment from 1984 to 2014 was used to estimate B_{MSY}. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

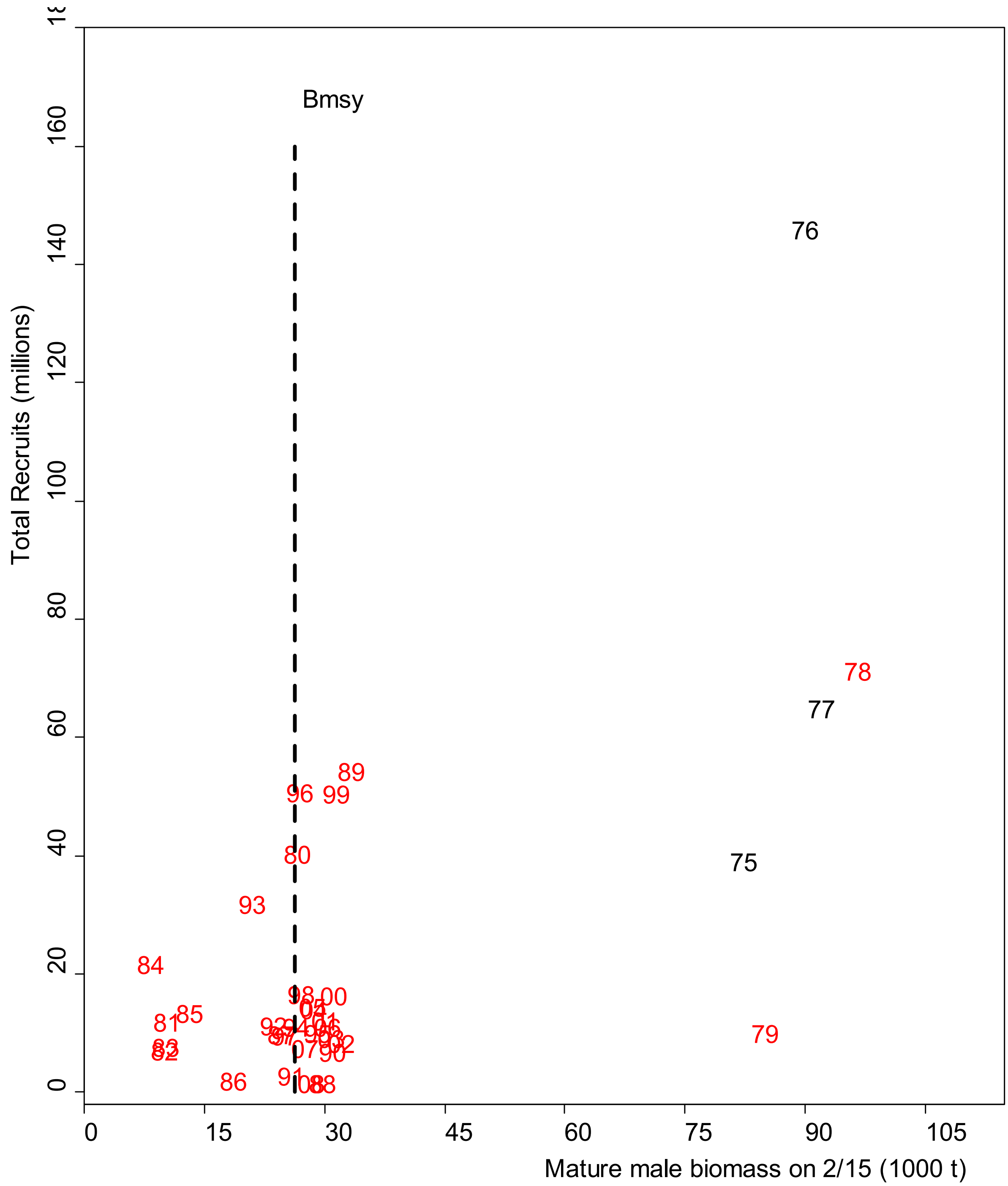

Figure 13a(na). Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6-year time lag) for Bristol Bay red king crab with pot handling mortality rate to be 0.2 under scenario 4na. Numerical labels are years of mating, and the vertical dotted line is the estimated $B_{35\%}$ based on the mean recruitment level during 1984 to 2014.

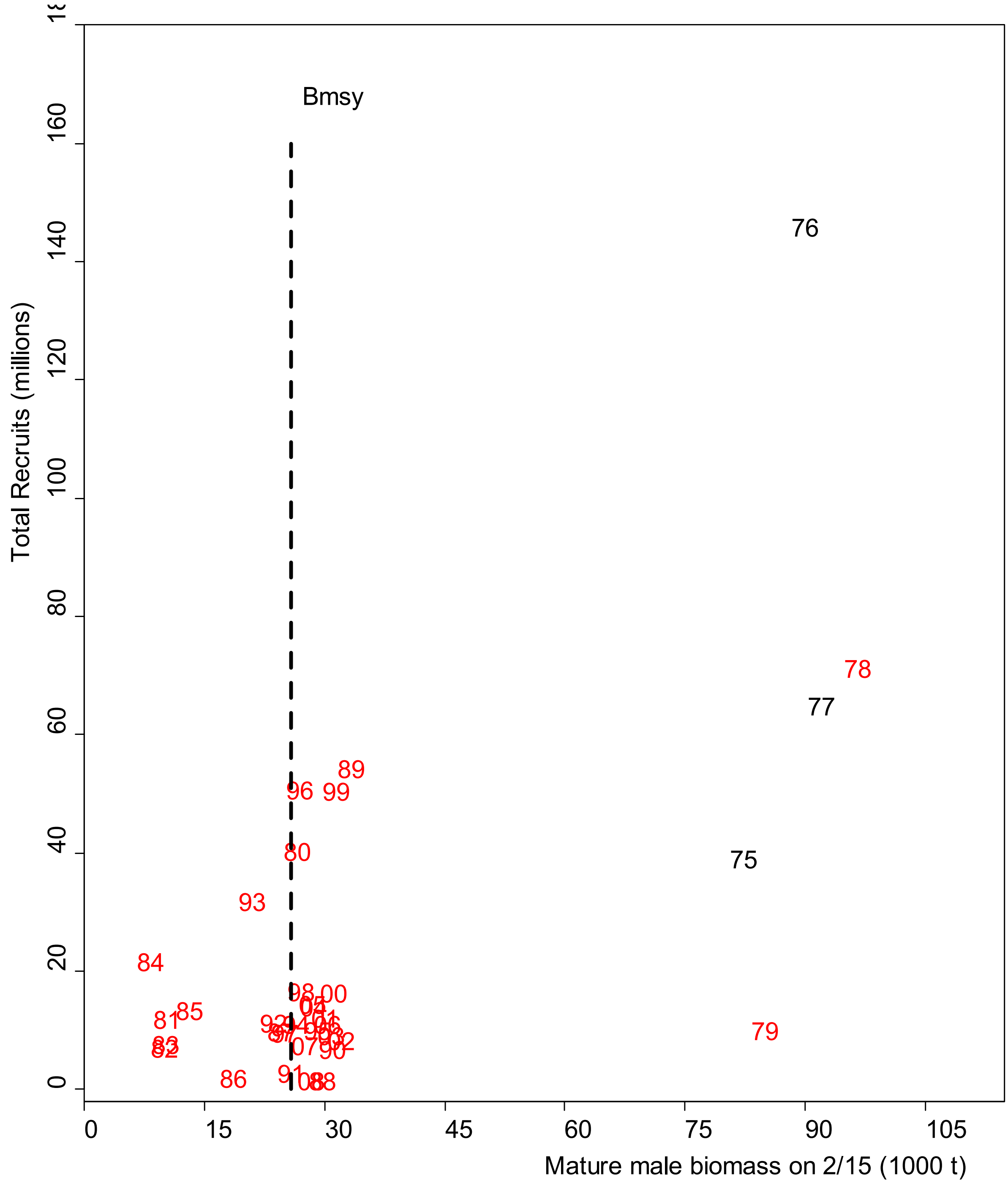

Figure 13a(nb). Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6-year time lag) for Bristol Bay red king crab with pot handling mortality rate to be 0.2 under scenario 4nb. Numerical labels are years of mating, and the vertical dotted line is the estimated $B_{35\%}$ based on the mean recruitment level during 1984 to 2014.

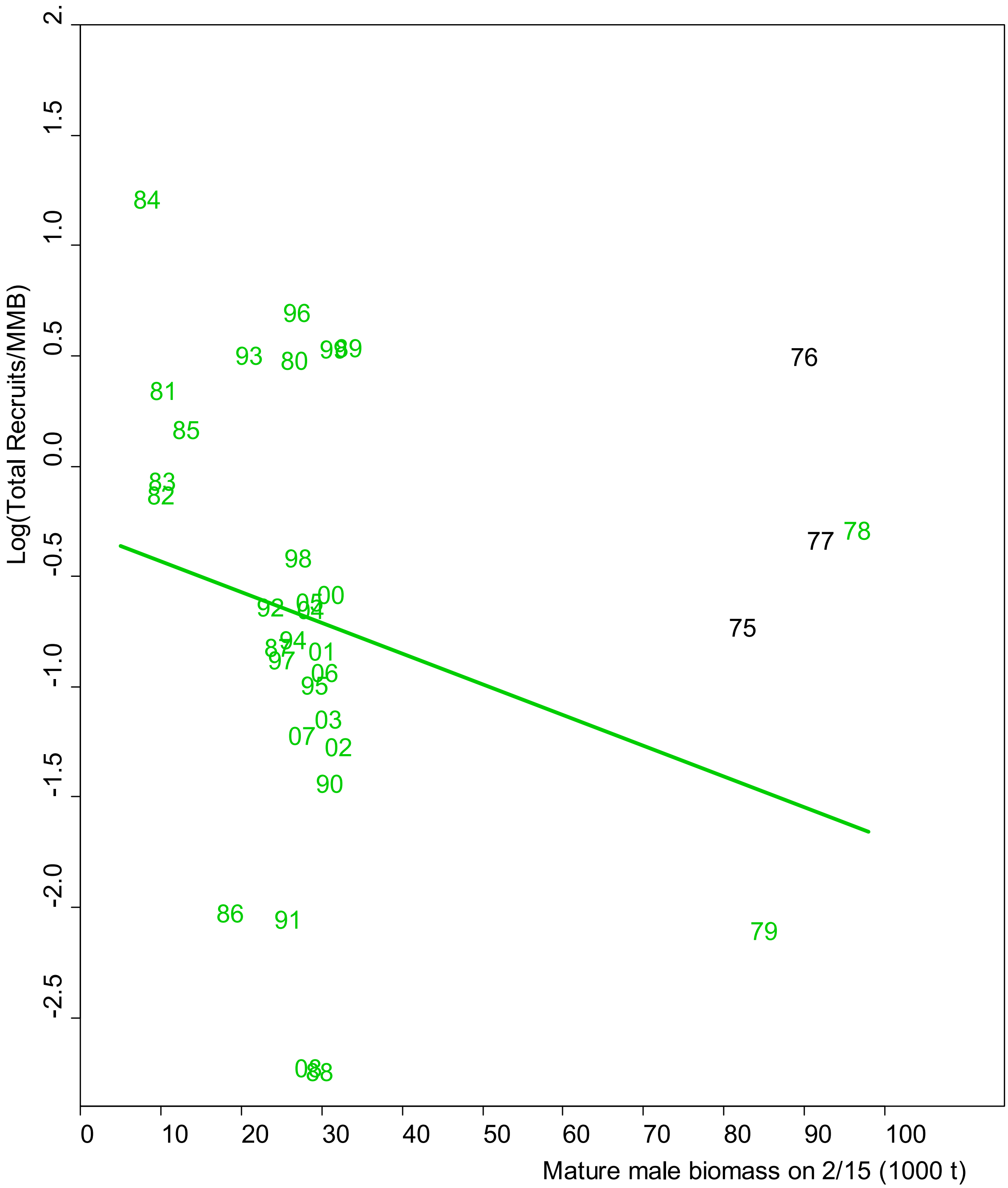

Figure 13b(na). Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate to be 0.2 under scenario 4na. Numerical labels are years of mating, and the line is the regression line for data of 1978-2008.

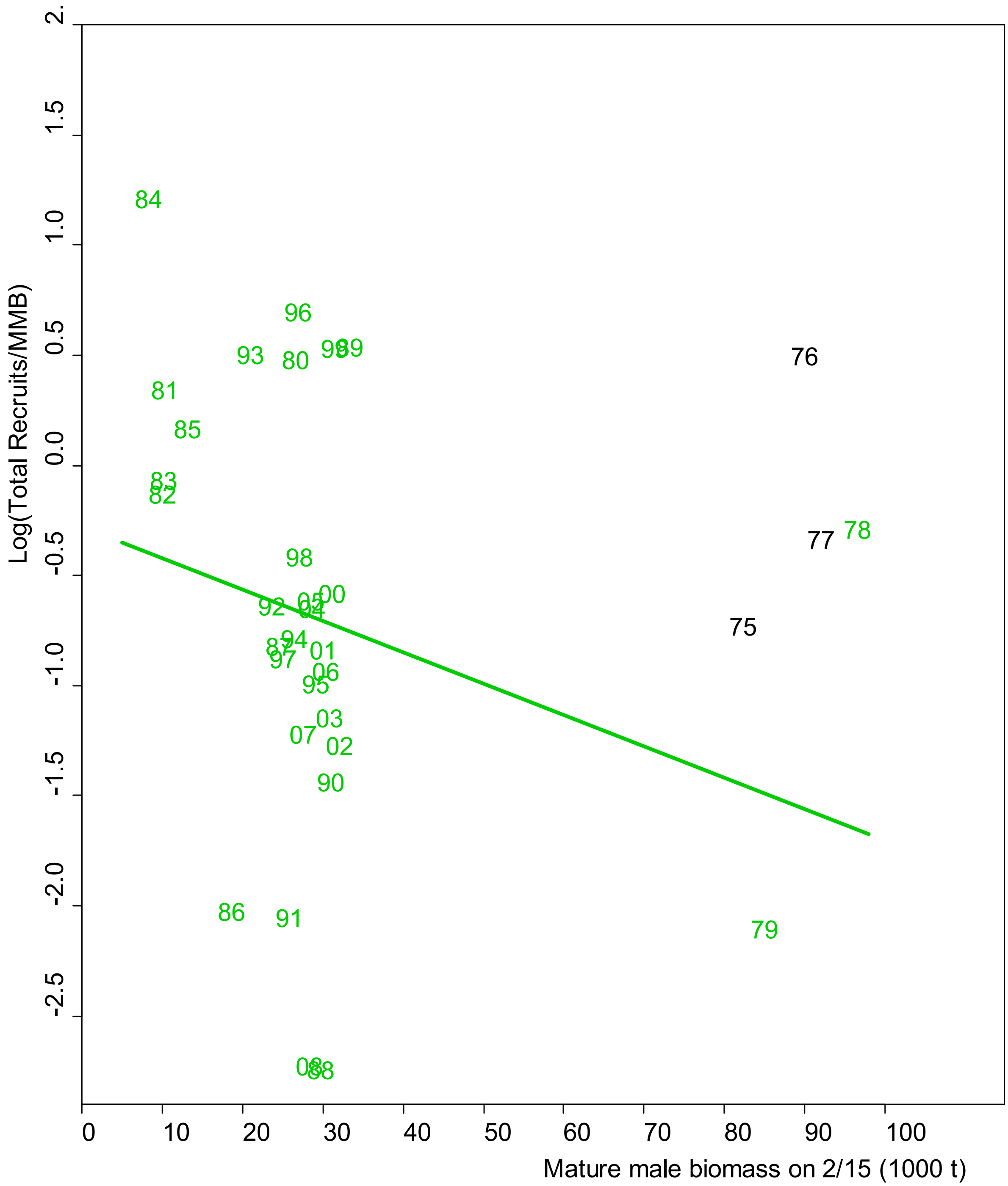

Figure 13b(nb). Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate to be 0.2 under scenario 4nb. Numerical labels are years of mating, and the line is the regression line for data of 1978-2008.

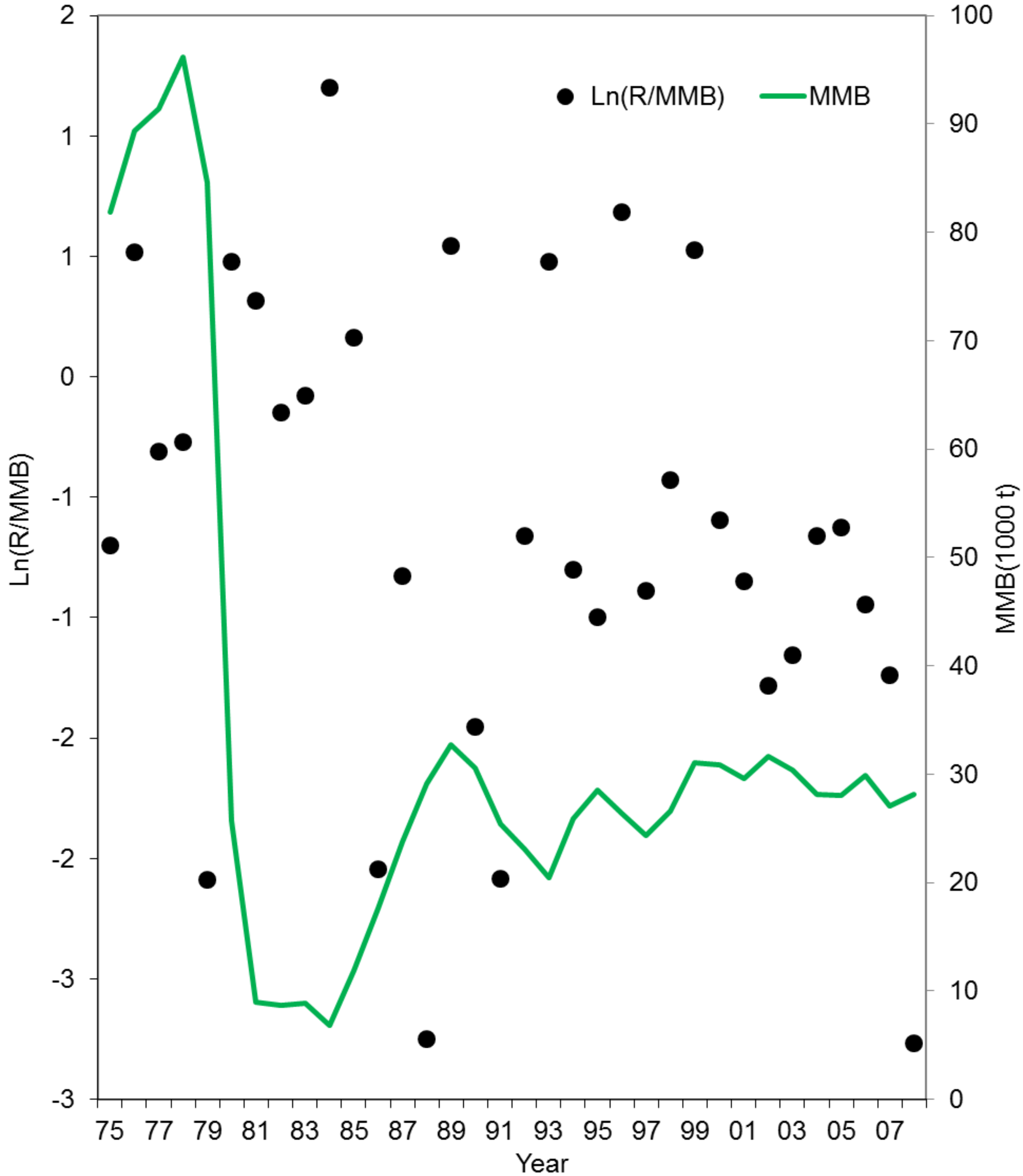

Figure 13c(4na). Time series of log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate to be 0.2 under scenario 4na.

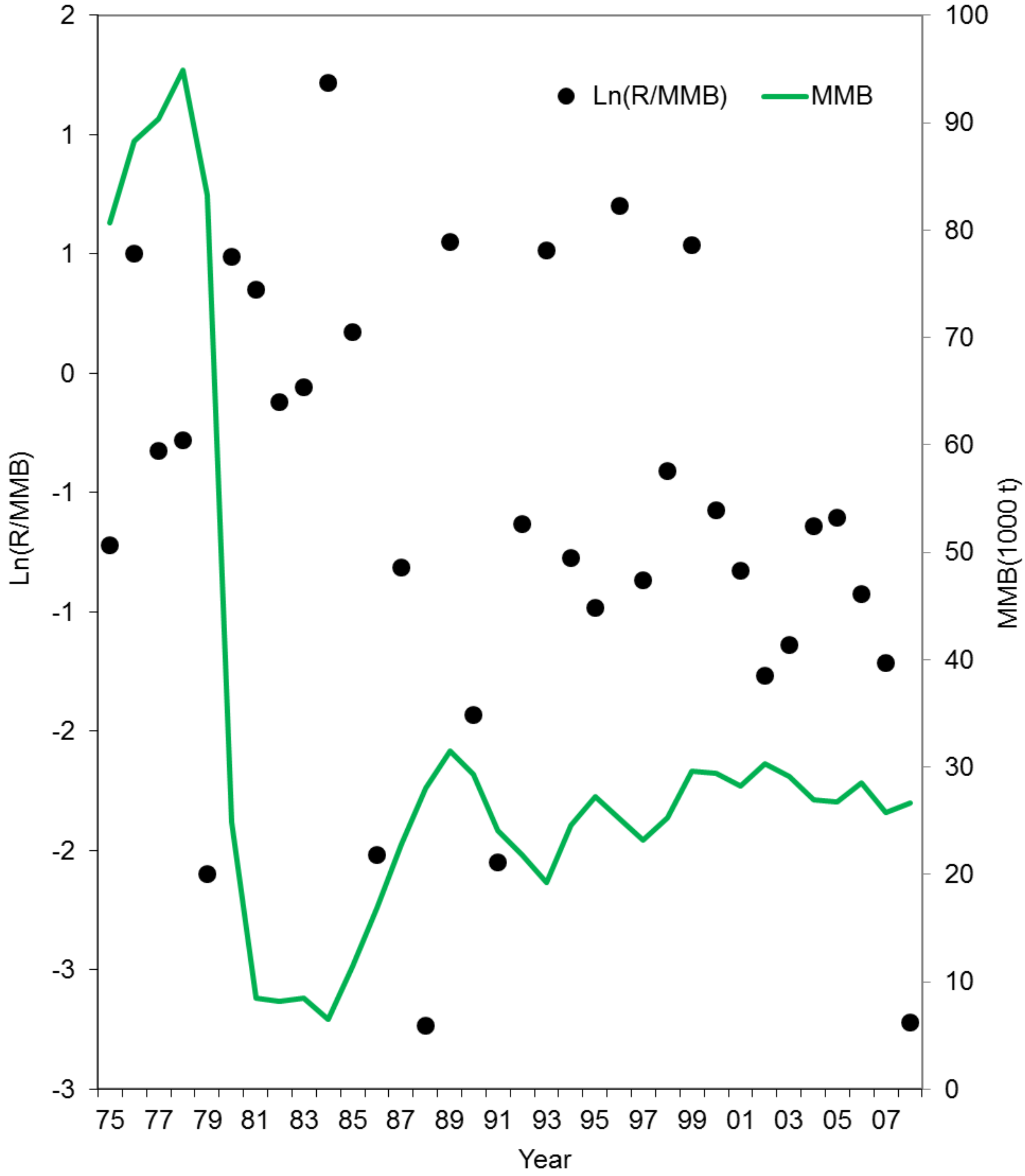

Figure 13c(4nb). Time series of log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate to be 0.2 under scenario 4nb.

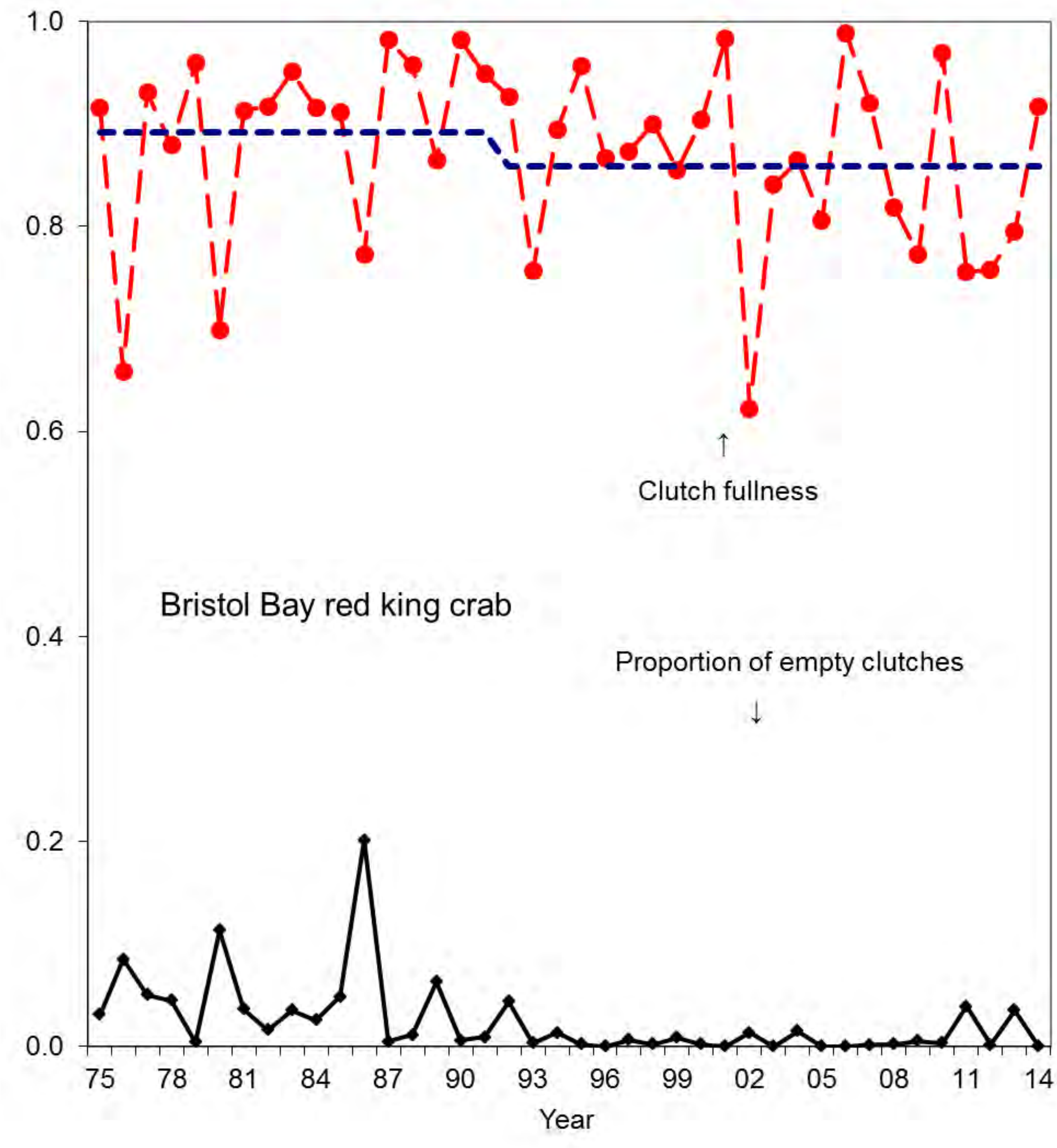

Figure 14. Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crab >89 mm CL from 1975 to 2014 from survey data. Oldshell females were excluded.

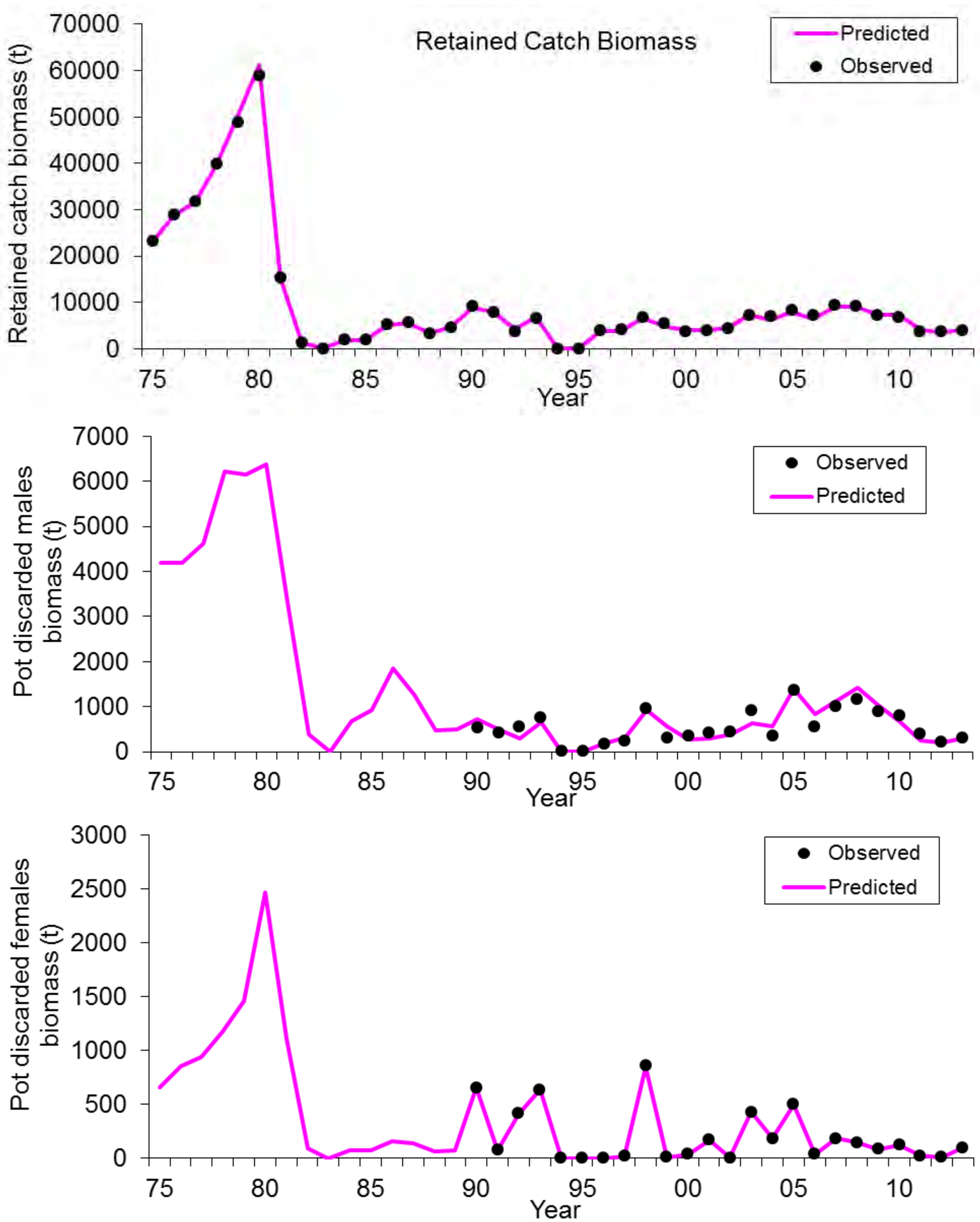

Figure 15a(4na). Observed and predicted catch mortality biomass under scenario 4na. Mortality biomass is equal to caught biomass times a handling mortality rate. Pot handling mortality rate is 0.2.

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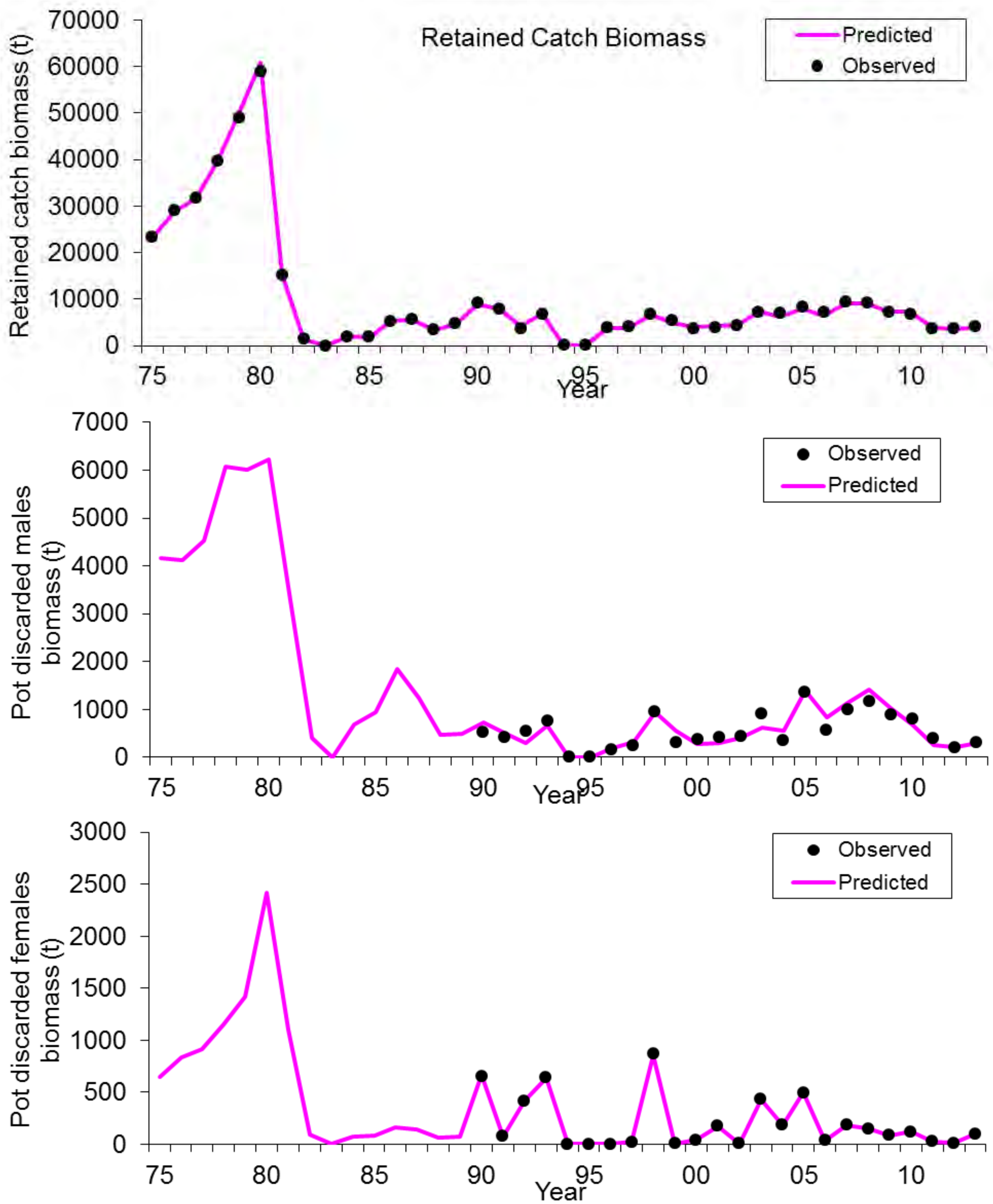


Figure 15a(4nb). Observed and predicted catch mortality biomass under scenario 4nb. Mortality biomass is equal to caught biomass times a handling mortality rate. Pot handling mortality rate is 0.2.

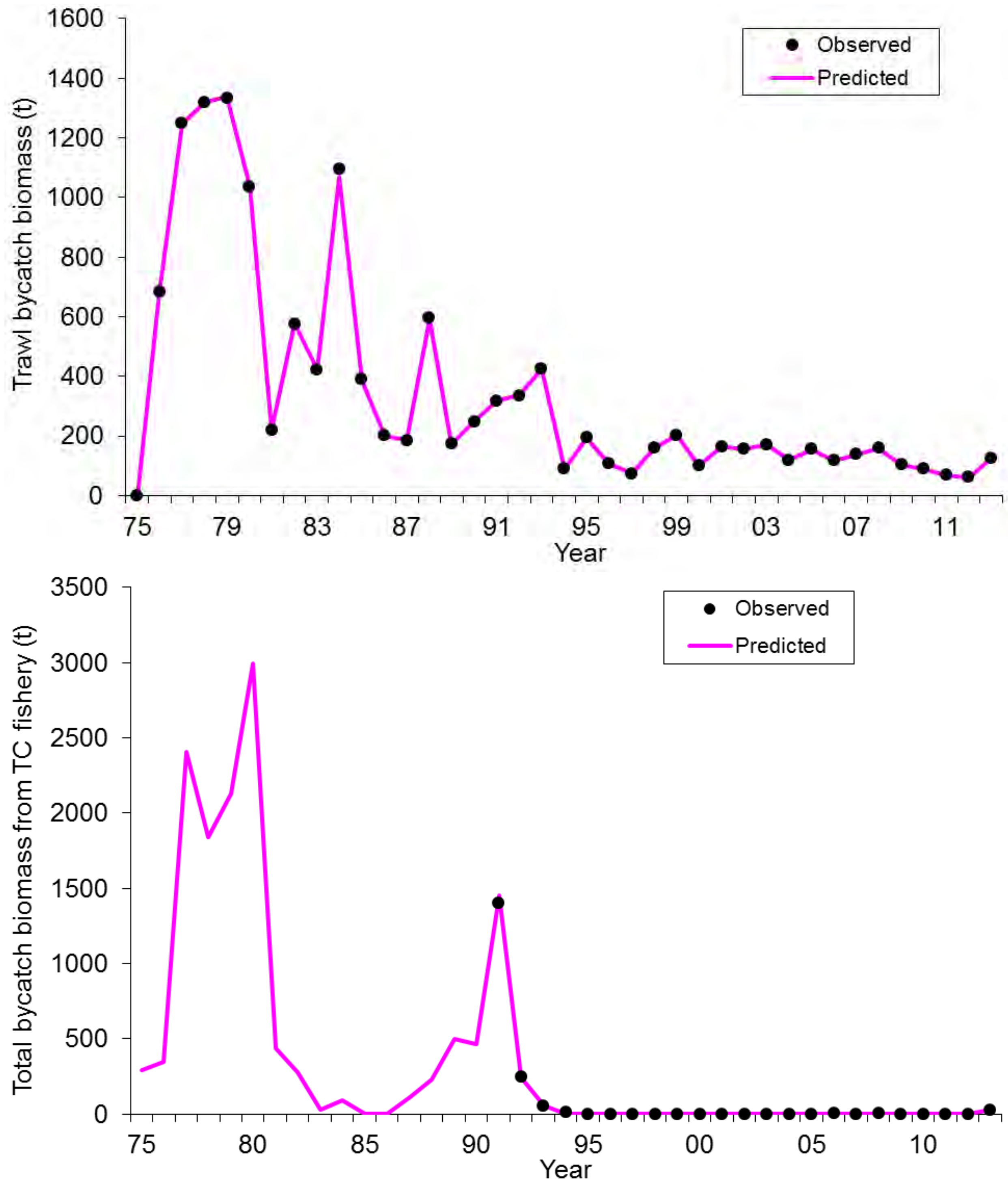
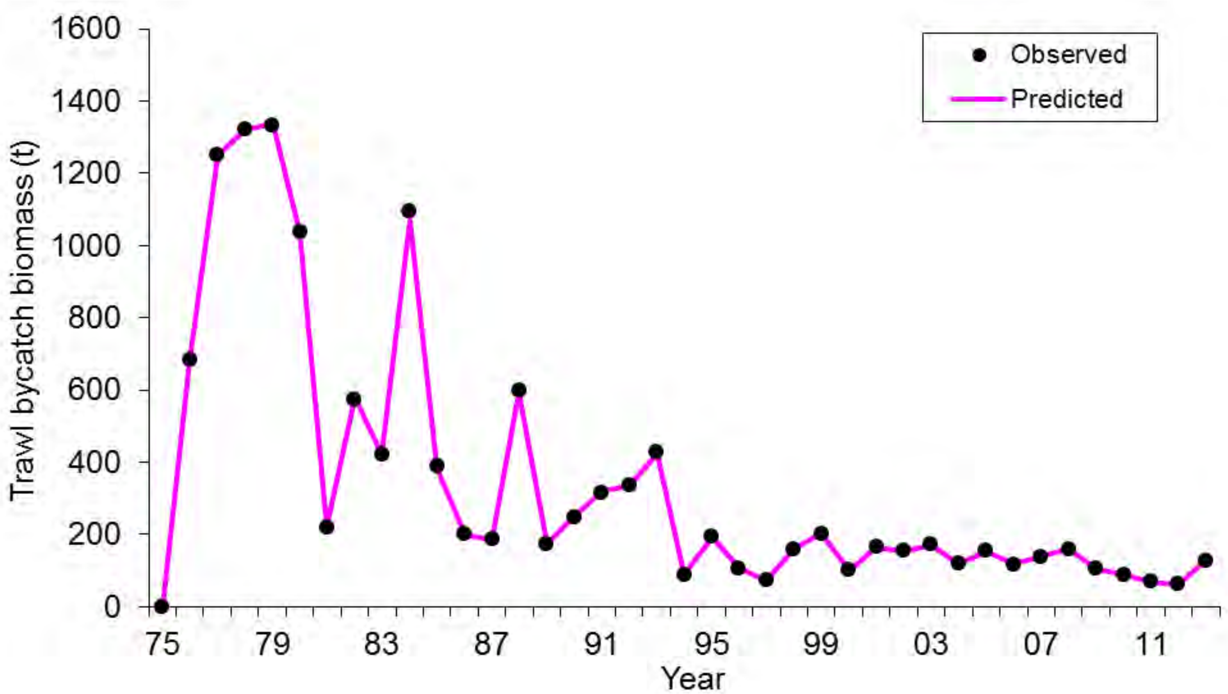


Figure 15b(4na). Observed and predicted bycatch mortality biomass from trawl fisheries and Tanner crab fishery under scenario 4na. Mortality biomass is equal to caught biomass times a handling mortality rate. Trawl handling mortality rate is 0.8, and Tanner crab pot handling mortality is 0.25. Trawl bycatch biomass was 0 before 1976.



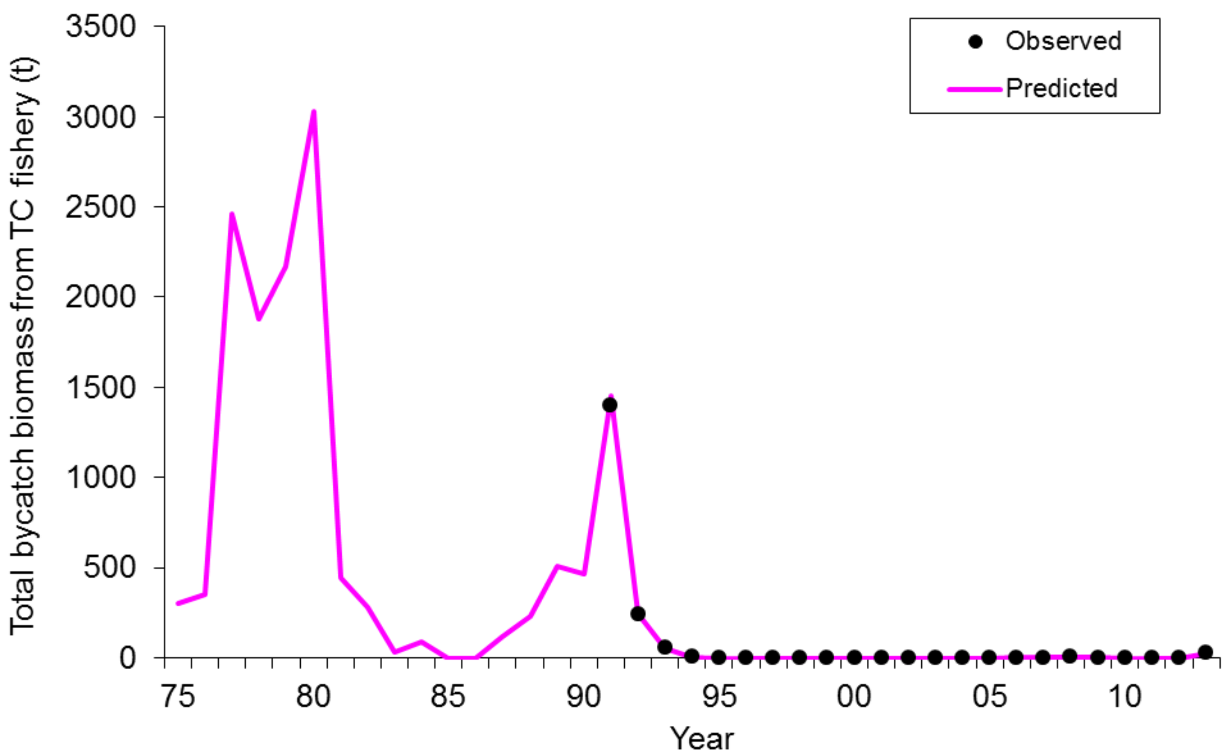


Figure 15b(4nb). Observed and predicted bycatch mortality biomass from trawl fisheries and Tanner crab fishery under scenario 4nb. Mortality biomass is equal to caught biomass times a handling mortality rate. Trawl handling mortality rate is 0.8, and Tanner crab pot handling mortality is 0.25. Trawl bycatch biomass was 0 before 1976.

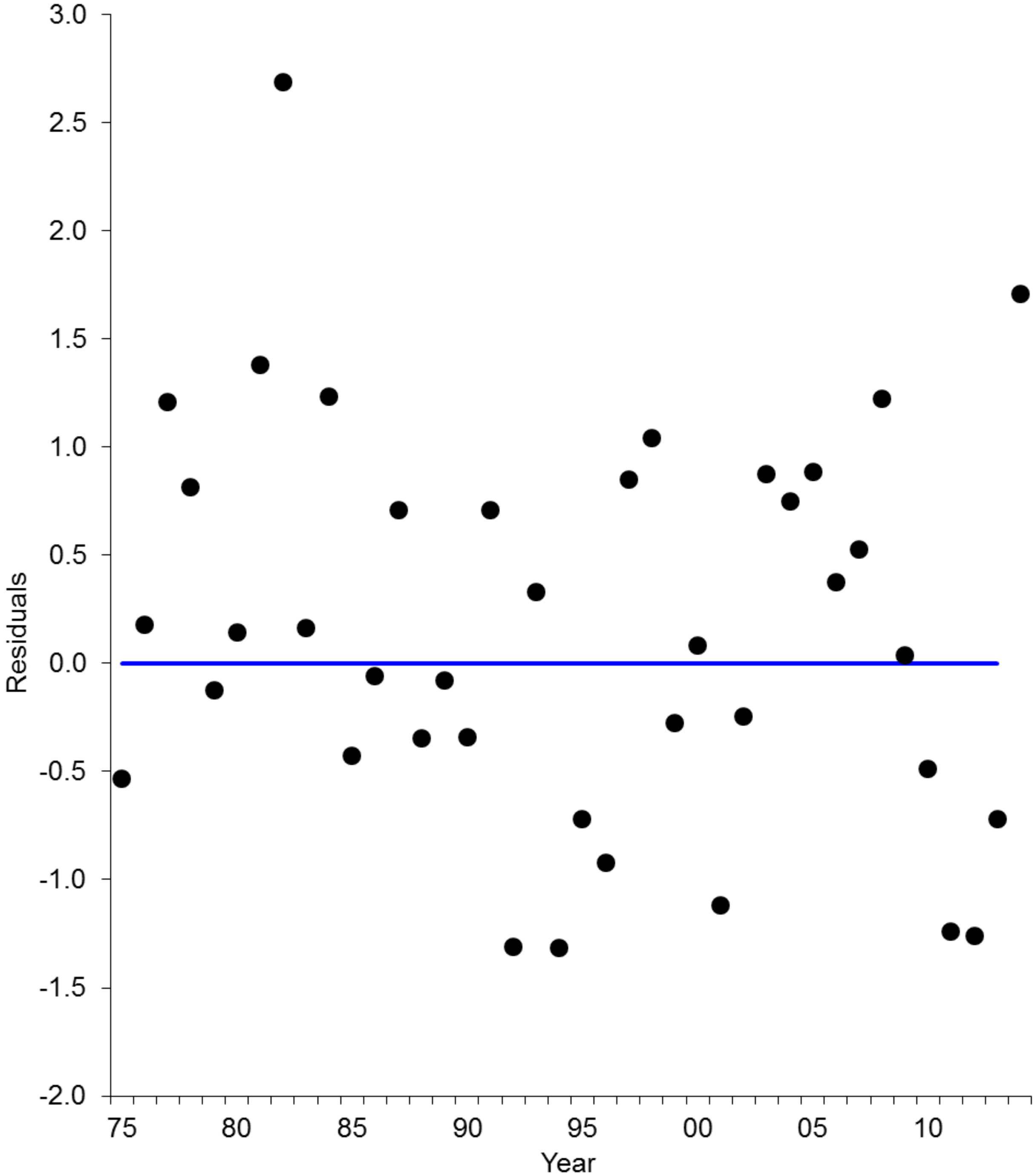


Figure 16(4na). Standardized residuals of total survey biomass under scenario 4na. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

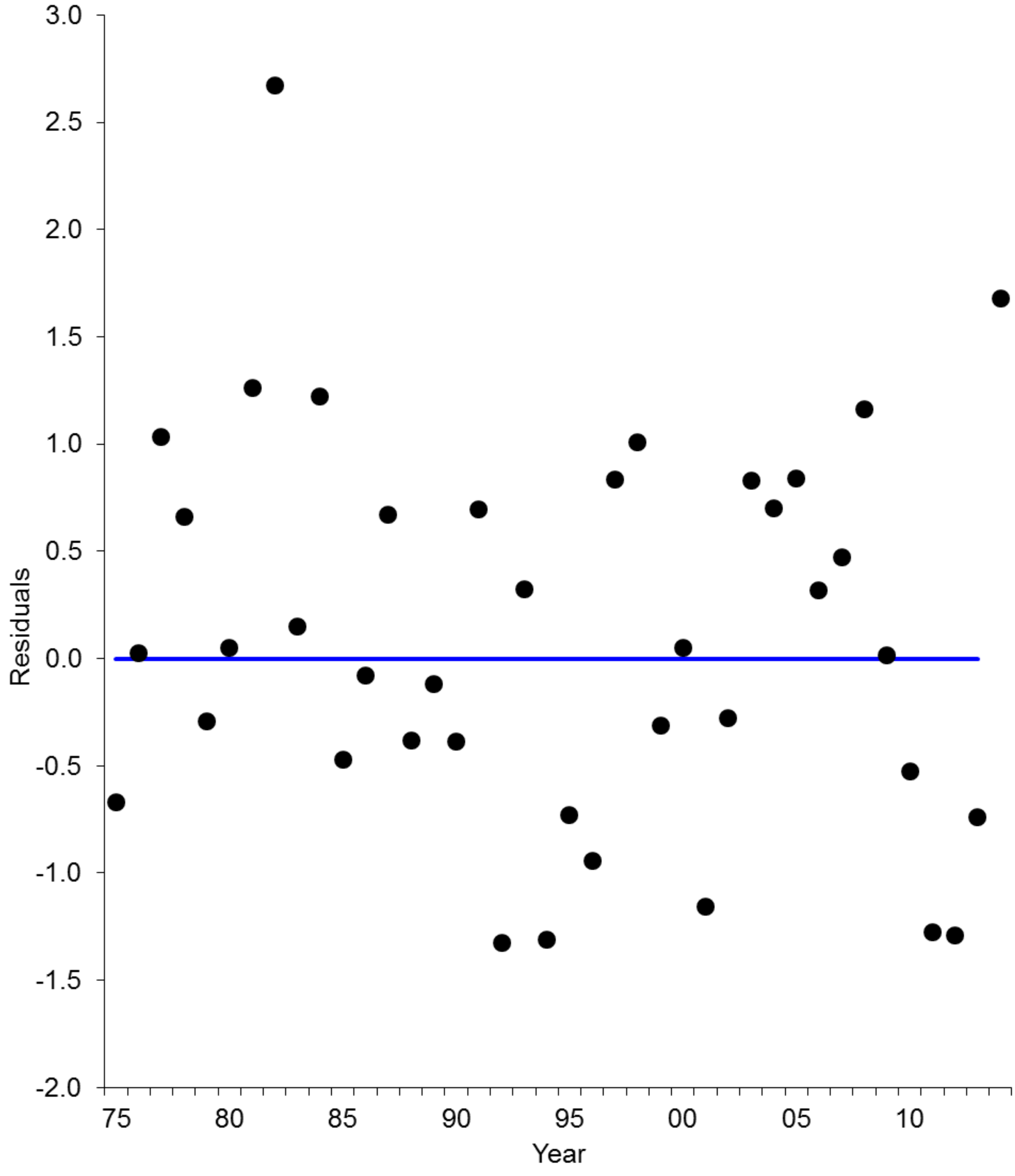


Figure 16(4nb). Standardized residuals of total survey biomass under scenario 4nb. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

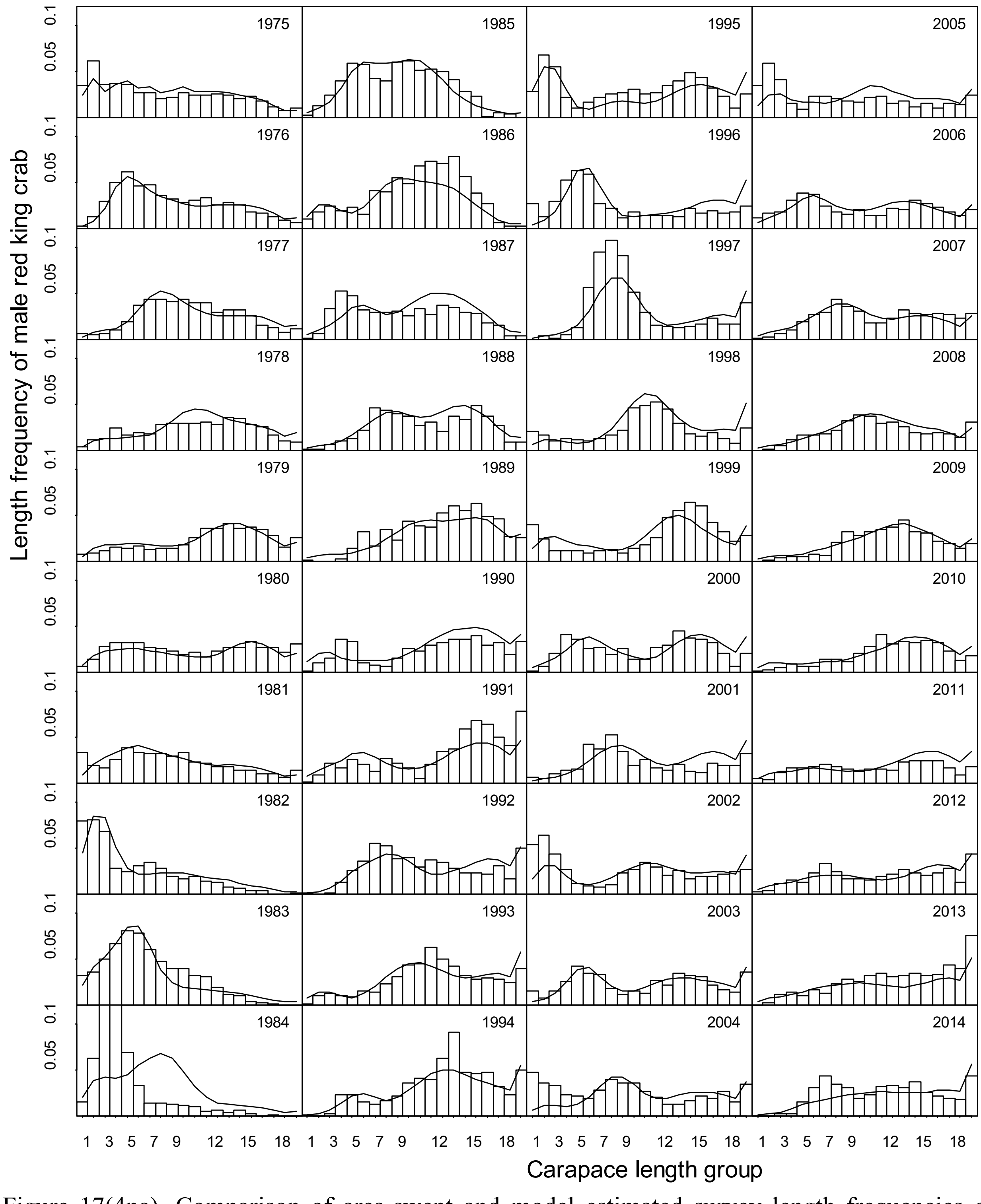


Figure 17(4na). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay male red king crab by year under scenario 4na. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, and the first length group is 67.5 mm.

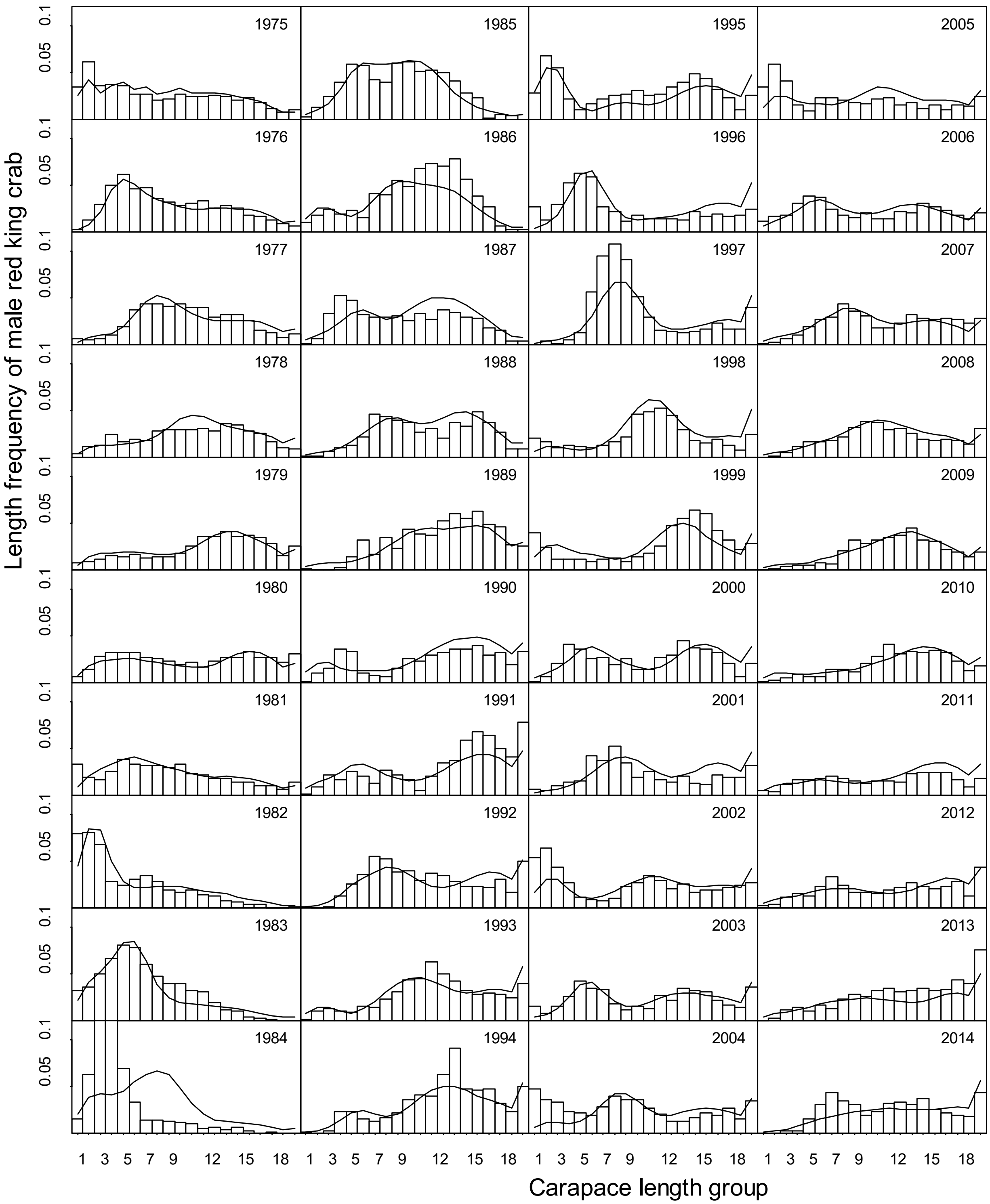


Figure 18(4nb). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay male red king crab by year under scenario 4nb. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

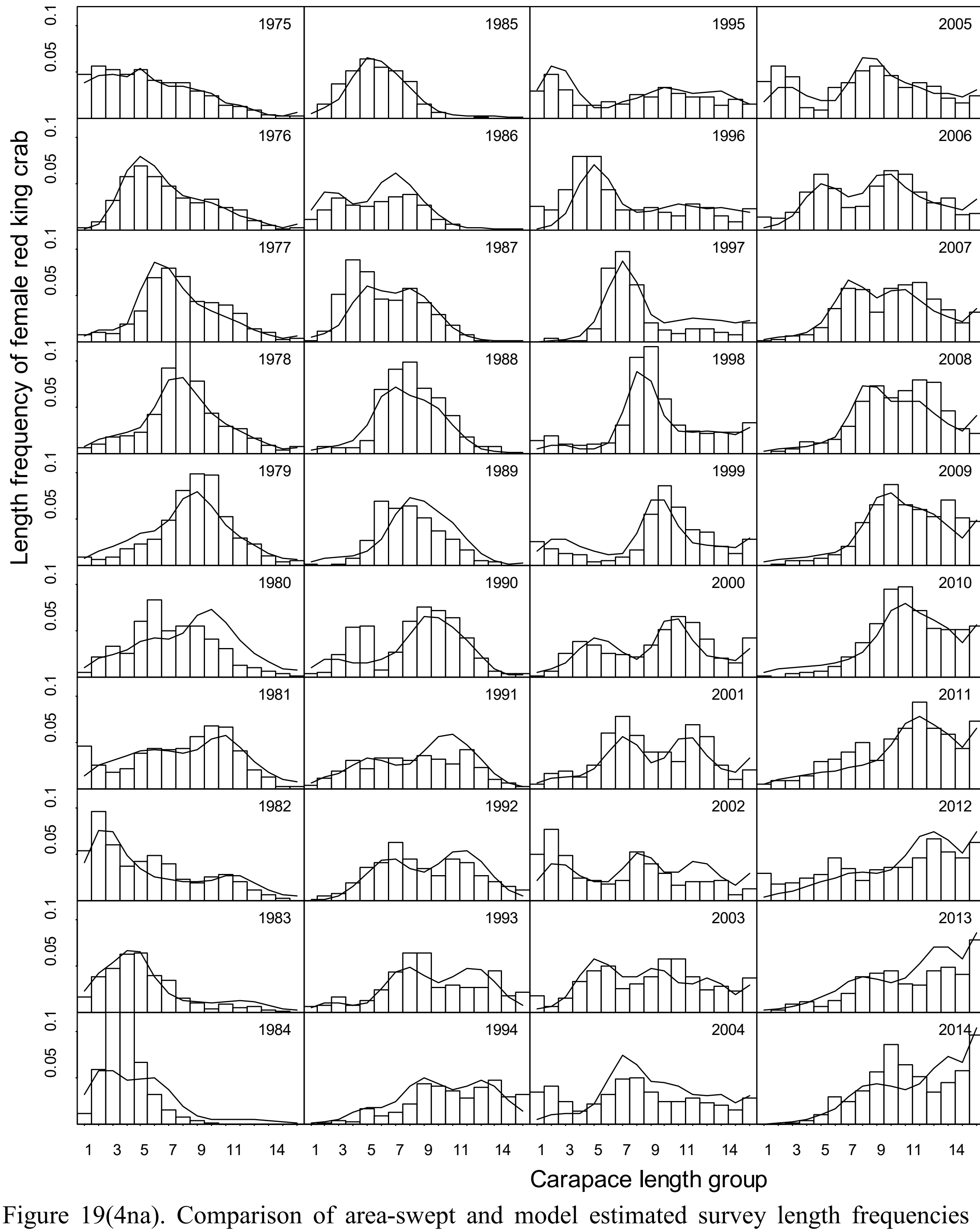


Figure 19(4na). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay female red king crab by year under scenario 4na. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

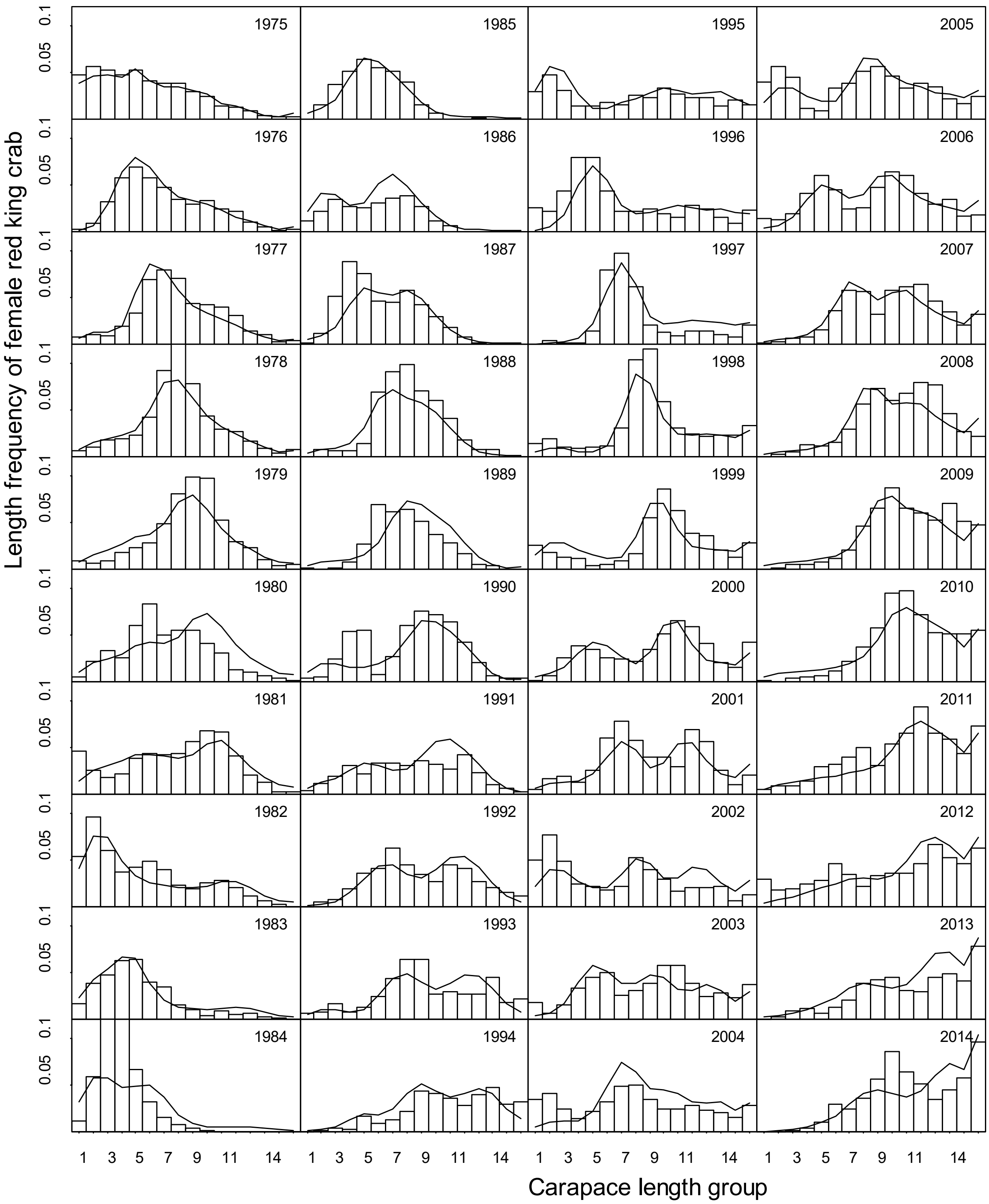


Figure 19(4nb). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay female red king crab by year under scenario 4nb. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

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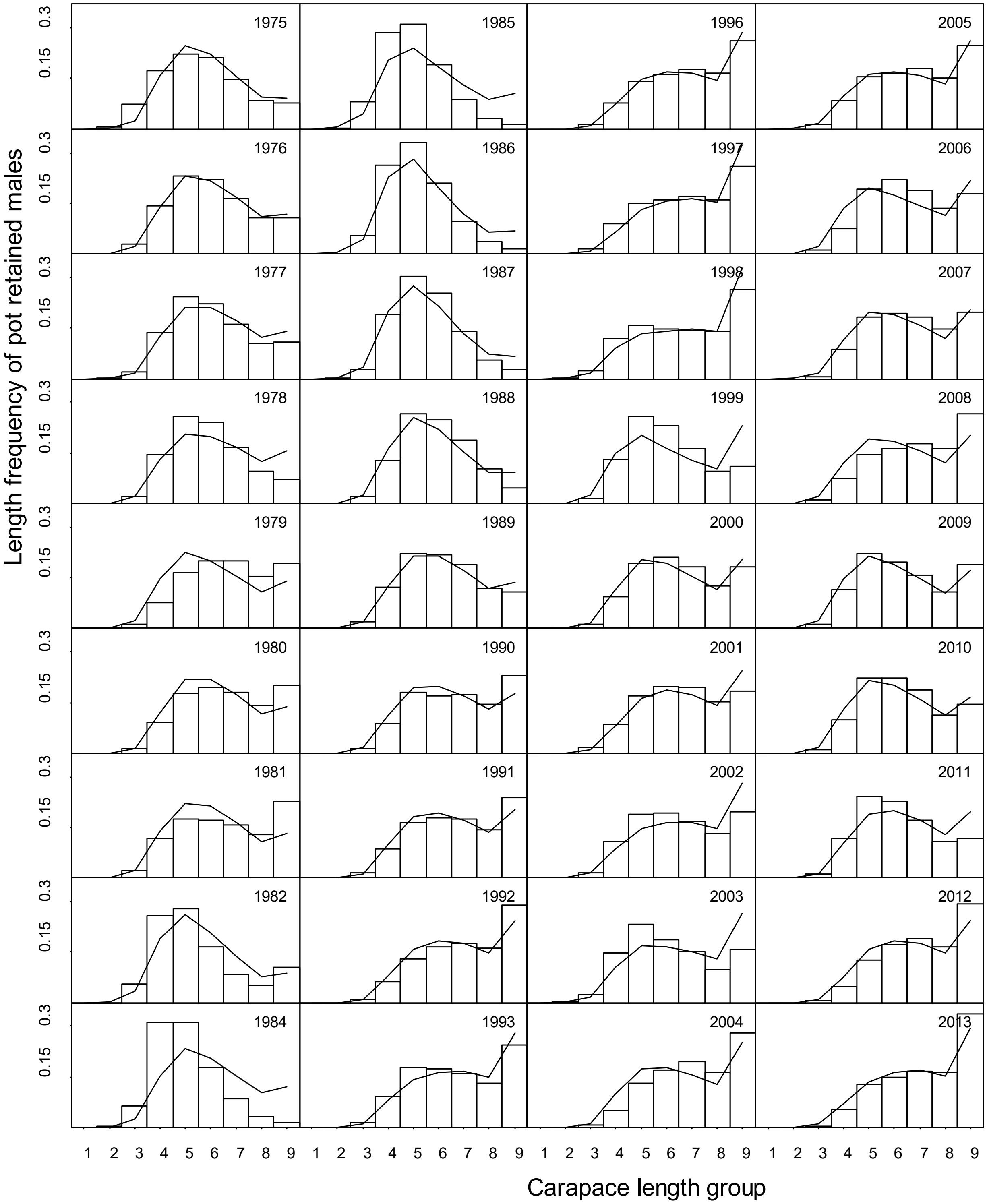

Figure 20(4na). Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under scenario 4na. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 122.5 mm.

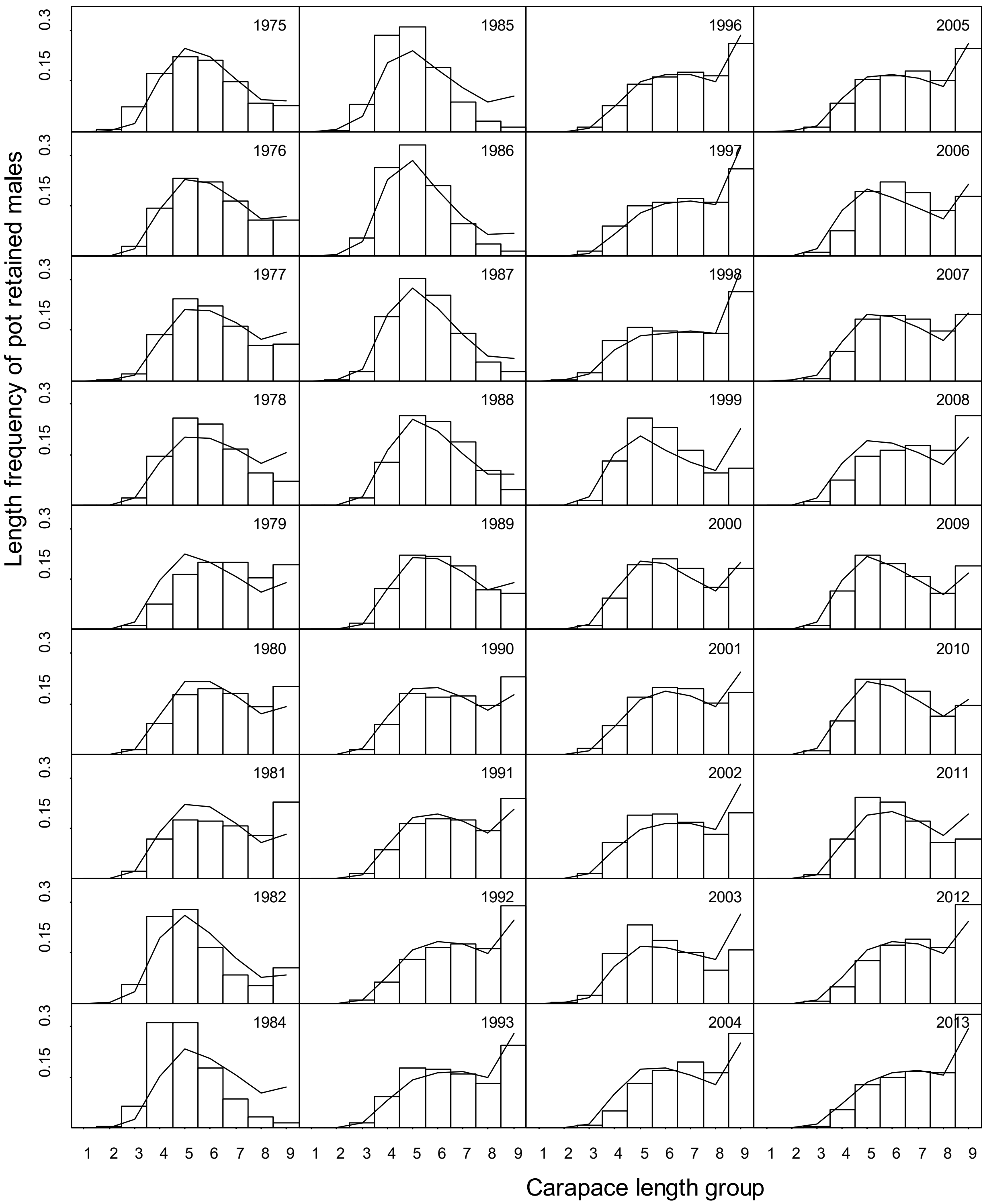

Figure 20(4nb). Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under scenario 4nb. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 122.5 mm.

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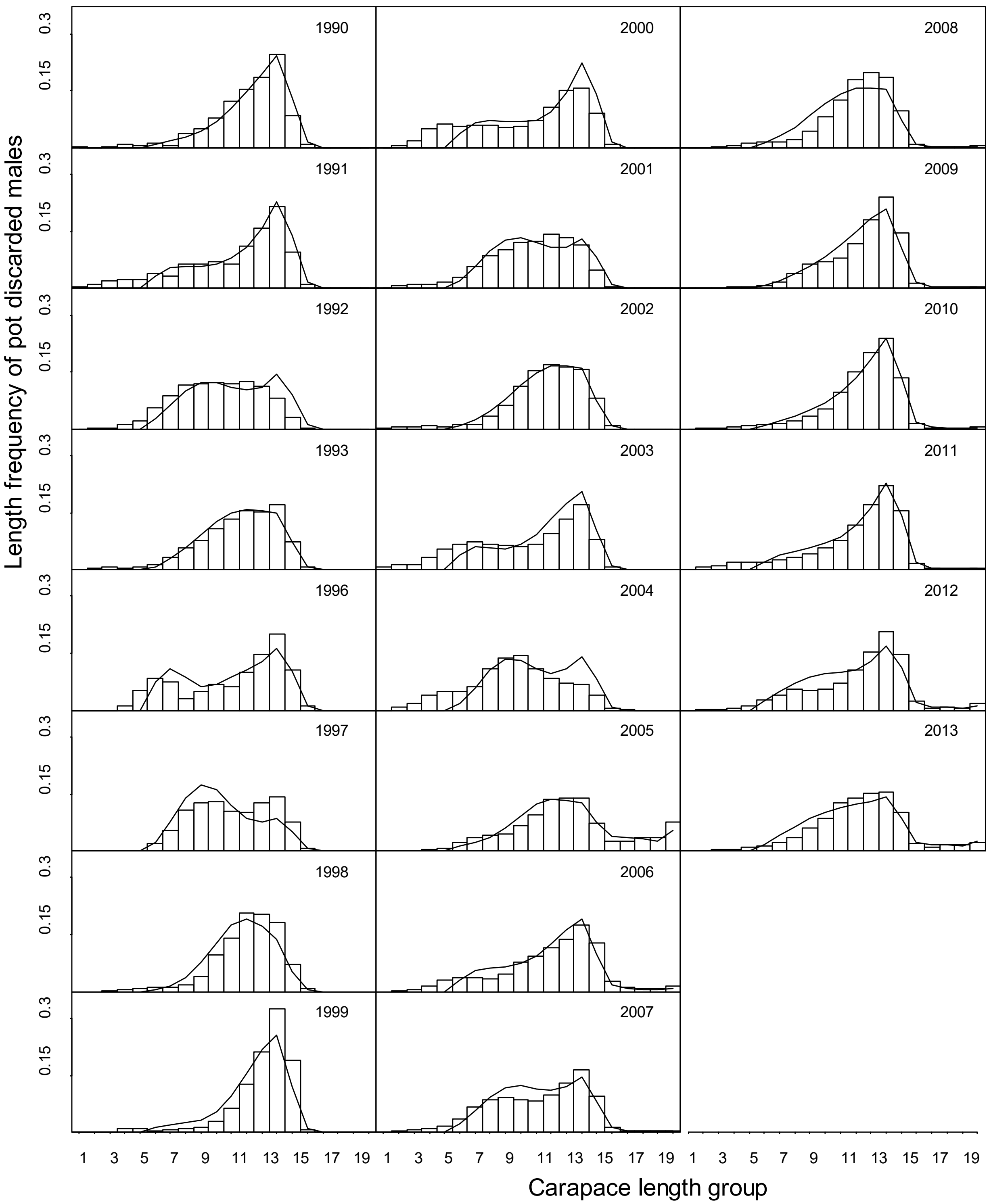

Figure 21(4na). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under scenario 4na. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

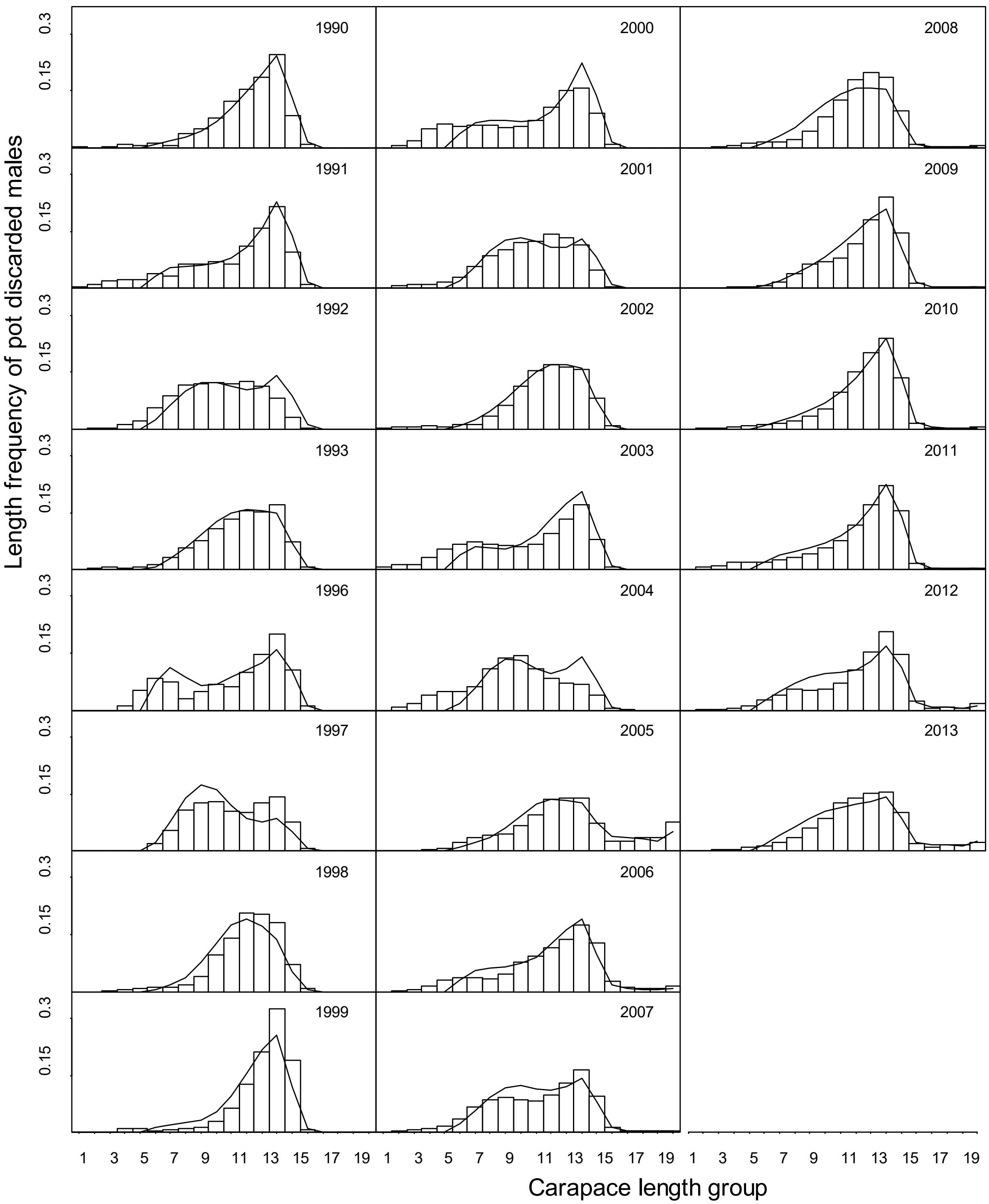

Figure 21(4nb). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under scenario 4nb. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

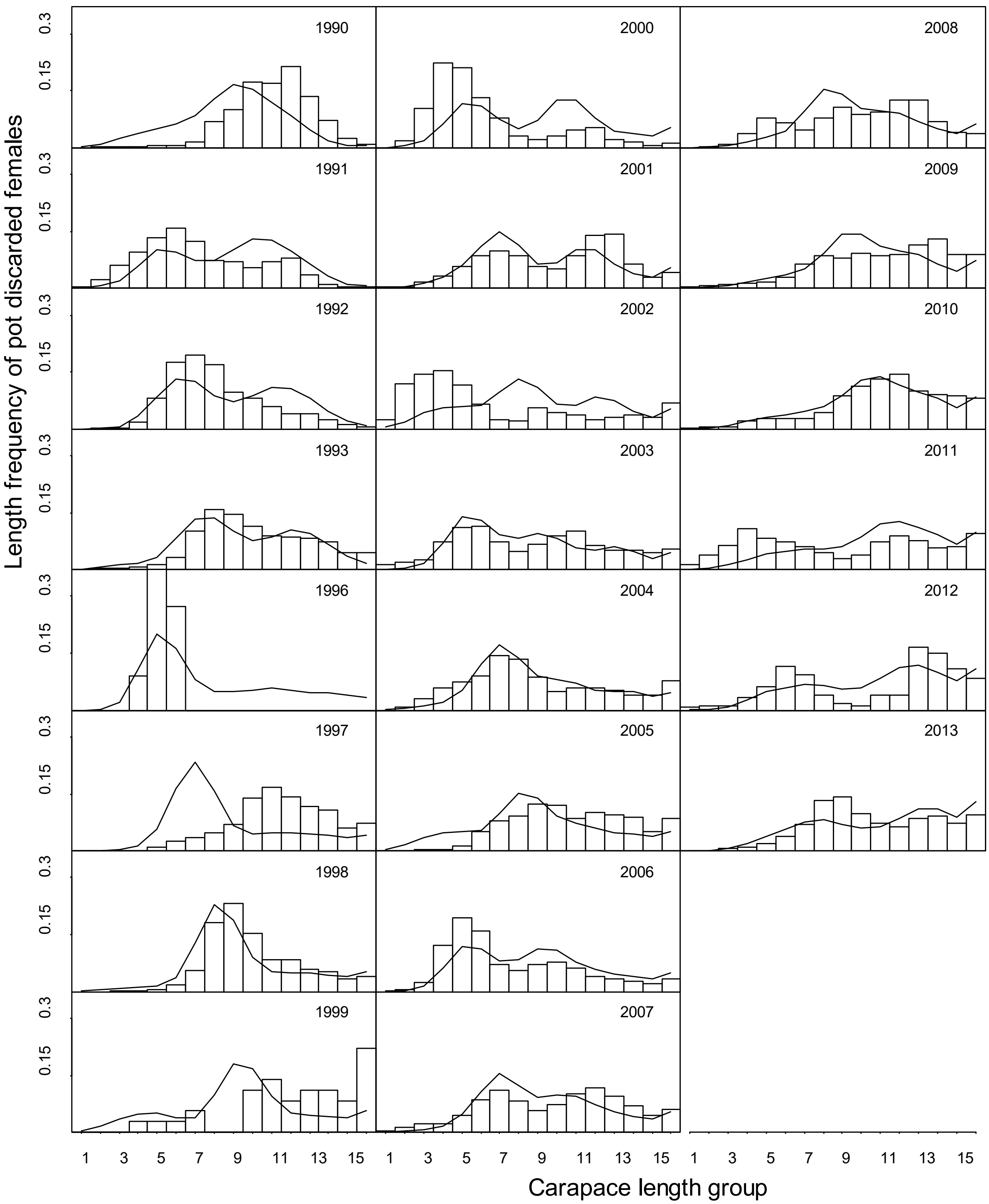

Figure 22(4na). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the directed pot fishery under scenario 4na. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

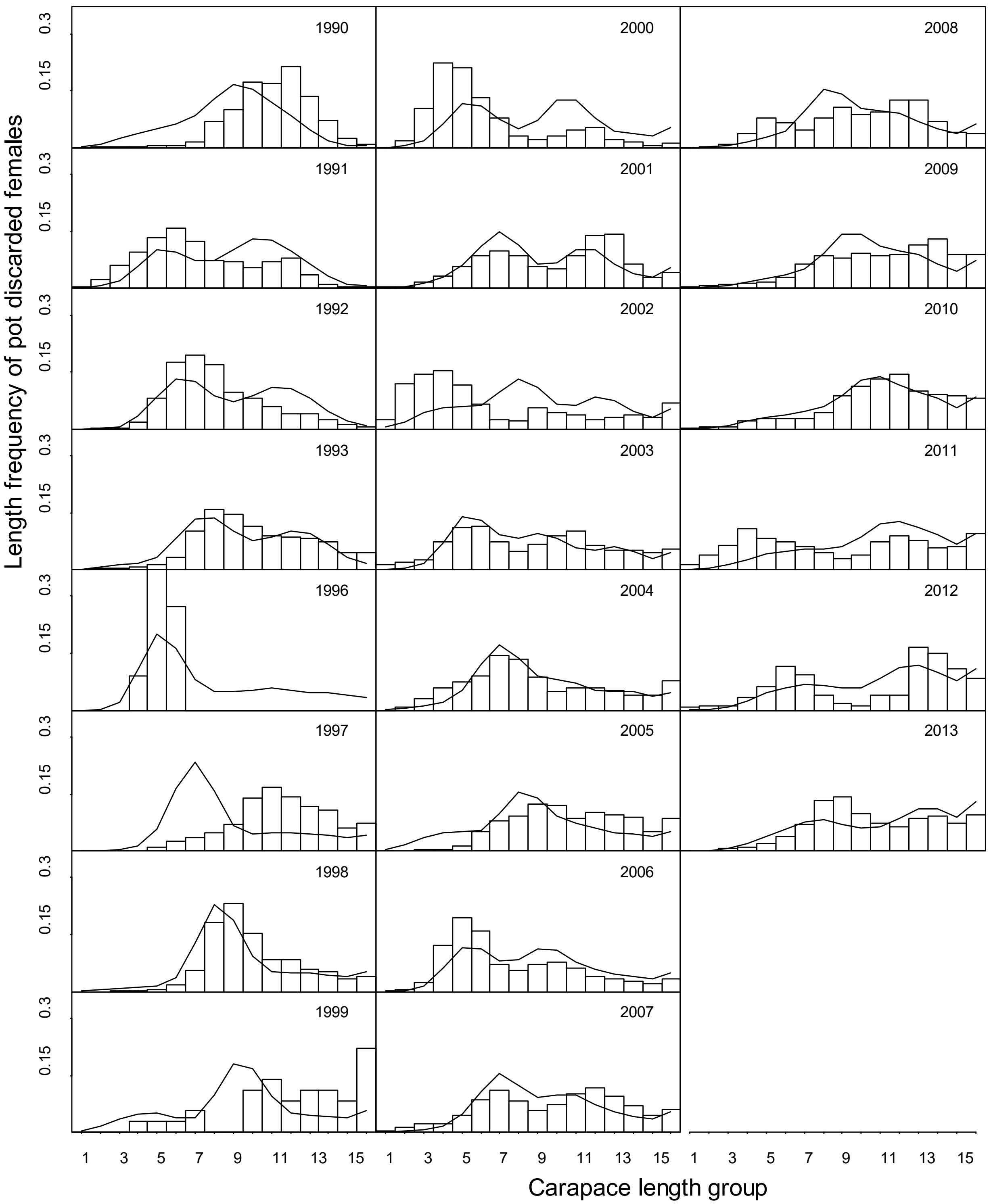

Figure 22(4nb). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the directed pot fishery under scenario 4nb. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

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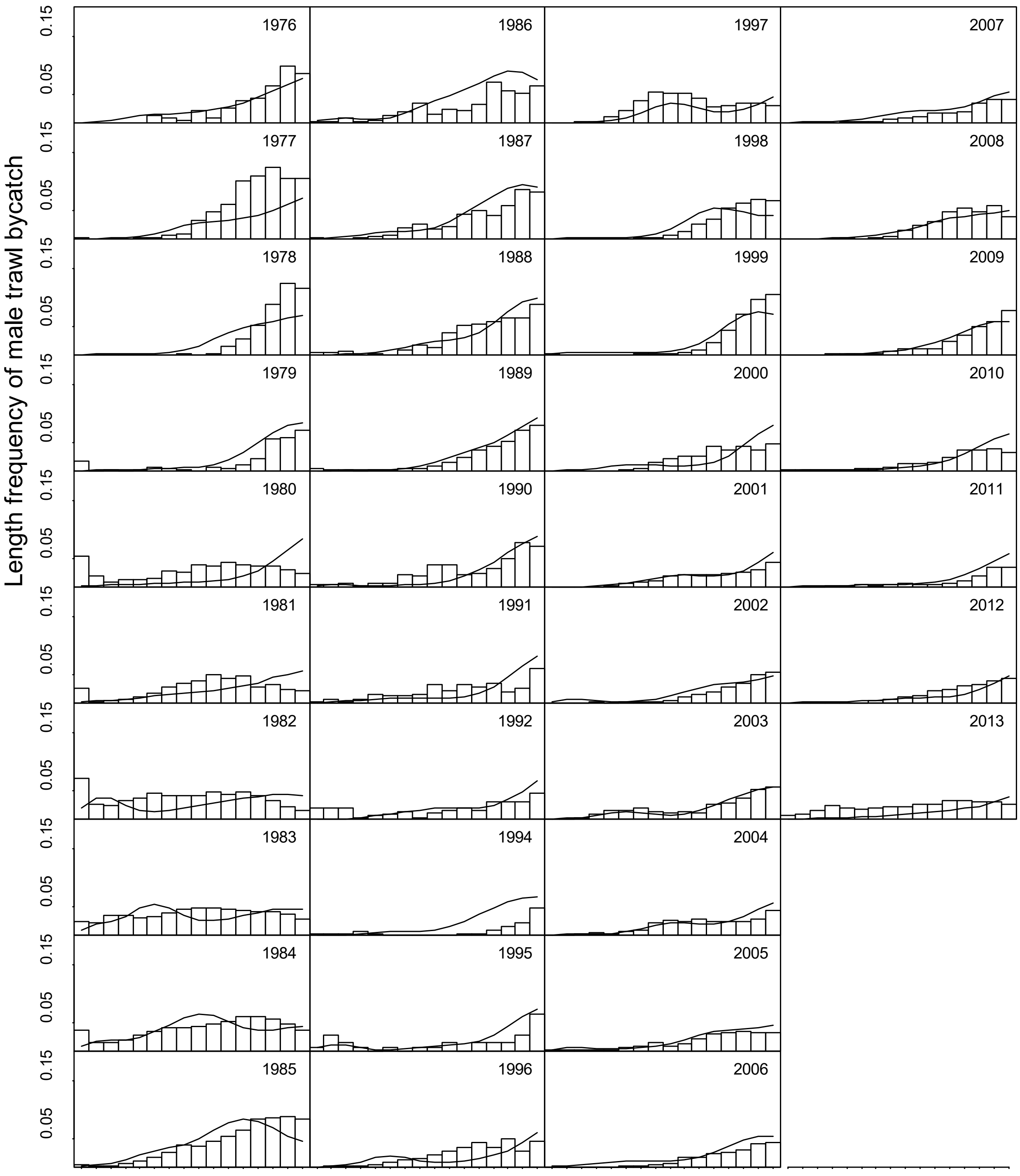

Figure 23(4na). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish trawl fisheries under scenario 4na. Pot handling mortality rate is 0.2, trawl bycatch mortality rate is 0.8, and the first length group is 67.5 mm.

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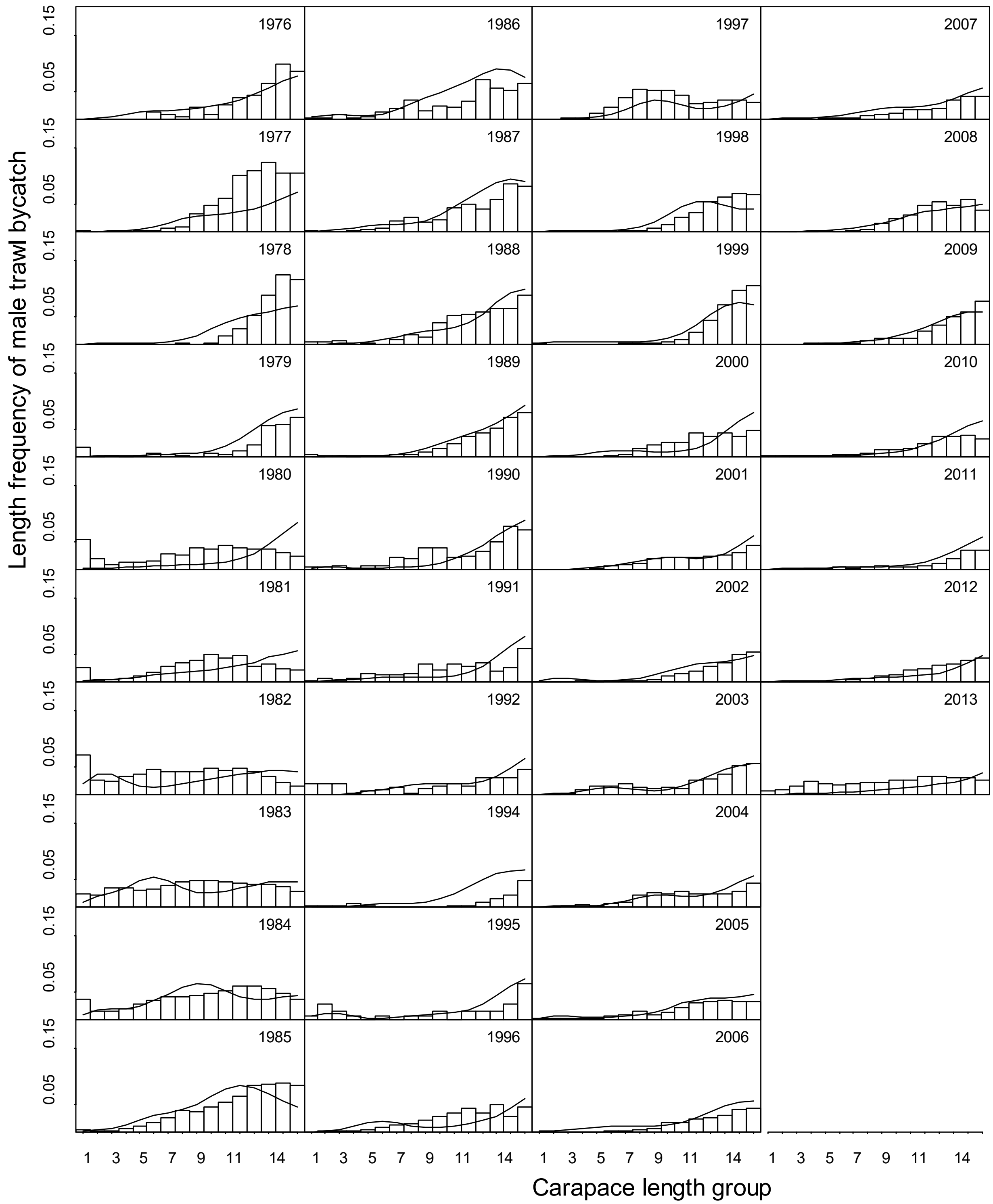

Figure 23(4nb). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish trawl fisheries under scenario 4nb. Pot handling mortality rate is 0.2, trawl bycatch mortality rate is 0.8, and the first length group is 67.5 mm.

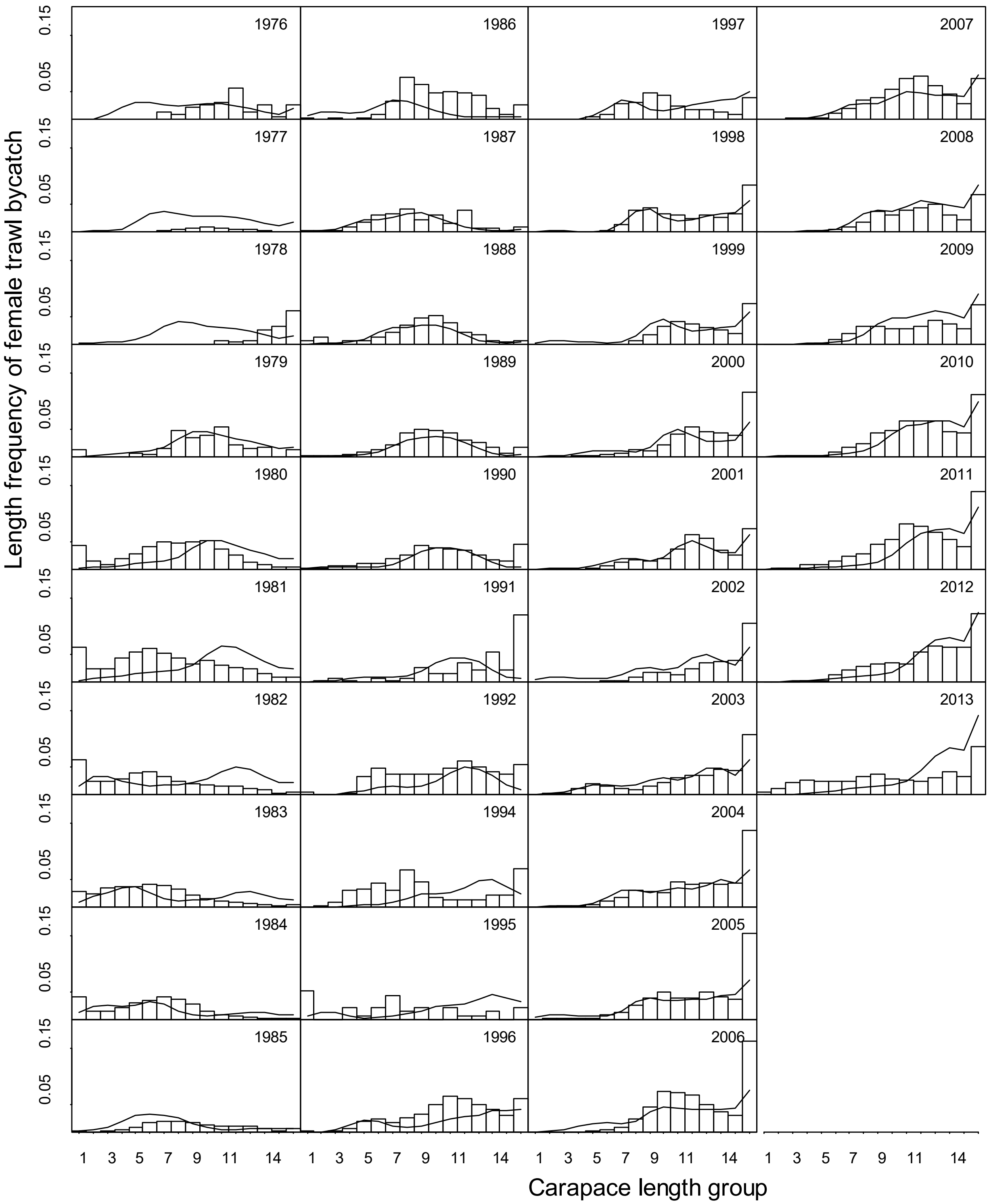

Figure 24(4na). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish trawl fisheries under scenario 4na. Pot handling mortality rate is 0.2, trawl bycatch mortality rate is 0.8, and the first length group is 67.5 mm.

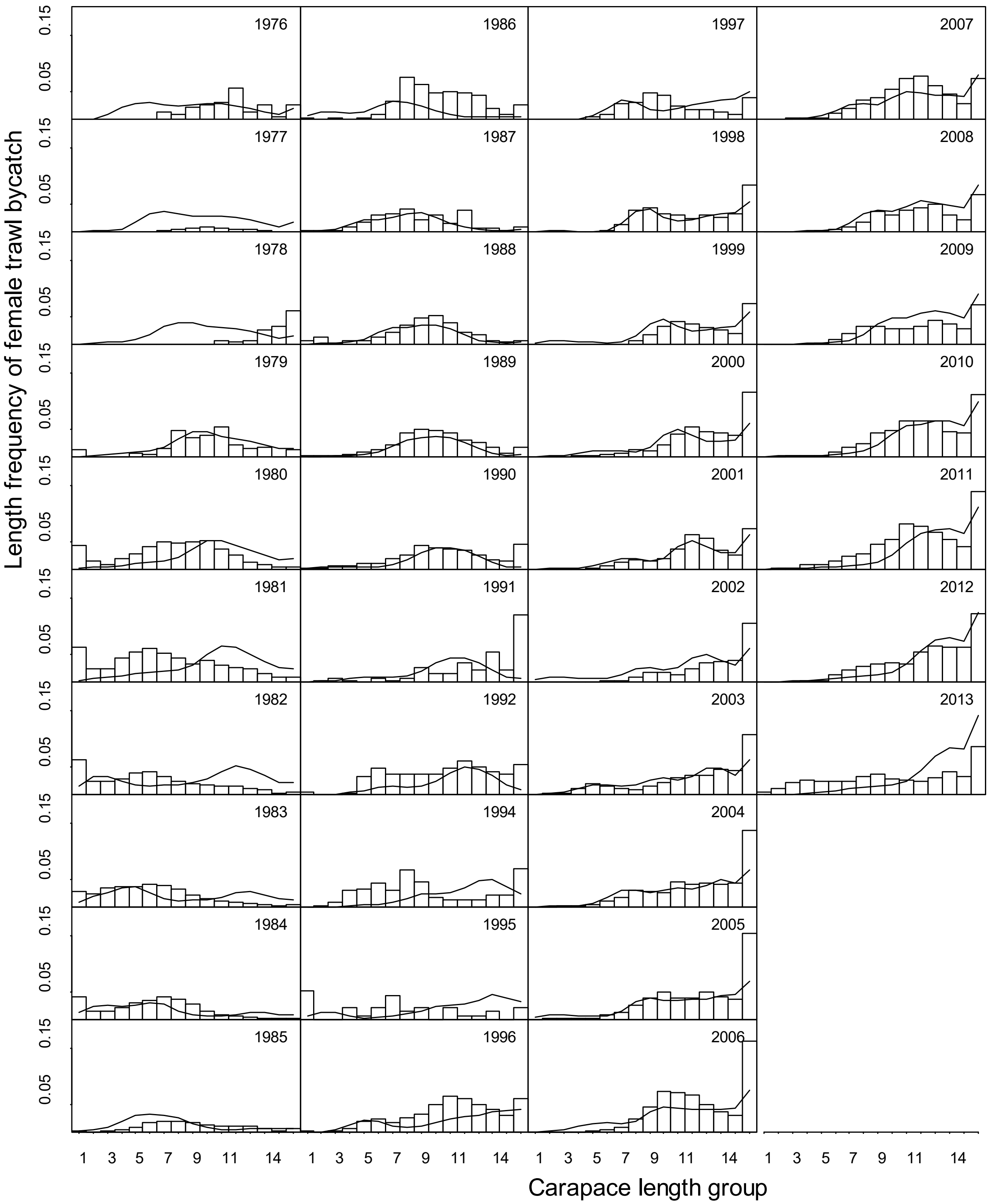

Figure 24(4nb). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish trawl fisheries under scenario 4nb. Pot handling mortality rate is 0.2, trawl bycatch mortality rate is 0.8, and the first length group is 67.5 mm.

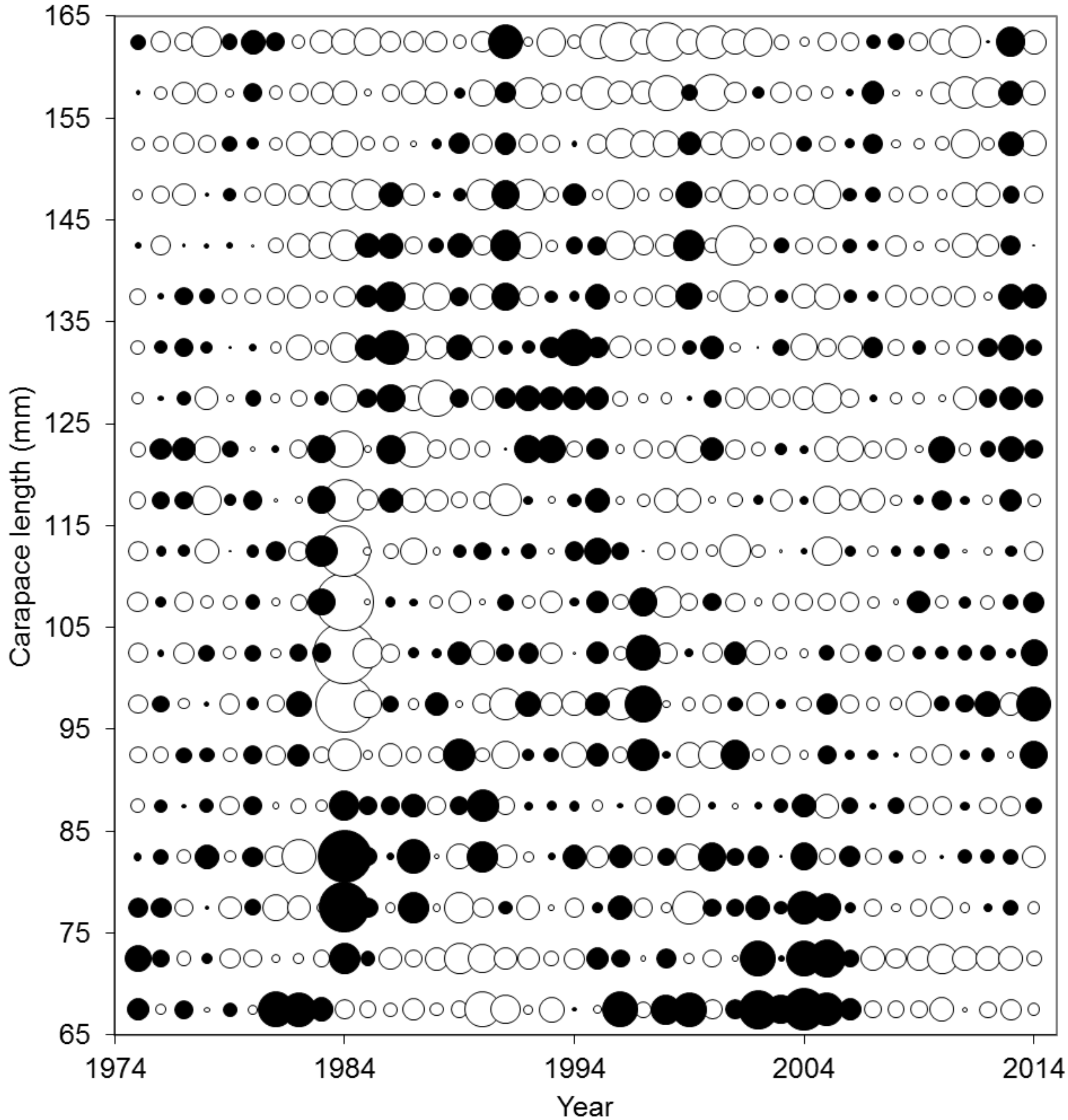

Figure 25. Standardized residuals of proportions of survey male red king crab under scenario 4na. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

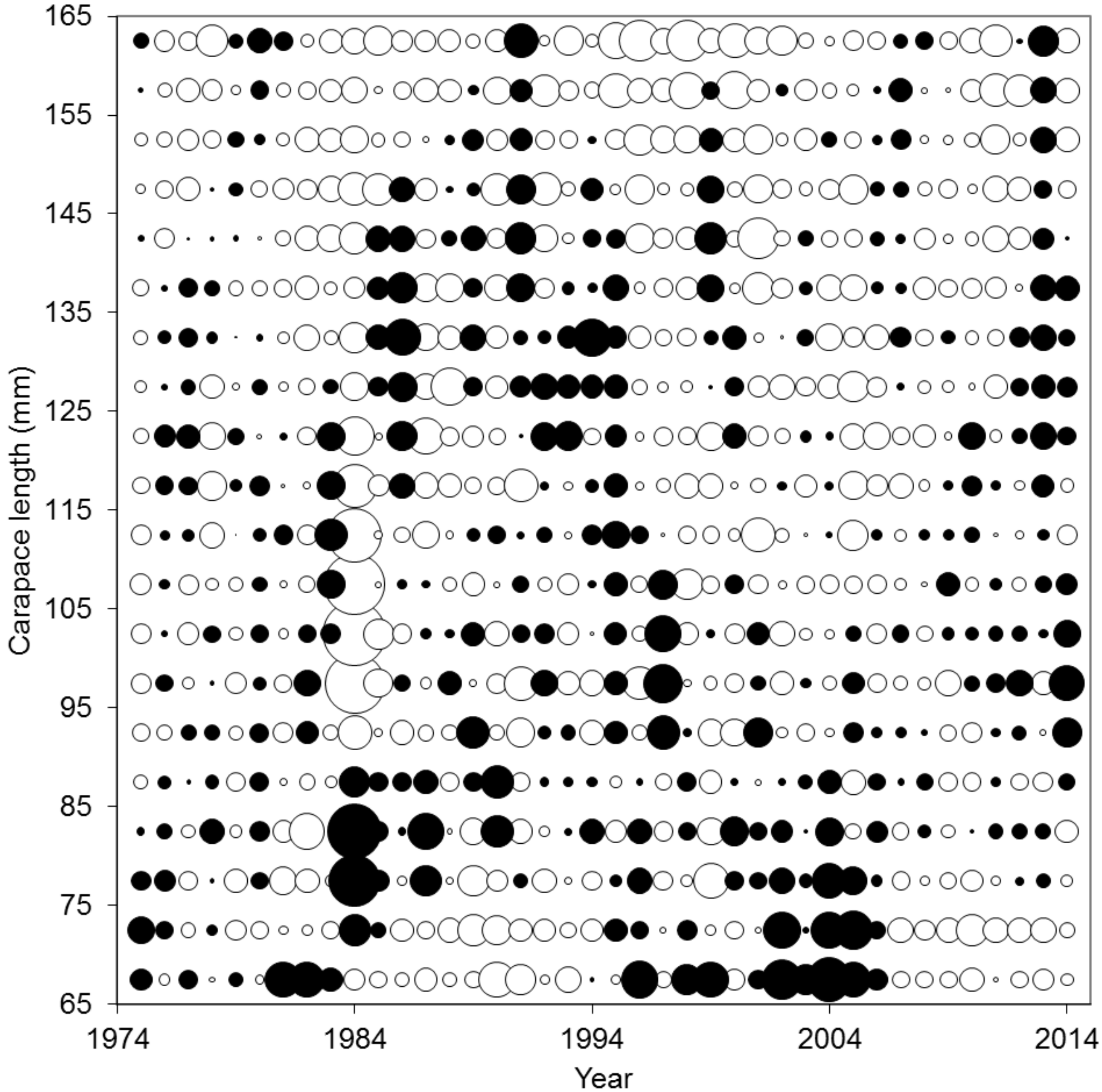

Figure 26. Standardized residuals of proportions of survey male red king crab under scenario 4nb. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

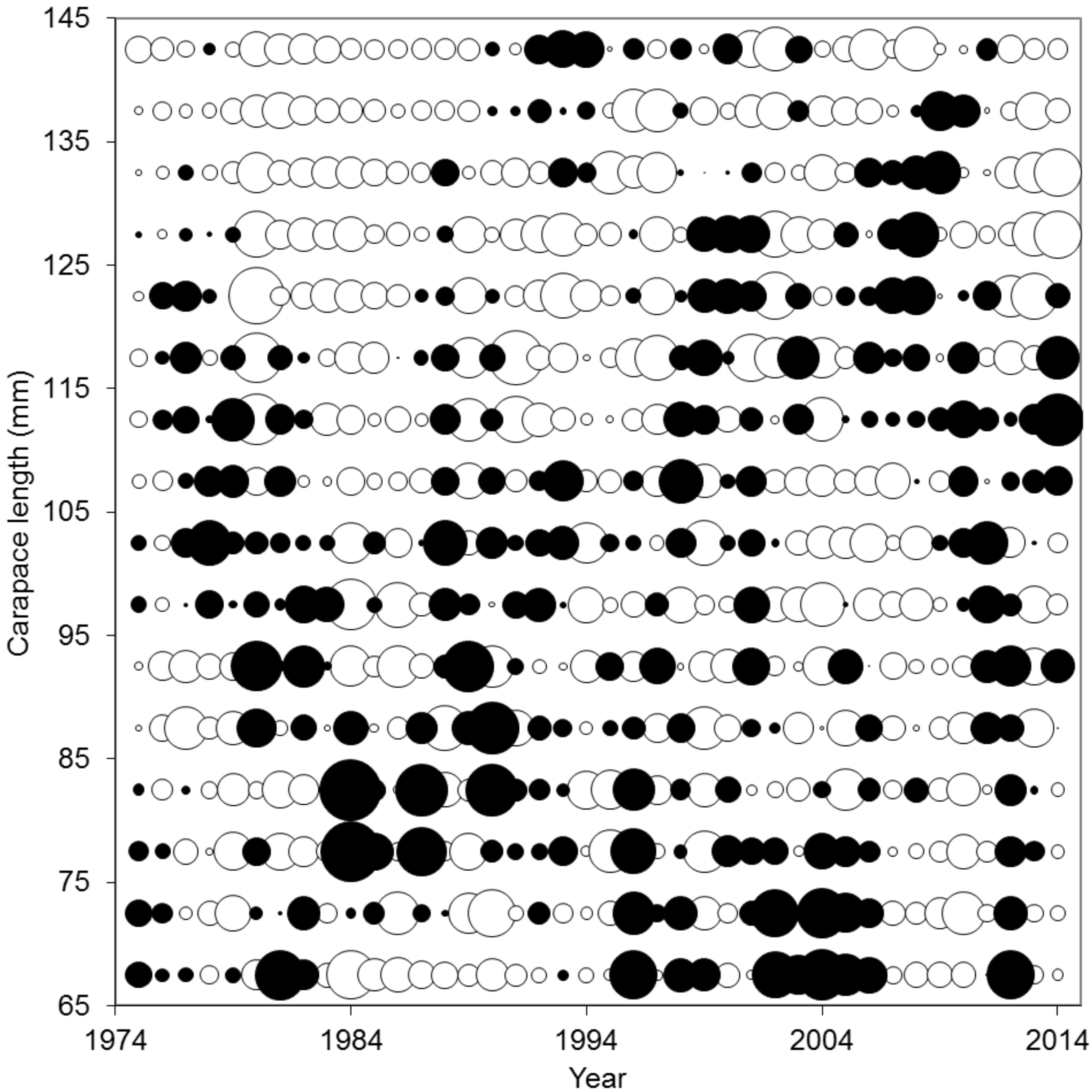

Figure 27(4na). Standardized residuals of proportions of survey female red king crab under scenario 4na. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

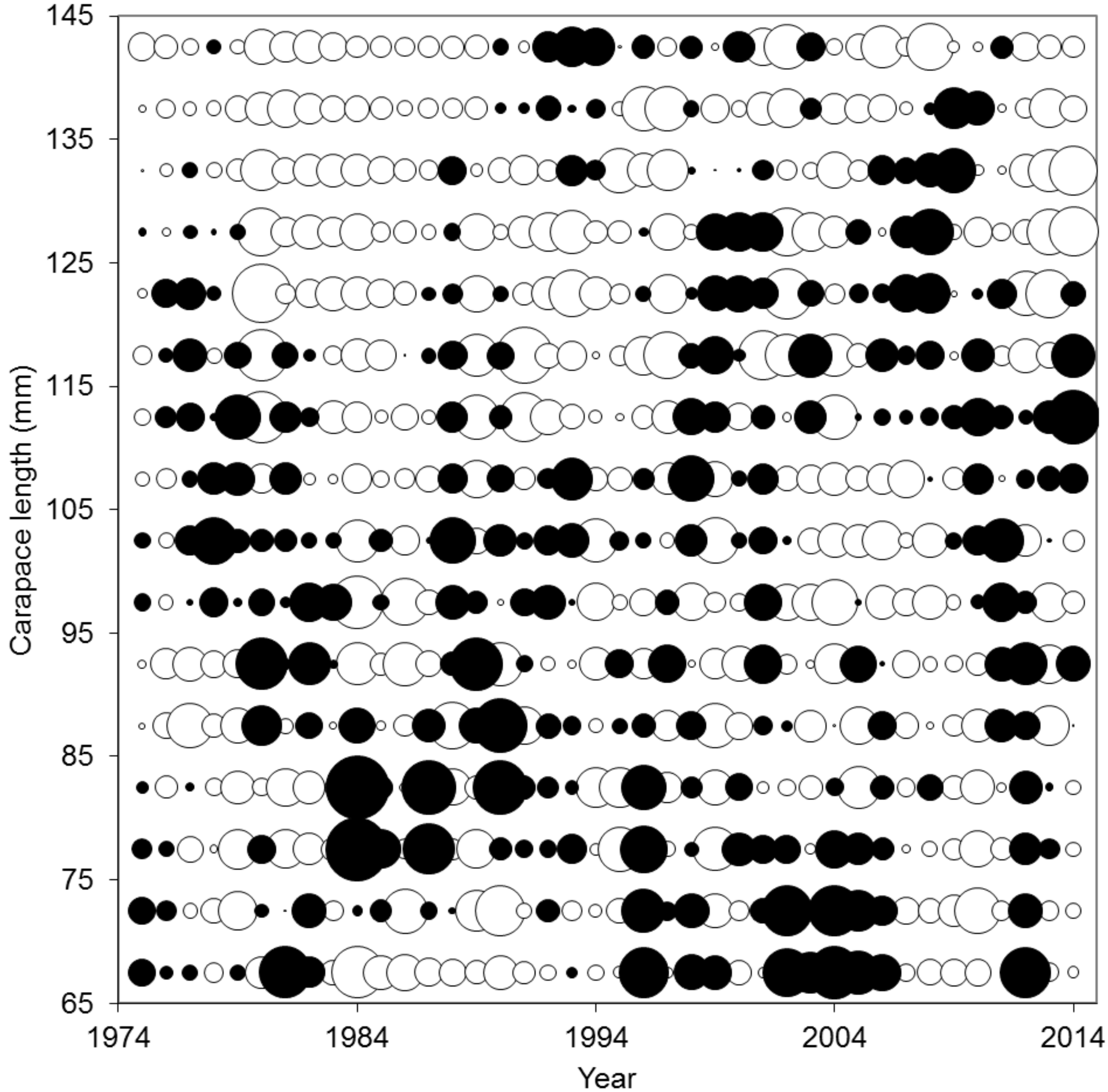

Figure 27(4nb). Standardized residuals of proportions of survey female red king crab under scenario 4nb. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

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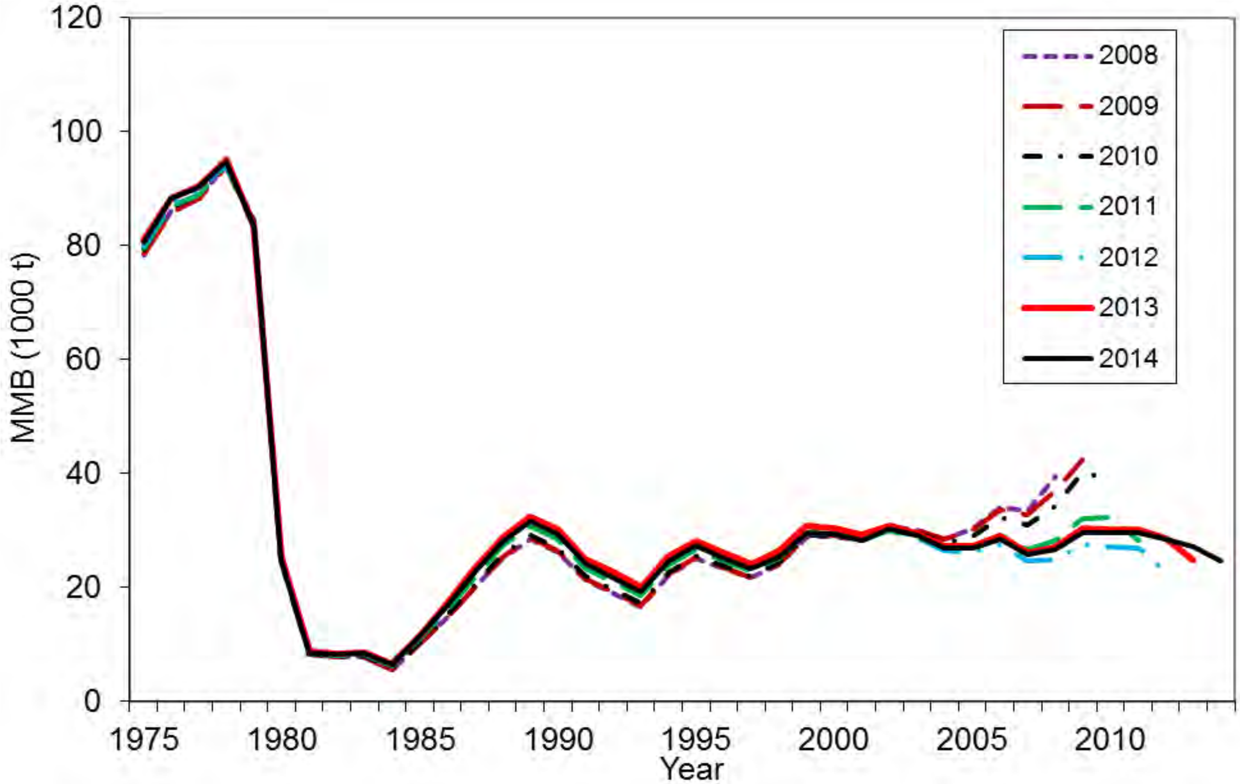

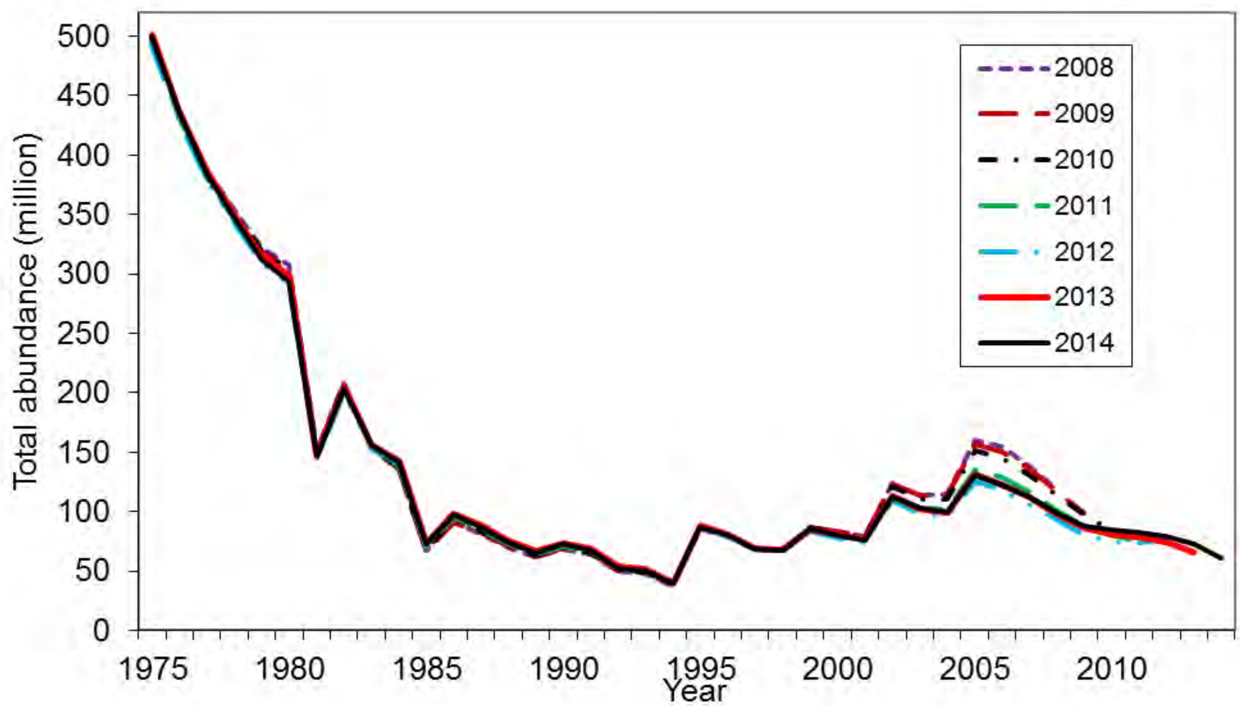

Figure 28(4nb). Comparison of hindcast estimates of mature male biomass on Feb. 15 (top) and total abundance (bottom) of Bristol Bay red king crab from 1975 to 2014 made with terminal years 2008-2014 with scenario 4nb. These are results of the 2014 model. Legend shows the terminal year. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

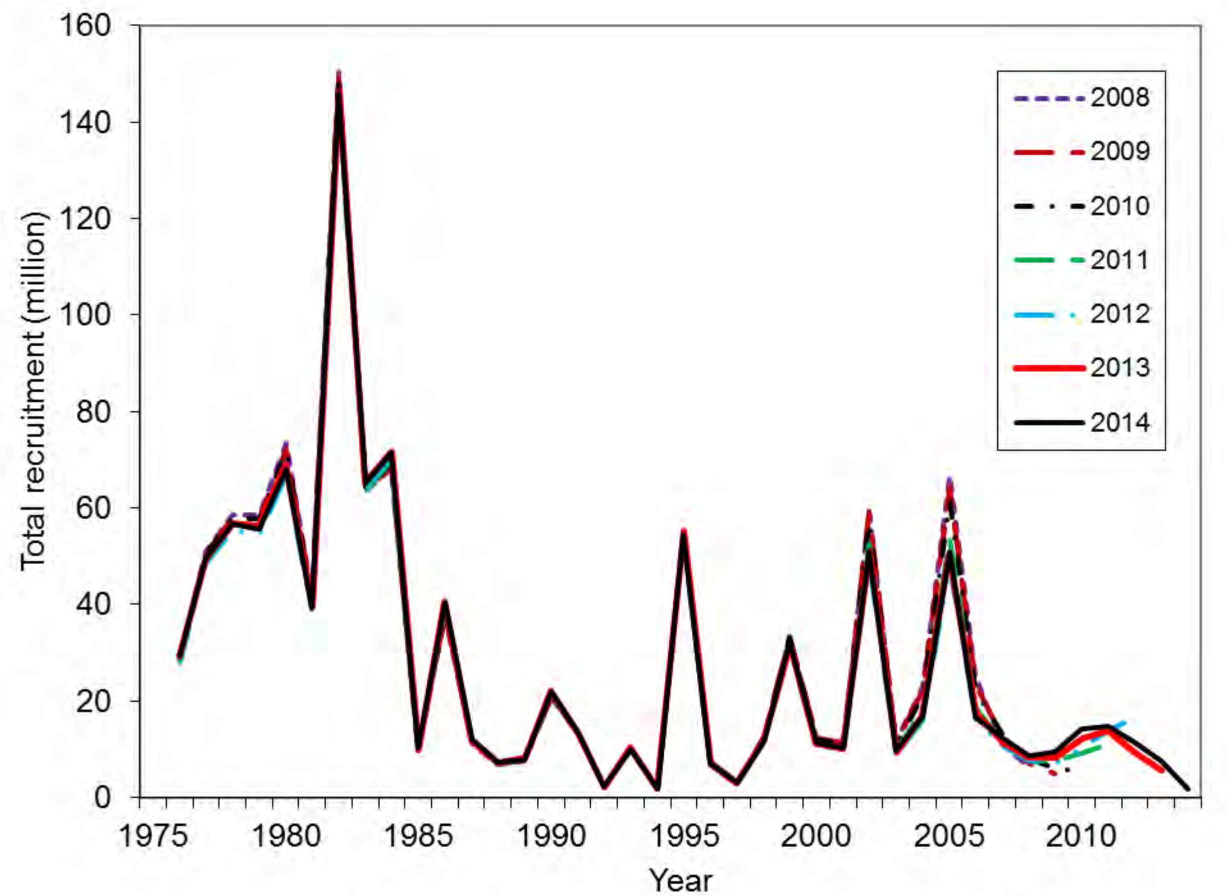

Figure 28(4nb). Comparison of hindcast estimates of total recruitment for scenario 4nb of Bristol Bay red king crab from 1976 to 2014 made with terminal years 2008-2014. These are results of the 2014 model. Legend shows the terminal year. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

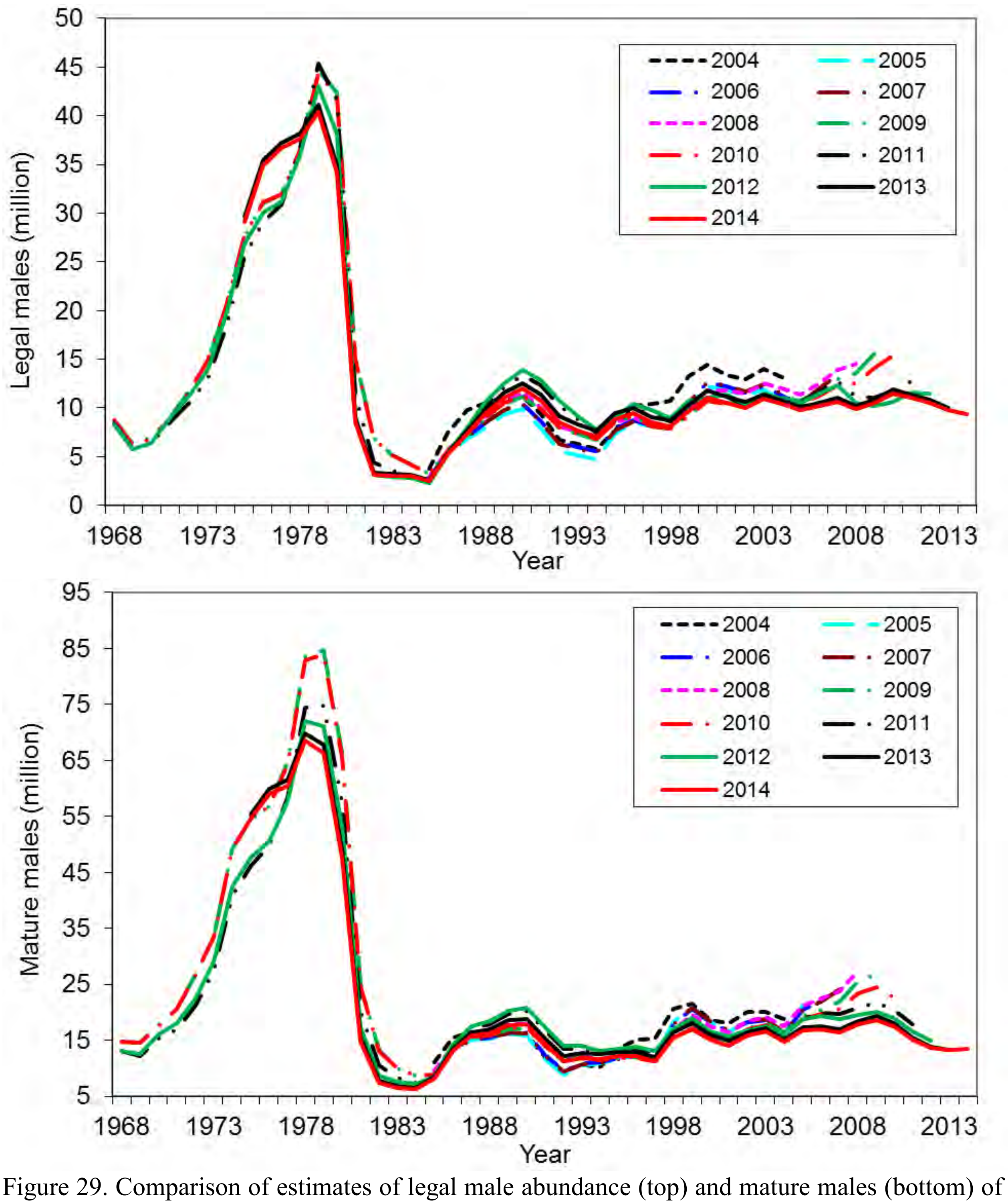

Figure 29. Comparison of estimates of legal male abundance (top) and mature males (bottom) of Bristol Bay red king crab from 1968 to 2014 made with terminal years 2004-2014 with the base scenarios. Scenario 4nb is used for 2014. These are results of historical assessments. Legend shows the year in which the assessment was conducted. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

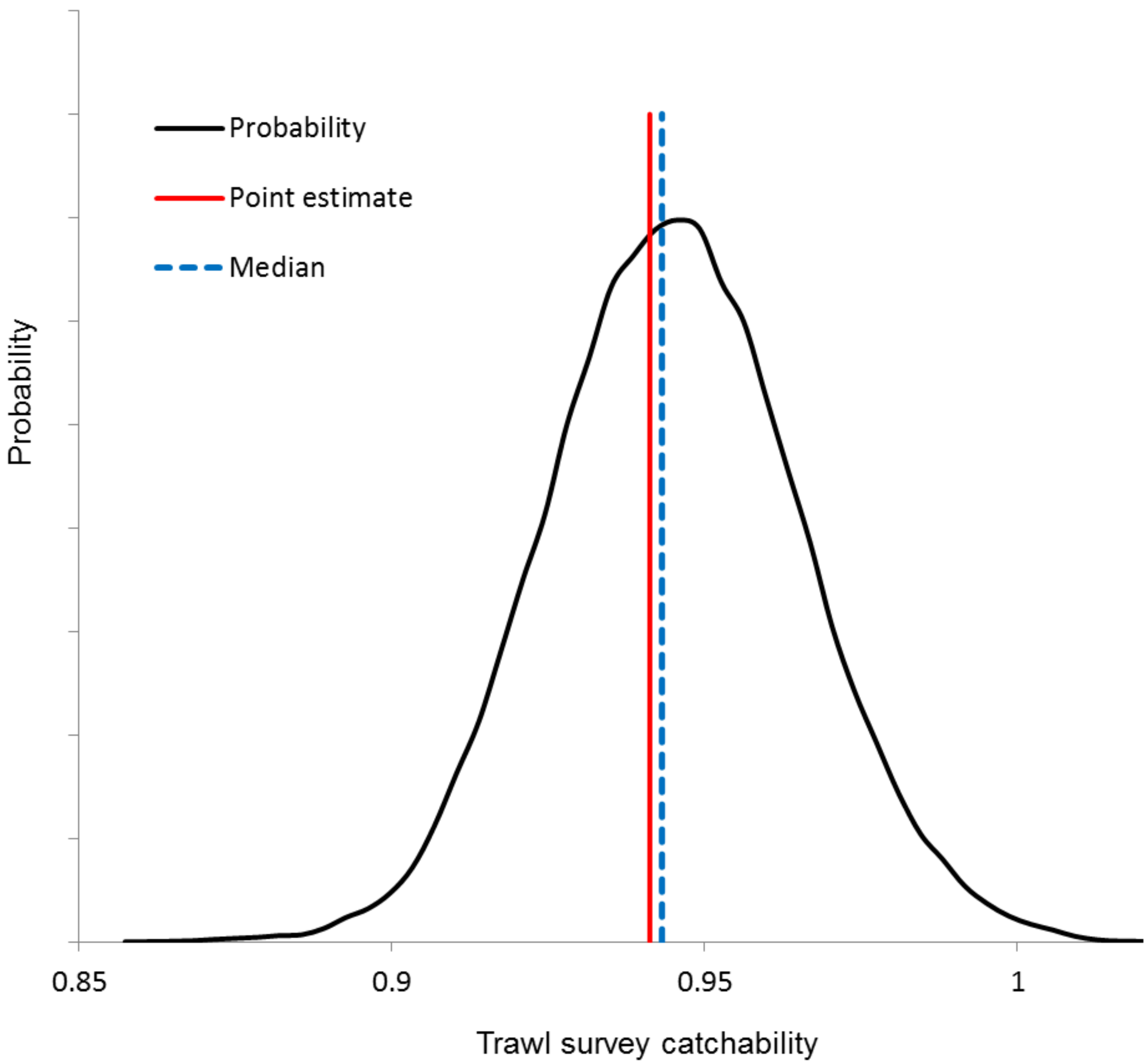

Figure 30(4nb). Probability distributions of estimated trawl survey catchability (*Q*) under scenario 4nb with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

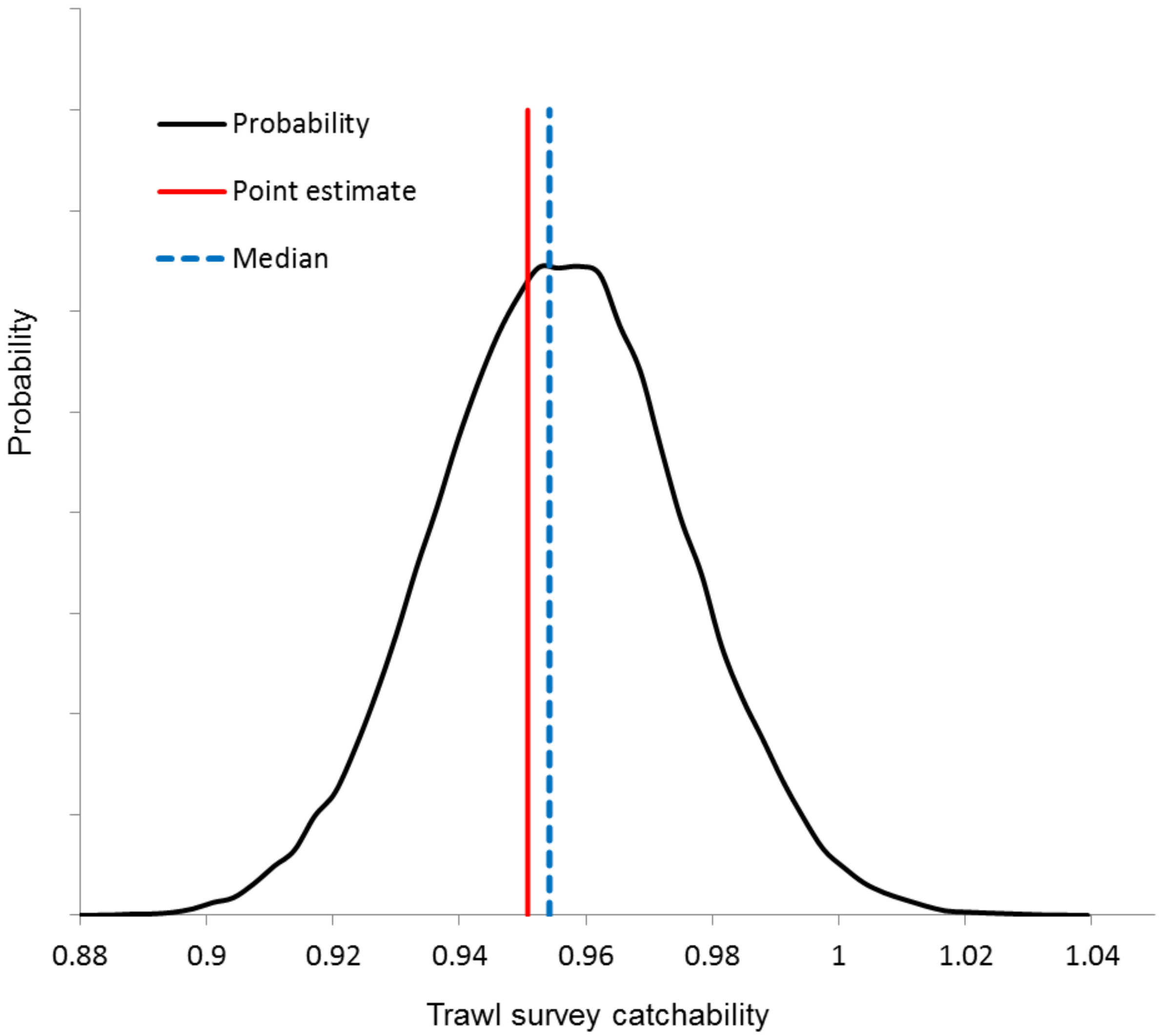

Figure 30(4n7). Probability distributions of estimated trawl survey catchability (*Q*) under scenario 4n7 with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

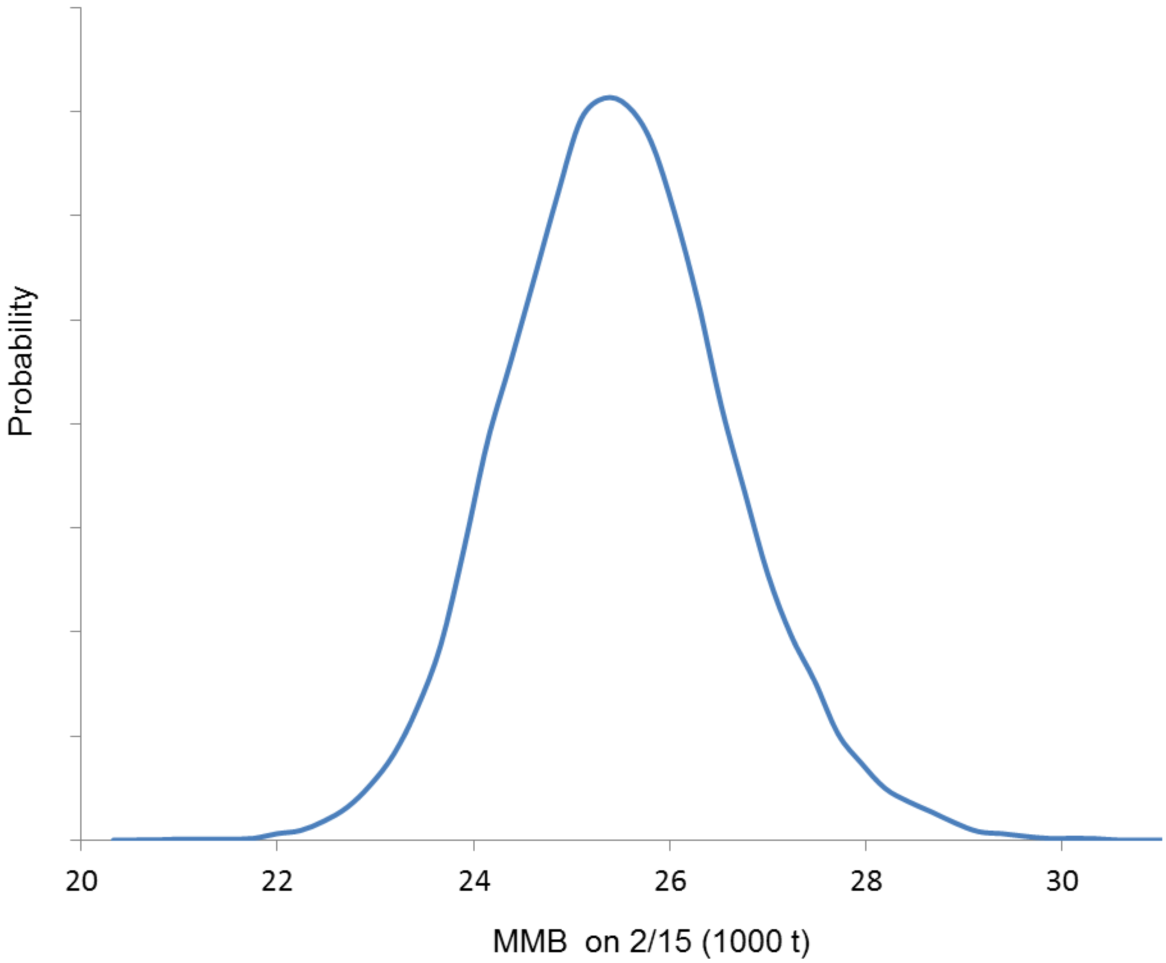

Figure 31a(4na). Probability distributions of estimated mature male biomass on Feb. 15, 2015 with $F_{35\%}$ under scenario 4na with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

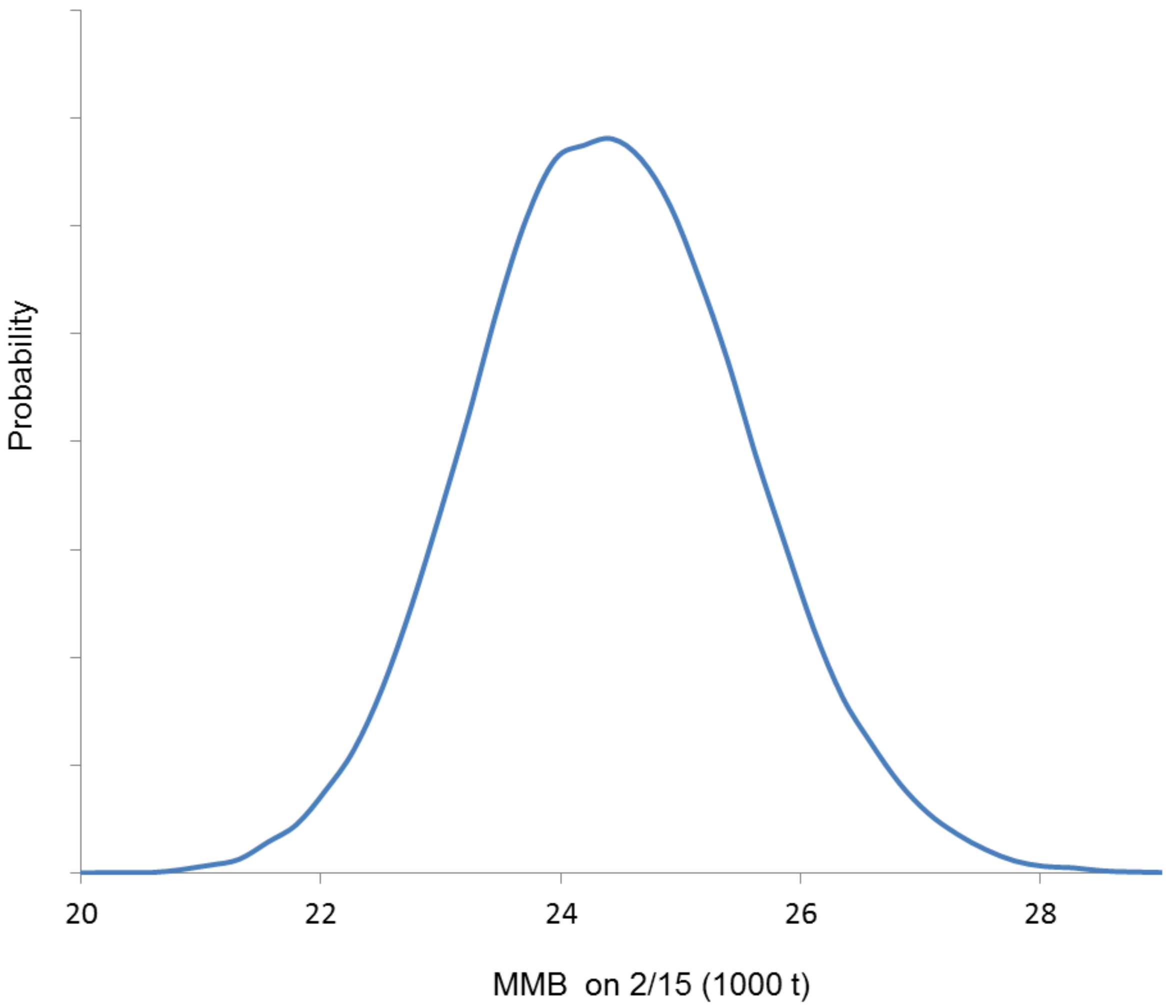

Figure 31a(4nb). Probability distributions of estimated mature male biomass on Feb. 15, 2015 with $F_{35\%}$ under scenario 4nb with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

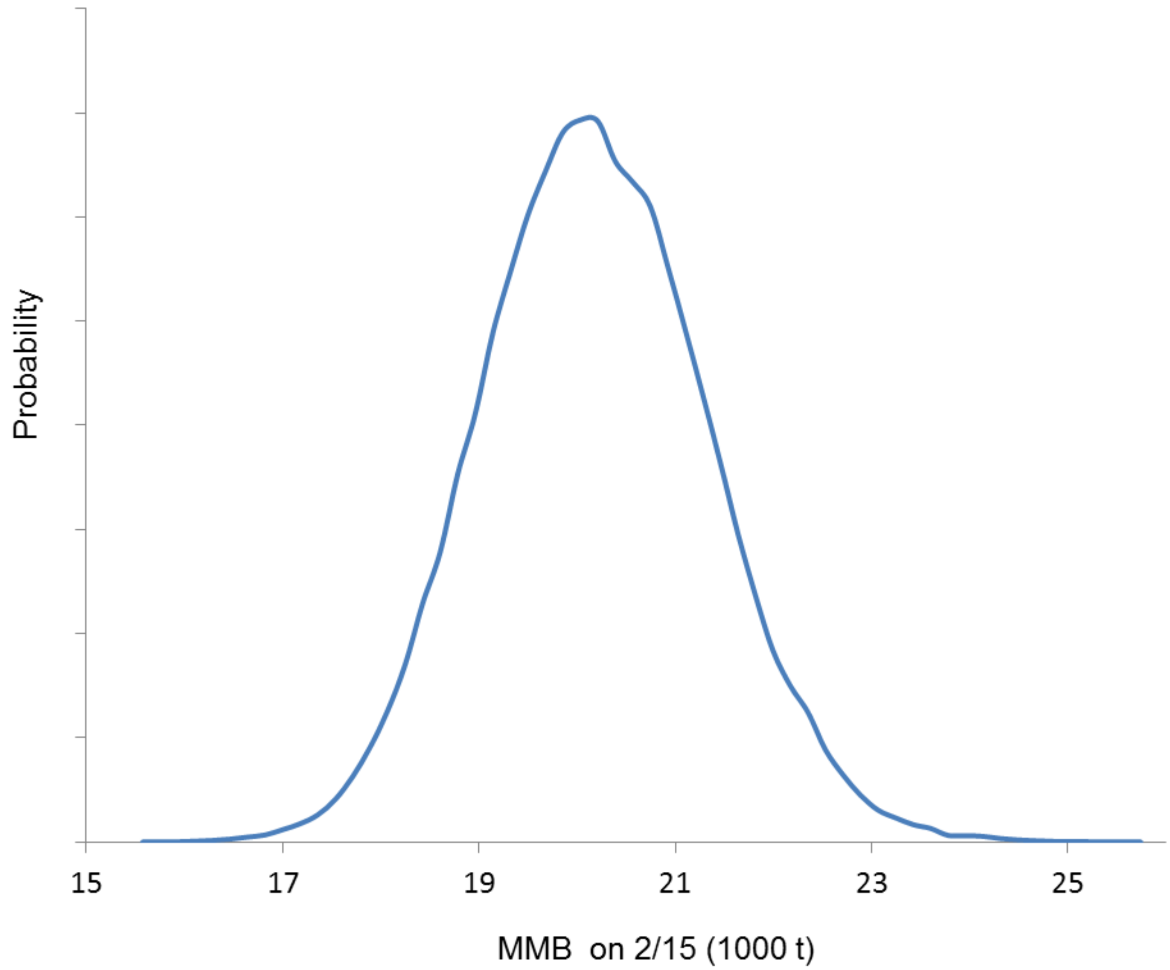

Figure 31a(4n7). Probability distributions of estimated mature male biomass on Feb. 15, 2015 with $F_{35\%}$ under scenario 4n7 with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

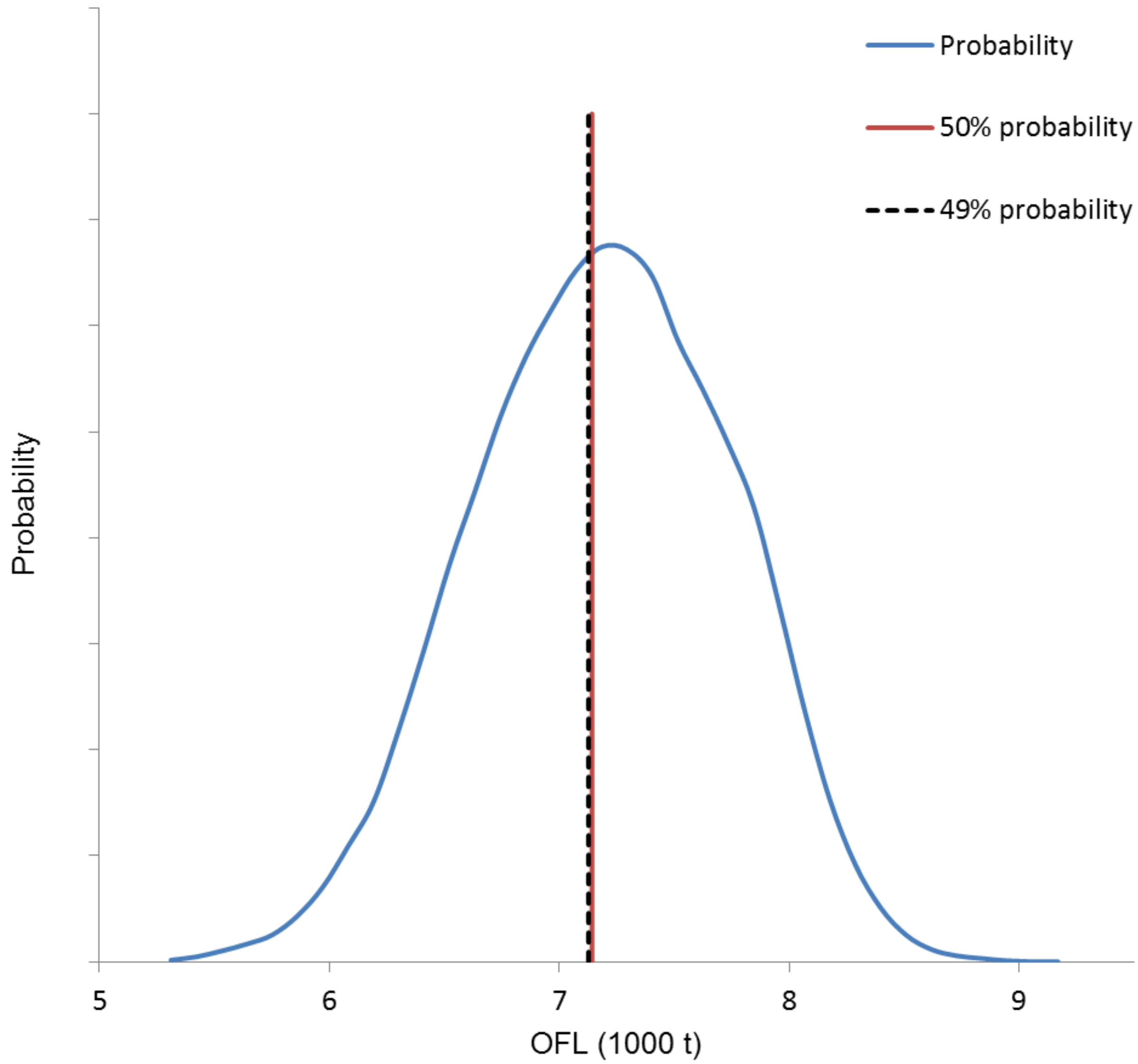

Figure 31b(4na). Probability distributions of the 2014 estimated OFL with scenario 4na with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

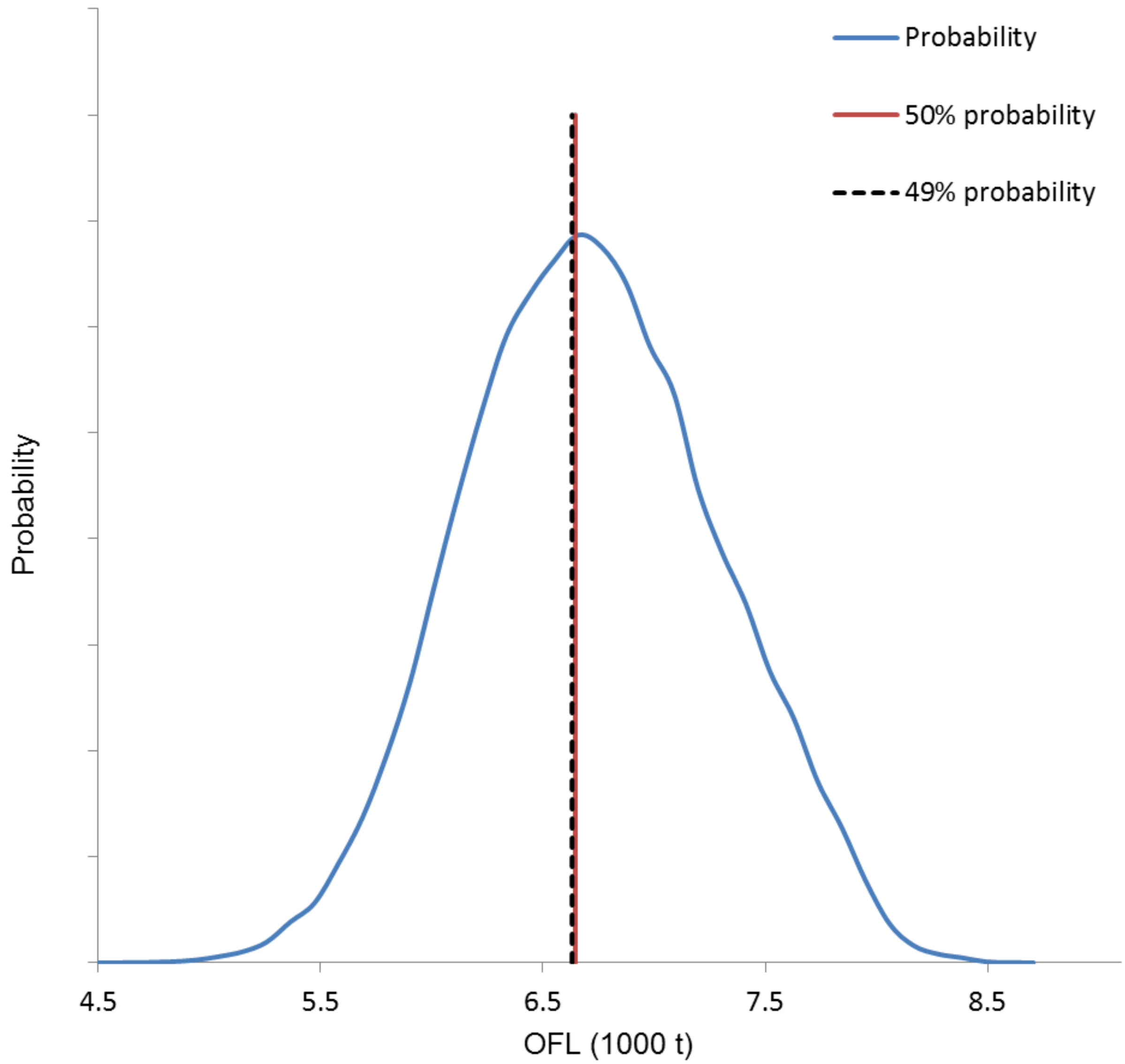

Figure 31b(4nb). Probability distributions of the 2014 estimated OFL with scenario 4nb with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

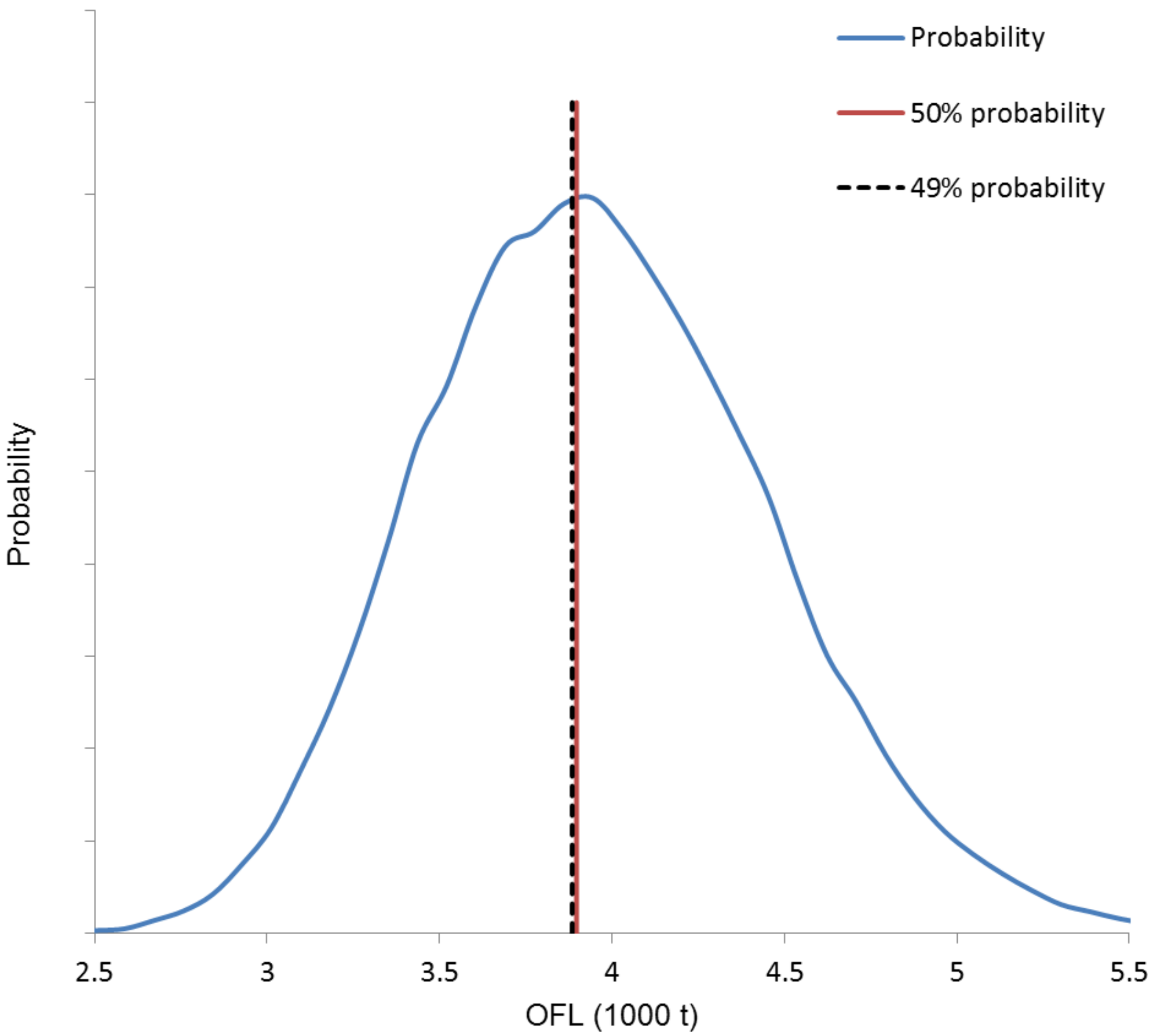

Figure 31b(4n7). Probability distributions of the 2014 estimated OFL with scenario 4n7 with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

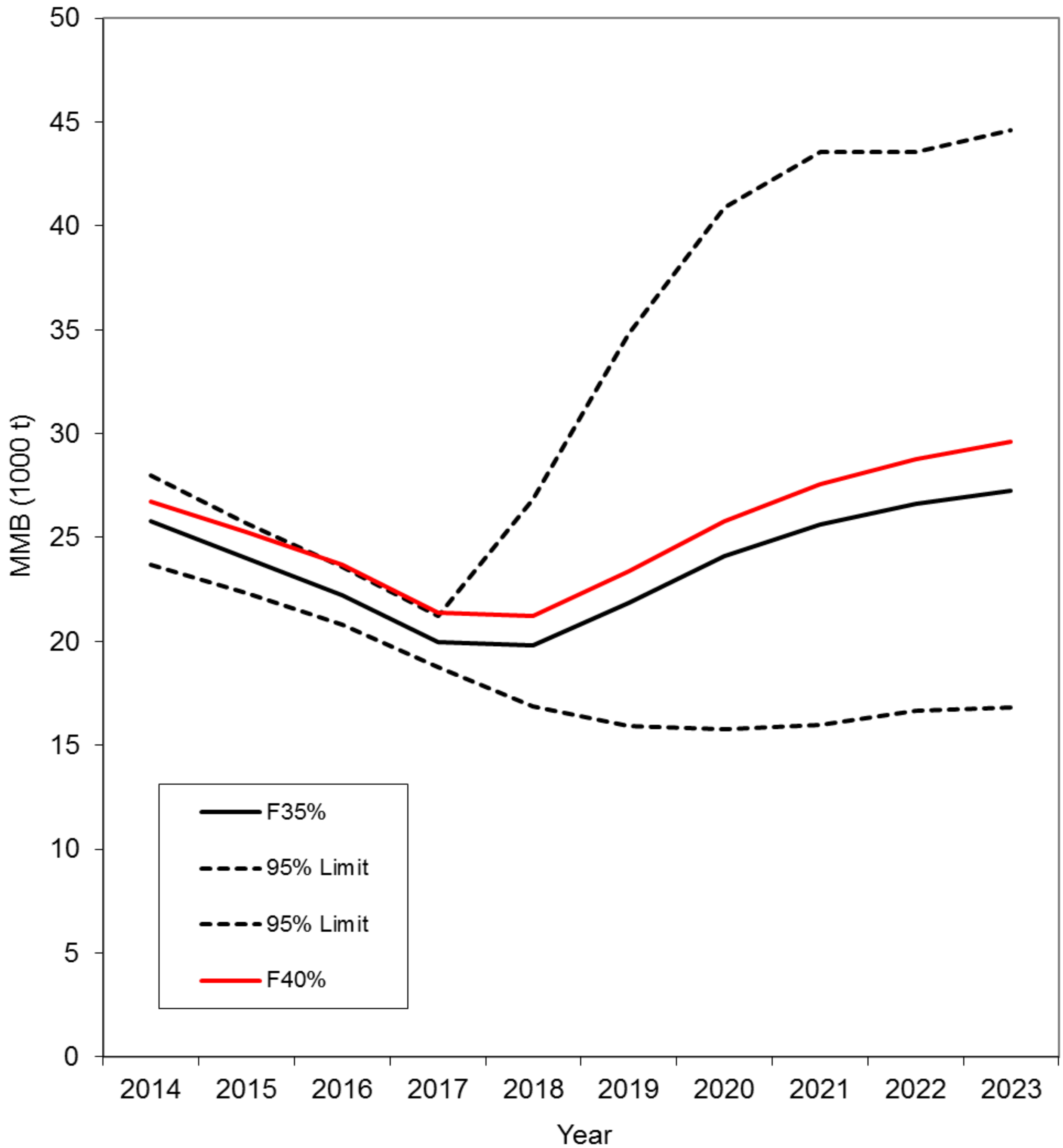

Figure 32(4na). Projected mature male biomass on Feb. 15 with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2014-2023. Input parameter estimates are based on scenario 4na. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

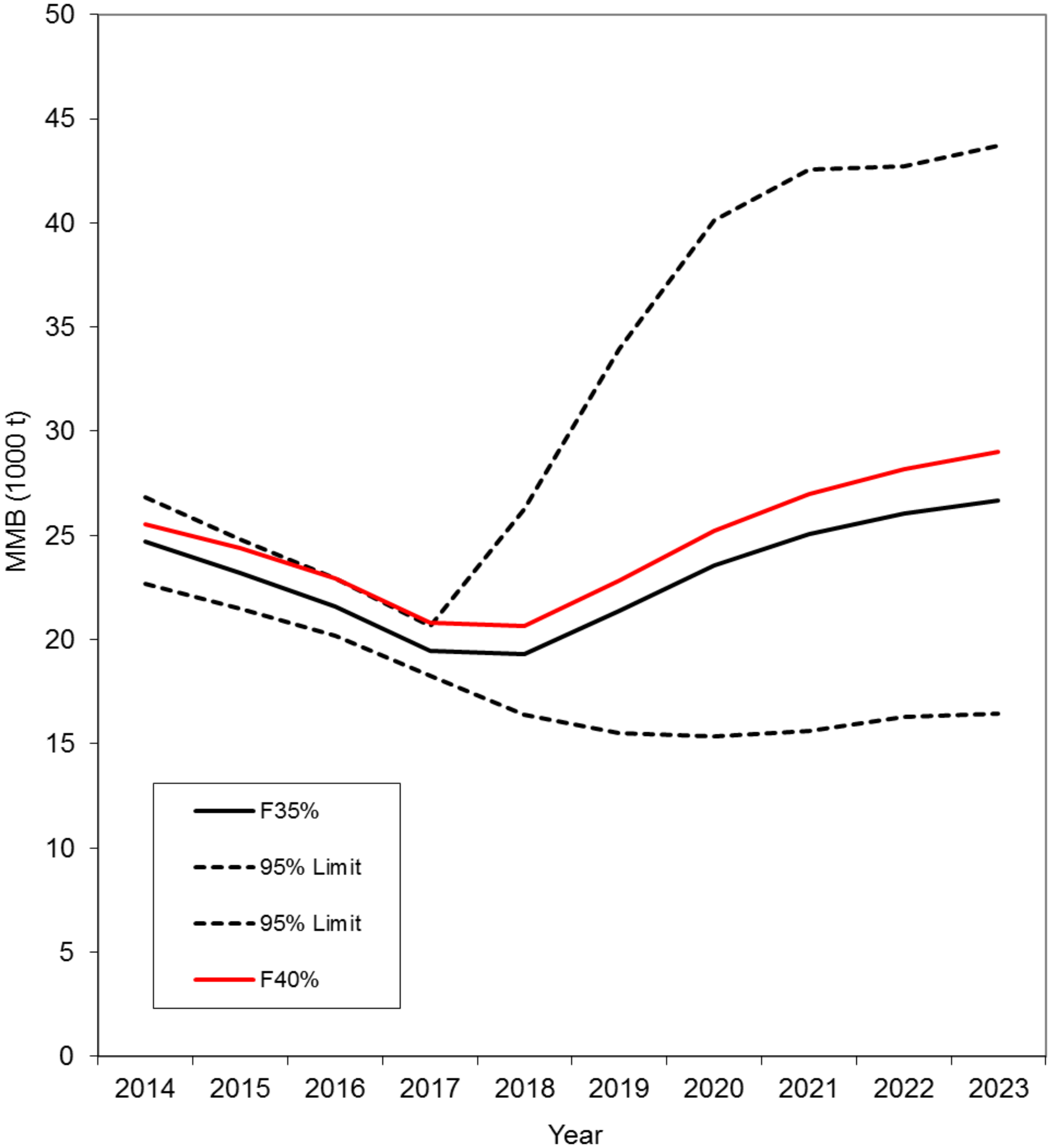

Figure 32(4nb). Projected mature male biomass on Feb. 15 with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2014-2023. Input parameter estimates are based on scenario 4nb. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

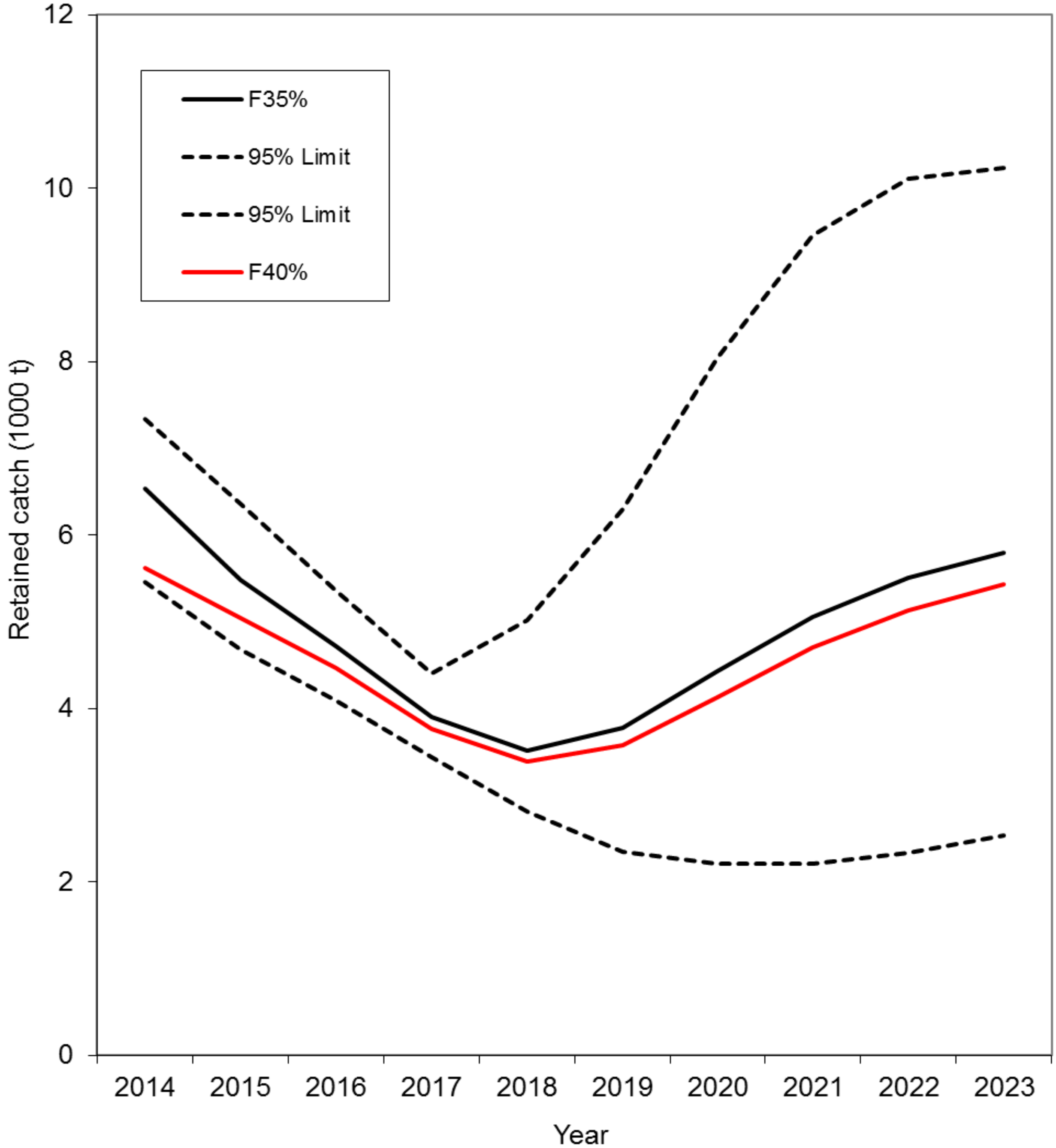

Figure 33(4na). Projected retained catch biomass with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2014-2123. Input parameter estimates are based on scenario 4na. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

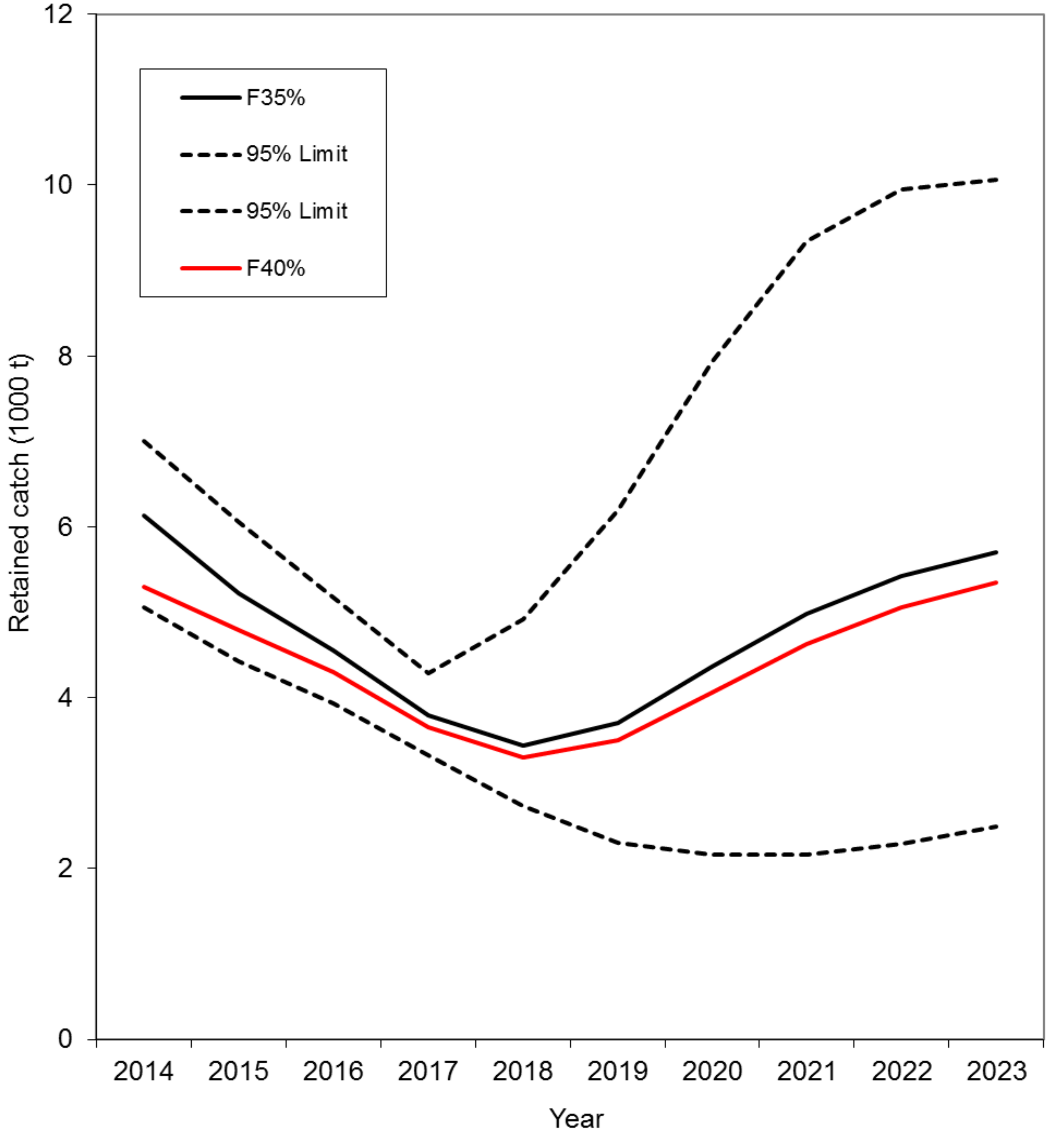

Figure 33(4nb). Projected retained catch biomass with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2014-2123. Input parameter estimates are based on scenario 4nb. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

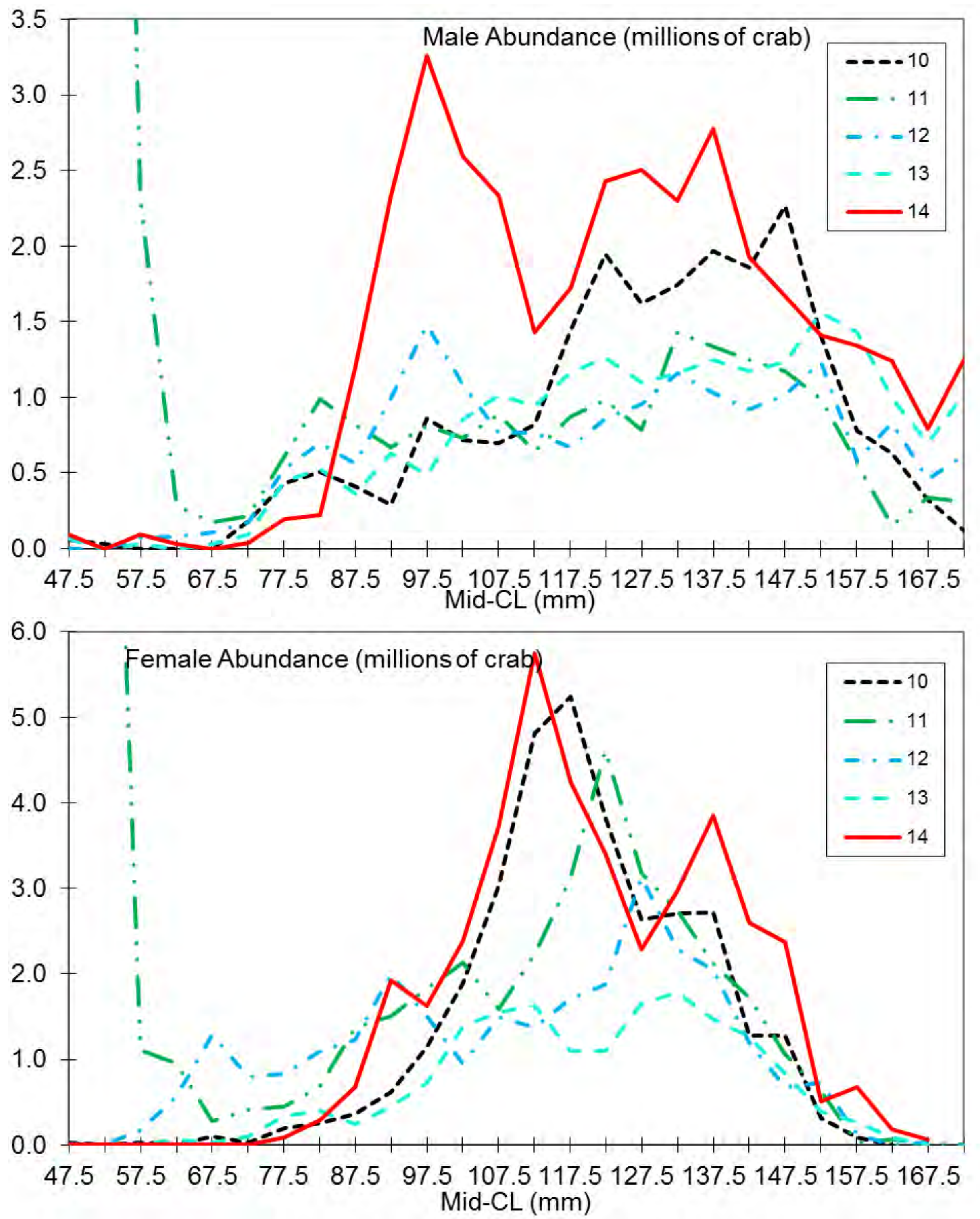

Figure 34. Length frequency distributions of male (top panel) and female (bottom panel) red king crab in Bristol Bay from NMFS trawl surveys during 2010-2014. For purposes of these graphs, abundance estimates are based on area-swept methods.

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Appendix A. Description of the Bristol Bay Red King Crab Model

a. Model Description

i. Population model

The original LBA model was described in detail by Zheng et al. (1995a, 1995b) and Zheng and Kruse (2002). Male crab abundances by carapace length and shell condition in any one year are modeled to result from abundances in the previous year minus catch and handling and natural mortalities, plus recruitment, and additions to or losses from each length class due to growth:

$$N_{l+1,t+1} = \sum_{l'=1}^{l'=l+1} \{P_{l',l+1}[(N_{l',t} + O_{l',t})\,e^{-M_t} - (C_{l',t} + D_{l',t})\,e^{(y_t-1)M_t} - T_{l,t}e^{(j_t-1)M_t}]\,m_{l',t}\} + R_{l+1,t+1},$$

$$O_{l+1,t+1} = [(N_{l+1,t} + O_{l+1,t})\,e^{-M_t} - (C_{l+1,t} + D_{l+1,t})\,e^{(y_t-1)M_t} - T_{l+1,t}e^{(j_t-1)M_t}](1 - m_{l+1,t}), \qquad (1)$$

where

$N_{l,t}$	is newshell crab abundance in length class l and year t,
$O_{l,t}$	is oldshell crab abundances in length class l and year t,
M	is the instantaneous natural mortality,
$m_{l,t}$	is the molting probability for length class l and year t,
$R_{l,t}$	is recruitment into length class l in year t,
y_t	is the lag in years between the assessment survey and the mid fishery time in year t,
j_t	is the lag in years between the assessment survey and the mid Tanner crab fishery time in year t,
$P_{l',l}$	is the proportion of molting crab growing from length class l' to l after one molt,
$C_{l,t}$	is the retained catch of length class l in year t, and
$D_{l,t}$	is the discarded mortality catch of length class l in year t, including directed pot and trawl bycatch,
$T_{l,t}$	is the discarded mortality catch of length class l in year t from the Tanner crab fishery.

The minimum carapace length for males is set at 65 mm, and crab abundance is modeled with a length-class interval of 5 mm. The last length class includes all crab ≥160-mm CL. There are 20 length classes/groups. $P_{l',l}$, m_l, $R_{l,t}$, $C_{l,t}$, and $D_{l,t}$ are computed as follows:

Mean growth increment per molt is assumed to be a linear function of pre-molt length:

$$G_l = a + b\,l, \qquad (2)$$

where a and b are constants. Growth increment per molt is assumed to follow a gamma distribution:

$$g(x \mid \alpha_l, \beta) = x^{\alpha_l -1}\ e^{-x/\beta} / [\beta^{\alpha_l}\ \Gamma(\alpha_l)]. \tag{3}$$

The expected proportion of molting individuals growing from length class l_1 to length class l_2 after one molt is equal to the sum of probabilities within length range [ι_1, ι_2] of the receiving length class l_2 at the beginning of the next year:

$$P_{l_1,l_2} = \int_{\iota_1 - \iota}^{\iota_2 - \iota} g(x \mid \alpha_l, \beta) dx, \tag{4}$$

where ι is the mid-length of length class l_1. For the last length class L, $P_{L,L} = 1$.

The molting probability for a given length class l is modeled by an inverse logistic function:

$$m_{l,t} = 1 - \frac{1}{1 + e^{-\beta\ (l - L_{50})}}, \tag{5}$$

where

β andL_{50} are parameters with three sets of values for three levels of molting probabilities, and ι is the mid-length of length class l.

Recruitment is defined as recruitment to the model and survey gear rather than recruitment to the fishery. Recruitment is separated into a time-dependent variable, R_t, and size-dependent variables, U_l, representing the proportion of recruits belonging to each length class. R_t is assumed to consist of crab at the recruiting age with different lengths and thus represents year class strength for year t. $R_{l,t}$ is computed as

$$R_{l,t} = R_t U_l, \tag{6}$$

where U_l is described by a gamma distribution similar to equations (3) and (4) with a set of parameters α_r and β_r. Because of different growth rates, recruitment was estimated separately for males and females under a constraint of approximately equal sex ratios of recruitment over time.

Before 1990, no observed bycatch data were available in the directed pot fishery; the crab that were discarded and died in those years were estimated as the product of handling mortality rate, legal harvest rates, and mean length-specific selectivities. It is difficult to estimate bycatch from the Tanner crab fishery before 1991. A reasonable index to estimate bycatch fishing mortalities is potlifts of the Tanner crab fishery within the distribution area of Bristol Bay red king crab. Thus, bycatch fishing mortalities from the Tanner crab fishery before 1991 were estimated to be proportional to the smoothing average of potlifts east of 163° W. The smoothing average is equal to $(P_{t-2}+2P_{t-1}+3P_t)/6$ for the potlifts in year t. The smoothing process not only smoothes the annual number of potlifts, it also indexes the effects of lost pots during the previous years. For bycatch, all fishery catch and discard mortality bycatch are estimated as:

$$C_{l,t}\ or\ D_{l,t} = (N_{l,t} + O_{l,t})\ e^{-y_t M_t} (1 - e^{-s_l F_t}) \tag{7}$$

where

s_l is selectivity for retained, pot or trawl discarded mortality catch of length class l, and

F_t is full fishing mortality of retained, pot or trawl discarded mortality catch in year t.

For discarded mortality bycatch from the Tanner crab fishery, y_t is replaced by j_t in the right side of equation (7).

The female crab model is the same as the male crab model except that the retained catch equals zero, molting probability equals 1.0 to reflect annual molting (Powell 1967), and growth matrix, P, changes over time due to change in size at maturity for females. The minimum carapace length for females is set at 65 mm, and the last length class includes all crab ≥140-mm CL, resulting in length groups 1-16. Three sets of growth increments per molt are used for females due to changes in sizes at maturity over time (Figures A2 and A3).

ii. Fisheries Selectivities

Retained selectivity, female pot bycatch selectivity, and both male and female trawl bycatch selectivity are estimated as a function of length:

$$s_l = \frac{1}{1 + e^{-\beta\ (\iota - L_{50})}}, \tag{8}$$

Different sets of parameters (β, L_{50}) are estimated for retained males, female pot bycatch, male and female trawl bycatch, and discarded males and females from the Tanner crab fishery. Because some catches were from the foreign fisheries during 1968-1972, a different set of parameters (β, L_{50}) are estimated for retained males for this period and a third parameter, sel_62.5mm, is used to explain the high proportion of catches in the last length group.

Male pot bycatch selectivity is modeled by two linear functions:

$$\begin{aligned} s_l &= \varphi + \kappa\,\iota, \quad \text{if } \iota < 135\,\text{mm CL}, \\ s_l &= s_{l-1} + 5\gamma, \quad \text{if } \iota > 134\,\text{mm CL} \end{aligned} \tag{9}$$

Where

φ, κ, γ are parameters.

During 2005-2012, a portion of legal males were also discarded in the pot fishery. The selectivity for this high grading was estimated to be the retained selectivity in each year times a high grading parameter, hg_t.

iii. Trawl Survey Selectivities/Catchability

Trawl survey selectivities/catchability are estimated as

$$s_l = \frac{Q}{1 + e^{-\beta\ (l - L_{50})}}, \qquad (10)$$

with different sets of parameters (β, L_{50}) estimated for males and females as well as two different periods (1975-81 and 1982-13). Survey selectivity for the first length group (67.5 mm) was assumed to be the same for both males and females, so only three parameters (β, L_{50} for females and L_{50} for males) were estimated in the model for each of the four periods. Parameter Q was called the survey catchability that was estimated based on a trawl experiment by Weinberg et al. (2004, Figure A1). Q was assumed to be constant over time.

Assuming that the BSFRF survey caught all crab within the area-swept, the ratio between NMFS abundance and BSFRF abundance is a capture probability for the NMFS survey net. The Delta method was used to estimate the variance for the capture probability. A maximum likelihood method was used to estimate parameters for a logistic function as an estimated capture probability curve (Figure A1). For a given size, the estimated capture probability is smaller based on the BSFRF survey than from the trawl experiment, but the Q value is similar between the trawl experiment and the BSFRF surveys (Figure A1). Because many small-sized crab are likely in the shallow water areas that are not accessible for the trawl survey, NMFS survey catchability/selectivity consists of capture probability and crab availability.

b. Software Used: AD Model Builder (Otter Research Ltd. 1994).

c. Likelihood Components

A maximum likelihood approach was used to estimate parameters. For length compositions ($p_{l,t,s,sh}$), the likelihood functions are :

$$Rf = \prod_{l=1}^{L}\prod_{t=1}^{T}\prod_{s=1}^{2}\prod_{sh=1}^{2} \frac{\left\{\exp\left[-\frac{(p_{l,t,s,sh} - \hat{p}_{l,t,s,sh})^2}{2\sigma^2}\right] + 0.01\right\}}{\sqrt{2\pi\sigma^2}}, \qquad (11)$$

$$\sigma^2 = \left[\hat{p}_{l,t,s,sh}(1 - \hat{p}_{l,t,s,sh}) + 0.1/L\right]/n,$$

where

L is the number of length groups,

T is the number of years, and

n is the effective sample size, which was estimated for trawl survey and pot retained catch and bycatch length composition data from the directed pot fishery, and was assumed to be 50 for groundfish trawl and Tanner crab fisheries bycatch length composition data.

The weighted negative log likelihood functions are:

$$
\begin{aligned}
&Length\ compositions: \quad -\sum \ln(Rf_i)\ ,\\
&Biomasses\ other\ than\ survey: \quad \lambda_j \sum \left[\ln(C_t / \hat{C}_t)^2\right],\\
&NMFS\ survey\ biomass: \quad \sum \left[\ln(B_t / \hat{B}_t)^2 / (2\ln(CV_t^2+1))\right],\\
&BSFRF\ mature\ males: \quad \sum [\ln(\ln(CV_t^2+1))^{0.5} + \ln(N_t / \hat{N}_t)^2 / (2\ln(CV_t^2+1))],\\
&R\ variation: \quad \lambda_R \sum [\ln(R_t / \overline{R})^2]\ ,\\
&R\ sex\ ratio: \quad \lambda_s [\ln(\overline{R}_M / \overline{R}_F)^2]\ ,\\
&Trawl\ bycatch\ fishing\ mortalities: \lambda_t [\ln(F_{t,t} / \overline{F}_t)^2]\ ,\\
&Pot\ female\ bycatch\ fishing\ mortalities: \lambda_p [\ln(F_{t,f} / \overline{F}_f)^2],\\
&Trawl\ survey\ catchability: (Q-\hat{Q})^2 / (2\sigma^2).
\end{aligned}
\tag{12}
$$

Where

R_t is the recruitment in year t,

$\overline{R}$ is the mean recruitment,

$\overline{R}_M$ is the mean male recruitment,

$\overline{R}_F$ is the mean female recruitment,

$\overline{F}_t$ is the mean trawl bycatch fishing mortality,

$\overline{F}_f$ is the mean pot female bycatch fishing mortality,

Q is summer trawl survey catchability,

σ is the estimated standard deviation of Q.

For BSFRF mature male abundance or total survey biomass, *CV* is the survey *CV* plus *AV*, where *AV* is additional *CV* and estimated in the model. The mature male abundance is used for all scenarios except scenario 2. Total survey biomass is used for scenario 2.

Weights λ_j are assumed to be 500 for retained catch biomass, and 100 for all bycatch biomasses, 2 for recruitment variation, 10 for recruitment sex ratio, 0.2 for pot female bycatch fishing mortality and 0.1 for trawl bycatch fishing mortality. These λ_j values represent prior assumptions about the accuracy of the observed catch biomass data and about the variances of these random variables.

d. Population State in Year 1.

The total abundance and proportions for the first year are estimated in the model.

e. Parameter estimation framework:

i. Parameters estimated independently

Basic natural mortality, length-weight relationships, and mean growth increments per molt were estimated independently outside of the model. Mean length of recruits to the model depends on growth and was assumed to be 72.5 for both males and females. High grading parameters hg_t were estimated to be 0.2785 in 2005, 0.0440 in 2006, 0.0197 in 2007, 0.0198 in 2008, 0.0337 in 2009, 0.0153 in 2010, 0.0113 in 2011, and 0.0240 in 2012, based on the proportions of discarded legal males to total caught legal males. Handling mortality rates were set to 0.2 for the directed pot fishery, 0.25 for the Tanner crab fishery, and 0.8 for the trawl fisheries.

(1). Natural Mortality

Based on an assumed maximum age of 25 years and the 1% rule (Zheng 2005), basic M was estimated to be 0.18 for both males and females. Natural mortality in a given year, M_t, equals to $M + Mm_t$ (for males) or $M + Mf_t$ (females). One value of Mm_t during 1980-1985 was estimated and two values of Mf_t during 1980-1984 and 1976-79, 1985-93 were estimated in the model.

(2). Length-weight Relationship

Length-weight relationships for males and females were as follows:

$$\begin{aligned} &\text{Immature Females:} && W = 0.000408\, L^{3.127956}, \\ &\text{Ovigerous Females:} && W = 0.003593\, L^{2.666076}, \\ &\text{Males:} && W = 0.0004031\, L^{3.141334}, \end{aligned} \tag{13}$$

where

W is weight in grams, and
L is CL in mm.

(3). Growth Increment per Molt

A variety of data are available to estimate male mean growth increment per molt for Bristol Bay RKC. Tagging studies were conducted during the 1950s, 1960s and 1990s, and mean growth increment per molt data from these tagging studies in the 1950s and 1960s were analyzed by Weber and Miyahara (1962) and Balsiger (1974). Modal analyses were conducted for the data during 1957-1961 and the 1990s (Weber 1967, Loher et al. 2001). Mean growth increment per molt may be a function of body size and shell condition and vary over time (Balsiger 1974, McCaughran and Powell 1977); however, for simplicity, mean growth increment per molt was assumed to be only a function of body size in the models. Tagging data were used to estimate mean growth increment per molt as a function of pre-molt length for males (Figure A2). The results from modal analyses of 1957-1961 and the 1990s were used to estimate mean growth increment per molt for immature females during 1975-1993 and 1994-2013, respectively, and the data presented in Gray (1963) were used to estimate those for mature females (Figure A2). To make a smooth transition of growth increment per molt from immature to mature females, weighted growth increment averages of 70% and 30% at 92.5 mm CL pre-molt length and 90% and 10% at 97.5 mm CL were used, respectively, for mature and immature females during 1983-1993. These percentages are roughly close to the composition of maturity. During 1975-1982, females matured at a smaller size, so the growth increment per molt as a function of length was shifted to smaller increments. Likewise, during 1994-2013, females matured at a slightly higher size, so the growth increment per molt was shifted to high increments for immature crab (Figure A2). Once mature, the growth increment per molt for male crab decreases slightly and annual molting probability decreases, whereas the growth increment for female crab decreases dramatically but annual molting probability remains constant at 1.0 (Powell 1967).

(4). Sizes at Maturity for Females

NMFS collected female reproductive condition data during the summer trawl surveys. Mature females are separated from immature females by a presence of egg clutches or egg cases. Proportions of mature females at 5-mm length intervals were summarized and a logistic curve was fitted to the data each year to estimate sizes at 50% maturity. Sizes at 50% maturity are illustrated in Figure A3 with mean values for three different periods (1975-82, 1983-93 and 1994-08).

(5). Sizes at Maturity for Males

Although size at sexual maturity for Bristol Bay red king crab males has been estimated (Paul et al. 1991), there are no data for estimating size of functional maturity collected in the natural environment. Sizes at functional maturity for Bristol Bay male RKC have been assumed to be 120 mm CL (Schmidt and Pengilly 1990). This is based on mating pair data collected off Kodiak Island (Figure A4). Sizes at maturity for Bristol Bay female RKC are about 90 mm CL, about 15 mm CL less than Kodiak female RKC (Pengilly et al. 2002). The size ratio of mature males to females is 1.3333 at sizes at maturity for Bristol Bay RKC, and since mature males grow at much larger increments than mature females, the mean size ratio of mature males to females is most likely larger than this ratio. Size ratios of the large majority of Kodiak mating pairs were less than 1.3333, and in some bays, only a small proportion of mating pairs had size ratios above 1.3333 (Figure A4).

In the laboratory, male RKC as small as 80 mm CL from Kodiak and SE Alaska can successfully mate with females (Paul and Paul 1990). But few males less than 100 mm CL were observed to mate with females in the wild. Based on the size ratios of males to females in the Kodiak mating pair data, setting 120 mm CL as a minimum size of functional maturity for Bristol Bay male RKC is proper in terms of managing the fishery.

(6) Potential Reasons for High Mortality during the Early 1980s

Bristol Bay red king crab abundance had declined sharply during the early 1980s. Many factors have been speculated for this decline: (i) completely wiped out by fishing: the directed pot fishery, the other directed pot fishery (Tanner crab fishery), and bottom trawling; and (ii) high fishing and natural mortality. With the survey abundance, harvest rates in 1980 and 1981 were among the highest, thus the directed fishing definitely had a big impact on the stock decline, especially legal and mature males. However, for the sharp decline during 1980-1884 for males, 3 out of 5 years had low mature harvest rates. During 1981-1984 for females, 3 out of 4 years had low mature harvest rates. Also pot catchability for females and immature males are generally much lower than for legal males, so the directed pot fishing alone cannot explain the sharp decline for all segments of the stock during the early 1980s.

Red king crab bycatch in the eastern Bering Sea Tanner crab fishery is another potential factor (Griffin et al. 1983). The main overlap between Tanner crab and Bristol Bay red king crab is east of 163° W. No absolute red king crab bycatch estimates are available until 1991. So there are insufficient data to fully evaluate the impact. Retained catch and potlifts from the eastern Bering Sea Tanner crab fishery are illustrated in Figure A5. The observed red king crab bycatch in the Tanner crab fishery during 1991-1993 and total potlifts east of 163° W during 1968 to 2005 were used to estimate the bycatch mortality in the current model. Because winter sea surface temperatures and air temperatures were warmer (which means a lower handling mortality rate) and there were fewer potlifts during the early 1980s than during the early 1990s, bycatch in the Tanner crab fishery is unlikely to have been a main factor for the sharp decline of Bristol Bay red king crab.

Several factors may have caused increases in natural mortality. Crab diseases in the early 1980s were documented by Sparks and Morado (1985), but inadequate data were collected to examine their effects on the stock. Stevens (1990) speculated that senescence may be a factor because many crab in the early 1980s were very old due to low temperatures in the 1960s and early 1970s. The biomass of the main crab predator, Pacific cod, increased about 10 times during the late 1970s and early 1980s. Yellowfin sole biomass also increased substantially during this period. Predation is primarily on juvenile and molting/softshell crab. But we lack stomach samples in shallow waters (juvenile habitat) and during the period when red king crab molt. Also cannibalism occurs during molting periods for red king crab. High crab abundance in the late 1970s and early 1980s may have increased the occurrence of cannibalism.

Overall, the likely causes for the sharp decline in the early 1980s are combinations of the above factors, such as pot fisheries on legal males, bycatch and predation on females and juvenile and sublegal males, senescence for older crab, and disease for all crab. In our model, we estimated one mortality parameter for males and another for females during 1980-1984. We also estimated a mortality parameter for females during 1976-1979 and 1985-1993. These three mortality parameters are additional to the basic natural mortality of 0.18, all directed fishing mortality and non-directed fishing mortality. These three mortality parameters could be attributed to natural mortality as well as undocumented non-directed fishing mortality. The model fit the data much better with these three parameters than without them.

ii. Parameters estimated conditionally

The following model parameters were estimated for male and female crab: total recruits for each year (year class strength R_t for t = 1976 to 2013), total abundance in the first year (1975), growth parameter β and recruitment parameter β_r for males and females separately. Molting probability parameters β and L_{50} were also estimated for male crab. Estimated parameters also include β and L_{50} for retained selectivity, β and L_{50} for pot-discarded female selectivity, β and L_{50} for pot-discarded male and female selectivities from the eastern Bering Sea Tanner crab fishery, β and L_{50} for groundfish trawl discarded selectivity, φ, κ and γ for pot-discarded male selectivity, and β for trawl survey selectivity and L_{50} for trawl survey male and females separately. NMFS survey catchabilities Q for some scenarios were also estimated. Three selectivity parameters are estimated for the survey data from the Bering Fisheries Research Foundation. Annual fishing mortalities were also estimated for the directed pot fishery for males (1975-2012), pot-discarded females from the directed fishery (1990-2012), pot-discarded males and females from the eastern Bering Sea Tanner crab fishery (1991-93), and groundfish trawl discarded males and females (1976-2013). Three additional mortality parameters for Mm_t and Mf_t were also estimated. Some estimated parameters were constrained in the model. For example, male and female recruitment estimates were forced to be close to each other for a given year.

f. Definition of model outputs.

i. Biomass: two population biomass measurements are used in this report: total survey biomass (crab >64 mm CL) and mature male biomass (males >119 mm CL). Mating time is assumed to Feb. 15.

ii. Recruitment: new number of males in the 1st seven length classes (65- 99 mm CL) and new number of females in the 1st five length classes (65-89 mm CL).

iii. Fishing mortality: full-selected instantaneous fishing mortality rate at the time of fishery.

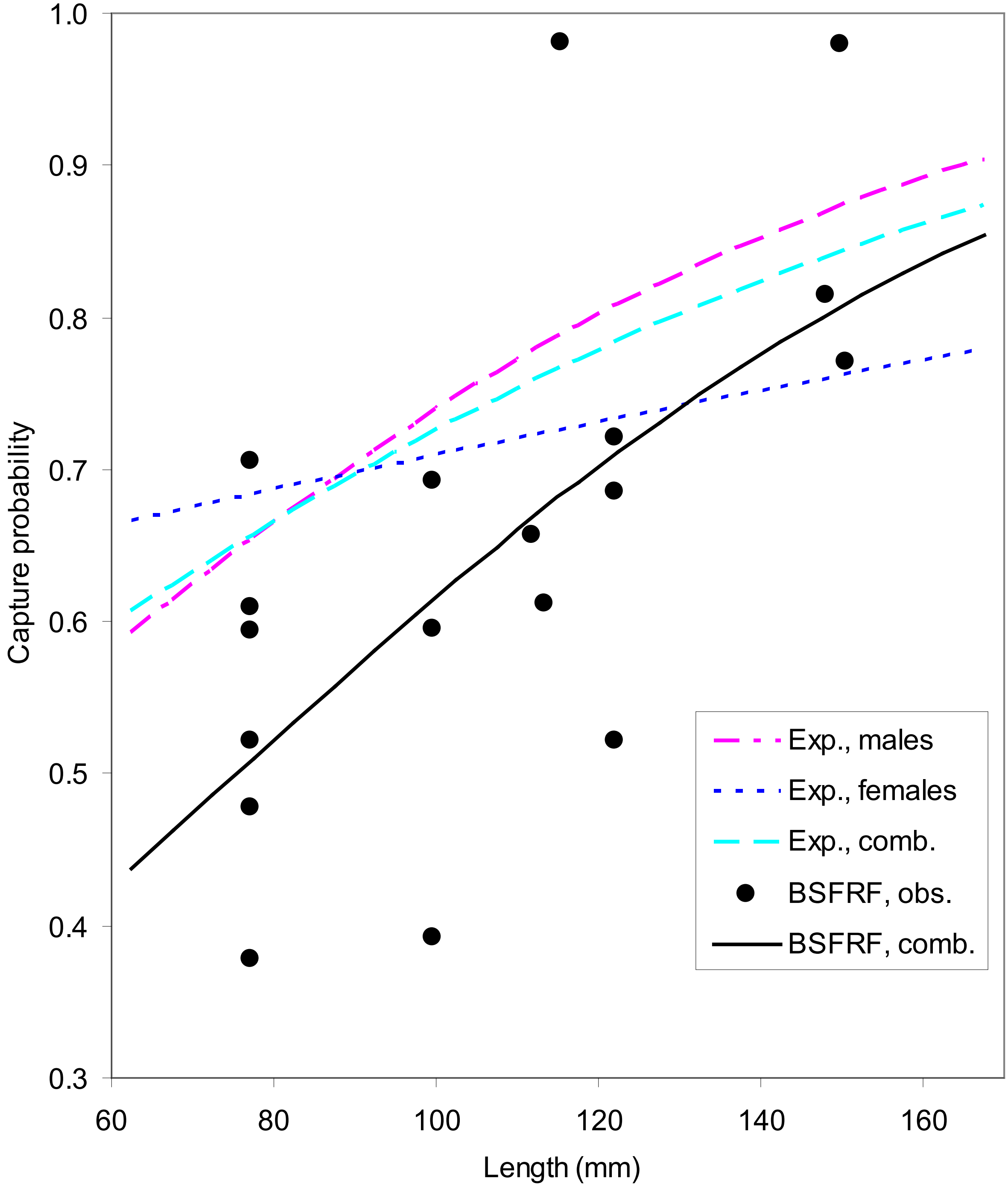

Figure A1. Estimated capture probabilities for NMFS Bristol Bay red king crab trawl surveys by Weinberg et al. (2004) and the Bering Sea Fisheries Research Foundation surveys.

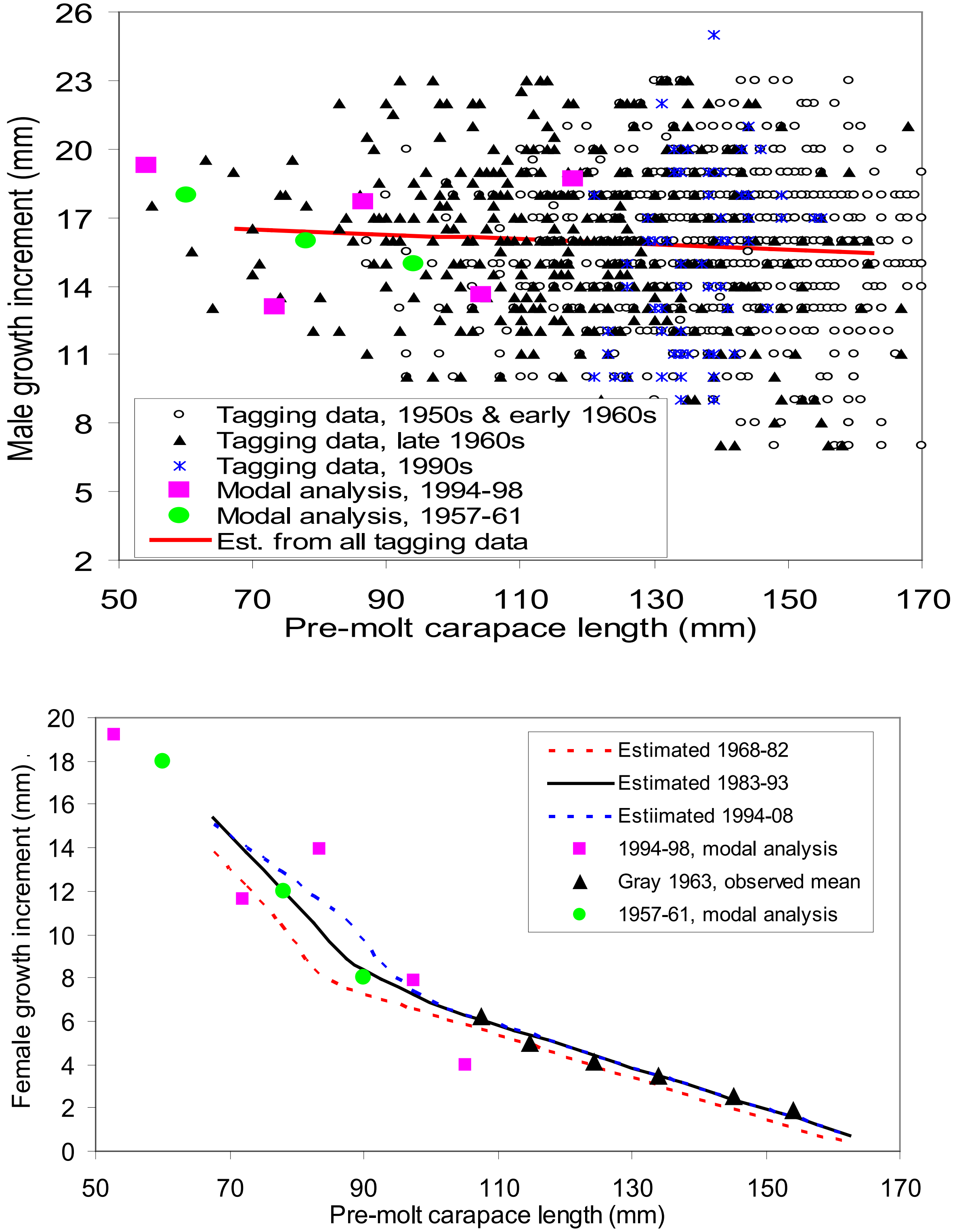

Figure A2. Mean growth increments per molt for Bristol Bay red king crab. Note: "tagging"---based on tagging data; "mode"---based on modal analysis.

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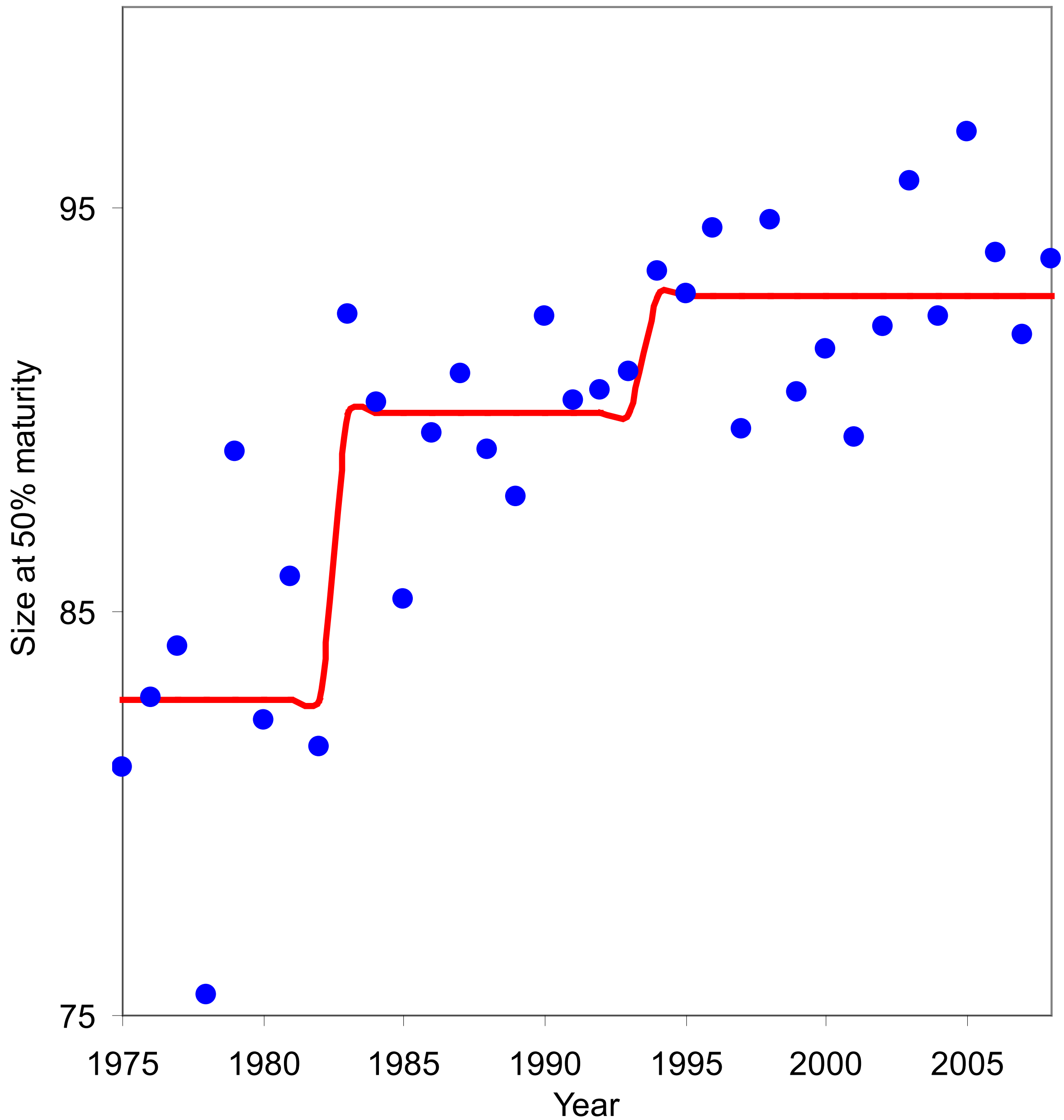

Figure A3. Estimated sizes at 50% maturity for Bristol Bay female red king crab from 1975 to 2008. Averages for three periods (1975-82, 1983-93, and 1994-08) are plotted with a line.

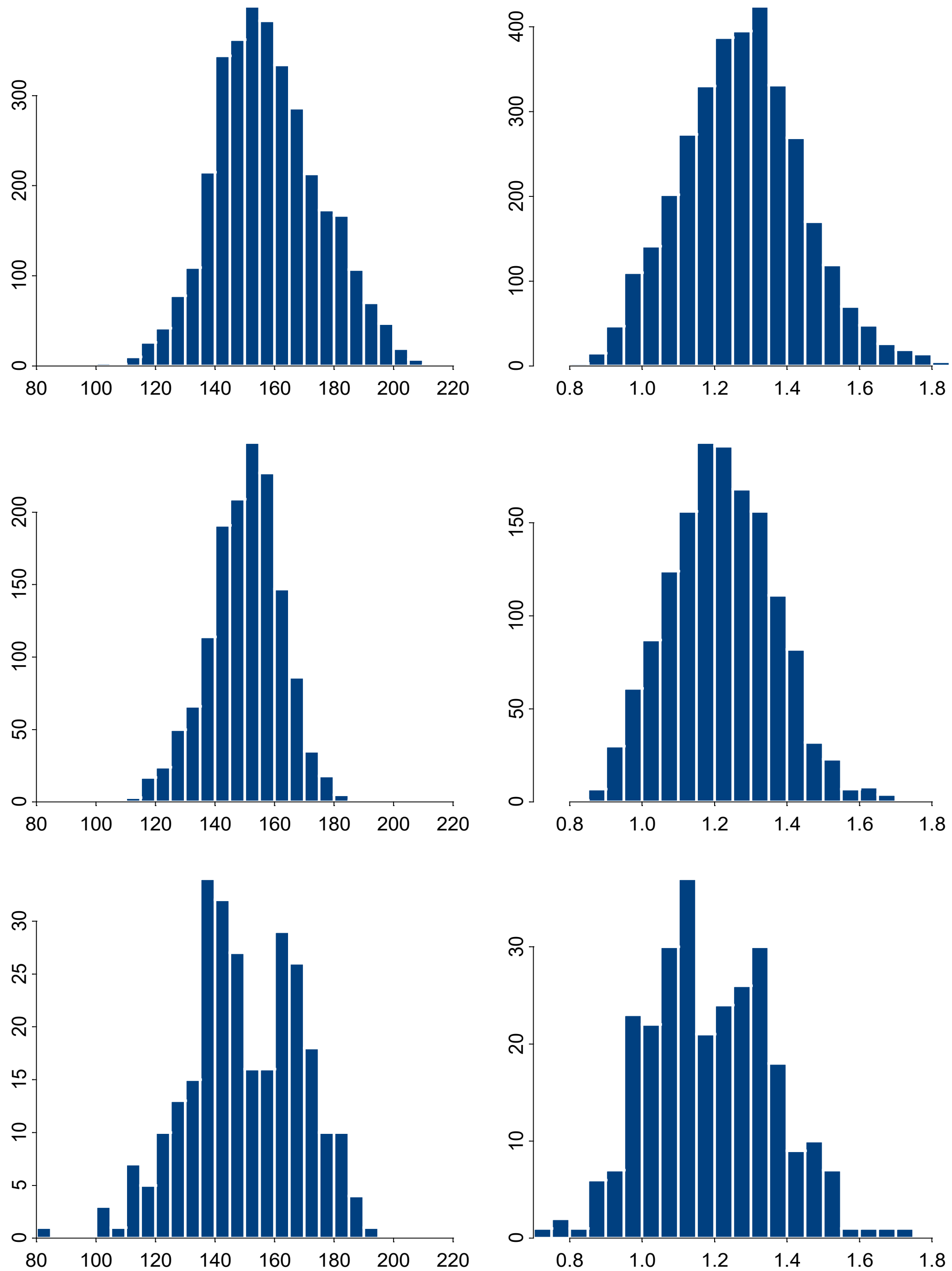

Figure A4. Histograms of carapace lengths (CL) and CL ratios of males to females for male shell ages ≤13 months of red king crab males in grasping pairs; Powell's Kodiak data. Upper plot: all locations and years pooled; middle plot: location 11; lower plot: locations 4 and 13. Sizes at maturity for Kodiak red king crab are about 15 mm larger than those for Bristol Bay red king crab. (Source: Doug Pengilly, ADF&G).

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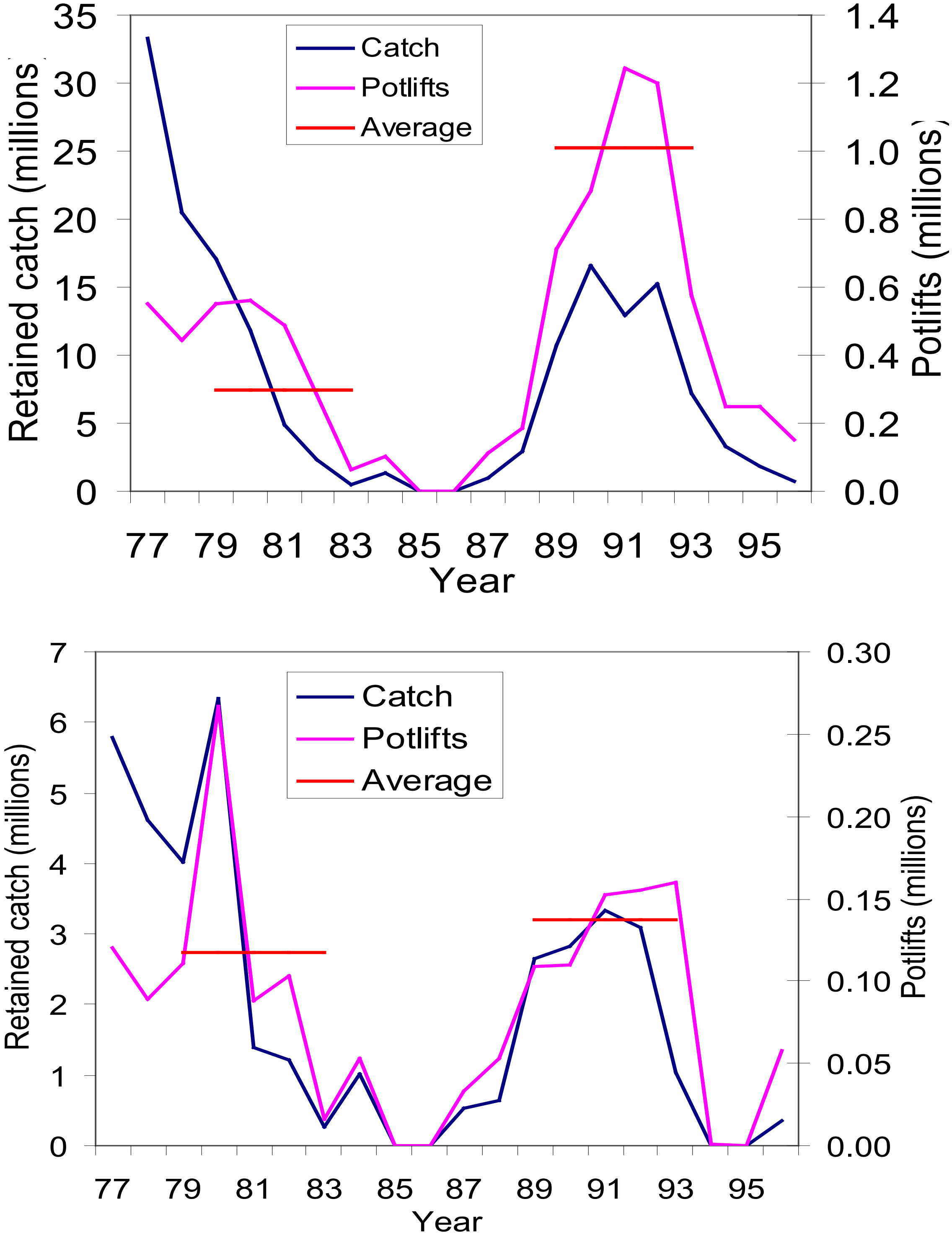

Figure A5. Retained catch and potlifts for total eastern Bering Sea Tanner crab fishery (upper plot) and the Tanner crab fishery east of 163° W (bottom).

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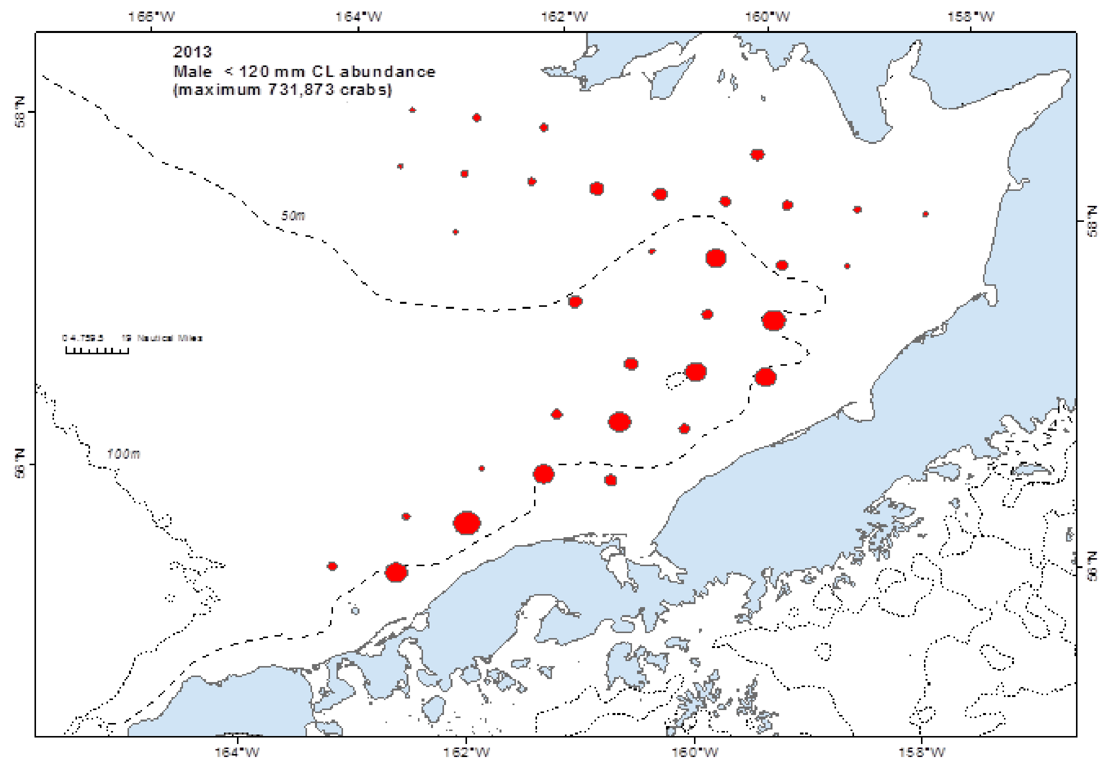
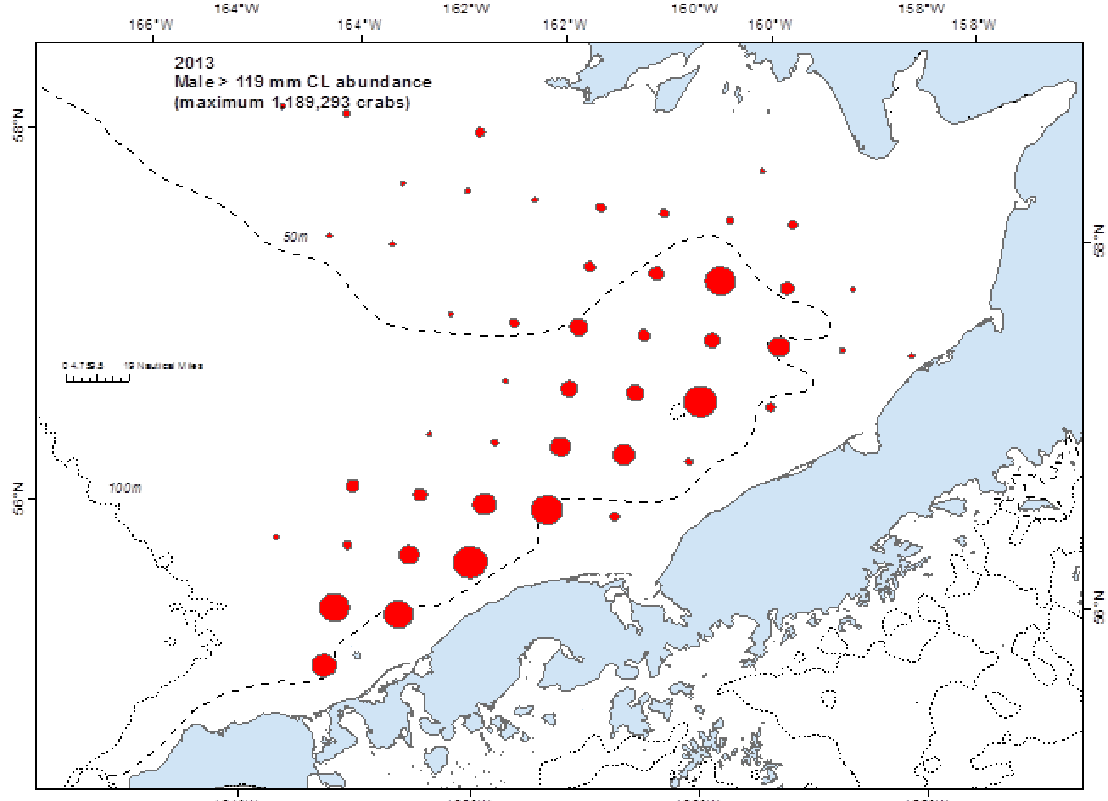
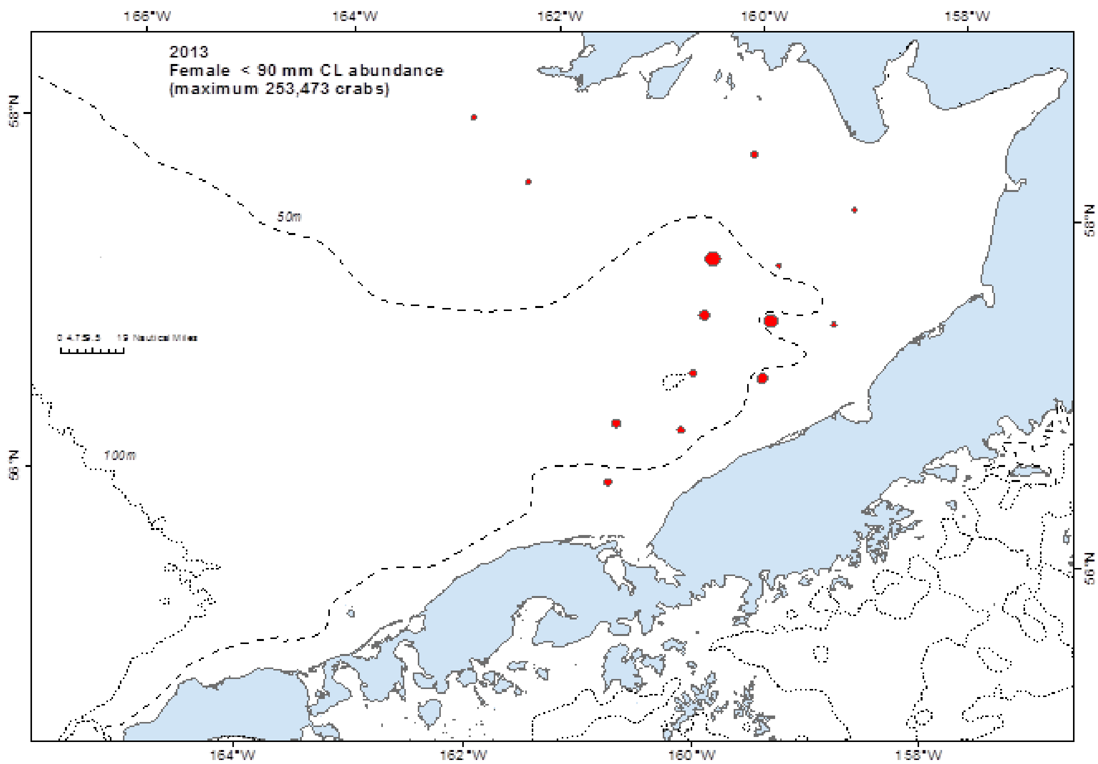
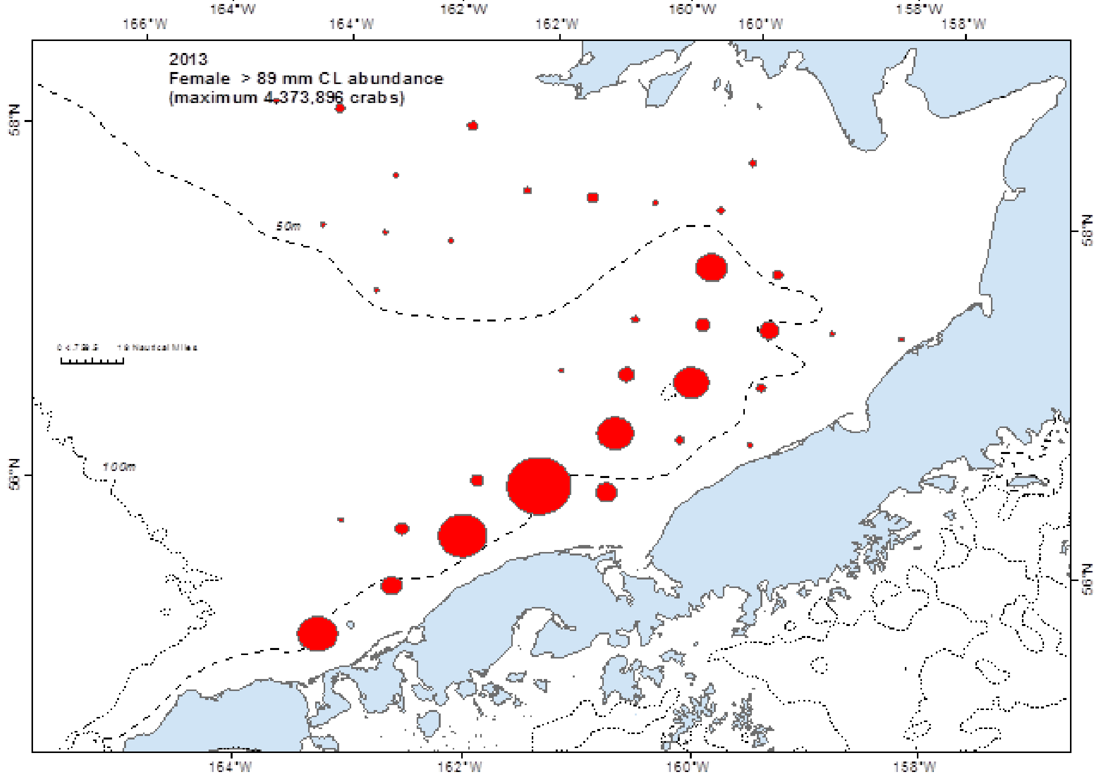
Appendix B. Spatial distributions of mature and juvenile male and female red king crab in Bristol Bay from 2013-2014 summer standard trawl surveys.


2013
Male < 120 mm CL abundance
(maximum 731,873 crabs)
50m
100m
166°W
164°W
162°W
160°W
158°W
58°N
56°N

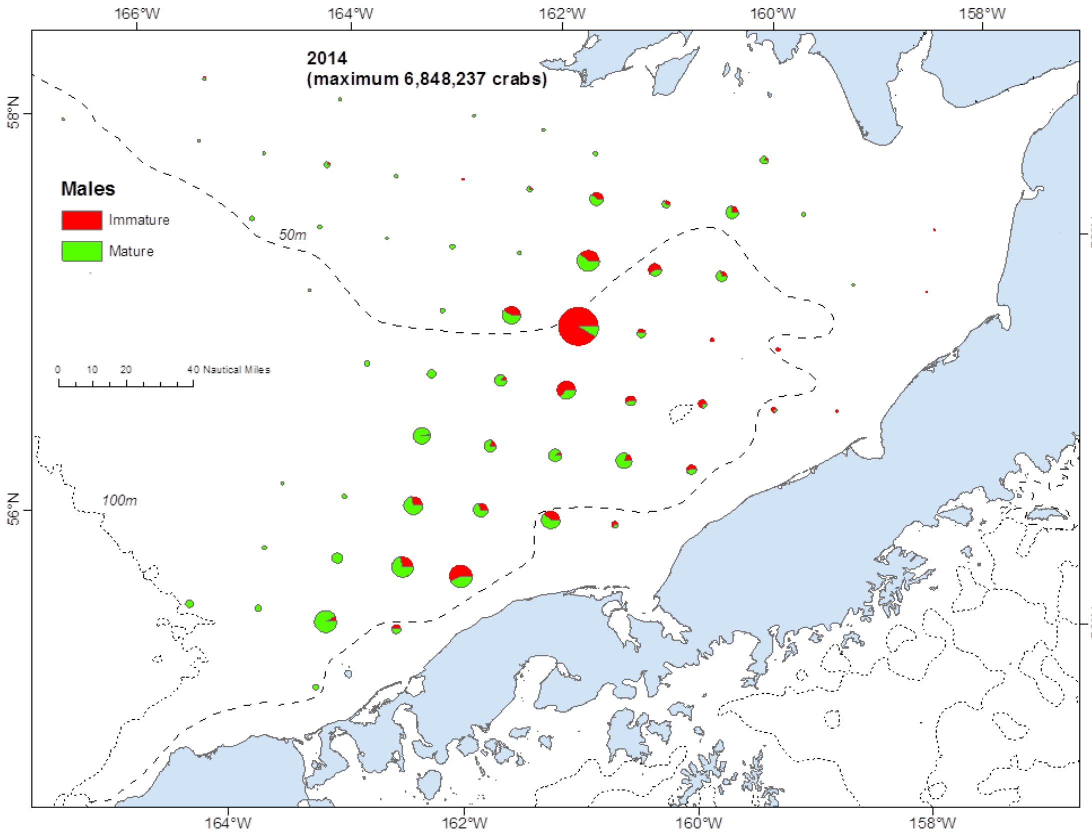

2013
Male > 119 mm CL abundance
(maximum 1,189,293 crabs)
50m
100m
166°W
164°W
162°W
160°W
158°W
58°N
56°N

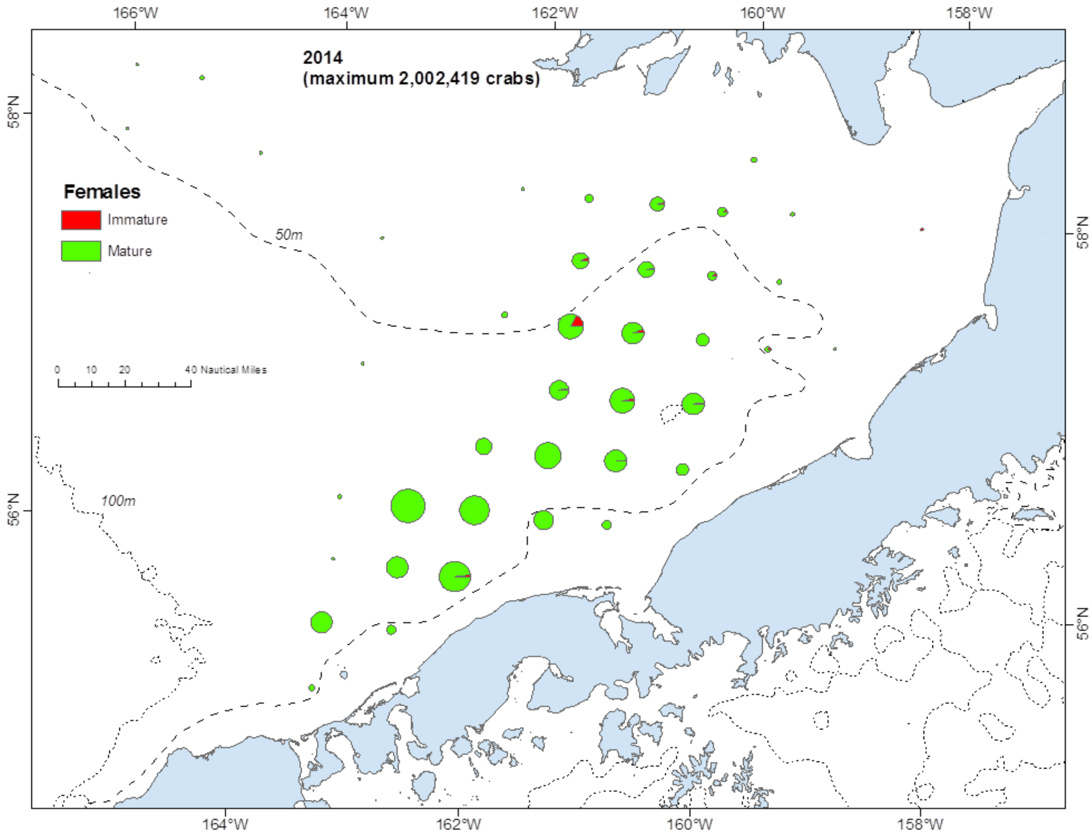
130


2013
Female < 90 mm CL abundance
(maximum 253,473 crabs)
50m
100m
166°W
164°W
162°W
160°W
158°W
58°N
56°N


2013
Female > 89 mm CL abundance
(maximum 4,373,896 crabs)
50m
100m
166°W
164°W
162°W
160°W
158°W
58°N
56°N

131


2014
(maximum 6,848,237 crabs)
Males
Immature
Mature
50m
100m
0 10 20 40 Nautical Miles
166°W
164°W
162°W
160°W
158°W
58°N
56°N


2014
(maximum 2,002,419 crabs)
Females
Immature
Mature
50m
100m
0 10 20 40 Nautical Miles
166°W
164°W
162°W
160°W
158°W
58°N
56°N

132

Appendix C. Temporal changes in spatial distributions of mature female red king crab and the causes

Temporal changes in spatial distributions of mature female red king crab

Temporal changes on spatial distributions of mature female red king crab in Bristol Bay have been documented in several studies (e.g., Hsu 1987, Loher and Armstrong 2005, and Zheng and Kruse 2006). The shift to northeast from southwest started in 1977 and the annual distribution centers from the NMFS standard summer surveys occurred in the most northern area during the early 1980s (Figures C1 and C2). The spatial distributions shifted southward somewhat during 1988-91, 1999-2000, and recent years, but did not reach as far to the southwest as during 1975 and 1976.

Causes for temporal changes in spatial distributions

Fishing

Factors causing the spatial distribution shifts can be classified as fishing related and non-fishing related. Fishing, either directed fishing or non-directed fishing (bycatch), could deplete the southern portion of the brood stock and thus cause the spatial distribution shifts. However, multiple lines of evidence do not support this hypothesis. First, the directed fishing concentrated in the middle Bristol Bay, and except in 1976, the distribution centers of the directed commercial catches were not different in the 1970s from the other years (Figure C3). Second, proportions for all size groups of red king crab), including immature crab that should have a very low selectivity/catchability from the commercial fishing gears, declined in the southern area (i.e., south of lat 56.0° N) from 1975 to 1983 (Figures C4-C7). Commercial trawling was also not allowed during the primary red king crab habitats during the 1970s. The decline of proportions was highest for mature females (Figures C6 and C7). Third, the decline of mature females occurred when the mature female abundances were very high (Figure B8), and some of mature females in the southern area might have moved into the middle area (Figures C9 and C10).

Environmental factors

Non-fishing related factors are environmental. We examined two environmental factors in this study: near-bottom temperatures in Bristol Bay during summer collected from the NMFS summer surveys and winter PDO index. Both near-bottom temperatures and winter PDO index were very low before 1977 and started to increase in 1977 (Figures C11 and C12), which corresponds to the beginning of northward shifts of Bristol Bay red king crab. Based on the temporal changes of these two factors, we averaged eight periods during 1975-2013 (Figure C13). The averages of latitude of distribution centers of large mature females are strongly correlated with the averages of these two environmental factors with R^2=0.52 (Figure C14). This pattern of large mature females may be exaggerated somewhat by within-year changes in distribution that change with the thermally modulated (and thus temporally variable) tempo of reproduction relative to a sampling frame that is relatively fixed in time. The associations of mature female distributions with these environmental factors make biological sense: northward shifts associating with high temperatures and southward movements relating to the low temperatures.

References

Hsu, C.-C. 1987. Spatial and temporal distribution patterns of female red king crabs in the southeastern Bering Sea. Ph.D. dissertation, University of Washington, Seattle, WA, 300 pp.

Loher, T. and Armstrong, D.A. 2005. Historical changes in the abundance and distribution of ovigerous red king crabs (Paralithodes camtschaticus) in Bristol Bay (Alaska), and potential relationship with bottom temperature. Fisheries Oceanography 14, 292–306.

Zheng, J. and Kruse, G. H. 2006. Recruitment variation of eastern Bering Sea crabs: climate forcing or top-down effects? Progress in Oceanography, 68: 184–204.

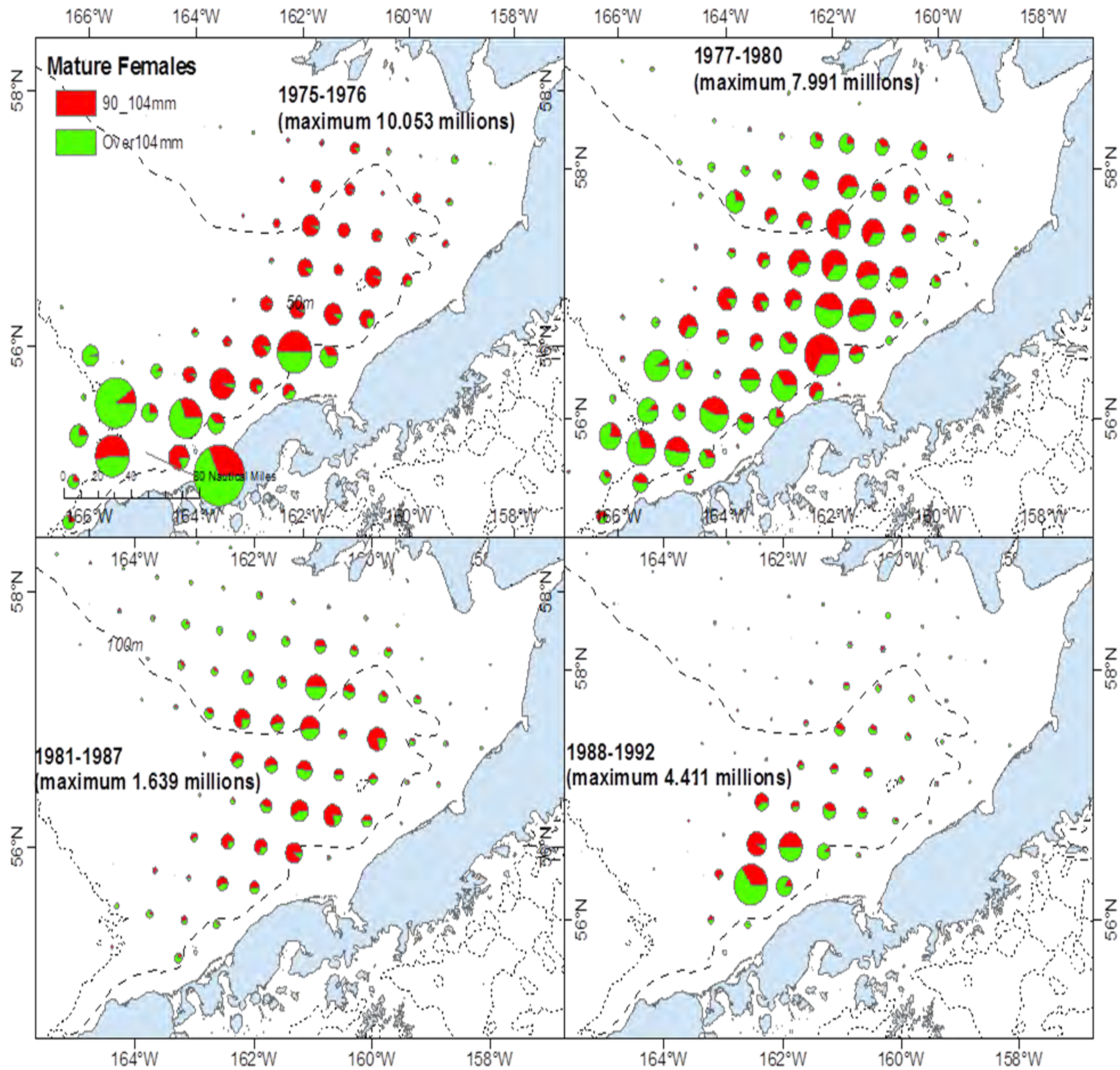


Fig. C1a. Spatial distributions of mature female red king crab in Bristol Bay during 1975-1992 from the summer trawl surveys.

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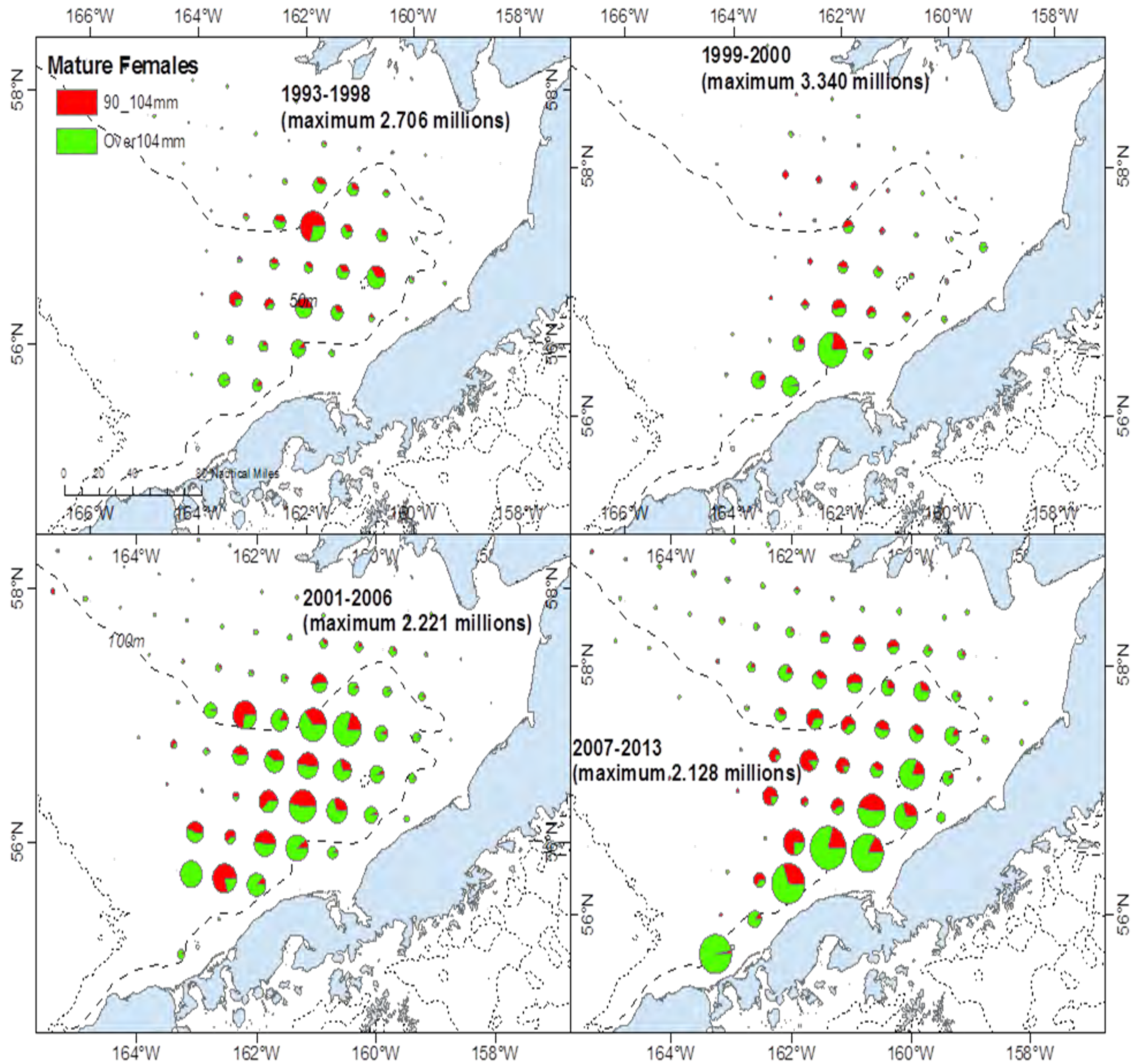

Fig. C1b. Spatial distributions of mature female red king crab in Bristol Bay during 1993-2013 from the summer trawl surveys.

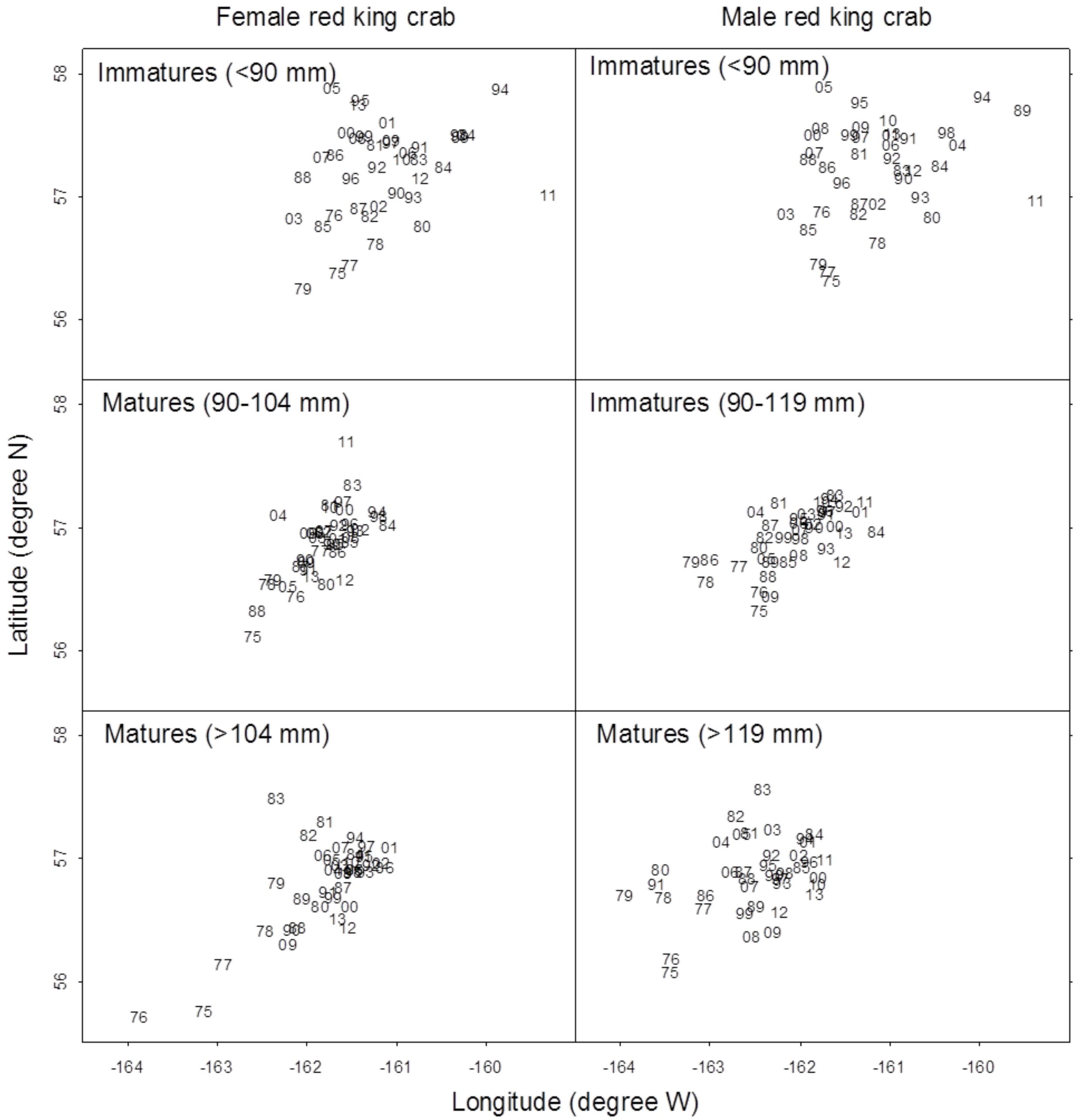

Fig. C2. Centroids of Bristol Bay red king crab distribution during 1975-2013 from the summer trawl surveys.

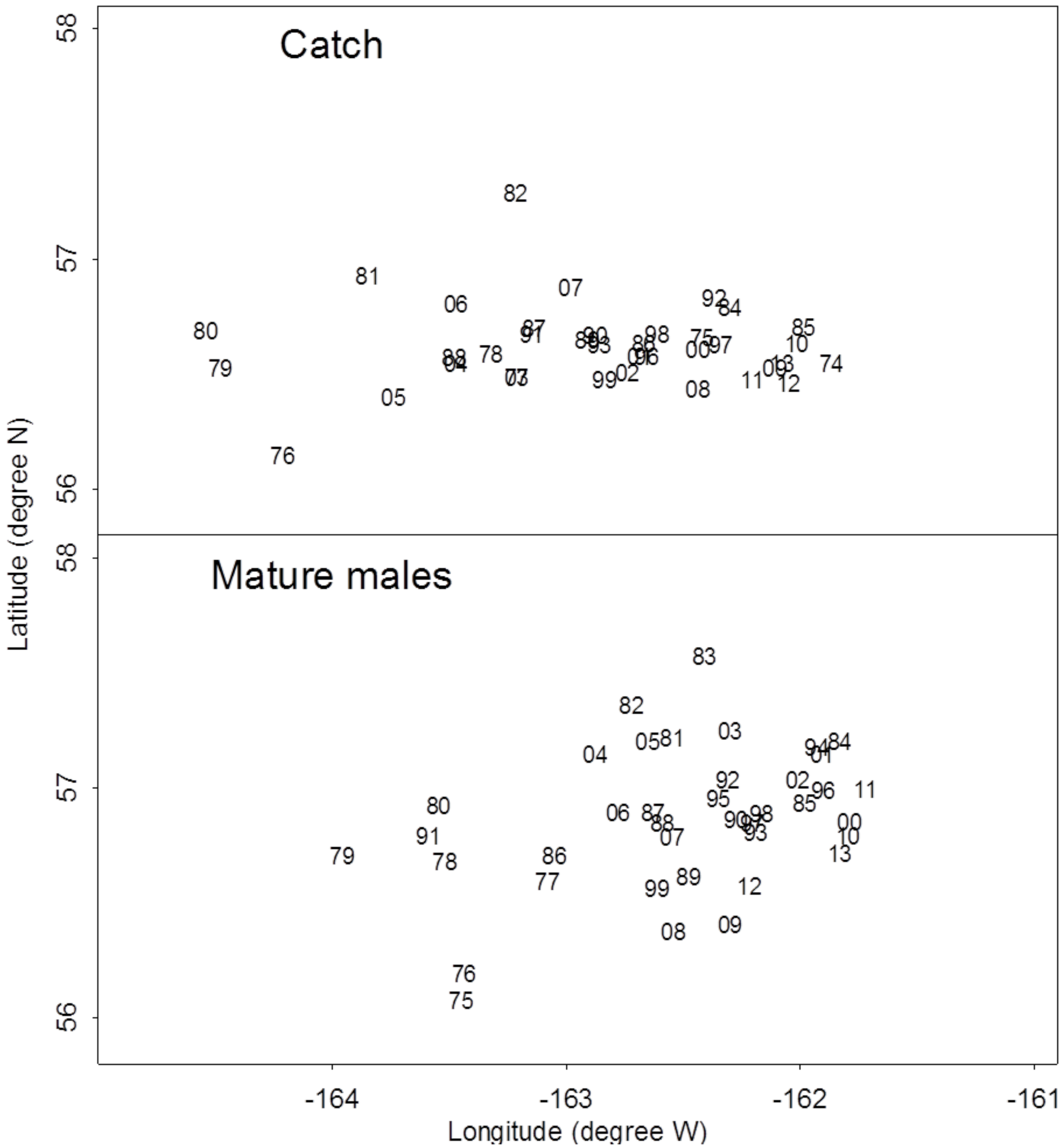

Fig. C3. Centroids of Bristol Bay red king crab commercial catch distribution during 1974-2013 (upper plot) and of mature male (>119 mm carapace length) distribution during 1975-2013 from the summer trawl surveys (lower plot).

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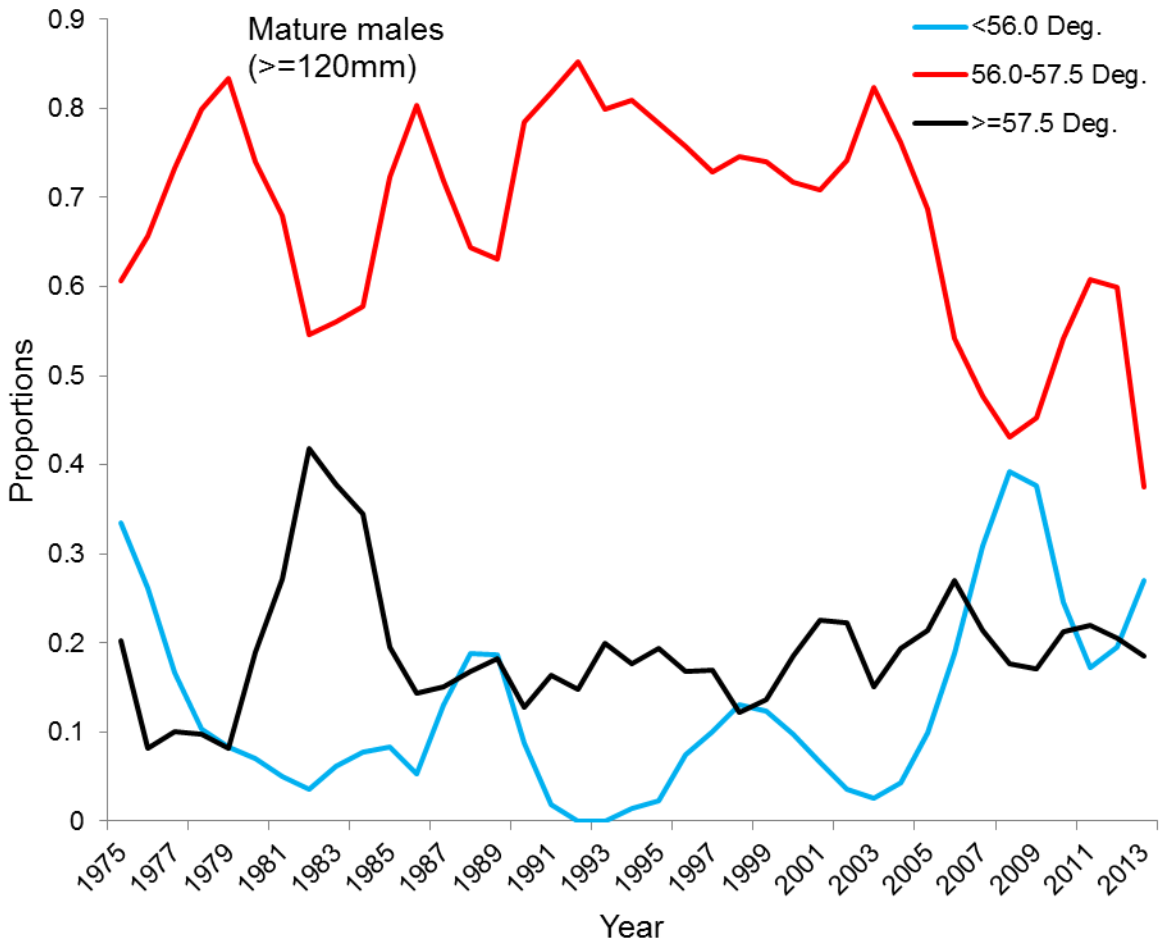

Fig. C4. Proportions (3-point-moving-average) in southern (<56°N), central (56-57.5°N), and northern (≥57.5°N) Bristol Bay for mature males (>119 mm carapace length) during 1975-2013 from the summer trawl surveys.

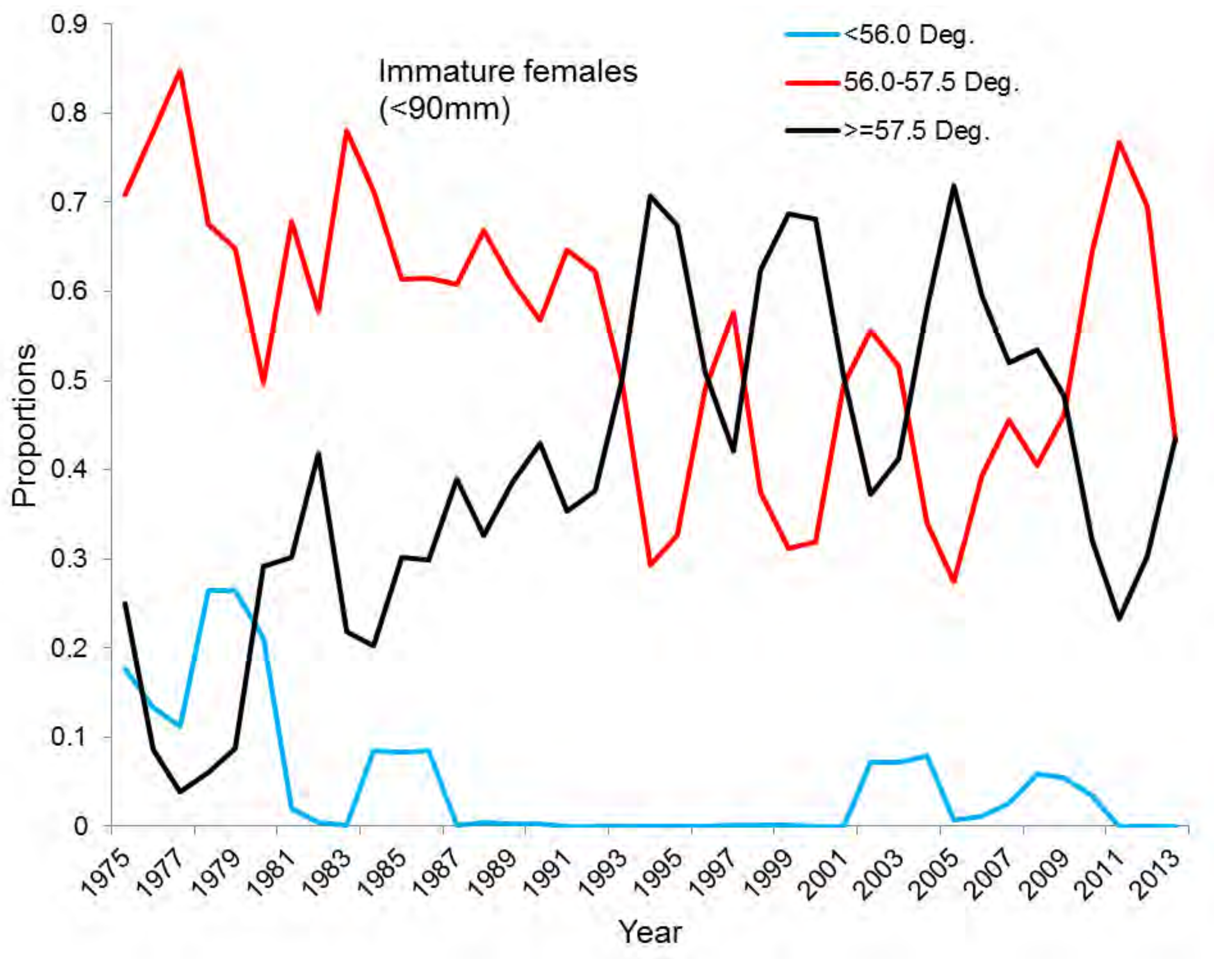

Fig. C5. Proportions (3-point-moving-average) in southern (<56°N), central (56-57.5°N), and northern (≥57.5°N) Bristol Bay for immature females (<90 mm carapace length) during 1975-2013 from the summer trawl surveys.

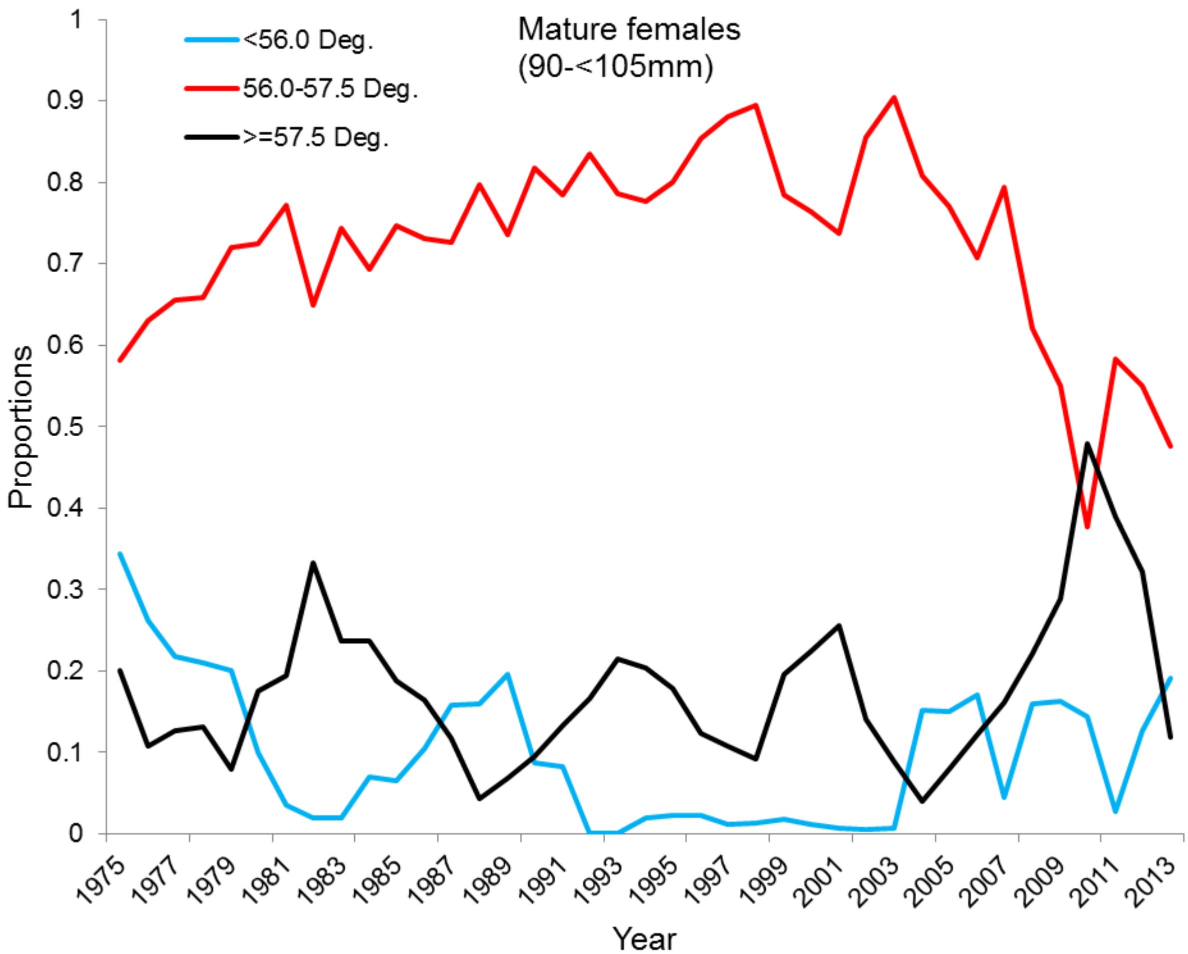

Fig. C6. Proportions (3-point-moving-average) in southern (<56^{o}N), central (56-57.5^{o}N), and northern (≥57.5^{o}N) Bristol Bay for mature females (90-104 mm carapace length) during 1975-2013 from the summer trawl surveys.

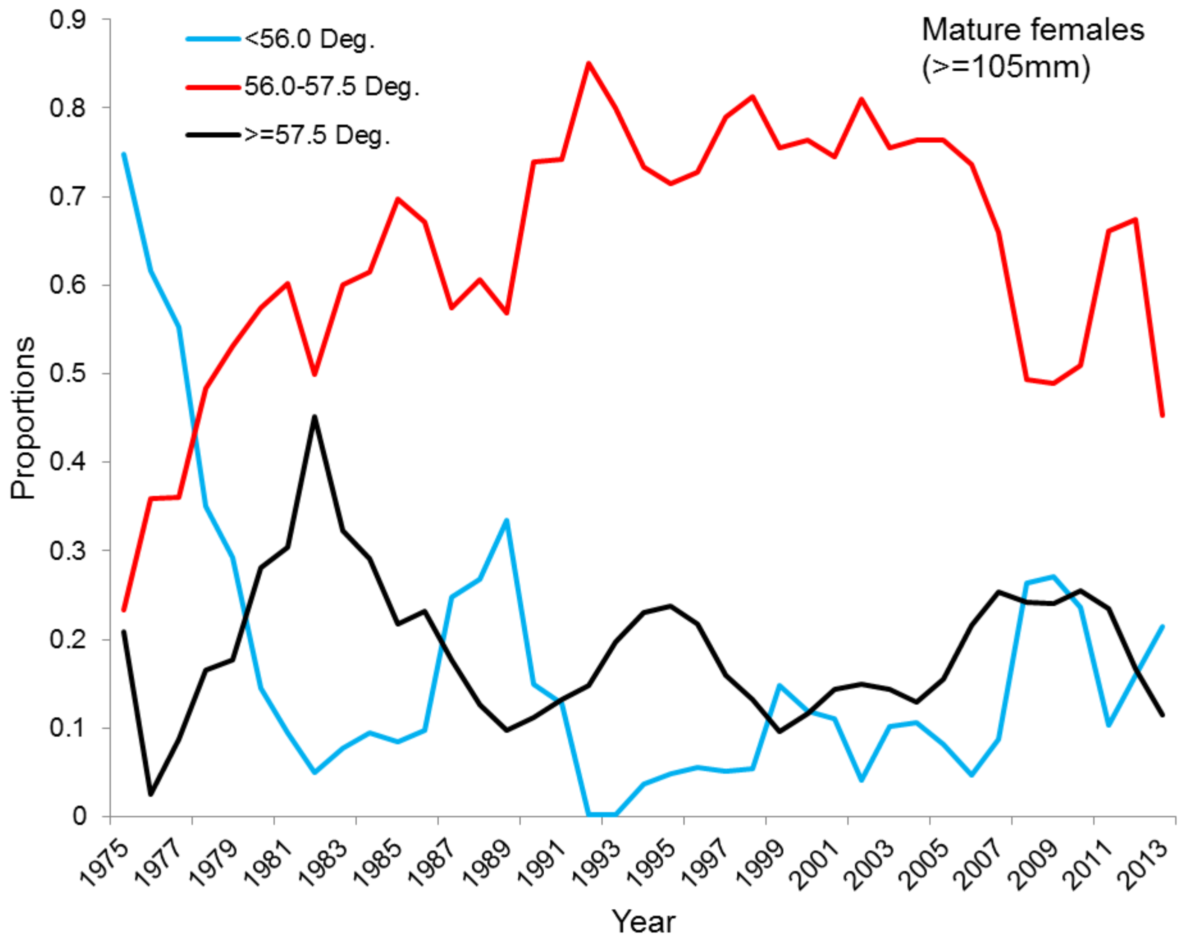

Fig. C7. Proportions (3-point-moving-average) in southern (<56°N), central (56-57.5°N), and northern (≥57.5°N) Bristol Bay for mature females (>104 mm carapace length) during 1975-2013 from the summer trawl surveys.

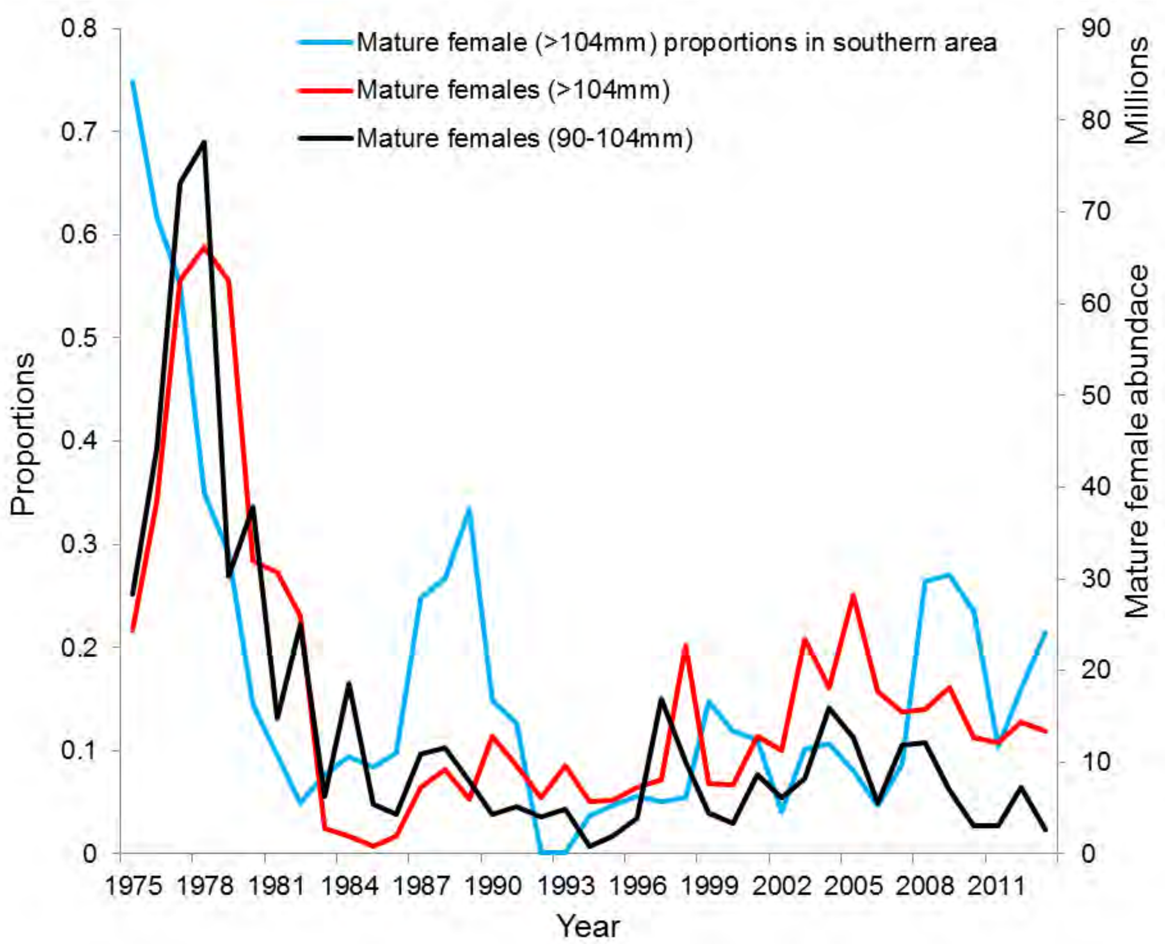

Fig. C8. Proportions (3-point-moving average) in southern Bristol Bay (<56°N) for mature females (>104 mm carapace length) and mature female red king crab abundances during 1975-2013 from the summer trawl surveys.

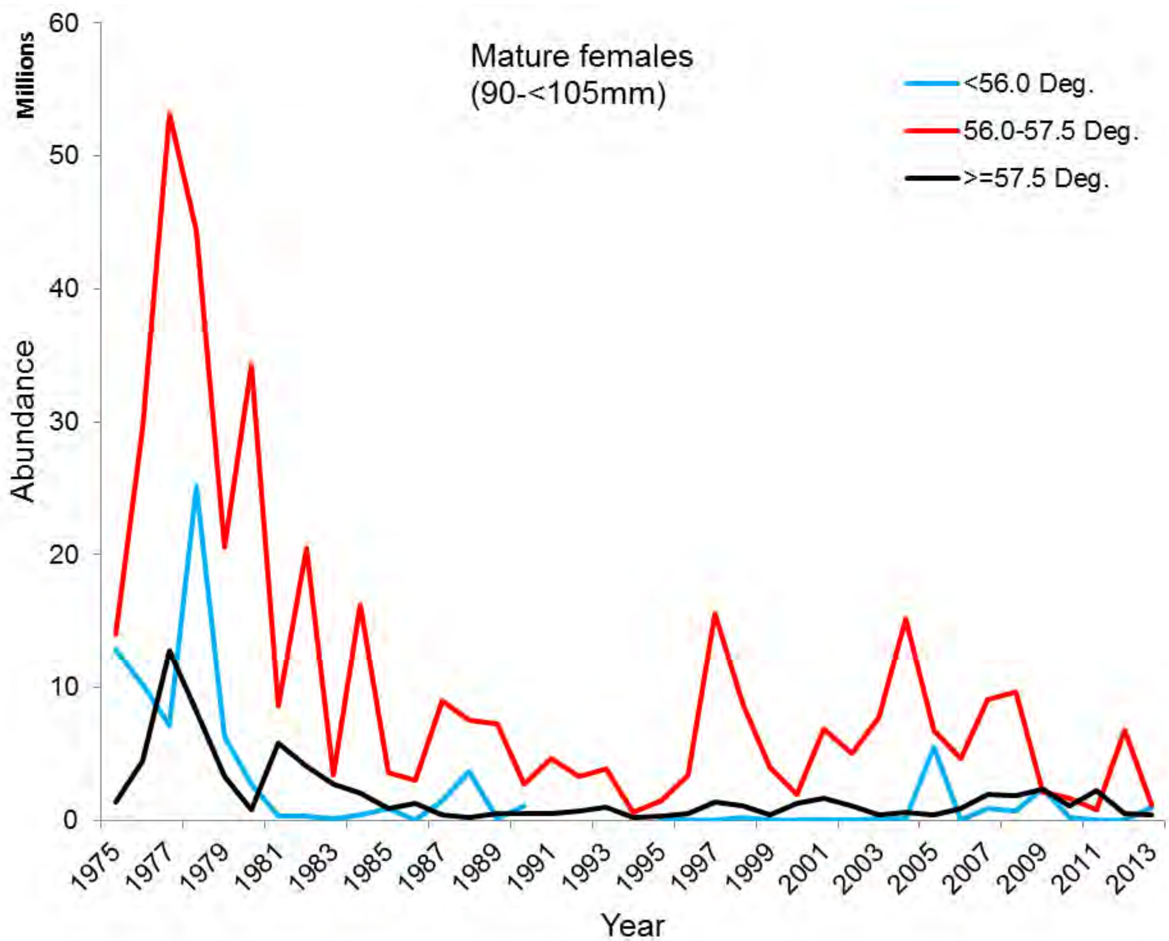

Fig. C9. Mature female (90-104 mm carapace length) abundances in southern (<56°N), central (56-57.5°N), and northern (≥57.5°N) Bristol Bay during 1975-2013 from the summer trawl surveys.

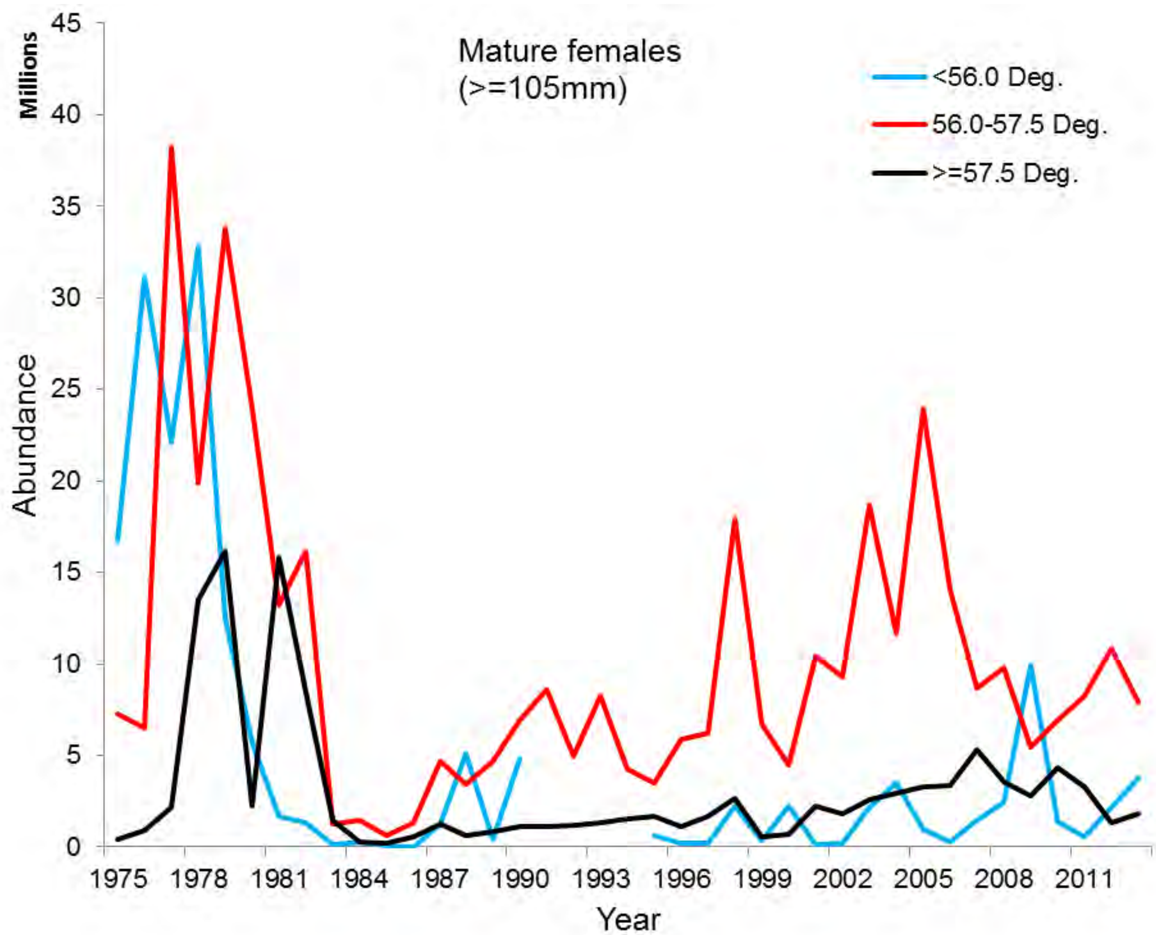

Fig. C10. Mature female (>104 mm carapace length) abundances in southern (<56°N), central (56-57.5°N), and northern (≥57.5°N) Bristol Bay during 1975-2013 from the summer trawl surveys.

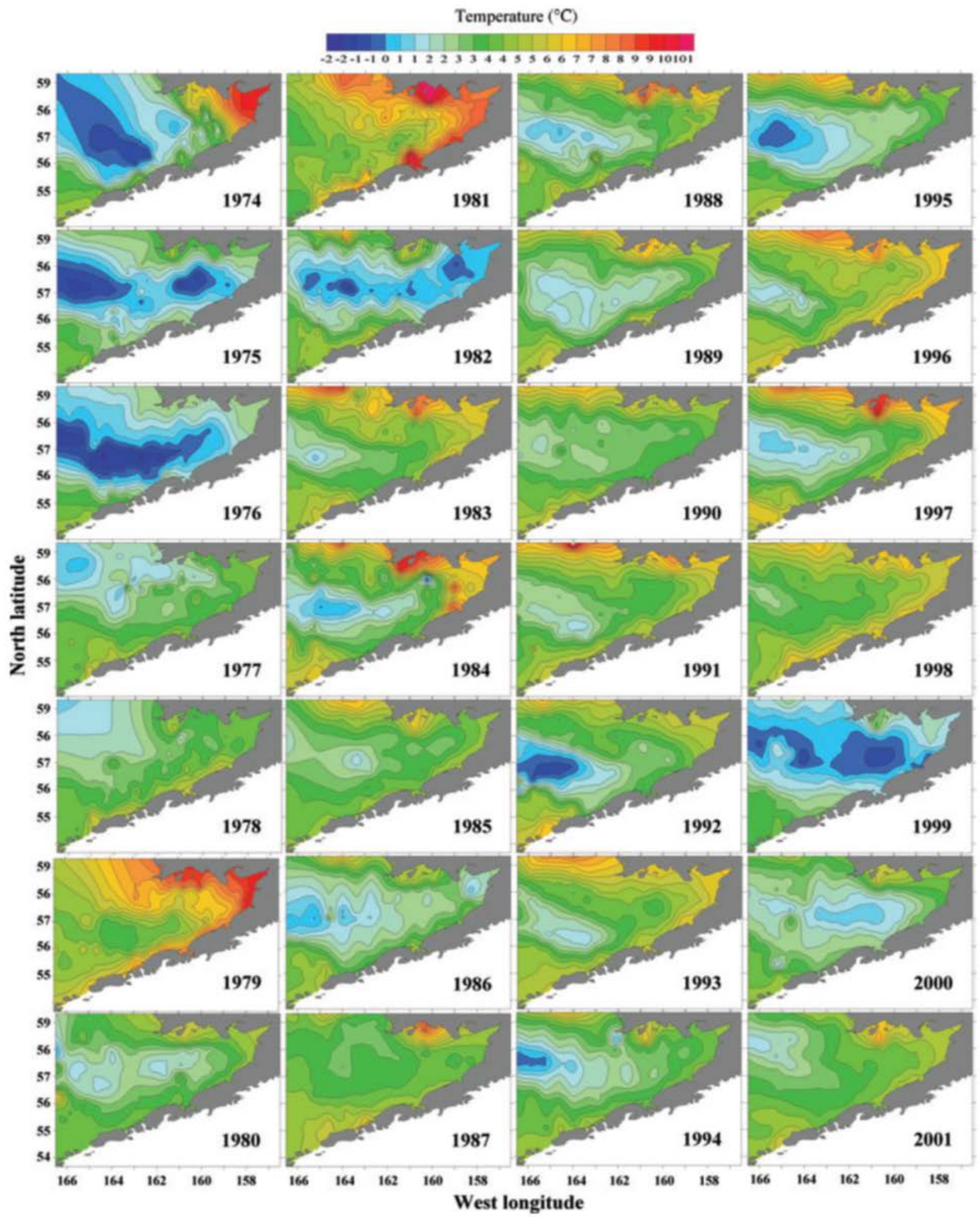

Fig. C11. Early summer near-bottom temperature patterns constructed for the Bristol Bay region, 1974–2001. Each year's plot represents a sampling period of 3–5 weeks, grouped around a target date of June 15. (After Loher and Armstrong 2005)

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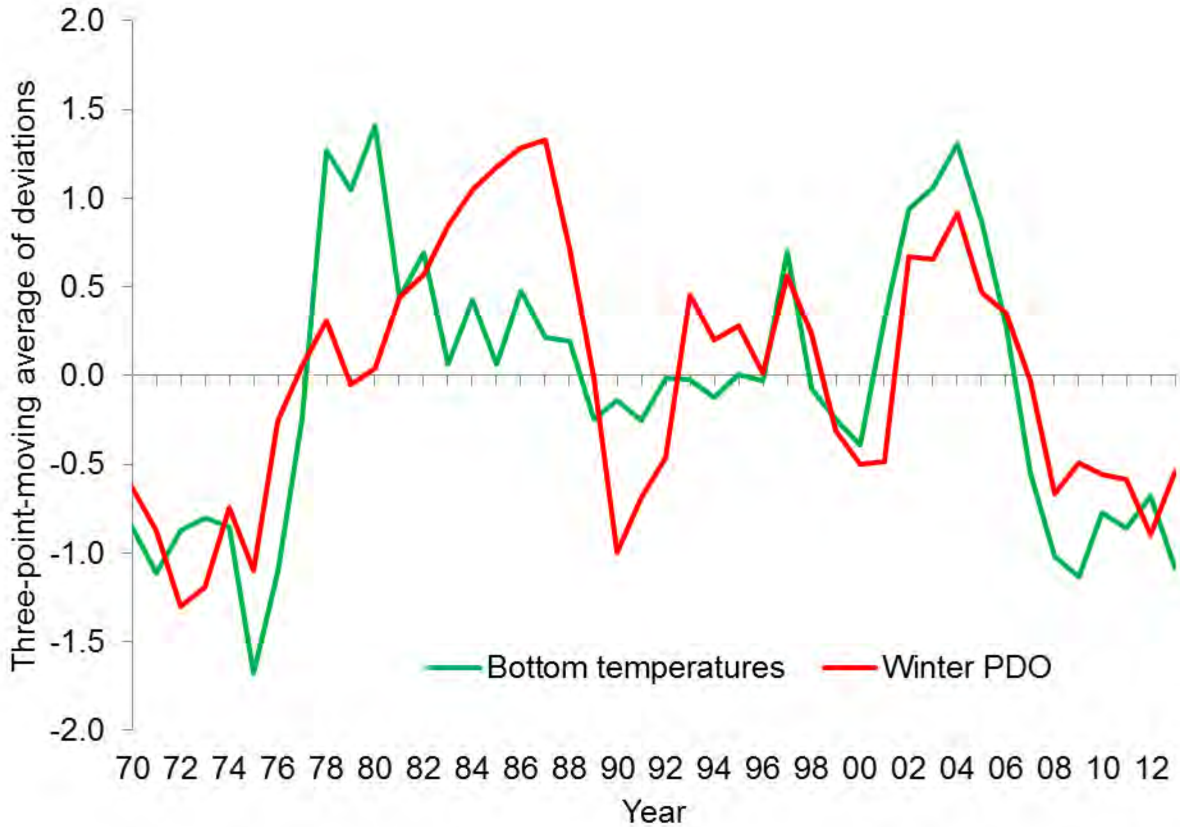


Fig. C12. Summer near-bottom temperature deviations in Bristol Bay from the summer trawl surveys and winter PDO deviations during 1970-2013.

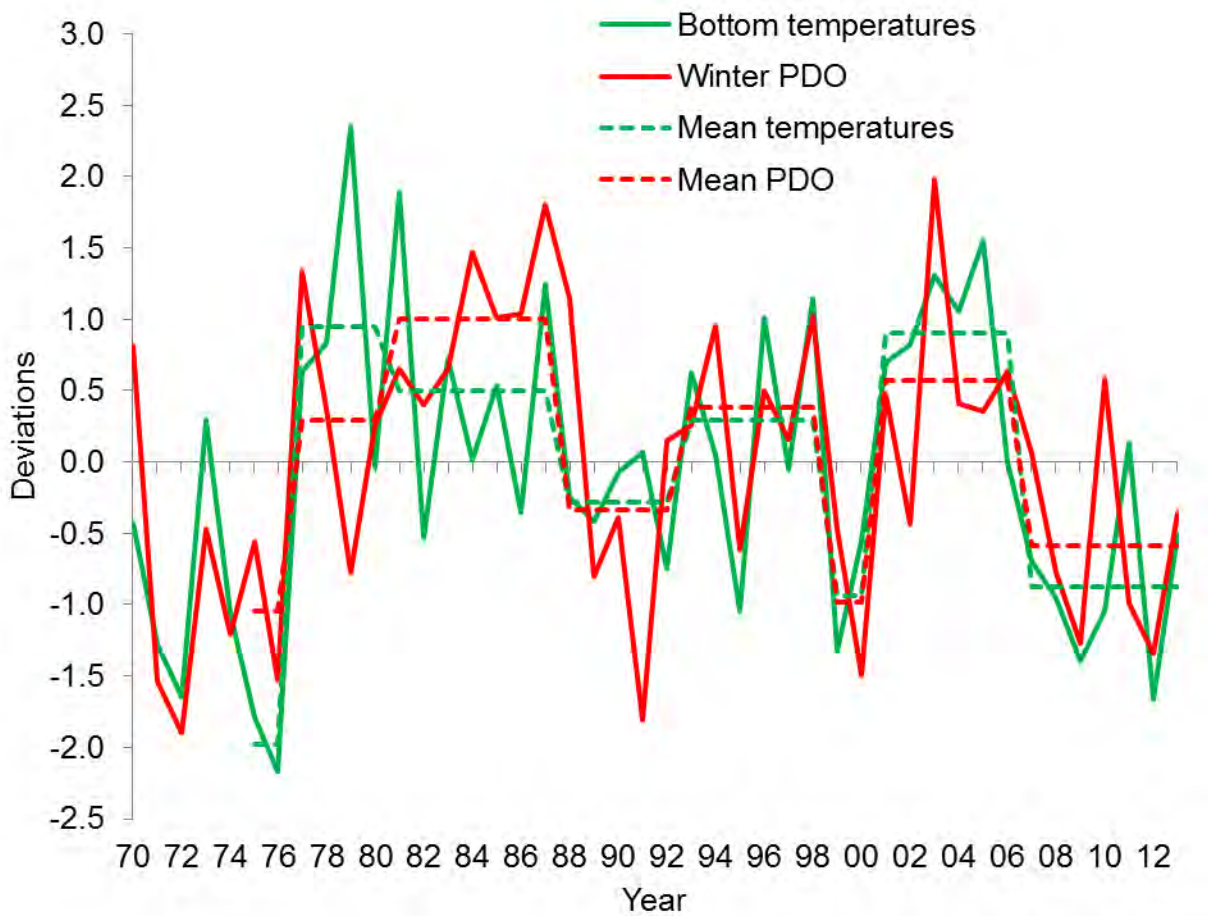
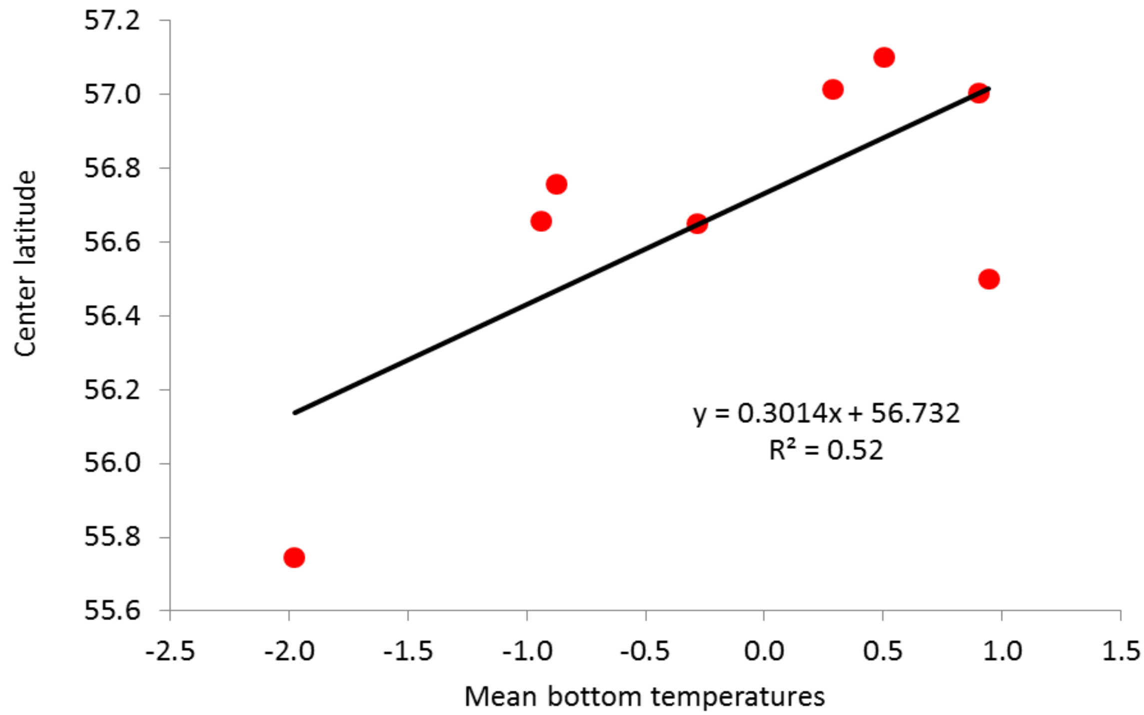


Fig. C13. Summer near-bottom temperature deviations in Bristol Bay from the summer trawl surveys and winter PDO deviations during 1970-2013.



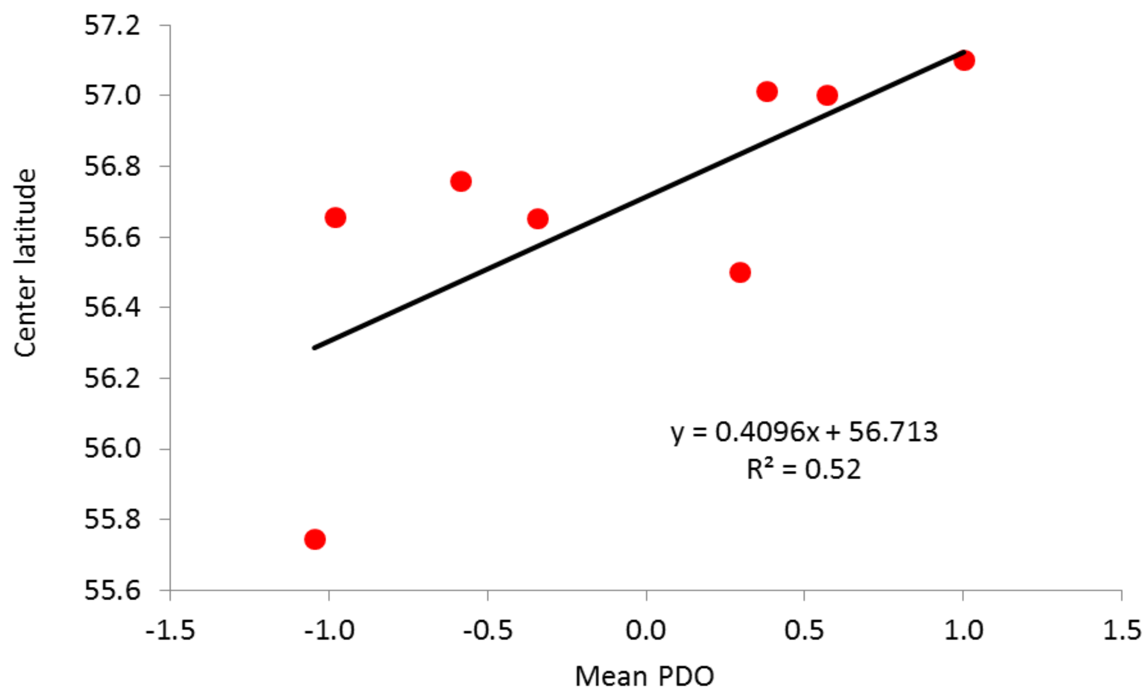


Fig. C14. Relationships between periodic mean latitudes of distribution centers for mature females (>104 mm carapace length) and mean summer near-bottom temperatures (upper plot) and mean winter PDO (lower plot) during 1975-2013. The 8 periods defined in Figure B13 are used.

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2014 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

William T. Stockhausen
Alaska Fisheries Science Center
20 September 2014

Executive Summary

1. Stock: species/area.
Southern Tanner crab (*Chionoecetes bairdi*) in the eastern Bering Sea (EBS).

2. Catches: trends and current levels.
Legal-sized male Tanner crab are caught and retained in the directed (male-only) Tanner crab fishery in the EBS. The directed fishery was opened in 2013/14 for the first time since 2009/10 because the stock was assessed last year as not overfished and stock metrics met the State of Alaska (SOA) criteria for opening the fishery in 2013/14. TAC was set at 1,645,000 lbs (746.2 t) for the area west of 166° W and at 1,463,000 lbs (663.6 t) for the area east of 166° W in the SOA's Eastern Subdistrict of Tanner crab Registration Area J. The fisheries opened on October 15 and closed on March 31. On closing, 80.9% (603.5 t) of the TAC had been taken in the western area while 99.5% (660.6 t) had been taken in the eastern area. Prior to the closures, the retained catch averaged 770 t per year between 2005/06-2009/10.

Non-retained females and sub-legal males are caught in the directed fishery as bycatch and discarded. Total bycatch (not discounted for assumed handling mortality) in the directed fishery was 560 t. Tanner crab are also caught as bycatch in the snow crab and Bristol Bay red king crab fisheries, in the groundfish fisheries and, to a minor extent, in the scallop fishery. Over the last five years, the snow crab fishery has been the major source of Tanner crab bycatch among these fisheries, averaging 1,439 t for the 5-year period 2007/08-2011/12. Bycatch in the snow crab fishery in 2013/14 was 1,846 t. The groundfish fisheries have been the next major source of Tanner crab bycatch over the five year time period, averaging 298 t. Bycatch in the groundfish fisheries in 2013/14 was 330 t. The Bristol Bay red king crab fishery has typically been the smallest source of Tanner crab bycatch among these fisheries, averaging 104 t over the 5-year time period, with 110 t caught and discarded in 2013/14.

In order to account for mortality of discarded crab, handling mortality rates have been assumed to be 50% for Tanner crab discarded in the crab fisheries and 80% for Tanner crab discarded in the groundfish fisheries to account for differences in gear and handling procedures used in the various fisheries. A new handling mortality rate of 32.1% for Tanner crab caught in pot gear is considered as an alternative in this assessment. The author's preferred model (Alt1a) is based on the old rate of 50%.

3. Stock biomass: trends and current levels relative to virgin or historic levels
For EBS Tanner crab, spawning stock biomass is expressed as mature male biomass (MMB) at the time of mating (mid February). From the author's preferred model (Alt1a), estimated MMB for 2013/14 was 79.5 thousand t (Table 14, Figure 30). This was larger than that for 2012/13 (63.6 thousand t). The 2013 model estimate for 2012/13 MMB was 59.4 thousand t. MMB had undergone a slight downward trend since its most recent peak in 2009/10, but 2013/14 represents a return to values similar to that peak. It remains above the very low levels seen in the mid-1990s to early 2000s (1990 to 2005 average: 31.1

thousand t). However, it is considerably below historic levels in the early 1970s when MMB peaked at 328.2 thousand t (1972/73).

4. Recruitment: trends and current levels relative to virgin or historic levels.
From the author's preferred model (Alt1a), the estimated male recruitment in 2014/15 (number of crab entering the population on July 1) is 99.8 million crab (Table 13, Figure 27; the number of females recruiting to the population is assumed identical to male recruitment). Recruitment is estimated to have been increasing over the past two years from a minimum of 24.2 million males in 2012.

5. Management performance

(a) Historical status and catch specifications (millions lb) for eastern Bering Sea Tanner crab.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2010/11	91.87	58.93[A]	0.00	0.00	1.92	3.20	
2011/12	25.13	129.17[A]	0.00	0.00	2.73	6.06[C]	5.47
2012/13	36.97	130.84[A]	0.00	0.00	1.57	41.93	18.01
2013/14	37.42	175.20[A]	3.11	2.79	6.14	55.89	39.29
2014/15		156.02 [B,C]				74.54[C]	49.63[C,D]

(b) Historical status and catch specifications (thousands t) for eastern Bering Sea Tanner crab.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2009/10	41.90	28.44[A]	0.61[a/]	0.6	1.64	2.27	
2010/11	41.67	26.73[A]	0	0	0.87	1.45	
2011/12	11.40	58.59[A]	0	0	1.24	2.75	2.48
2012/13	16.77	59.35[A]	0	0	0.71	19.02	8.17
2013/14	16.98	79.47[A,C]	1.41	1.26	2.78	25.35	17.82
2014/15		70.77[B,C]				33.81[C]	22.51[C,D]

a/ Only the area east of 166° W opened in 2009/10.
A—Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate, based on the subsequent assessment, from the projection the previous year.
B—Projected biomass from the current stock assessment. This value will be updated next year.
C—Based on the author's preferred model (Alt1a).
D—The author's recommended ABC, based on remaining at step 2 of the 3-step staircase to ABC_{max} (= p^* ABC = 33.76 thousand t).

6. Basis for the OFL

Basis for the OFL (thousands t).

Year	Tier[A]	B_{MSY}[A]	Current MMB[A]	B/B_{MSY} (MMB)[A]	F_{OFL}[A]	Years to define B_{MSY}[A]	Natural Mortality[A,B]
2012/13	3a	33.45	58.59	1.75	0.61 yr^{-1}	1982-2012	0.23 yr^{-1}
2013/14	3a	33.54	59.35	1.77	0.73 yr^{-1}	1982-2013	0.23 yr^{-1}
2014/15	3a	33.95	70.77	2.08	0.58 yr^{-1}	1982-2014	0.23 yr^{-1}

A—Calculated from the assessment reviewed by the Crab Plan Team in 20XX of 20XX/YY or based on the author's preferred model for 2014/15.
B—Nominal rate of natural mortality. Actual rates used in the assessment are estimated and may be different.

Current male spawning stock biomass (MMB) is estimated at 70.77 thousand t. B_{MSY} for this stock is calculated to be 33.95 thousand t, so MSST is 16.98 thousand t. Because current MMB > MSST, **the stock is not overfished**. Total catch mortality (retained + discard mortality in all fisheries, using a discard mortality rate of 50% for pot gear and 0.8 for trawl gear) in 2013/14 was 2.78 thousand t, which was less than the OFL for 2013/14 (25.35 thousand t); consequently **overfishing did not occur**. The OFL for 2014/15 based on the author's preferred model is 33.81 thousand t. The ABC_{max} for 2014/15, based on the p^* ABC, is 33.76 thousand t. The ABC for 2013/14 was the 2nd step of a 3-year incremental stair-step approach adopted by the SSC to set ABC for this stock. The author recommends remaining on this step for 2014/15, and consequently his recommended ABC is 2/3 *x* p^* ABC = 22.51 thousand t.

7. Rebuilding analyses summary.

The EBS Tanner crab stock was found to be above MSST (and B_{MSY}) in the 2012 assessment (Rugolo and Turnock, 2012b) and was subsequently declared rebuilt. Consequently no rebuilding analyses were conducted.

A. Summary of Major Changes

1. Changes (if any) to the management of the fishery.

The Science and Statistical Committee (SSC) of the North Pacific Fisheries Management Council (NPFMC) moved the Tanner crab stock from Tier 4 to Tier 3 for status determination and OFL setting in October 2012 based on a newly-accepted assessment model (Rugolo and Turnock, 2012a). Status determination and OFL setting for Tier 4 stocks generally depend on current survey biomass and a proxy for B_{MSY} based on survey biomass averaged over a specified time period. In Tier 3, status determination and OFL setting depend on a model-estimated value for current MMB at mating time as well as proxies for F_{MSY} and B_{MSY} based on spawning biomass-per-recruit calculations and average recruitment to the population over a specified time period. The change from Tier 4 to Tier 3 resulted in a large reduction in the B_{MSY} used for status determination from 83.33 thousand t in 2011 to 33.45 thousand t in 2012. Concurrently, the estimated assessment-year MMB increased from 26.73 thousand t in 2011 to 58.59 thousand t in 2012. As a consequence, the status of Tanner crab changed from being an overfished stock following the 2011 assessment to one that was not-overfished following the 2012 assessment. The stock was subsequently declared rebuilt and an OFL of 19.02 thousand t was set for 2012/13. Although the stock was declared rebuilt as a result of the 2012 assessment, the directed fishery for Tanner crab remained closed by the SOA on the basis of its algorithms for setting harvest levels.

In the September 2013 assessment (Stockhausen et al., 2013), the Tanner crab stock was again found to be not overfished. For the 2013/14 fishing season, the SOA opened the fisheries for Tanner crab and set Total Allowable Catch limits in the two areas in which Tanner crab is commercially fished in the eastern Bering Sea (east and west of 166° W in the Eastern Subdistrict of Tanner crab Registration Area J, Fig. 1). TAC was set at 1,645,000 lbs (746.2 t) for the area west of 166° W and at 1,463,000 lbs (663.6 t) for the area east of 166° W. The fisheries opened on October 15 and closed on March 31. On closing, 80.9% of the TAC (603.5 t) had been taken in the western area while 99.5% (660.6 t) had been taken in the eastern area.

2. Changes to the input data

No new data sources were incorporated into this assessment. Much of the crab fishery data since 1990 has been recalculated (Appendix 1). Retained size frequencies in the directed fishery were recalculated for 1990/91-2009/10 and updated to include 2013/14. Effort data in the crab fisheries was recalculated for 1990/91-2012/13 from fish ticket data by H. Fitch (ADFG) to better apportion effort among fisheries. Effort data was also updated to include 2013/14. Bycatch time series for the crab fisheries, based on at-sea crab fishery observer data, were recalculated for 1992/93-2012/13, as were annual total at-sea size compositions. These time series were also updated to include 2013/14. Tanner crab bycatch time series in the groundfish fisheries were recalculated for 2009/10-2012/13 using revised methods for expanding groundfish observer data to unobserved catch based on state statistical reporting areas (Appendix 2). New groundfish bycatch estimates for 2013/14 also use this new expansion method. Bycatch size frequencies in the groundfish fisheries were recalculated for 1973/74-2012/13 based on the crab fishing year (July 1-June 30) rather than the groundfish year (Jan. 1- Dec. 1), as were new data for 2013/14. Abundance, biomass and size frequency estimates from the 2014 NMFS EBS bottom trawl survey were also added to the assessment. The following table summarizes data sources that have been updated for this assessment:

Data source	Data types	Time frame	Notes	Agency
NMFS EBS Bottom Trawl Survey	abundance, size compositions	2014	new	NMFS
Directed fishery	retained catch (numbers, biomass)	2013/14	new	ADFG
	size compositions	1990/91-2013/14	recalculated, new	ADFG
	effort	1990/91-2013/14	recalculated, new	ADFG
	total catch, discards (biomass)	1992/93-2013/14	recalculated, new	ADFG
	size compositions	1991/92-2013/14	recalculated, new	ADFG
Snow Crab Fishery	effort	1990/91-2013/14	recalculated, new	ADFG
	total catch, discards (biomass)	1992/93-2013/14	recalculated, new	ADFG
	size compositions	1992/93-2013/14	recalculated, new	ADFG
Bristol Bay Red King Crab Fishery	effort	1990/91-2013/14	recalculated, new	ADFG
	total catch, discards (biomass)	1992/93-2013/14	recalculated, new	ADFG
	size compositions	1992/93-2013/14	recalculated, new	ADFG
Groundfish Fisheries	total catch, discards (biomass)	2009/10-2013/14	recalculated, new	NMFS
	size compositions	1973/74-2013/14	recalculated, new	NMFS

Updated data sources.

3. Changes to the assessment methodology.

The major change to the assessment methodology this year is consideration of a new value for handling mortality in the crab fisheries (old value = 0.5, new value = 0.321) based on data presented at the May 2014 CPT meeting. Model runs using both values were successfully completed. In models based on the recalculated fisheries data, using the new value resulted in a 2014/15 OFL of 31.30 thousand t while using the old value resulted in a 2014/15 OFL of 33.81 thousand t.

A new assessment model is under development but has not yet been completed. The assessment methodology (i.e., a Tier 3 assessment model) remains unchanged (see Appendix 3 for a detailed description of the current model). A number of potential algorithmic changes to the existing model (e.g.,

Appendix 4) were implemented, but none proved satisfactory. The author's preferred model for status determination and OFL/ABC setting is the same as the one used in the 2013 assessment.

4. Changes to the assessment results
Results from the author's preferred model (incorporating the old handling mortality rate) are reasonably similar to those from the previous assessment, considering the large number of changes in the (primarily fisheries-related) data. Average recruitment (1982-present) was estimated at 211.9 million in last year's models, whereas it was estimated at 209.7 million in the author's preferred model this year. F_{MSY} was estimated at 0.73 yr^{-1} last year and 0.58 yr^{-1} this year. B_{MSY} was estimated at 33.5 thousand t last year and 33.8 thousand t this year.

B. Responses to SSC and CPT Comments

1. Responses to the most recent two sets of SSC and CPT comments on assessments in general. [Note: for continuity with the previous assessment, the following includes comments prior to the most recent two sets of comments.]

September 2013 Crab Plan Team Meeting
Comment: The CPT "recommends that crab authors apply the [groundfish stock structure template] criteria for considering spatial issues in stocks."
Response: Not yet addressed.

Comment: The CPT "recommends that all assessment authors document assumptions and simulate data under those assumptions to test the ability of the model to estimate key parameters in an unbiased manner."
Response: Not yet addressed. Simulation testing will be possible with the new model under development.

Comment: The CPT "recommends that weighting factors be expressed as sigmas or CVs or effective sample sizes."
Response: This has been done.

Comment: The CPT encourages authors to "…develop approaches for accounting for this source of process error" (i.e., fitting to length-composition data accounts for sampling error but not within-year variability in selectivity).
Response: Not yet addressed.

Comment: The CPT reminds authors that "assessments should include the time series of stock estimates at the time of the survey for at least the author's recommended model in that year."
Response: This has been addressed in Tables 21 and 22.

October 2013 SSC Meeting
No general comments.

January 2014 Crab Modeling Workshop
Comment: The CPT requested "all assessment authors should provide model scenarios which mimic the September 2013 assessments by replacing the bycatch data in the crab fisheries with updated data from Bill Gaeuman using the 'simple averaging' method and by replacing the NMFS survey data with recalculated series based on updated methodologies so the CPT can evaluate the implications of these changes to the data."
Response: This was addressed for the crab bycatch data provided by W. Gaeuman at the May, 2014 CPT Meeting (see http://www.npfmc.org/wp-content/PDFdocuments/membership/PlanTeam/Crab/CrabSafe14/tanner_rev.docx). The revised NMFS time series data (abundance, biomass and size frequencies) are still being evaluated and have not yet been provided to assessment authors.

May 2014 Crab Plan Team Meeting

Comment: "For all likelihood results presented, add a row to tables showing differences in likelihoods comparing to the base models."
Response: This has been addressed in Tables 19 and 20.

Comment: "When comparing likelihoods and model output, do not show models that cannot be compared next to each other. Make it clear which models are comparable..."
Response: Models that are not comparable are not directly compared.

Comment: "The CPT recommends that assessment authors investigate the effects of the new [NMFS trawl survey] time series on size frequencies."
Response: Results (e.g., abundance and biomass estimates, size frequencies) for the revised NMFS trawl survey data have only recently been released in an informal manner, so there has been no time to meet this request. It is expected that the issue will be undertaken at the Crab Modeling Workshop during the winter and again at the Spring CPT meeting.

June 2014 SSC Meeting

No general comments.

2. Responses to the most recent two sets of SSC and CPT comments specific to the assessment. [Note: for continuity with the previous assessment, the following includes comments prior to the most recent two sets of comments.]

May 2013 Crab Plan Team Meeting

Comment: "The CPT recommended that a sensitivity analysis on handling mortality be done in the Tanner crab assessment…"
Response: The author attempted to address this request using the 2013 assessment model and data for direct comparison with last year's OFL. However, it appears (based on the model runs done for this assessment) that the results are really not generalizable to the new data. Consequently, this request remains to be addressed.

Comment: "The CPT suggested starting the analysis from 2012 and moving backwards as alternative future evaluation [in the average recruitment analysis]."
Response: Not yet addressed.

June 2013 SSC Meeting

No specific comments.

September 2013 Crab Plan Team Meeting

Comment: "Evaluate bycatch in other fisheries, such as the scallop fishery, to determine whether it is of sufficient magnitude to be accounted for in the assessment."
Response: In the Bering Sea, bycatch of Tanner crab in the scallop fishery was estimated to be approximately 6.7 t (15 thousand lbs, 13 thousand crab) in 2011/12. This represents a miniscule fraction of bycatch when compared with the snow crab (1.2 *thousand* t), BBRKC (0.1 *thousand* t), and groundfish (0.333 *thousand* t) fisheries for the same year.

Comment: "All questionable size composition data should be extracted afresh from databases and the size compositions recompiled."
Response: W. Gaeuman (ADFG) re-extracted size composition data from the ADFG crab fisheries databases for (dockside) retained catch in the directed Tanner crab fishery and total and discarded catch in the directed, snow crab, and BBRKC fisheries. I re-extracted size frequencies for Tanner bycatch in the groundfish fisheries from the NMFS groundfish observer database and adjusted them to the crab fishery year (July 1-June 30) from the groundfish fishery year (Jan. 1-Dec.31). Results based on the new data sets

were discussed at the May 2014 CPT Meeting (see http://www.npfmc.org/wp-content/PDFdocuments/membership/PlanTeam/Crab/CrabSafe14/tanner_rev.docx).

Comment: "Fisheries should be modeled as a pulse at the midpoint of the fishery with the pulse based on the midpoint of the actual fishery."
Response: This will be implemented in the new model code under development.

Comment: "Examine how random walks in fishery selectivity parameters are handled during periods when the fishery is closed to ensure that reasonable assumptions are being made."
Response: The parameters describing size-at-50%-selected in the directed fishery are currently independent of one another (i.e., no autoregressive is imposed), so fishery closure periods have no effect on parameter values. This will be a issue to consider if an autoregressive structure is implemented in the future.

Comment: "The model should be fit to total biomass when that is all that is available from the survey, and fit to mature and immature biomass with separate likelihood components when both are available."
Response: This will be implemented in the new model code.

Comment: "Maturation probabilities should be estimated on a logit scale, and the smoothing penalties should be set up so the curves are non-decreasing. A parametric curve should also be considered."
Response: This has been implemented in the new model code.

Comment: "Collection of growth data specific to the Tanner crab stock in the EBS should be given a high research priority."
Response: The author agrees wholeheartedly.

Comment: "Evaluate the feasibility of estimating F_{MSY} (and B_{MSY}) for the stock using the estimates of recruitment and MMB during the post-1982 period, and compare to the $F_{35\%}$ MSY proxy."
Response: Not yet addressed.

Comment: "If time permits, apply the groundfish plan team's stock structure template to Tanner crab to synthesize the available information on stock structure."
Response: Time has not permitted. Not yet addressed.

October 2013 SSC Meeting
Comment: "The SSC recommends conducting a management strategy evaluation (MSE) to determining [sic] the long-term consequences of alternative harvest rates on stock status and yield under various sources of uncertainty."
Response: It will not be feasible to address this request at least until the new model code is completed.

Comment: "The SSC continues to encourage alternative model specifications to address these patterns" [i.e., retrospective patterns in model-estimated biomass], which "inclusion of a time-varying growth function may address…"
Response: The option for time-varying growth (constant over blocks of time) has been implemented in the new model code under development.

Comment: "The SSC…encourages a thorough review and re-compilation of all data sources."
Response: The review has been initiated and is ongoing. W. Gaeuman (ADFG) has re-extracted size composition data from the ADFG crab fisheries databases for (dockside) retained catch in the directed Tanner crab fishery and total and discarded catch in the directed, snow crab, and BBRKC fisheries. I have re-extracted size frequencies for Tanner bycatch in the groundfish fisheries from the NMFS groundfish observer database which I have adjusted to the crab fishery year (July 1-June 30) from the groundfish fishery year (Jan. 1-Dec.31). Effort in the directed Tanner crab, snow crab and BBRKC fisheries has been

painstakingly re-evaluated by D. Pengilly (ADFG), resulting in substantially revised estimates for effort in the Tanner crab fishery primarily during the early 1990s. R. Foy (NMFS) is also revising data from the NMFS trawl survey; changes, however, will not be reviewed until the 2015 Crab Modeling Workshop.

May 2014 Crab Plan Team Meeting

Comment: "The revised data sets should be used in future assessments."
Response: The revised fisheries datasets have been incorporated in the author's preferred model.

Comment: "Run the model using: (a) the old data set, (b) the revised data set and the composite fleet fishing mortality formula as used in Gmacs, and (c) the revised data set and bycatch fishing mortality formula as used in Gmacs."
Response: I'm not sure I understand how the composite fleet fishing mortality formula differs from the bycatch fishing mortality formula used in Gmacs. I've run the model using (a) the old data set (and fishing mortality formulation) , (b') the old data set and the Gmacs fishing mortality formulation (retained+bycatch), and (c') the revised dataset and the Gmacs fishing mortality formulation (retained+bycatch). Unfortunately, none of the model runs using the Gmacs fishing mortality formulation had good convergence properties and were subsequently rejected as potential alternatives for the old model formulation.

Comment: "Compare actual discarded catch with model-estimated discarded catch (separately for directed fishery bycatch, snow crab bycatch, red king crab bycatch, and groundfish bycatch)."
Response: Time did not permit addressing this request.

Comment: "The CPT requested that the next Tanner crab assessment use 0.321 as handling mortality for all pot fisheries (crab and groundfish) in the base run and 0.5 as an alternative scenario."
Response: Models with both handling mortality values. Because the 2013 assessment model used 0.5, the model using this value for handling mortality is referred to in the text as the "base" model (in contrast to the CPT's suggestion). However, the author's preferred model (Alt1a) is based on the old value.

June 2014 SSC Meeting

Comment: "Examine retrospective patterns of models being brought forward."
Response: Not yet addressed.

Comment: "Use the new handling mortality rate (0.321) as recommended by the CPT."
Response: Model runs using 0.321 as the handling mortality rate are included in this assessment. However, the author's preferred model is based on the old value.

Comment: "…the SSC advises the assessment author to explore the buffer between ABC and OFL and asks the author and Plan Team to consider the control rule for this stock. The author and Plan Team are referred to the discussion in the SSC's report for October, 2013."
Response: I assume the "discussion" refers to the SSC's recommendation for conducting an MSE for Tanner crab. It will not be feasible to address this request until the new model code is completed.

Comment: "Explore model fit to survey data using only male information."
Response: The author requests clarification on this request. Is the request to fit a male-only model to male-only data? The current assessment model is "hard-wired" as a two-sex model. It will not be feasible to address this request until the new model code is completed.

3. Older comments that remain to be addressed:

May 2012 Crab Plan Team Meeting

Comment 2: "Plot the input effective sample sizes for the compositional data versus the effective sample sizes inferred by the fit of the model…"
Response: Not yet addressed.

Comment E: "Allow M for immature as well as mature males to change during 1980-83 (the data on changes in abundance do not suggest that only mature males declined substantially) and test whether it is necessary to allow female M to change over time."
Response: Not yet addressed.

Comment 1 (Longer-term tasks): "Consider implementing the ability to change the penalty weight on F-deviations as a function of estimation phase…"
Response: This suggestion was implemented in the current model. Models using decreasing penalty weights as a function of estimation phase did not have good convergence properties. However, the suggestion will also be implmented in the new model code under development.

Comment 2 (Longer-term tasks): "Consider treating all of the F-deviations (except for which catch is known to be zero) as parameters, and include the fishing mortality-effort relationship as a prior—this will allow the uncertainty associated with this relationship to be reflected in the measures of uncertainty."
Response: Not yet addressed.

Comment 3 (Longer-term tasks): "Consider different effective sample sizes for each category of survey compositional data (males+females*mature+immature)."
Response: Different effective sample sizes (EFFs) are currently used for male and female compositional survey data, but these are not broken down further. One issue with providing different EFFs for different compositional components is that they are non-additive—that is, the effective sample sizes you would get from simply summing the EFFs from the disaggregated components are not the same as those you would get by starting from the aggregated components. The solution would be to calculate the EFFs inside the assessment code directly from the compositional data at the required level of aggregation.

Comment 4 (Longer-term tasks): "Consider fitting to total biomass (by sex?) and to the compositional data rather than to mature biomass (include the fit to mature biomass by sex as a diagnostic)."
Response: Not yet addressed.

Comment 5 (Longer-term tasks): "Do not fit to male compositional data by maturity state for the years for which chela height-maturity relationships are not available."
Response: Not yet addressed.

September 2012 Crab Plan Team Meeting

Comment: "Plot input sample sizes for LF data vs. effective sample sizes inferred by the fit of the model"
Response: Not yet addressed.

Comment: "The description of the model should be carefully checked. Two errors in model description were noted: (a) fishing mortality by the Bristol Bay red king crab and EBS snow crab fisheries is related to effort not catch; and (b) selectivity for bycatch by the EBS snow crab fishery is assumed to be dome-shaped and not asymptotic."
Response: The current model description has been rewritten and provided as an appendix (Appendix 3).

Comment: "The seemingly anomalous values [for length at 50% selectivity] may be due to confounding among parameters and need to be explored further."
Response: I attempted to address this issue this summer by fixing sizes at which crab were considered to be "fully selected", as well as options for implementing ln-scale offsets to fully-selected male fishing mortality rates for females in the various fisheries. However, models implementing these changes failed to converge satisfactorily and are not discussed in detail in this chapter due to time constraints in preparing it.

Comment: "The fits to the groundfish length-frequency data (e.g. Fig. 51) and to the total catch are unexpectedly poor. Model configurations which better capture the data should be explored."
Response: Input sample sizes associated with the male and female size compositions were found this year to have been reversed in the 2012 assessment and carried over to the 2013 assessment. Correcting this mistake has somewhat improved the fits to the groundfish size compositions, but the fits are still relatively poor.

Comment: "There is still a residual pattern in the fit to the size-composition data for the survey. This could be due to time-varying growth, which should be examined as an alternative model for May 2013."
Response: Not yet addressed. Time-varying growth (using time blocks) is an option in the new model code under development.

Comment: "A major concern for the CPT was the inability of the model to match the magnitude of discards in the EBS snow crab and Bristol Bay red king crab fisheries…The CPT requested the analysts conduct further analyses in which mimicking the observer data was given higher weight."
Response: Not yet addressed.

October 2012 SSC Meeting

Comment: "The SSC encourages the analysts to continue to explore alternative model formulations (variable growth, variable mortality, etc.) that may address patterns in model residuals (e.g., Fig. 37 and 39)."
Response: Time-varying growth and mortality have been implemented in the new model code under development.

Comment: "The SSC requests the assessment authors to include a plot similar to Fig. 54 of the assessment chapter in which recruitment (y-axis) is plotted against egg production indices (x-axis) from Fig. 14."
Response: Not yet addressed.

C. Introduction

1. Scientific name.
*Chionocoetes bairdi.*Tanner crab is one of five species in the genus *Chionoecetes* (Rathbun, 1924). The common name "Tanner crab" for *C. bairdi* (Williams et al. 1989) was recently modified to "southern Tanner crab" (McLaughlin et al. 2005). Prior to this change, the term "Tanner crab" had also been used to refer to other members of the genus, or the genus as a whole. Hereafter, the common name "Tanner crab" will be used in reference to "southern Tanner crab".

2. Description of general distribution
Tanner crabs are found in continental shelf waters of the north Pacific. In the east, their range extends as far south as Oregon (Hosie and Gaumer 1974) and in the west as far south as Hokkaido, Japan (Kon 1996). The northern extent of their range is in the Bering Sea (Somerton 1981a), where they are found along the Kamchatka peninsula (Slizkin 1990) to the west and in Bristol Bay to the east.

In the eastern Bering Sea (EBS), the Tanner crab distribution may be limited by water temperature (Somerton 1981a). The unit stock is that defined across the geographic range of the EBS continental shelf, and managed as a single unit (Figure 1). *C. bairdi* is common in the southern half of Bristol Bay, around the Pribilof Islands, and along the shelf break, although sub-legal sized males (≤138 mm CW) and ovigerous and immature females of all sizes are distributed broadly from southern Bristol Bay northwest to St. Matthew Island (Rugolo and Turnock, 2011a). The southern range of the cold water congener the snow crab, *C. opilio*, in the EBS is near the Pribilof Islands (Turnock and Rugolo, 2011). The distributions of snow and Tanner crab overlap on the shelf from approximately 56° to 60°N, and in this area, the two species hybridize (Karinen and Hoopes 1971).

3. Evidence of stock structure
Tanner crabs in the EBS are considered to be a separate stock distinct from Tanner crabs in the eastern and western Aleutian Islands (NPFMC 1998). Somerton (1981b) suggests that clinal differences in some biological characteristics may exist across the range of the unit stock. These conclusions may be limited since terminal molt at maturity in this species was not recognized at the time of that analysis, nor was stock movement with ontogeny considered. Biological characteristics estimated based on comparisons of length frequency distributions across the range of the stock, or on modal length analysis over time may be confounded as a result.

Although the State of Alaska's (SOA) harvest strategy and management controls for this stock are different east and west of 166°W, the unit stock of Tanner crab in the EBS appears to encompass both regions and comprises crab throughout the geographic range of the NMFS bottom trawl survey. Evidence is lacking that the EBS shelf is home to two distinct, non-intermixing, non-interbreeding stocks that should be assessed and managed separately.

4. Life history characteristics

a. Molting and Shell Condition
Tanner crabs, like all crustaceans, normally exhibit a hard exoskeleton of chitin and calcium carbonate. This hard exoskeleton requires individuals to grow through a process referred to as molting, in which the individual sheds its current hard shell, revealing a new, larger exoskeleton that is initially soft but which rapidly hardens over several days. Newly-molted crab in this "soft shell" phase can be vulnerable to predators because they are generally torpid and have few defenses if discovered. Subsequent to hardening, an individual's shell provides a settlement substrate for a variety of epifaunal "fouling" organisms such as barnacles and bryozoans. The degree of hard-shell fouling was once thought to correspond closely to post-molt age and led to a classification of Tanner crab by shell condition (SC) in survey and fishery data similar to that described in the following table (NMFS/AFSC/RACE, unpublished):

Shell Condition Class	Description
0	pre-molt and molting crab
1	carapace soft and pliable
2	carapace firm to hard, clean
3	carapace hard; topside usually yellowish brown; thoracic sternum and underside of legs yellow with numerous scratches; pterygostomial and bronchial spines worn and polished; dactyli on meri and metabranchial region rounded; epifauna (barnacles and leech cases) usually present but not always.
4	carapace hard, topside yellowish-brown to dark brown; thoracic sternum and undersides of legs data yellow with many scratches and dark stains; pterygostomial and branchial spines rounded with tips sometimes worn off; dactyli very worn, sometimes flattened on tips; spines on meri and metabranchial region worn smooth, sometimes completely gone; epifauna most always present (large barnacles and bryozoans).
5	conditions described in Shell Condition 4 above much advanced; large epifauna almost completely covers crab; carapace is worn through in metabranchial regions, pterygostomial branchial spines, or on meri; dactyli flattened, sometimes worn through, mouth parts and eyes sometimes nearly immobilized by barnacles.

Although these shell classifications continue to be applied to crab in the field, it has been shown that there is little real correspondence between post-molt age and shell classifications SC 3 through 5, other than that they indicate that the individual has probably not molted within the previous year (Nevisi et al, 1996). In this assessment, crab classified into SCs 3-5 have been aggregated as “old-shell” crab, indicating that these are crab likely to have not molted within the previous year. In a similar fashion, crab classified in SCs 0-2 have been combined as “new shell” crab, indicating that these are crab have certainly (SCs 0 and 1), or are likely to have (SC 2), molted within the previous year.

b. Growth

Growth in immature Tanner crab larger than 25 mm CW proceeds by a series of annual molts, up to a final (terminal) molt to maturity (Tamone et al., 2007). Growth relationships specific to Tanner crab in the EBS are unknown. Rugolo and Turnock (2012a) derived the growth relationships for male and female Tanner crab used in this assessment from data on observed growth in males to approximately 140 mm carapace width (CW) and in females to approximately 115 mm CW that were collected near Kodiak Island in the Gulf of Alaska (Munk, pers. comm.; Donaldson et al. 1981). The relationship between pre-molt and post-molt size for males and females was modeled as two parameter exponential functions of the general form $y = ax^b$, where *y* is post-molt size (CW) and *x* is pre-molt size. The resulting parameters are:

sex	parameter a	parameter b
male	1.55	0.949
female	1.76	0.913

Rugolo and Turnock (2010) compared the resulting growth per molt (gpm) relationships with those of Stone et al. (2003) for Tanner crab in southeast Alaska in terms of the overall pattern of gpm over the size range of crab and found that the pattern of gpm for both males and females was characterized by a higher rate of growth to an intermediate size (90-100 mm CW) followed by a decrease in growth rate from that size thereafter. Similarly-shaped growth curves were found by Somerton (1981a) and Donaldson et al. (1981), as well.

Previous work by Somerton (1981a) estimated growth for EBS Tanner crab based on modal size frequency analysis of Tanner crab in survey data assuming no terminal molt at maturity. Somerton’s approach did not directly measure molt increments and his findings are constrained by not considering that the progression of modal lengths between years was biased because crab ceased growing after their terminal molt to maturity

c. Weight at Length

Rugolo and Turnock (2012a) derived weight-at-size relationships for male (regardless of maturity state), immature female, and mature female Tanner crab in the EBS based on special collections of size and weight data during the summer bottom trawl surveys in 2006, 2007 and 2009. Power-law models of the form $w = a \cdot z^b$, where w is weight in grams and z is size in mm CW, were fit to the survey data. The resulting parameter estimates are given in the following table:

parameter	males	females	
	all	immature	mature
a	0.00016	0.00064	0.00034
b	3.136	2.794	2.956

These relationships are used in the assessment model to convert individual size to biomass.

d. Maturity and Reproduction

It is now generally accepted that both Tanner crab males (Tamone et al. 2007) and females (Donaldson and Adams 1989) undergo a terminal molt to maturity, as in most majid crabs. Females usually undergo their terminal molt from their last juvenile, or pubescent, instar while being grasped by a male (Donaldson and Adams 1989). Subsequent mating takes place annually in a hard shell state (Hilsinger 1976) and after extruding the female's clutch of eggs. While mating involving old-shell adult females has been documented (Donaldson and Hicks 1977), fertile egg clutches can be produced in the absence of males by using sperm stored in the spermathacae (Adams and Paul 1983, Paul and Paul 1992). Two or more consecutive egg fertilization events can follow a single copulation using stored sperm to self-fertilize the new clutch (Paul 1982, Adams and Paul 1983), although egg viability decreases with time and age of the stored sperm (Paul 1984).

Maturity in males can be classified either physiologically or morphometrically. Physiological maturity refers to the presence or absence of spermataphores in the gonads whereas morphometric maturity refers to the presence or absence of a large claw (Brown and Powell 1972). During the molt to morphometric maturity, there is a disproportionate increase in the size of the chelae in relation to the carapace (Somerton 1981a). While many earlier studies on Tanner crabs assumed that morphometrically mature male crabs continued to molt and grow, there is now substantial evidence supporting a terminal molt for males (Otto 1998, Tamone et al. 2007). A consequence of the terminal molt in male Tanner crab is that a substantial portion of the population may never achieve legal size (NPFMC 2007).

Although observations are lacking in the EBS, seasonal differences have been observed between mating periods for pubescent and multiparous females in the Gulf of Alaska and Prince William Sound. There, pubescent molting and mating takes place over a protracted period from winter through early summer, whereas multiparous mating occurs over a relatively short period during mid April to early June (Hilsinger 1976, Munk et al. 1996, and Stevens 2000). In the EBS, egg condition for multiparous Tanner crabs assessed between April and July 1976 also suggested that hatching and extrusion of new clutches for this maturity state began in April and ended sometime in mid-June (Somerton 1981a).

e. Fecundity

A variety of factors affect female fecundity, including somatic size, maturity status (primiparous vs. multiparous), age post terminal molt, and egg loss (NMFS 2004). Of these factors, somatic size is the most important, with estimates of 89 to 424 thousand eggs for females 75 to 124 mm CW, respectively

(Haynes et al. 1976). Maturity status is another important factor affecting fecundity, with primiparous females being only ~70% as fecund as equal size multiparous females (Somerton and Meyers 1983). The number of years post maturity molt, and whether or not, a female has had to use stored sperm from that first mating can also affect egg counts (Paul 1984, Paul and Paul 1992). Additionally, older senescent females often carry small clutches or no eggs (i.e., are barren) suggesting that female crab reproductive output is a concave function of age (NMFS 2004).

f. Size at Maturity

Rugolo and Turnock (2012b) estimated size at 50% mature for females (all shell classes combined) from data collected in the NMFS bottom trawl survey at 68.8 mm CW, and 74.6 mm CW for new shell females. For males, Rugolo and Turnock (2012a) estimated classification lines using mixture-of-two-regressions analysis to define morphometric maturity for the unit Tanner crab stock, and for the sub-stock components east and west of 166°W, based on chela height and carapace width data collected during the 2008 NMFS bottom trawl survey. These rules were then applied to historical survey data from 1990-2007 to apportion male crab as immature or mature based on size (Rugolo and Turnock, 2012b). Rugolo and Turnock (2012a) found no significant differences between the classification lines of the sub-stock components (i.e., east and west of 166°W), or between the sub-stock components and that of the unit stock classification line. Size at 50% mature for males (all shell condition classes combined) was estimated at 91.9 mm CW, and at 104.4 mm CW for new shell males. By comparison, Zheng and Kruse (1999) used knife-edge maturity at >79 mm CW for females and >112 mm CW for males in development of the current SOA harvest strategy.

g. Mortality

Due to the lack of age information for crab, Somerton (1981a) estimated mortality separately for individual EBS cohorts of immature and adult Tanner crab. Somerton postulated that age five crab (mean CW = 95 mm) were the first cohort to be fully recruited to the NMFS trawl survey sampling gear and estimated an instantaneous natural mortality rate of 0.35 for this size class using catch curve analysis. Using this analysis with two different data sets, Somerton estimated natural mortality rates of adult male crab from the fished stock to range from 0.20 to 0.28. When using CPUE data from the Japanese fishery, estimates of M ranged from 0.13 to 0.18. Somerton concluded that estimates of M from 0.22 to 0.28 obtained from models that used both the survey and fishery data were the most representative.

Rugolo and Turnock (2011a) examined empirical evidence for reliable estimates of oldest observed age for male Tanner crab. Unlike its congener the snow crab, information on longevity of the Tanner crab is lacking. They reasoned that longevity in a virgin population of Tanner crab would be analogous to that of the snow crab, where longevity would be at least 20 years, given the close analogues in population dynamic and life-history characteristics (Turnock and Rugolo 2011a). Employing 20 years as a proxy for longevity and assuming that this age represented the upper 98.5th percentile of the distribution of ages in an unexploited population, M was estimated to be 0.23 based on Hoenig's (1983) method. If 20 years was assumed to represent the 95% percentile of the distribution of ages in the unexploited stock, the estimate for M was 0.15. Rugolo and Turnock (2011a) adopted M=0.23 for both male and female Tanner because the value corresponded with the range estimated by Somerton (1981a), as well as the value used in the analysis to estimate new overfishing definitions underlying Amendment 24 to the Crab Fishery Management Plan (NPFMC 2007).

5. Brief summary of management history.

A complete summary of the management history is provided in the ADF&G Area Management Report appended to the annual SAFE. Fisheries have historically taken place for Tanner crab throughout their range in Alaska, but currently only the fishery in the EBS is managed under a federal Fishery Management Plan (FMP; NPFMC 1998). The plan defers certain management controls for Tanner crab to the State of Alaska, with federal oversight (Bowers et al. 2008). The State of Alaska manages Tanner crab based on registration areas divided into districts. Under the FMP, the state can adjust districts as needed to avoid overharvest in a particular area, change size limits from other stocks in the registration area, change fishing seasons, or encourage exploration (NPFMC 1998).

The Bering Sea District of Tanner crab Registration Area J (Figure 1) includes all waters of the Bering Sea north of Cape Sarichef at 54° 36'N and east of the U.S.-Russia Maritime Boundary Line of 1991. This district is divided into the Eastern and Western Subdistricts at 173°W. The Eastern Subdistrict is further divided at the Norton Sound Section north of the latitude of Cape Romanzof and east of 168°W and the General Section to the south and west of the Norton Sound Section (Bowers et al. 2008).

In March 2011, the Alaska Board of Fisheries approved a new minimum size limit strategy for Tanner crab effective for the 2011/12 fishery. Prior to this change, the minimum legal size limit was 5.5" (138 mm CW) throughout the Bering Sea District. The new regulations established different minimum size limits east and west of 166° W. The minimum size limit for the fishery to the east of 166°W is now 4.8" (122 mm CW) and that to the west is 4.4" (112 mm CW). For economic reasons, fishers may adopt larger minimum sizes for retention of crab in both areas: above 5.5" (138 mm CW) in the east and 5" (>127 mm CW) in the west.

In this report, we will use the terms "east region" and "west region" as shorthand to refer to the regions demarcated by 166°W. We will also use the term "legal males" to refer to male crab ≥ 138 mm CW, although this is not strictly correct as it now refers to the industry's "preferred" crab size in the east region.

Landings of Tanner crab in the Japanese pot and tangle net fisheries were reported in the period 1965-1978, peaking at 19.95 thousand t in 1969. The Russian tangle net fishery was prosecuted during 1965-1971 with peak landings in 1969 at 7.08 thousand t. Both the Japanese and Russian Tanner crab fisheries were displaced by the domestic fishery by the late-1970s (Table 1; Figures 2 and 3). Foreign fishing for Tanner crab ended in 1980.

The domestic Tanner crab pot fishery developed rapidly in the mid-1970s (Tables 1 and 2; Figures 2 and 3). Domestic US landings were first reported for Tanner crab in 1968 at 0.46 thousand t taken incidentally to the EBS red king crab fishery (Table 1). Tanner crab was targeted thereafter by the domestic fleet and landings rose sharply in the early 1970s, reaching a high of 30.21 thousand t in 1977/78 (Tables 1 and 2; Figure 2). Landings fell sharply after the peak in 1977/78 through the early 1980s, and domestic fishing was closed in 1985/86 and 1986/87 due to depressed stock status. In 1987/88, the fishery reopened and landings rose again in the late-1980s to a second peak in 1990/91 at 18.19 thousand t, and then fell sharply through the mid-1990s. The domestic Tanner crab fishery was closed between 1996/97 and 2004/05 as a result of conservation concerns regarding depressed stock status. It re-opened in 2005/06 and averaged 0.77 thousand t retained catch between 2005/06-2009/10 (Tables 1 and 2). For the 2010/11-2012/13 seasons, the State of Alaska closed directed commercial fishing for Tanner crab due to estimated female stock metrics being below thresholds adopted in the state harvest strategy. However, these thresholds were met in fall 2013 and the directed fishery was opened in 2013/14. TAC was set at 1,645,000 lbs (746.2 t) for the area west of 166° W and at 1,463,000 lbs (663.6 t) for the area east of 166° W in the State of Alaska's Eastern Subdistrict of Tanner crab Registration Area J. The fisheries opened on October 15 and closed on March 31. On closing, 80.9% (603.5 t) of the TAC had been taken in the western area while 99.5% (660.6 t) had been taken in the eastern area. Prior to the closures, the retained catch averaged 770 t per year between 2005/06-2009/10.

Bycatch and discard losses of Tanner crab originate from the directed pot fishery, non-directed snow crab and Bristol Bay red king crab pot fisheries, and the groundfish fisheries (Table 3, Fig. 4). In previous assessments, discard mortalities were estimated using post-release handling mortality rates (HM) of 50% for pot fishery discards and 80% for groundfish fishery bycatch (NPFMC 2008). In this assessment, an alternative HM of 32.1% for the pot fisheries is considered based on information presented by D. Urban (AFSC) to the CPT at its May 2014 meeting. Regardless of the HM selected, the pattern of total bycatch/discard losses is similar to that of the retained catch. Bycatch was persistently high during the early-1970s; a subsequent peak mode of discard losses occurred in the early-1990s. In the early-1970s, the groundfish fisheries contributed significantly to total bycatch losses. The combined crab pot fisheries are the principal source of contemporary non-retained losses to the stock when the older value for handling mortality in the pot fisheries is used, but the groundfish fisheries remain the principal source if the new value is used.

D. Data

1. Summary of new information

No new data sources were incorporated into this assessment. Much of the crab fishery data since 1990 has been recalculated (see Appendix 1). Retained size frequencies in the directed fishery were recalculated for 1990/91-2009/10 and updated for 2013/14. Effort data in the crab fisheries was recalculated for 1990/91-2012/13 from fish ticket data by D. Pengilly (ADFG) to better apportion it among fisheries. Effort data was also updated for 2013/14. Bycatch time series for the crab fisheries, based on at-sea crab fishery observer data, were recalculated for 1992/93-2012/13, as were annual total at-sea size compositions. Tanner crab bycatch time series in the groundfish fisheries were recalculated for 2009/10-2012/13 using revised methods for expanding groundfish observer data to unobserved catch based on state statistical reporting areas (Appendix 2). Groundfish bycatch estimates for 2013/14 also use this revised expansion method. Bycatch size frequencies in the groundfish fisheries were recalculated for 1973/74-2012/13 based on the crab fishing year (July 1-June 30) rather than the groundfish year (Jan. 1- Dec. 1); size frequencies for 2013/14 were calculated in this fashion, as well. Abundance, biomass and size frequency estimates from the 2014 NMFS EBS bottom trawl survey were also added to the assessment. Trawl survey data (1974-2013) included in last year's assessment were also included in this assessment. The following table summarizes data sources that have been updated for this assessment:

Updated data sources.

Data source	Data types	Time frame	Notes	Agency
NMFS EBS Bottom Trawl Survey	abundance, size compositions	2014	new	NMFS
Directed fishery	retained catch (numbers, biomass)	2013/14	new	ADFG
	size compositions	1990/91-2013/14	recalculated, new	ADFG
	effort	1990/91-2013/14	recalculated, new	ADFG
	total catch, discards (biomass)	1992/93-2013/14	recalculated, new	ADFG
	size compositions	1991/92-2013/14	recalculated, new	ADFG
Snow Crab Fishery	effort	1990/91-2013/14	recalculated, new	ADFG
	total catch, discards (biomass)	1992/93-2013/14	recalculated, new	ADFG
	size compositions	1992/93-2013/14	recalculated, new	ADFG
Bristol Bay Red King Crab Fishery	effort	1990/91-2013/14	recalculated, new	ADFG
	total catch, discards (biomass)	1992/93-2013/14	recalculated, new	ADFG
	size compositions	1992/93-2013/14	recalculated, new	ADFG
Groundfish Fisheries	total catch, discards (biomass)	2009/10-2013/14	recalculated, new	NMFS
	size compositions	1973/74-2013/14	recalculated, new	NMFS

2. Data presented as time series

For the stock biomass and fishery data presented in this document, the convention is that 'year' refers to the year in which the NMFS bottom trawl survey was conducted (nominally July 1, yyyy), and fishery data are those subsequent to the survey (July 1, yyyy to June 30, yyyy+1)--e.g., 2008/09 indicates the 2008 bottom trawl survey and the winter 2008/09 fishery.

a. Total catch

Retained catch (1000's t) in the directed fisheries for Tanner crab conducted by the foreign fisheries (Japan and Russia) and the domestic fleet, starting in 1965/66, is presented in Table 1 (and Fig.s 2 and 3) by fishery year. More detailed information on retained catch in the directed domestic pot fishery is provided in Table 2, which lists total annual catches in numbers of crab and biomass (in lbs), as well as the SOA's Guideline Harvest Level (GHL) or Total Allowable Catch (TAC) , number of vessels participating in the directed fishery, and the fishery season. Information from the Community Development Quota (CDQ) is included in the totals starting in 2005/06.

b. Information on bycatch and discards

Annual discards (1000's t) of Tanner crab by sex are provided in Table 3 (and Fig.s 4 and 5) from crab observer sampling, starting in 1992/93 for the directed Tanner crab fishery, the snow crab fishery, and the BBRKC fishery. Annual discards for the groundfish fisheries are also provided starting in 1973/74, but sex is undifferentiated.

c. Catch-at-size for fisheries, bycatch, and discards

Retained (male) catch at size in the directed Tanner crab fishery from landings data is presented in Figure 6 by fishery region for the most recent fishery periods from 2005/06-2013/14. Size compositions of total catch (retained + discards) from at-sea crab fishery observer sampling are presented by shell condition and fishery region in Fig. 7 for male crab and in Fig. 8 for female crab. Size compositions for bycatch in the snow crab fishery from at-sea crab fishery observer sampling are presented by shell condition in Fig. 9 for male Tanner crab and in Fig. 10 for females. Figures 11 and 12 present similar information for the BBRKC fishery. Figures 13 and 14 present relative catch size composition information from groundfish observer sampling in the groundfish fisheries for undifferentiated males and females, respectively, from 1973/74 to the present. Raw sample sizes (number of individuals measured) for the various fisheries are presented in Tables 4-8.

d. Survey biomass estimates

Annual estimates (1,000's t) of mature biomass by sex from the summertime NMFS bottom trawl survey (Daly et al., in prep.) are given in Table 9 (Fig. 15), as is abundance (numbers) of "legal" crab (≥ 138 mm CW). Survey estimates for mature male biomass, total mature biomass, and "legal" male abundance increased from 2013 to 2014 by 23%, 17%, and 34% respectively, while estimates for mature female biomass declined by 17% (Fig. 16).

e. Survey catch-at-length

Plots of survey catch-at-size are presented for male and female crab in Fig.s 17 and 18, respectively, by shell condition and fishery region. Sample sizes for these size compositions are presented in Table 10.

f. Other time series data.

The spatial patterns of abundance in the 2010-2013 NMFS bottom trawl surveys are plotted in Fig.s 19-23 for immature males, mature males, "legal" males, immature females, and mature females, respectively. A table of annual effort (number of potlifts) is provided for the snow crab and BBRKC fisheries (Table 11).

3. Data which may be aggregated over time:

a. Growth-per-molt

Sex-specific growth curves derived by Rugolo and Turnock (2010) are presented in Fig. 24. These curves provide the basis for priors on sex-specific growth estimated within the assessment model.

b. Weight-at size

Weight-at-size curves used in the assessment model for males, immature females, and mature females are presented in Fig. 25.

c. Size distribution at recruitment

The assumed size distribution for recruits to the population in the assessment model is presented in Fig. 26.

4. Information on any data sources that were available, but were excluded from the assessment.

None.

E. Analytic Approach

1. History of modeling approaches for this stock

Prior to the 2012 stock assessment, Tanner crab was managed as a Tier-4 stock using a survey-based assessment approach (Rugolo and Turnock 2011b). The Tier 3 Tanner Crab Stock Assessment Model (TCSAM) was developed by Rugolo and Turnock and presented for review in February 2011 to the Crab Modeling Workshop (Martel and Stram 2011), to the SSC in March 2011, to the CPT in May 2011, and to the CPT and SSC in September 2011. The model was revised after May 2011 and the report to the CPT in September 2011 (Rugolo and Turnock 2011a) described the developments in the model per recommendations of the CPT, SSC and Crab Modeling Workshop through September 2011. In January 2012, the TCSAM was reviewed at a second Crab Modeling Workshop. Model revisions were made during the Workshop based on consensus recommendations. The model resulting from the Workshop was presented to the SSC in January 2012. Recommendations from the January 2012 Workshop and the SSC, as well as Rugolo's and Turnock's research plans, guided changes to the model. A model incorporating all revisions recommended by the CPT, the SSC and both Crab Modeling Workshops was presented to the SSC in March 2012.

In May 2012 and June 2012, respectively, the TCSAM was presented to the CPT and SSC to determine its suitability for stock assessment and the rebuilding analysis (Rugolo and Turnock 2012b). The CPT agreed that the model could be accepted for management of the stock in the 2011/12 cycle, and that the stock should be promoted to Tier-3 status. The CPT also agreed that the TCSAM could be used as the basis for rebuilding analyses to underlie a rebuilding plan developed in 2012. In June 2012, the SSC reviewed the model and accepted the recommendations of the CPT. The Council subsequently approved the SSC recommendations in June 2012. For 2011/12, the Tanner crab was assessed as a Tier-3 stock and the model was used for the first time to estimate status determination criteria and overfishing levels.

In December 2012, a new analyst (Stockhausen) was assigned as principal author for the Tanner crab assessment. Modifications have been made to the TCSAM computer code to improve code readability, computational speed, model output, and user friendliness without altering its underlying dynamics and overall framework. A new description of the 2013 model (TCSAM2013) is presented in Appendix 3.

2. Model Description

a. Overall modeling approach

TCSAM is a stage/size-based population dynamics model that incorporates sex (male, female), shell condition (new shell, old shell), and maturity (immature, mature) as different categories into which the overall stock is divided on a size-specific basis. For details of the model, the reader is referred to Appendix 3 and Rugolo and Turnock (2012b).

In brief, crab enter the modeled population as recruits following the size distribution in Fig. 26. An equal (50:50) sex ratio is assumed at recruitment, and all recruits begin as immature, new shell crab. Within a model year, new shell, immature recruits are added to the population numbers-at-sex/shell condition/maturity state/size remaining on July 1 from the previous year. These are then projected forward to Feb. 15 ($\delta t = 0.625$ yr) and reduced for the interim effects of natural mortality. Subsequently, the various fisheries that either target Tanner crab or catch them as bycatch are prosecuted as pulse fisheries (i.e., instantaneously). Catch by sex/shell condition/maturity state/size in the directed Tanner crab, snow crab, BBRKC, and groundfish fisheries is calculated based on fishery-specific stage/size-based selectivity curves and fully-selected fishing mortalities and removed from the population. The numbers of surviving immature, new shell crab that will molt to maturity are then calculated based on sex/size-specific probabilities of maturing, and growth (via molt) is calculated for all surviving new shell crab. Crab that were new shell, mature crab become old shell, mature crab (i.e., they don't molt) and old shell crab remain old shell. Population numbers are then adjusted for the effects of maturation, growth, and change in shell condition. Finally, population numbers are reduced for the effects of natural mortality operating from Feb. 15 to July 1 ($\delta t = 0.375$ yr) to calculate the population numbers (prior to recruitment) on July 1.

Model parameters are estimated using a maximum likelihood approach, with Bayesian-like priors on some parameters and penalties for smoothness and regularity on others. Data components entering the likelihood include fits to survey biomass, survey size compositions, retained catch, retained catch size compositions, discard mortality in the bycatch fisheries, and discard size compositions in the bycatch fisheries (Appendix 3).

b. Changes since the previous assessment.

Following the January 2014 Crab Modeling Workshop, it was realized that the equations describing fishing mortality and retention in TCSAM2013 were not the same as those being implemented in the Generalized Model for Alaskan Crab Stocks (Gmacs). Gmacs is intended to be a generalized framework for developing crab stock assessment models. Although the fishing mortality equations implemented in the current Tanner crab model (TCSAM2013) represent a workable description of the fishing mortality process, the interpretation of the retention function in the Tanner crab model and in Gmacs are inconsistent with one another. The retention function used in Gmacs represents a simple and intuitive description of the on-deck process of retention and discarding whereas the one used in the Tanner crab model does not (Appendix 4). An alternative version of the Tanner crab model implementing the Gmacs equations (TCSAM-FRev) was developed by modifying a copy of the TCSAM2013 code in Spring 2014, with results from initial model runs presented to the CPT in May. Following this, the CPT requested that model runs based on TCSAM-FRev would be presented at the September 2014 as alternative models on which to base status determination and OFL calculation.

The TCSAM2013 code has also been modified with options to: 1) provide jittering of initial parameter values (as a basis for automating the testing model convergence from multiple starting parameter value sets); 2) estimate ln-scale female offset parameters to fully-selected male fishing mortality rates, 3) "anchor" selectivity functions by fixing fully-selected sizes, and 4) implement phase-specific reductions on the weights used for various penalties in the likelihood function. These options were also incorporated in the TCSAM-FRev code. Initial model explorations using options 2-4 typically resulted in unsatisfactory model convergence properties and are not discussed further. However, these options deserve to be more fully explored in the future.

As part of revising the size frequencies for bycatch in the groundfish fisheries, it was realized that the input sample sizes previously used for fitting these data had inadvertently been switched for males and females. This error was propagated through both the 2012 and 2013 assessments. One impact that correcting this error has on the assessment is that the parameter estimating size at 50%-selection for total selectivity on males in the directed fishery in 1996 is now driven to its lower bound. The sample sizes associated with catch size frequencies in the 1996 directed fishery are quite small (less than 3, Table 5), which means there is very little penalty in the overall likelihood for poorly fitting this data, even though it results in a very poor fit to the data and an unreasonably small value for the parameter. The error in sample sizes is included in scenarios that use the "2013 data" and corrected in scenarios that use the 2014 recalculated data.

i. Methods used to validate the code used to implement the model

The model code has been reviewed by members of the CPT and the assessment author.

3. Model Selection and Evaluation

a. Description of alternative model configurations

The following ten alternative model configurations were considered in this assessment:

Model Scenario	Model converged?	Handling Mortality	Data	Model Type	Model Options
Alt0a	yes	50.0%	2013 data + 2014	TCSAM2013	base model: same as 2013 model
Alt0b	yes	32.1%	2013 data + 2014	TCSAM2013	base model
Alt1a	yes	50.0%	2014 revised data	TCSAM2013	base model with sample sizes corrected for groundfish bycatch size frequencies
Alt1b	yes	32.1%	2014 revised data	TCSAM2013	base model with sample sizes corrected for groundfish bycatch size frequencies
Alt2a	no	50.0%	2014 revised data	TCSAM-FRev	options same as base TCSAM2013 model with corrected sample sizes
Alt2b	no	32.1%	2014 revised data	TCSAM-FRev	options same as base TCSAM2013 model with corrected sample sizes
Alt2c	no	50.0%	2014 revised data	TCSAM-FRev	increased weights on fitting 1996 directed fishery discards
Alt2d	no	32.1%	2014 revised data	TCSAM-FRev	increased weights on fitting 1996 directed fishery discards
Alt3a	no	50.0%	2014 revised data	TCSAM-FRev	ln-scale female fsihing mortality offsets estimated
Alt3b	no	32.1%	2014 revised data	TCSAM-FRev	ln-scale female fsihing mortality offsets estimated

Model scenario Alt0a (this year's base model) represents last year's accepted model (referred to subsequently as the "2013 Model") updated with only the new data for 2013/14 (2013/14 retained catch numbers, biomass and size frequencies; 2013/14 bycatch biomass and size frequencies in the crab and groundfish fisheries; 2014 trawl survey abundance, biomass, and size frequencies). Scenario Alt0b uses the new handling mortality rate for pot fisheries to convert discard biomass to discard mortality, but is otherwise identical to Alt0a. Scenarios Alt1a and Alt1b incorporate the recalculated size frequencies from the dockside and at-sea observer sampling in the crab and groundfish fisheries, recalculated effort data in the crab fisheries, and recalculated discard biomass in the crab and groundfish fisheries as well as the new data for 2013/14. The model used to fit the data in the "Alt1-" scenarios is otherwise identical to that used to fit the "Alt 0-" scenarios (and the 2013 Model) except that the input sample sizes used for bycatch size frequencies for the groundfish fisheries have been corrected.

The "Alt2-" and "Alt3-" scenarios fit the TCSAM-FRev model, which incorporates the Gmacs fishing mortality equations, to the recalculated data with several different options. However, none of these latter scenarios resulted in converged models. Results presented at the May CPT meeting were initially encouraging, although concerns regarding model convergence were raised at the meeting. Subsequently these models displayed rather poor convergence properties and none achieved satisfactory convergence. Further modifications to the code implementing jittering of initial parameter values, ln-scale offsets for females to fully-selected male fishing mortality rates, "anchoring" selectivity functions by fixing fully-selected sizes, and phase-specific weight reductions on penalties in the likelihood function were unsuccessful at achieving converged models, as well. These results probably stem from an unsuccessful attempt to graft, as a shortcut, the Gmacs fishing mortality equations onto the TCSAM2013 model framework. Due to time constraints on preparing this SAFE chapter, results from these model runs will not be discussed further.

Model scenario Alt1a, which used the old value for handling mortality on discards in the pot fisheries, emerged as the author's preferred model because model scenarios using the new value for handling mortality exhibited undesirable behavior. [**Note:** In reviewing the assessment, the CPT was unsatisfied with the author's justification for basing status determination and OFL setting on Alt1a. In the course of the meeting, the author subsequently modified the assessment model code to re-parameterize the selectivity function for male bycatch in the snow crab fishery to address certain deficiencies, ran 3 new model scenarios based on the revised model, and presented the results to the CPT. After reviewing all the scenarios, the CPT selected the new model scenario basded on the new value for handling mortality in the pot fisheries (Alt4b) as its preferred model. The changes to the model and the additional model scenarios are discussed in Appendix 6.]

b. Progression of results from the previous assessment to the preferred base model

Parameter values from the model scenarios are compared in Table 12 for the previous assessment model (2013 Model) and the four alternative models that converged. Parameter bounds, initial estimation phase, valid indices, type and name in the corresponding TCSAM2013 code are also listed. Estimates from the 2013 Model and Alt0a (the base 2014 model) are reasonably similar (within one standard deviation of the 2013 Model estimate) for most parameters, the exceptions being the 2013 recruitment deviation (pRevDevs for 2013), the size at 50%-selected for females in the BBRKC fishery in time stanza 1 ("rkfish_disc_sel50_f1" in Table 12), the slope and size at 50% selected for females in the groundfish fisheries in the "current" time stanza (fish_disc_slope_tf3, fish_disc_sel50_tf3), and the size at 50% selected for males in the groundfish fisheries in the "current " time stanza (fish_disc_sel50_tm3). The difference in the 2013 recruitment deviation is not unexpected because there was little information (only the 2013 trawl survey) to inform this estimate last year whereas it is now based on 2 surveys.

Parameter values that were at their bounds in the 2013 Model (highlighted in Table 12) similarly hit their bounds in Alt0a. Sizes at 50%-selected also hit their bounds in Alt1a for female bycatch in the BBRKC fishery in time stanzas 1 and 2 (rk_disc_sel50_f1, rk_disc_sel50_f2).

Considering Alt0b, the following parameters were located at one of their bounds in the converged model but not in the 2013 Model or Alt0b: the scalar growth parameter for females (af1) and the ln-scale deviation to size at 50%-selected in the directed fishery corresponding to 1996 (log_sel50_dev_3, index 6). This was also the case for the Alt1a and b scenarios. The af1 parameter was also fairly close to (but not at) its upper bound (0.70) for both the 2013 Model and tAlt0b (0.688) and is not really statistically different from the latter estimates (the estimated standard deviations on the latter were 0.05). The ln-scale deviation to mean size at 50%-selected was at its lower limit (-0.5). The corresponding sample sizes for the 1996 directed fishery total catch size frequencies are quite small (< 3), which puts very little constraint on this parameter in the fitting process. For the Alt1- scenarios, the change to the lower limit was traced back to correcting the legacy input sample sizes to the groundfish bycatch size frequencies for a male/female switch made prior to the 2012 assessment. That Alt0b ends up in the same place for this parameter, with only pot fishery handling mortality changed reinforces the inherent uncertainty associated with this parameter.

Parameters that were substantially different between Alt0b and Alt0a (regarded as the new base) included: the multiplier on mature female natural mortality (Mmult_f), several ln-scale deviations to total (retained+discards) mean fishing mortality in the directed fishery (pFmDevsTCF) in the early 1990s (years with substantial bycatch, which the change in handling mortality would impact as far as total mortality was concerned), several ln-scale deviations to discard mortality in the groundfish fisheries in the early 1990s (pFmDevsGTF), the average ln-scale discard mortality in the snow crab fishery (pAvgLnFmSCF), the ln-scale average (1991/92-2013/14) size at 50% selected in the directed fishery (log_avg_sel50_3), all the annual ln-scale deviations from the log_avg_sel50_3 (log_sel50_dev_3), and parameters affecting the slope and size at 50% selected for the bycatch selectivity curves in the groundfish fishery, survey q in survey time stanzas 2 and 3 (srv2_q and srv3_q), and size at 50% selected for females in the trawl survey in survey time stanza 3 (srv3_sel50_f).

Considering Alt1a, which used the revised fishery data but the old pot fishery handling mortality, it exhibited results similar to Alt0b in terms of the parameters that ended up at one of their bounds. The size at 50% selected in time stanza 1 for male bycatch in the BBRKC fishery (rkfish_disc_sel50_m1) additionally ended up at its upper bound, as did size at 50%-selected for female bycatch in time stanza 1in the groundfish fisheries (fish_disc_sel50_tf1). However, 50% selectivity for female bycatch time stanza 2 in the groundfish fisheries (fish_disc_sel50_tf2) was estimated well inside the bounds in Alt1a as opposed to Alt0b.

Parameter values that were substantially different between Alt1a and Alt0a (regarded as the base from which to identify changes due solely to the re-calculated fishery data), parameters that were substantially different between the two included: the natural mortality multiplier for mature females during the enhanced mortality period (1980-84; mat_big[1]), ln-scale deviations to total (retained+discards) mean fishing mortality in the directed fishery (pFmDevsTCF) corresponding to the early 1990s and 1996, several ln-scale deviations to discard mortality in the groundfish fisheries in the early 1990s (pFmDevsGTF), the ln-scale mean bycatch mortality rate in the groundfish fisheries (pAvgLnFmGTF) and deviations corresponding to 1991 and 1992, the ln-scale average size at 50% selected in the directed fishery (log_avg_sel50_3), all the annual ln-scale deviations from the log_avg_sel50_3 (log_sel50_dev_3), and some of the parameters affecting the bycatch selectivity curves in the snow crab, BBRKC, and groundfish fisheries.

Finally, Alt1b exhibited results similar to Alt1a in terms of parameters that ended up at one of their bounds, except that rkfish_disc_sel50_f2 (size at 50% selected for female bycatch in time stanza 2 for the BBRKC fishery) was well-estimated in the interior of the parameter domain.

Parameter values that were substantially different between Alt1b and Alt1a (regarded as the base to distinguish changes due only to the change in handling mortality) included: ln-scale mean recruitment post 1973 (pAvgLnRec), the ln-scale mean bycatch fishing mortality in the snow crab fishery (pAvgLnFmSCF) and several associated devs (pFmDevsSCF, not unexpected given the different handling mortality values used in the two models), and some parameters influencing bycatch selectivity curves in the snow crab and BBRKC pot fisheries.

Overall, however, time series results from the four model scenarios and the 2013 Model are remarkably similar (Tables 13-18 and Figures 27-37) in most cases. Changes in the data (Alt0- scenarios vs Alt1- scenarios) and in assumed pot fishery handling mortality (Alt-a scenarios vs. Alt-b scenarios) appear to have relatively little impact on many of the estimated time series. All four model scenarios estimated somewhat lower recruitment for 2013 than the 2013 Model did, and all estimated slightly higher recruitment in 2014 than in 2013 (Fig. 27, Table 13; with the caveat that model-end estimates of recruitment are highly uncertain). Estimates of fully-selected fishing mortality (including discards) and retention rates in the directed fishery are quite similar, as well (Figures 28 and 29). Estimates of MMB (at mating time; Table 14 and Figure 30) are also quite similar across the modeled time period: the trajectories are very similar, although they differ as to the magnitude of MMB across the main peak in MMB during the mid-1970s. Final MMB differs by less than 10% across the models. Estimates of the time series of the numbers of male crab ≥ 138 mm CW in the survey (Table 15, Figure 31) differ by less than 5% over the final 20 years of the model runs.

Time series where differences are more evident include those for quantities directly related to bycatch mortality, such as the fully-selected fishing mortality rates in the snow crab (Figure 32) and groundfish fisheries (Figure 34). This is a direct consequence of different assumed pot fishery handling mortalities between the “a” and “b” models. The differences are not very apparent in the results for the BBRKC fisheries because fishing mortality for this bycatch fishery is fixed (or estimated from fishing effort) across most of the time period (Figure 33). The behavior of the fully-selected fishing mortality rate for bycatch in the groundfish fisheries is interesting in that the models with decreased handling mortality in the pot fisheries (Alt0b, Alt1b) exhibit higher bycatch fishing mortality rates in the groundfish fisheries.

The four models follow very similar trajectories and appear to fit retained catch in the directed fishery equally well (Table 16, Figure 35), except in 1996 where all the models except Alt0a (and the 2013

Model) under-estimate the observed retained catch (0.82 thousand t) by nearly 50%. This latter deficiency presumably relates to the models' inability to estimate the size at 50% selected in the directed fishery in 1996, as well.

Fits to total mortality for males in the directed fishery are biased slightly high for all models (Table 17, Figure 36). Fits to discard mortality for females in the directed fishery are relatively poor for all models (Table 18, Figure 37). This is not surprising given that annual rates of fully-selected fishing mortality on females in the directed fishery are assumed to be the same as for males (and given patterns of spatial aggregation of males and females there may be good reason not to make this assumption).

c. Evidence of search for balance between realistic (but possibly overparameterized) and simpler (but not realistic) models.

No such search was conducted for this assessment.

d. Convergence status and convergence criteria

Convergence in all models was assessed by running each model iteratively from a set of initial parameter configurations. Following an initial run, the final parameter estimates from the run were used as initial parameter estimates in a following run and this sequence was repeated until the final objective function value obtained was identical to that from the previous run (generally four times). The final model (with the smallest objective function value) was selected as the "converged" model if it was possible to invert the associated hessian and obtain standard deviation estimates for parameter values. For a subset of the models, this approach was checked by generating 50 randomly-chosen initial parameter settings, running the model for each setting, and checking that the minimum objective function among the 50 model runs was no smaller than that final model run selected using the iterative procedure. This latter procedure was also used to try to find convergent models for those in which the iterative procedure failed to produce a run with a valid model hessian.

e. Sample sizes assumed for the compositional data

Sample sizes assumed for compositional data used in the Alt1- models are listed in Tables 4-8 for fishery-related size compositions. Sample sizes for all survey size compositions were set to 200, which was also the maximum allowed for the fishery-related sample sizes. Otherwise, input sample sizes were scaled using (Appendix 5)

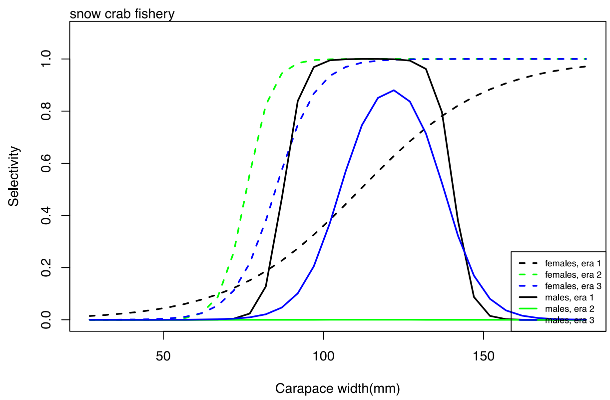
$$SS_y^{inp} = \min\left(200, \frac{SS_y}{(\overline{SS}/200)}\right)$$

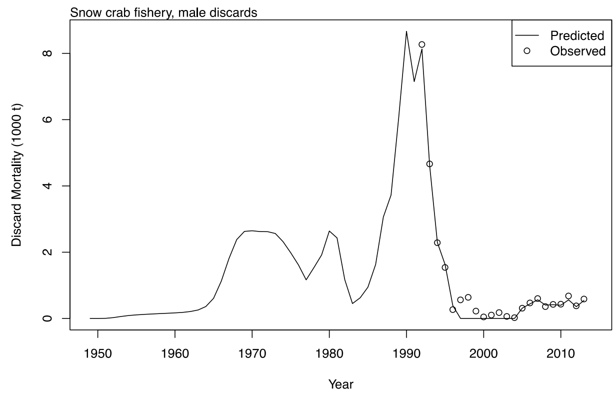
where $\overline{SS}$ was the mean sample size for all males from dockside sampling in the directed fishery. Input sample sizes for all the Alt1- model size compositions are compared in Figure 38.

f. Parameter sensibility

Most model parameter estimates obtained from the alternative models appear to be reasonable, or at least consistent with the 2013 Model. One notable exception is the estimate for the ln-scale deviation from mean size at 50%-selected for males in the directed fishery (log_sel50_dev_3, index 6) for 1996, which hits the lower bounds put on the parameter (-0.5) in models Alt0b, Alt1a, and Alt1b. This results in an unreasonably small estimate (~75 mm CW) for size at 50%-selected in 1996 in the directed fishery. Factors apparently responsible for this result are: 1) the small input sample sizes associated with total catch size frequencies in the directed fishery for 1996 (< 3) and 2) incorrect input sample sizes previously used for bycatch size frequencies in the groundfish fisheries.

The other notable exception is the estimate for size at 50% selected on the downward sloping limb of the double-logistic bycatch selectivity curve for males during 1997-2004 in the snow crab fishery (snowfish_disc_sel50_m2_2) for model Alt1b. The value for this parameter is 94.9 mm CW, which is quite a bit less than the corresponding parameter for the ascending arm (snowfish_disc_sel50_m_2), which is 139 mm CW. The implications for this are illustrated in the two plots below. The lefthand plot shows the bycatch selectivity curves estimated by Alt1b for the snow crab fishery (the horizontal green line at the bottom is male bycatch selectivity during 1997-2004). The righthand plot shows the corresponding fit to the discard data (note the flat line almost at 0 for 1997-2004):





The result is that male bycatch in the snow crab fishery is estimated as nearly 0 during 1997-2004. To some extent, this result is due to a poor parameterization of the double-logistic which does not guarantee that the size at 50% selected on the descending limb is larger than that on the ascending limb. It may also be a consequence of formulating the likelihood for bycatch in the snow crab fishery using an assumption of normally-distributed errors with constant variance, as opposed to an assumption of lognormally distributed errors.

g. Criteria used to evaluate the model or to choose among alternative models

Criteria used to evaluate the alternative models included: 1) data reliability, 2) goodness of fit and likelihood criteria, 3) parameter sensibility, and 4) biological realism.

h. Residual analysis

Residual analysis for the preferred model is presented below. Residual analysis for the four alternative models is available online at the CPT archive website[1]. Residuals for the author's preferred model are discussed below under the Results section.

i. Evaluation of the model(s)

The two "Alt0-" models were not considered as possible preferred models because: 1) they were based on incorrect input sample sizes for bycatch size frequencies in the groundfish fisheries and 2) because they were fit to data that has subsequently been recalculated and revised. However, Table 19 and Figure 39, which present a comparison of components in the objective function for the two models, are included for the sake of completeness.

Considering goodness of fit and likelihood criteria, model Alt1a fits the data better in an overall sense compared with Alt1b by 6 likelihood units (Table 20, Figure 40), but not for every component in the objective function. Although it is not strictly valid, as was done in the table and figure, to directly compare the overall likelihoods and some of the components because they essentially involve fits to different data because different values for pot fishery handling mortality are applied to the discard data, in this case one *can* conclude that Alt1a fits the data better, and better than the difference in objective function values suggests, because it is based on the larger value for pot fishery handling mortality (and

[1] http://legistar2.granicus.com/npfmc/meetings/2014/9/898_A_Crab_Plan_Team_14-09-15_Meeting_Agenda.pdf

thus one would expect larger differences between observed and estimated values). Alt1a fits much better than Alt1b to size frequencies and catch mortality for retained males and all males from the directed fishery, as well as for size frequencies for immature males in the trawl survey. Alt1a fits more poorly than Alt1b for mature males, immature females and mature females for trawl survey size frequencies. It appears to fit more poorly for female bycatch mortality in the directed fishery, and for total bycatch mortality in the BBRKC fishery, but these comparisons are affected by the difference in assumed handling mortality in the pot fisheries.

The pot fishery handling mortality used in model Alt1b is presumably more biologically realistic than that in Alt1a, given that it is based on the new value of 32.1% for handling mortality in the pot fisheries—which in turn is based on a substantial body of evidence (at least regarding short term mortality). However, the author feels that Alt1a results in a better fit to the data than Alt1b. Additionally, its estimated parameter values are the more reasonable of the two, given the rather nonsensical result obtained for male bycatch selectivity curves in the snow crab fishery using Alt1b (as illustrated above).

4. Results (best model(s))

Model Alt1a, which uses the recalculated data and the old estimate for handling mortality in the crab fisheries, is the author's preferred model and is considered the "best" model. **[Note: see Appendix 6 for the model scenario selected by the CPT.]**

a. List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties.

Input sample sizes for the various fishery-related size compositions are given in Tables 4-8 and Figure 38. Input sample sizes for all survey-related size compositions were set to 200. Weighting factors for likelihood components and penalties are listed in Table 20, as are the associated objective function values from the converged model.

b. Tables of estimates:

i. All parameters

Parameter estimates and associated standard errors, based on inversion of the converged model's Hessian, are listed in Table 12.

ii. Abundance and biomass time series, including spawning biomass and MMB.

Estimates of MMB are listed in Table 14. Estimates of the number of "legal" males (≥ 138 mm CW) are listed in Table 15. Numbers at size for males and females are given by year in 5 mm CW size bins in Tables 21 and 22, respectively.

iii. Recruitment time series

The estimated recruitment time series is listed in Table 13 and plotted in Figure 27.

iv. Time series of catch divided by biomass.

Catch divided by biomass (i.e., exploitation rate) is plotted for the author's preferred model (Fig. 41).

c. Graphs of estimates

i. Fishery and survey selectivities, molting probabilities, and other schedules depending on parameter estimates.

Model-estimated growth curves from last year's model and the author's preferred model (Alt1a) are compared with empirical curves developed from growth data on Tanner crab in the GOA near Kodiak Island in Figure 42. The model-estimated female growth is almost identical to that from Kodiak, while the model-estimated male growth curve suggests that molt increments are larger in the EBS than in the GOA. Model-estimated sex-specific probabilities at size of immature crab molting to maturity are compared in

Figure 43. The curve for males suggests an unlikely decline at the largest sizes, but it not constrained to increase. In addition, size bins for which the curve is 1 (or 0) have corresponding parameter estimates that are on the upper (lower) boundary of the range of allowable values. This does not seem to affect model convergence or its ability to estimate standard deviations, which would ordinarily be a concern under such circumstances.

Estimates of natural mortality by sex and maturity state are shown in Figure 44. Mortality rates are assumed equal by sex for immature crab, but are allowed to differ by sex for mature crab. Mortality rates for mature crab are estimated by sex across two time periods: 1949-1979+1985-2013 and 1980-1984. The latter period has been identified as a period of high natural mortality in the BBRKC stock (Zheng et al., 2012) and was identified as a separate period for Tanner crab in the 2012 assessment. The values estimated by the author's preferred model are similar to those estimated in the 2013 assessment model, except for mature females during the 1980-84 time period. The estimated "normal" values were 0.25 for immature crab, 0.34 for mature females and 0.25 for mature males from the previous assessment while the Alt1b model estimates were 0.25 for immature crab, 0.33 for mature females, and 0.26 for mature males. The values estimated for mature crab during the "high mortality" period from the previous assessment were 0.31 for females and 0.73 for males while the Alt1a estimates were 0.36 for females (an increase, rather than a decrease, in M) and 0.65 for males (slightly smaller, but well within the confidence bounds).

The major difference in estimated total selectivity curves for males in the directed fishery between the previous assessment and the author's preferred model is the curve for 1996, which shifted toward much smaller sizes at 50% selected in the preferred model compared with last year's assessment model (Fig. 45). Otherwise the curves are fairly similar. Comparing curves from the most recent fisheries, the 2013/14 selectivity curve is shifter to the right (larger sizes) of curves for 2005/06, 2006/07, and 2007/08 but is shifted to the left of those for 2008/09 and 2009/10. Retained selectivity shows a much narrower range over time, with only the curve for 2009/10 standing out from the rest. This may reflect the closure of the area west of 166^{o} W to fishing in 2009/10, because crab tend to be larger in the eastern area.

Estimated bycatch selectivity curves for males and females are shown in Fig. 46 for the snow crab fishery, in Fig. 47 for the BBRKC fishery, and in Fig. 48 for the groundfish fisheries. Separate curves are estimated for 3 different time periods for each fishery, corresponding to changes in available data and fishery activity. For the snow crab fishery, separate sex-specific curves are estimated for 1989/90-1996/97, 1997/98-2004/05, and 2005/06-present. The time periods are the same for the BBRKC fishery. The directed Tanner crab fishery was closed during 1997/98-2004/05, which may have encouraged changes in how the snow crab and BBRKC fisheries were prosecuted—with associated changes in bycatch selectivity on Tanner crab. For the groundfish fisheries, the three time periods corresponding to the selectivity curves are 1973-1987, 1988-1996, and 1997-present. These correspond to changes in the groundfish fleets and Tanner crab fishery, with the curtailment of foreign and joint-venture fishing by 1988, the expansion of domestic fisheries from 1988 to 1996, and the closure of the tanner crab fishery in 1996/97.

The estimated selectivity curves for the snow crab fishery from Alt0b are similar to those from the 2013 Model for both sexes (Figure 46). The estimated selectivity curves for the BBRKC fishery are generally shifted toward the right, such that only the largest size classes for both sexes are fully selected (Figure 47). In fact, the selectivity on females is close to (but not) zero through most of the size range for females in the population. This may reflect differences in sex/size-specific bycatch fishing mortality in the BBRKC fishery such that the largest females and similarly-sized males are not subject to the same fishing mortality, as is assumed in the model by applying a fully-selected fishing mortality equally to selectivity curves for both sexes. If such were the case, the model might achieve a "better" fit to data by adjusting either the slope or location parameter (size at 50% selected) such that selectivity on females was less than

1 across the range of sizes found in the data. The other models (see online material) exhibit similar results in regards to selectivity in the BBRKC fishery. A possible solution to this confounding would be fix sex-specific sizes for "fully-selected" animals in each fishery within observed size ranges and then estimate female-specific offsets to male "fully-selected" fishing mortality.

A similar phenomenon may be occurring in the groundfish selectivity curves for Alt1a (Figure 48), but with effects seen on the slope of the curves for females rather on size at 50% selected. For Alt1a, the slopes of the female selectivity curves are such that the curves never reach 1 (fully-selected) within the model's size range (the largest size bin corresponds to 182.5 mm CW). This did not occur in the 2013 Model, but the difference can be traced, at least in part, to the extra emphasis placed on fitting the female bycatch size compositions as a result of the switch in input sample sizes between male and female groundfish bycatch size compositions (the true male sample sizes were always several times larger than the corresponding female ones).

Estimated survey selectivity curves for males and females in three time periods (1974-1981, 1982-1987, and 1988-present) are shown in Fig. 49, together with the selectivity curves inferred from Somerton's "underbag" experiments (Somerton and Otto, 1999). The curves are quite similar to those obtained by the 2013 Model.

iii. Estimated full selection F over time

The trajectory of full selection fishing mortality in the directed fishery (Fig. 50) estimated by Alt1a is similar to that estimated by the 2013 Model. It peaked in 1980 at a value larger than 2, then rapidly declined and was at low levels in the mid-1980s. It peaked again in 1993 and subsequently declined to low levels (when the fishery was open). Exploitation rates (catch/biomass) in the directed fishery for total catch and legal-sized males followed similar trends (Fig. 41), with exploitation rates reaching almost 80% on legal males in 1981 and 50 % in 1993.

ii. Estimated male, female, mature male, total and effective mature biomass time series

Time series of observed biomass of mature crab in the NMFS bottom trawl surveys are compared by sex with model-predicted values in Fig. 51. The model under-predicts mature female survey biomass in the early 1980s and 1990s. It also under-predicts mature male survey biomass in the early 1990s as well as in the mid-2000s. However, this is similar to the results obtained with the 2013 Model. The scale of the standardized log-scale residuals (Fig. 52) indicates a mediocre fit between the model and the data (the standard deviation of the residuals is ~2, whereas ~1 would indicate a good fit).

The time series of total mature biomass in the survey is compared to the model-predicted total mature biomass in the survey in Fig. 53. Also plotted is the model-predicted total mature biomass at the time of the survey. The model consistently underestimates total mature biomass as seen in the survey.

The time series of model-predicted MMB (i.e., mature male biomass at the time of mating), mature female biomass at the time of mating, and total mature biomass at the time of mating in Fig. 54. All three time series build relatively slowly from zero in 1949 (when the model starts) until the mid-1960s, when the spawning stock rapidly builds to a peak in 1972 and just as rapidly declines to a minimum in 1985. It rebuilds somewhat to a much lower peak in 1989 and subsequently declines to a minimum in 1999. Since 1999, MMB has increased rather steadily while mature female biomass at mating time has remained low.

iv. Estimated fishing mortality versus estimated spawning stock biomass

See Section F (Calculation of the OFL).

v. Fit of a stock-recruitment relationship, if feasible.

Not available.

e. Evaluation of the fit to the data:

i. Graphs of the fits to observed and model-predicted catches

The model fit to retained catch in the directed fishery is provided in Fig. 35. The model fit to total male (retained + discarded) catch in the directed fishery is provided in Fig. 36. The model fit to female discard mortality in the directed fishery is shown in Fig. 37. The fits are quite good for males, but less so for females.

ii. Graphs of model fits to survey numbers

Model predictions for total numbers of legal males (≥ 138 mm CW) in the population and in the survey are compared with observations from the survey in Fig. 55 (and Fig. 31). The model over-predict numbers of crab in recent years. Model-estimated numbers of males and females in the survey are compared with observed numbers in Fig. 56. The model under-predicts the decline in survey numbers of both males and females in the mid-1980s and anticipates the subsequent increase in survey numbers to 1990. More recently, the model under-estimates the numbers of both sexes in the survey. The model appears to predict survey numbers of all mature female crab (Fig. 57, bottom graph) and all mature male crab (Fig. 58, bottom graph) reasonably well, but not as sub-components broken into new shell and old shell categories. It also appears to estimate the fraction of mature crab by sex fairly well (Fig. 59).

iii. Graphs of model fits to catch proportions by length

Model-predicted proportions at size for retained males in the directed Tanner crab fishery are presented in Fig.s 60 and 61. The model appears to fit the observed proportions quite well, except at the smallest retained sizes in the 1980/81-1996/97 time period. The data suggests some sub-legal crab (≤ 138 mm CW) were retained in the 125-130 and 130-135 mm CW bins (although the overall proportions were quite small) and the model under-estimates these proportion relative to that observed. Conversely, the model over-estimates the proportion retained in the 135-140 mm CW size bin (the first size bin in which legal crab at the time would have been observed). This pattern is less apparent in the previous fishery period (2005/06 -2009/10), when the residuals are much smaller. For 2013/14, the model underestimates again the proportions of the smallest retained crab and overestimates the proportion of the most retained. It seems possible that the model's retention function may rise from 0 too steeply to accommodate the pattern seen in the directed fishery.

Model-predicted patterns for the proportion caught-at-size in the directed fishery for all males is shown in Fig.s 62 and 63. General residual patterns again indicate, more strongly than with the retained catch, that the fishery catches a larger proportion of smaller crab than predicted by the model and catches fewer larger crab than predicted by the model. Conceivably, among other potential explanations, this pattern may indicate that an asymptotic selectivity curve is inappropriate for the selection process or that the model overestimates growth into the largest size classes for males. 1996 is the exception to this, and exhibits an extremely poor fit to the data. However, as previously noted, the relative weight (input sample size) put on fitting this weight in the likelihood is quite small. It is notable that the fit to the 1996 size composition for females taken in the directed fishery (Fig.s 64 and 65) is much better. The general pattern of residuals for females is similar to the general pattern for males. It should be noted, however, that the scale of the residuals for males is larger than that for females.

iv. Graphs of model fits to survey proportions by length

Model fits to observed proportions at size in the annual NMFS trawl survey are shown for males in Fig.s 66 and 67 (the latter as a bubble plot). The model appears to be suitably sensitive to relatively large cohorts recruiting to the model size range (e.g., 1997-2002), but appears to be less able to track strong cohorts through time (the mode in the model proportions at ~100 mm CW in 1982 disappears after two years, but appears to last until at least 1985 in the observed proportions. After 1982, the model tends to under-predict size proportions for males in the 70-120 mm range and over-predict the proportion of large (> 120 mm CW) males after 2000. Model fits to proportions at size in the survey for females are shown in

Fig.s 68 and 69. The model tends to over-predict proportions-at-size in the 65-85 mm CW range. The patterns of residuals for males and females evinced in the bubble plots (Fig.s 67 and 69) are almost identical to those obtained from the 2013 model in last year's assessment (Stockhausen et. al., 2013, Fig.s 66 and 68).

v. Marginal distributions for the fits to the compositional data.

Model Alt1a-predicted marginal fits of the proportion of crab by size in the directed fishery catch (Fig. 70) are quite good at all sizes for retained males (upper graph) but underestimate the proportions caught for all males (retained and discarded, middle graph) at smaller sizes (< 130 mm CW) and over-estimate the proportion at larger sizes. A similar effect is evident for the model-predicted marginal proportion at size for female bycatch in the directed fishery (Fig. 70, lower graph).

The observed and predicted (Alt1a) marginal proportions of males taken as bycatch in the snow crab fishery are in good agreement at all sizes, while the model tends to underestimate the proportion of females taken as bycatch near the peak proportions (~80-90 mm CW) and over-estimate the proportions at larger sizes (Fig. 71, upper graph). The opposite pattern is true of the proportion-at-size of females taken as bycatch in the BBRKC fishery, where intermediate-size females are over-represented in the model predictions and under-represented at larger sizes (Fig. 71, middle graph). The pattern of model-predicted marginal proportions-at-size for males taken as bycatch in the BBRKC fishery is similar to that found for the snow crab fishery, but shifted to larger sizes by ~20 mm CW. Unfortunately, it presents a poorer fit to the observations, overestimating proportions at larger sizes and underestimating them at smaller sizes, than in the snow crab fishery. These patterns are all quite similar to those obtained with the 2013 Model in last year's assessment.

The patterns of marginal predicted proportions at size for males and females taken in the groundfish fishery (Fig. 71, lower graph) obtained by Alt1a are strikingly different from those obtained by the 2013 Model. As noted last year, the patterns for the 2013 Model "…indicate a sex-specific bias in the fits to the groundfish fisheries size compositions, given that male proportions-at-size are consistently underestimated in the model and female proportions-at-size are almost always overestimated. This may be indicative of model mis-specification or an error in the model code." As noted previously, this was traced to the input sample sizes being switched prior to the 2012 assessment and is corrected in Alt1a. The agreement of between the observed and predicted marginal distributions is much better for Alt1a than for the 2013 Model, although it certainly leaves room for improvement.

vi. Plots of implied versus input effective sample sizes and time-series of implied effective sample sizes.

Not available.

vii. Tables of the RMSEs for the indices (and a comparison with the assumed values for the coefficients of variation assumed for the indices).

Not available.

viii. Quantile-quantile (q-q) plots and histograms of residuals (to the indices and compositional data) to justify the choices of sampling distributions for the data.

Not available.

f. Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments).

i. Retrospective analysis (retrospective bias in base model or models).

As currently coded, it is not possible to perform retrospective analyses with the TCSAM in the compressed time span allowed for this assessment. This deficiency will be addressed in the future.

ii. Historic analysis (plot of actual estimates from current and previous assessments).

Many of the plots contained in this assessment feature comparisons between results from the 2013 assessment model and the author's preferred model for this assessment. Most of them indicate little difference between the two models, particularly for more recent periods (e.g., since 1990), except where these were explicitly expected (as in the fits to the marginal proportions for bycatch size compositions in the groundfish fisheries).

g. Uncertainty and sensitivity analyses

Not available.

F. Calculation of the OFL and ABC

1. Status determination and OFL calculation

EBS Tanner crab was elevated to Tier 3 status following acceptance of the TCSAM by the CPT and SSC in 2012. Based upon results from the model, the stock was subsequently declared rebuilt and not overfished. Consequently, EBS Tanner crab is assessed as a Tier 3 stock for status determination and OFL setting.

The (total catch) OFL for 2013/14 was 25.35 thousand t while the total catch mortality for 2013/14 was 2.78 thousand t, based on applying discard mortality rates of 0.50 for pot fisheries and 0.8 for the groundfish fisheries to the reported catch by fleet for 2014/15 (Tables 1 and 3). Therefore overfishing did not occur.

Amendment 24 to the NPFMC fishery management plan (NPFMC 2007) revised the definitions for overfishing for EBS crab stocks. The information provided in this assessment is sufficient to estimate overfishing limits for Tanner crab under Tier 3. The OFL control rule for Tier 3 is (Fig. 73):

B, $F_{35\%}$, $B_{35\%}$	3	a. $\frac{B}{B_{35\%^*}} > 1$	$F_{OFL} = F_{35\%}$ *	
		b. $\beta < \frac{B}{B_{35\%}*} \le 1$	$F_{OFL} = F^*_{35\%} \frac{\frac{B}{B^*_{35\%}} - \alpha}{1-\alpha}$	ABC≤(1-b$_y$) * OFL
		c. $\frac{B}{B_{35\%}*} \le \beta$	Directed fishery F = 0 $F_{OFL} \le F_{MSY}$ †	

and is based on an estimate of "current" spawning biomass at mating (B above, taken as MMB at mating in the assessment year) and spawning biomass per recruit (SBPR)-based proxies for F_{MSY} and B_{MSY}. In the above equations, α=0.1 and β=0.25. For Tanner crab, the proxy for F_{MSY} is $F_{35\%}$, the fishing mortality that reduces the SBPR to 35% of its value for an unfished stock. Thus, if $\phi(F)$ is the SBPR at fishing mortality F, then $F_{35\%}$ is the value of fishing mortality that yields $\phi(F) = 0.35 \cdot \phi(0)$. The Tier 3 proxy for B_{MSY} is $B_{35\%}$, the equilibrium biomass achieved when fishing at $F_{35\%}$, where $B_{35\%}$ is simply 35% of the unfished stock biomass. Given an estimate of average recruitment $\bar{R}$, $B_{35\%} = 0.35 \cdot \bar{R} \cdot \phi(0)$.

Thus Tier 3 status determination and OFL setting for 2014/15 require estimates of B = MMB$_{2014/15}$ (the projected MMB at mating time for the coming year), $F_{35\%}$, spawning biomass per recruit in an unfished stock ($\phi(0)$), and $\bar{R}$. Current stock status is determined by the ratio $B/B_{35\%}$ for Tier 3 stocks. If the ratio is greater than 1, then the stock falls into Tier 3a and $F_{OFL} = F_{35\%}$. If the ratio is less than one but greater than β, then the stock falls into Tier 3b and F_{OFL} is reduced from $F_{35\%}$ following the descending limb of the control rule (Fig. 73). If the ratio is less than β, then the stock falls into Tier 3c and directed fishing must cease. In addition, if B is less than ½ $B_{35\%}$ (the minimum stock size threshold, MSST), the stock must be declared overfished and a rebuilding plan subsequently developed.

The estimate of B from Model Alt1b (the author's preferred model) is 70.77 thousand t (Table 23). Spawning biomass per recruit in an unfished stock was calculated using the TCSAM population dynamics equations (Appendix 3) with total recruitment set to 1 and fishing mortality from all sources (directed fishery and all bycatch fisheries) set to 0, resulting in $\phi(0)$ = 0.451 kg/recruit. Fully-selected fishing mortality and selectivity curves in the bycatch fisheries were set using the same approach as in the 2012 and 2013 assessments (Rugolo and Turnock, 2012b; Stockhausen et al., 2013), as were selectivities for all (retained+discarded) males and for retained males in the directed Tanner crab fishery (Fig. 74). The value for $F_{35\%}$ was then estimated using an iterative approach by varying the fully-selected F on males in the directed fishery until $\phi(F) = 0.35 \cdot \phi(0)$. The resulting value for $F_{35\%}$ is 0.58 yr^{-1}, which is similar to that calculated in 2012 (0.61) but smaller than that calculated last year (0.73 yr^{-1}). Changes from the 2013 assessment model to Model Alt1a in the probability of males maturing at size, bycatch selectivity in the groundfish fisheries, and bycatch selectivity in the snow crab fishery accounted for changes in the estimated value for $F_{35\%}$, as well.

The determination of $B_{MSY}=B_{35\%}$ for Tanner crab depends on the selection of an appropriate time period over which to calculate average recruitment ($\bar{R}$). After much discussion in 2012 and 2013, the SSC endorsed an averaging period of 1982+. Starting the average recruitment period in 1982 is consistent with a 5-6 year recruitment lag from 1976/77, when a well-known climate regime shift occurred in the EBS (Rodionov and Overland, 2005) that may have affected stock productivity. The value of $\bar{R}$ for this period from the author's preferred model is 209.749 million. The estimates of average recruitment are quite similar between the 2013 assessment model and the author's preferred model (Table 23). The value of $B_{MSY}=B_{35\%}$ for $\bar{R}$ is 33.95 thousand t. Thus, the stock is "not overfished" because $B/B_{35\%} > 0.5$ (i.e., B > MSST).

Once F_{OFL} is determined using the control rule (Fig. 73), the (total catch) OFL can be calculated based on projecting the population forward one year assuming that $F = F_{OFL}$. In the absence of uncertainty, the OFL would then be the predicted total catch taken when fishing at $F = F_{OFL}$. When uncertainty (e.g. assessment uncertainty, variability in future recruitment) is taken into account, the OFL is taken as the median total catch when fishing at $F = F_{OFL}$.

The total catch (biomass), including all bycatch of both sexes from all fisheries, was estimated using

$$C = \sum_f \sum_x \sum_z \frac{F_{f,x,z}}{F_{.,x,z}} \cdot (1 - e^{-F_{.,x,z}}) \cdot w_{x,z} \cdot [e^{-M_x \cdot \delta t} \cdot N_{x,z}]$$

where C is total catch (biomass), $F_{f,x,z}$ is the fishing mortality in fishery f on crab in size bin z by sex (x), $F_{.,x,z} = \sum_f F_{f,x,z}$ is the total fishing mortality by sex on crab in size bin z, $w_{x,z}$ is the mean weight of crab in size bin z by sex, M_x is the sex-specific rate of natural mortality, δt is the time from July 1 to the time of the fishery (0.625 yr), and $N_{x,z}$ is the numbers by sex in size bin z on July 1, 2014 as estimated by the assessment model.

Assessment uncertainty was included in the calculation of OFL using the same approach as that used for the 2012 and 2013 assessments (Rugolo and Turnock, 2012; Stockhausen et al, 2013). Basically, initial numbers at size on July 1, 2014 were randomized based on an assumed lognormal assessment error distribution and the cv of estimated MMB for 2013/14 from the assessment model, the control rule was applied to obtain F_{OFL}, and the population projected forward to next year assuming that fishing occurred consistent with F_{OFL}. This was repeated 10,000 times to generate a distribution of total catch OFLs for each of the four model scenarios. The OFL for each model scenario was taken as the median of the resulting distribution. Values for the OFLs ranged from 30.04 thousand t for model scenario Alt0b to 33.81 thousand t for scenarioAlt1a (Table 23, Figure 75). **The value of OFL for 2014/15 from the author's preferred model (Alt1a) is 33.81 thousand t.**

Model Alt1a is the author's preferred model for calculating the B_{MSY} proxy as $B_{35\%}$, so MSST = 0.5 B_{MSY} = 16.98 thousand t. Because current *B* = 70.77 thousand t > MSST, **the stock is not overfished**. The population state (directed F vs. MMB) is plotted for each year from 1965-2013 in Fig. 76 against the Tier 3 harvest control rule.

2. ABC calculation

Amendments 38 and 39 to the Fishery Management Plan (NPFMC 2010) established methods for the Council to set Annual Catch Limits (ACLs). The Magnuson-Stevens Act requires that ACLs be established based upon an acceptable biological catch (ABC) control rule that accounts for scientific uncertainty in the OFL such that ACL=ABC and the total allowable catch (TAC) and guideline harvest levels (GHLs) be set below the ABC so as not to exceed the ACL. ABCs must be recommended annually by the Council's SSC.

Two methods for establishing the ABC control rule are: 1) a constant buffer where the ABC is set by applying a multiplier to the OFL to meet a specified buffer below the OFL; and 2) a variable buffer where the ABC is set based on a specified percentile (P*) of the distribution of the OFL that accounts for uncertainty in the OFL. P* is the probability that ABC would exceed the OFL and overfishing occur. In 2010, the NPFMC prescribed that ABCs for BSAI crab stocks be established at P*=0.49 (following Method 2). Thus, annual ACL=ABC levels should be established such that the risk of ovefishing, P[ABC>OFL], is 49%. For 2011/12, however, the SSC adopted a buffer of 10% on OFL for all crab stocks for calculating ABC (Method 1). Here, ABCs are provided based on both methods.

ABCs based on the P*=0.49 approach were calculated from quantiles of the associated OFL distributions such that probability that the selected ABC was greater than the true OFL was 0.49. The resulting ABC for each scenario was almost identical to the associated OFL (Table 23). ABCs were also calculated using the SSC's 10% OFL buffer (Table 23).

For the author's preferred model (Alt1a), the P* ABC_{max} is 33.76 thousand t while the 10% Buffer ABC_{max} is 30.43 thousand t. Following the 3-year incremental approach to setting ABC for this stock adopted by the CPT and SSC in 2012 after the Tier 3 model was accepted (and continued in 2013), the full ABC_{max} would be applied to the stock this year. The author remains concerned that both of these choices for ABC are overly optimistic regarding the actual productivity of the stock. Fishery-related mortality similar to these ABC levels has occurred only in the latter half of the 1970s and in 1992/93, coincident with collapses in stock biomass to low levels (Fig. 77). This suggests that $F_{35\%}$ may not be a realistic proxy for F_{msy} and/or that MMB may not be a good proxy for reproductive success, as are the current assumptions for this stock. Given this uncertainty concerning the stock, **the author recommends not advancing this year to the final step of the 3 rung stair step used to set ABC. Consequently, using the p^* ABC as ABC_{max}, the author's recommended ABC is 2/3 *x* 33.76 thousand t = 22.51 thousand t**.

G. Rebuilding Analyses

Tanner crab is not currently under a rebuilding plan. Consequently no rebuilding analyses were conducted.

H. Data Gaps and Research Priorities

Information on growth-per-molt should be collected for the EBS Tanner crab stock. An extensive collection of data of this type exists for Tanner crab in the GOA, but assessment model results suggest that growth rates for males in the EBS are different from those in the GOA. Secondarily, data on temperature-dependent effects on molting frequency would be helpful to assess potential impacts of the EBS cold pool on the stock. In addition, it would be extremely worthwhile to develop a "better" index of reproductive potential than MMB and to revisit the issue of MSY proxies for this stock.

Effort needs to continue on developing the TCSAM model code, particularly so that model output can accommodate the wide range of diagnostic and evaluation protocols requested of SAFE documents (e.g., retrospective analyses, simulation testing). In a similar vein, the model code needs to be revised so the model is more configurable using control files, rather than requiring the code itself to be altered to run different configurations, than it currently is. These issues are being addressed in the new code under development.

I. Ecosystem Considerations

Mature male biomass is currently used as the "currency" of Tanner crab spawning biomass for assessment purposes. However, its relationship to stock-level rates of egg production, perhaps an ideal measure of stock-level reproductive capacity, is unclear. Nor is it likely that mature female biomass has a clear relationship to annual egg production. For Tanner crab, the fraction of barren mature females by shell condition appears to vary on a decadal time scale (Fig. 78), suggesting a potential climatic driver. The observation that "very old shell" females have much higher rates of barrenness and are more likely to exhibit smaller clutch sizes also (Fig. 79) suggests that older females decline into senescence and it may not be as important to maintain "old, fat" female crabs as is appears to be for many species of fish. senesce. The trend in the fraction of new shell mature females (ones that mate for the first time following the molt to maturity) with clutches one-half full or is also potentially troubling (Fig. 79). Prior to 1991, this rate was similar to that for old shell (multiparous) females. After 1991, the rate increased to 20-40%, similar to that for very old shell females. Rugolo and Turnock (2010) developed an Egg Production Index (EPI) by female shell condition that incorporated observed clutch size measurements taken on the bottom trawl survey and fecundity by carapace width for 1976-2009 (Fig. 80). Figure 80 also includes estimates of male and female mature biomass relative to the shell condition class EPIs in these years. Although both male and female mature biomass increased after 2005, egg production has not increased proportionally to mature biomass. Thus use of MMB to reflect Tanner crab reproductive potential may be misleading as to stock health.

1. Ecosystem Effects on Stock

Time series trends in prey availability or abundance are generally unknown for Tanner crab because typical survey gear is not quantitative for Tanner crab prey. On the other hand, Pacific cod (*Gadus macrocephalus*) is thought to account for a substantial fraction of annual mortality on Tanner crab (Fig.s 81, 82; Aydin et al., 2007). Total P. cod biomass is estimated to have been slowly declining from 1990 to 2008, during the time frame of a collapse in the Tanner crab stock, but has been increasing rather rapidly since 2008 (Thompson and Lauth, 2012). This suggests that the rates of "natural mortality" used in the stock assessment for the period post-1980 may be underestimates (and increasingly biased low if the trend in P. cod abundance continues). This trend is definitely one of potential concern.

2. Effects of Tanner crab fishery on ecosystem

Potential effects of the Tanner crab fishery on the ecosystem are considered in the following table:

Effects of Tanner crab fishery on ecosystem			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	salmon are unlikely to be trapped inside a pot when it is pulled, although halibut can be	unlikely to have substantial effects at the stock level	minimal to none
Forage (including herring, Atka mackerel, cod and pollock)	Forage fish are unlikely to be trapped inside a pot when it is pulled	unlikely to have substantial effects	minimal to none
HAPC biota	crab pots have a very small footprint on the bottom	unlikely to be having substantial effects post-rationalization	minimal to none
Marine mammals and birds	crab pots are unlikely to attract birds given the depths at which they are fished	unlikely to have substantial effects	minimal to none
Sensitive non-target species	Non-targets are unlikely to be trapped in crab pot gear in substantial numbers	unlikely to have substantial effects	minimal to none
Fishery concentration in space and time	substantially reduced in time following rationalization of the fishery	unlikely to be having substantial effects	probably of little concern
Fishery effects on amount of large size target fish	Fishery selectively removes large males	May impact stock reproductive potential as large males can mate with a wider range of females	possible concern
Fishery contribution to discards and offal production	discarded crab suffer some mortality	May impact female spawning biomass and numbers recruiting to the fishery	possible concern
Fishery effects on age-at-maturity and fecundity	none	unknown	possible concern

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Tables

Table 1. Retained catch (males) in directed Tanner crab fisheries.

Eastern Bering Sea *Chionoecetes bairdi* Retained Catch (1000T)				
Year	US Pot	Japan	Russia	Total
1965/66		1.17	0.75	1.92
1966/67		1.69	0.75	2.44
1967/68		9.75	3.84	13.60
1968/69	0.46	13.59	3.96	18.00
1969/70	0.46	19.95	7.08	27.49
1970/71	0.08	18.93	6.49	25.49
1971/72	0.05	15.90	4.77	20.71
1972/73	0.10	16.80		16.90
1973/74	2.29	10.74		13.03
1974/75	3.30	12.06		15.24
1975/76	10.12	7.54		17.65
1976/77	23.36	6.66		30.02
1977/78	30.21	5.32		35.52
1978/79	19.28	1.81		21.09
1979/80	16.60	2.40		19.01
1980/81	13.47			13.43
1981/82	4.99			4.99
1982/83	2.39			2.39
1983/84	0.55			0.55
1984/85	1.43			1.43
1985/86	0.00			0.00
1986/87	0.00			0.00
1987/88	1.00			1.00
1988/89	3.15			3.18
1989/90	11.11			11.11
1990/91	18.19			18.19
1991/92	14.42			14.42
1992/93	15.92			15.92
1993/94	7.67			7.67
1994/95	3.54			3.54
1995/96	1.92			1.92
1996/97	0.82			0.82
1997/98	0.00			0.00
1998/99	0.00			0.00
1999/00	0.00			0.00
2000/01	0.00			0.00
2001/02	0.00			0.00
2002/03	0.00			0.00
2003/04	0.00			0.00
2004/05	0.00			0.00
2005/06	0.43			0.43
2006/07	0.96			0.96
2007/08	0.96			0.96
2008/09	0.88			0.88
2009/10	0.60			0.60
2010/11	0.00			0.00
2011/12	0.00			0.00
2012/13	0.00			0.00
2013/14	1.26			1.26

Table 2. Retained catch (males) in the US domestic pot fishery. Information from the Communnity Development Quota (CDQ) fisheries is included in the table for fishery years 2005/06 to the present. Number of crabs caught and harvest includes deadloss. The “Fishery Year” YYYY/YY+1 runs from July 1, YYYY to June 30, YYYY+1. The ADF&G year (in parentheses, if different from the “Fishery Year”) indicates the year ADF&G assigned to the fishery season in compiled reports.

year (ADF&G year)	Total Crab (no.)	Total Harvest (lbs)	GHL/TAC (millions lbs)	Vessels (no.)	Season
1968/69 (1969)	353,300	1,008,900			
1969/70 (1970)	482,300	1,014,700			
1970/71 (1971)	61,300	166,100			
1971/72 (1972)	42,061	107,761			
1972/73 (1973)	93,595	231,668			
1973/74 (1974)	2,531,825	5,044,197			
1974/75	2,773,770	7,028,378		28	
1975/76	8,956,036	22,358,107		66	
1976/77	20,251,508	51,455,221		83	
1977/78	26,350,688	66,648,954		120	
1978/79	16,726,518	42,547,174		144	
1979/80	14,685,611	36,614,315	28-36	152	11/01-05/11
1980/81 (1981)	11,845,958	29,630,492	28-36	165	01/15-04/15
1981/82 (1982)	4,830,980	11,008,779	12-16	125	02/15-06/15
1982/83 (1983)	2,286,756	5,273,881	5.6	108	02/15-06/15
1983/84 (1984)	516,877	1,208,223	7.1	41	02/15-06/15
1984/85 (1985)	1,272,501	3,036,935	3	44	01/15-06/15
1985/86 (1986)	closed	closed	closed	closed	closed
1986/87 (1987)	closed	closed	closed	closed	closed
1987/88 (1988)	957,318	2,294,997	5.6	98	01/15-04/20
1988/89 (1989)	2,894,480	6,982,865	13.5	109	01/15-05/07
1989/90 (1990)	9,800,763	22,417,047	29.5	179	01/15-04/24
1990/91	16,608,625	40,081,555	42.8	255	11/20-03/25
1991/92	12,924,102	31,794,382	32.8	285	11/15-03/31
1992/93	15,265,865	35,130,831	39.2	294	11/15-03/31
1993/94	7,235,898	16,892,320	9.1	296	11/01-11/10, 11/20-01/01
1994/95 (1994)	3,351,639	7,766,886	7.5	183	11/01-11/21
1995/96 (1995)	1,877,303	4,233,061	5.5	196	11/01-11/16
1996/97 (1996)	734,296	1,806,077	6.2	196	11/01-11/05, 11/15-11/27
1997/98-2004/05	closed	closed	closed	closed	closed
2005/06	443,978	952,887	1.7	49	10/15-03/31
2006/07	927,086	2,122,589	3.0	64	10/15-03/31
2007/08	927,164	2,106,655	5.7	50	10/15-03/31
2008/09	830,363	1,939,571	4.3	53	10/15-03/31
2009/10	485,676	1,327,952	1.3	45	10/15-03/31
2010/11	closed	closed	closed	closed	closed
2011/12	closed	closed	closed	closed	closed
2012/13	closed	closed	closed	closed	closed
2013/14	1,445,768	2,786,845	3.108	32	10/15-03/31

Table 3. Total bycatch (1000's t) of Tanner crab in various fisheries. Discard mortality rates have not been applied.

Discards (1000 t) of Tanner Crab by Fishery							
	Tanner Crab		Snow Crab		Red King Crab		Groundfish
Year	Male	Female	Male	Female	Male	Female	All
1973/74							17.735
1974/75							24.449
1975/76							9.408
1976/77							4.699
1977/78							2.776
1978/79							1.869
1979/80							3.397
1980/81							2.114
1981/82							1.474
1982/83							0.449
1983/84							0.671
1984/85							0.644
1985/86							0.399
1986/87							0.649
1987/88							0.640
1988/89							0.463
1989/90							0.671
1990/91							0.943
1991/92							2.545
1992/93	6.175	1.005	25.759	1.787	1.188	0.029	2.758
1993/94	3.870	1.028	14.530	1.814	2.967	0.198	1.760
1994/95	3.130	1.270	7.124	1.271	0.000	0.000	2.096
1995/96	2.762	1.760	4.797	1.759	0.000	0.000	1.524
1996/97	0.116	0.045	0.833	0.229	0.027	0.004	1.597
1997/98	0.000	0.000	1.750	0.226	0.165	0.003	1.179
1998/99	0.000	0.000	1.989	0.175	0.119	0.003	0.934
1999/00	0.000	0.000	0.695	0.145	0.076	0.004	0.630
2000/01	0.000	0.000	0.146	0.022	0.067	0.002	0.739
2001/02	0.000	0.000	0.323	0.011	0.043	0.002	1.184
2002/03	0.000	0.000	0.557	0.037	0.062	0.003	0.721
2003/04	0.000	0.000	0.193	0.026	0.056	0.003	0.422
2004/05	0.000	0.000	0.078	0.014	0.048	0.003	0.676
2005/06	0.462	0.044	0.968	0.043	0.042	0.002	0.621
2006/07	1.370	0.355	1.462	0.169	0.026	0.003	0.717
2007/08	2.041	0.097	1.872	0.102	0.056	0.009	0.694
2008/09	0.431	0.014	1.119	0.050	0.269	0.004	0.531
2009/10	0.071	0.002	1.324	0.014	0.150	0.001	0.374
2010/11	0.000	0.000	1.344	0.016	0.033	0.001	0.231
2011/12	0.000	0.000	2.119	0.014	0.017	0.000	0.203
2012/13	0.000	0.000	1.187	0.009	0.042	0.001	0.153
2013/14	0.536	0.024	1.829	0.016	0.109	0.001	0.333

Table 4. Sample sizes from the recalculated fishery data for retained catch-at-size in the directed fishery. N = number of individuals. N` = scaled sample size used in assessment.

year	new + old shell	
	N	N'
1980/81	13,310	95.4
1981/82	11,311	81.1
1982/83	13,519	96.9
1983/84	1,675	12.0
1984/85	2,542	18.2
1988/89	12,380	88.8
1989/90	4,123	29.6
1990/91	120,676	200.0
1991/92	126,299	200.0
1992/93	125,193	200.0
1993/94	71,622	200.0
1994/95	27,658	198.3
1995/96	1,525	10.9
1996/97	4,430	31.8
2005/06	705	5.1
2006/07	2,940	21.1
2007/08	6,935	49.7
2008/09	3,490	25.0
2009/10	2,417	17.3
2013/14	5,158	37.0

Table 5. Sample sizes from the recalculated fishery data for total catch-at-size in the directed fishery, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.

	N		N'	
year	males	females	males	females
1991/92	31,252	5,605	200.0	40.2
1992/93	54,836	8,755	200.0	62.8
1993/94	40,388	10,471	200.0	75.1
1994/95	5,792	2,132	41.5	15.3
1995/96	5,589	3,119	40.1	22.4
1996/97	352	168	2.5	1.2
2005/06	19,715	1,107	141.3	7.9
2006/07	24,226	4,432	173.7	31.8
2007/08	61,546	3,318	200.0	23.8
2008/09	29,166	646	200.0	4.6
2009/10	17,289	147	124.0	1.1
2013/14	17,288	710	123.9	5.1

Table 6. Sample sizes from the recalculated fishery data for total bycatch-at-size in the snow crab fishery, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.

year	N		N'	
	males	females	males	females
1992/93	6,280	859	45.0	6.2
1993/94	6,969	1,542	50.0	11.1
1994/95	2,982	1,523	21.4	10.9
1995/96	1,898	428	13.6	3.1
1996/97	3,265	662	23.4	4.7
1997/98	3,970	657	28.5	4.7
1998/99	1,911	324	13.7	2.3
1999/00	976	82	7.0	0.6
2000/01	1,237	74	8.9	0.5
2001/02	3,113	160	22.3	1.1
2002/03	982	118	7.0	0.8
2003/04	688	152	4.9	1.1
2004/05	848	707	6.1	5.1
2005/06	9,792	368	70.2	2.6
2006/07	10,391	1,256	74.5	9.0
2007/08	13,797	728	98.9	5.2
2008/09	8,455	722	60.6	5.2
2009/10	11,057	474	79.3	3.4
2010/11	12,073	250	86.6	1.8
2011/12	9,453	189	67.8	1.4
2012/13	7,336	190	52.6	1.4
2013/14	12,935	356	92.7	2.6

Table 7. Sample sizes from the recalculated fishery data for total bycatch-at-size in the BBRKC fishery, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.

year	N		N'	
	males	females	males	females
1992/93	2,056	105	14.7	0.8
1993/94	7,359	1,196	52.8	8.6
1996/97	114	5	0.8	0.0
1997/98	1,030	41	7.4	0.3
1998/99	457	20	3.3	0.1
1999/00	207	14	1.5	0.1
2000/01	845	44	6.1	0.3
2001/02	456	39	3.3	0.3
2002/03	750	50	5.4	0.4
2003/04	555	46	4.0	0.3
2004/05	487	44	3.5	0.3
2005/06	983	70	7.0	0.5
2006/07	798	76	5.7	0.5
2007/08	1,399	91	10.0	0.7
2008/09	3,797	121	27.2	0.9
2009/10	3,395	72	24.3	0.5
2010/11	595	30	4.3	0.2
2011/12	344	4	2.5	0.0
2012/13	618	48	4.4	0.3
2013/14	2,110	60	15.1	0.4

Table 8. Sample sizes from the recalculated fishery data for total catch-at-size in the groundfish fisheries, from groundfish observer sampling. N = number of individuals. N` = scaled sample size used in the assessment.

year	N		N'	
	males	females	males	females
1973/74	3,155	2,277	22.6	16.3
1974/75	2,492	1,600	17.9	11.5
1975/76	1,251	839	9.0	6.0
1976/77	6,950	6,683	49.8	47.9
1977/78	10,685	8,386	76.6	60.1
1978/79	18,596	13,665	133.3	98.0
1979/80	19,060	11,349	136.7	81.4
1980/81	12,806	5,917	91.8	42.4
1981/82	6,098	4,065	43.7	29.1
1982/83	13,439	8,006	96.4	57.4
1983/84	18,363	8,305	131.7	59.5
1984/85	27,403	13,771	196.5	98.7
1985/86	23,128	12,728	165.8	91.3
1986/87	14,860	7,626	106.5	54.7
1987/88	23,508	15,857	168.5	113.7
1988/89	10,586	7,126	75.9	51.1
1989/90	59,943	41,234	200.0	200.0
1990/91	23,545	11,212	168.8	80.4
1991/92	6,817	3,479	48.9	24.9
1992/93	3,128	1,175	22.4	8.4
1993/94	1,217	358	8.7	2.6
1994/95	3,628	1,820	26.0	13.0
1995/96	3,904	2,669	28.0	19.1
1996/97	8,306	3,400	59.6	24.4
1997/98	9,949	3,900	71.3	28.0
1998/99	12,105	4,440	86.8	31.8
1999/00	11,053	4,522	79.2	32.4
2000/01	12,895	3,087	92.5	22.1
2001/02	15,788	3,083	113.2	22.1
2002/03	15,401	3,249	110.4	23.3
2003/04	9,572	2,733	68.6	19.6
2004/05	13,844	4,460	99.3	32.0
2005/06	17,785	3,709	127.5	26.6
2006/07	15,903	3,047	114.0	21.8
2007/08	16,031	3,788	114.9	27.2
2008/09	25,976	4,164	186.2	29.9
2009/10	18,842	2,611	135.1	18.7
2010/11	15,069	2,207	108.0	15.8
2011/12	16,119	4,244	115.6	30.4
2012/13	12,987	3,083	93.1	22.1
2013/14	27,490	5,773	197.1	41.4

Table 9. Trends in mature Tanner crab biomass and abundance of legal crab (nominally defined as ≥ 138 mm CW) in the NMFS summer bottom trawl survey.

Observed Survey Mature Male and Female Biomass and Legal Male Abundance				
	Mature Biomass (1000 t)			Male ≥ 138 mm (10^6 crab)
Year	Male	Female	Total	
1974	212.01	55.76	267.77	87.53
1975	259.90	48.84	308.74	278.36
1976	152.94	69.47	222.41	165.96
1977	126.93	60.11	187.04	133.73
1978	77.67	35.42	113.09	83.57
1979	47.54	23.62	71.16	55.86
1980	81.11	58.99	140.10	91.12
1981	46.51	39.62	86.13	53.48
1982	46.24	51.79	98.03	58.48
1983	27.49	22.96	50.45	36.16
1984	23.99	18.70	42.69	30.50
1985	10.89	7.60	18.49	13.07
1986	11.23	5.95	17.18	11.82
1987	20.10	14.32	34.42	24.58
1988	54.16	39.32	93.48	58.16
1989	96.14	32.63	128.77	109.58
1990	99.04	46.17	145.21	114.44
1991	102.45	55.06	157.51	123.45
1992	104.33	34.59	138.92	125.15
1993	59.48	14.20	73.68	72.68
1994	41.72	12.90	54.62	50.91
1995	31.51	16.53	48.03	41.22
1996	24.99	11.83	36.82	31.43
1997	9.64	4.24	13.88	11.60
1998	9.03	2.95	11.98	10.50
1999	8.81	4.89	13.70	9.27
2000	14.20	5.38	19.58	15.85
2001	15.72	5.73	21.45	18.53
2002	14.67	4.56	19.23	16.38
2003	19.42	7.22	26.64	22.81
2004	22.78	4.94	27.72	28.59
2005	40.29	12.54	52.82	52.69
2006	55.24	19.00	74.24	71.90
2007	64.05	16.35	80.40	81.06
2008	55.98	13.18	69.15	71.22
2009	34.95	9.63	44.58	46.00
2010	32.01	3.89	35.91	42.30
2011	38.08	4.36	42.44	47.61
2012	29.68	6.74	36.42	34.46
2013	59.61	10.93	70.53	64.04
2014	73.30	9.02	82.33	85.70

Table 10. Sample sizes for NMFS survey catch-at-size. In the model, an effective sample size of 200 is used for all survey-related compositional data. Due to a change in software, non-zero hauls were not calculated for 2014.

Year	total hauls	Females				Males			
		new shell		old shell		new shell		old shell	
		non-zero hauls	crab	non-zero hauls	crab	non-zero hauls	crab	non-zero hauls	crab
1975	136	99	2,813	40	712	127	6,800	80	398
1976	209	154	4,660	80	872	169	7,282	92	598
1977	158	88	1,964	61	748	114	3,734	79	484
1978	230	104	2,593	67	1,320	147	4,548	103	699
1979	443	146	2,263	76	728	247	5,034	156	937
1980	360	156	3,409	80	723	202	9,636	101	854
1981	348	127	2,033	112	1,433	194	6,373	150	1,085
1982	342	117	1,338	104	2,391	181	3,182	147	2,083
1983	353	128	2,700	102	2,159	166	3,870	132	1,183
1984	355	146	2,228	99	1,543	176	2,528	126	1,399
1985	355	155	1,129	65	601	178	1,513	86	459
1986	353	175	1,855	68	338	213	2,772	115	468
1987	356	200	4,780	73	387	226	6,081	103	496
1988	373	220	5,611	102	538	252	7,754	102	476
1989	416	257	7,631	134	1,018	276	12,785	170	1,222
1990	383	230	4,826	134	1,597	261	9,103	163	1,541
1991	377	192	3,623	147	2,681	233	7,341	187	3,087
1992	355	151	2,391	123	2,205	215	5,099	177	1,925
1993	389	138	1,566	127	1,445	215	3,922	188	1,949
1994	376	112	1,088	107	1,403	179	2,089	176	1,902
1995	380	122	1,105	113	1,156	159	1,438	142	1,770
1996	375	131	1,086	99	1,000	150	1,390	135	1,427
1997	376	135	1,839	85	510	165	1,965	126	588
1998	375	154	1,989	75	350	177	2,529	129	640
1999	404	156	3,318	95	542	189	4,142	136	619
2000	395	162	2,672	57	349	200	3,708	144	686
2001	375	171	4,621	72	647	213	5,173	145	817
2002	375	162	4,062	70	502	188	4,485	155	1,093
2003	380	173	4,182	85	757	208	6,062	156	1,356
2004	383	192	4,439	86	1,028	245	6,101	187	1,912
2005	373	214	4,229	76	934	255	6,030	185	1,754
2006	410	228	6,013	134	1,452	275	8,457	241	4,569
2007	412	218	4,321	148	1,463	280	7,645	229	3,215
2008	410	189	2,821	127	1,804	258	6,199	219	2,334
2009	408	194	3,207	117	1,337	227	4,726	205	2,093
2010	403	205	3,877	111	1,011	234	5,888	180	2,080
2011	396	205	6,479	104	724	222	8,136	175	2,056
2012	396	219	5,141	103	768	235	7,987	148	1,367
2013	376	178	4,880	109	1,048	208	8,850	138	1,360
2014	376		3,067		1,589		8,311		3,067

Table 11. Effort data (1000's potlifts) in the snow crab and BBRKC fisheries (recalculated for 1990/91-2012/13).

Year	Effort (1000's Potlifts) BBRKC Fishery	Snow Crab Fishery	Year	Effort (1000's Potlifts) BBRKC Fishery	Snow Crab Fishery
1951/52			1981/82	536.646	469.091
1952/53			1982/83	140.492	287.127
1953/54	30.083	--	1983/84	0	173.591
1954/55	17.122	--	1984/85	107.406	370.082
1955/56	28.045	--	1985/86	84.443	542.346
1956/57	41.629	--	1986/87	175.753	616.113
1957/58	23.659	--	1987/88	220.971	747.395
1958/59	27.932	--	1988/89	146.179	665.242
1959/60	22.187	--	1989/90	205.528	912.718
1960/61	26.347	--	1990/91	262.761	1382.908
1961/62	72.646	--	1991/92	227.555	1278.502
1962/63	123.643	--	1992/93	206.815	969.209
1963/64	181.799	--	1993/94	254.389	716.524
1964/65	180.809	--	1994/95	0.697	507.603
1965/66	127.973	--	1995/96	0.547	520.685
1966/67	129.306	--	1996/97	77.081	754.14
1967/68	135.283	--	1997/98	91.085	930.794
1968/69	184.666	--	1998/99	145.689	945.533
1969/70	175.374	--	1999/00	151.212	182.634
1970/71	168.059	--	2000/01	104.056	191.2
1971/72	126.305	--	2001/02	66.947	326.977
1972/73	208.469	--	2002/03	72.514	153.862
1973/74	194.095	--	2003/04	134.515	123.709
1974/75	212.915	--	2004/05	97.621	75.095
1975/76	205.096	--	2005/06	116.32	117.375
1976/77	321.01	--	2006/07	72.404	86.288
1977/78	451.273	--	2007/08	113.948	140.857
1978/79	406.165	190.746	2008/09	139.937	163.537
1979/80	315.226	255.102	2009/10	118.521	136.477
1980/81	567.292	435.742	2010/11	131.627	147.244
			2011/12	45.166	270.602
			2012/13	38.159	225.489
			2013/14	45.927	225.245

Table 12. Comparison of parameter estimates and approximate standard deviations from the 2013 model and 2014 alternative models. Parameter names, types, bounds, and associated indices are also given. Blue highlighting indicates the parameter estimate is at the lower bound set for the parameter, whereas red highlighting indicates the parameter estimate is at the upper bound.

Parameter characteristics					Model Scenarios									
					Alt0a		Alt0b		Alt1a		Alt1b		2013	
name	type	min	max	index	value	std.dev	value	std.dev	value	std.dev	value	std.dev	value	std.dev
af1	'param_init_bounded_number'	0.4	0.7	1	6.88E-01	5.21E-02	7.00E-01	1.40E-04	7.00E-01	7.93E-05	7.00E-01	7.62E-05	6.82E-01	5.20E-02
bf1	'param_init_bounded_number'	0.6	1.2	1	8.87E-01	1.25E-02	8.83E-01	1.20E-03	8.83E-01	1.23E-03	8.83E-01	1.24E-03	8.88E-01	1.24E-02
am1	'param_init_bounded_number'	0.3	0.6	1	4.46E-01	2.27E-02	4.32E-01	2.23E-02	4.27E-01	2.20E-02	4.26E-01	2.19E-02	4.43E-01	2.28E-02
bm1	'param_init_bounded_number'	0.7	1.2	1	9.66E-01	5.32E-03	9.70E-01	5.26E-03	9.71E-01	5.17E-03	9.71E-01	5.18E-03	9.66E-01	5.33E-03
Mmult_imat	'param_init_bounded_number'	0.2	2	1	1.08E+00	5.14E-02	1.06E+00	5.13E-02	1.07E+00	5.13E-02	1.07E+00	5.06E-02	1.07E+00	5.13E-02
Mmultm	'param_init_bounded_number'	0.1	1.9	1	1.09E+00	4.27E-02	1.13E+00	4.28E-02	1.08E+00	4.32E-02	1.12E+00	4.28E-02	1.09E+00	4.21E-02
Mmultf	'param_init_bounded_number'	0.1	1.9	1	1.46E+00	3.65E-02	1.42E+00	3.81E-02	1.46E+00	3.73E-02	1.44E+00	3.72E-02	1.46E+00	3.63E-02
mat_big	'param_init_bounded_vector'	0.1	10	1	9.54E-01	1.05E-01	9.71E-01	1.02E-01	1.07E+00	9.75E-02	1.12E+00	9.84E-02	9.38E-01	1.05E-01
mat_big	'param_init_bounded_vector'	0.1	10	2	2.96E+00	3.79E-01	2.85E+00	3.73E-01	2.59E+00	3.52E-01	2.58E+00	3.42E-01	2.89E+00	3.70E-01
pMnLnRec	'param_init_number'	-Inf	Inf	1	1.12E+01	8.36E-02	1.11E+01	7.85E-02	1.13E+01	7.11E-02	1.12E+01	7.10E-02	1.12E+01	8.66E-02
pRecDevs	'param_init_bounded_vector'	-15	15	1974	-1.08E+00	1.83E+00	-8.16E-01	1.47E+00	-1.94E-01	7.88E-01	-1.44E-01	7.89E-01	-1.16E+00	1.93E+00
pRecDevs	'param_init_bounded_vector'	-15	15	1975	1.04E+00	2.77E-01	1.09E+00	2.69E-01	1.03E+00	2.64E-01	1.09E+00	2.59E-01	1.03E+00	2.76E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1976	1.72E+00	1.40E-01	1.79E+00	1.37E-01	1.85E+00	1.27E-01	1.87E+00	1.27E-01	1.69E+00	1.41E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1977	1.40E+00	1.76E-01	1.44E+00	1.70E-01	1.36E+00	1.67E-01	1.38E+00	1.68E-01	1.38E+00	1.78E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1978	1.28E+00	1.60E-01	1.28E+00	1.58E-01	1.20E+00	1.58E-01	1.21E+00	1.59E-01	1.25E+00	1.62E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1979	-3.64E-02	3.53E-01	-7.49E-02	3.50E-01	-2.10E-01	3.75E-01	-1.82E-01	3.73E-01	-6.95E-02	3.57E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1980	-1.56E+00	1.01E+00	-1.39E+00	8.46E-01	-1.16E+00	6.44E-01	-1.14E+00	6.44E-01	-1.62E+00	1.05E+00
pRecDevs	'param_init_bounded_vector'	-15	15	1981	-3.36E-01	2.79E-01	-3.56E-01	2.75E-01	-3.02E-01	2.50E-01	-2.77E-01	2.49E-01	-3.53E-01	2.82E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1982	-1.26E+00	4.70E-01	-1.17E+00	4.29E-01	-1.00E+00	3.83E-01	-9.92E-01	3.84E-01	-1.27E+00	4.69E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1983	9.81E-01	1.24E-01	9.94E-01	1.18E-01	9.66E-01	1.08E-01	9.72E-01	1.08E-01	9.69E-01	1.27E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1984	8.03E-01	1.85E-01	8.21E-01	1.78E-01	7.70E-01	1.59E-01	7.69E-01	1.58E-01	7.99E-01	1.87E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1985	1.59E+00	1.35E-01	1.50E+00	1.35E-01	1.43E+00	1.18E-01	1.41E+00	1.18E-01	1.57E+00	1.37E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1986	1.35E+00	1.60E-01	1.34E+00	1.52E-01	1.26E+00	1.33E-01	1.22E+00	1.33E-01	1.34E+00	1.61E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1987	1.31E+00	1.54E-01	1.21E+00	1.50E-01	1.19E+00	1.33E-01	1.13E+00	1.33E-01	1.30E+00	1.56E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1988	1.00E+00	1.59E-01	9.14E-01	1.53E-01	1.09E+00	1.25E-01	1.00E+00	1.26E-01	9.86E-01	1.61E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1989	4.02E-01	1.75E-01	3.20E-01	1.72E-01	2.61E-01	1.68E-01	1.91E-01	1.68E-01	3.95E-01	1.77E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1990	-4.49E-01	2.43E-01	-5.16E-01	2.39E-01	-5.51E-01	2.31E-01	-6.09E-01	2.31E-01	-4.56E-01	2.46E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1991	-1.15E+00	2.98E-01	-1.25E+00	3.01E-01	-1.31E+00	3.08E-01	-1.37E+00	3.10E-01	-1.15E+00	3.00E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1992	-1.40E+00	2.68E-01	-1.43E+00	2.60E-01	-1.48E+00	2.62E-01	-1.50E+00	2.61E-01	-1.40E+00	2.68E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1993	-1.60E+00	2.56E-01	-1.62E+00	2.55E-01	-1.66E+00	2.56E-01	-1.69E+00	2.57E-01	-1.58E+00	2.57E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1994	-1.62E+00	2.42E-01	-1.61E+00	2.38E-01	-1.53E+00	2.22E-01	-1.56E+00	2.24E-01	-1.61E+00	2.44E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1995	-1.27E+00	1.92E-01	-1.28E+00	1.91E-01	-1.16E+00	1.74E-01	-1.17E+00	1.75E-01	-1.27E+00	1.94E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1996	-1.15E+00	2.02E-01	-1.16E+00	2.01E-01	-1.19E+00	1.99E-01	-1.19E+00	2.00E-01	-1.15E+00	2.03E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1997	-1.98E-01	1.16E-01	-1.73E-01	1.12E-01	-1.96E-01	1.04E-01	-1.72E-01	1.04E-01	-2.02E-01	1.18E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1998	-1.06E+00	1.92E-01	-1.05E+00	1.91E-01	-1.13E+00	1.87E-01	-1.10E+00	1.87E-01	-1.06E+00	1.94E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1999	6.85E-02	1.17E-01	8.75E-02	1.12E-01	1.35E-02	1.05E-01	4.33E-02	1.05E-01	6.68E-02	1.19E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2000	-4.69E-01	1.87E-01	-4.62E-01	1.86E-01	-4.84E-01	1.77E-01	-4.60E-01	1.78E-01	-4.73E-01	1.88E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2001	6.72E-01	1.09E-01	6.87E-01	1.04E-01	6.45E-01	9.68E-02	6.73E-01	9.66E-02	6.62E-01	1.11E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2002	-2.70E-01	2.00E-01	-2.71E-01	1.98E-01	-2.37E-01	1.87E-01	-2.14E-01	1.88E-01	-2.87E-01	2.01E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2003	3.03E-01	1.51E-01	3.04E-01	1.48E-01	3.47E-01	1.36E-01	3.67E-01	1.36E-01	2.88E-01	1.52E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2004	1.01E+00	1.02E-01	1.02E+00	9.74E-02	9.46E-01	9.11E-02	9.70E-01	9.11E-02	9.81E-01	1.04E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2005	-2.09E-01	2.04E-01	-2.11E-01	2.02E-01	-2.34E-01	1.95E-01	-2.12E-01	1.95E-01	-2.43E-01	2.06E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2006	-4.13E-01	2.21E-01	-4.17E-01	2.19E-01	-4.20E-01	2.08E-01	-4.00E-01	2.08E-01	-4.44E-01	2.23E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2007	-6.59E-01	2.57E-01	-6.63E-01	2.54E-01	-7.68E-01	2.57E-01	-7.55E-01	2.57E-01	-6.91E-01	2.59E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2008	-5.67E-01	2.58E-01	-5.80E-01	2.57E-01	-6.21E-01	2.50E-01	-6.15E-01	2.51E-01	-5.86E-01	2.58E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2009	1.06E+00	1.20E-01	1.06E+00	1.16E-01	1.05E+00	1.07E-01	1.07E+00	1.07E-01	9.88E-01	1.34E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2010	1.05E+00	1.27E-01	1.04E+00	1.24E-01	1.11E+00	1.14E-01	1.11E+00	1.14E-01	1.16E+00	1.40E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2011	4.48E-01	1.69E-01	4.28E-01	1.67E-01	4.25E-01	1.65E-01	4.18E-01	1.65E-01	5.42E-01	1.88E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2012	-1.06E+00	4.14E-01	-1.08E+00	4.13E-01	-1.17E+00	4.28E-01	-1.18E+00	4.28E-01	-7.92E-01	4.16E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2013	1.32E-01	2.03E-01	9.92E-02	2.00E-01	-1.76E-01	2.30E-01	-1.93E-01	2.30E-01	4.81E-01	2.40E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2014	1.92E-01	2.49E-01	1.48E-01	2.47E-01	2.45E-01	2.38E-01	2.21E-01	2.38E-01		

Table 12 (cont.)

					Model Scenarios									
	Parameter characteristics				Alt0a		Alt0b		Alt1a		Alt1b		2013	
name	type	min	max	index	value	std.dev	value	std.dev	value	std.dev	value	std.dev	value	std.dev
pMnLnRecEarly	'param_init_number'	-Inf	Inf	1	1.19E+01	5.05E-01	1.18E+01	5.12E-01	1.19E+01	5.08E-01	1.18E+01	5.11E-01	1.18E+01	5.04E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1949	-1.51E+00	1.61E+00	-1.51E+00	1.62E+00	-1.50E+00	1.61E+00	-1.49E+00	1.62E+00	-1.54E+00	1.61E+00
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1950	-1.51E+00	1.47E+00	-1.50E+00	1.48E+00	-1.49E+00	1.47E+00	-1.49E+00	1.48E+00	-1.54E+00	1.46E+00
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1951	-1.50E+00	1.33E+00	-1.50E+00	1.34E+00	-1.49E+00	1.33E+00	-1.48E+00	1.34E+00	-1.53E+00	1.33E+00
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1952	-1.49E+00	1.20E+00	-1.49E+00	1.21E+00	-1.47E+00	1.20E+00	-1.47E+00	1.21E+00	-1.52E+00	1.20E+00
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1953	-1.47E+00	1.08E+00	-1.47E+00	1.09E+00	-1.46E+00	1.08E+00	-1.45E+00	1.09E+00	-1.50E+00	1.08E+00
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1954	-1.44E+00	9.72E-01	-1.44E+00	9.80E-01	-1.43E+00	9.75E-01	-1.42E+00	9.79E-01	-1.47E+00	9.70E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1955	-1.39E+00	8.81E-01	-1.40E+00	8.88E-01	-1.38E+00	8.85E-01	-1.38E+00	8.87E-01	-1.42E+00	8.80E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1956	-1.33E+00	8.10E-01	-1.34E+00	8.15E-01	-1.32E+00	8.13E-01	-1.32E+00	8.14E-01	-1.36E+00	8.09E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1957	-1.23E+00	7.59E-01	-1.25E+00	7.62E-01	-1.22E+00	7.61E-01	-1.23E+00	7.62E-01	-1.26E+00	7.58E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1958	-1.09E+00	7.27E-01	-1.11E+00	7.29E-01	-1.08E+00	7.29E-01	-1.09E+00	7.30E-01	-1.12E+00	7.26E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1959	-8.75E-01	7.12E-01	-9.06E-01	7.13E-01	-8.69E-01	7.13E-01	-8.83E-01	7.14E-01	-9.01E-01	7.11E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1960	-5.37E-01	7.10E-01	-5.76E-01	7.12E-01	-5.34E-01	7.11E-01	-5.52E-01	7.12E-01	-5.59E-01	7.09E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1961	1.59E-02	7.21E-01	-3.08E-02	7.23E-01	1.36E-02	7.22E-01	-8.63E-03	7.23E-01	5.19E-04	7.19E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1962	8.12E-01	7.23E-01	7.61E-01	7.26E-01	8.05E-01	7.25E-01	7.81E-01	7.26E-01	8.02E-01	7.21E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1963	1.58E+00	7.12E-01	1.53E+00	7.13E-01	1.57E+00	7.12E-01	1.55E+00	7.13E-01	1.57E+00	7.08E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1964	1.93E+00	6.94E-01	1.86E+00	6.91E-01	1.89E+00	6.90E-01	1.88E+00	6.91E-01	1.91E+00	6.89E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1965	1.90E+00	6.93E-01	1.81E+00	6.91E-01	1.82E+00	6.87E-01	1.81E+00	6.89E-01	1.88E+00	6.90E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1966	1.72E+00	6.91E-01	1.64E+00	6.94E-01	1.62E+00	6.88E-01	1.62E+00	6.91E-01	1.72E+00	6.90E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1967	1.55E+00	6.76E-01	1.52E+00	6.80E-01	1.46E+00	6.75E-01	1.47E+00	6.78E-01	1.58E+00	6.74E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1968	1.43E+00	6.65E-01	1.50E+00	6.58E-01	1.41E+00	6.58E-01	1.44E+00	6.58E-01	1.51E+00	6.58E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1969	1.36E+00	6.80E-01	1.52E+00	6.65E-01	1.42E+00	6.62E-01	1.47E+00	6.61E-01	1.48E+00	6.74E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1970	1.12E+00	6.21E-01	1.28E+00	6.19E-01	1.24E+00	6.11E-01	1.28E+00	6.12E-01	1.20E+00	6.17E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1971	7.44E-01	5.71E-01	8.18E-01	5.76E-01	8.36E-01	5.68E-01	8.51E-01	5.71E-01	7.81E-01	5.70E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1972	6.46E-01	5.49E-01	6.94E-01	5.55E-01	6.68E-01	5.51E-01	6.71E-01	5.55E-01	6.89E-01	5.48E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1973	5.46E-01	5.46E-01	5.93E-01	5.52E-01	4.68E-01	5.57E-01	4.62E-01	5.60E-01	5.92E-01	5.45E-01
pAvgLnFmTCF	'param_init_number'	-Inf	Inf	1	-1.60E+00	1.04E-01	-1.61E+00	9.07E-02	-1.66E+00	8.73E-02	-1.62E+00	8.72E-02	-1.50E+00	1.07E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	1	-5.11E-01	4.96E-01	-5.14E-01	4.95E-01	-5.21E-01	4.94E-01	-5.17E-01	4.95E-01	-5.12E-01	4.96E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	2	-7.55E-01	3.85E-01	-7.57E-01	3.83E-01	-7.65E-01	3.82E-01	-7.59E-01	3.83E-01	-7.54E-01	3.84E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	3	4.03E-01	3.46E-01	4.07E-01	3.40E-01	3.98E-01	3.37E-01	4.06E-01	3.39E-01	4.10E-01	3.46E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	4	1.80E-01	3.31E-01	2.11E-01	3.24E-01	2.10E-01	3.19E-01	2.17E-01	3.21E-01	1.91E-01	3.30E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	5	2.81E-01	3.22E-01	3.40E-01	3.15E-01	3.49E-01	3.08E-01	3.56E-01	3.11E-01	2.97E-01	3.24E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	6	6.32E-02	3.13E-01	1.47E-01	3.13E-01	1.69E-01	3.02E-01	1.76E-01	3.07E-01	7.79E-02	3.18E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	7	-1.93E-01	2.84E-01	-1.05E-01	2.94E-01	-6.51E-02	2.80E-01	-6.04E-02	2.87E-01	-1.89E-01	2.94E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	8	-4.01E-01	2.26E-01	-3.37E-01	2.41E-01	-2.74E-01	2.28E-01	-2.76E-01	2.34E-01	-4.19E-01	2.37E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	9	-6.48E-01	1.47E-01	-6.34E-01	1.55E-01	-5.46E-01	1.48E-01	-5.60E-01	1.52E-01	-6.94E-01	1.52E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	10	-4.26E-01	9.72E-02	-4.61E-01	9.90E-02	-3.60E-01	9.65E-02	-3.84E-01	9.76E-02	-4.94E-01	9.92E-02
pFmDevsTCF	'param_init_bounded_vector'	-15	15	11	-1.32E-01	9.02E-02	-1.91E-01	9.08E-02	-9.45E-02	8.79E-02	-1.22E-01	8.90E-02	-2.08E-01	9.22E-02
pFmDevsTCF	'param_init_bounded_vector'	-15	15	12	6.76E-01	8.94E-02	6.08E-01	8.90E-02	6.99E-01	8.56E-02	6.76E-01	8.67E-02	6.02E-01	9.14E-02
pFmDevsTCF	'param_init_bounded_vector'	-15	15	13	1.32E+00	9.59E-02	1.25E+00	9.19E-02	1.36E+00	8.86E-02	1.35E+00	8.98E-02	1.25E+00	9.73E-02
pFmDevsTCF	'param_init_bounded_vector'	-15	15	14	1.42E+00	1.23E-01	1.35E+00	1.11E-01	1.49E+00	1.06E-01	1.50E+00	1.08E-01	1.35E+00	1.23E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	15	2.19E+00	2.19E-01	2.11E+00	1.73E-01	2.25E+00	1.60E-01	2.27E+00	1.64E-01	2.15E+00	2.23E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	16	2.35E+00	2.45E-01	2.39E+00	2.38E-01	2.35E+00	2.17E-01	2.36E+00	2.22E-01	2.30E+00	2.51E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	17	6.92E-01	1.38E-01	8.01E-01	1.55E-01	7.30E-01	1.54E-01	6.99E-01	1.50E-01	6.14E-01	1.38E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	18	-3.29E-01	1.31E-01	-3.03E-01	1.31E-01	-3.60E-01	1.28E-01	-3.72E-01	1.28E-01	-4.16E-01	1.31E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	19	-1.47E+00	2.54E-01	-1.46E+00	2.54E-01	-1.52E+00	2.50E-01	-1.51E+00	2.50E-01	-1.55E+00	2.52E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	20	-3.52E-01	1.87E-01	-3.39E-01	1.88E-01	-4.51E-01	1.81E-01	-4.28E-01	1.81E-01	-4.54E-01	1.87E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	21	-9.15E-01	2.18E-01	-9.74E-01	2.18E-01	-1.08E+00	2.16E-01	-1.07E+00	2.16E-01	-9.89E-01	2.17E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	22	-2.07E-01	1.15E-01	-2.72E-01	1.14E-01	-3.19E-01	1.10E-01	-3.20E-01	1.10E-01	-2.89E-01	1.16E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	23	8.56E-01	9.36E-02	8.20E-01	9.10E-02	7.98E-01	8.67E-02	8.11E-01	8.72E-02	7.75E-01	9.55E-02

Table 12 (cont.).

					Model Scenarios									
	Parameter characteristics				Alt0a		Alt0b		Alt1a		Alt1b		2013	
name	type	min	max	index	value	std.dev	value	std.dev	value	std.dev	value	std.dev	value	std.dev
pFmDevsTCF	'param_init_bounded_vector'	-15	15	24	1.34E+00	9.82E-02	1.36E+00	9.64E-02	1.37E+00	9.16E-02	1.40E+00	9.22E-02	1.26E+00	1.00E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	25	1.26E+00	1.19E-01	1.35E+00	1.10E-01	1.39E+00	1.07E-01	1.40E+00	1.06E-01	1.16E+00	1.20E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	26	1.75E+00	1.29E-01	2.00E+00	1.48E-01	1.91E+00	1.41E-01	2.04E+00	1.55E-01	1.64E+00	1.29E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	27	1.23E+00	1.38E-01	1.43E+00	1.55E-01	1.14E+00	1.25E-01	1.24E+00	1.32E-01	1.11E+00	1.37E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	28	6.26E-01	1.53E-01	7.83E-01	1.64E-01	6.12E-01	1.45E-01	7.25E-01	1.55E-01	4.99E-01	1.52E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	29	1.06E-01	1.49E-01	1.43E-01	1.54E-01	1.18E-01	1.37E-01	1.01E-01	1.47E-01	-2.22E-02	1.49E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	30	-5.66E-01	3.78E-01	-1.14E+00	1.77E-01	-1.16E+00	1.76E-01	-1.12E+00	1.77E-01	-5.76E-01	3.69E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	31	-2.08E+00	2.22E-01	-2.07E+00	2.23E-01	-1.99E+00	2.10E-01	-2.03E+00	2.17E-01	-2.18E+00	2.22E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	32	-1.51E+00	1.50E-01	-1.56E+00	1.52E-01	-1.47E+00	1.41E-01	-1.56E+00	1.48E-01	-1.61E+00	1.53E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	33	-1.47E+00	1.38E-01	-1.56E+00	1.41E-01	-1.50E+00	1.30E-01	-1.63E+00	1.39E-01	-1.56E+00	1.41E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	34	-1.60E+00	1.79E-01	-1.61E+00	1.77E-01	-1.69E+00	1.66E-01	-1.73E+00	1.69E-01	-1.69E+00	1.81E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	35	-1.05E+00	2.81E-01	-1.07E+00	2.75E-01	-1.06E+00	2.89E-01	-1.10E+00	2.86E-01	-1.10E+00	2.88E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	36	-2.14E+00	1.91E-01	-2.15E+00	1.93E-01	-2.12E+00	1.86E-01	-2.15E+00	1.92E-01		
pAvgLnFmGTF	'param_init_number'	-Inf	Inf	1	-4.52E+00	7.31E-02	-4.33E+00	1.08E-01	-4.26E+00	7.66E-02	-4.21E+00	7.45E-02	-4.57E+00	7.24E-02
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1973	8.22E-01	8.93E-02	7.68E-01	1.20E-01	8.07E-01	9.73E-02	7.91E-01	9.61E-02	8.79E-01	8.73E-02
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1974	1.26E+00	7.83E-02	1.19E+00	1.10E-01	1.22E+00	8.35E-02	1.20E+00	8.16E-02	1.32E+00	7.57E-02
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1975	4.68E-01	8.02E-02	3.86E-01	1.11E-01	4.15E-01	8.45E-02	4.00E-01	8.26E-02	5.19E-01	7.77E-02
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1976	-2.59E-02	9.32E-02	-9.77E-02	1.21E-01	-6.27E-02	9.66E-02	-7.46E-02	9.48E-02	2.61E-02	9.11E-02
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1977	-2.94E-01	1.22E-01	-3.28E-01	1.44E-01	-2.72E-01	1.24E-01	-2.80E-01	1.22E-01	-2.42E-01	1.20E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1978	-4.83E-01	1.60E-01	-4.72E-01	1.77E-01	-4.03E-01	1.61E-01	-4.08E-01	1.59E-01	-4.31E-01	1.59E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1979	2.04E-01	1.19E-01	2.42E-01	1.41E-01	3.12E-01	1.19E-01	3.12E-01	1.18E-01	2.60E-01	1.16E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1980	-5.91E-02	1.53E-01	1.52E-02	1.72E-01	8.24E-02	1.55E-01	8.58E-02	1.54E-01	-6.18E-03	1.51E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1981	-2.44E-01	1.93E-01	-1.79E-01	2.08E-01	-1.22E-01	1.95E-01	-1.19E-01	1.94E-01	-1.97E-01	1.92E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1982	-9.56E-01	3.86E-01	-9.25E-01	3.95E-01	-9.02E-01	3.94E-01	-8.95E-01	3.94E-01	-9.18E-01	3.88E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1983	-4.82E-01	3.46E-01	-4.56E-01	3.57E-01	-4.43E-01	3.57E-01	-4.32E-01	3.58E-01	-4.46E-01	3.47E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1984	-2.70E-01	3.69E-01	-2.26E-01	3.84E-01	-2.24E-01	3.90E-01	-2.06E-01	3.92E-01	-2.37E-01	3.71E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1985	-6.43E-01	4.50E-01	-6.05E-01	4.64E-01	-6.39E-01	4.77E-01	-6.26E-01	4.81E-01	-6.12E-01	4.52E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1986	-6.12E-01	3.64E-01	-5.75E-01	3.76E-01	-5.92E-01	3.78E-01	-5.77E-01	3.81E-01	-5.77E-01	3.66E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1987	-9.37E-01	3.53E-01	-7.35E-01	4.09E-01	-7.47E-01	3.81E-01	-7.94E-01	3.79E-01	-8.98E-01	3.54E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1988	-1.33E+00	3.79E-01	-1.14E+00	4.35E-01	-1.18E+00	4.07E-01	-1.21E+00	4.05E-01	-1.29E+00	3.81E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1989	-1.20E+00	3.21E-01	-1.00E+00	3.85E-01	-1.05E+00	3.45E-01	-1.08E+00	3.43E-01	-1.16E+00	3.22E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1990	-8.84E-01	2.63E-01	-6.61E-01	3.40E-01	-7.12E-01	2.88E-01	-7.31E-01	2.85E-01	-8.47E-01	2.64E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1991	2.16E-01	1.24E-01	4.61E-01	2.55E-01	4.13E-01	1.47E-01	4.05E-01	1.40E-01	2.51E-01	1.23E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1992	5.69E-01	1.17E-01	7.96E-01	2.54E-01	7.23E-01	1.37E-01	7.24E-01	1.31E-01	6.03E-01	1.16E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1993	4.68E-01	1.62E-01	6.59E-01	2.75E-01	5.85E-01	1.77E-01	5.81E-01	1.72E-01	4.98E-01	1.61E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1994	9.70E-01	1.41E-01	1.14E+00	2.63E-01	1.09E+00	1.55E-01	1.08E+00	1.49E-01	9.97E-01	1.40E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1995	1.01E+00	1.77E-01	1.16E+00	2.79E-01	1.13E+00	1.91E-01	1.12E+00	1.85E-01	1.04E+00	1.76E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1996	1.35E+00	1.67E-01	1.50E+00	2.69E-01	1.48E+00	1.82E-01	1.47E+00	1.76E-01	1.37E+00	1.66E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1997	1.56E+00	2.33E-01	1.42E+00	2.39E-01	1.51E+00	2.34E-01	1.56E+00	2.28E-01	1.39E+00	2.28E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1998	1.32E+00	3.25E-01	1.18E+00	3.23E-01	1.25E+00	3.22E-01	1.26E+00	3.16E-01	1.14E+00	3.20E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1999	8.69E-01	4.81E-01	7.48E-01	4.62E-01	7.31E-01	4.84E-01	7.23E-01	4.81E-01	7.14E-01	4.60E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2000	9.56E-01	3.87E-01	8.30E-01	3.80E-01	7.92E-01	3.94E-01	7.87E-01	3.94E-01	7.94E-01	3.77E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2001	1.26E+00	2.46E-01	1.12E+00	2.52E-01	1.11E+00	2.47E-01	1.10E+00	2.47E-01	1.10E+00	2.43E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2002	5.80E-01	3.77E-01	4.55E-01	3.72E-01	4.70E-01	3.66E-01	4.70E-01	3.66E-01	4.28E-01	3.69E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2003	-6.14E-03	4.88E-01	-1.15E-01	4.73E-01	-1.09E-01	4.73E-01	-1.09E-01	4.73E-01	-1.32E-01	4.70E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2004	1.27E-01	3.70E-01	5.69E-03	3.66E-01	1.61E-02	3.61E-01	1.83E-02	3.60E-01	-1.67E-02	3.64E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2005	-1.13E-01	3.76E-01	-2.32E-01	3.72E-01	-2.48E-01	3.69E-01	-2.42E-01	3.69E-01	-2.38E-01	3.71E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2006	-8.71E-02	3.33E-01	-2.08E-01	3.33E-01	-2.34E-01	3.28E-01	-2.23E-01	3.28E-01	-2.09E-01	3.28E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2007	-2.17E-01	3.33E-01	-3.38E-01	3.32E-01	-3.68E-01	3.27E-01	-3.55E-01	3.26E-01	-3.34E-01	3.27E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2008	-5.15E-01	3.76E-01	-6.31E-01	3.72E-01	-6.69E-01	3.67E-01	-6.54E-01	3.67E-01	-6.01E-01	3.70E-01

Table 12 (cont.).

					Model Scenarios									
	Parameter characteristics				Alt0a		Alt0b		Alt1a		Alt1b		2013	
name	type	min	max	index	value	std.dev	value	std.dev	value	std.dev	value	std.dev	value	std.dev
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2009	-8.07E-01	4.50E-01	-9.13E-01	4.41E-01	-8.91E-01	4.21E-01	-8.75E-01	4.22E-01	-8.68E-01	4.42E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2010	-9.04E-01	4.94E-01	-1.00E+00	4.84E-01	-1.02E+00	4.73E-01	-1.00E+00	4.75E-01	-9.57E-01	4.85E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2011	-8.88E-01	5.06E-01	-9.83E-01	4.95E-01	-1.01E+00	4.89E-01	-9.93E-01	4.92E-01	-9.51E-01	4.94E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2012	-1.09E+00	5.19E-01	-1.18E+00	5.09E-01	-1.14E+00	4.95E-01	-1.13E+00	4.98E-01	-1.16E+00	5.03E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2013	-9.68E-01	4.47E-01	-1.07E+00	4.41E-01	-1.10E+00	4.31E-01	-1.08E+00	4.34E-01		
pAvgLnFmSCF	'param_init_number'	-Inf	Inf	1	-3.42E+00	1.25E-01	-3.72E+00	1.40E-01	-3.54E+00	1.12E-01	-3.85E+00	1.61E-01	-3.43E+00	1.32E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1992	2.09E+00	1.41E-01	2.00E+00	1.50E-01	2.08E+00	1.07E-01	2.04E+00	1.58E-01	2.09E+00	1.46E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1993	1.87E+00	1.48E-01	1.74E+00	1.59E-01	1.84E+00	1.12E-01	1.78E+00	1.64E-01	1.87E+00	1.54E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1994	1.52E+00	1.61E-01	1.36E+00	1.81E-01	1.49E+00	1.25E-01	1.42E+00	1.83E-01	1.51E+00	1.66E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1995	1.51E+00	1.74E-01	1.35E+00	2.03E-01	1.48E+00	1.42E-01	1.42E+00	2.05E-01	1.49E+00	1.78E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1996	1.19E-01	4.31E-01	1.48E-01	5.19E-01	1.61E-01	4.10E-01	2.86E-01	5.05E-01	6.58E-02	4.41E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1997	7.18E-01	2.78E-01	6.71E-01	3.95E-01	8.03E-01	2.75E-01	-3.71E-02	8.19E-01	6.71E-01	2.81E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1998	7.79E-01	2.95E-01	5.61E-01	4.80E-01	8.16E-01	3.00E-01	-3.58E-01	7.97E-01	7.22E-01	3.01E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1999	-3.05E-01	5.82E-01	-3.10E-01	6.92E-01	-2.74E-01	5.90E-01	-3.74E-01	7.99E-01	-3.60E-01	5.86E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2000	-7.93E-01	6.01E-01	-5.89E-01	6.66E-01	-7.65E-01	6.09E-01	-3.94E-01	7.93E-01	-8.29E-01	6.01E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2001	-7.52E-01	5.57E-01	-5.80E-01	6.32E-01	-7.11E-01	5.65E-01	-4.29E-01	7.80E-01	-7.86E-01	5.60E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2002	-6.81E-01	5.07E-01	-5.69E-01	5.97E-01	-6.19E-01	5.13E-01	-4.87E-01	7.63E-01	-7.13E-01	5.12E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2003	-1.08E+00	5.22E-01	-8.36E-01	5.82E-01	-1.02E+00	5.29E-01	-4.30E-01	7.57E-01	-1.09E+00	5.24E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2004	-1.36E+00	5.11E-01	-1.09E+00	5.61E-01	-1.32E+00	5.18E-01	-5.91E-01	7.19E-01	-1.38E+00	5.13E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2005	-5.45E-01	4.03E-01	-5.36E-01	5.14E-01	-5.76E-01	3.99E-01	-5.33E-01	5.17E-01	-5.88E-01	4.05E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2006	-2.10E-01	3.08E-01	-2.62E-01	4.30E-01	-2.57E-01	3.02E-01	-2.64E-01	4.31E-01	-2.48E-01	3.10E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2007	-1.19E-01	2.55E-01	-1.80E-01	3.62E-01	-1.69E-01	2.49E-01	-1.84E-01	3.66E-01	-1.45E-01	2.58E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2008	-6.90E-01	3.36E-01	-6.48E-01	4.32E-01	-7.40E-01	3.34E-01	-6.63E-01	4.41E-01	-7.05E-01	3.36E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2009	-5.51E-01	3.21E-01	-5.50E-01	4.30E-01	-5.96E-01	3.17E-01	-5.61E-01	4.36E-01	-5.62E-01	3.21E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2010	-4.64E-01	3.30E-01	-4.84E-01	4.50E-01	-5.00E-01	3.24E-01	-4.84E-01	4.53E-01	-4.66E-01	3.29E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2011	4.51E-02	2.48E-01	-5.26E-02	3.68E-01	1.70E-02	2.41E-01	-3.67E-02	3.71E-01	4.66E-02	2.49E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2012	-6.14E-01	3.62E-01	-6.20E-01	4.75E-01	-6.37E-01	3.55E-01	-6.11E-01	4.78E-01	-5.89E-01	3.57E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2013	-4.72E-01	2.66E-01	-5.22E-01	3.71E-01	-5.04E-01	2.58E-01	-5.01E-01	3.71E-01		
fish_fit_slope_mn1	'param_init_bounded_number'	0.25	1.001	1	7.33E-01	1.40E-01	7.30E-01	1.35E-01	7.12E-01	1.26E-01	7.28E-01	1.31E-01	7.33E-01	1.41E-01
fish_fit_sel50_mn1	'param_init_bounded_number'	85	160	1	1.38E+02	4.11E-01	1.38E+02	4.00E-01	1.38E+02	4.15E-01	1.38E+02	3.94E-01	1.38E+02	4.08E-01
fish_fit_slope_mn2	'param_init_bounded_number'	0.25	2.001	1	8.25E-01	1.33E-01	8.41E-01	1.31E-01	8.44E-01	1.24E-01	8.42E-01	1.18E-01	1.02E+00	2.83E-01
fish_fit_sel50_mn2	'param_init_bounded_number'	85	160	1	1.38E+02	2.43E-01	1.37E+02	2.47E-01	1.37E+02	2.63E-01	1.37E+02	3.03E-01	1.38E+02	2.42E-01
fish_slope_1	'param_init_bounded_number'	0.05	0.75	1	1.31E-01	9.97E-03	1.33E-01	9.08E-03	1.23E-01	7.10E-03	1.24E-01	6.89E-03	1.30E-01	9.95E-03
fish_slope_yr_3	'param_init_bounded_number'	0.1	0.4	1	1.37E-01	8.91E-03	1.38E-01	9.08E-03	1.35E-01	8.36E-03	1.36E-01	8.52E-03	1.34E-01	9.21E-03
log_avg_sel50_3	'param_init_bounded_number'	4	5	1	4.87E+00	1.29E-02	4.83E+00	9.40E-03	4.82E+00	9.18E-03	4.83E+00	8.90E-03	4.88E+00	1.28E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	1	1.92E-02	2.33E-02	4.89E-02	2.08E-02	5.63E-02	1.78E-02	4.71E-02	1.78E-02	1.40E-02	2.27E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	2	7.13E-02	1.63E-02	1.31E-01	1.49E-02	1.37E-01	1.48E-02	1.45E-01	1.53E-02	6.40E-02	1.55E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	3	4.97E-02	1.87E-02	1.12E-01	1.70E-02	9.63E-02	1.56E-02	1.05E-01	1.56E-02	4.21E-02	1.80E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	4	3.63E-02	2.42E-02	9.79E-02	2.10E-02	7.73E-02	2.30E-02	9.81E-02	2.15E-02	2.83E-02	2.35E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	5	-5.42E-02	3.28E-02	6.63E-03	2.84E-02	-1.79E-02	3.09E-02	-3.78E-03	2.99E-02	-6.17E-02	3.23E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	6	-2.60E-02	1.05E-01	-4.99E-01	2.21E-02	-4.99E-01	2.02E-02	-4.99E-01	1.81E-02	2.46E-03	8.65E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	7	-9.50E-02	2.43E-02	-6.23E-02	2.30E-02	-3.93E-02	2.01E-02	-4.64E-02	2.01E-02	-1.02E-01	2.43E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	8	-9.29E-02	2.21E-02	-6.00E-02	2.06E-02	-4.57E-02	2.00E-02	-5.28E-02	2.00E-02	-1.00E-01	2.22E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	9	-1.11E-01	2.01E-02	-7.64E-02	1.84E-02	-7.62E-02	1.82E-02	-8.20E-02	1.81E-02	-1.19E-01	2.01E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	10	4.40E-02	2.00E-02	7.69E-02	1.82E-02	6.42E-02	1.67E-02	5.64E-02	1.67E-02	3.69E-02	2.02E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	11	1.99E-01	2.07E-02	2.30E-01	1.87E-02	2.40E-01	2.09E-02	2.32E-01	2.07E-02	1.95E-01	2.14E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	12	-4.03E-02	2.16E-02	-6.26E-03	1.99E-02	7.53E-03	1.98E-02	5.26E-04	1.98E-02		
fish_disc_slope_f	'param_init_bounded_number'	0.1	0.4	1	1.32E-01	1.06E-02	1.27E-01	1.01E-02	1.41E-01	8.94E-03	1.37E-01	8.62E-03	1.27E-01	1.06E-02
fish_disc_sel50_f	'param_init_bounded_number'	80	150	1	1.15E+02	2.74E+00	1.21E+02	3.35E+00	1.17E+02	2.82E+00	1.20E+02	3.28E+00	1.16E+02	2.90E+00

Table 12 (cont.).

					Model Scenarios									
Parameter characteristics					Alt0a		Alt0b		Alt1a		Alt1b		2013	
name	type	min	max	index	value	std.dev	value	std.dev	value	std.dev	value	std.dev	value	std.dev
snowfish_disc_slope_f_1	'param_init_bounded_number'	0.05	0.5	1	5.00E-02	1.21E-05	5.00E-02	1.65E-05	5.00E-02	1.56E-05	5.00E-02	2.37E-05	5.00E-02	1.09E-05
snowfish_disc_sel50_f_1	'param_init_bounded_number'	50	150	1	1.19E+02	5.35E+00	1.15E+02	5.62E+00	1.16E+02	3.62E+00	1.12E+02	4.70E+00	1.18E+02	5.69E+00
snowfish_disc_slope_f_2	'param_init_bounded_number'	0.05	0.5	1	2.06E-01	1.19E-01	2.32E-01	1.38E-01	2.09E-01	1.06E-01	2.59E-01	1.35E-01	2.25E-01	1.34E-01
snowfish_disc_sel50_f_2	'param_init_bounded_number'	50	120	1	8.20E+01	6.28E+00	8.01E+01	5.74E+00	7.89E+01	5.64E+00	7.61E+01	4.88E+00	8.02E+01	5.80E+00
snowfish_disc_slope_f_3	'param_init_bounded_number'	0.05	0.5	1	1.27E-01	3.97E-02	1.53E-01	5.14E-02	1.33E-01	4.18E-02	1.58E-01	5.32E-02	1.30E-01	4.44E-02
snowfish_disc_sel50_f_3	'param_init_bounded_number'	50	120	1	8.98E+01	7.96E+00	8.46E+01	6.26E+00	9.01E+01	7.95E+00	8.51E+01	6.30E+00	8.90E+01	8.38E+00
snowfish_disc_slope_m_1	'param_init_bounded_number'	0.1	0.5	1	3.21E-01	9.80E-02	3.67E-01	1.16E-01	3.01E-01	9.67E-02	3.57E-01	1.27E-01	3.21E-01	9.89E-02
snowfish_disc_sel50_m_1	'param_init_bounded_number'	60	150	1	8.79E+01	1.90E+00	8.68E+01	1.66E+00	8.88E+01	1.92E+00	8.74E+01	1.77E+00	8.80E+01	1.96E+00
snowfish_disc_slope_m2_1	'param_init_bounded_number'	0.1	0.5	1	1.39E-01	7.20E-02	1.69E-01	9.06E-02	3.22E-01	1.86E-01	3.71E-01	2.42E-01	1.28E-01	6.98E-02
snowfish_disc_sel50_m2_1	'param_init_bounded_number'	40	200	1	1.36E+02	5.60E+00	1.37E+02	4.66E+00	1.41E+02	2.17E+00	1.41E+02	1.97E+00	1.36E+02	6.06E+00
snowfish_disc_slope_m_2	'param_init_bounded_number'	0.1	0.5	1	2.54E-01	9.10E-02	2.39E-01	8.52E-02	2.52E-01	8.15E-02	2.08E-01	6.44E-02	2.53E-01	9.03E-02
snowfish_disc_sel50_m_2	'param_init_bounded_number'	60	150	1	9.25E+01	3.01E+00	9.32E+01	3.31E+00	9.31E+01	2.77E+00	1.39E+02	6.50E+00	9.26E+01	3.02E+00
snowfish_disc_slope_m2_2	'param_init_bounded_number'	0.1	0.5	1	1.79E-01	1.12E-01	1.63E-01	9.47E-02	1.99E-01	1.03E-01	2.10E-01	6.07E-02	1.74E-01	1.07E-01
snowfish_disc_sel50_m2_2	'param_init_bounded_number'	40	200	1	1.42E+02	5.44E+00	1.40E+02	5.43E+00	1.42E+02	4.18E+00	9.49E+01	5.25E+00	1.42E+02	5.41E+00
snowfish_disc_slope_m_3	'param_init_bounded_number'	0.1	0.5	1	1.68E-01	1.75E-02	1.65E-01	1.75E-02	1.68E-01	1.74E-02	1.66E-01	1.74E-02	1.66E-01	1.86E-02
snowfish_disc_sel50_m_3	'param_init_bounded_number'	60	150	1	1.06E+02	1.94E+00	1.06E+02	2.09E+00	1.05E+02	1.85E+00	1.05E+02	2.00E+00	1.05E+02	2.08E+00
snowfish_disc_slope_m2_3	'param_init_bounded_number'	0.1	0.5	1	1.92E-01	3.28E-02	1.85E-01	3.20E-02	1.76E-01	3.05E-02	1.70E-01	2.95E-02	1.96E-01	3.59E-02
snowfish_disc_sel50_m2_3	'param_init_bounded_number'	40	200	1	1.36E+02	1.73E+00	1.36E+02	1.91E+00	1.39E+02	1.85E+00	1.38E+02	2.03E+00	1.37E+02	1.78E+00
rkfish_disc_slope_f1	'param_init_bounded_number'	0.05	0.5	1	1.70E-01	4.14E-02	1.68E-01	4.18E-02	1.72E-01	3.98E-02	1.70E-01	4.00E-02	2.52E-01	1.45E-01
rkfish_disc_sel50_f1	'param_init_bounded_number'	50	150	1	1.50E+02	1.16E+00	1.50E+02	1.16E+00	1.50E+02	1.23E+00	1.50E+02	1.14E+00	9.61E+01	1.14E+01
rkfish_disc_slope_f2	'param_init_bounded_number'	0.05	0.5	1	1.46E-01	7.48E-02	1.46E-01	7.58E-02	1.51E-01	6.91E-02	1.78E-01	1.73E-01	1.65E-01	1.74E-01
rkfish_disc_sel50_f2	'param_init_bounded_number'	50	150	1	1.50E+02	3.07E+00	1.50E+02	2.82E+00	1.50E+02	2.31E+01	1.03E+02	4.54E+01	1.04E+02	5.67E+01
rkfish_disc_slope_f3	'param_init_bounded_number'	0.05	0.5	1	1.82E-01	5.91E-02	1.84E-01	5.99E-02	1.84E-01	5.58E-02	1.85E-01	5.62E-02	1.73E-01	6.44E-02
rkfish_disc_sel50_f3	'param_init_bounded_number'	50	170	1	1.59E+02	3.83E+02	1.58E+02	3.74E+02	1.57E+02	3.60E+02	1.57E+02	3.57E+02	1.63E+02	6.18E+02
rkfish_disc_slope_m1	'param_init_bounded_number'	0.01	0.5	1	1.80E-01	7.00E-02	1.56E-01	5.90E-02	1.03E-01	1.06E-02	1.06E-01	1.08E-02	1.80E-01	6.99E-02
rkfish_disc_sel50_m1	'param_init_bounded_number'	95	150	1	1.16E+02	5.46E+00	1.20E+02	5.99E+00	1.50E+02	1.52E-03	1.50E+02	8.75E-04	1.16E+02	5.41E+00
rkfish_disc_slope_m2	'param_init_bounded_number'	0.01	0.5	1	9.09E-02	2.90E-02	8.98E-02	2.86E-02	9.57E-02	2.82E-02	9.29E-02	2.67E-02	8.95E-02	2.85E-02
rkfish_disc_sel50_m2	'param_init_bounded_number'	95	150	1	1.34E+02	1.42E+01	1.34E+02	1.44E+01	1.31E+02	1.15E+01	1.33E+02	1.21E+01	1.34E+02	1.45E+01
rkfish_disc_slope_m3	'param_init_bounded_number'	0.01	0.5	1	7.68E-02	7.34E-03	7.56E-02	7.26E-03	8.27E-02	7.20E-03	8.13E-02	7.13E-03	7.30E-02	7.94E-03
rkfish_disc_sel50_m3	'param_init_bounded_number'	95	150	1	1.50E+02	2.46E-03	1.50E+02	2.94E-03	1.50E+02	7.86E-04	1.50E+02	8.55E-04	1.50E+02	1.71E-03
fish_disc_slope_tf1	'param_init_bounded_number'	0.01	0.5	1	1.35E-01	3.05E-02	2.24E-02	8.72E-03	2.69E-02	1.68E-03	2.67E-02	1.69E-03	1.36E-01	3.03E-02
fish_disc_sel50_tf1	'param_init_bounded_number'	40	125.01	1	4.28E+01	2.10E+00	6.64E+01	1.11E+01	1.25E+02	3.17E-04	1.25E+02	2.94E-04	4.28E+01	2.09E+00
fish_disc_slope_tf2	'param_init_bounded_number'	0.005	0.5	1	1.77E-01	7.95E-02	7.68E-03	1.96E-02	1.34E-02	5.31E-03	1.20E-02	5.44E-03	1.78E-01	7.88E-02
fish_disc_sel50_tf2	'param_init_bounded_number'	40	250.01	1	4.00E+01	1.47E-04	4.00E+01	4.23E-03	1.77E+02	4.77E+01	1.78E+02	5.40E+01	4.00E+01	1.47E-04
fish_disc_slope_tf3	'param_init_bounded_number'	0.01	0.5	1	6.95E-02	7.00E-03	6.74E-02	6.84E-03	5.48E-02	8.52E-03	5.41E-02	8.49E-03	9.93E-02	1.17E-02
fish_disc_sel50_tf3	'param_init_bounded_number'	40	150.01	1	8.57E+01	3.60E+00	8.66E+01	3.70E+00	1.48E+02	1.13E+01	1.48E+02	1.14E+01	6.88E+01	2.96E+00
fish_disc_slope_tm1	'param_init_bounded_number'	0.01	0.5	1	1.48E-01	2.62E-02	1.19E-01	2.13E-02	1.13E-01	1.24E-02	1.14E-01	1.26E-02	1.48E-01	2.61E-02
fish_disc_sel50_tm1	'param_init_bounded_number'	40	120.01	1	4.74E+01	2.00E+00	5.20E+01	2.72E+00	5.42E+01	2.00E+00	5.37E+01	1.97E+00	4.74E+01	2.00E+00
fish_disc_slope_tm2	'param_init_bounded_number'	0.01	0.5	1	1.55E-01	1.19E-01	2.57E-02	2.12E-02	4.34E-02	9.56E-03	4.86E-02	1.27E-02	1.48E-01	1.15E-01
fish_disc_sel50_tm2	'param_init_bounded_number'	40	120.01	1	4.15E+01	5.08E+00	6.34E+01	2.65E+01	7.11E+01	9.80E+00	6.41E+01	8.87E+00	4.20E+01	5.27E+00
fish_disc_slope_tm3	'param_init_bounded_number'	0.01	0.5	1	7.01E-02	6.96E-03	7.05E-02	7.10E-03	7.04E-02	3.65E-03	7.10E-02	3.69E-03	7.82E-02	1.10E-02
fish_disc_sel50_tm3	'param_init_bounded_number'	40	120.01	1	9.27E+01	4.13E+00	9.22E+01	4.12E+00	9.45E+01	2.37E+00	9.38E+01	2.33E+00	8.29E+01	4.60E+00
srv2_q	'param_init_bounded_number'	0.5	1.001	1	5.07E-01	3.46E-02	5.49E-01	3.51E-02	5.35E-01	3.21E-02	5.61E-01	3.34E-02	5.13E-01	3.50E-02
srv2_seldiff	'param_init_bounded_number'	0	100	1	2.18E+01	3.56E+00	2.26E+01	3.75E+00	2.33E+01	3.76E+00	2.31E+01	3.74E+00	2.18E+01	3.57E+00
srv2_sel50	'param_init_bounded_number'	0	90	1	4.55E+01	1.93E+00	4.61E+01	2.02E+00	4.72E+01	2.03E+00	4.69E+01	2.02E+00	4.55E+01	1.93E+00
srv3_q	'param_init_bounded_number'	0.2	2	1	7.30E-01	3.63E-02	7.75E-01	3.76E-02	7.04E-01	3.52E-02	7.53E-01	3.64E-02	7.21E-01	3.64E-02
srv3_seldiff	'param_init_bounded_number'	0	100	1	5.98E+01	8.52E+00	5.75E+01	8.17E+00	5.98E+01	8.52E+00	5.68E+01	8.02E+00	6.03E+01	8.81E+00
srv3_sel50	'param_init_bounded_number'	0	69	1	2.97E+01	3.36E+00	2.83E+01	3.32E+00	2.95E+01	3.36E+00	2.82E+01	3.29E+00	3.02E+01	3.40E+00

Table 12 (cont.).

Parameter characteristics					Model Scenarios									
					Alt0a		Alt0b		Alt1a		Alt1b		2013	
name	type	min	max	index	value	std.dev	value	std.dev	value	std.dev	value	std.dev	value	std.dev
matestf	'param_init_bounded_vector'	-15	0	1	-1.50E+01	2.65E-03	-1.50E+01	2.63E-03	-1.50E+01	2.63E-03	-1.50E+01	2.62E-03	-1.50E+01	2.71E-03
matestf	'param_init_bounded_vector'	-15	0	2	-1.37E+01	7.77E-01	-1.37E+01	7.75E-01	-1.37E+01	7.78E-01	-1.37E+01	7.78E-01	-1.37E+01	7.77E-01
matestf	'param_init_bounded_vector'	-15	0	3	-1.23E+01	1.17E+00	-1.23E+01	1.17E+00	-1.24E+01	1.17E+00	-1.24E+01	1.17E+00	-1.23E+01	1.17E+00
matestf	'param_init_bounded_vector'	-15	0	4	-1.09E+01	1.26E+00	-1.09E+01	1.26E+00	-1.09E+01	1.27E+00	-1.09E+01	1.27E+00	-1.09E+01	1.26E+00
matestf	'param_init_bounded_vector'	-15	0	5	-9.29E+00	1.12E+00	-9.29E+00	1.11E+00	-9.32E+00	1.13E+00	-9.33E+00	1.12E+00	-9.26E+00	1.12E+00
matestf	'param_init_bounded_vector'	-15	0	6	-7.50E+00	8.28E-01	-7.50E+00	8.22E-01	-7.53E+00	8.34E-01	-7.55E+00	8.33E-01	-7.47E+00	8.28E-01
matestf	'param_init_bounded_vector'	-15	0	7	-5.51E+00	4.95E-01	-5.51E+00	4.92E-01	-5.54E+00	4.99E-01	-5.56E+00	4.99E-01	-5.49E+00	4.95E-01
matestf	'param_init_bounded_vector'	-15	0	8	-3.42E+00	2.21E-01	-3.42E+00	2.19E-01	-3.45E+00	2.24E-01	-3.46E+00	2.24E-01	-3.41E+00	2.20E-01
matestf	'param_init_bounded_vector'	-15	0	9	-1.83E+00	9.87E-02	-1.84E+00	9.92E-02	-1.83E+00	1.01E-01	-1.84E+00	1.01E-01	-1.83E+00	9.92E-02
matestf	'param_init_bounded_vector'	-15	0	10	-8.72E-01	5.73E-02	-8.79E-01	5.78E-02	-8.58E-01	5.76E-02	-8.68E-01	5.81E-02	-8.81E-01	5.79E-02
matestf	'param_init_bounded_vector'	-15	0	11	-5.26E-01	4.13E-02	-5.28E-01	4.14E-02	-5.17E-01	4.13E-02	-5.24E-01	4.15E-02	-5.39E-01	4.24E-02
matestf	'param_init_bounded_vector'	-15	0	12	-3.96E-01	4.16E-02	-3.99E-01	4.09E-02	-3.85E-01	4.07E-02	-3.91E-01	4.08E-02	-4.06E-01	4.31E-02
matestf	'param_init_bounded_vector'	-15	0	13	-1.66E-01	4.10E-02	-1.72E-01	3.90E-02	-1.43E-01	3.65E-02	-1.44E-01	3.70E-02	-1.68E-01	4.18E-02
matestf	'param_init_bounded_vector'	-15	0	14	-3.98E-09	1.54E-05	-5.34E-09	2.07E-05	-2.61E-09	1.01E-05	-2.37E-09	9.19E-06	-3.98E-09	1.54E-05
matestf	'param_init_bounded_vector'	-15	0	15	-8.00E-09	3.11E-05	-2.89E-08	1.12E-04	-6.13E-03	1.10E-02	-5.61E-03	1.06E-02	-5.56E-09	2.15E-05
matestf	'param_init_bounded_vector'	-15	0	16	-1.62E-03	5.59E-03	-1.79E-03	5.70E-03	-4.17E-04	8.20E-03	-4.78E-04	7.95E-03	-8.65E-05	4.45E-03
matestm	'param_init_bounded_vector'	-15	0	1	-1.50E+01	6.42E-03	-1.50E+01	6.49E-03	-1.50E+01	6.41E-03	-1.50E+01	6.42E-03	-1.50E+01	6.37E-03
matestm	'param_init_bounded_vector'	-15	0	2	-1.39E+01	1.10E+00	-1.39E+01	1.10E+00	-1.39E+01	1.10E+00	-1.39E+01	1.10E+00	-1.39E+01	1.10E+00
matestm	'param_init_bounded_vector'	-15	0	3	-1.28E+01	1.66E+00	-1.28E+01	1.66E+00	-1.27E+01	1.65E+00	-1.27E+01	1.65E+00	-1.28E+01	1.66E+00
matestm	'param_init_bounded_vector'	-15	0	4	-1.16E+01	1.80E+00	-1.15E+01	1.80E+00	-1.15E+01	1.78E+00	-1.15E+01	1.79E+00	-1.16E+01	1.80E+00
matestm	'param_init_bounded_vector'	-15	0	5	-1.03E+01	1.62E+00	-1.02E+01	1.61E+00	-1.02E+01	1.59E+00	-1.02E+01	1.60E+00	-1.03E+01	1.62E+00
matestm	'param_init_bounded_vector'	-15	0	6	-8.79E+00	1.25E+00	-8.72E+00	1.24E+00	-8.67E+00	1.22E+00	-8.65E+00	1.22E+00	-8.77E+00	1.24E+00
matestm	'param_init_bounded_vector'	-15	0	7	-7.15E+00	8.70E-01	-7.08E+00	8.58E-01	-7.02E+00	8.34E-01	-6.98E+00	8.32E-01	-7.12E+00	8.62E-01
matestm	'param_init_bounded_vector'	-15	0	8	-5.48E+00	6.37E-01	-5.40E+00	6.23E-01	-5.34E+00	6.00E-01	-5.30E+00	5.94E-01	-5.44E+00	6.32E-01
matestm	'param_init_bounded_vector'	-15	0	9	-4.52E+00	3.69E-01	-4.45E+00	3.62E-01	-4.44E+00	3.49E-01	-4.39E+00	3.45E-01	-4.49E+00	3.68E-01
matestm	'param_init_bounded_vector'	-15	0	10	-3.90E+00	2.62E-01	-3.84E+00	2.60E-01	-3.85E+00	2.53E-01	-3.78E+00	2.51E-01	-3.89E+00	2.64E-01
matestm	'param_init_bounded_vector'	-15	0	11	-3.32E+00	2.00E-01	-3.28E+00	2.00E-01	-3.28E+00	1.94E-01	-3.23E+00	1.93E-01	-3.33E+00	2.04E-01
matestm	'param_init_bounded_vector'	-15	0	12	-2.76E+00	1.57E-01	-2.75E+00	1.57E-01	-2.78E+00	1.53E-01	-2.75E+00	1.53E-01	-2.77E+00	1.60E-01
matestm	'param_init_bounded_vector'	-15	0	13	-2.26E+00	1.29E-01	-2.26E+00	1.29E-01	-2.32E+00	1.26E-01	-2.30E+00	1.25E-01	-2.24E+00	1.31E-01
matestm	'param_init_bounded_vector'	-15	0	14	-1.71E+00	1.03E-01	-1.72E+00	1.02E-01	-1.80E+00	1.01E-01	-1.78E+00	9.97E-02	-1.70E+00	1.05E-01
matestm	'param_init_bounded_vector'	-15	0	15	-1.38E+00	8.83E-02	-1.39E+00	8.69E-02	-1.44E+00	8.41E-02	-1.42E+00	8.31E-02	-1.37E+00	9.00E-02
matestm	'param_init_bounded_vector'	-15	0	16	-1.17E+00	7.90E-02	-1.18E+00	7.84E-02	-1.18E+00	7.44E-02	-1.19E+00	7.36E-02	-1.18E+00	8.13E-02
matestm	'param_init_bounded_vector'	-15	0	17	-1.02E+00	7.14E-02	-1.05E+00	7.21E-02	-9.86E-01	6.60E-02	-1.03E+00	6.65E-02	-1.03E+00	7.40E-02
matestm	'param_init_bounded_vector'	-15	0	18	-7.86E-01	6.34E-02	-8.20E-01	6.45E-02	-7.36E-01	5.66E-02	-7.90E-01	5.84E-02	-8.03E-01	6.59E-02
matestm	'param_init_bounded_vector'	-15	0	19	-5.56E-01	5.81E-02	-5.72E-01	5.94E-02	-5.12E-01	5.14E-02	-5.46E-01	5.36E-02	-5.76E-01	6.09E-02
matestm	'param_init_bounded_vector'	-15	0	20	-2.84E-01	5.05E-02	-2.83E-01	4.97E-02	-2.55E-01	4.34E-02	-2.70E-01	4.50E-02	-2.96E-01	5.37E-02
matestm	'param_init_bounded_vector'	-15	0	21	-1.15E-01	3.73E-02	-1.08E-01	3.38E-02	-9.47E-02	2.88E-02	-9.88E-02	2.96E-02	-1.17E-01	3.90E-02
matestm	'param_init_bounded_vector'	-15	0	22	-6.29E-04	1.42E-02	-5.84E-05	7.46E-03	-6.02E-09	2.25E-05	-7.01E-09	2.61E-05	-9.79E-04	1.46E-02
matestm	'param_init_bounded_vector'	-15	0	23	-2.33E-09	9.06E-06	-3.09E-09	1.18E-05	-2.23E-09	8.56E-06	-2.58E-09	9.88E-06	-2.46E-09	9.52E-06
matestm	'param_init_bounded_vector'	-15	0	24	-1.27E-09	4.93E-06	-1.26E-09	4.89E-06	-1.15E-09	4.47E-06	-1.01E-09	4.00E-06	-1.38E-09	5.36E-06
matestm	'param_init_bounded_vector'	-15	0	25	-1.63E-09	6.32E-06	-1.81E-09	6.99E-06	-1.82E-09	7.02E-06	-1.52E-09	5.91E-06	-1.69E-09	6.56E-06
matestm	'param_init_bounded_vector'	-15	0	26	-1.63E-09	6.33E-06	-1.94E-09	7.50E-06	-1.74E-09	6.71E-06	-1.60E-09	6.21E-06	-1.66E-09	6.43E-06
matestm	'param_init_bounded_vector'	-15	0	27	-2.21E-09	8.58E-06	-2.71E-09	1.05E-05	-2.25E-09	8.71E-06	-2.18E-09	8.43E-06	-2.23E-09	8.65E-06
matestm	'param_init_bounded_vector'	-15	0	28	-3.59E-09	1.39E-05	-4.36E-09	1.68E-05	-3.48E-09	1.35E-05	-3.46E-09	1.34E-05	-3.73E-09	1.45E-05
matestm	'param_init_bounded_vector'	-15	0	29	-8.44E-09	3.27E-05	-9.75E-09	3.77E-05	-8.30E-09	3.21E-05	-8.20E-09	3.17E-05	-9.19E-09	3.56E-05
matestm	'param_init_bounded_vector'	-15	0	30	-4.59E-08	1.78E-04	-6.18E-08	2.39E-04	-3.76E-08	1.45E-04	-3.85E-08	1.49E-04	-5.86E-08	2.25E-04
matestm	'param_init_bounded_vector'	-15	0	31	-6.90E-02	3.57E-01	-8.07E-02	3.14E-01	-5.05E-02	2.80E-01	-5.13E-02	2.82E-01	-6.93E-02	3.66E-01
matestm	'param_init_bounded_vector'	-15	0	32	-1.41E-01	1.24E+00	-1.66E-01	1.20E+00	-1.04E-01	1.16E+00	-1.05E-01	1.16E+00	-1.41E-01	1.25E+00
srv2_femQ	'param_init_bounded_number'	0.5	1.001	1	7.34E-01	2.61E-01	5.81E-01	1.64E-01	6.65E-01	3.01E-01	6.03E-01	2.09E-01	6.92E-01	1.99E-01
srv2_seldiff_f	'param_init_bounded_number'	0	100	1	6.03E+01	2.27E+01	5.17E+01	2.56E+01	6.28E+01	3.13E+01	5.52E+01	2.93E+01	5.54E+01	2.01E+01
srv2_sel50_f	'param_init_bounded_number'	-200	100.01	1	6.45E+01	1.78E+01	5.43E+01	1.41E+01	6.38E+01	2.38E+01	5.70E+01	1.77E+01	6.08E+01	1.41E+01
srv3_femQ	'param_init_bounded_number'	0.2	1	1	5.51E-01	4.04E-02	5.48E-01	4.04E-02	5.22E-01	3.83E-02	5.59E-01	3.88E-02	5.61E-01	4.11E-02
srv3_seldiff_f	'param_init_bounded_number'	0	100	1	1.00E+02	7.15E-04	1.00E+02	1.23E-03	1.00E+02	6.88E-04	1.00E+02	8.30E-04	1.00E+02	6.46E-04
srv3_sel50_f	'param_init_bounded_number'	-50	69	1	-4.95E-01	1.58E+01	-1.81E+01	2.13E+01	-6.39E-01	1.49E+01	-5.29E+00	1.58E+01	4.96E+00	1.42E+01

Table 13. Comparison of estimated male recruitment (in millions) from the four alternative 2014 models and the 2013 model.

year	Alt0a	Alt0b	Alt1a	Alt1b	2013 Model
1949	31.7	30.6	32.5	31.2	29.0
1950	31.8	30.7	32.5	31.3	29.1
1951	32.0	30.9	32.8	31.5	29.3
1952	32.4	31.2	33.2	31.9	29.7
1953	33.1	31.8	33.8	32.5	30.3
1954	34.1	32.7	34.8	33.4	31.2
1955	35.6	34.0	36.4	34.8	32.6
1956	38.0	36.2	38.8	37.1	34.8
1957	41.8	39.6	42.7	40.6	38.4
1958	48.2	45.4	49.1	46.6	44.3
1959	59.8	55.9	60.7	57.4	55.0
1960	83.9	77.7	84.9	79.9	77.4
1961	145.8	134.0	146.8	137.6	135.5
1962	323.0	295.9	324.0	303.1	302.0
1963	698.2	638.5	696.8	653.2	650.7
1964	991.4	890.2	961.4	905.2	915.3
1965	962.2	848.5	897.4	850.1	888.2
1966	800.3	712.6	732.3	699.1	752.6
1967	673.4	631.1	626.0	605.1	656.8
1968	602.5	618.6	592.4	583.3	615.8
1969	560.2	632.6	599.9	602.6	592.0
1970	440.2	494.6	500.3	500.9	448.7
1971	301.8	313.1	333.9	325.1	295.8
1972	273.7	276.7	282.5	271.4	269.7
1973	247.8	250.0	231.2	220.4	244.7
1974	24.9	30.0	64.4	61.1	23.3
1975	208.0	201.9	218.0	209.8	208.5
1976	412.1	406.5	494.6	459.2	403.6
1977	298.9	284.9	304.3	279.3	295.1
1978	265.4	244.9	258.3	237.7	260.5
1979	71.0	62.9	63.3	58.8	69.5
1980	15.5	16.9	24.5	22.6	14.8

year	Alt0a	Alt0b	Alt1a	Alt1b	2013 Model
1981	52.6	47.5	57.8	53.5	52.4
1982	20.9	21.1	28.7	26.2	21.0
1983	196.3	183.1	205.3	186.5	196.4
1984	164.3	154.1	168.8	152.3	165.7
1985	359.8	304.7	327.5	287.8	357.6
1986	284.6	258.9	274.5	240.0	283.3
1987	273.9	227.8	258.1	217.5	274.6
1988	200.2	169.2	231.3	192.0	199.8
1989	110.1	93.3	101.5	85.4	110.6
1990	47.0	40.5	45.0	38.4	47.3
1991	23.4	19.5	21.0	17.9	23.6
1992	18.1	16.3	17.8	15.7	18.5
1993	14.9	13.4	14.8	13.0	15.3
1994	14.6	13.6	16.9	14.9	14.8
1995	20.7	18.9	24.6	22.0	21.0
1996	23.3	21.3	23.8	21.5	23.6
1997	60.4	57.0	64.2	59.4	60.9
1998	25.5	23.7	25.4	23.5	25.8
1999	78.8	74.0	79.2	73.7	79.7
2000	46.1	42.7	48.2	44.6	46.5
2001	144.1	134.7	148.9	138.3	144.5
2002	56.2	51.7	61.7	57.0	55.9
2003	99.7	91.9	110.5	101.8	99.4
2004	202.6	187.1	201.2	186.1	198.9
2005	59.7	54.9	61.8	57.1	58.5
2006	48.7	44.7	51.3	47.3	47.8
2007	38.1	34.9	36.3	33.2	37.3
2008	41.8	38.0	42.0	38.2	41.5
2009	211.8	195.1	224.3	205.2	200.1
2010	209.8	192.7	237.1	214.8	238.4
2011	115.2	104.0	119.5	107.2	128.2
2012	25.6	22.9	24.2	21.7	33.8
2013	84.0	74.9	65.6	58.2	120.6
2014	89.2	78.6	99.8	88.0	

Table 14. Comparison of time series of estimated mature male biomass (1000's t) at mating from the four alternative 2014 models and the 2013 model.

year	Alt0a	Alt0b	Alt1a	Alt1b	2013 Model
1949	0.0	0.0	0.0	0.0	0.0
1950	0.0	0.0	0.0	0.0	0.0
1951	0.2	0.1	0.2	0.2	0.1
1952	1.2	1.2	1.3	1.2	1.1
1953	4.6	4.5	4.8	4.6	4.1
1954	8.9	8.6	9.2	8.8	8.1
1955	12.4	11.9	12.7	12.1	11.3
1956	15.0	14.3	15.4	14.6	13.7
1957	17.1	16.2	17.4	16.5	15.6
1958	18.8	17.7	19.1	18.1	17.2
1959	20.3	19.0	20.6	19.5	18.6
1960	21.9	20.4	22.2	20.9	20.0
1961	23.7	22.0	24.0	22.6	21.8
1962	26.3	24.4	26.6	25.0	24.2
1963	30.6	28.2	31.0	29.0	28.1
1964	39.3	36.0	39.7	37.0	36.1
1965	57.5	52.3	57.9	53.8	52.8
1966	101.6	92.2	102.1	94.6	93.3
1967	167.8	148.1	163.8	151.6	153.2
1968	256.6	221.7	242.9	225.3	233.8
1969	322.5	271.3	293.7	272.9	293.7
1970	359.0	297.7	317.3	295.5	328.8
1971	371.9	311.0	325.1	304.2	345.5
1972	371.1	320.7	328.2	309.6	352.5
1973	360.2	326.3	327.9	312.5	349.8
1974	326.2	305.2	304.7	292.3	321.2
1975	283.1	267.4	268.3	257.6	279.9
1976	219.2	203.1	203.8	195.0	216.6
1977	148.5	131.2	128.9	122.7	146.9
1978	101.2	85.7	82.9	79.0	100.4
1979	67.8	53.6	51.6	49.0	66.8
1980	44.4	32.7	35.8	34.3	44.1
1981	48.5773	39.7859	46.4	44.5	48.7
1982	49.5313	43.9855	51.4	48.7	49.9
1983	39.6824	36.1691	43.1	40.3	40.2
1984	23.1478	21.1712	26.9	25.0	23.7
1985	21.4109	20.0808	25.5	23.9	21.7
1986	26.8208	25.7369	31.4	29.6	26.9
1987	40.2668	39.2561	45.5	43.1	40.1
1988	59.1293	56.9034	63.2	59.7	59.0
1989	70.7535	64.9185	69.9	65.7	70.6
1990	66.3634	57.4888	59.7	56.1	66.7
1991	60.6508	52.844	55.4	51.3	61.2
1992	47.3385	42.778	47.0	43.5	48.0
1993	38.4778	36.3178	40.4	37.8	39.2
1994	30.8891	29.723	32.1	30.2	31.6
1995	22.8559	22.3924	23.5	22.4	23.5
1996	18.5012	17.7947	18.7	17.5	19.1
1997	15.7434	15.0234	15.8	15.0	16.4
1998	13.8585	13.2992	14.2	13.8	14.5
1999	13.7661	13.1456	14.6	14.1	14.3
2000	15.5387	14.7048	16.7	15.9	16.0
2001	19.2094	18.159	20.6	19.4	19.6
2002	23.183	21.9193	24.5	23.2	23.6
2003	28.5593	26.9895	29.9	28.2	28.9
2004	35.8489	33.8038	37.5	35.2	36.1
2005	44.8483	42.3122	47.3	44.1	44.9
2006	50.8531	47.9885	54.0	50.3	50.9
2007	56.6765	53.5437	60.8	56.5	56.4
2008	68.4938	64.4988	72.9	67.4	67.6
2009	72.5499	67.9475	76.2	70.3	71.6
2010	66.8796	62.2956	70.0	64.4	65.9
2011	60.329	56.0701	62.9	57.8	59.3
2012	60.7291	56.302	63.6	58.1	59.4
2013	74.3676	69.1918	79.5	72.3	

Table 15. Comparison of time series of observed and estimated numbers of male crab ≥ 138 mmCW (millions) in the survey from the four alternative 2014 models and the 2013 model.

year	Observed	2014 Model Cases				2013
		Alt0a	Alt0b	Alt1a	Alt1b	Model
1949		0.00	0.00	0.00	0.00	0.00
1950		0.00	0.00	0.00	0.00	0.00
1951		0.00	0.00	0.00	0.00	0.00
1952		0.08	0.09	0.09	0.09	0.07
1953		0.69	0.77	0.77	0.80	0.63
1954		1.88	2.06	2.04	2.12	1.74
1955		2.86	3.10	3.08	3.19	2.66
1956		3.58	3.86	3.85	3.97	3.34
1957		4.13	4.42	4.43	4.55	3.86
1958		4.57	4.86	4.89	5.01	4.27
1959		4.95	5.24	5.28	5.41	4.63
1960		5.31	5.60	5.67	5.79	4.97
1961		5.72	6.01	6.10	6.22	5.36
1962		6.26	6.54	6.67	6.78	5.86
1963		7.07	7.36	7.54	7.64	6.62
1964		8.54	8.86	9.10	9.20	8.00
1965		11.72	12.15	12.52	12.63	11.00
1966		19.02	19.66	20.29	20.43	17.83
1967		35.94	37.08	38.14	38.41	33.72
1968		57.60	57.96	59.23	59.69	53.74
1969		79.29	78.00	79.02	79.65	73.82
1970		88.71	85.19	85.33	86.00	82.52
1971		90.80	86.70	85.41	86.25	85.17
1972		89.85	87.69	84.49	85.85	85.92
1973		87.74	89.68	84.55	86.85	86.17
1974	90.82	83.48	89.34	83.33	86.43	83.64
1975	153.74	72.63	79.27	74.25	77.15	73.24
1976	89.16	60.56	66.31	62.60	64.80	61.01
1977	69.32	43.94	47.98	44.89	46.22	44.20
1978	40.09	24.58	26.58	24.46	24.96	24.73
1979	22.39	14.87	16.09	15.30	15.60	14.88
1980	29.96	13.80	14.41	13.96	14.37	13.69

year	Observed	2014 Model Cases				2013
		Alt0a	Alt0b	Alt1a	Alt1b	Model
1981	10.83	14.30	13.75	14.07	14.66	14.3352
1982	7.75	23.88	23.67	22.59	23.71	23.5424
1983	5.01	21.62	21.66	20.95	21.65	21.4726
1984	6.60	13.97	14.01	14.34	14.61	14.0037
1985	3.71	8.03	8.15	9.11	9.21	8.088
1986	2.44	9.01	9.28	10.16	10.37	8.99951
1987	6.47	12.88	13.68	14.26	14.65	12.7366
1988	16.37	19.98	21.34	21.16	21.84	19.7785
1989	34.04	28.27	29.47	28.32	28.98	27.9265
1990	44.52	32.25	32.49	30.39	30.84	31.9349
1991	36.30	26.95	26.19	24.12	24.25	26.8509
1992	42.44	23.16	22.15	21.47	20.98	23.1869
1993	20.28	15.44	14.78	15.44	14.84	15.5813
1994	15.91	11.09	10.72	11.40	10.88	11.2771
1995	10.17	8.18	7.89	8.27	7.85	8.36462
1996	9.27	6.02	5.86	5.99	5.74	6.17713
1997	3.45	5.00	4.96	5.04	4.78	5.12244
1998	2.16	4.51	4.48	4.52	4.36	4.65216
1999	2.08	4.33	4.37	4.46	4.42	4.46927
2000	4.71	4.76	4.83	4.99	4.98	4.88238
2001	5.98	6.11	6.25	6.35	6.40	6.19705
2002	6.07	7.61	7.82	7.78	7.90	7.71162
2003	6.61	9.14	9.43	9.21	9.42	9.21249
2004	4.77	11.56	11.93	11.54	11.84	11.6134
2005	11.21	14.87	15.36	14.92	15.30	14.8417
2006	14.42	18.19	18.73	18.28	18.68	18.1377
2007	11.97	19.28	19.84	19.67	20.06	19.1568
2008	13.14	23.29	24.06	23.75	24.25	22.9342
2009	7.97	26.72	27.38	26.75	27.19	26.2613
2010	9.40	24.82	25.20	24.74	25.00	24.3725
2011	15.74	22.35	22.56	22.20	22.34	21.9077
2012	8.17	20.62	20.79	20.42	20.49	20.134
2013	9.02	23.98	24.34	24.14	24.21	23.1692
2014	19.55	31.70	32.28	32.56	32.64	

Table 16. Comparison of time series of observed retained catch (1000's t) in the directed fishery and predicted catch from the four alternative 2014 models and the 2013 model.

year	Observed	2014 Model Cases				2013
		Alt0a	Alt0b	Alt1a	Alt1b	Model
1949		0.00	0.00	0.00	0.00	0.00
1950		0.00	0.00	0.00	0.00	0.00
1951		0.00	0.00	0.00	0.00	0.00
1952		0.00	0.01	0.01	0.01	0.00
1953		0.05	0.05	0.05	0.05	0.04
1954		0.13	0.14	0.14	0.14	0.12
1955		0.20	0.22	0.22	0.22	0.18
1956		0.26	0.27	0.28	0.27	0.23
1957		0.30	0.31	0.32	0.31	0.27
1958		0.33	0.34	0.35	0.35	0.30
1959		0.36	0.37	0.38	0.37	0.33
1960		0.38	0.40	0.41	0.40	0.35
1961		0.41	0.42	0.44	0.43	0.38
1962		0.45	0.46	0.48	0.47	0.41
1963		0.51	0.52	0.54	0.52	0.46
1964		0.61	0.62	0.65	0.63	0.56
1965	1.92	1.95	1.95	1.95	1.95	1.95
1966	2.45	2.47	2.47	2.47	2.47	2.47
1967	13.60	13.59	13.59	13.59	13.59	13.59
1968	18.00	18.00	18.00	18.00	18.00	18.00
1969	27.49	27.48	27.49	27.48	27.49	27.48
1970	25.49	25.49	25.49	25.49	25.49	25.49
1971	20.71	20.71	20.71	20.71	20.71	20.71
1972	16.91	16.90	16.90	16.90	16.90	16.90
1973	13.03	13.02	13.02	13.02	13.02	13.02
1974	15.24	15.23	15.23	15.23	15.23	15.23
1975	17.65	17.65	17.65	17.66	17.66	17.65
1976	30.02	30.01	30.01	30.01	30.01	30.01
1977	35.53	35.52	35.52	35.52	35.52	35.52
1978	21.09	21.09	21.09	21.08	21.08	21.09
1979	19.01	18.97	18.96	18.95	18.95	18.97
1980	13.43	13.43	13.44	13.46	13.46	13.43
1981	4.99	5.04	5.06	5.07	5.07	5.04
1982	2.39	2.47	2.47	2.47	2.48	2.47
1983	0.55	0.77	0.77	0.78	0.78	0.78
1984	1.43	1.48	1.48	1.50	1.50	1.49
1985	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00
1987	1.00	1.02	1.01	1.00	1.00	1.02
1988	3.18	3.10	3.08	3.08	3.07	3.10
1989	11.11	11.01	10.99	10.99	10.98	11.01
1990	18.19	18.08	18.06	18.05	18.05	18.08
1991	14.43	14.30	14.30	14.30	14.29	14.30
1992	15.92	15.31	15.08	14.73	14.50	15.32
1993	7.67	7.47	7.26	6.97	6.77	7.48
1994	3.54	3.45	3.33	3.53	3.38	3.46
1995	1.92	1.83	1.68	1.89	1.70	1.84
1996	0.82	0.71	0.40	0.43	0.42	0.77
1997	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.00	0.00	0.00	0.00	0.00	0.00
2004	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.43	0.43	0.42	0.47	0.46	0.43
2006	0.96	0.93	0.86	0.97	0.90	0.94
2007	0.96	1.03	0.91	1.02	0.91	1.04
2008	0.88	0.92	0.89	0.90	0.88	0.92
2009	0.60	0.69	0.69	0.70	0.70	0.69
2010	0.00	0.00	0.00	0.00	0.00	0.00
2011	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.00	0.00	0.00	0.00	0.00	0.00
2013	0.66	0.63	0.61	0.65	0.63	

Table 17. Comparison of time series of observed total male mortality (retained+discards) in the directed fishery (1000's t) with the respective predicted catch from thefour alternative models and the 2013 model. Note that each 2014 model scenario has its own associated "observed" total mortality because the datasets differ between the 0 and 1 scenarios and the assumed handling mortality rates differ between the a's and b's.

year	observed 0a	Alt0a	2013 Model	observed 0b	Alt0b	observed 1a	Alt1a	observed 1b	Alt1b
1949		0.00	0.00		0.00		0.00		0.00
1950		0.00	0.00		0.00		0.00		0.00
1951		0.00	0.00		0.00		0.00		0.00
1952		0.01	0.01		0.02		0.03		0.02
1953		0.09	0.08		0.12		0.14		0.13
1954		0.21	0.19		0.26		0.29		0.27
1955		0.31	0.28		0.38		0.42		0.39
1956		0.39	0.35		0.46		0.51		0.47
1957		0.44	0.40		0.53		0.58		0.54
1958		0.49	0.44		0.58		0.64		0.59
1959		0.53	0.47		0.62		0.69		0.63
1960		0.57	0.51		0.66		0.74		0.68
1961		0.62	0.55		0.71		0.80		0.73
1962		0.68	0.60		0.78		0.88		0.80
1963		0.77	0.69		0.89		1.01		0.92
1964		0.95	0.84		1.10		1.25		1.14
1965		3.17	3.11		3.68		4.03		3.78
1966		4.20	4.11		4.93		5.42		5.07
1967		23.31	22.83		27.16		29.73		27.89
1968		29.78	29.23		34.29		37.27		35.10
1969		43.71	43.02		49.68		53.58		50.72
1970		39.59	39.06		44.79		48.10		45.68
1971		31.75	31.38		35.93		38.51		36.64
1972		25.74	25.45		29.17		31.27		29.79
1973		19.69	19.43		22.23		23.90		22.76
1974		22.82	22.45		25.46		27.44		26.11
1975		26.44	25.96		29.18		31.46		29.90
1976		46.15	45.31		50.67		54.58		51.85
1977		57.98	57.00		63.03		68.33		64.93
1978		37.11	36.53		39.90		44.53		42.40
1979		43.29	42.78		47.18		54.56		51.86
1980		33.22	32.77		39.35		44.48		41.39
1981		8.84	8.65		10.68		11.61		10.75
1982		3.79	3.73		4.32		4.62		4.37
1983		1.08	1.07		1.18		1.27		1.22
1984		2.02	2.00		2.21		2.39		2.31
1985		0.00	0.00		0.00		0.00		0.00
1986		0.00	0.00		0.00		0.00		0.00
1987		1.61	1.59		1.85		1.94		1.84
1988		4.86	4.77		5.52		5.84		5.54
1989		17.88	17.51		20.26		21.45		20.36
1990		29.36	28.82		33.31		35.24		33.78
1991		23.16	23.02		22.78		23.12		23.04
1992	21.42	21.74	21.74	19.45	19.98	19.01	19.80	17.90	18.89
1993	11.08	11.23	11.23	9.86	10.15	9.60	10.09	8.91	9.53
1994	5.10	5.23	5.23	4.54	4.74	5.10	5.18	4.54	4.71
1995	3.30	3.47	3.46	2.81	3.05	3.30	3.44	2.81	3.05
1996	0.94	1.23	1.19	0.90	1.29	0.88	1.27	0.86	1.28
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.57	0.86	0.87	0.52	0.83	0.66	0.90	0.58	0.85
2006	1.58	1.75	1.75	1.36	1.58	1.65	1.78	1.40	1.60
2007	2.01	2.10	2.10	1.63	1.81	1.98	2.08	1.61	1.79
2008	1.10	1.26	1.27	1.02	1.21	1.10	1.29	1.02	1.24
2009	0.64	0.74	0.74	0.63	0.73	0.64	0.74	0.63	0.74
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2013	0.92	1.12		0.83	1.05	0.92	1.12	0.83	1.05

Table 18. Comparison of time series of observed female discard mortality (1000's t) in the directed fishery with the predicted catch from the 2012 assessment model and the two alternative models.

year	observed 0a	Alt0a	2013 Model	observed 0b	Alt0b	observed 1a	Alt1a	observed 1b	Alt1b
1949		0.00	0.00		0.00		0.00		0.00
1950		0.00	0.00		0.00		0.00		0.00
1951		0.00	0.00		0.00		0.00		0.00
1952		0.00	0.00		0.00		0.00		0.00
1953		0.00	0.00		0.00		0.00		0.00
1954		0.01	0.01		0.00		0.00		0.00
1955		0.01	0.01		0.00		0.01		0.00
1956		0.01	0.01		0.01		0.01		0.00
1957		0.01	0.01		0.01		0.01		0.01
1958		0.01	0.01		0.01		0.01		0.01
1959		0.01	0.01		0.01		0.01		0.01
1960		0.01	0.01		0.01		0.01		0.01
1961		0.01	0.01		0.01		0.01		0.01
1962		0.02	0.02		0.01		0.01		0.01
1963		0.02	0.02		0.01		0.01		0.01
1964		0.03	0.03		0.02		0.02		0.01
1965		0.10	0.11		0.06		0.06		0.04
1966		0.15	0.16		0.08		0.09		0.06
1967		0.80	0.86		0.44		0.47		0.34
1968		0.93	1.01		0.53		0.58		0.41
1969		1.27	1.37		0.74		0.82		0.59
1970		1.11	1.19		0.67		0.73		0.53
1971		0.86	0.93		0.53		0.58		0.43
1972		0.67	0.72		0.42		0.47		0.34
1973		0.50	0.53		0.31		0.34		0.25
1974		0.55	0.58		0.34		0.39		0.28
1975		0.64	0.66		0.39		0.45		0.33
1976		1.21	1.25		0.75		0.85		0.62
1977		1.87	1.92		1.18		1.34		1.01
1978		1.62	1.66		1.06		1.23		0.95
1979		3.01	3.17		1.96		2.29		1.81
1980		3.49	3.69		2.55		2.52		1.92
1981		0.70	0.71		0.52		0.50		0.36
1982		0.25	0.25		0.17		0.16		0.11
1983		0.07	0.07		0.04		0.04		0.03
1984		0.17	0.16		0.11		0.09		0.07
1985		0.00	0.00		0.00		0.00		0.00
1986		0.00	0.00		0.00		0.00		0.00
1987		0.08	0.08		0.04		0.04		0.03
1988		0.19	0.20		0.10		0.10		0.07
1989		0.68	0.71		0.37		0.38		0.27
1990		1.21	1.26		0.70		0.74		0.52
1991		1.09	1.11		0.68		0.75		0.52
1992	0.89	1.54	1.56	0.57	1.13	0.50	1.14	0.32	0.89
1993	0.91	0.71	0.72	0.58	0.51	0.51	0.43	0.33	0.33
1994	0.64	0.30	0.29	0.41	0.20	0.64	0.19	0.41	0.15
1995	0.88	0.13	0.13	0.56	0.08	0.88	0.09	0.56	0.06
1996	0.05	0.05	0.05	0.03	0.02	0.02	0.02	0.01	0.01
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01
2006	0.16	0.03	0.03	0.10	0.01	0.18	0.02	0.11	0.01
2007	0.05	0.03	0.03	0.03	0.02	0.05	0.02	0.03	0.01
2008	0.01	0.03	0.03	0.00	0.02	0.01	0.02	0.00	0.01
2009	0.00	0.06	0.06	0.00	0.03	0.00	0.04	0.00	0.02
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2013	0.01	0.02		0.01	0.01	0.01	0.01	0.01	0.01

Table 19. Comparison of the final objective function components for the alternative models Alt0a and Alt0b, which can be compared directly. Component differences greater or less than 2 units are highlighted. Positive differences (red highlighting) indicate better fits with Alt0b. Negative differences (blue highlighting) indicate better fits with Alt0a. Overall, Alt0b fits the data better, with smaller penalties, by 3.60 likelihood units compared with Alt0a.

weight	sigma	Model Case Alt1a	Alt0b	Difference a-b	Component Description
1.0000	1.0000	2.20	2.20	0.00	recruitment penalty
0.0000	NA	0.00	0.00	0.00	sex ratio penalty
1.0000	1.0000	1.17	1.23	-0.06	immatures natural mortality penalty
1.0000	1.0000	1.46	2.44	-0.97	mature male natural mortality penalty
1.0000	1.0000	42.00	38.19	3.81	mature female natural mortality penalty
1.0000	1.0000	4.48	1.85	2.63	survey q penalty
1.0000	1.0000	21.64	16.00	5.63	female survey q penalty
1.0000	1.0000	0.75	0.79	-0.03	prior on female growth parameter a
1.0000	1.0000	0.57	0.61	-0.04	prior on female growth parameter b
1.0000	1.0000	0.05	0.02	0.02	prior on male growth parameter a
1.0000	1.0000	0.01	0.02	0.00	prior on male growth parameter b
1.0000	1.0000	1.23	1.23	0.00	smoothing penalty on female maturity curve
0.5000	1.4142	0.40	0.41	-0.01	smoothing penalty on male maturity curve
0.0000	NA	0.00	0.00	0.00	1st difference penalty on changes in male size at 50% selectivity in directed fishery
1.0000	1.0000	46.63	48.94	-2.32	penalty on F-devs in directed fishery
0.5000	1.4142	10.14	7.99	2.15	penalty on F-devs in snow crab fishery
0.0000	NA	0.00	0.00	0.00	penalty on F-devs in BBRKC fishery
0.5000	1.4142	13.33	13.18	0.14	penalty on F-devs in groundfish fishery
1.0000	1.0000	47.47	52.33	-4.86	likelihood for directed fishery: retained males
1.0000	1.0000	56.95	69.76	-12.81	likelihood for directed fishery: total males
1.0000	1.0000	9.56	10.10	-0.54	likelihood for directed fishery: discarded females
1.0000	1.0000	40.37	40.30	0.08	likelihood for snow crab fishery: discarded males
1.0000	1.0000	13.97	13.04	0.93	likelihood for snow crab fishery: discarded females
1.0000	1.0000	27.66	27.22	0.44	likelihood for BBRKC fishery: discarded males
1.0000	1.0000	1.88	1.91	-0.02	likelihood for BBRKC fishery: discarded females
1.0000	1.0000	94.10	95.75	-1.66	likelihood for groundfish fishery
1.0000	1.0000	301.48	309.24	-7.76	likelihood for survey: immature males
1.0000	1.0000	223.15	220.68	2.47	likelihood for survey: mature males
1.0000	1.0000	253.09	247.51	5.58	likelihood for survey: immature females
1.0000	1.0000	88.72	86.44	2.28	likelihood for survey: mature females
1.0000	1.0000	186.94	187.66	-0.72	likelihood for survey: mature survey biomass
10.0000	0.3162	5.65	12.40	-6.75	likelihood for directed fishery: male retained catch biomass
10.0000	0.3162	4.51	8.97	-4.46	likelihood for directed fishery: male total catch biomass
10.0000	0.3162	11.57	6.02	5.55	likelihood for directed fishery: female catch biomass
10.0000	0.3162	13.19	9.81	3.39	likelihood for snow crab fishery: total catch biomass
10.0000	0.3162	19.27	7.63	11.64	likelihood for BBRKC fishery: total catch biomass
10.0000	0.3162	2.25	2.39	-0.14	likelihood for groundfish fishery: total catch biomass

Table 20. Comparison of the final objective function components for the alternative models Alt1a and Alt1b, which can be compared directly. Component differences greater or less than 2 units are highlighted. Positive differences (red highlighting) indicate better fits with Alt0b. Negative differences (blue highlighting) indicate better fits with Alt0a. Overall, Alt1a fits the data better, with smaller penalties, by 6.06 likelihood units compared with Alt1b.

weight	sigma	Model Case Alt1a	Alt1b	Difference a-b	Description
1.0000	1.0000	2.19	2.20	-0.02	recruitment penalty
0.0000	NA	0.00	0.00	0.00	sex ratio penalty
1.0000	1.0000	0.85	0.92	-0.07	immatures natural mortality penalty
1.0000	1.0000	1.44	2.69	-1.25	mature male natural mortality penalty
1.0000	1.0000	42.70	38.99	3.71	mature female natural mortality penalty
1.0000	1.0000	6.17	3.24	2.94	survey q penalty
1.0000	1.0000	25.70	20.59	5.11	female survey q penalty
1.0000	1.0000	0.90	0.90	0.00	prior on female growth parameter a
1.0000	1.0000	0.72	0.73	-0.01	prior on female growth parameter b
1.0000	1.0000	0.09	0.12	-0.03	prior on male growth parameter a
1.0000	1.0000	0.02	0.03	0.00	prior on male growth parameter b
1.0000	1.0000	1.26	1.25	0.00	smoothing penalty on female maturity curve
0.5000	1.4142	0.43	0.43	-0.01	smoothing penalty on male maturity curve
0.0000	NA	0.00	0.00	0.00	1st difference penalty on changes in male size at 50% selectivity in directed fishery
1.0000	1.0000	49.24	51.45	-2.21	penalty on F-devs in directed fishery
0.5000	1.4142	10.02	7.40	2.62	penalty on F-devs in snow crab fishery
0.0000	NA	0.00	0.00	0.00	penalty on F-devs in BBRKC fishery
0.5000	1.4142	13.12	13.09	0.03	penalty on F-devs in groundfish fishery
1.0000	1.0000	57.82	64.72	-6.90	likelihood for directed fishery: retained males
1.0000	1.0000	93.14	102.11	-8.97	likelihood for directed fishery: total males
1.0000	1.0000	13.53	13.93	-0.40	likelihood for directed fishery: discarded females
1.0000	1.0000	42.42	41.71	0.71	likelihood for snow crab fishery: discarded males
1.0000	1.0000	13.60	12.91	0.69	likelihood for snow crab fishery: discarded females
1.0000	1.0000	22.23	22.48	-0.25	likelihood for BBRKC fishery: discarded males
1.0000	1.0000	1.83	1.93	-0.09	likelihood for BBRKC fishery: discarded females
1.0000	1.0000	150.68	154.55	-3.87	likelihood for groundfish fishery
1.0000	1.0000	289.76	300.72	-10.96	likelihood for survey: immature males
1.0000	1.0000	225.55	220.33	5.22	likelihood for survey: mature males
1.0000	1.0000	259.86	253.73	6.13	likelihood for survey: immature females
1.0000	1.0000	90.58	88.32	2.27	likelihood for survey: mature females
1.0000	1.0000	199.70	201.38	-1.68	likelihood for survey: mature survey biomass
10.0000	0.3162	22.14	32.18	-10.04	likelihood for directed fishery: male retained catch biomass
10.0000	0.3162	12.05	18.83	-6.79	likelihood for directed fishery: male total catch biomass
10.0000	0.3162	12.57	6.54	6.04	likelihood for directed fishery: female catch biomass
10.0000	0.3162	13.79	15.75	-1.96	likelihood for snow crab fishery: total catch biomass
10.0000	0.3162	24.05	9.93	14.12	likelihood for BBRKC fishery: total catch biomass
10.0000	0.3162	2.07	2.19	-0.13	likelihood for groundfish fishery: total catch biomass

Table 21. Estimated population size (thousands) for females on July 1 of year. from the author's preferred model (Alt1a).

year	Size bin 27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5	147.5	152.5	157.5	162.5	167.5	172.5	177.5	182.5
1975	3.34E+04	7.64E+04	6.29E+04	4.63E+04	3.84E+04	4.04E+04	4.40E+04	5.09E+04	7.75E+04	1.25E+05	1.43E+05	1.31E+05	1.13E+05	8.36E+04	5.32E+04	2.62E+04	7.60E+03	1.19E+03	1.72E+02	2.56E+01	2.57E+00	1.79E-01	1.52E-02	3.05E-03	9.00E-04	2.78E-04	8.61E-05	2.66E-05	8.17E-06	2.50E-06	7.79E-07	2.99E-07
1976	7.58E+04	1.75E+05	1.49E+05	1.13E+05	7.59E+04	4.94E+04	3.55E+04	3.54E+04	5.82E+04	1.02E+05	1.20E+05	1.11E+05	9.66E+04	7.23E+04	4.62E+04	2.27E+04	6.58E+03	1.03E+03	1.48E+02	2.21E+01	2.21E+00	1.57E-01	1.41E-02	2.98E-03	8.87E-04	2.75E-04	8.51E-05	2.63E-05	8.10E-06	2.48E-06	7.72E-07	2.97E-07
1977	4.66E+04	1.15E+05	1.29E+05	1.44E+05	1.24E+05	9.51E+04	6.99E+04	5.32E+04	5.76E+04	8.49E+04	9.73E+04	9.02E+04	8.00E+04	6.06E+04	3.88E+04	1.90E+04	5.42E+03	8.24E+02	1.16E+02	1.69E+01	1.69E+00	1.31E-01	1.54E-02	3.72E-03	1.11E-03	3.41E-04	1.05E-04	3.23E-05	9.93E-06	3.04E-06	9.46E-07	3.64E-07
1978	3.96E+04	9.52E+04	9.80E+04	1.04E+05	1.00E+05	1.00E+05	9.45E+04	8.41E+04	8.39E+04	9.77E+04	9.70E+04	8.20E+04	6.81E+04	4.98E+04	3.12E+04	1.49E+04	4.09E+03	5.88E+02	7.82E+01	1.08E+01	1.05E+00	8.24E-02	1.02E-02	2.44E-03	7.06E-04	2.11E-04	6.38E-05	1.95E-05	5.94E-06	1.81E-06	5.63E-07	2.16E-07
1979	9.71E+03	2.71E+04	4.29E+04	6.48E+04	6.91E+04	7.04E+04	7.08E+04	7.43E+04	9.02E+04	1.13E+05	1.13E+05	9.21E+04	7.05E+04	4.77E+04	2.81E+04	1.26E+04	3.27E+03	4.40E+02	5.34E+01	6.87E+00	6.49E-01	5.26E-02	6.90E-03	1.65E-03	4.67E-04	1.36E-04	4.06E-05	1.23E-05	3.73E-06	1.13E-06	3.52E-07	1.35E-07
1980	3.75E+03	9.73E+03	1.31E+04	1.96E+04	2.74E+04	3.83E+04	4.58E+04	5.28E+04	7.20E+04	1.03E+05	1.10E+05	9.56E+04	7.55E+04	5.08E+04	2.91E+04	1.25E+04	3.06E+03	3.91E+02	4.23E+01	4.93E+00	4.36E-01	2.83E-02	2.14E-03	3.48E-04	8.68E-05	2.39E-05	6.87E-06	2.03E-06	6.10E-07	1.85E-07	5.70E-08	2.18E-08
1981	8.85E+03	2.04E+04	1.74E+04	1.38E+04	1.19E+04	1.31E+04	1.70E+04	2.62E+04	4.87E+04	8.25E+04	9.44E+04	8.47E+04	6.96E+04	4.84E+04	2.83E+04	1.22E+04	3.03E+03	3.99E+02	4.71E+01	6.13E+00	5.71E-01	3.45E-02	1.61E-03	1.14E-04	2.04E-05	5.17E-06	1.43E-06	4.15E-07	1.23E-07	3.69E-08	1.13E-08	4.25E-09
1982	4.40E+03	1.11E+04	1.33E+04	1.59E+04	1.40E+04	1.12E+04	9.65E+03	1.23E+04	2.77E+04	5.66E+04	7.07E+04	6.72E+04	5.89E+04	4.30E+04	2.61E+04	1.19E+04	3.10E+03	4.39E+02	5.85E+01	8.39E+00	8.19E-01	5.20E-02	2.90E-03	3.41E-04	8.67E-05	2.57E-05	7.80E-06	2.38E-06	7.26E-07	2.21E-07	6.85E-08	2.62E-08
1983	3.15E+04	7.13E+04	5.58E+04	3.50E+04	2.15E+04	1.55E+04	1.26E+04	1.25E+04	2.14E+04	4.11E+04	5.10E+04	4.89E+04	4.45E+04	3.40E+04	2.15E+04	1.02E+04	2.78E+03	4.11E+02	5.91E+01	8.92E+00	8.90E-01	5.71E-02	3.22E-03	3.91E-04	1.03E-04	3.11E-05	9.55E-06	2.94E-06	9.01E-07	2.76E-07	8.56E-08	3.26E-08
1984	2.59E+04	6.24E+04	6.43E+04	6.50E+04	5.08E+04	3.42E+04	2.21E+04	1.67E+04	2.11E+04	3.45E+04	4.04E+04	3.75E+04	3.36E+04	2.56E+04	1.63E+04	7.80E+03	2.17E+03	3.29E+02	5.00E+01	7.87E+00	8.19E-01	6.09E-02	6.11E-03	1.40E-03	4.29E-04	1.35E-04	4.24E-05	1.32E-05	4.09E-06	1.26E-06	3.92E-07	1.51E-07
1985	5.02E+04	1.16E+05	1.02E+05	8.21E+04	6.34E+04	5.24E+04	4.32E+04	3.42E+04	3.11E+04	3.59E+04	3.66E+04	3.18E+04	2.71E+04	2.01E+04	1.25E+04	5.94E+03	1.64E+03	2.47E+02	3.69E+01	5.74E+00	6.05E-01	5.02E-02	6.62E-03	1.72E-03	5.33E-04	1.68E-04	5.25E-05	1.63E-05	5.05E-06	1.55E-06	4.84E-07	1.86E-07
1986	4.21E+04	1.01E+05	1.04E+05	1.06E+05	8.79E+04	6.85E+04	5.36E+04	4.47E+04	4.40E+04	4.83E+04	4.50E+04	3.56E+04	2.69E+04	1.83E+04	1.09E+04	5.08E+03	1.40E+03	2.11E+02	3.11E+01	4.83E+00	5.36E-01	5.53E-02	1.02E-02	2.95E-03	9.34E-04	2.96E-04	9.29E-05	2.90E-05	8.97E-06	2.76E-06	8.61E-07	3.32E-07
1987	3.96E+04	9.45E+04	9.47E+04	9.53E+04	8.54E+04	7.80E+04	6.92E+04	5.95E+04	5.61E+04	5.92E+04	5.48E+04	4.36E+04	3.23E+04	2.11E+04	1.22E+04	5.48E+03	1.49E+03	2.24E+02	3.10E+01	4.61E+00	5.17E-01	5.79E-02	1.17E-02	3.46E-03	1.10E-03	3.47E-04	1.09E-04	3.40E-05	1.05E-05	3.22E-06	1.00E-06	3.86E-07
1988	3.54E+04	8.50E+04	8.60E+04	8.76E+04	7.79E+04	7.04E+04	6.45E+04	6.10E+04	6.52E+04	7.35E+04	6.88E+04	5.42E+04	3.94E+04	2.55E+04	1.47E+04	6.69E+03	1.85E+03	2.81E+02	3.79E+01	5.47E+00	5.97E-01	6.29E-02	1.20E-02	3.49E-03	1.10E-03	3.46E-04	1.08E-04	3.36E-05	1.04E-05	3.18E-06	9.90E-07	3.80E-07
1989	1.56E+04	3.97E+04	4.99E+04	6.40E+04	6.37E+04	6.15E+04	5.80E+04	5.58E+04	6.28E+04	7.70E+04	7.67E+04	6.34E+04	4.79E+04	3.15E+04	1.83E+04	8.37E+03	2.32E+03	3.54E+02	4.74E+01	6.77E+00	7.17E-01	6.82E-02	1.14E-02	3.20E-03	9.98E-04	3.12E-04	9.72E-05	3.01E-05	9.27E-06	2.84E-06	8.83E-07	3.39E-07
1990	6.90E+03	1.76E+04	2.22E+04	2.98E+04	3.44E+04	4.05E+04	4.40E+04	4.68E+04	5.77E+04	7.57E+04	7.79E+04	6.60E+04	5.16E+04	3.51E+04	2.09E+04	9.71E+03	2.71E+03	4.09E+02	5.42E+01	7.57E+00	7.58E-01	5.99E-02	7.36E-03	1.82E-03	5.50E-04	1.69E-04	5.22E-05	1.60E-05	4.92E-06	1.50E-06	4.66E-07	1.79E-07
1991	3.22E+03	8.15E+03	1.01E+04	1.33E+04	1.53E+04	1.86E+04	2.22E+04	2.84E+04	4.39E+04	6.67E+04	7.29E+04	6.37E+04	5.12E+04	3.54E+04	2.12E+04	9.83E+03	2.69E+03	3.95E+02	5.16E+01	7.10E+00	6.83E-01	4.65E-02	3.79E-03	7.20E-04	2.04E-04	6.11E-05	1.85E-05	5.63E-06	1.71E-06	5.22E-07	1.61E-07	6.17E-08
1992	2.73E+03	6.56E+03	6.76E+03	7.28E+03	7.52E+03	8.59E+03	1.02E+04	1.43E+04	2.75E+04	4.98E+04	5.91E+04	5.44E+04	4.61E+04	3.30E+04	2.01E+04	9.32E+03	2.52E+03	3.64E+02	4.71E+01	6.44E+00	6.09E-01	3.84E-02	2.31E-03	3.08E-04	7.96E-05	2.33E-05	6.96E-06	2.10E-06	6.35E-07	1.93E-07	5.94E-08	2.27E-08
1993	2.27E+03	5.47E+03	5.64E+03	5.89E+03	5.40E+03	5.18E+03	5.45E+03	7.79E+03	1.75E+04	3.53E+04	4.35E+04	4.09E+04	3.60E+04	2.65E+04	1.63E+04	7.46E+03	1.95E+03	2.66E+02	3.38E+01	4.57E+00	4.26E-01	2.59E-02	1.29E-03	1.16E-04	2.51E-05	6.93E-06	2.01E-06	5.94E-07	1.78E-07	5.35E-08	1.65E-08	6.25E-09
1994	2.59E+03	6.14E+03	5.88E+03	5.55E+03	4.80E+03	4.37E+03	4.23E+03	5.48E+03	1.23E+04	2.55E+04	3.17E+04	3.00E+04	2.69E+04	2.01E+04	1.24E+04	5.70E+03	1.48E+03	2.02E+02	2.67E+01	3.77E+00	3.57E-01	2.20E-02	1.12E-03	1.08E-04	2.49E-05	7.10E-06	2.10E-06	6.28E-07	1.90E-07	5.75E-08	1.77E-08	6.75E-09
1995	3.77E+03	8.83E+03	8.06E+03	6.99E+03	5.52E+03	4.50E+03	3.95E+03	4.61E+03	9.49E+03	1.91E+04	2.35E+04	2.21E+04	1.98E+04	1.49E+04	9.16E+03	4.20E+03	1.08E+03	1.47E+02	1.98E+01	2.82E+00	2.69E-01	1.70E-02	9.95E-04	1.30E-04	3.39E-05	1.00E-05	3.04E-06	9.24E-07	2.82E-07	8.58E-08	2.66E-08	1.02E-08
1996	3.65E+03	8.70E+03	8.63E+03	8.44E+03	7.00E+03	5.65E+03	4.66E+03	4.66E+03	7.94E+03	1.49E+04	1.79E+04	1.67E+04	1.48E+04	1.10E+04	6.73E+03	3.06E+03	7.87E+02	1.07E+02	1.43E+01	2.04E+00	1.95E-01	1.30E-02	1.00E-03	1.85E-04	5.32E-05	1.62E-05	4.97E-06	1.53E-06	4.68E-07	1.43E-07	4.44E-08	1.70E-08
1997	9.85E+03	2.26E+04	1.90E+04	1.40E+04	9.82E+03	7.44E+03	6.02E+03	5.53E+03	7.63E+03	1.25E+04	1.45E+04	1.31E+04	1.14E+04	8.45E+03	5.16E+03	2.36E+03	6.11E+02	8.42E+01	1.14E+01	1.64E+00	1.60E-01	1.15E-02	1.12E-03	2.51E-04	7.55E-05	2.34E-05	7.28E-06	2.25E-06	6.93E-07	2.13E-07	6.61E-08	2.53E-08
1998	3.89E+03	1.01E+04	1.31E+04	1.68E+04	1.49E+04	1.16E+04	8.69E+03	7.11E+03	8.19E+03	1.16E+04	1.26E+04	1.10E+04	9.15E+03	6.57E+03	3.98E+03	1.82E+03	4.78E+02	6.73E+01	9.29E+00	1.36E+00	1.40E-01	1.22E-02	1.83E-03	5.04E-04	1.58E-04	5.00E-05	1.57E-05	4.88E-06	1.51E-06	4.62E-07	1.44E-07	5.52E-08
1999	1.21E+04	2.78E+04	2.30E+04	1.70E+04	1.32E+04	1.24E+04	1.16E+04	1.04E+04	1.06E+04	1.25E+04	1.23E+04	1.02E+04	8.05E+03	5.59E+03	3.34E+03	1.52E+03	4.06E+02	5.86E+01	8.07E+00	1.18E+00	1.22E-01	1.09E-02	1.69E-03	4.70E-04	1.48E-04	4.67E-05	1.46E-05	4.55E-06	1.40E-06	4.30E-07	1.34E-07	5.12E-08
2000	7.38E+03	1.82E+04	2.05E+04	2.29E+04	1.93E+04	1.45E+04	1.12E+04	9.95E+03	1.14E+04	1.43E+04	1.41E+04	1.13E+04	8.47E+03	5.63E+03	3.28E+03	1.49E+03	4.05E+02	5.99E+01	8.25E+00	1.21E+00	1.32E-01	1.38E-02	2.60E-03	7.67E-04	2.44E-04	7.74E-05	2.43E-05	7.59E-06	2.35E-06	7.22E-07	2.25E-07	8.64E-08
2001	2.28E+04	5.23E+04	4.33E+04	3.14E+04	2.28E+04	1.88E+04	1.60E+04	1.35E+04	1.30E+04	1.48E+04	1.46E+04	1.21E+04	9.36E+03	6.32E+03	3.72E+03	1.70E+03	4.68E+02	7.05E+01	9.57E+00	1.39E+00	1.50E-01	1.52E-02	2.79E-03	8.14E-04	2.59E-04	8.20E-05	2.58E-05	8.04E-06	2.49E-06	7.64E-07	2.38E-07	9.13E-08
2002	9.45E+03	2.43E+04	3.11E+04	3.92E+04	3.45E+04	2.64E+04	1.97E+04	1.61E+04	1.61E+04	1.82E+04	1.72E+04	1.37E+04	1.02E+04	6.82E+03	4.06E+03	1.90E+03	5.40E+02	8.40E+01	1.18E+01	1.77E+00	2.01E-01	2.28E-02	4.65E-03	1.40E-03	4.46E-04	1.42E-04	4.46E-05	1.39E-05	4.31E-06	1.32E-06	4.12E-07	1.59E-07
2003	1.69E+04	3.93E+04	3.49E+04	2.98E+04	2.66E+04	2.71E+04	2.62E+04	2.31E+04	2.15E+04	2.23E+04	2.04E+04	1.62E+04	1.21E+04	8.00E+03	4.70E+03	2.18E+03	6.18E+02	9.65E+01	1.36E+01	2.04E+00	2.27E-01	2.39E-02	4.51E-03	1.33E-03	4.23E-04	1.34E-04	4.23E-05	1.32E-05	4.08E-06	1.25E-06	3.90E-07	1.50E-07
2004	3.08E+04	7.16E+04	6.31E+04	5.10E+04	3.69E+04	2.70E+04	2.17E+04	2.06E+04	2.36E+04	2.79E+04	2.64E+04	2.07E+04	1.50E+04	9.68E+03	5.65E+03	2.63E+03	7.49E+02	1.18E+02	1.66E+01	2.47E+00	2.74E-01	2.86E-02	5.34E-03	1.57E-03	5.01E-04	1.59E-04	5.02E-05	1.57E-05	4.85E-06	1.49E-06	4.65E-07	1.79E-07
2005	9.48E+03	2.54E+04	3.65E+04	5.06E+04	4.76E+04	3.97E+04	3.14E+04	2.50E+04	2.40E+04	2.79E+04	2.79E+04	2.35E+04	1.82E+04	1.22E+04	7.21E+03	3.35E+03	9.52E+02	1.49E+02	2.08E+01	3.09E+00	3.48E-01	3.82E-02	7.53E-03	2.25E-03	7.18E-04	2.29E-04	7.22E-05	2.26E-05	6.99E-06	2.15E-06	6.72E-07	2.59E-07
2006	7.87E+03	1.90E+04	1.98E+04	2.23E+04	2.57E+04	3.16E+04	3.38E+04	3.24E+04	3.25E+04	3.51E+04	3.25E+04	2.59E+04	1.97E+04	1.34E+04	8.12E+03	3.90E+03	1.13E+03	1.81E+02	2.57E+01	3.84E+00	4.16E-01	3.96E-02	6.60E-03	1.89E-03	5.99E-04	1.91E-04	6.01E-05	1.88E-05	5.81E-06	1.79E-06	5.57E-07	2.15E-07
2007	5.56E+03	1.35E+04	1.46E+04	1.62E+04	1.54E+04	1.54E+04	1.69E+04	2.10E+04	2.93E+04	3.89E+04	3.91E+04	3.19E+04	2.37E+04	1.56E+04	9.20E+03	4.32E+03	1.24E+03	1.97E+02	2.81E+01	4.22E+00	4.49E-01	3.91E-02	5.68E-03	1.55E-03	4.88E-04	1.55E-04	4.88E-05	1.52E-05	4.71E-06	1.45E-06	4.52E-07	1.74E-07
2008	6.44E+03	1.52E+04	1.46E+04	1.38E+04	1.23E+04	1.17E+04	1.14E+04	1.25E+04	1.88E+04	3.04E+04	3.48E+04	3.16E+04	2.59E+04	1.80E+04	1.09E+04	5.17E+03	1.48E+03	2.33E+02	3.24E+01	4.74E+00	4.90E-01	3.91E-02	4.84E-03	1.24E-03	3.89E-04	1.23E-04	3.87E-05	1.21E-05	3.73E-06	1.15E-06	3.58E-07	1.38E-07
2009	3.44E+04	7.81E+04	6.20E+04	4.00E+04	2.41E+04	1.56E+04	1.15E+04	1.07E+04	1.52E+04	2.46E+04	2.85E+04	2.62E+04	2.27E+04	1.69E+04	1.08E+04	5.37E+03	1.59E+03	2.56E+02	3.72E+01	5.60E+00	5.78E-01	4.35E-02	4.63E-03	1.10E-03	3.42E-04	1.08E-04	3.40E-05	1.06E-05	3.28E-06	1.01E-06	3.14E-07	1.21E-07
2010	3.63E+04	8.63E+04	8.38E+04	7.85E+04	5.94E+04	3.98E+04	2.54E+04	1.73E+04	1.67E+04	2.24E+04	2.47E+04	2.23E+04	1.93E+04	1.45E+04	9.35E+03	4.69E+03	1.40E+03	2.28E+02	3.48E+01	5.46E+00	5.88E-01	5.11E-02	7.26E-03	1.96E-03	6.15E-04	1.95E-04	6.13E-05	1.91E-05	5.93E-06	1.83E-06	5.70E-07	2.20E-07
2011	1.83E+04	4.60E+04	5.51E+04	6.73E+04	6.41E+04	5.79E+04	4.89E+04	3.84E+04	3.16E+04	3.04E+04	2.73E+04	2.20E+04	1.76E+04	1.27E+04	8.06E+03	4.01E+03	1.20E+03	1.96E+02	3.04E+01	4.85E+00	5.43E-01	5.40E-02	9.39E-03	2.71E-03	8.60E-04	2.74E-04	8.63E-05	2.70E-05	8.37E-06	2.58E-06	8.05E-07	3.11E-07
2012	3.72E+03	1.08E+04	1.87E+04	3.07E+04	3.68E+04	4.28E+04	4.51E+04	4.44E+04	4.56E+04	4.73E+04	4.15E+04	3.09E+04	2.16E+04	1.38E+04	8.03E+03	3.80E+03	1.10E+03	1.78E+02	2.67E+01	4.19E+00	4.72E-01	4.82E-02	8.71E-03	2.54E-03	8.08E-04	2.57E-04	8.11E-05	2.53E-05	7.86E-06	2.42E-06	7.56E-07	2.92E-07
2013	1.00E+04	2.31E+04	1.95E+04	1.56E+04	1.53E+04	1.92E+04	2.36E+04	2.91E+04	3.91E+04	5.08E+04	5.08E+04	4.14E+04	3.02E+04	1.92E+04	1.09E+04	4.95E+03	1.38E+03	2.15E+02	2.95E+01	4.30E+00	4.60E-01	4.26E-02	6.84E-03	1.93E-03	6.12E-04	1.94E-04	6.13E-05	1.91E-05	5.93E-06	1.83E-06	5.70E-07	2.20E-07
2014	1.53E+04	3.57E+04	3.24E+04	2.73E+04	2.00E+04	1.44E+04	1.20E+04	1.42E+04	2.41E+04	4.01E+04	4.59E+04	4.14E+04	3.36E+04	2.32E+04	1.40E+04	6.61E+03	1.89E+03	2.97E+02	4.04E+01	5.79E+00	5.97E-01	4.90E-02	6.46E-03	1.71E-03	5.37E-04	1.71E-04	5.37E-05	1.68E-05	5.19E-06	1.60E-06	5.00E-07	1.93E-07

Table 22. Estimated population size (thousands) for males on July 1 of year. from the author's preferred model (Alt1a).

year	Size bin 27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5
1975	3.34E+04	7.60E+04	6.17E+04	4.26E+04	3.11E+04	2.81E+04	3.04E+04	3.16E+04	3.20E+04	3.27E+04	3.43E+04	3.60E+04	3.82E+04	4.34E+04	4.82E+04	5.17E+04
1976	7.58E+04	1.73E+05	1.46E+05	1.06E+05	7.07E+04	4.68E+04	3.17E+04	2.36E+04	2.05E+04	2.07E+04	2.33E+04	2.64E+04	2.98E+04	3.55E+04	4.06E+04	4.42E+04
1977	4.66E+04	1.12E+05	1.21E+05	1.28E+05	1.10E+05	8.82E+04	6.79E+04	5.06E+04	3.80E+04	2.96E+04	2.48E+04	2.28E+04	2.31E+04	2.70E+04	3.12E+04	3.47E+04
1978	3.96E+04	9.32E+04	9.28E+04	9.08E+04	8.21E+04	7.72E+04	7.63E+04	6.99E+04	6.11E+04	5.26E+04	4.53E+04	3.93E+04	3.49E+04	3.38E+04	3.34E+04	3.28E+04
1979	9.71E+03	2.54E+04	3.87E+04	5.48E+04	5.67E+04	5.50E+04	5.39E+04	5.12E+04	4.90E+04	4.84E+04	4.89E+04	4.82E+04	4.66E+04	4.60E+04	4.46E+04	4.20E+04
1980	3.75E+03	9.30E+03	1.18E+04	1.58E+04	1.94E+04	2.45E+04	3.10E+04	3.37E+04	3.45E+04	3.50E+04	3.60E+04	3.69E+04	3.77E+04	4.01E+04	4.17E+04	4.14E+04
1981	8.85E+03	2.02E+04	1.70E+04	1.26E+04	9.61E+03	8.79E+03	9.75E+03	1.15E+04	1.39E+04	1.69E+04	2.04E+04	2.31E+04	2.49E+04	2.71E+04	2.82E+04	2.81E+04
1982	4.40E+03	1.07E+04	1.24E+04	1.40E+04	1.24E+04	1.01E+04	8.05E+03	6.69E+03	6.21E+03	6.50E+03	7.58E+03	9.10E+03	1.08E+04	1.33E+04	1.55E+04	1.69E+04
1983	3.15E+04	7.11E+04	5.53E+04	3.37E+04	1.96E+04	1.27E+04	1.01E+04	8.56E+03	7.38E+03	6.50E+03	5.98E+03	5.80E+03	5.94E+03	6.74E+03	7.63E+03	8.40E+03
1984	2.59E+04	6.10E+04	6.12E+04	5.86E+04	4.68E+04	3.42E+04	2.31E+04	1.52E+04	1.05E+04	7.98E+03	6.86E+03	6.30E+03	5.97E+03	6.01E+03	6.08E+03	6.08E+03
1985	5.02E+04	1.15E+05	9.89E+04	7.55E+04	5.54E+04	4.36E+04	3.75E+04	3.11E+04	2.49E+04	1.95E+04	1.48E+04	1.12E+04	8.66E+03	7.17E+03	6.30E+03	5.78E+03
1986	4.21E+04	9.91E+04	9.89E+04	9.50E+04	7.84E+04	6.20E+04	4.86E+04	3.79E+04	3.06E+04	2.60E+04	2.31E+04	2.05E+04	1.78E+04	1.55E+04	1.33E+04	1.13E+04
1987	3.96E+04	9.27E+04	9.02E+04	8.47E+04	7.25E+04	6.34E+04	5.81E+04	5.06E+04	4.28E+04	3.62E+04	3.07E+04	2.61E+04	2.25E+04	2.02E+04	1.84E+04	1.69E+04
1988	3.54E+04	8.32E+04	8.18E+04	7.78E+04	6.65E+04	5.76E+04	5.22E+04	4.64E+04	4.16E+04	3.83E+04	3.61E+04	3.35E+04	3.06E+04	2.81E+04	2.57E+04	2.33E+04
1989	1.56E+04	3.81E+04	4.61E+04	5.52E+04	5.32E+04	4.95E+04	4.67E+04	4.23E+04	3.81E+04	3.51E+04	3.34E+04	3.17E+04	3.01E+04	2.94E+04	2.87E+04	2.77E+04
1990	6.90E+03	1.69E+04	2.04E+04	2.50E+04	2.66E+04	2.87E+04	3.20E+04	3.24E+04	3.15E+04	3.06E+04	3.02E+04	2.95E+04	2.84E+04	2.82E+04	2.79E+04	2.74E+04
1991	3.22E+03	7.85E+03	9.31E+03	1.12E+04	1.18E+04	1.28E+04	1.46E+04	1.60E+04	1.73E+04	1.91E+04	2.13E+04	2.28E+04	2.35E+04	2.44E+04	2.49E+04	2.49E+04
1992	2.73E+03	6.42E+03	6.40E+03	6.32E+03	5.96E+03	6.04E+03	6.69E+03	7.37E+03	8.23E+03	9.42E+03	1.11E+04	1.29E+04	1.43E+04	1.61E+04	1.77E+04	1.90E+04
1993	2.27E+03	5.35E+03	5.35E+03	5.21E+03	4.56E+03	4.07E+03	3.91E+03	4.01E+03	4.38E+03	5.05E+03	6.16E+03	7.38E+03	8.29E+03	9.48E+03	1.07E+04	1.18E+04
1994	2.59E+03	6.04E+03	5.64E+03	4.98E+03	4.10E+03	3.52E+03	3.27E+03	3.17E+03	3.26E+03	3.54E+03	4.17E+03	4.91E+03	5.39E+03	6.04E+03	6.77E+03	7.56E+03
1995	3.77E+03	8.71E+03	7.79E+03	6.38E+03	4.86E+03	3.82E+03	3.23E+03	2.91E+03	2.83E+03	2.96E+03	3.39E+03	3.88E+03	4.11E+03	4.43E+03	4.83E+03	5.31E+03
1996	3.65E+03	8.53E+03	8.24E+03	7.58E+03	6.17E+03	4.96E+03	4.07E+03	3.43E+03	3.05E+03	2.93E+03	3.09E+03	3.34E+03	3.38E+03	3.49E+03	3.69E+03	3.96E+03
1997	9.85E+03	2.25E+04	1.86E+04	1.31E+04	8.79E+03	6.34E+03	5.09E+03	4.26E+03	3.71E+03	3.39E+03	3.30E+03	3.29E+03	3.15E+03	3.10E+03	3.14E+03	3.25E+03
1998	3.89E+03	9.62E+03	1.21E+04	1.46E+04	1.33E+04	1.08E+04	8.33E+03	6.28E+03	4.94E+03	4.17E+03	3.85E+03	3.68E+03	3.44E+03	3.30E+03	3.22E+03	3.20E+03
1999	1.21E+04	2.76E+04	2.26E+04	1.57E+04	1.11E+04	9.31E+03	9.11E+03	8.49E+03	7.55E+03	6.58E+03	5.73E+03	5.00E+03	4.33E+03	3.91E+03	3.62E+03	3.44E+03
2000	7.38E+03	1.77E+04	1.92E+04	2.04E+04	1.74E+04	1.36E+04	1.02E+04	7.84E+03	6.52E+03	6.02E+03	6.02E+03	5.97E+03	5.69E+03	5.41E+03	5.05E+03	4.68E+03
2001	2.28E+04	5.20E+04	4.25E+04	2.93E+04	1.99E+04	1.51E+04	1.33E+04	1.15E+04	9.74E+03	8.19E+03	6.96E+03	6.03E+03	5.38E+03	5.14E+03	5.06E+03	5.03E+03
2002	9.45E+03	2.33E+04	2.87E+04	3.43E+04	3.09E+04	2.48E+04	1.88E+04	1.40E+04	1.10E+04	9.39E+03	8.62E+03	8.02E+03	7.39E+03	6.94E+03	6.47E+03	6.01E+03
2003	1.69E+04	3.89E+04	3.38E+04	2.68E+04	2.17E+04	2.00E+04	2.06E+04	1.93E+04	1.70E+04	1.45E+04	1.22E+04	1.03E+04	8.84E+03	8.08E+03	7.61E+03	7.26E+03
2004	3.08E+04	7.09E+04	6.13E+04	4.71E+04	3.35E+04	2.42E+04	1.84E+04	1.48E+04	1.31E+04	1.27E+04	1.29E+04	1.28E+04	1.22E+04	1.17E+04	1.10E+04	1.01E+04
2005	9.48E+03	2.41E+04	3.33E+04	4.37E+04	4.16E+04	3.56E+04	2.92E+04	2.29E+04	1.80E+04	1.46E+04	1.24E+04	1.10E+04	1.03E+04	1.04E+04	1.07E+04	1.09E+04
2006	7.87E+03	1.85E+04	1.86E+04	1.89E+04	1.94E+04	2.16E+04	2.51E+04	2.52E+04	2.34E+04	2.10E+04	1.87E+04	1.63E+04	1.43E+04	1.32E+04	1.24E+04	1.17E+04
2007	5.56E+03	1.32E+04	1.38E+04	1.42E+04	1.28E+04	1.18E+04	1.16E+04	1.18E+04	1.27E+04	1.41E+04	1.57E+04	1.66E+04	1.67E+04	1.68E+04	1.65E+04	1.57E+04
2008	6.44E+03	1.50E+04	1.39E+04	1.23E+04	1.03E+04	9.11E+03	8.72E+03	8.25E+03	7.92E+03	7.91E+03	8.36E+03	9.09E+03	1.01E+04	1.18E+04	1.34E+04	1.44E+04
2009	3.44E+04	7.78E+04	6.13E+04	3.85E+04	2.25E+04	1.38E+04	9.70E+03	7.59E+03	6.62E+03	6.32E+03	6.54E+03	6.94E+03	7.51E+03	8.75E+03	9.93E+03	1.08E+04
2010	3.63E+04	8.48E+04	8.04E+04	7.14E+04	5.48E+04	3.94E+04	2.67E+04	1.77E+04	1.21E+04	8.89E+03	7.34E+03	6.72E+03	6.71E+03	7.58E+03	8.51E+03	9.27E+03
2011	1.83E+04	4.44E+04	5.13E+04	5.85E+04	5.45E+04	4.86E+04	4.34E+04	3.62E+04	2.91E+04	2.28E+04	1.78E+04	1.39E+04	1.13E+04	1.02E+04	9.69E+03	9.47E+03
2012	3.72E+03	1.00E+04	1.66E+04	2.52E+04	2.85E+04	3.09E+04	3.38E+04	3.32E+04	3.12E+04	2.90E+04	2.70E+04	2.45E+04	2.18E+04	1.97E+04	1.77E+04	1.57E+04
2013	1.00E+04	2.29E+04	1.90E+04	1.40E+04	1.16E+04	1.22E+04	1.49E+04	1.68E+04	1.82E+04	1.97E+04	2.13E+04	2.20E+04	2.21E+04	2.25E+04	2.23E+04	2.16E+04
2014	1.53E+04	3.53E+04	3.13E+04	2.52E+04	1.83E+04	1.31E+04	9.73E+03	8.11E+03	7.96E+03	8.86E+03	1.06E+04	1.23E+04	1.40E+04	1.64E+04	1.83E+04	1.96E+04

year	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5	147.5	152.5	157.5	162.5	167.5	172.5	177.5	182.5
1975	5.31E+04	5.58E+04	5.64E+04	5.74E+04	5.39E+04	4.85E+04	4.10E+04	3.47E+04	2.84E+04	2.20E+04	1.56E+04	9.77E+03	5.12E+03	2.02E+03	4.58E+02	1.64E+01
1976	4.57E+04	4.82E+04	4.86E+04	4.92E+04	4.60E+04	4.11E+04	3.46E+04	2.92E+04	2.39E+04	1.86E+04	1.32E+04	8.25E+03	4.34E+03	1.71E+03	3.89E+02	1.49E+01
1977	3.63E+04	3.86E+04	3.87E+04	3.84E+04	3.50E+04	3.06E+04	2.53E+04	2.11E+04	1.72E+04	1.32E+04	9.35E+03	5.81E+03	3.04E+03	1.20E+03	2.70E+02	1.03E+01
1978	3.12E+04	3.04E+04	2.81E+04	2.58E+04	2.17E+04	1.79E+04	1.42E+04	1.16E+04	9.34E+03	7.14E+03	5.01E+03	3.09E+03	1.60E+03	6.26E+02	1.41E+02	5.00E+00
1979	3.79E+04	3.39E+04	2.86E+04	2.34E+04	1.80E+04	1.36E+04	1.01E+04	7.73E+03	5.83E+03	4.21E+03	2.82E+03	1.68E+03	8.42E+02	3.21E+02	7.10E+01	2.34E+00
1980	3.87E+04	3.49E+04	2.91E+04	2.34E+04	1.80E+04	1.37E+04	1.03E+04	7.72E+03	5.50E+03	3.65E+03	2.19E+03	1.15E+03	5.06E+02	1.68E+02	3.36E+01	4.51E-01
1981	2.62E+04	2.36E+04	2.01E+04	1.68E+04	1.38E+04	1.14E+04	9.33E+03	7.49E+03	5.66E+03	3.93E+03	2.44E+03	1.30E+03	5.75E+02	1.90E+02	3.76E+01	1.56E-01
1982	1.72E+04	1.70E+04	1.58E+04	1.47E+04	1.31E+04	1.15E+04	9.87E+03	8.35E+03	6.74E+03	5.08E+03	3.47E+03	2.07E+03	1.04E+03	3.92E+02	8.80E+01	9.42E-01
1983	8.77E+03	9.25E+03	9.39E+03	9.66E+03	9.45E+03	8.98E+03	8.12E+03	7.26E+03	6.18E+03	4.90E+03	3.51E+03	2.20E+03	1.15E+03	4.54E+02	1.05E+02	2.97E+00
1984	5.92E+03	5.94E+03	5.89E+03	6.08E+03	6.01E+03	5.80E+03	5.29E+03	4.80E+03	4.17E+03	3.38E+03	2.49E+03	1.61E+03	8.70E+02	3.53E+02	8.23E+01	3.94E+00
1985	5.35E+03	5.11E+03	4.83E+03	4.68E+03	4.37E+03	4.01E+03	3.53E+03	3.12E+03	2.66E+03	2.12E+03	1.54E+03	9.83E+02	5.28E+02	2.13E+02	4.92E+01	2.96E+00
1986	9.48E+03	8.08E+03	6.92E+03	6.16E+03	5.41E+03	4.75E+03	4.06E+03	3.53E+03	2.98E+03	2.34E+03	1.68E+03	1.06E+03	5.65E+02	2.26E+02	5.18E+01	2.75E+00
1987	1.53E+04	1.39E+04	1.23E+04	1.09E+04	9.29E+03	7.80E+03	6.38E+03	5.27E+03	4.21E+03	3.16E+03	2.17E+03	1.32E+03	6.76E+02	2.63E+02	5.90E+01	2.64E+00
1988	2.07E+04	1.87E+04	1.67E+04	1.50E+04	1.30E+04	1.11E+04	9.26E+03	7.77E+03	6.29E+03	4.74E+03	3.26E+03	1.97E+03	1.00E+03	3.84E+02	8.61E+01	2.61E+00
1989	2.62E+04	2.47E+04	2.26E+04	2.06E+04	1.80E+04	1.53E+04	1.26E+04	1.05E+04	8.42E+03	6.29E+03	4.29E+03	2.58E+03	1.30E+03	4.98E+02	1.11E+02	3.22E+00
1990	2.62E+04	2.51E+04	2.33E+04	2.15E+04	1.88E+04	1.60E+04	1.33E+04	1.12E+04	9.09E+03	6.82E+03	4.65E+03	2.78E+03	1.39E+03	5.27E+02	1.17E+02	2.98E+00
1991	2.40E+04	2.29E+04	2.08E+04	1.85E+04	1.56E+04	1.30E+04	1.07E+04	8.97E+03	7.26E+03	5.42E+03	3.66E+03	2.16E+03	1.07E+03	4.02E+02	8.80E+01	2.20E+00
1992	1.93E+04	1.94E+04	1.82E+04	1.67E+04	1.42E+04	1.17E+04	9.57E+03	8.00E+03	6.45E+03	4.80E+03	3.24E+03	1.92E+03	9.49E+02	3.55E+02	7.76E+01	1.59E+00
1993	1.24E+04	1.30E+04	1.28E+04	1.22E+04	1.07E+04	8.92E+03	7.16E+03	5.88E+03	4.60E+03	3.35E+03	2.25E+03	1.34E+03	6.77E+02	2.58E+02	5.77E+01	8.23E-01
1994	8.05E+03	8.64E+03	8.67E+03	8.49E+03	7.50E+03	6.27E+03	5.04E+03	4.22E+03	3.39E+03	2.52E+03	1.73E+03	1.06E+03	5.43E+02	2.11E+02	4.78E+01	1.21E+00
1995	5.60E+03	6.02E+03	6.05E+03	5.96E+03	5.25E+03	4.39E+03	3.53E+03	3.00E+03	2.46E+03	1.86E+03	1.29E+03	7.95E+02	4.14E+02	1.63E+02	3.68E+01	1.28E+00
1996	4.10E+03	4.31E+03	4.24E+03	4.09E+03	3.56E+03	2.98E+03	2.43E+03	2.13E+03	1.79E+03	1.37E+03	9.61E+02	5.95E+02	3.11E+02	1.23E+02	2.77E+01	1.14E+00
1997	3.29E+03	3.41E+03	3.35E+03	3.25E+03	2.88E+03	2.45E+03	2.03E+03	1.78E+03	1.51E+03	1.16E+03	8.13E+02	5.04E+02	2.64E+02	1.04E+02	2.35E+01	9.80E-01
1998	3.12E+03	3.12E+03	3.00E+03	2.88E+03	2.55E+03	2.19E+03	1.82E+03	1.60E+03	1.35E+03	1.04E+03	7.32E+02	4.54E+02	2.38E+02	9.37E+01	2.12E+01	8.80E-01
1999	3.26E+03	3.18E+03	3.02E+03	2.87E+03	2.55E+03	2.19E+03	1.83E+03	1.59E+03	1.33E+03	1.02E+03	7.18E+02	4.44E+02	2.31E+02	9.06E+01	2.04E+01	8.05E-01
2000	4.27E+03	3.97E+03	3.64E+03	3.38E+03	2.97E+03	2.55E+03	2.11E+03	1.79E+03	1.47E+03	1.13E+03	7.90E+02	4.87E+02	2.52E+02	9.85E+01	2.22E+01	7.90E-01
2001	4.91E+03	4.84E+03	4.63E+03	4.40E+03	3.94E+03	3.40E+03	2.81E+03	2.33E+03	1.87E+03	1.41E+03	9.75E+02	5.94E+02	3.04E+02	1.18E+02	2.64E+01	8.55E-01
2002	5.52E+03	5.25E+03	4.97E+03	4.80E+03	4.41E+03	3.92E+03	3.31E+03	2.80E+03	2.29E+03	1.76E+03	1.24E+03	7.63E+02	3.95E+02	1.54E+02	3.49E+01	1.00E+00
2003	6.87E+03	6.66E+03	6.33E+03	6.07E+03	5.52E+03	4.85E+03	4.04E+03	3.36E+03	2.70E+03	2.05E+03	1.43E+03	8.80E+02	4.56E+02	1.78E+02	4.02E+01	1.35E+00
2004	9.12E+03	8.48E+03	7.86E+03	7.47E+03	6.79E+03	5.98E+03	5.01E+03	4.18E+03	3.38E+03	2.58E+03	1.81E+03	1.12E+03	5.79E+02	2.26E+02	5.11E+01	1.58E+00
2005	1.08E+04	1.07E+04	1.04E+04	1.00E+04	9.15E+03	8.04E+03	6.68E+03	5.50E+03	4.37E+03	3.30E+03	2.28E+03	1.40E+03	7.19E+02	2.79E+02	6.29E+01	1.99E+00
2006	1.10E+04	1.08E+04	1.06E+04	1.06E+04	1.00E+04	9.10E+03	7.78E+03	6.57E+03	5.36E+03	4.12E+03	2.91E+03	1.80E+03	9.34E+02	3.65E+02	8.27E+01	2.40E+00
2007	1.46E+04	1.39E+04	1.30E+04	1.25E+04	1.15E+04	1.02E+04	8.54E+03	7.11E+03	5.74E+03	4.39E+03	3.09E+03	1.92E+03	1.00E+03	3.94E+02	8.94E+01	3.09E+00
2008	1.48E+04	1.52E+04	1.51E+04	1.50E+04	1.39E+04	1.24E+04	1.05E+04	8.70E+03	6.97E+03	5.28E+03	3.68E+03	2.26E+03	1.16E+03	4.54E+02	1.02E+02	3.37E+00
2009	1.14E+04	1.23E+04	1.30E+04	1.39E+04	1.37E+04	1.28E+04	1.11E+04	9.50E+03	7.83E+03	6.09E+03	4.33E+03	2.70E+03	1.42E+03	5.57E+02	1.27E+02	3.88E+00
2010	9.70E+03	1.06E+04	1.12E+04	1.22E+04	1.22E+04	1.15E+04	1.01E+04	8.72E+03	7.23E+03	5.66E+03	4.04E+03	2.54E+03	1.34E+03	5.32E+02	1.22E+02	4.67E+00
2011	9.26E+03	9.66E+03	1.00E+04	1.08E+04	1.08E+04	1.02E+04	8.99E+03	7.78E+03	6.48E+03	5.09E+03	3.65E+03	2.30E+03	1.22E+03	4.85E+02	1.11E+02	4.81E+00
2012	1.39E+04	1.27E+04	1.18E+04	1.16E+04	1.08E+04	9.90E+03	8.49E+03	7.23E+03	5.95E+03	4.64E+03	3.31E+03	2.08E+03	1.10E+03	4.36E+02	9.91E+01	4.40E+00
2013	2.03E+04	1.92E+04	1.79E+04	1.68E+04	1.51E+04	1.31E+04	1.09E+04	8.92E+03	7.07E+03	5.32E+03	3.68E+03	2.25E+03	1.16E+03	4.51E+02	1.01E+02	3.95E+00
2014	2.00E+04	2.05E+04	2.04E+04	2.03E+04	1.90E+04	1.70E+04	1.44E+04	1.19E+04	9.57E+03	7.25E+03	5.03E+03	3.07E+03	1.58E+03	6.11E+02	1.37E+02	3.93E+00

Table 23. OFLs and ABCs for the 2013 assessment and the four alternative 2014 model scenarios. The author's preferred model is Alt1a.

Model Case	average recruitment (millions)	B (1000's t)	Fmsy	Bmsy (1000's t)	B/Bmsy	OFL (1000's t)	ABC (p*) (1000's t)	ABC (10% buffer) (1000's t)
2013	211.9	59.35	0.73	33.54	1.77	25.35	25.31	22.82
Alt0a	206.6	63.91	0.69	32.95	1.94	32.84	32.78	29.55
Alt0b	185.4	59.65	0.61	29.12	2.05	30.04	30.00	27.04
Alt1a	209.7	70.77	0.58	33.95	2.08	33.81	33.76	30.43
Alt1b	187.0	63.37	0.61	29.51	2.15	31.35	31.30	28.21

Figures

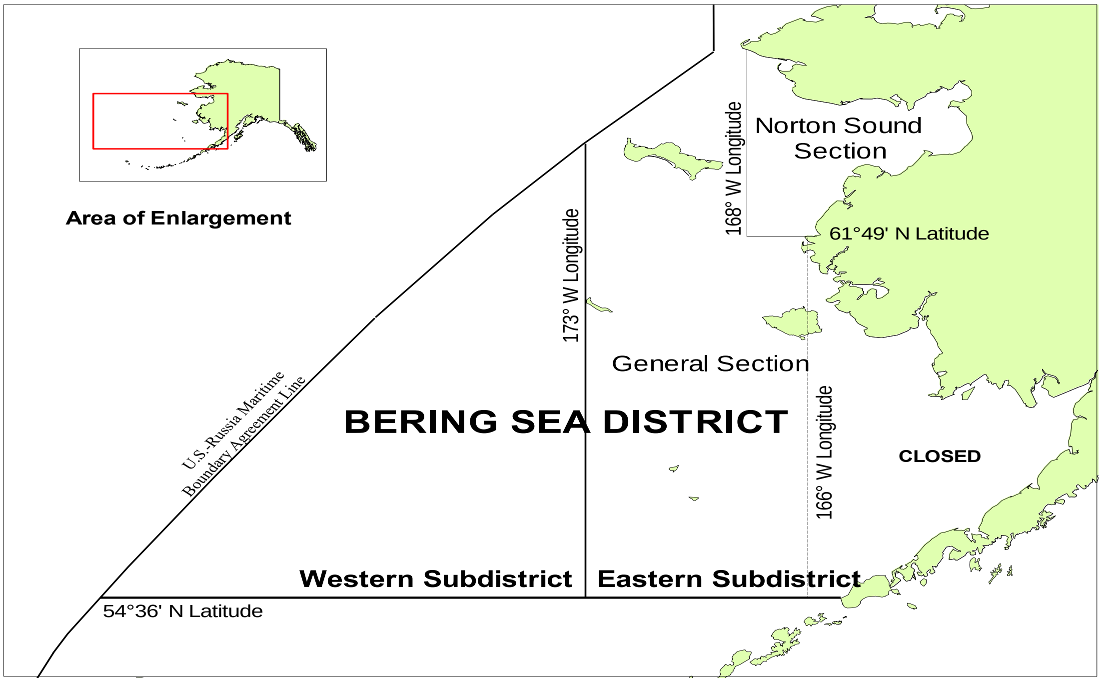


Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008).

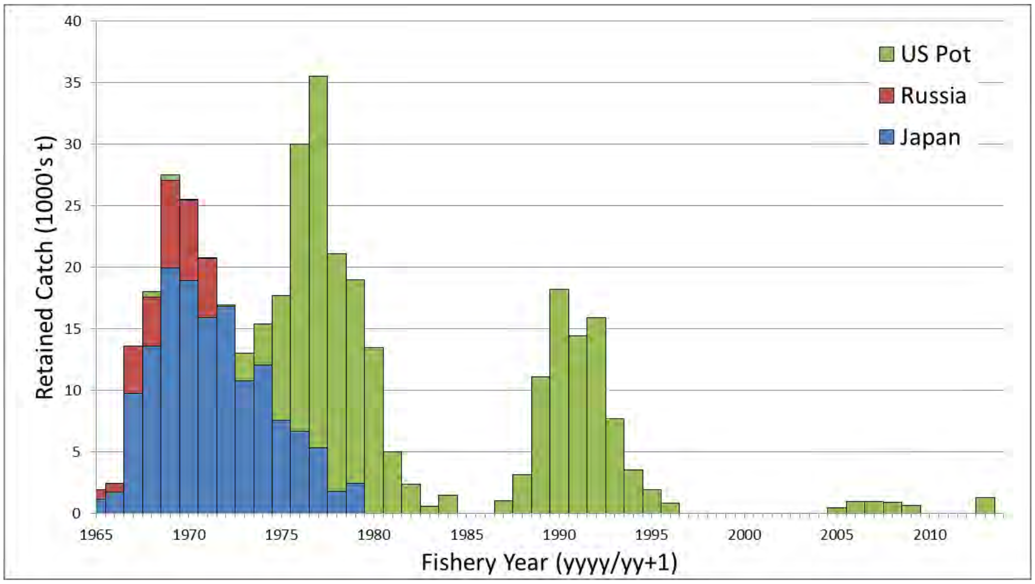


Figure 2. Retained catch (males, 1000's t) in the directed fisheries (US pot fishery [green bars], Russian tangle net fishery [red bars], and Japanese tangle net fisheries [blue bars]) for Tanner crab since 1965/66.

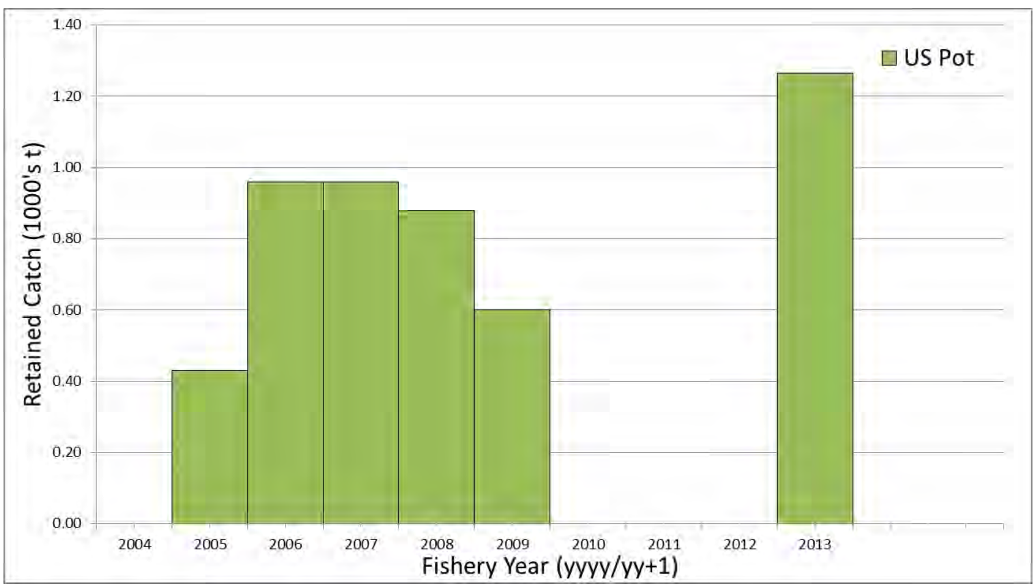


Figure 3. Retained catch (males, 1000's t) in directed fishery for Tanner crab since 2001/02. The directed fishery was closed from 1996/97 to 2004/05 and from 2010/11 to 2012/13.

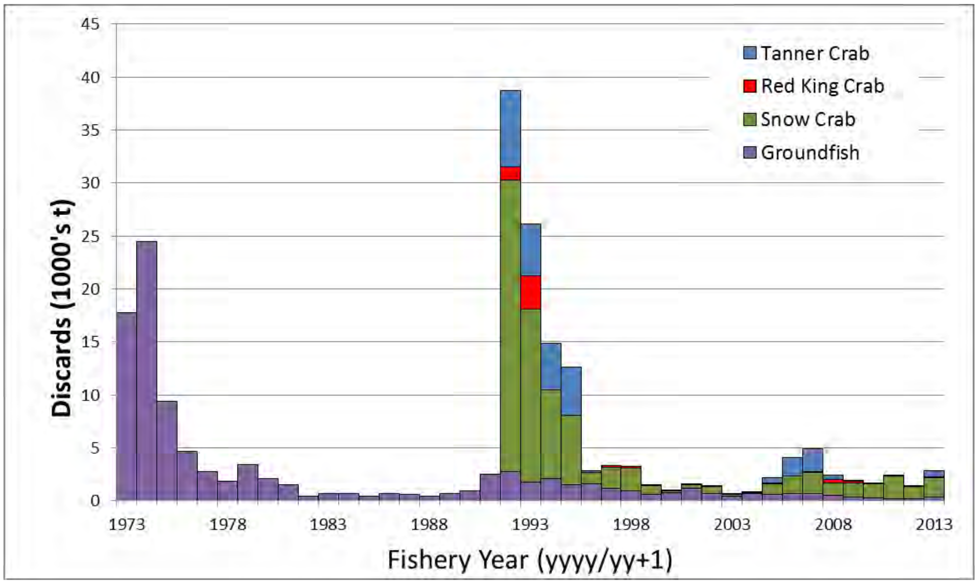


Figure 4. Tanner crab discards (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Discard reporting began in 1973 for the groundfish fisheries and in 1992 for the crab fisheries.

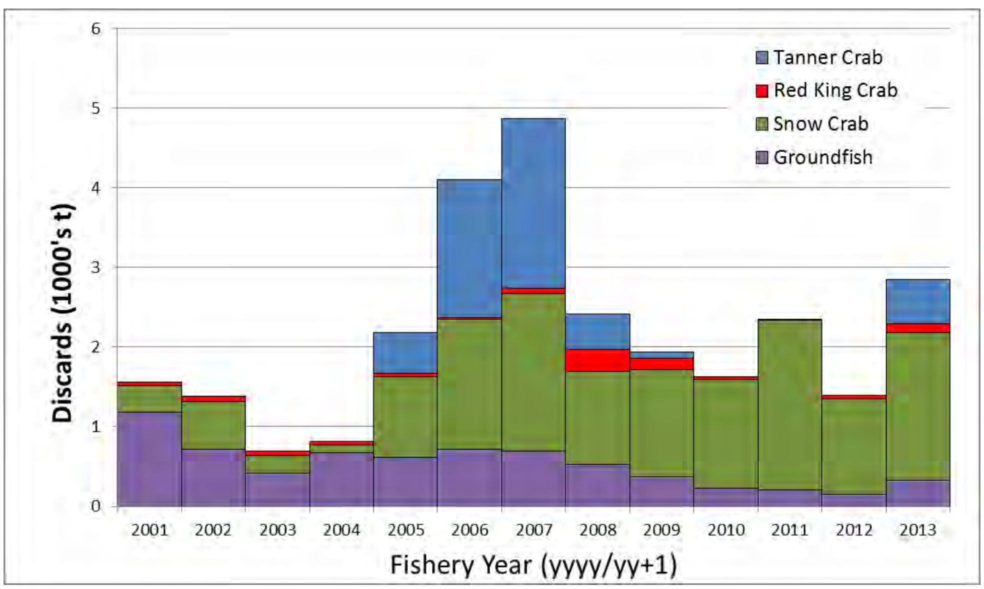


Figure 5.Tanner crab discards (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries since 2001.

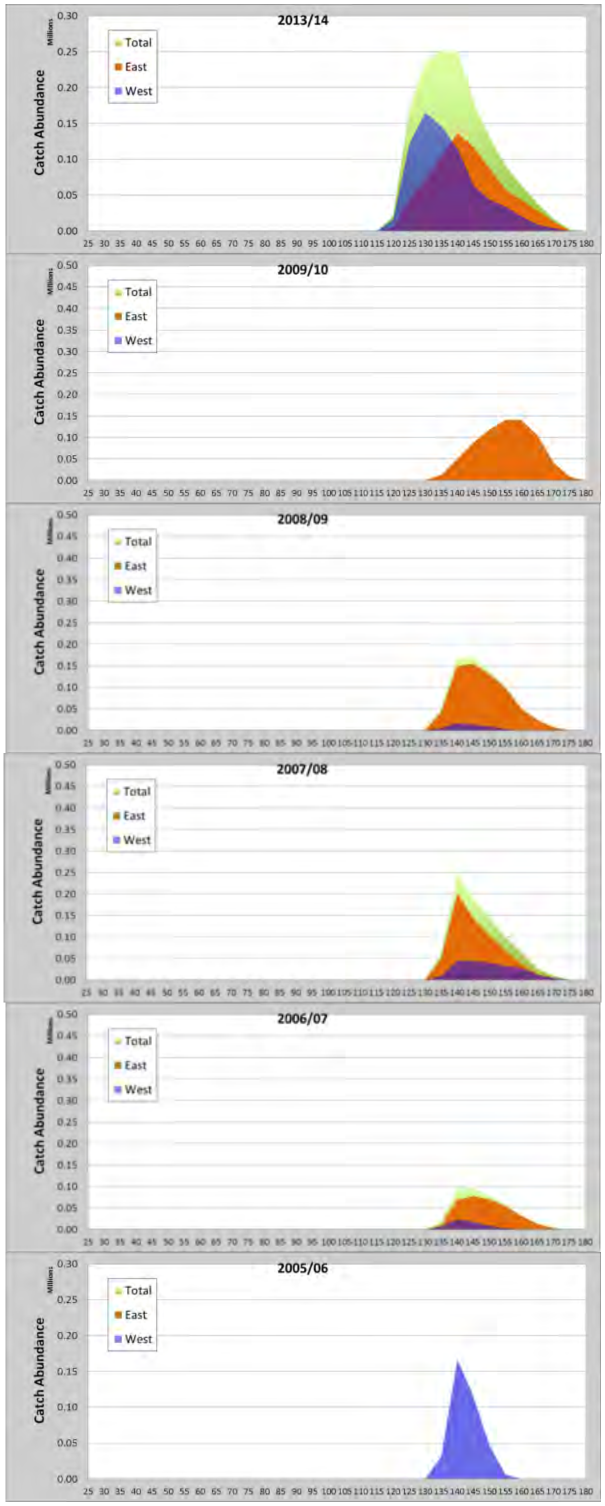


Figure 6. Size compositions, by 5 mm CW bins and expanded to total retained catch, for retained (male) crab in the directed Tanner crab pot fisheries since 2005/06, from dockside crab fishery observer sampling. Fishing occurred only west of 166°W in 2005/06 and east of 166°W in 2009/10. The entire fishery was closed in 2010/11-2012/13.

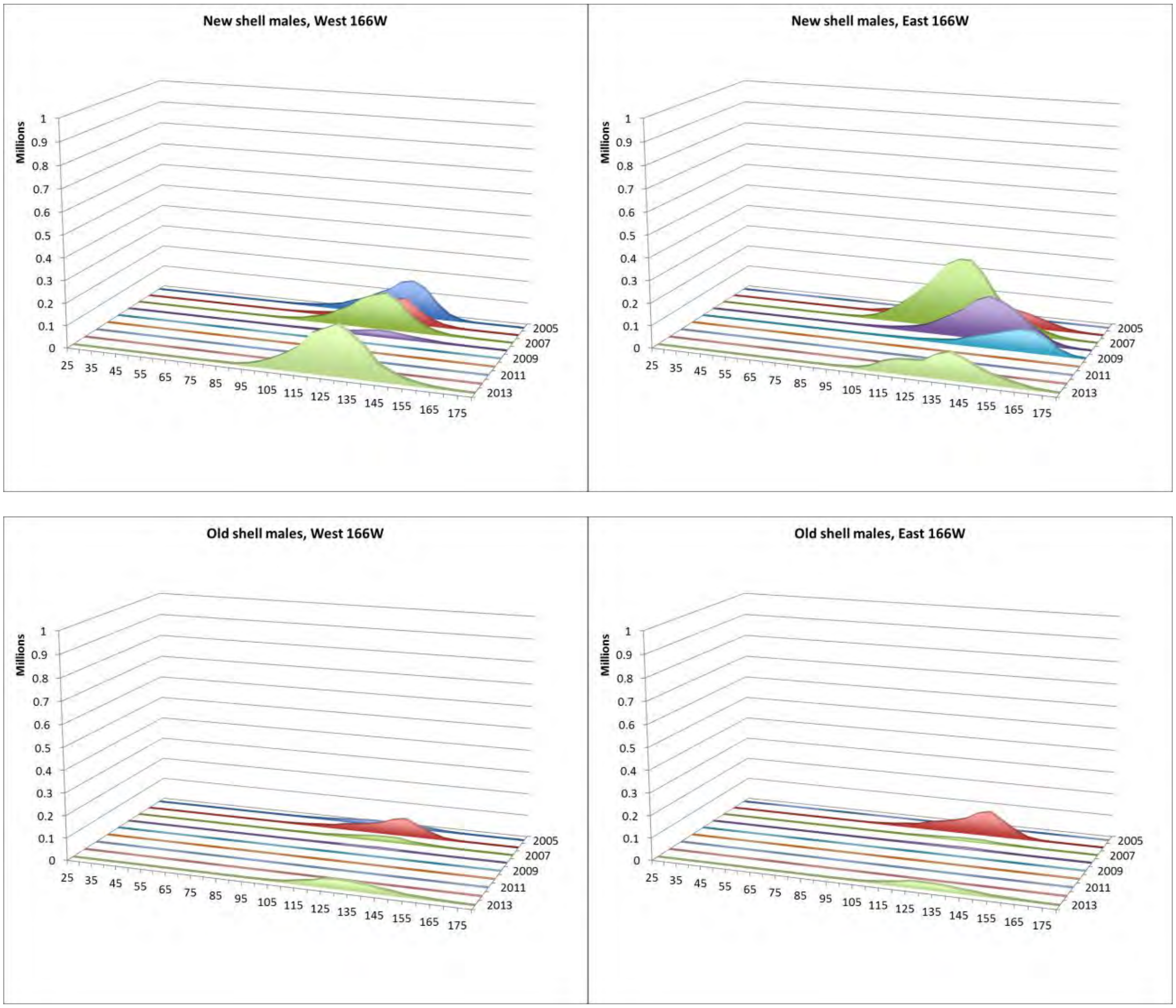


Figure 7. Male Tanner crab catch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling.

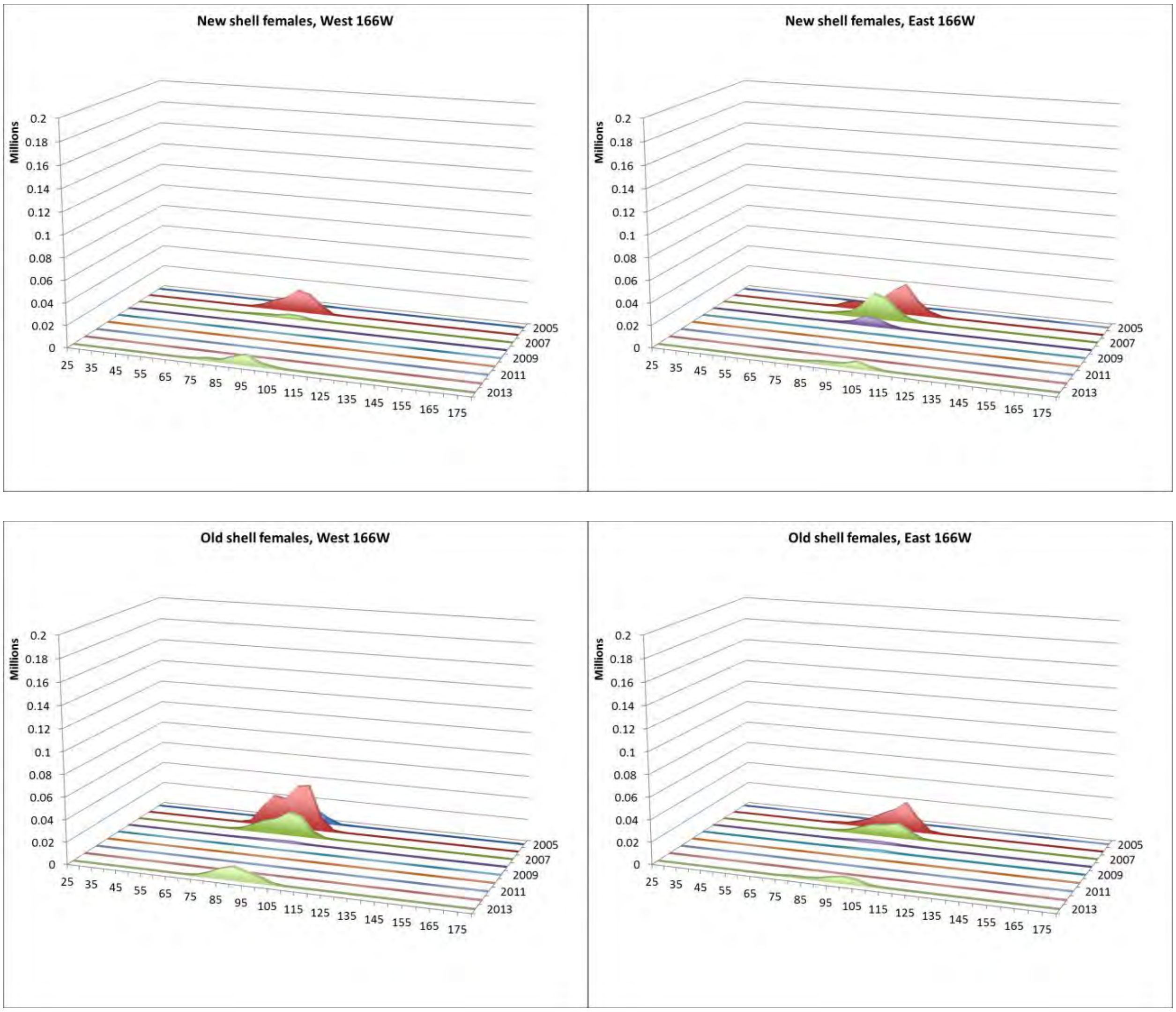


Figure 8. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling.

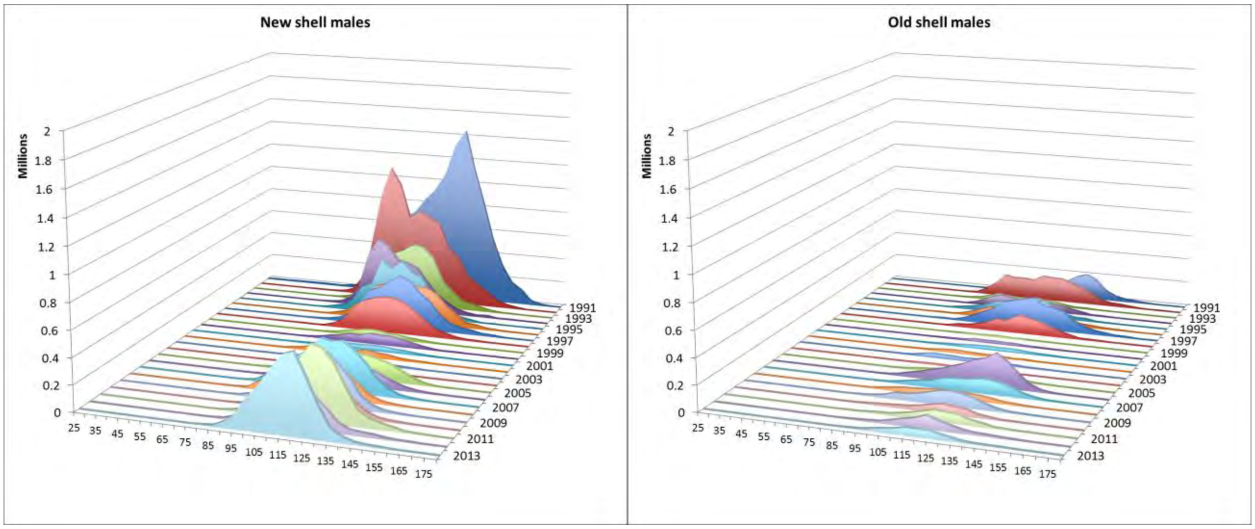


Figure 9. Male Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the snow crab pot fishery, from at-sea crab fishery observer sampling.

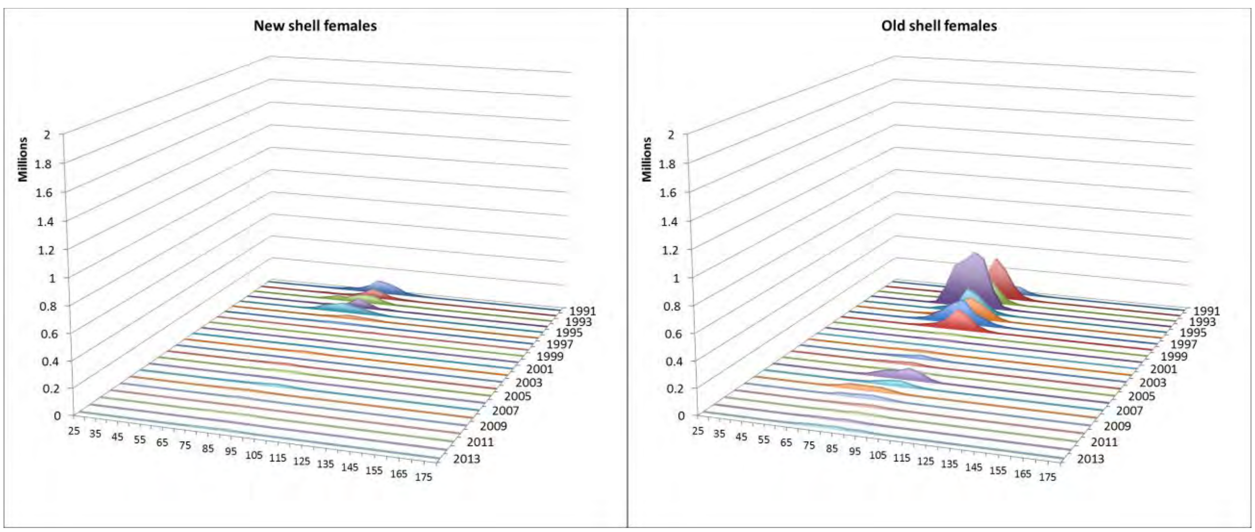


Figure 10. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the snow crab pot fishery, from at-sea crab fishery observer sampling.

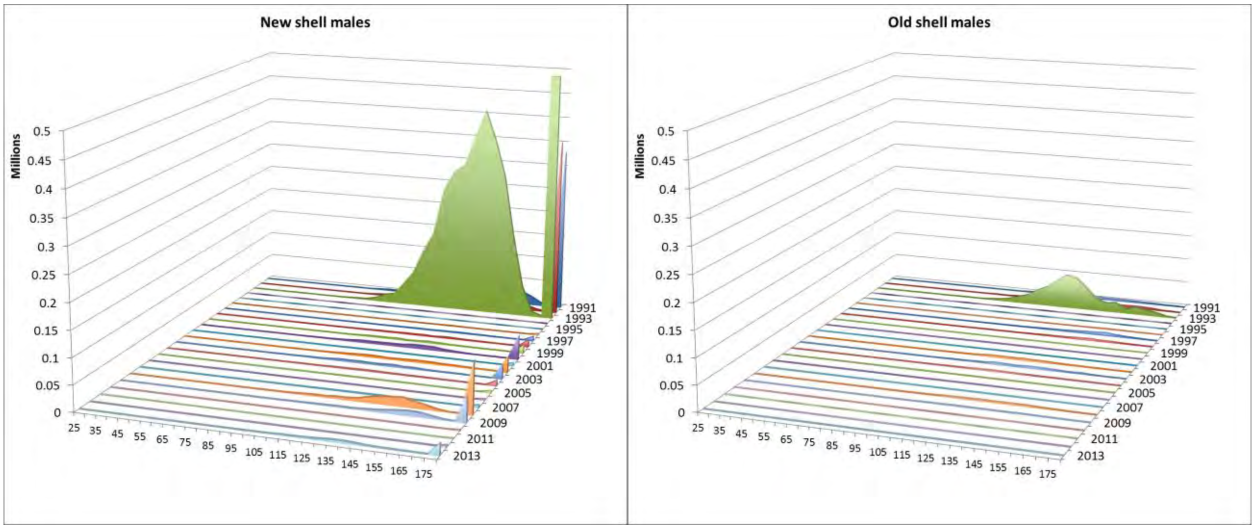


Figure 11. Male Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the BBRKC pot fishery, from at-sea crab fishery observer sampling.

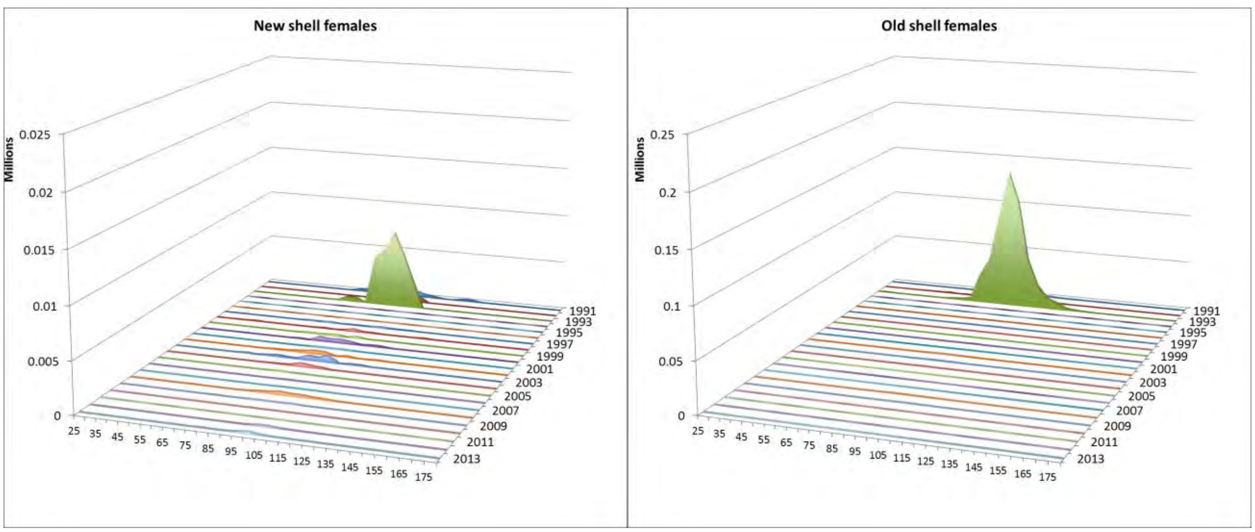


Figure 12. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the BBRKC pot fishery, from at-sea crab fishery observer sampling.

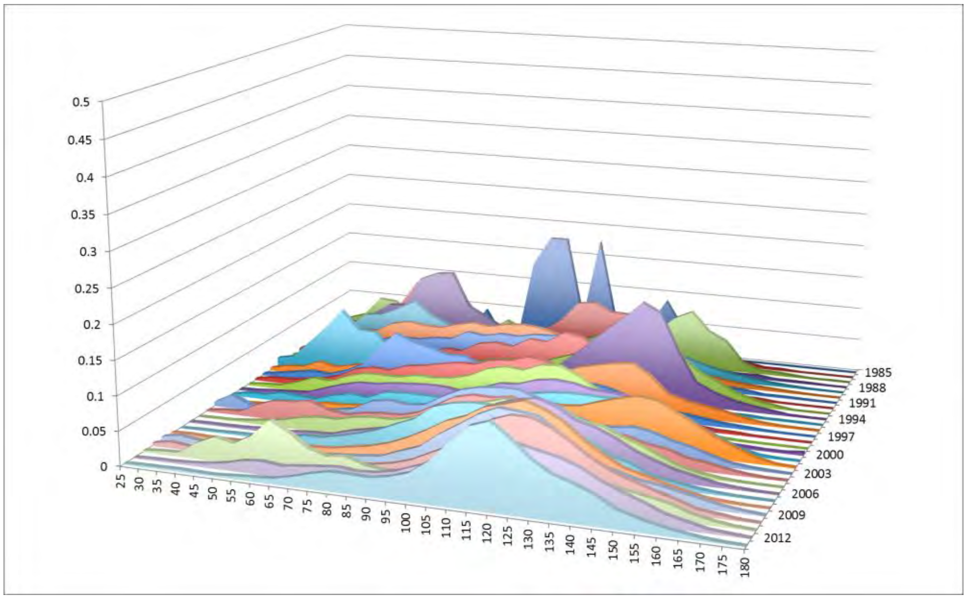


Figure 13. Normalized male Tanner crab bycatch size compositions in the groundfish fisheries, from groundfish observer sampling. Size compositions have been normalized to sum to 1 for each year.

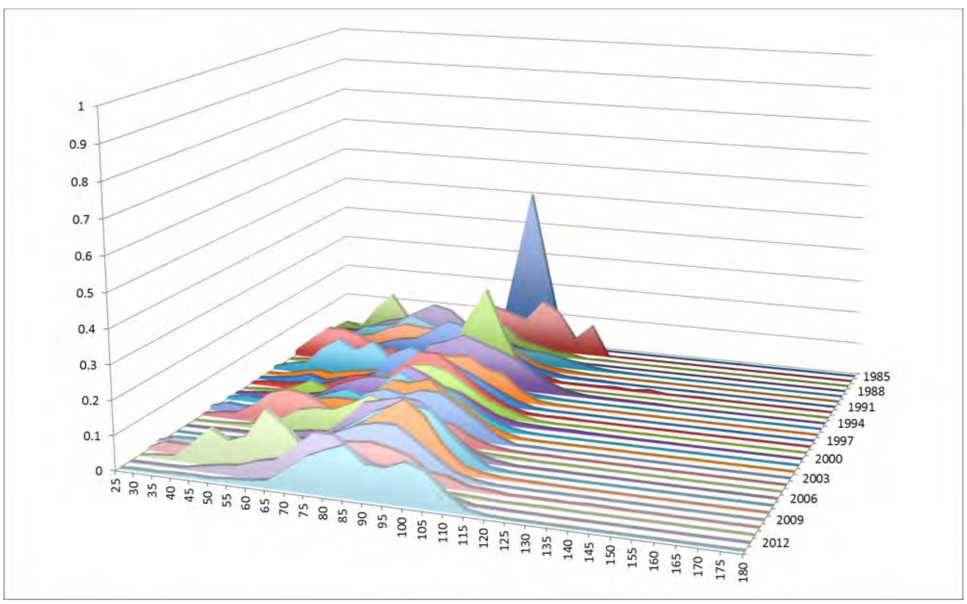


Figure 14. Normalized female Tanner crab bycatch size compositions in the groundfish fisheries, from groundfish observer sampling. Size compositions have been normalized to sum to 1 for each year.

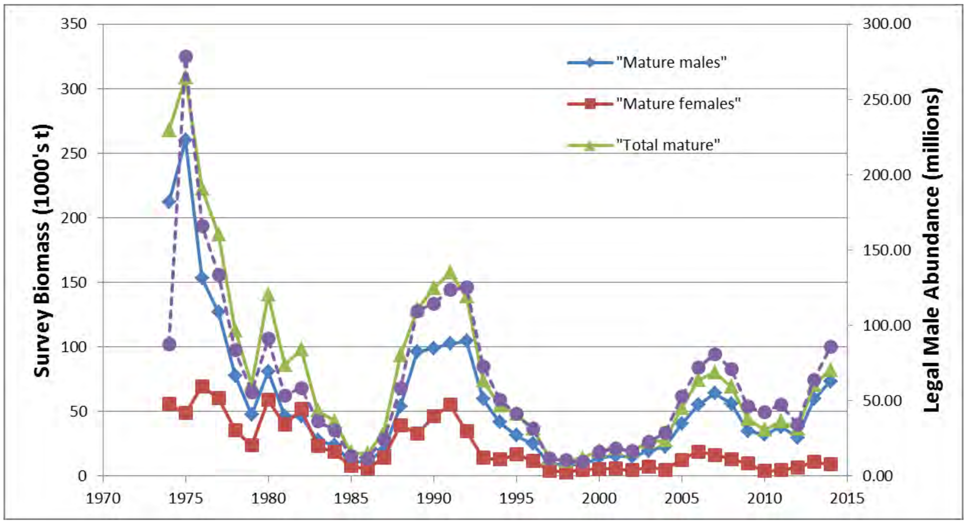


Figure 15. Trends in mature Tanner crab biomass and abundance of legal crab (≥ 138 mm CW) in the summer bottom trawl survey.

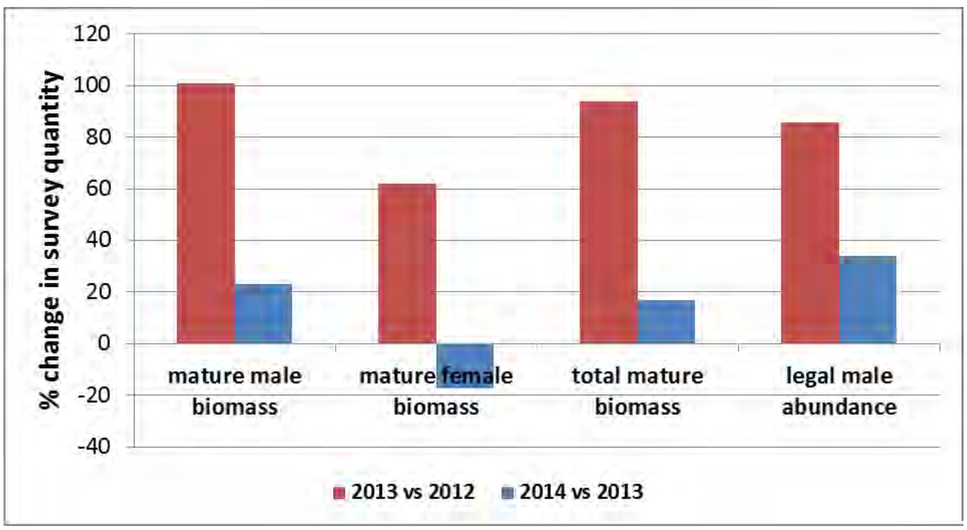


Figure 16. Percent change in mature male biomass, mature female biomass, total mature biomass and number of legal male crab observed in the summer bottom trawl survey.

West of 166° W East of 166° W

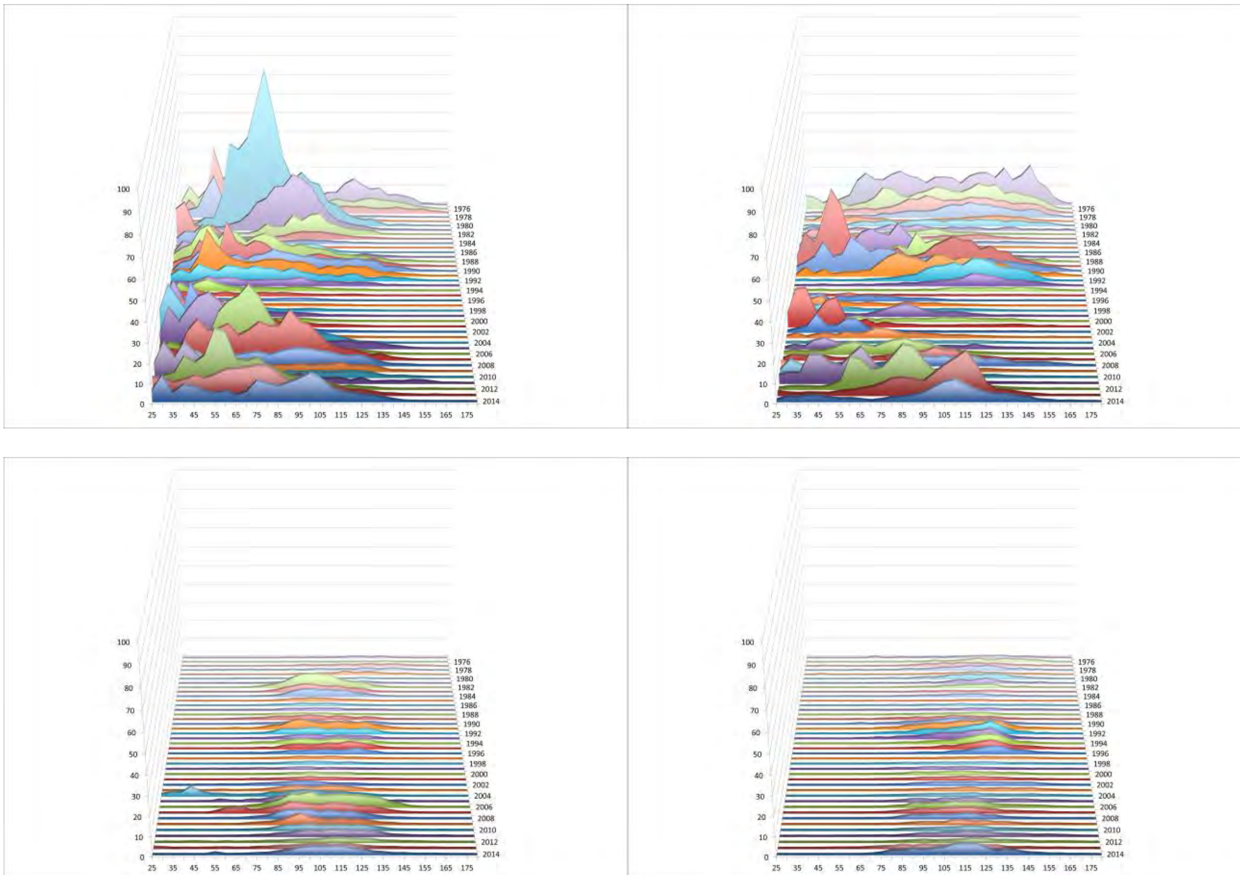


Figure 17. Numbers at size (millions) for male Tanner crab, by area and shell condition, in the NMFS summer bottom trawl survey. Upper row: new shell crab. Lower row: old shell crab.

West of 166^{o} W East of 166^{o} W

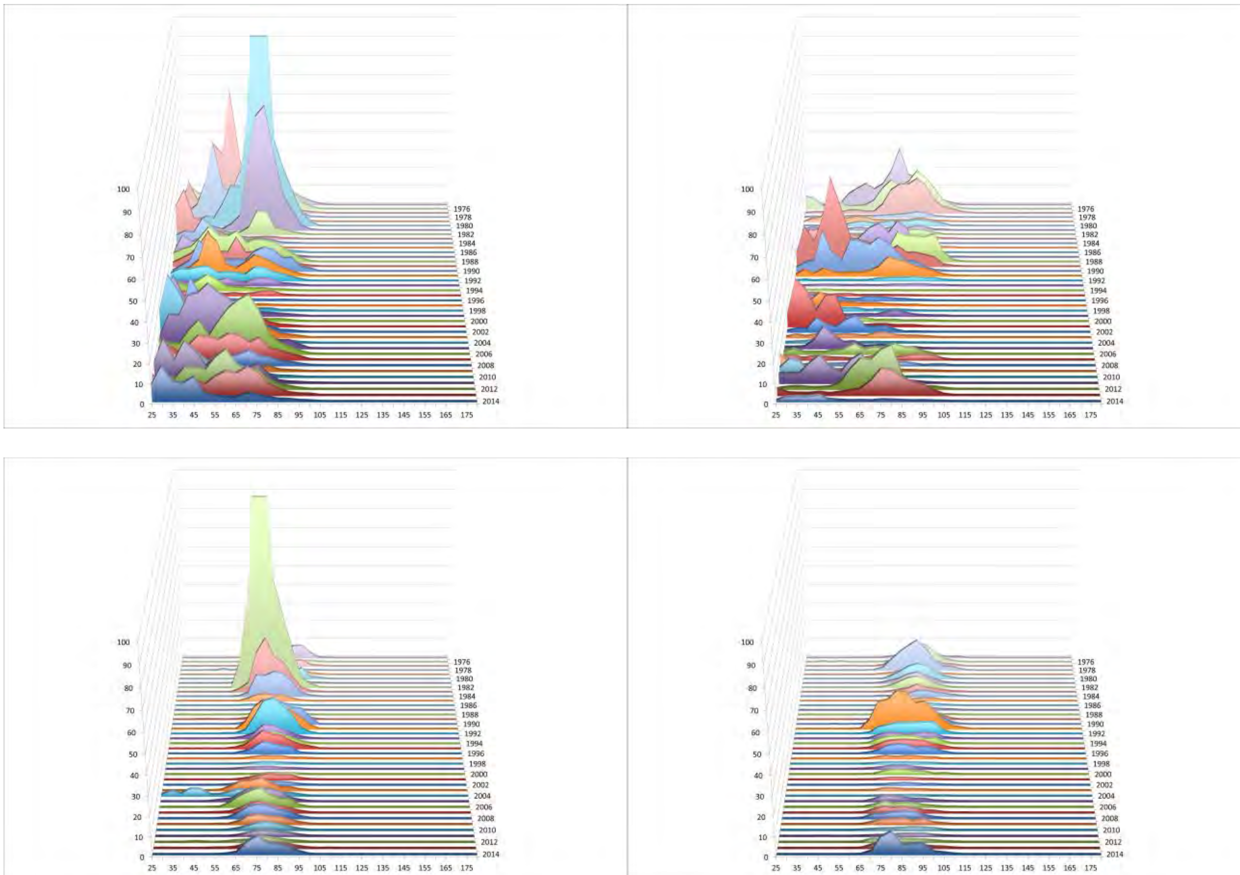


Figure 18. Numbers at size (millions) for female Tanner crab, by area and shell condition, in the NMFS summer bottom trawl survey. Upper row: new shell crab. Lower row: old shell crab.

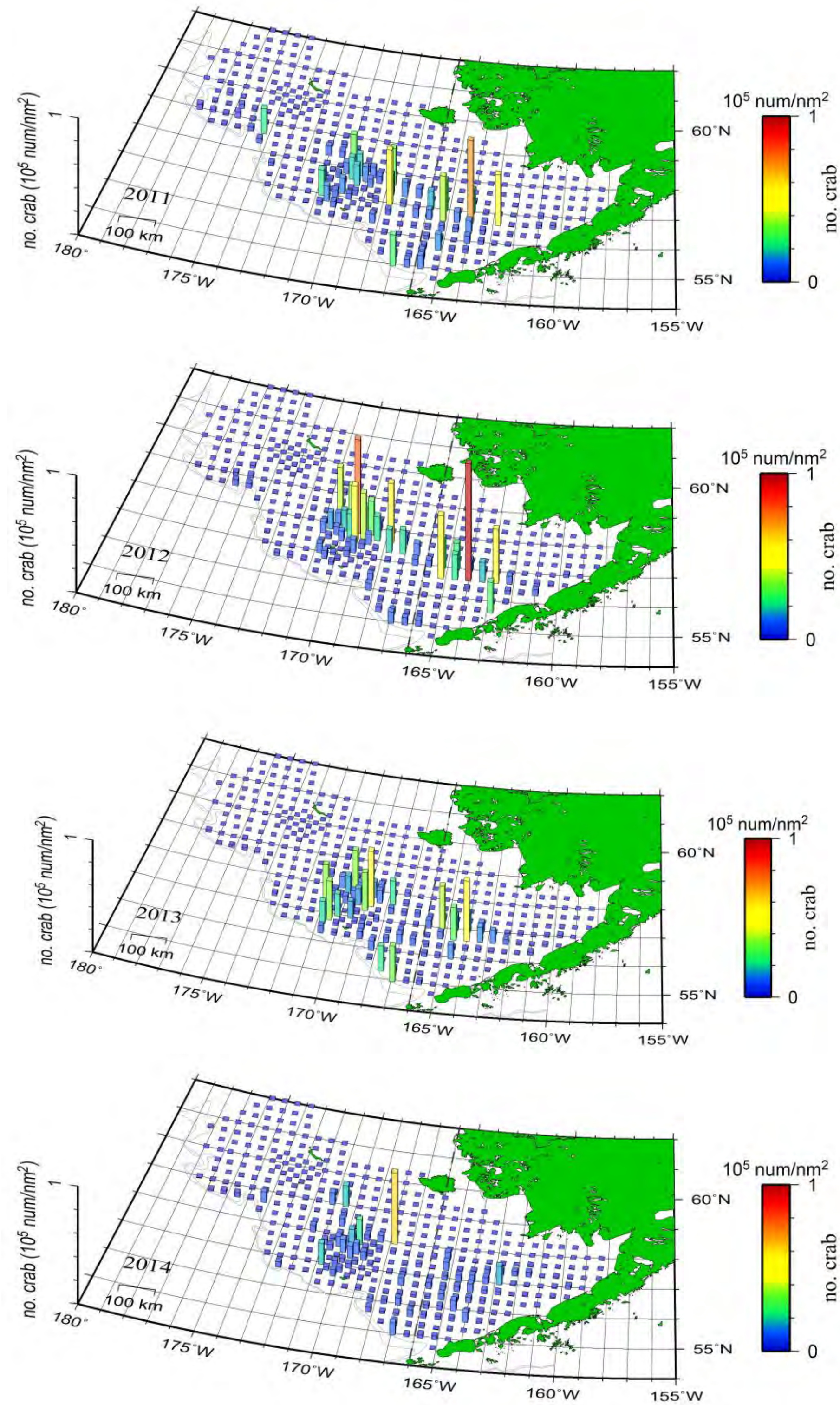


Figure 19. Distribution of immature males (number/ sq. nm) in the summer trawl survey for 2011-14.

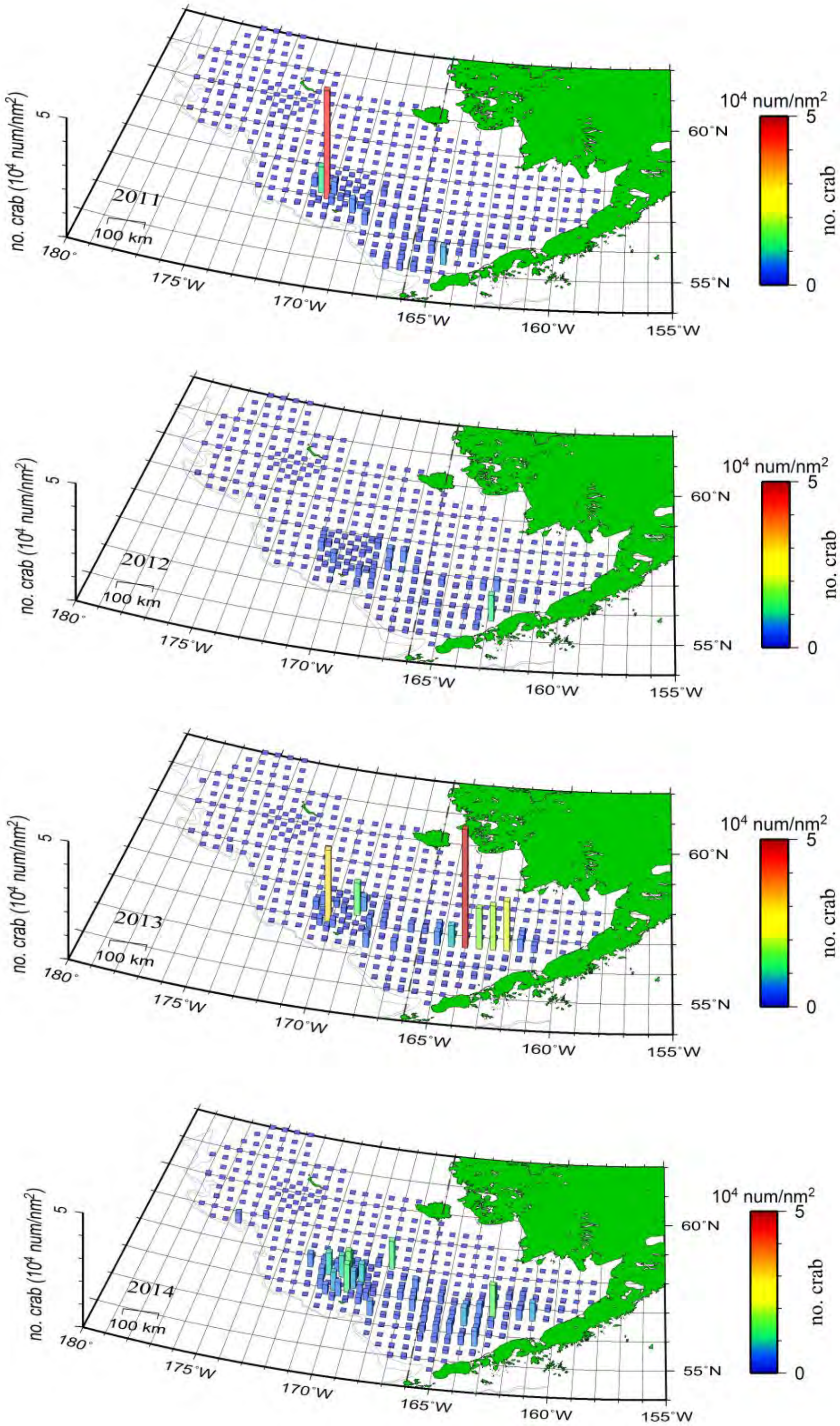


Figure 20. Distribution of mature males (number/ sq. nm) in the summer trawl survey for 2011-14.

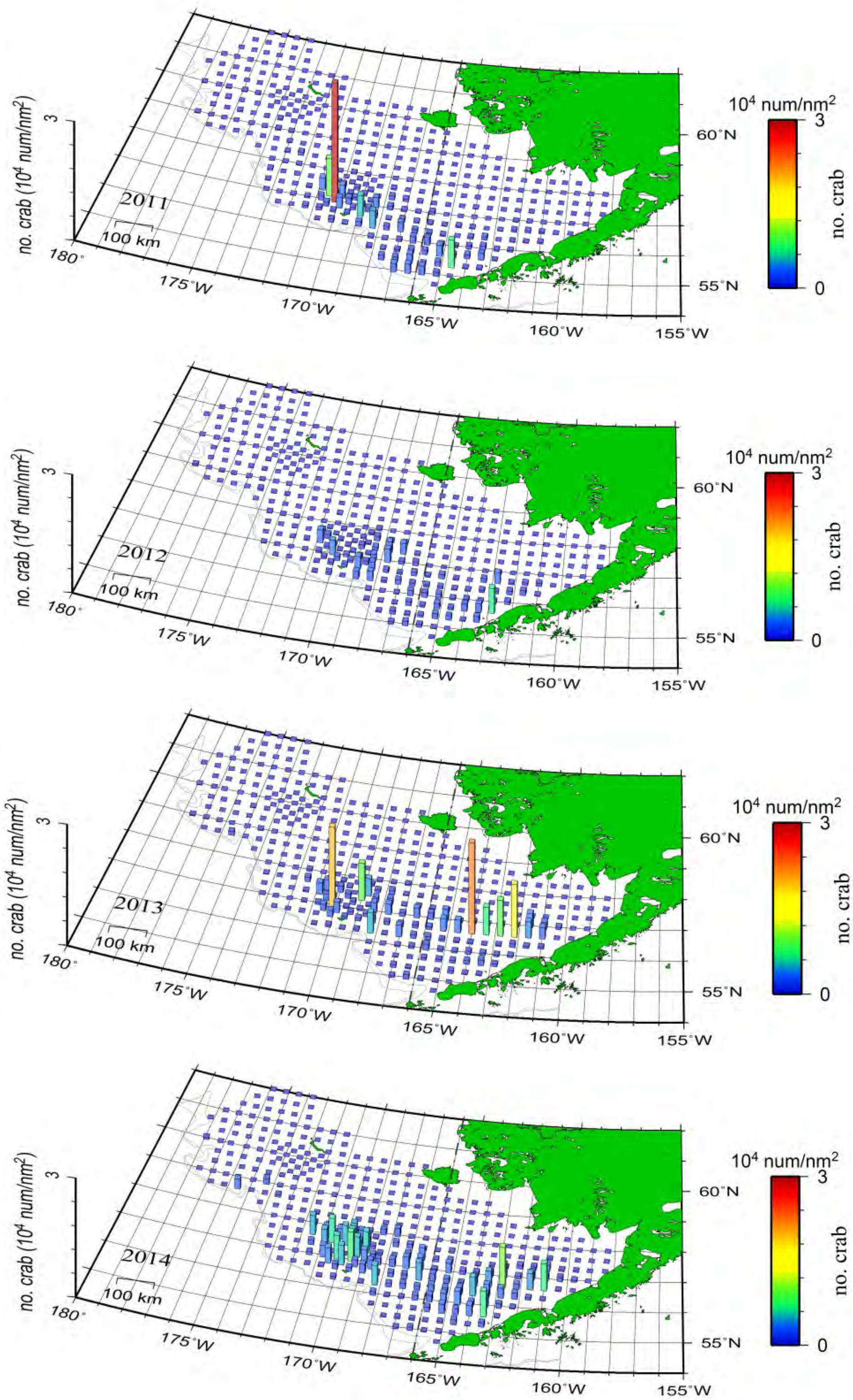


Figure 21. Distribution of legal males (≥ 110 mm CW west of 166°W, ≥ 120 mm CW east of 166°W; number/ sq. nm) in the summer trawl survey for 2011-14.

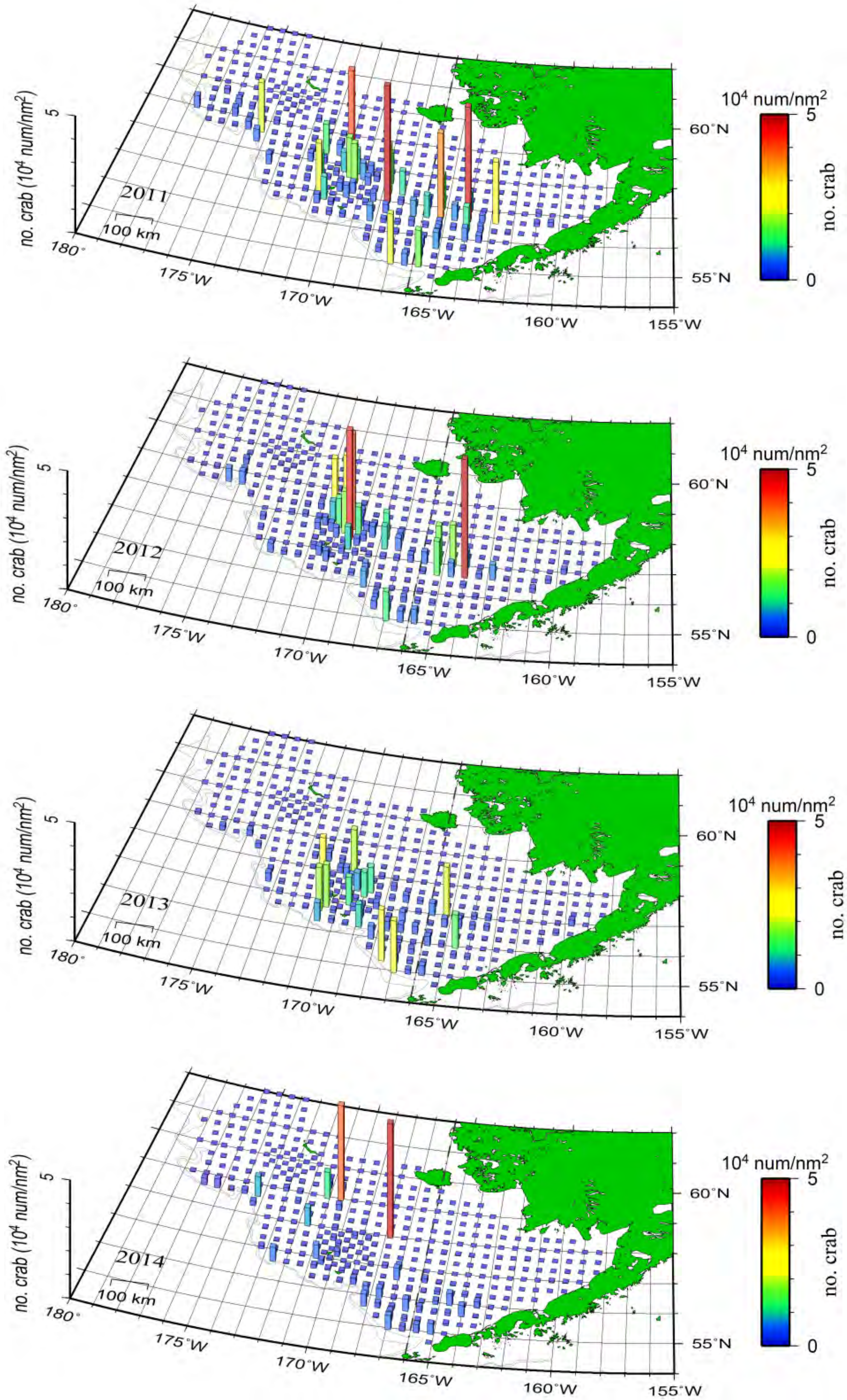


Figure 22. Distribution of immature females (number/ sq. nm) in the summer trawl survey for 2011-14.

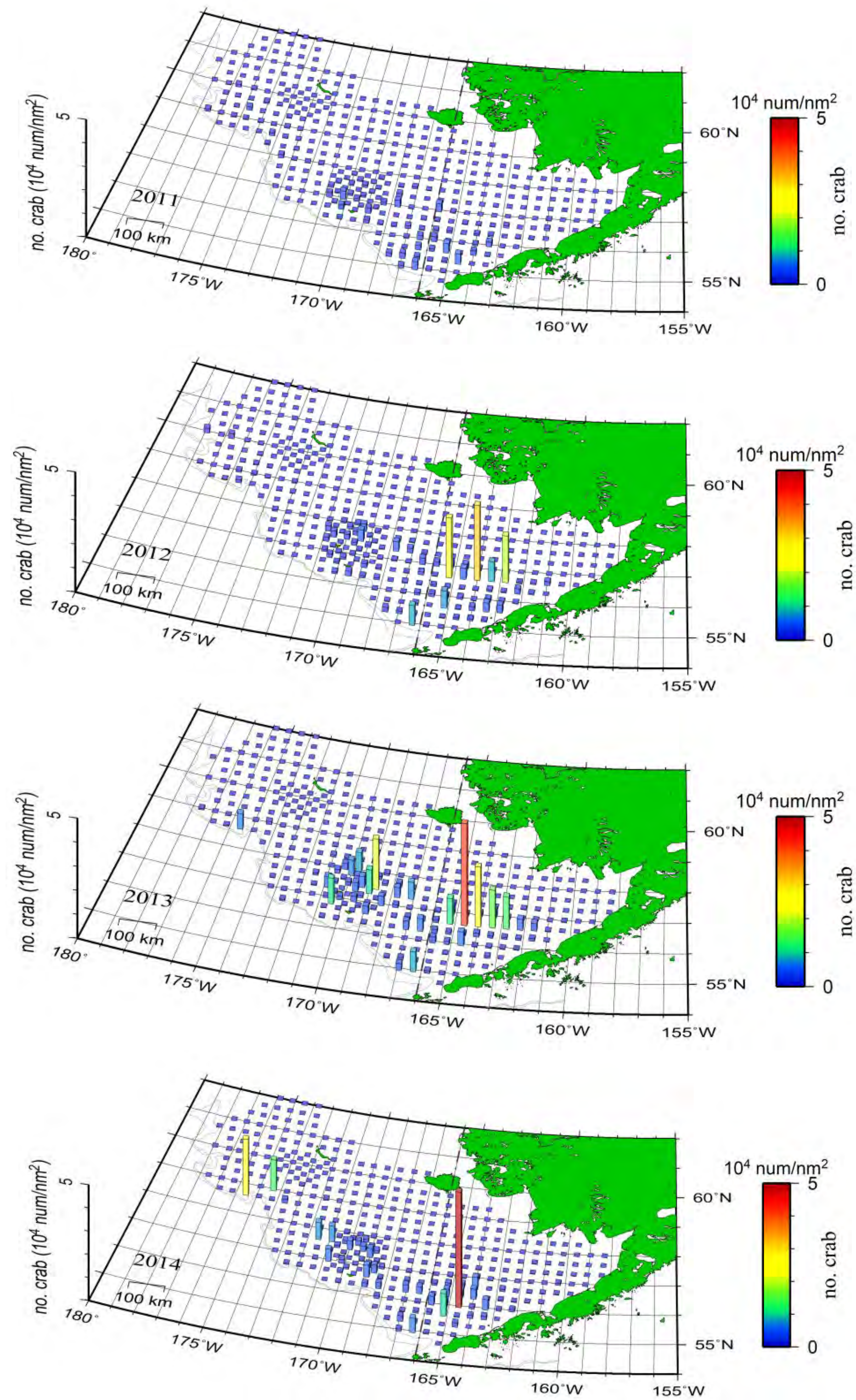
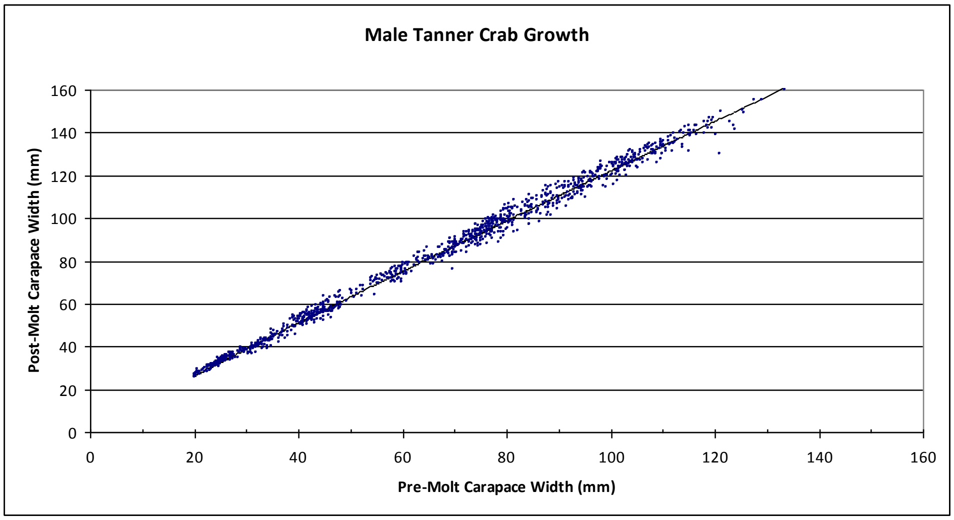


Figure 23. Distribution of mature females (number/ sq. nm) in the summer trawl survey for 2011-14.

(a)



(b)

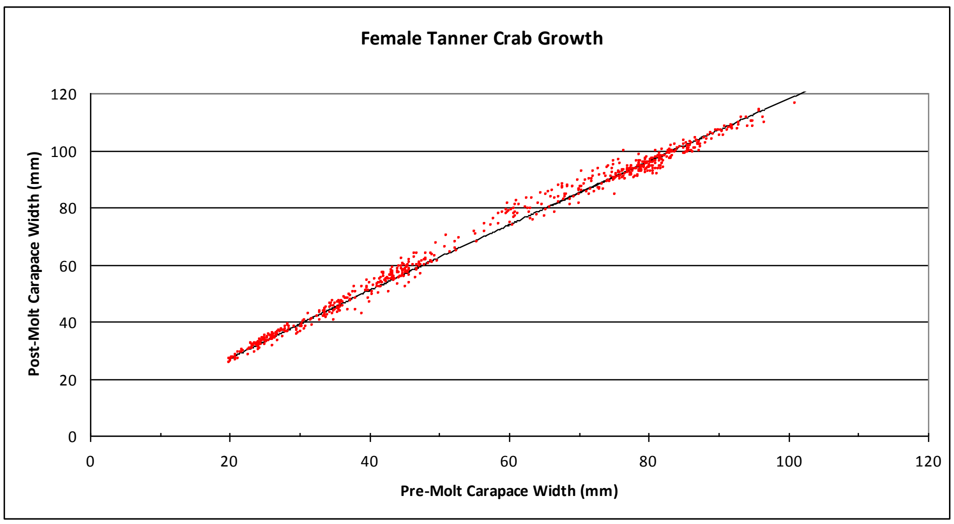


Figure 24. Growth of male (a) and female (b) Tanner crab as a function of premolt size. Estimated by Rugolo and Turnock (2010) based on data from Gulf of Alaska Tanner crab (Munk, unpublished data).

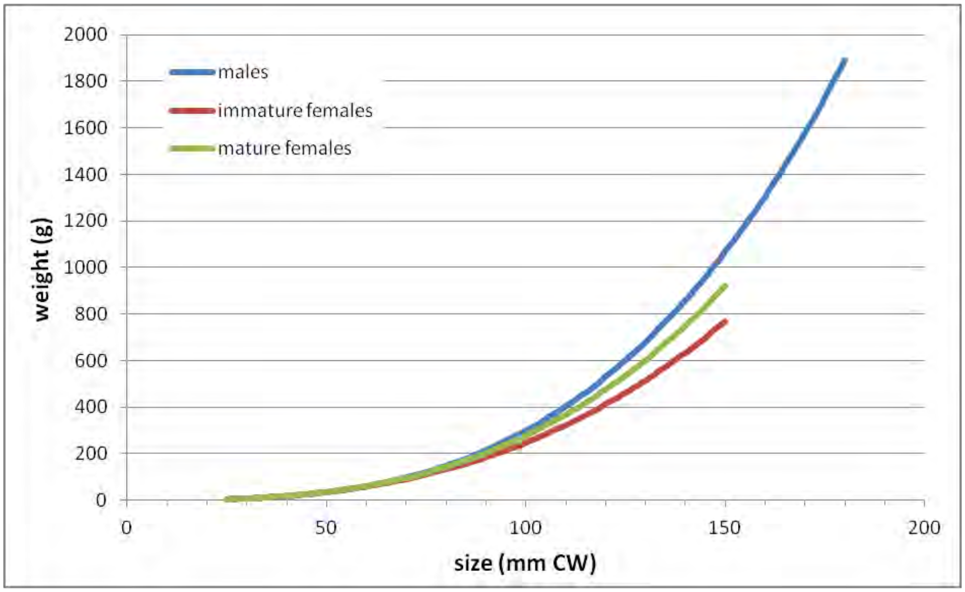


Figure 25. Fitted weight-at size relationships for males (immature and mature; blue line), immature females (red line), and mature females (green line).

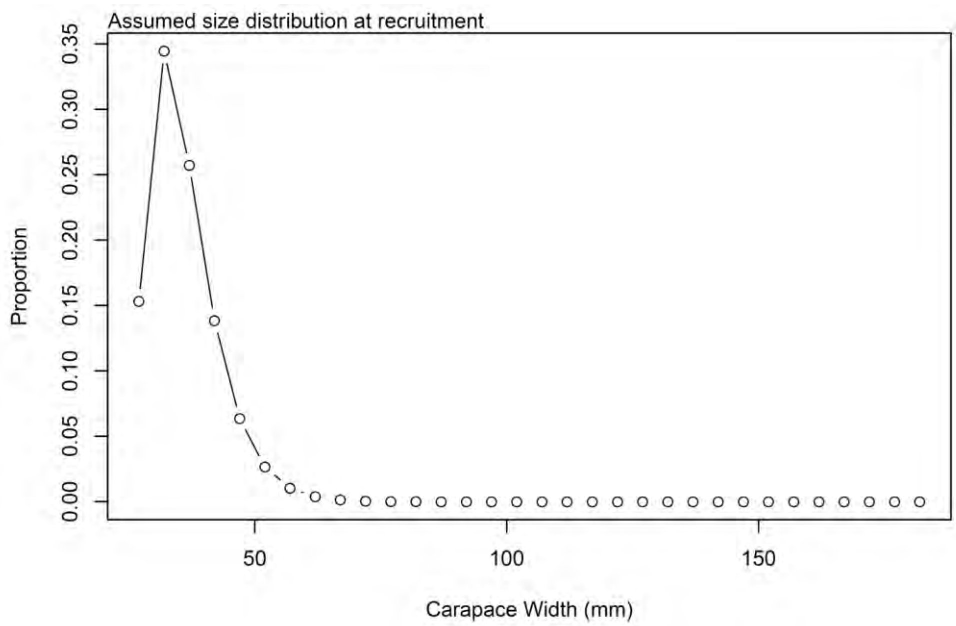


Figure 26. Assumed size distribution for recruits entering the population.

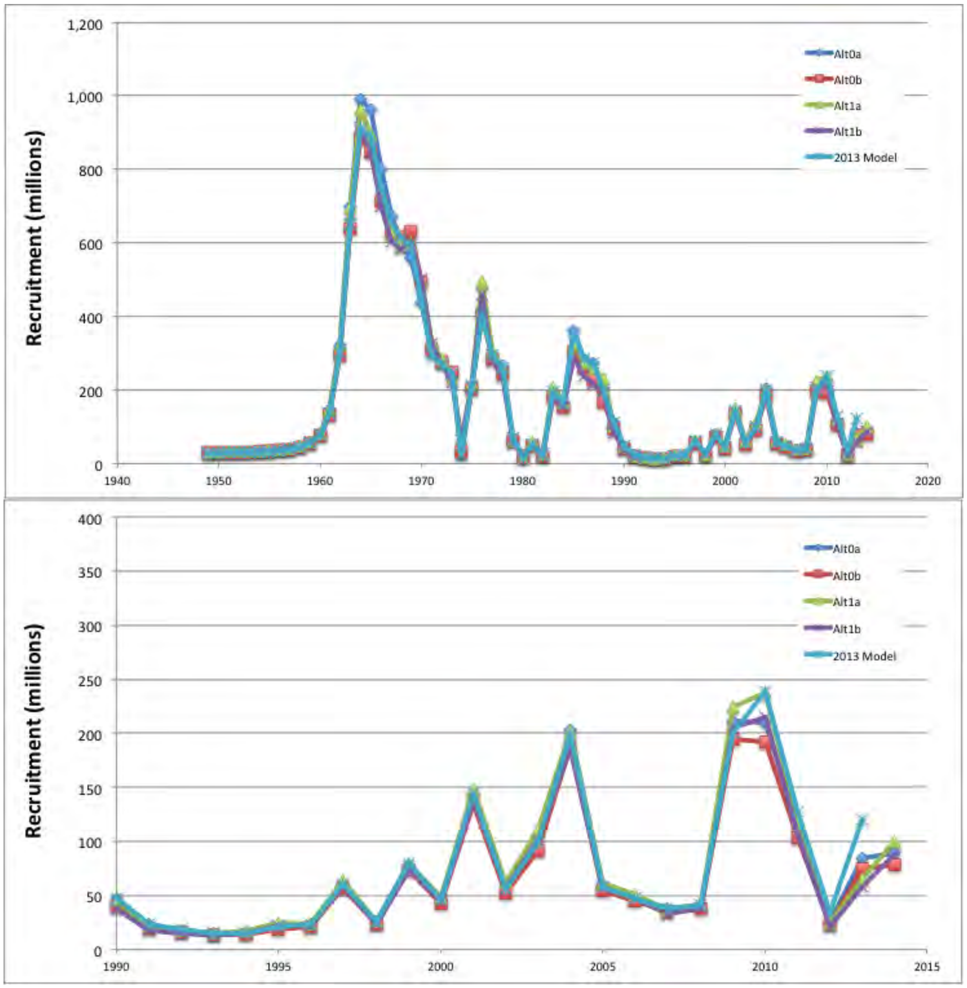


Figure 27. Comparison of model-estimated time series for (male) recruitment from the four alternative models and the 2013 model.

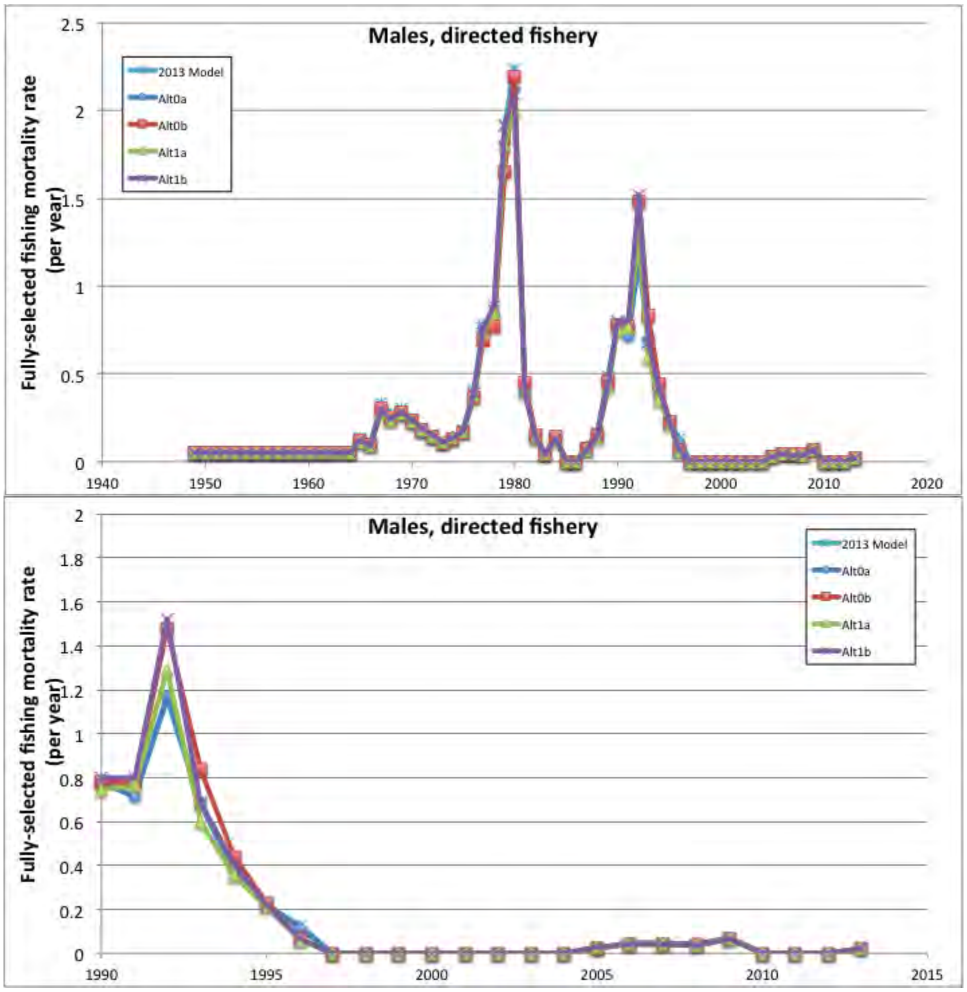


Figure 28. Comparison of model-estimated time series for fully-selected total F (retained + discards) on males in the directed Tanner crab fishery from the four alternative models and the 2013 model.

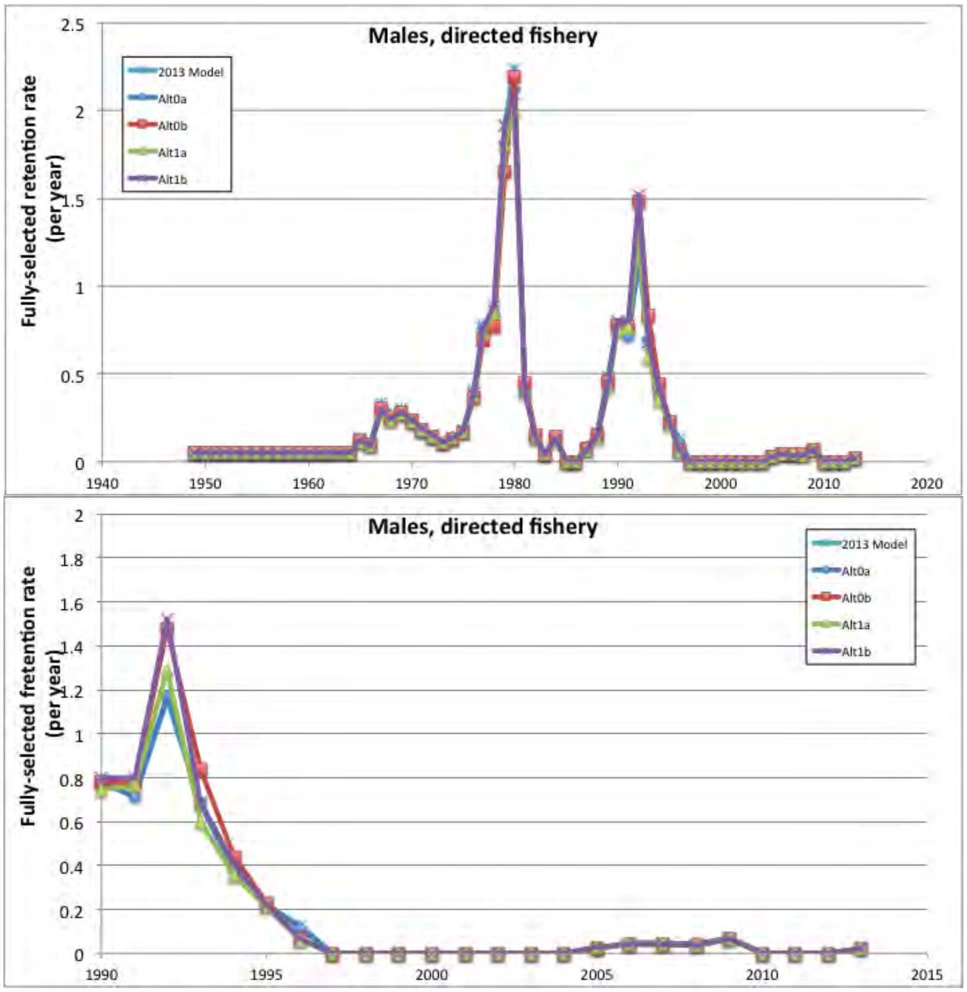
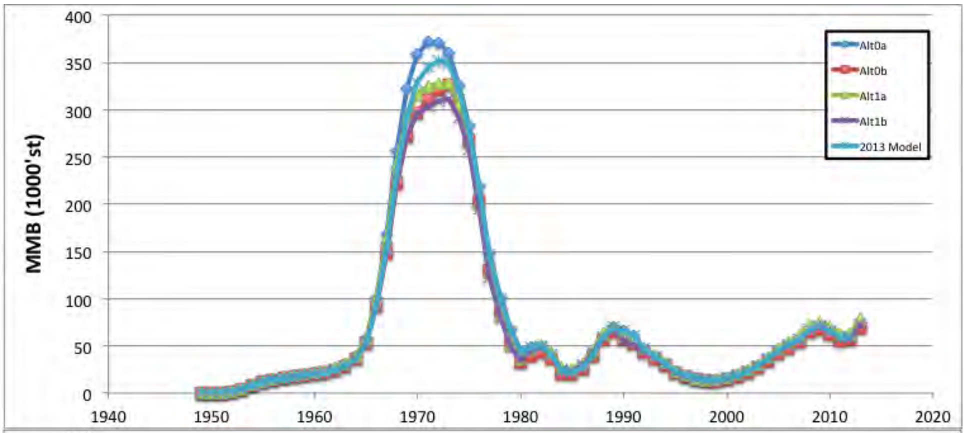


Figure 29. Comparison of model-estimated time series for fully-selected F on retained males in the directed Tanner crab fishery from the four alternative models and the 2013 model.



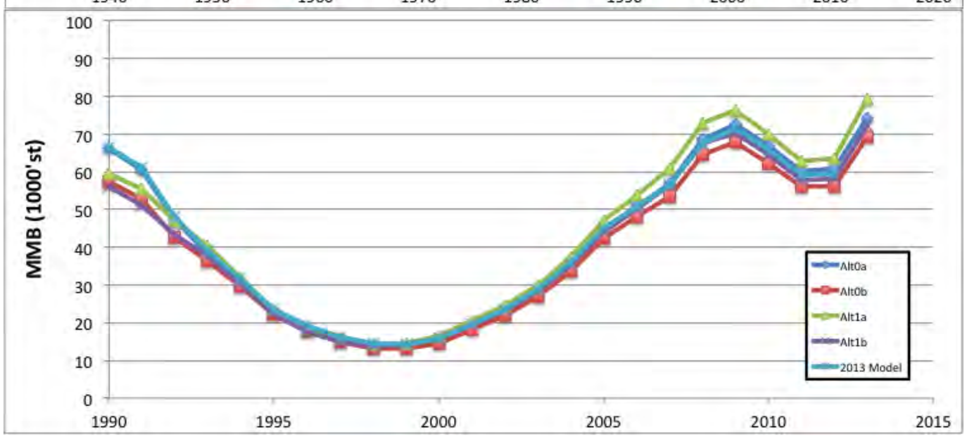


Figure 30. Comparison of estimated time series for mature male biomass at mating time from the four alternative models and the 2013 model.

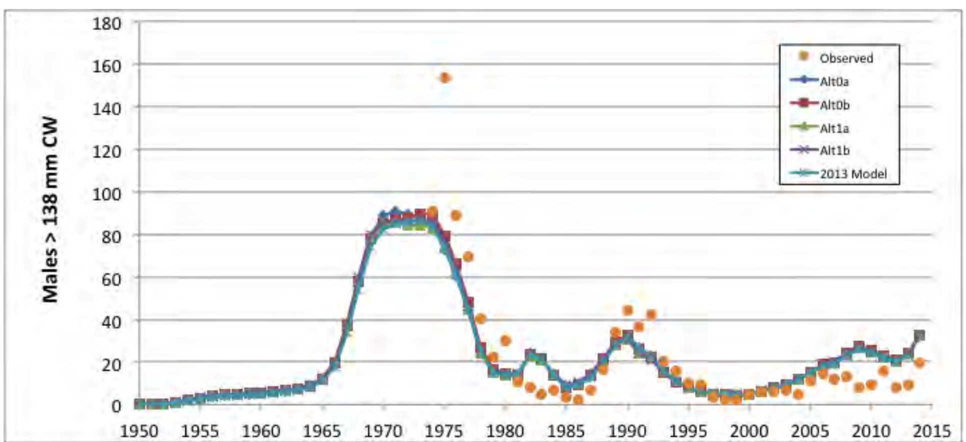
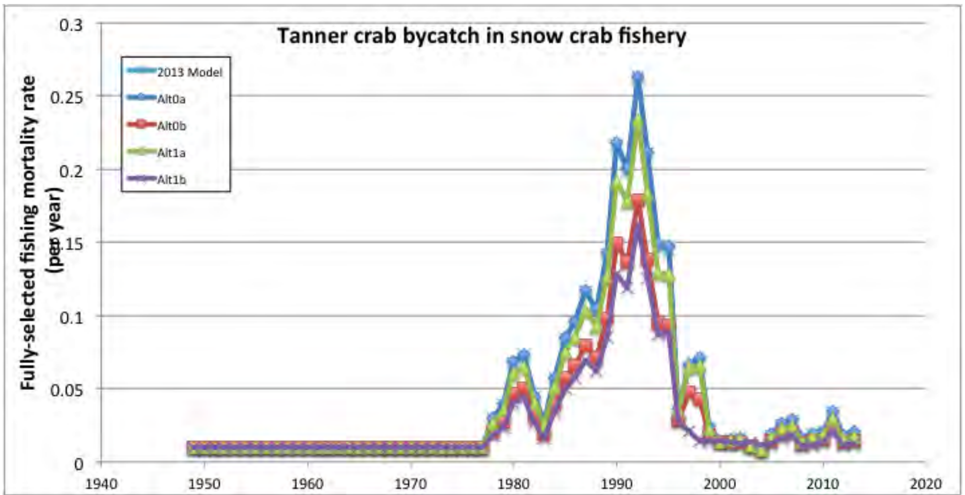


Figure 31. Comparison of observed and estimated survey time series for the number of males ≥ 138 mm CW from the four alternative models and the 2013 model.



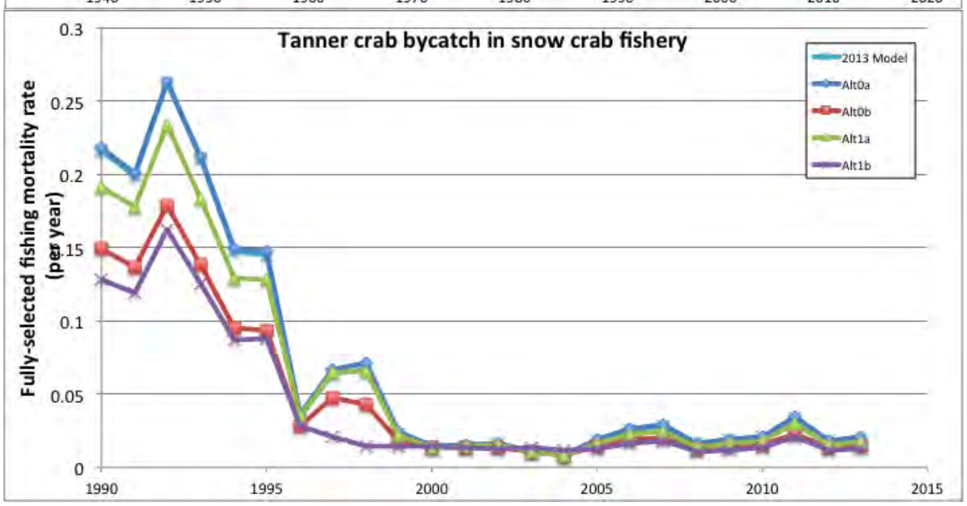


Figure 32. Comparison of model-estimated time series for fully-selected F in the snow crab fishery from the four alternative models and the 2013 model.

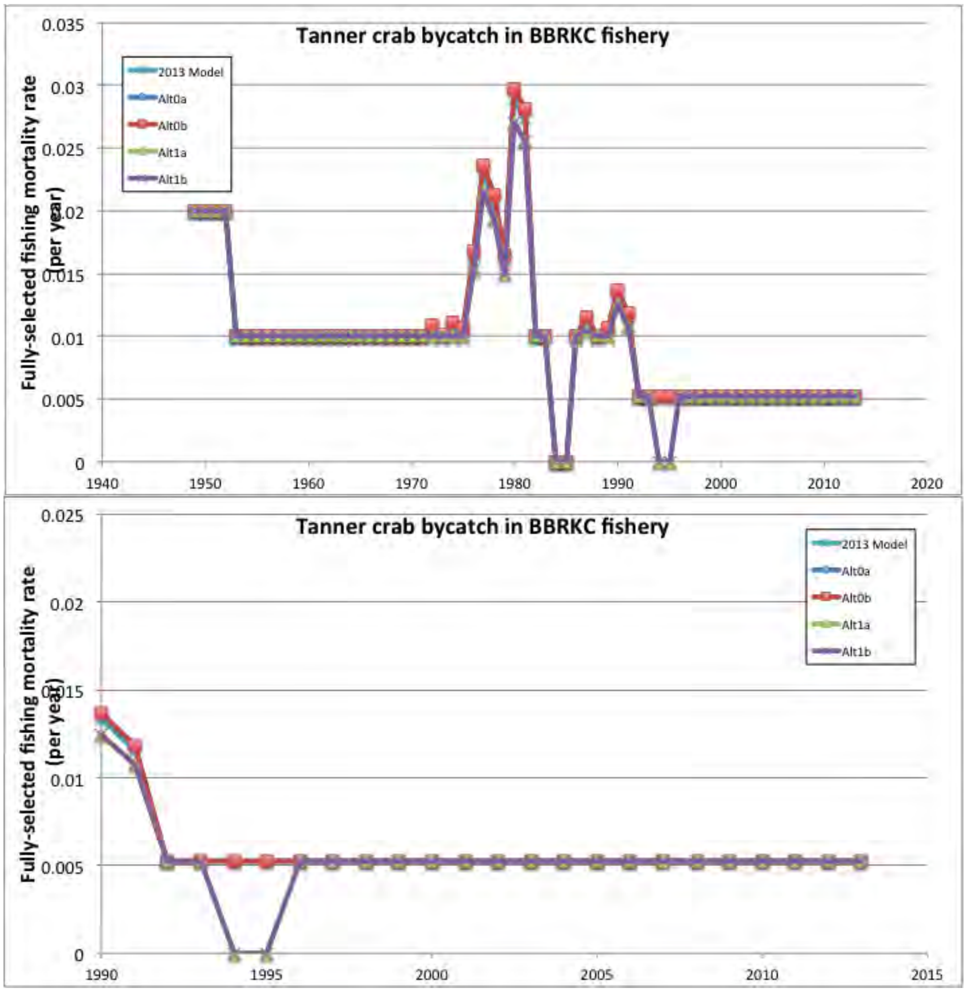


Figure 33. Comparison of model-estimated time series for fully-selected F in the BBRKC fishery from the four alternative models and the 2013 model.

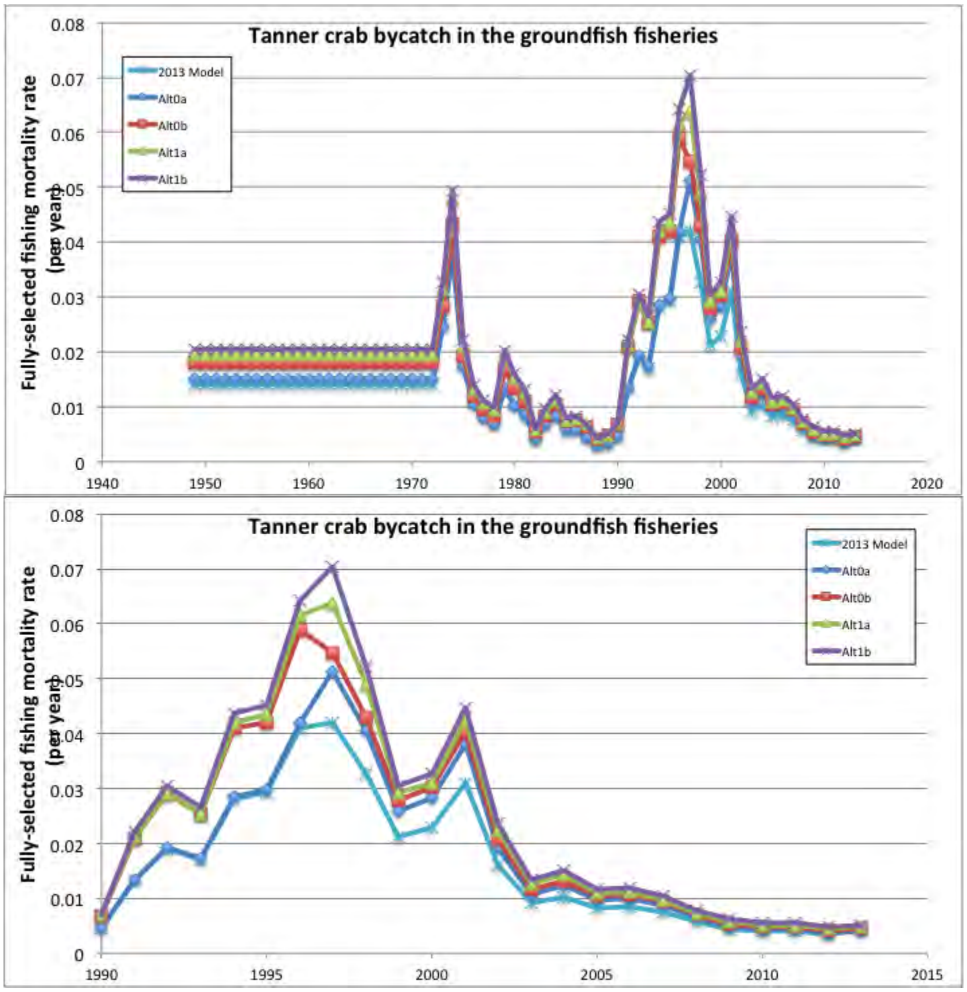


Figure 34. Comparison of model-estimated time series for fully-selected F in the groundfish fisheries from the four alternative models and the 2013 model.

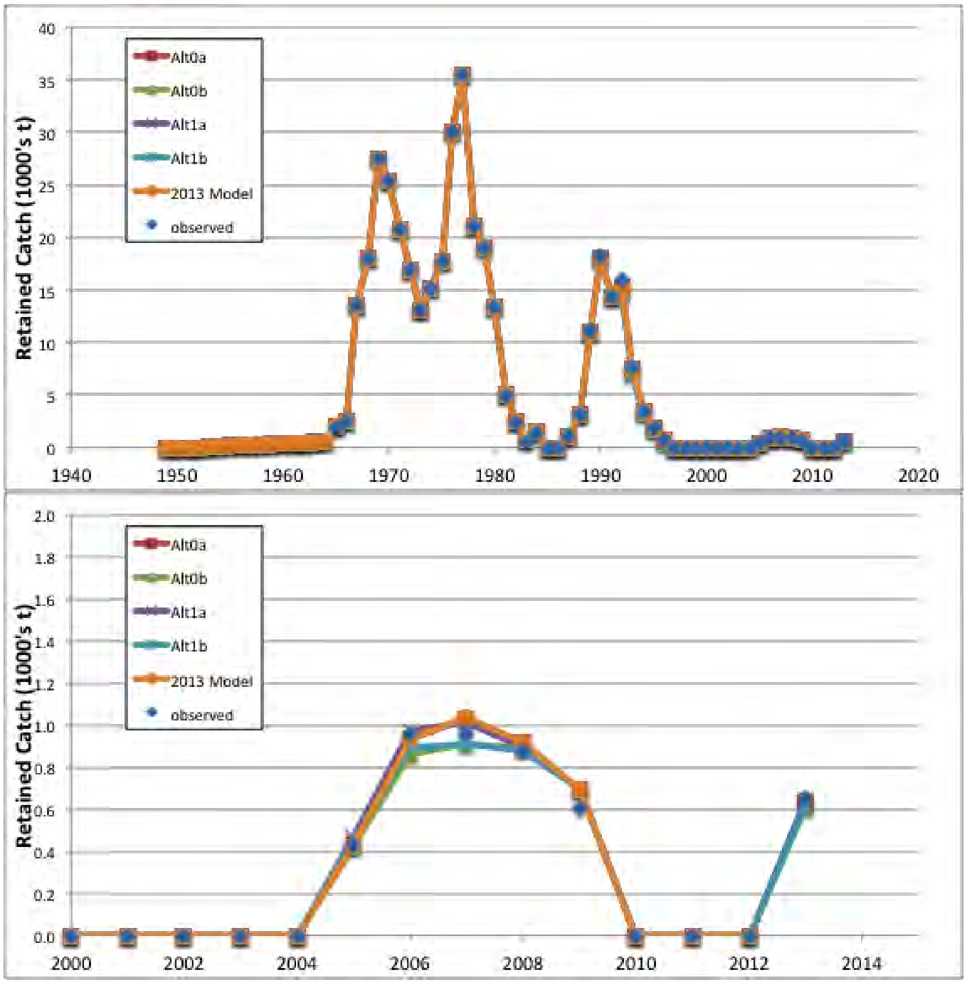
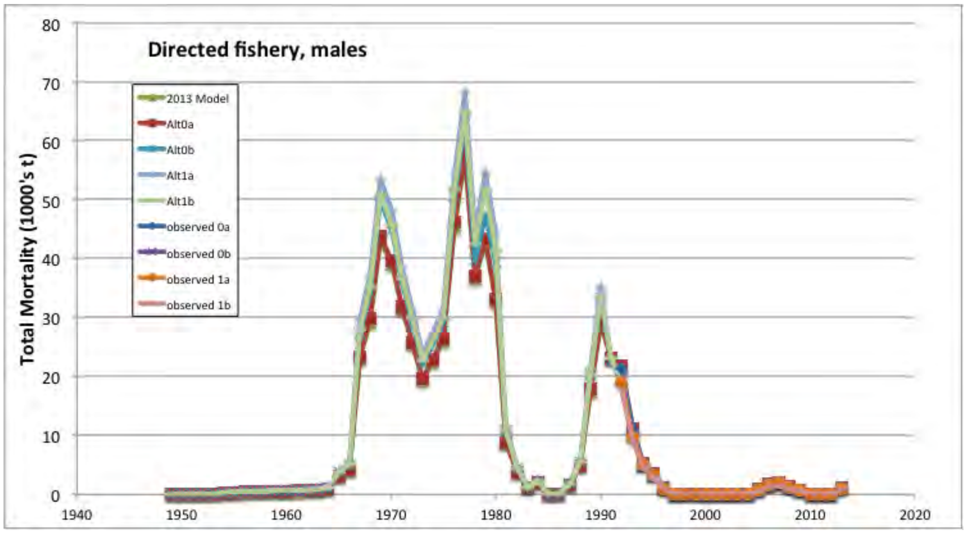


Figure 35. Comparison of estimated time series for retained (male) catch (1000's t) in the directed tanner crab fishery from the four alternative models and the 2013 model with the observed catches.



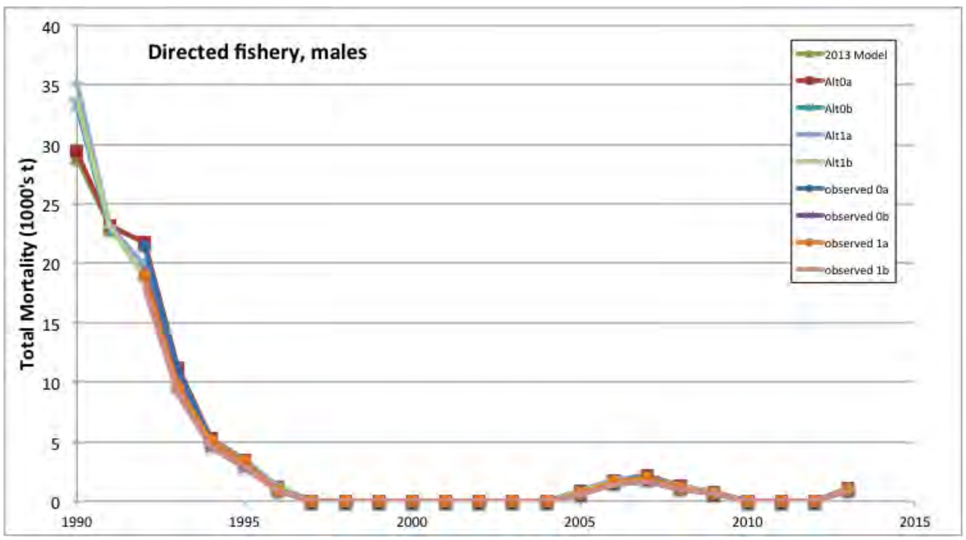


Figure 36. Comparison of estimated time series for total male (retained+discarded) catch (1000's t) in the directed tanner crab fishery from the four alternative models and the 2013 model with the corresponding observed mortality. Note that the "observed" mortality is different for the four alternative models because '0'/'1' models are based on different datasets and 'a'/'b' models use different rates for handling mortality.

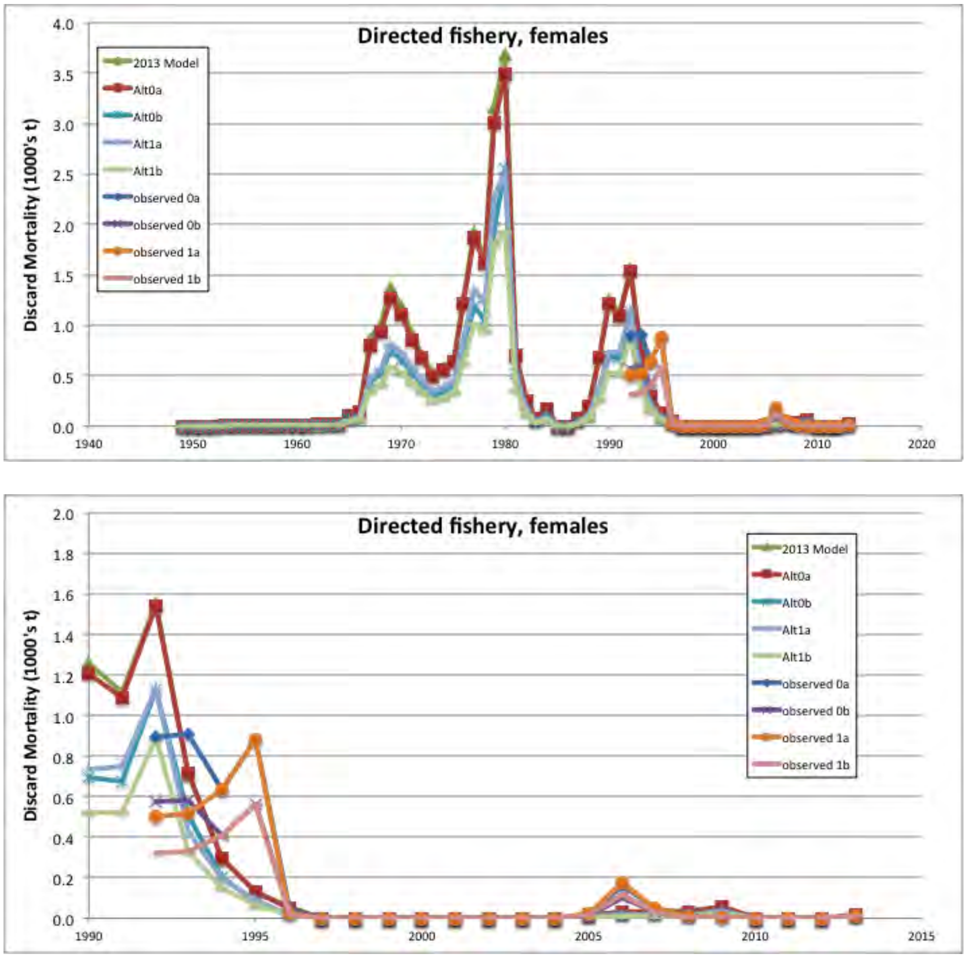


Figure 37. Comparison of "observed" and estimated time series for female discard mortality (1,000's t) in the directed tanner crab fishery from the four alternative models and the 2013 model. Note that the "observed" mortality is different for the four alternative models because '0'/'1' models are based on different datasets and 'a'/'b' models use different rates for handling mortality.

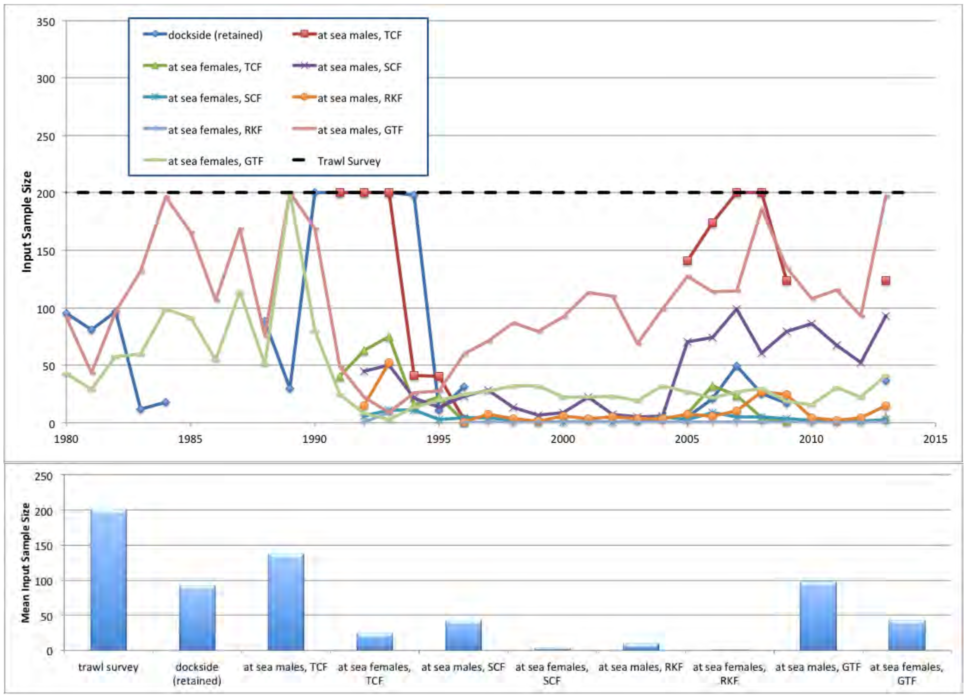


Figure 38. Input sample sizes used for the various likelihood components associated with size frequency data. The upper graph shows the sample by year for each component, the lower graph shows the mean sample size for each component. A value of 200 is used for all trawl survey components.

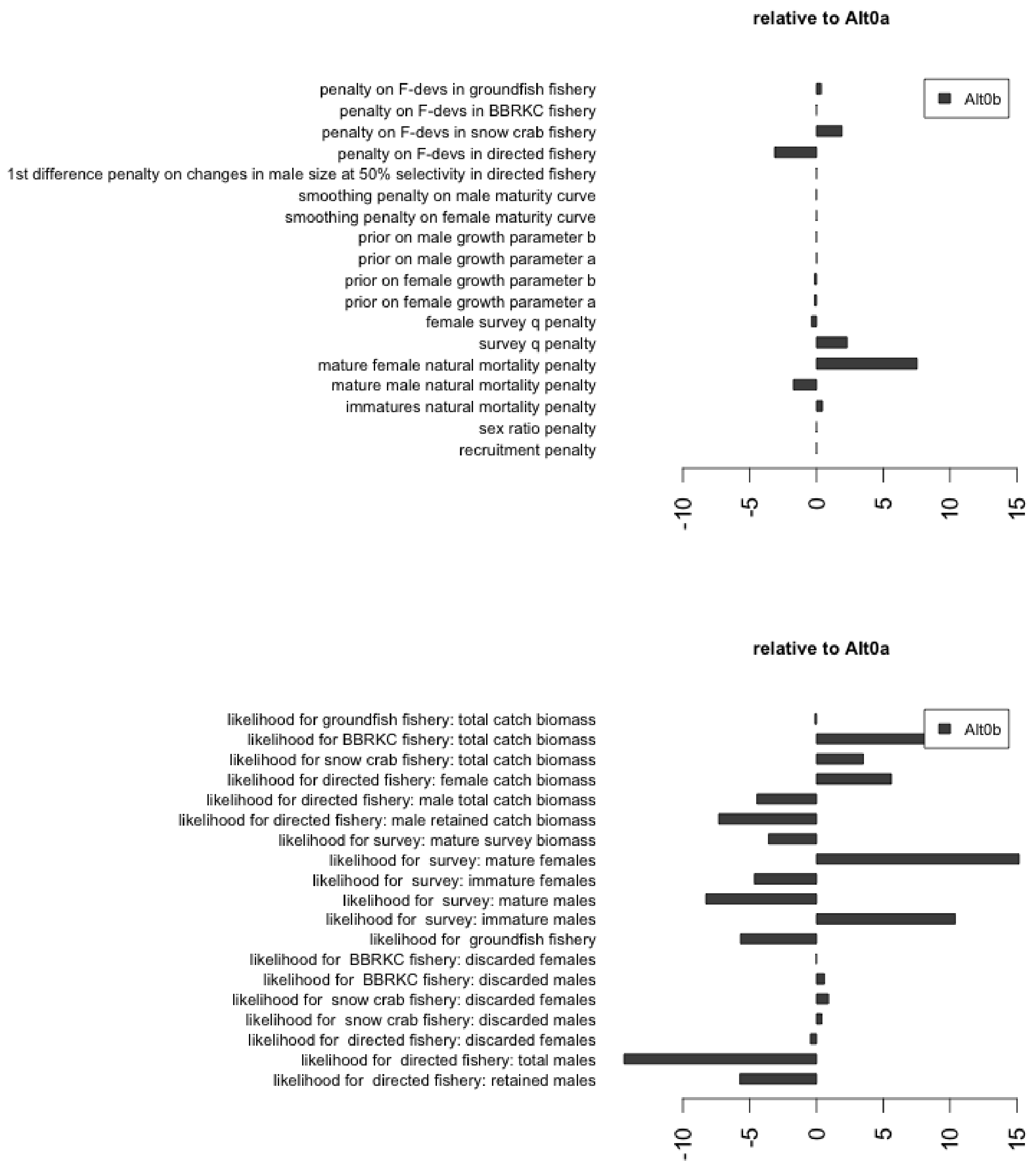


Figure 39. Comparison of the components of the converged objective function values (weights *x* –log-likelihood components) for models Alt0a and Alt0b. Positive values indicate better fits for Alt0b. Overall, the value of the total objective function for Alt0b is 3.60 likelihood units smaller than that for Alt0a.

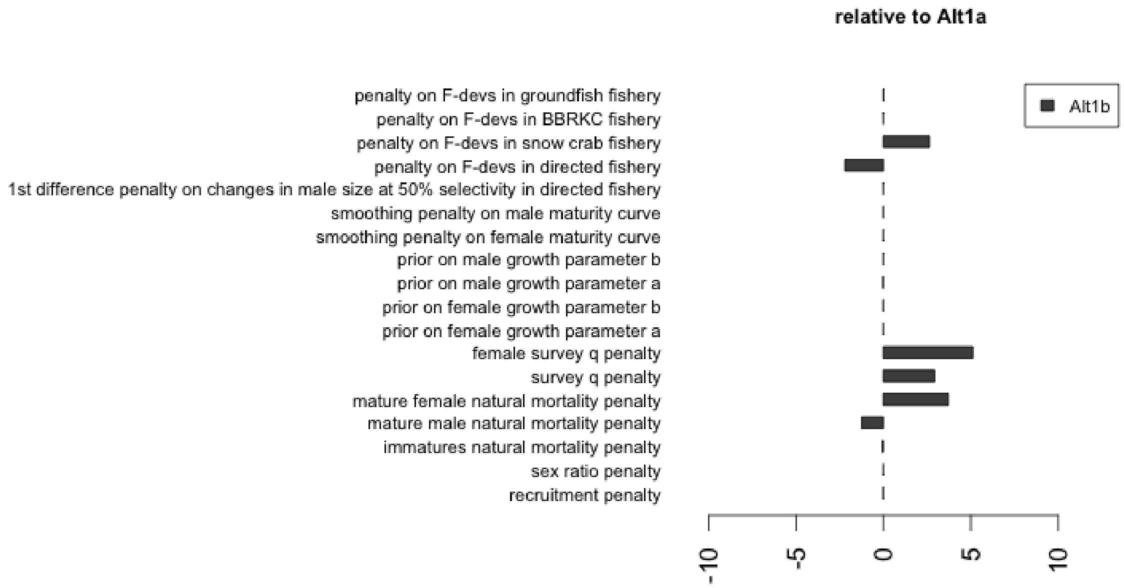


Figure 40. Comparison of the components of the converged objective function values (weights *x* –log-likelihood components) for model Alt1b relative to Alt1a. Positive values indicate better fits for Alt1b. Overall, the value of the total objective function for Alt1a is 6.06 likelihood units smaller than that for Alt1b.

2013 Model Alt1a

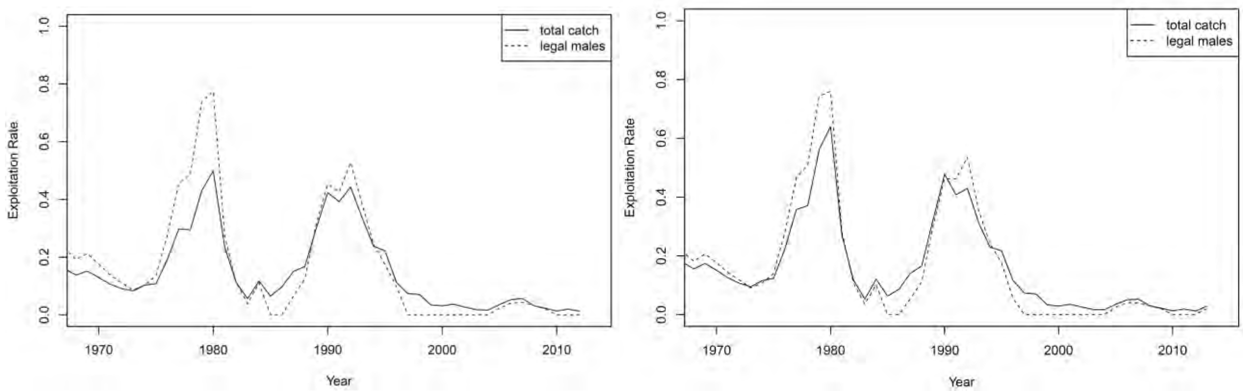
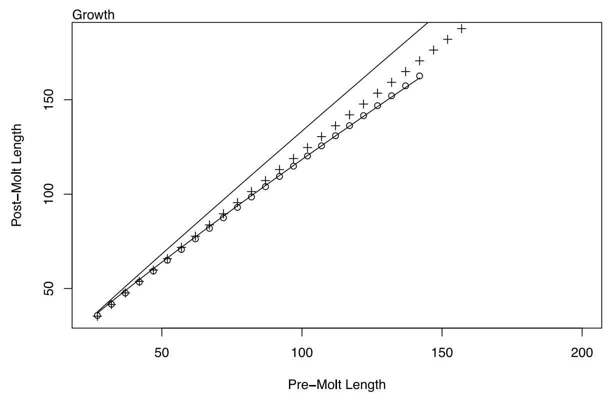


Figure 41. Estimated exploitation rates in the directed fishery for total catch and legal-sized males (≥ 138 mm CW) from the 2013 model (left) and the author's preferred 2014 model, Alt1a (right).

From 2013 Model



Model Alt1a

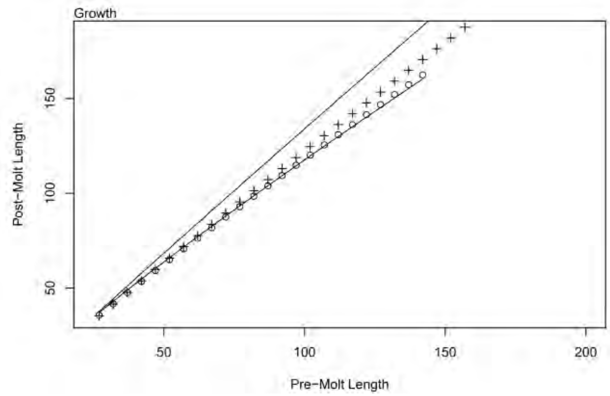
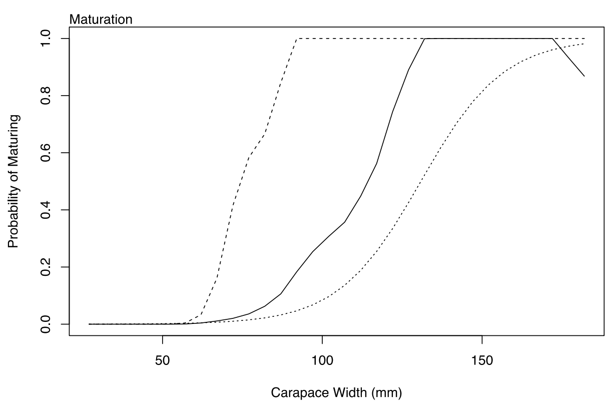


Figure 42. Comparison of model-estimated growth curves (solid lines, upper=males, lower=females) from the author's preferred model, Alt1a, and empirical curves ("+"=males, circles=females) developed from growth data on Tanner crab in the Gulf of Alaska near Kodiak Island.

From 2013 Model



Model Alt1a

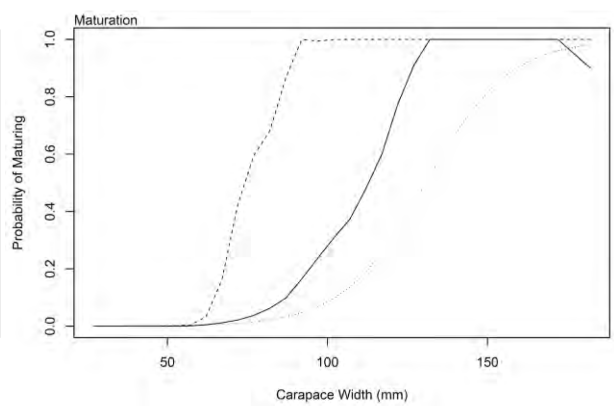


Figure 43. Comparison of model-estimated probability of maturing by size for new shell crab (solid line = males, dashed line = females) from the author's preferred model, Alt1a, with that used for males (dotted line) in the Amendment 24 OFL analysis (NPFMC 2007).

From 2013 Model Model Alt1a

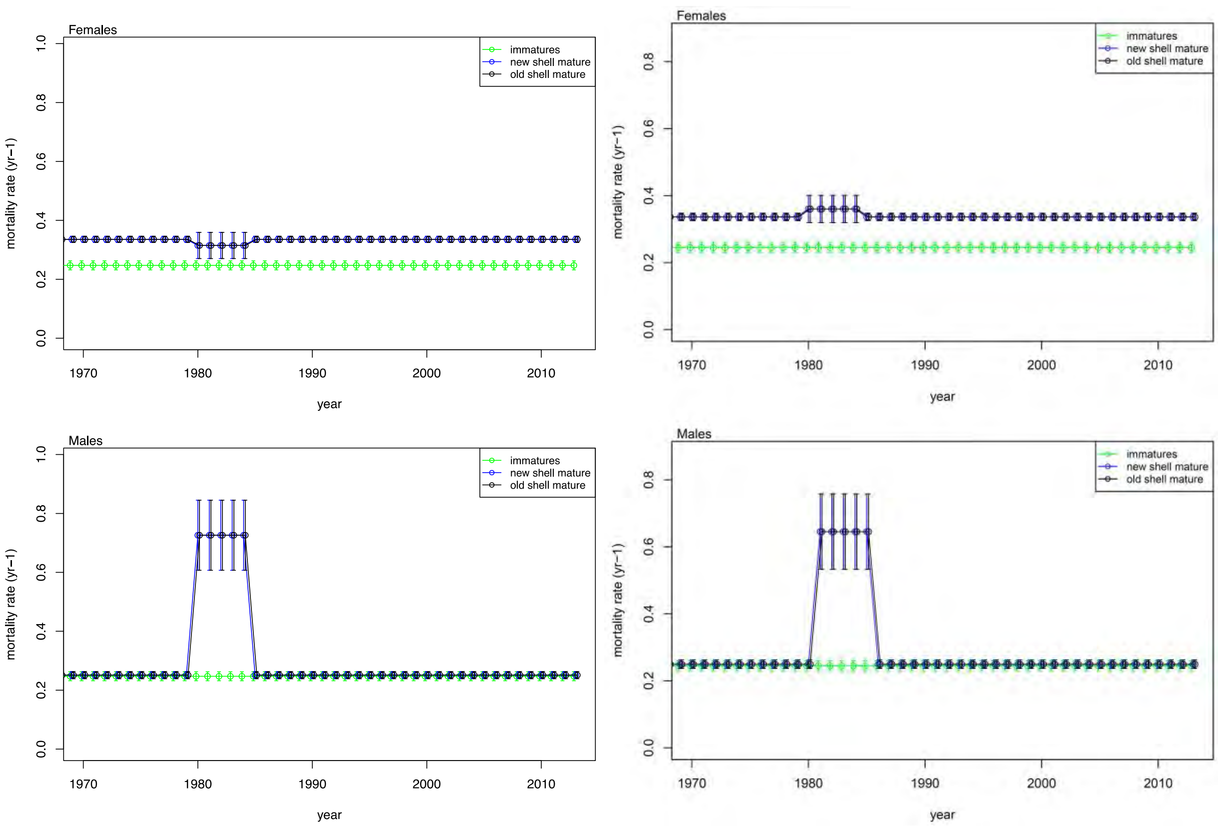


Figure 44. Estimated natural mortality for immature (single time period: 1949-2013) and mature (two time periods: 1949-1979+2005-2013 and 1980-1984) crab by sex (upper graph: females; lower graph: males) from the author's preferred model, Alt1b.

From 2013 Model Model Alt1a

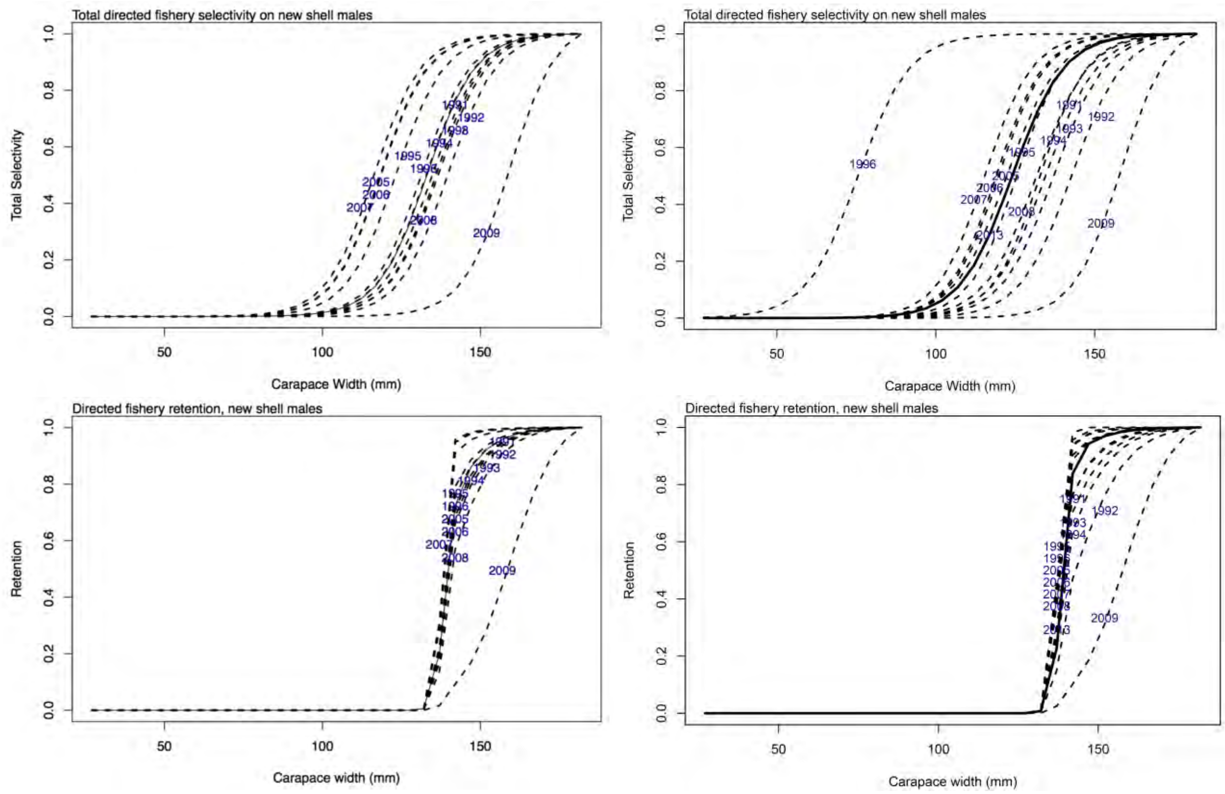


Figure 45.Estimated annual selectivity curves (solid line, pre-1991; dashed lines, 1991-2009) in the directed Tanner crab fishery for all new shell males (upper graph) and retained crab (lower graph) from the 2013 model (left column) and the author's preferred 2014 model, Alt1a(right column). The year indicated denotes the beginning of the fishery year; e.g. "2009" indicates the 2009/10 fishery year. Selectivity curves for old shell males are identical to those for new shell males.

2013 Model Alt1a

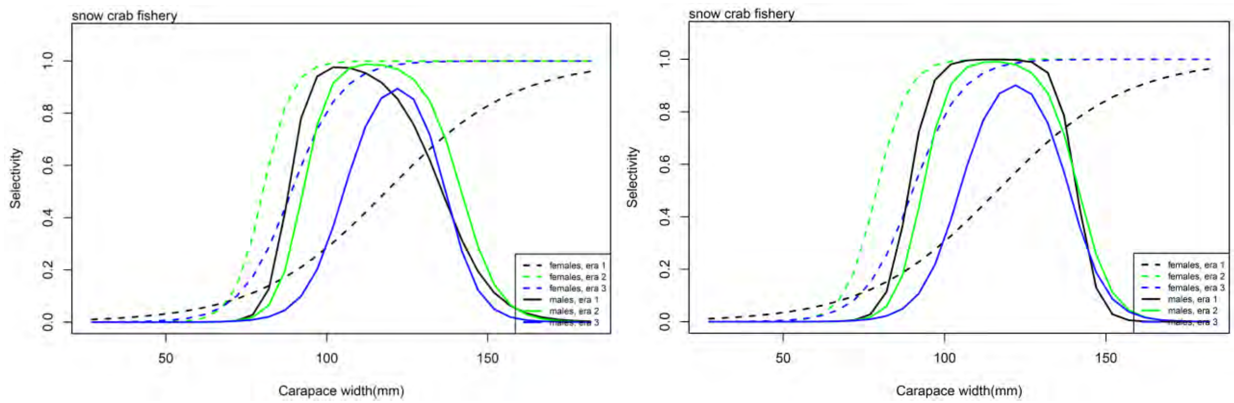


Figure 46. Estimated selectivity curves by sex (solid lines = males, dashed lines = females) for 3 eras in the snow crab fishery (era 1 [1989-1996] =black lines, era 2 [1997-2004] = green lines, era 3 [2005-present] = blue lines) from the 2013 model (left) and author's preferred 2014 model, Alt1a (right).

2013 Model Alt1a

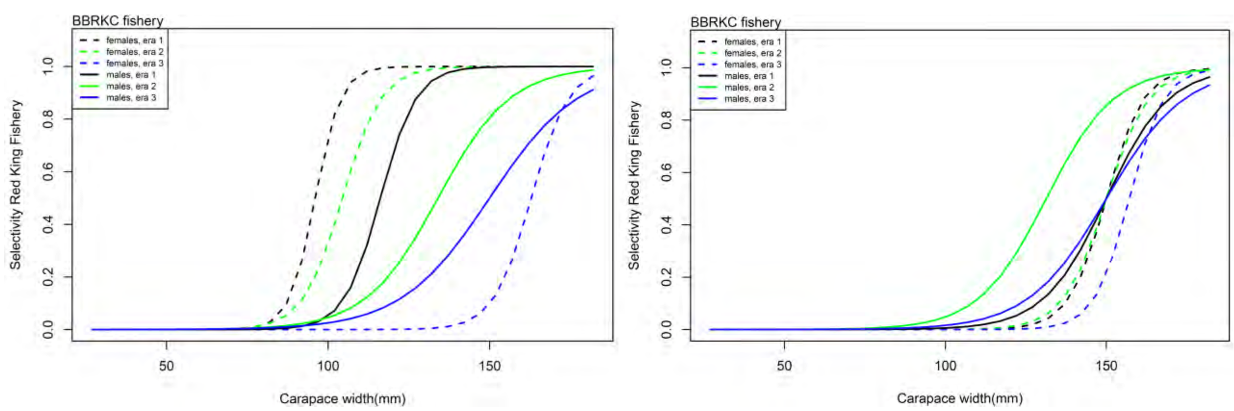


Figure 47. Estimated selectivity curves by sex (solid lines = males, dashed lines = females) for 3 eras in the BBRKC fishery (era 1 [1989-1996] =black lines, era 2 [1997-2004] = green lines, era 3 [2005-present] = blue lines) from the 2013 model (left) and author's preferred 2014 model, Alt1a (right).

2013 Model Alt1a

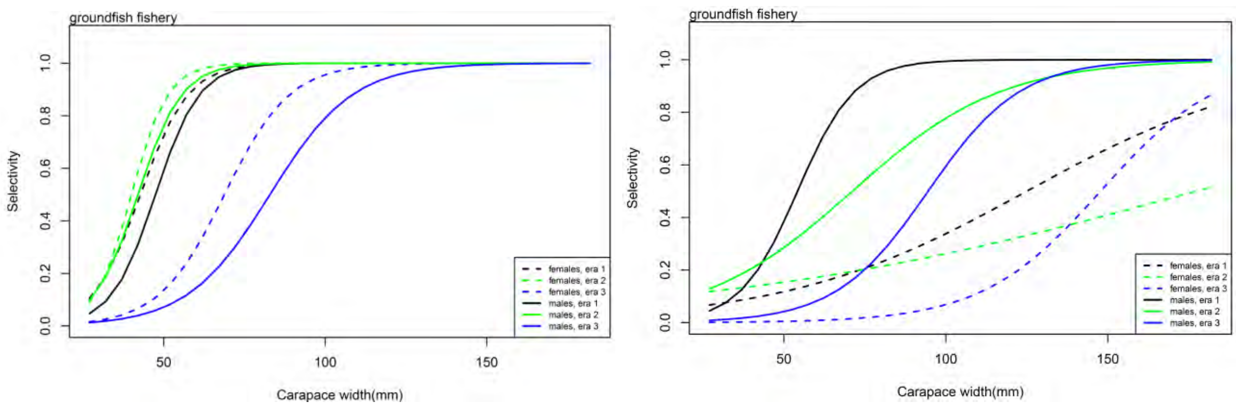


Figure 48. Estimated selectivity curves by sex (solid lines = males, dashed lines = females) for 3 eras in the groundfish fisheries (era 1[1973-1987] =black lines, era 2 [1988-1996] = green lines, era 3 [1997-present] = blue lines) from the 2013 model (left) and author's preferred 2014 model, Alt1a (right).

2013 Model Alt1a

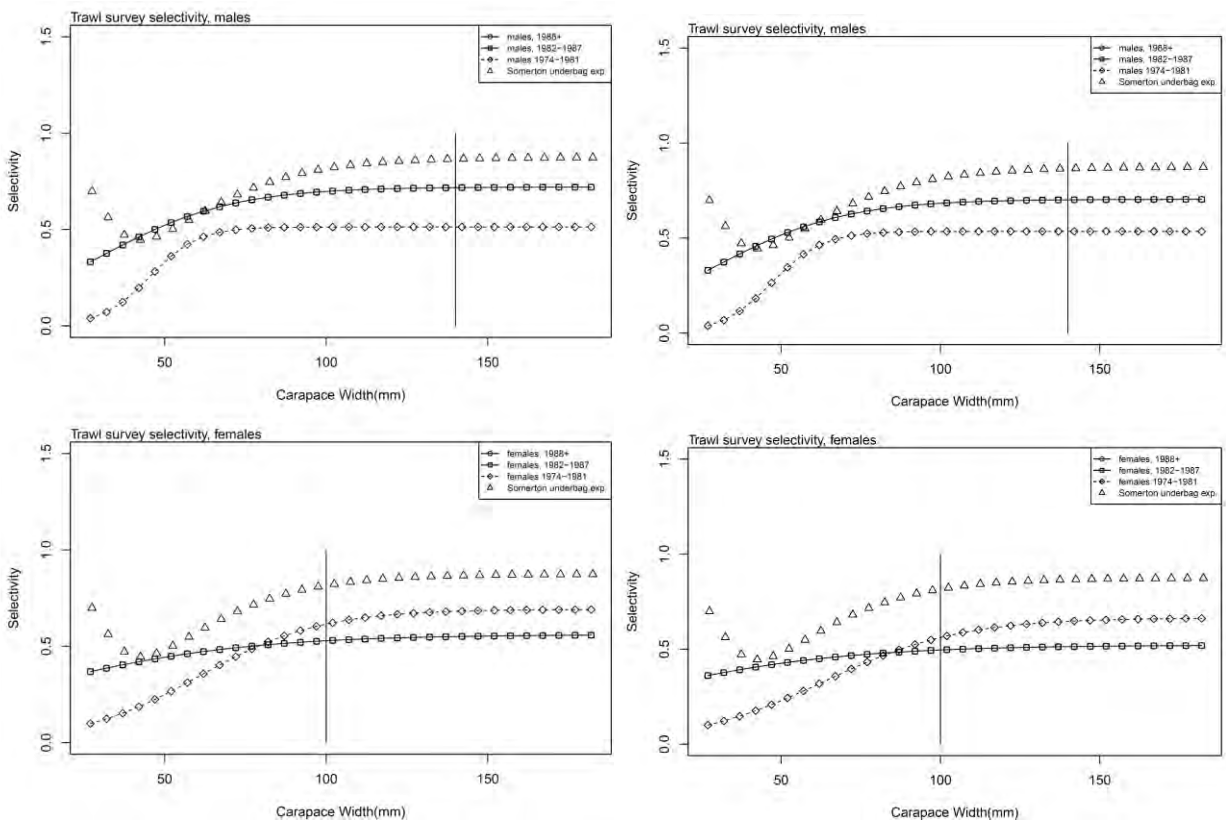


Figure 49. Comparison of estimated sex-specific selectivity curves for the NMFS bottom trawl survey in three time periods with those obtained by Somerton and Otto (1999) in the underbag experiment. The curves for 1982-87 and 1988+ are identical. Vertical lines indicate the size corresponding to survey q for both sexes. Left column: 2013 model (left), right column: author's preferred 2014 model, Alt1a.

2013 Model Alt1a

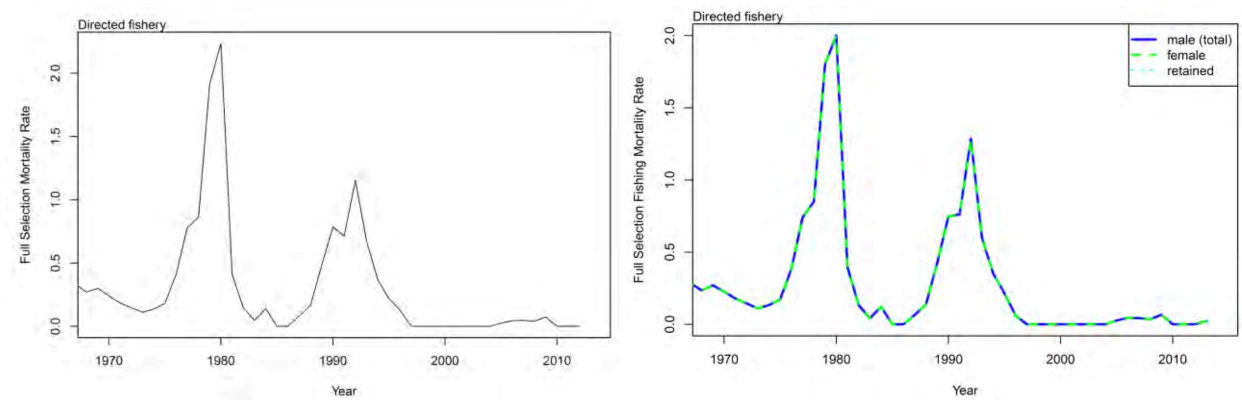


Figure 50. Estimated full selection fishing mortality in the directed fishery from the 2013 model (left) and the author's preferred 2014 model, Alt1a (right).

2013 Model Alt1a

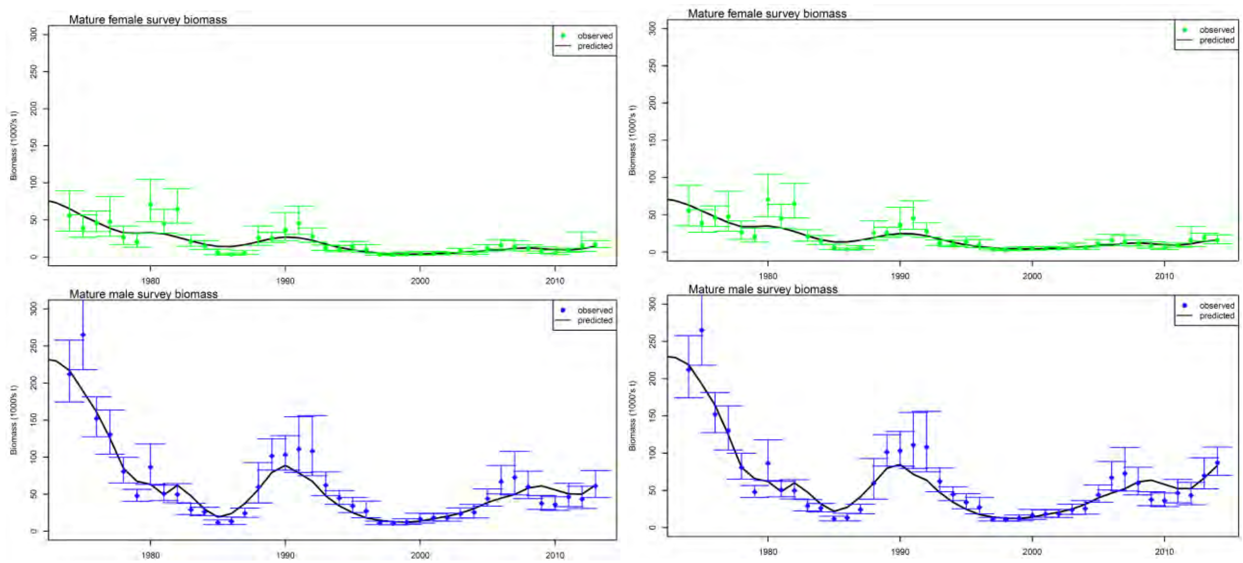


Figure 51. Comparison of observed survey biomass (circles with 95% CIs) and predicted survey biomass (solid line) for mature females (upper graph) and mature males (lower graph) from the 2013 model (left) and the author's preferred 2014 model, Alt1a (right).

2013 Model Alt1a

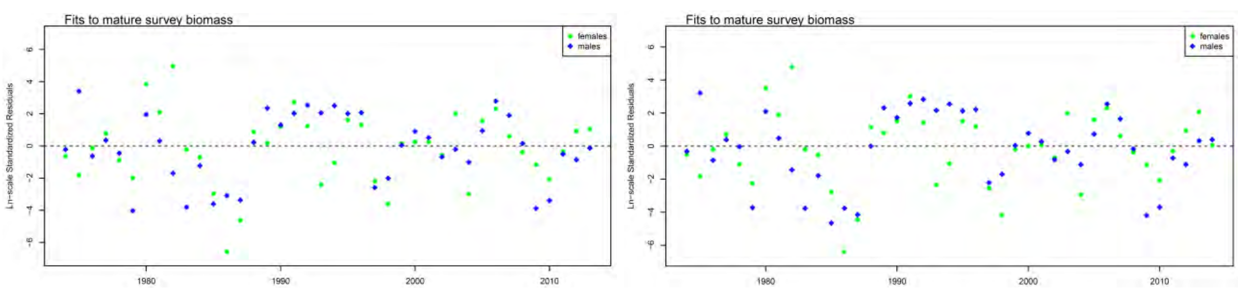


Figure 52. Standardized residuals (ln-scale) of mature survey biomass from the 2013 model (left) and the author's preferred 2014 model, Alt1a (right).

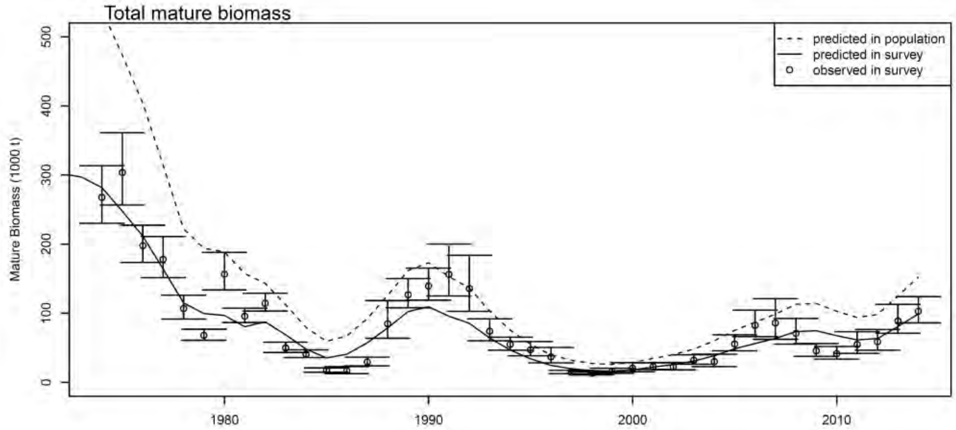


Figure 53. Comparison of observed survey biomass for mature crab (circles with 95% CIs), predicted survey biomass for mature crab (solid line) and predicted spawning (males + females) biomass (dashed line) from the author's preferred model, Alt1a.

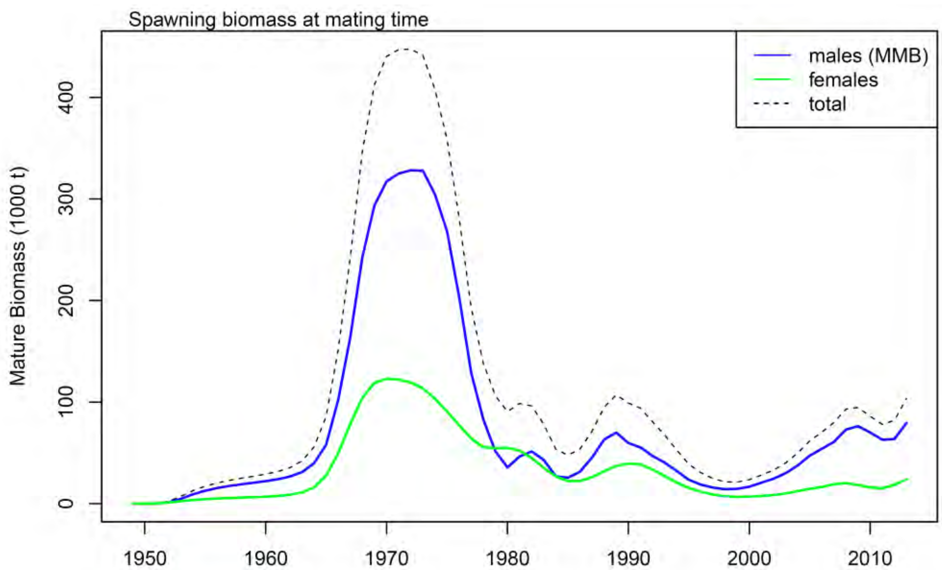


Figure 54.Model-predicted mature biomass at mating time for males (i.e., MMB; blue line), females (green line), and total (dotted line), from the author's preferred model, Alt1a.

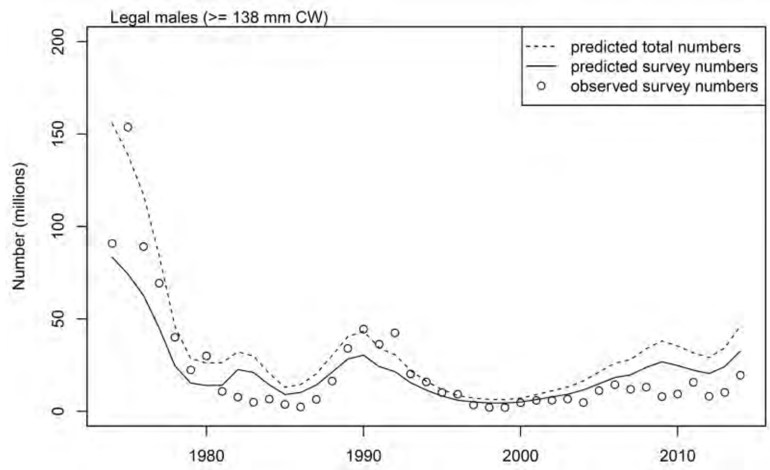


Figure 55. Comparison of numbers of male crab ≥ 138 mm CW in the trawl survey with predicted total survey numbers from the author's preferred model Alt1a.

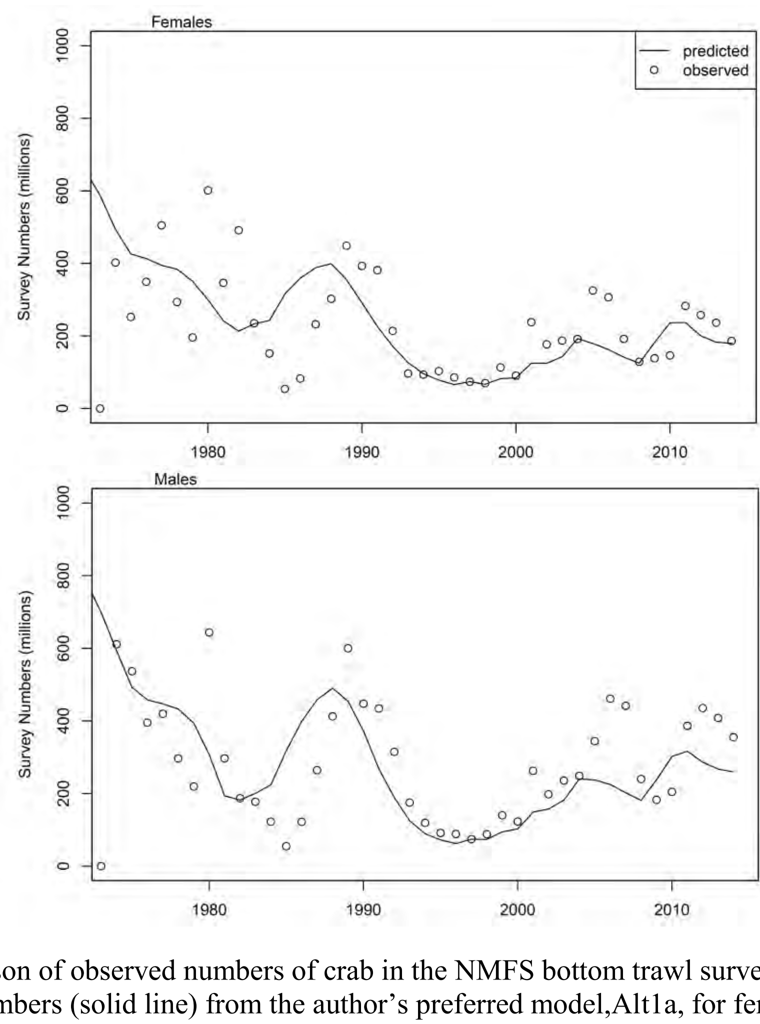


Figure 56. Comparison of observed numbers of crab in the NMFS bottom trawl survey (circles) and predicted survey numbers (solid line) from the author's preferred model,Alt1a, for females (top graph) and males (bottom graph).

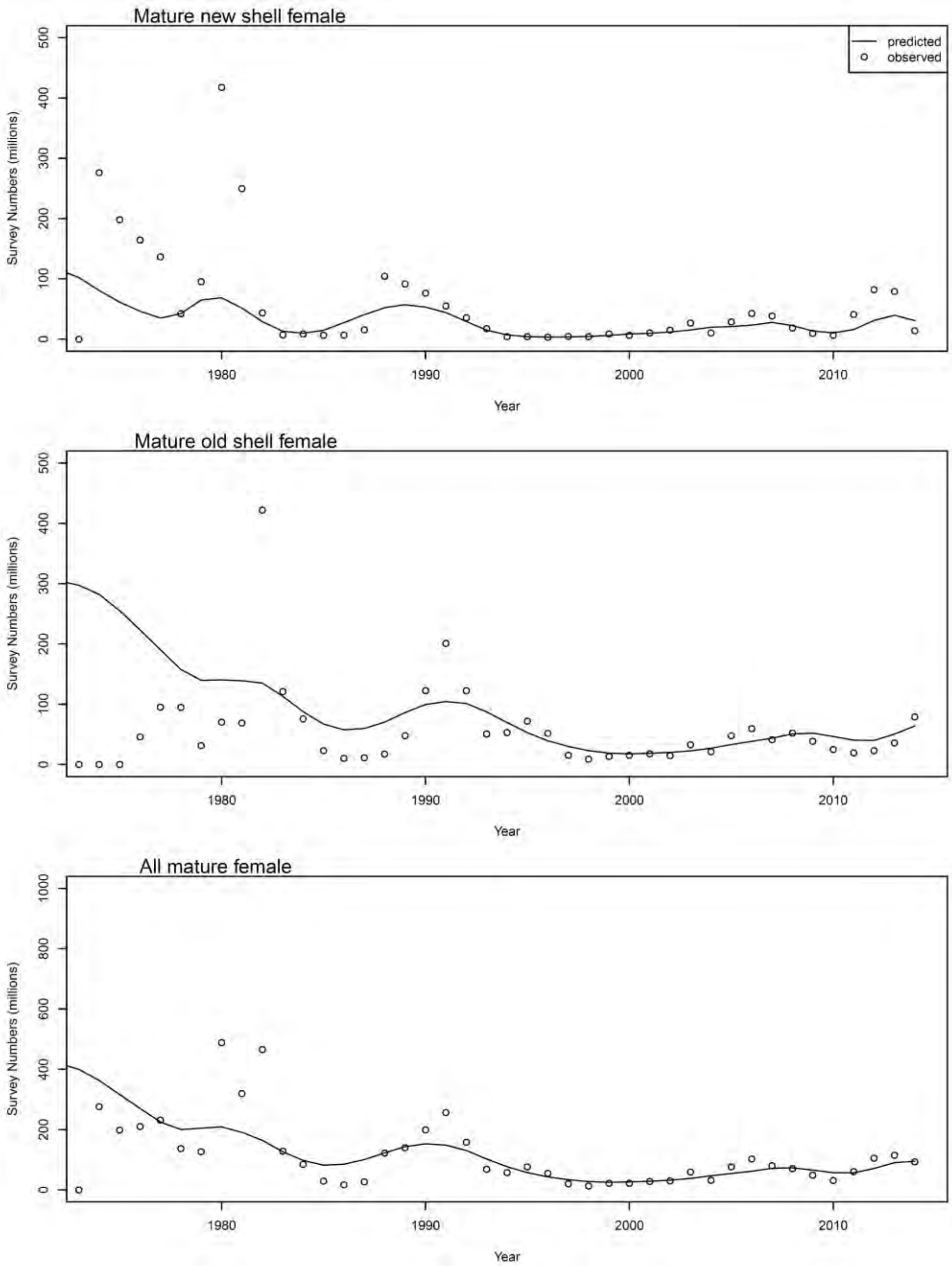


Figure 57. Comparison of observed numbers in the NMFS bottom trawl survey for mature males by shell condition (new shell, old shell) and combined with predictions from the author's preferred model, Alt1a.

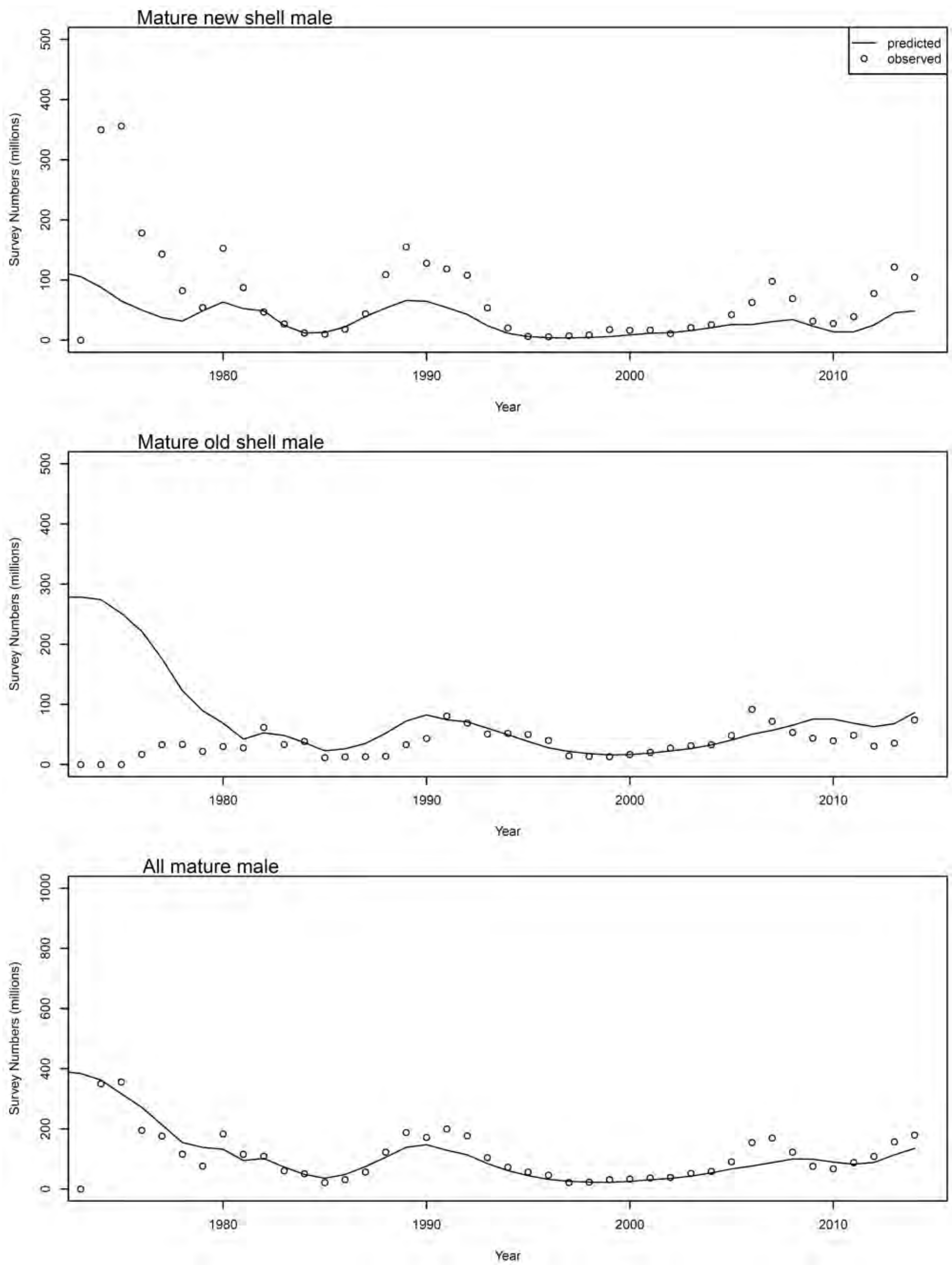
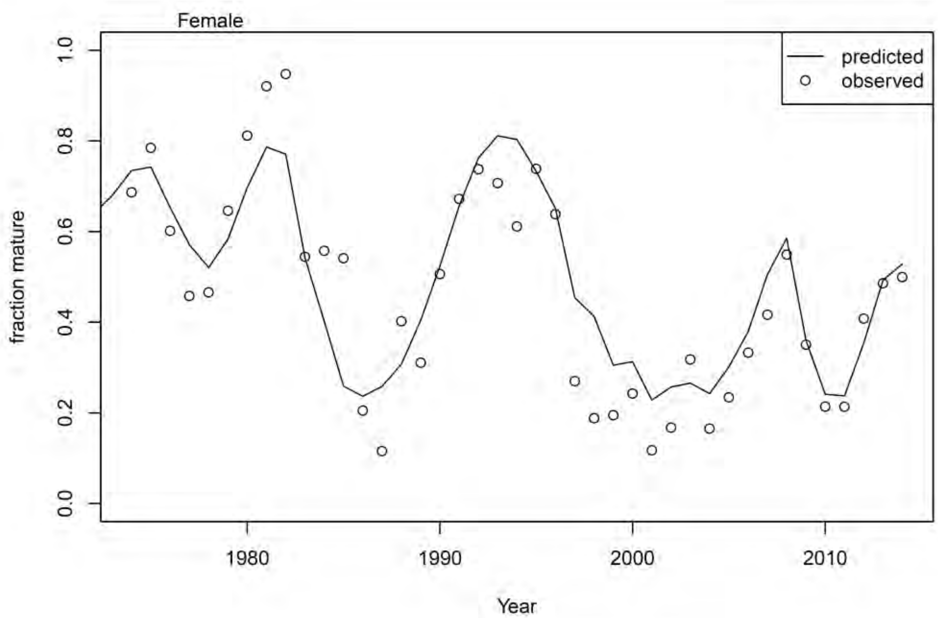


Figure 58. Comparison of observed numbers in the NMFS bottom trawl survey for mature males by shell condition (new shell, old shell) and combined with predictions from the author's preferred model, Alt1a.



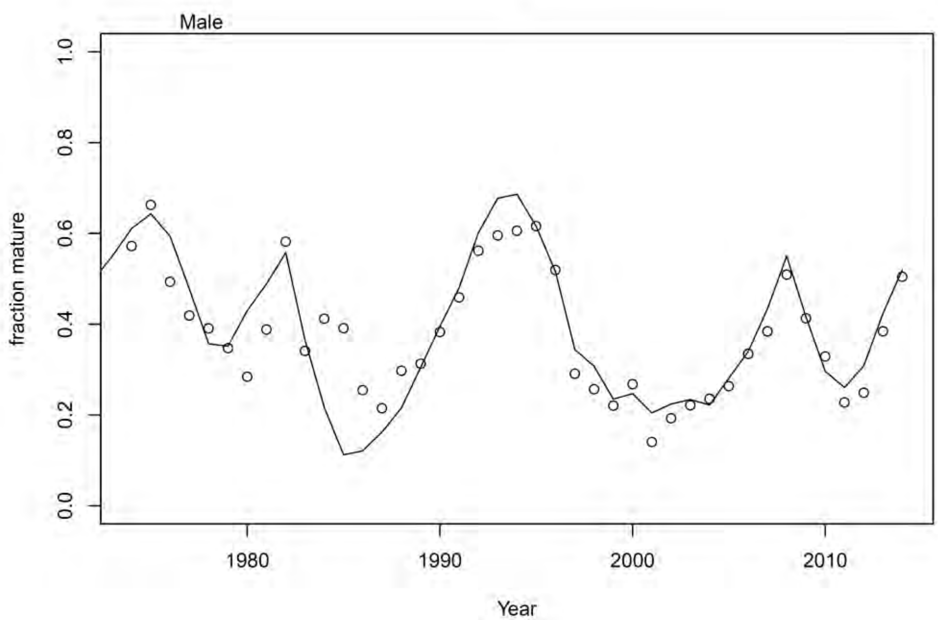


Figure 59. Comparison of estimates of the fraction of mature crab by sex in the NMFS bottom trawl survey and as predicted by the author's preferred model, Alt1a.

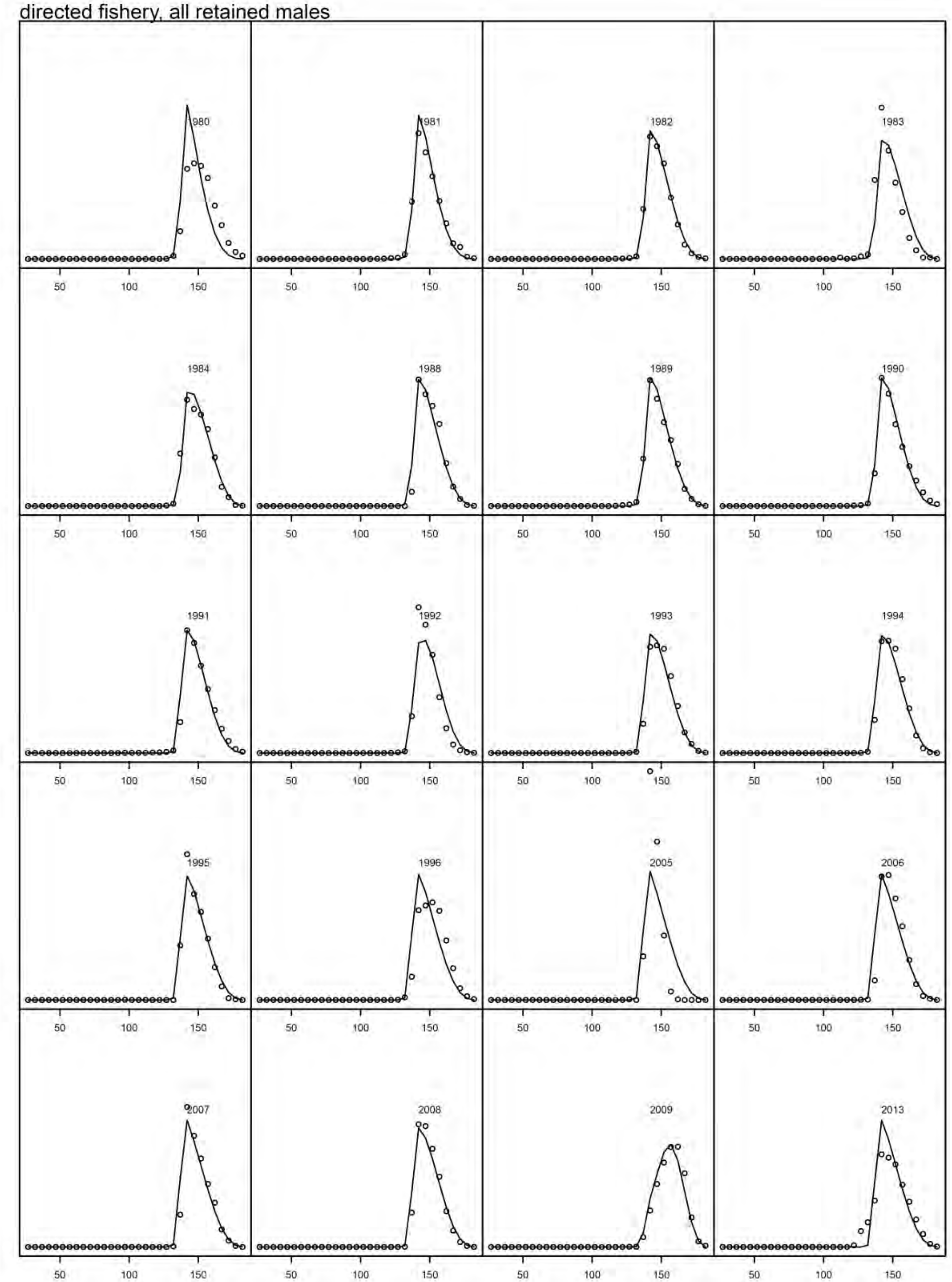


Figure 60. Comparison of predicted (solid line) and observed (circles) proportions-at-size for retained males in the directed Tanner crab fishery from the author's preferred model (Alt1a).

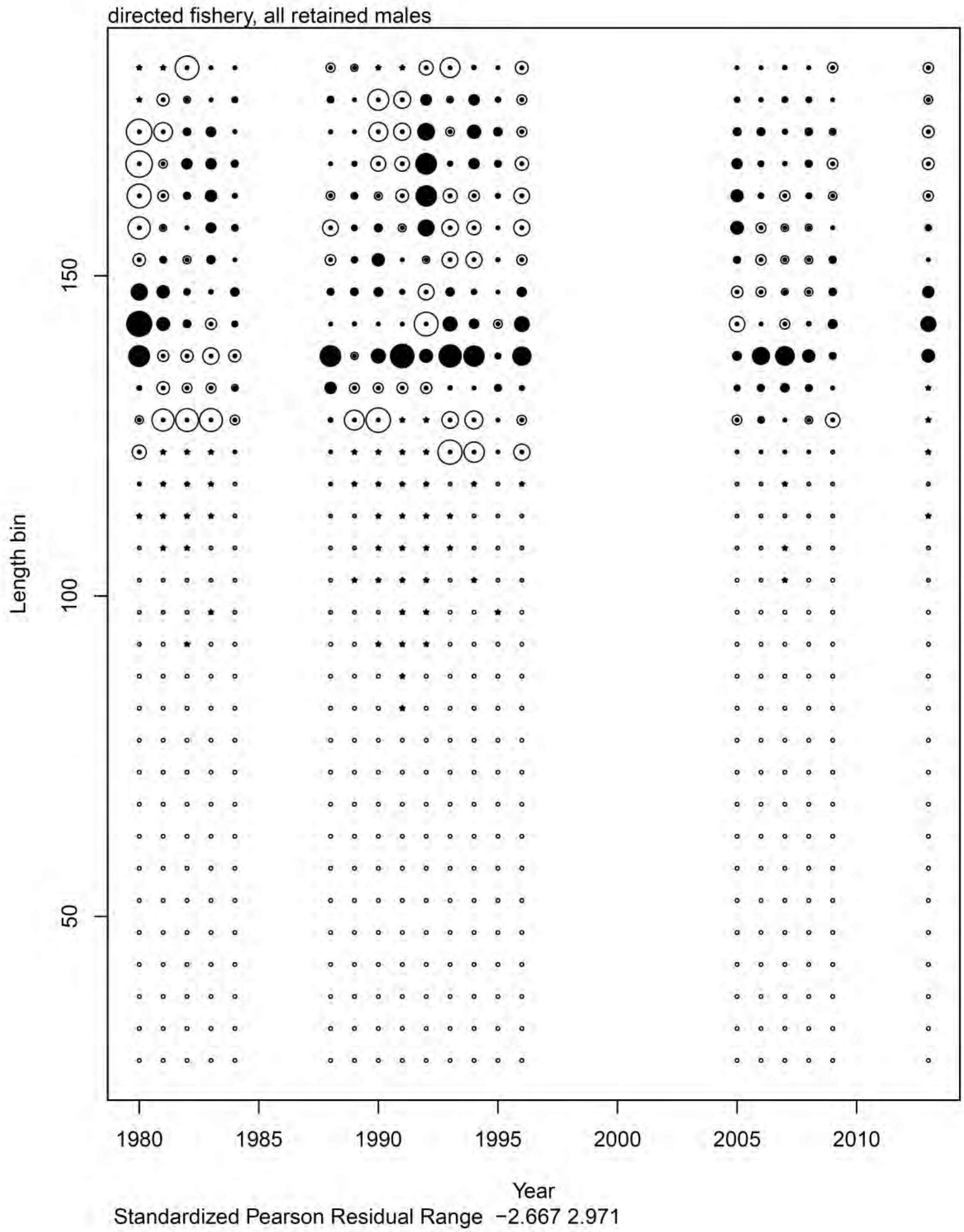


Figure 61.Pearson residuals for predicted proportions at size for retained males in the directed Tanner crab fishery for the author’s preferred model (Alt1a). White circles represent positive anomalies (observed>predicted), black circles represent negative anomalies.

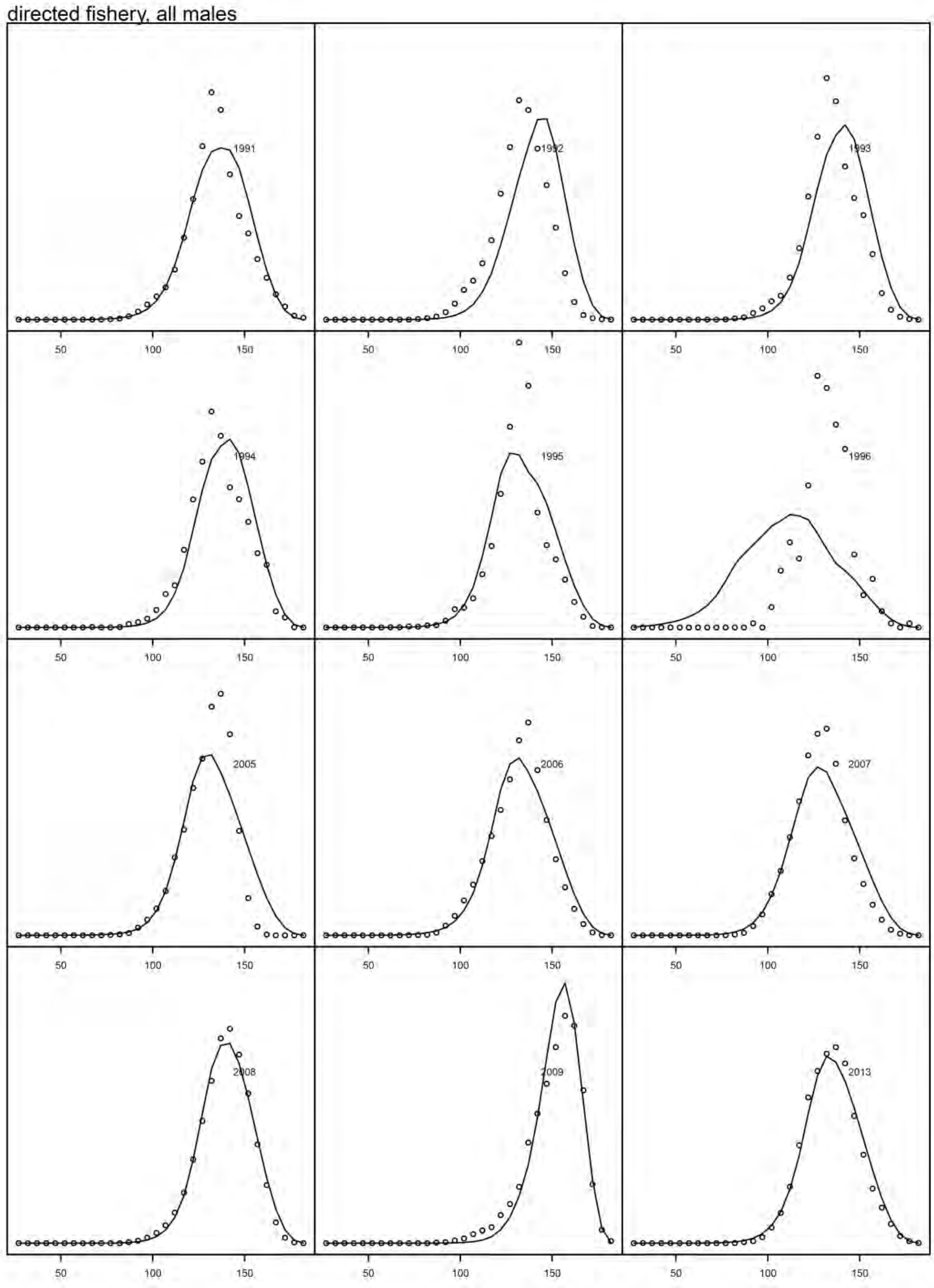


Figure 62. Comparison of predicted (solid line) and observed (circles) proportions-at-size for all males (retained+discarded) males in the directed Tanner crab fishery from the author's preferred model, Alt1a.

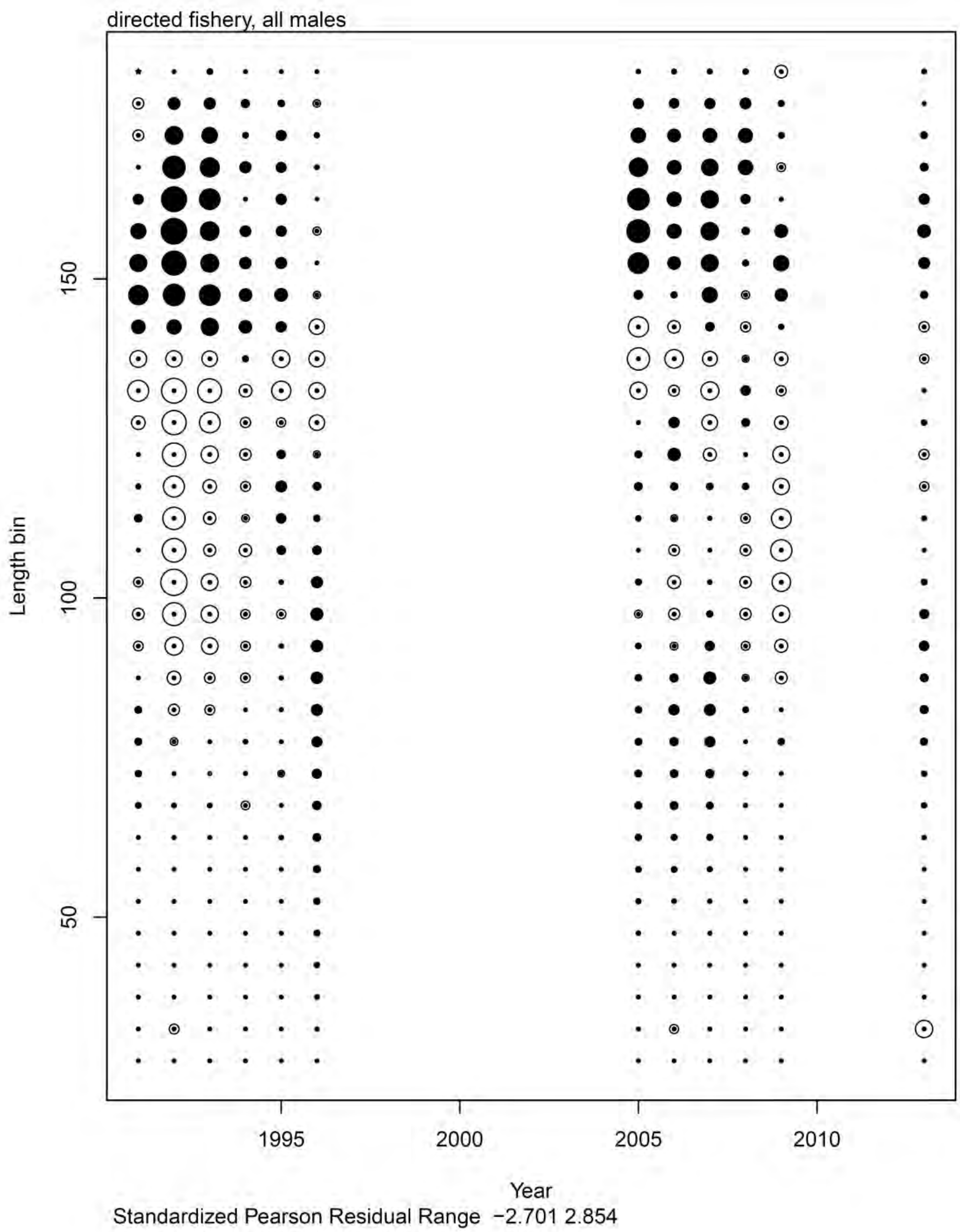


Figure 63.Pearson residuals for predicted proportions at size for all males in the directed Tanner crab fishery from the author's preferred model (Alt1a). White circles represent positive anomalies (observed>predicted), black circles represent negative anomalies.

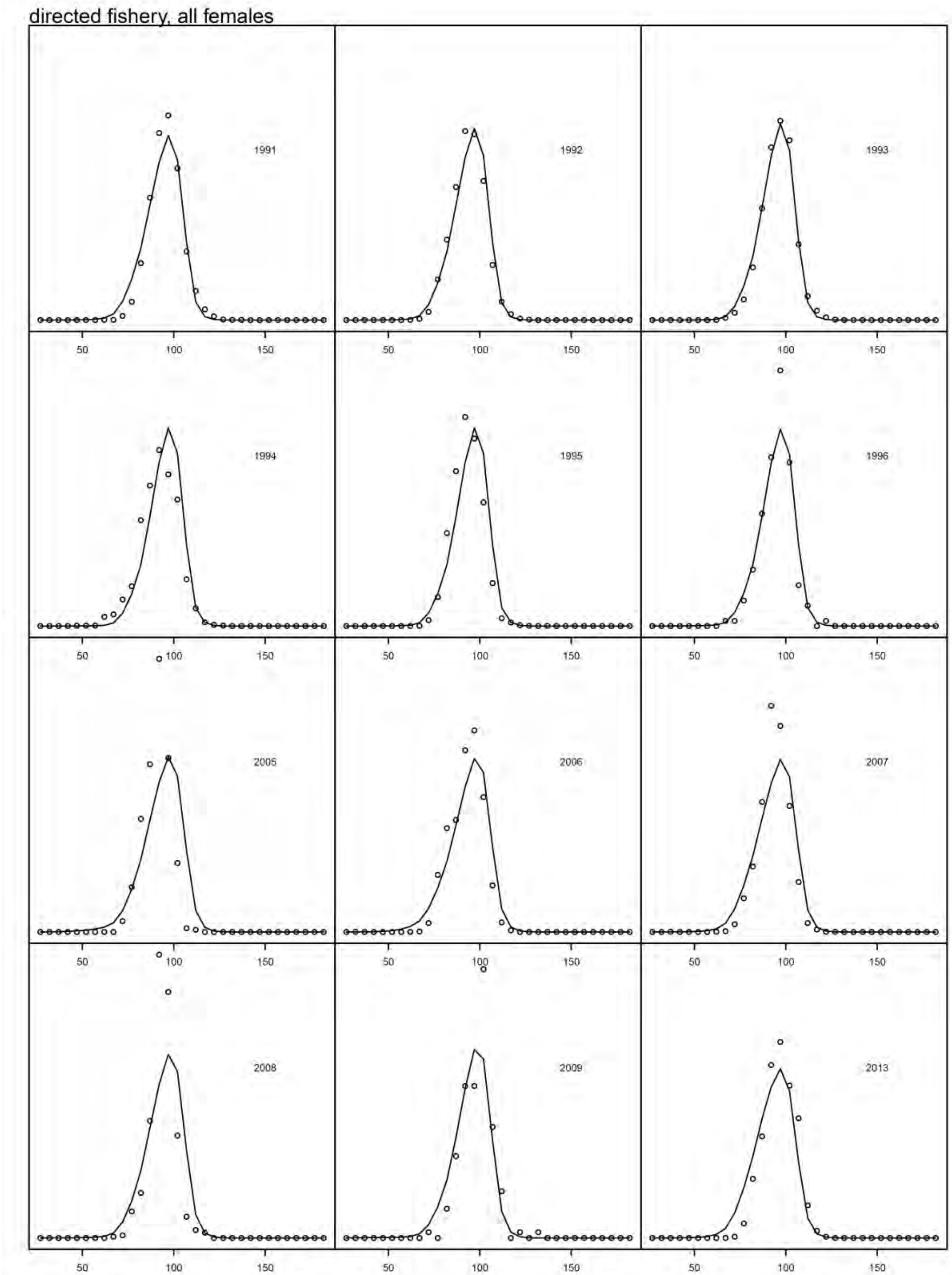


Figure 64.Comparison of predicted (solid line) and observed (circles) proportions at size for females in the directed Tanner crab fishery from the author's preferred model (Alt1a).

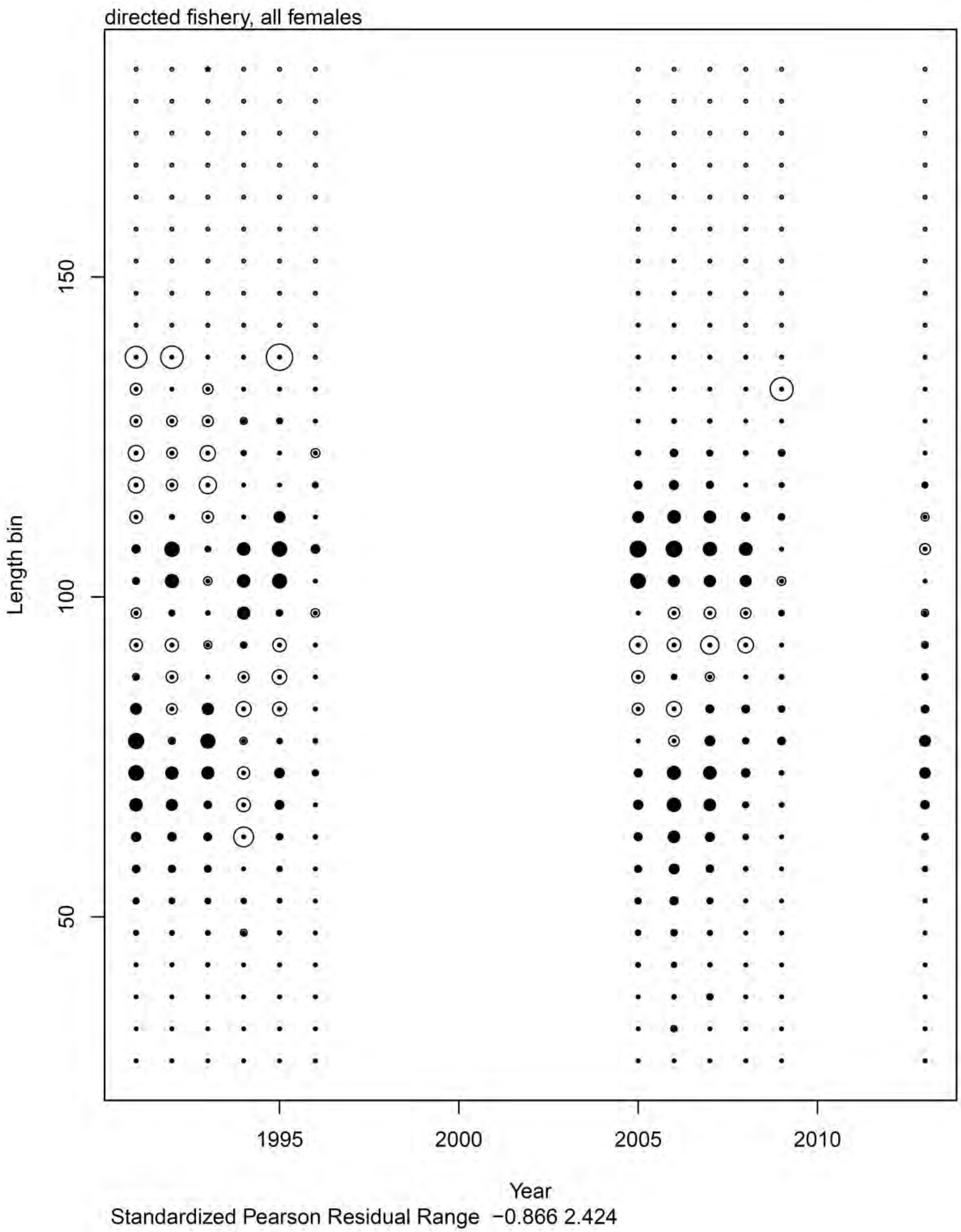


Figure 65. Pearson residuals for predicted proportions at size for females in the directed Tanner crab fishery from the author’s preferred model (Alt1a). White circles represent positive anomalies (observed>predicted), black circles represent negative anomalies.

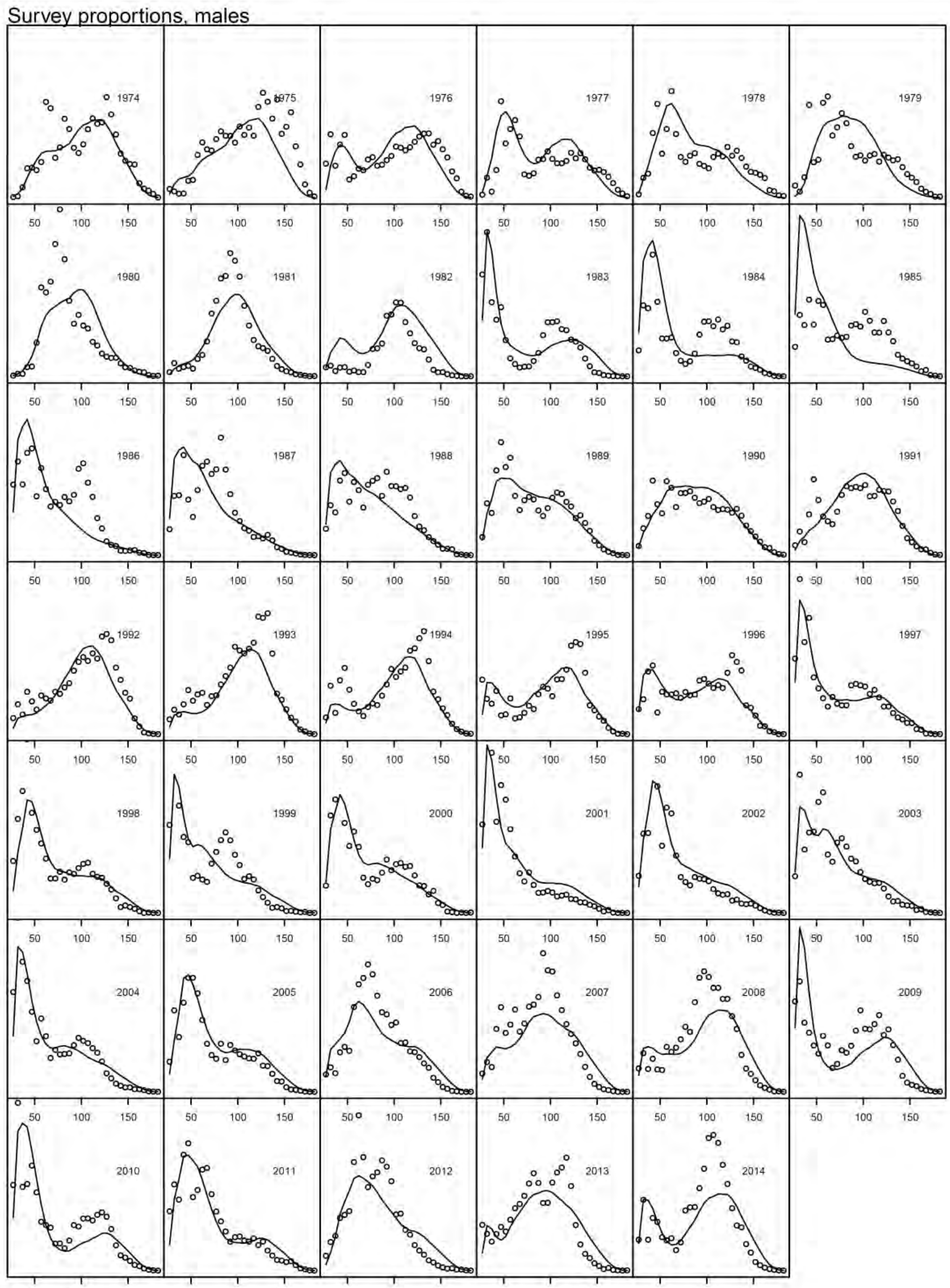


Figure 66. Comparison of predicted (solid line) and observed (circles) proportions-at-size for males in the NMFS bottom trawl survey from the author's preferred model (Alt1a).

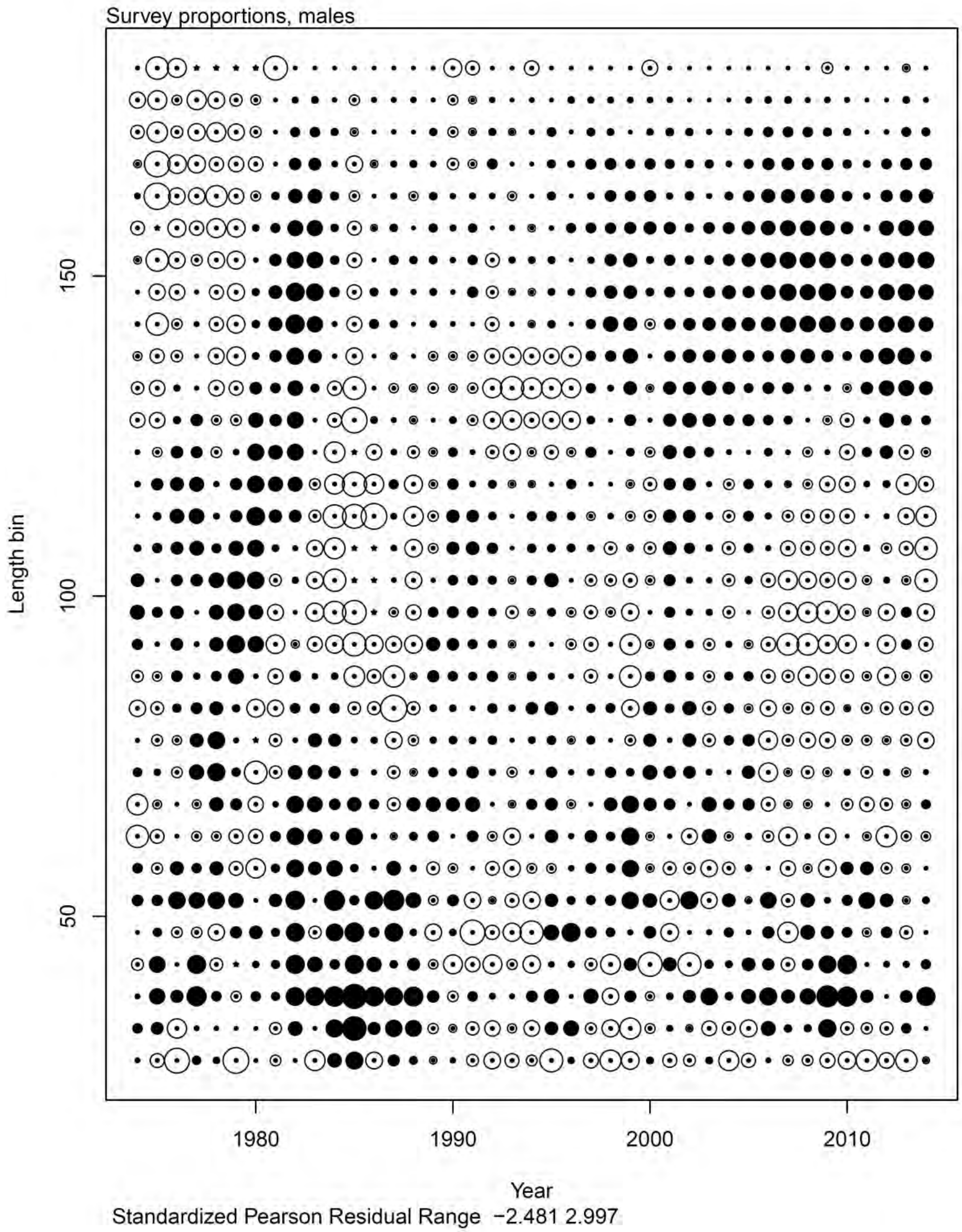


Figure 67.Pearson residuals for predicted proportions at size for all males in the NMFS bottom trawl survey from the author’s preferred model (Alt1a). White circles represent positive anomalies (observed>predicted), black circles represent negative anomalies.

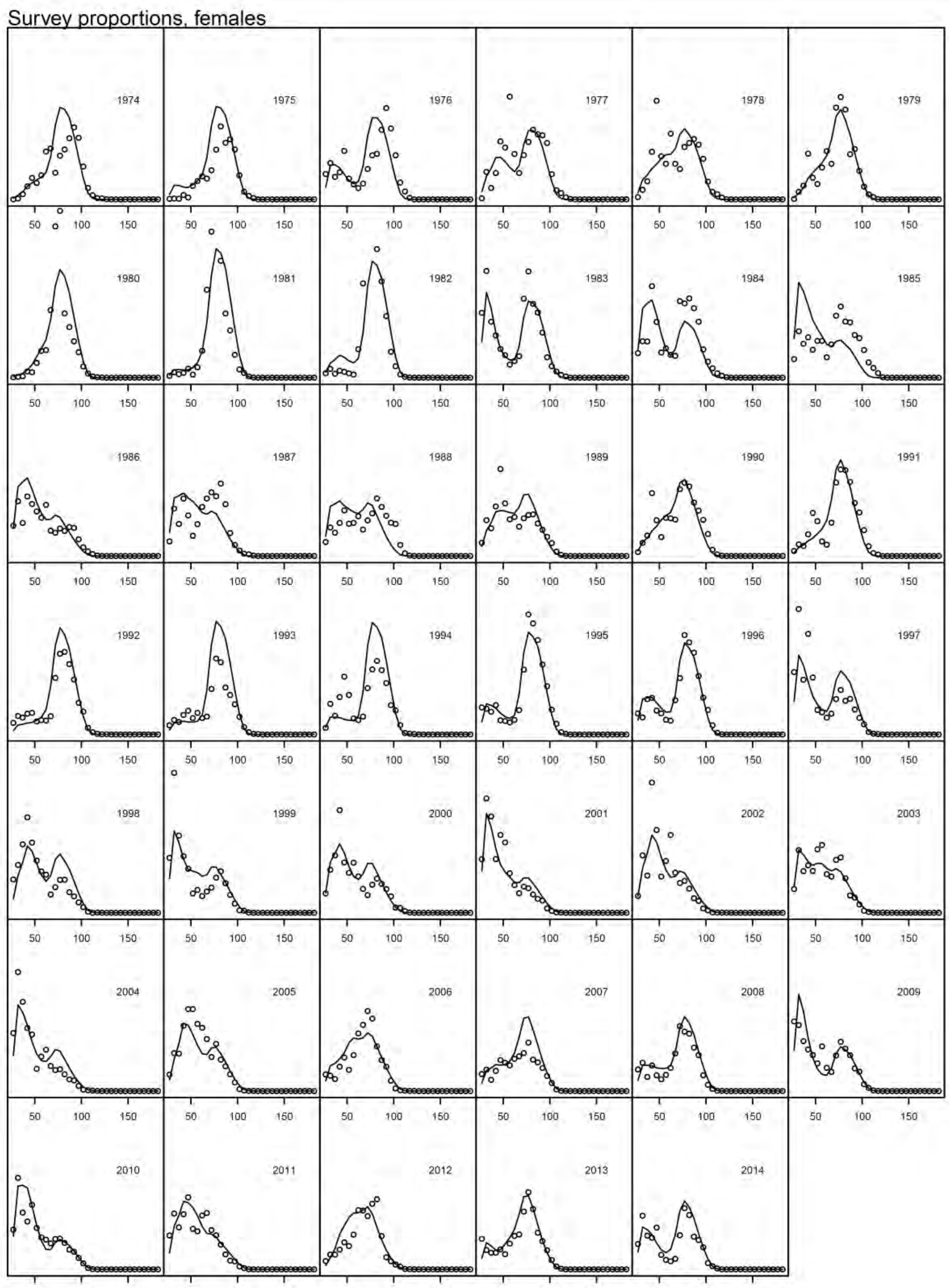


Figure 68.Comparison of predicted (solid line) and observed (circles) proportions-at-size for females in the NMFS bottom trawl survey from the author's preferred model (Alt1a).

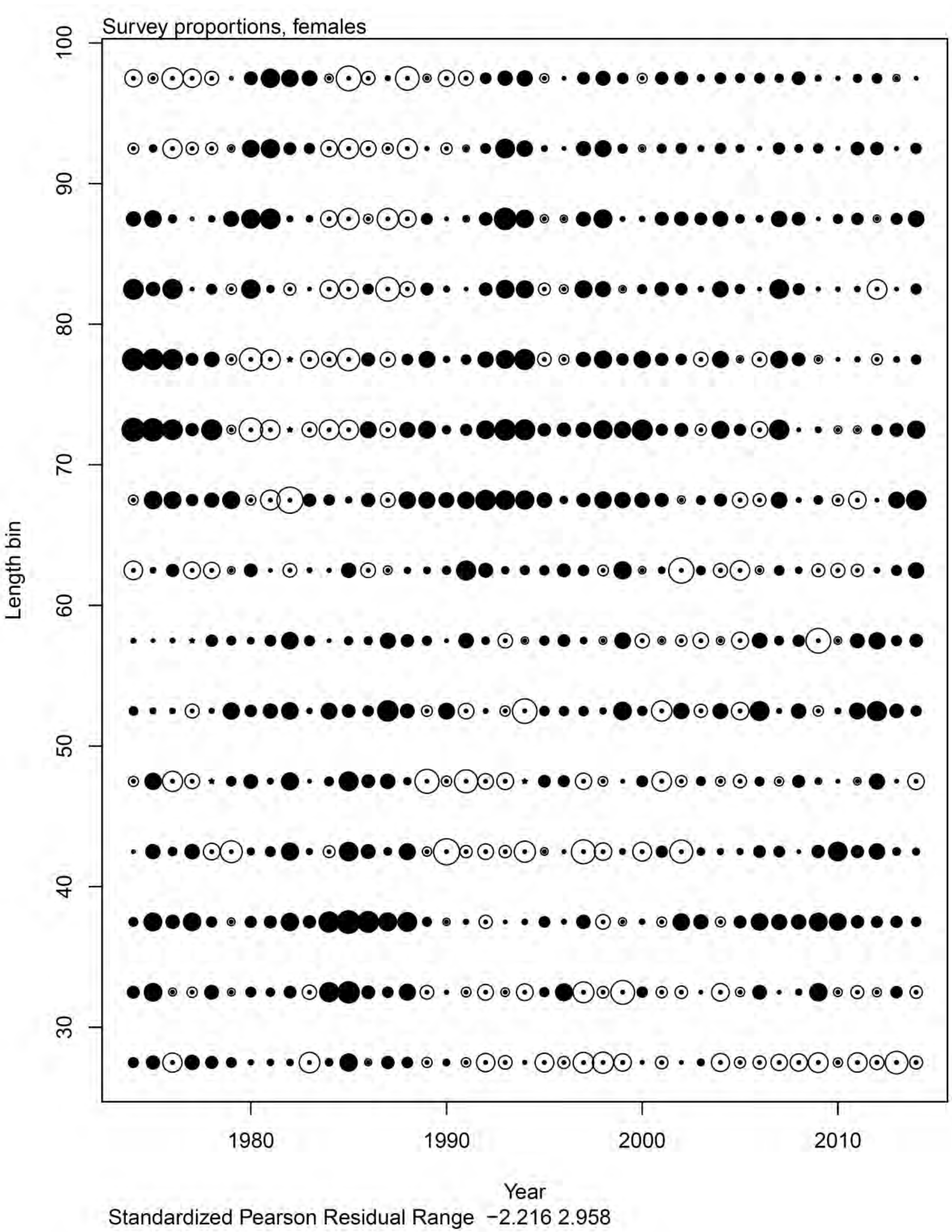


Figure 69.Pearson residuals for predicted proportions at size for females in the NMFS bottom trawl survey from the author's preferred model (Alt1a). White circles represent positive anomalies (observed>predicted), black circles represent negative anomalies.

2013 Model Alt1a

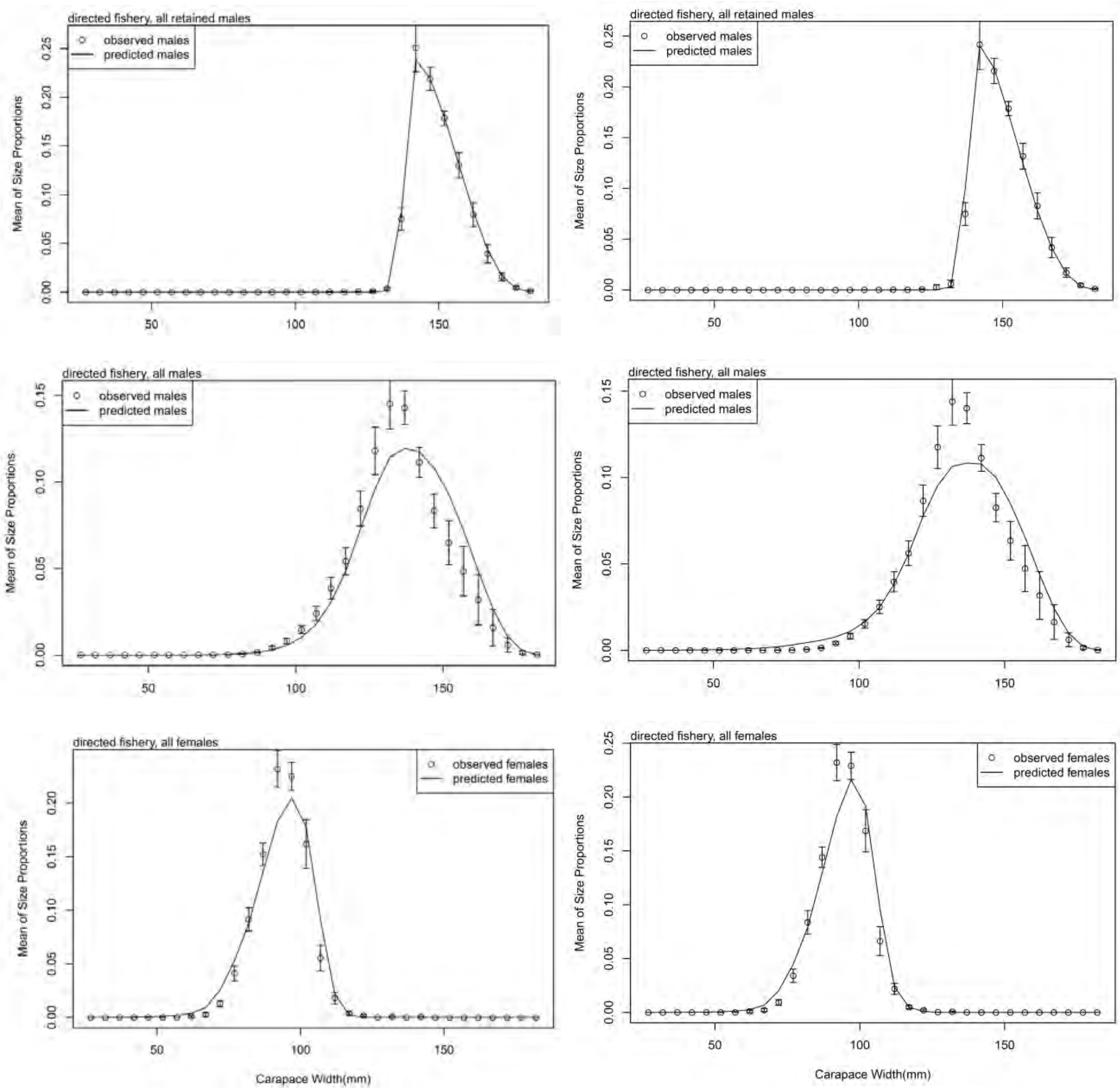


Figure 70. Comparison of marginal (mean) proportions-at-size in the directed Tanner crab fishery for retained males (upper plot) and all males (center plot) and females (lower plot) from the 2013 assessment model (left column) and the author's preferred model (Alt1a, right column). 80% confidence intervals are shown for the observed values, based on observed variance-at-size and assuming normal distributions.

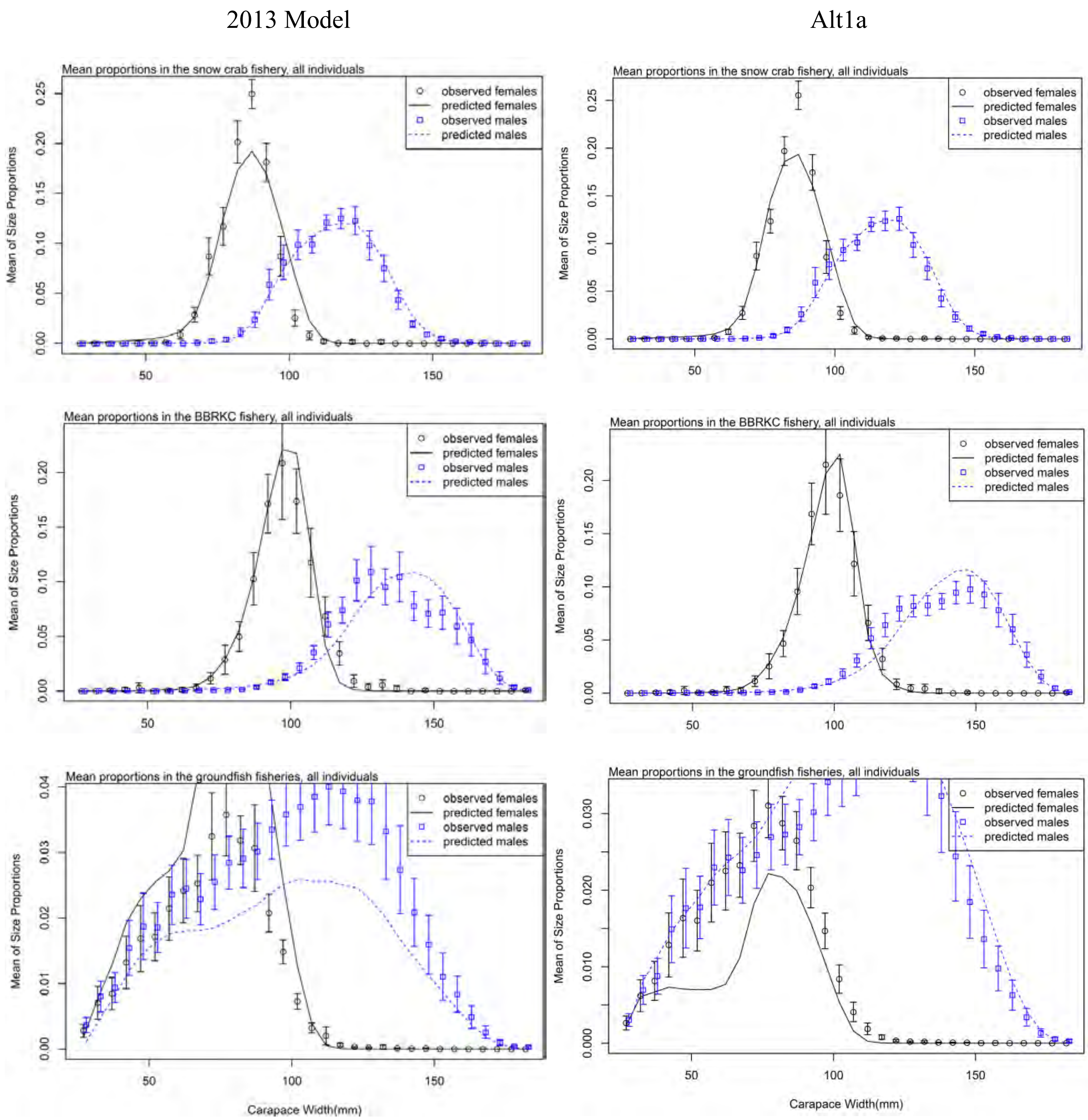


Figure 71. Comparison of marginal (mean) proportions-at-size for males and females in the snow crab fishery (upper plot), the BBRKC fishery (center plot), and the groundfish fisheries (lower plot) from the 2013 assessment model (left column) and the author's preferred model (Alt1a, left column). 80% confidence intervals are shown for the observed values, based on observed variance-at-size and assuming normal distributions.

2013 Model Alt1a

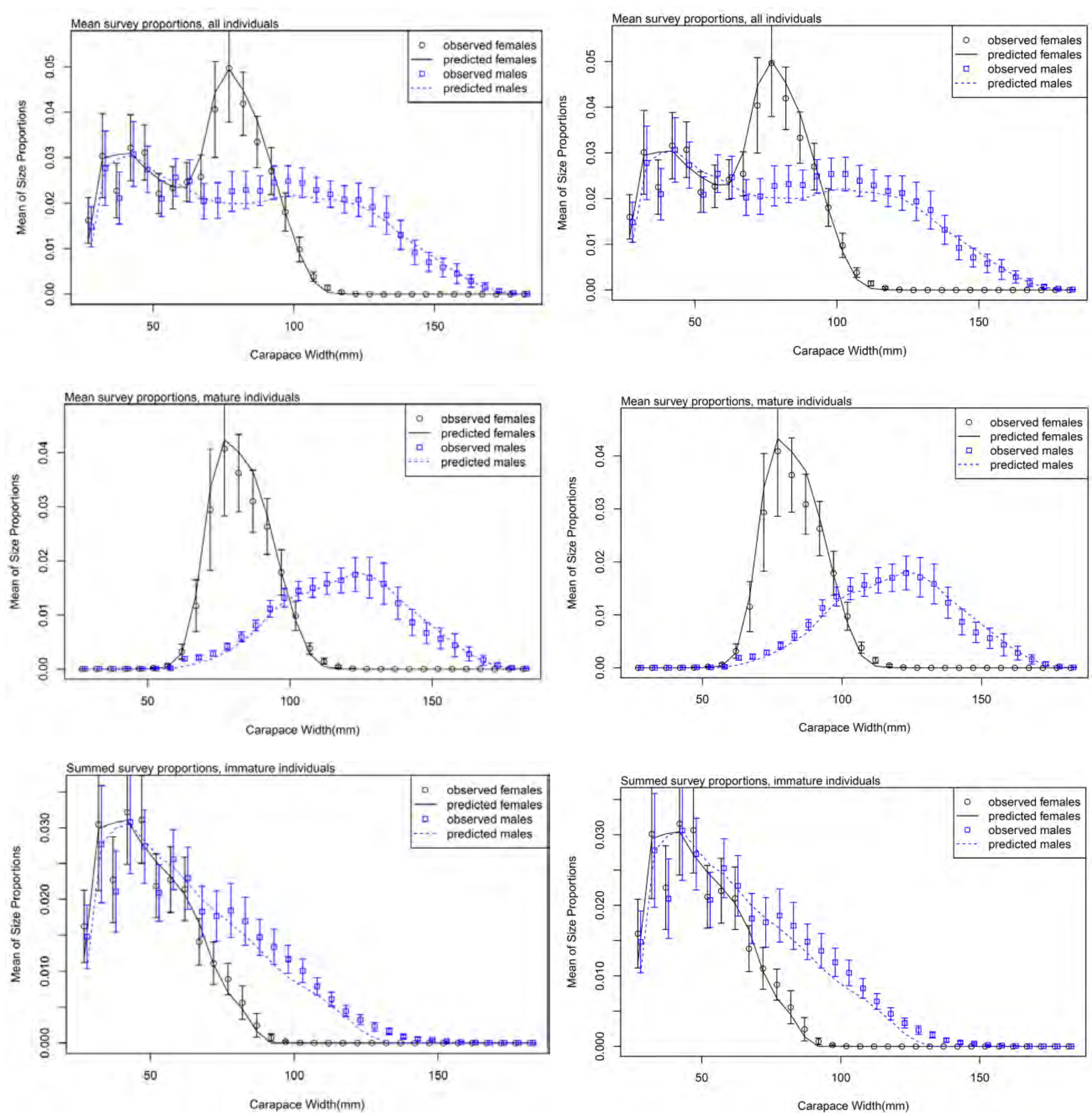


Figure 72. Comparison of marginal (mean) proportions-at-size in the NMFS bottom trawl survey for all (male+female) crab (upper plot), mature crab (center plot), and immature crab (lower plot) from the 2013 assessment model (left column) and the author's preferred model (Alt1a, right column). 80% confidence intervals are shown for the observed values, based on observed variance-at-size and assuming normal distributions.

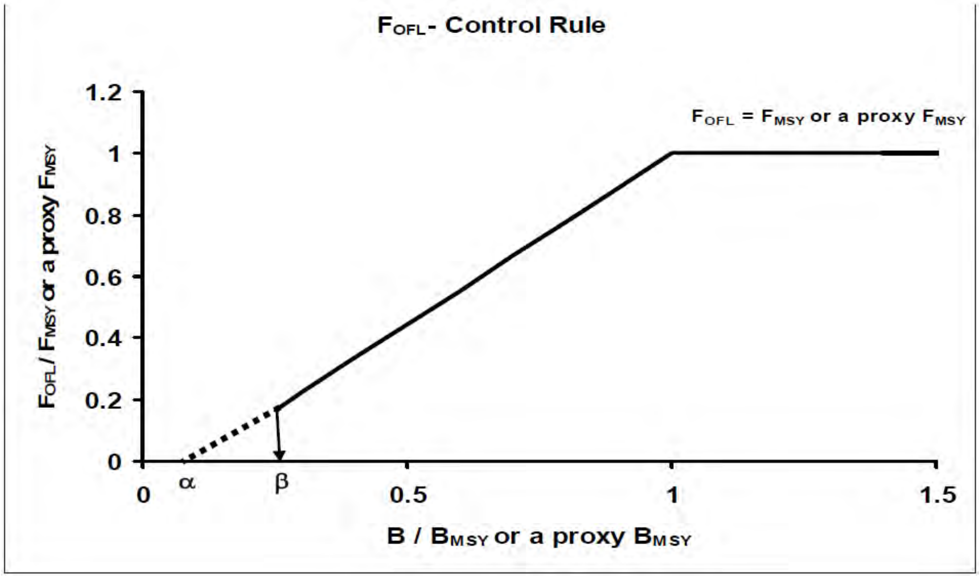


Figure 73. The F_{OFL} harvest control rule. For Tier 3 stocks such as EBS Tanner crab, F_{MSY} and B_{MSY} are based on spawning biomass per recruit proxies, where $F_{MSY} = F_{35\%}$ and $B_{MSY} = B_{35\%}$ and MMB at mating time is used as spawning biomass.

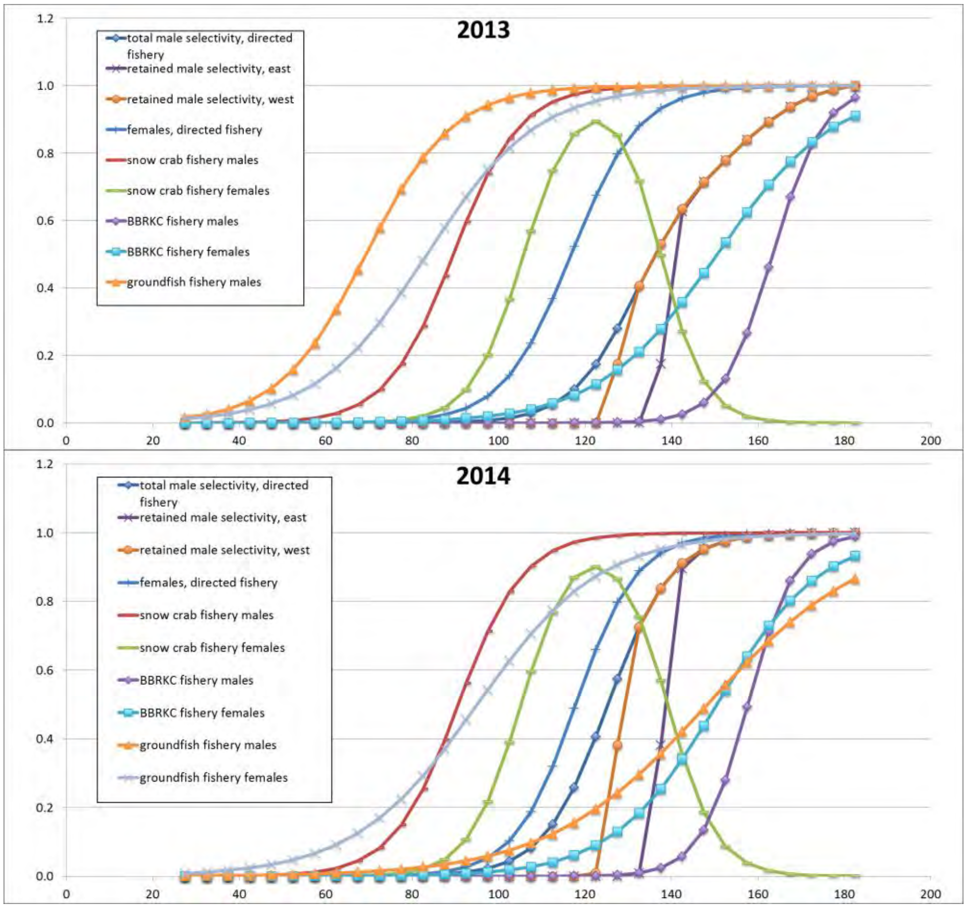


Figure 74. Comparison of selectivity curves used in the projection model for status determination and OFL calculation in 2013 (upper plot) and the preferred model for 2014 (Alt1a, lower plot). The total (retained+ discards) selectivity curve (dark blue curve, triangles) is assumed to apply to the fisheries east and west of 166°W longitude. Retained selectivity in the fishery east of 166°W (purple curve, asterisks) is assumed to be the same as the last year of the directed fishery. Retained selectivity west of 166°W is assumed to be a left-shifted version of that east of 166°W, reflecting the smaller legal and preferred size limits there (orange curve, circles).

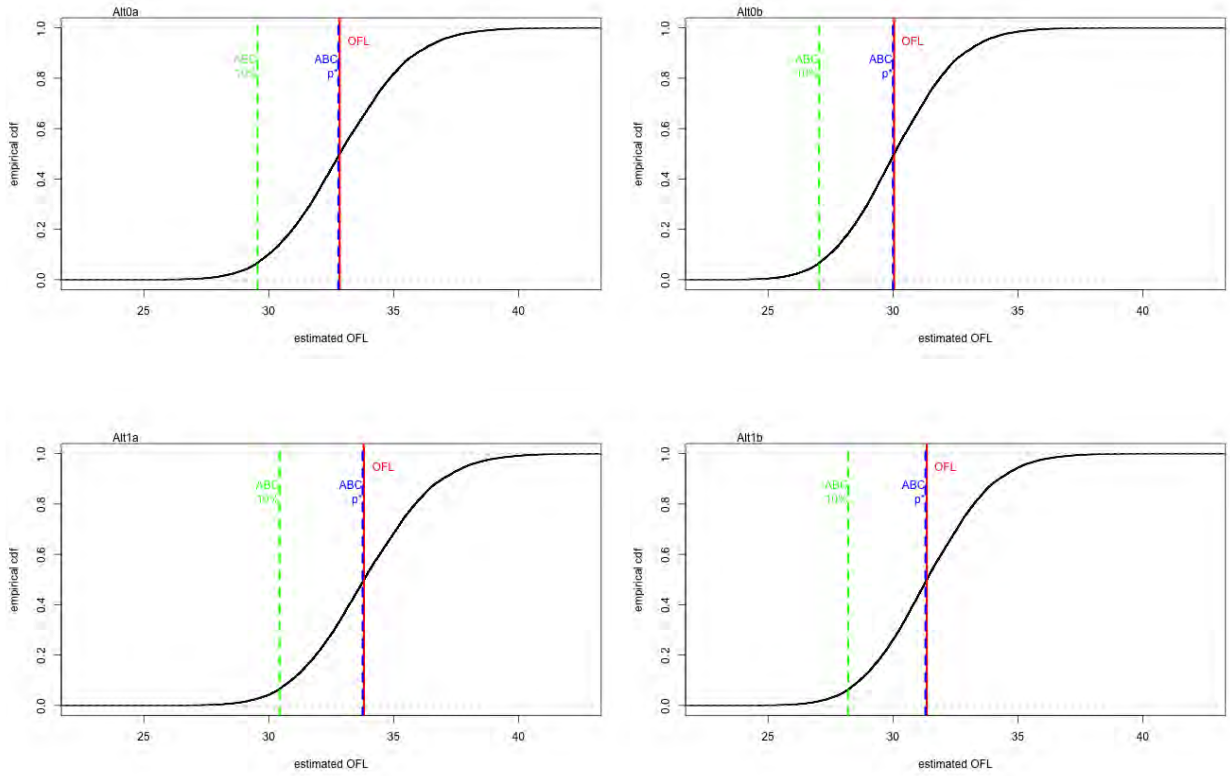


Figure 75. Tier 3 OFL and ABC calculations using the empirical cumulative probability distribution (white line) for the OFL (indicated by the vertical red line) based on 10,000 1-year projection model runs. Initial (July 1, 2013) population numbers-at-size were randomized based on the CV of 2013 MMB at mating time for each alternative model (upper left: Alt0a, upper right: Alt0b, lower left: Alt1a, lower right: Alt1b). For each year, directed fishing mortality was set using F_{msy} = F35% and the Tier 3 F_{OFL} control rule, and total catch was calculated. The OFL for each model is the median of the resulting distribution of catches (possible OFLs). The "p-star" ABC (indicated by the dashed blue line) is the ABC that yields p^* = 0.49—i.e., the probability that the selected ABC exceeds the true OFL is 49%. $ABC_{10\%}$ (indicated by the dashed green line) is the ABC based on applying a 10% buffer to the OFL. The units for OFL and ABC are 1000's t.

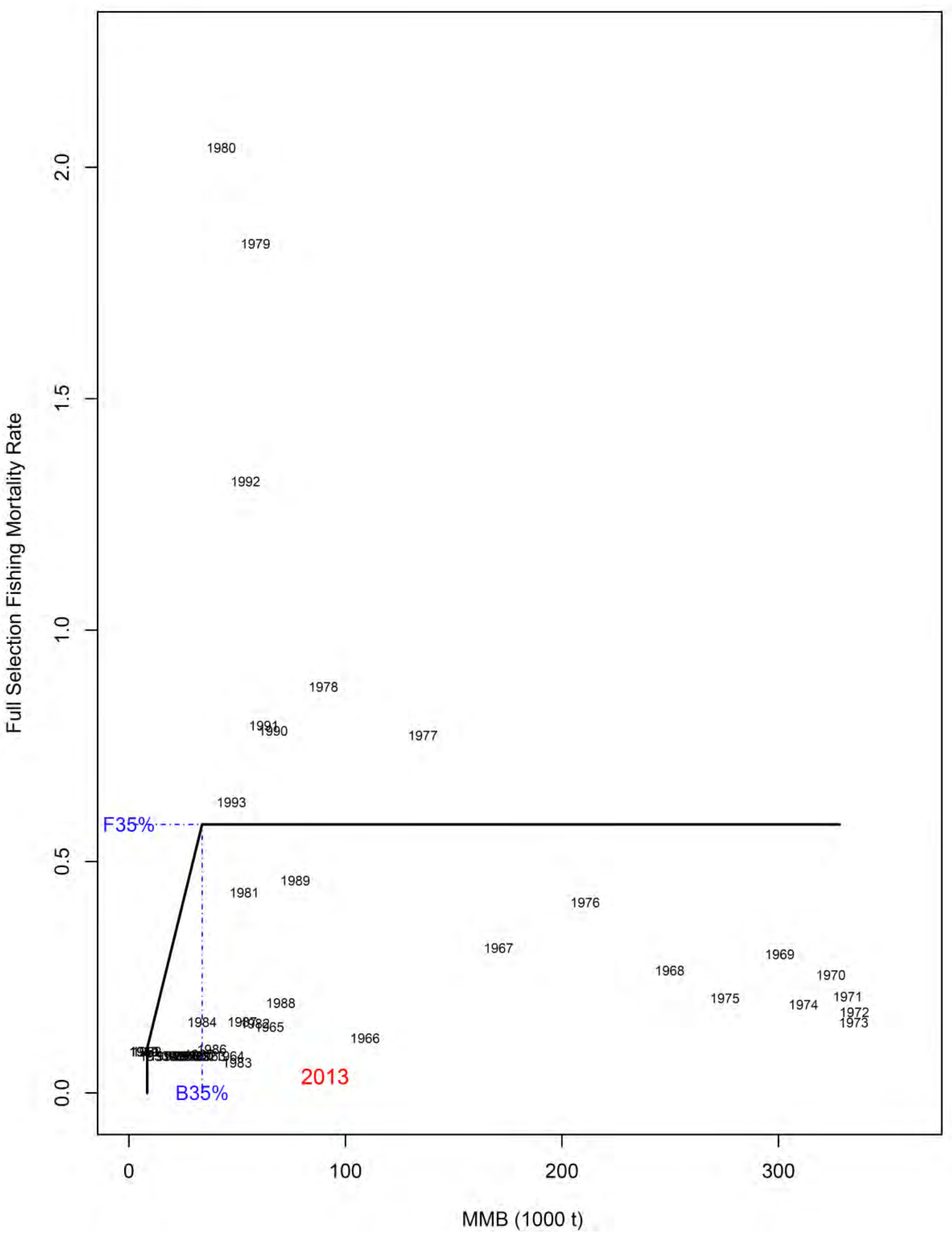


Figure 76. The Tier 3 F_{OFL} harvest control rule, with the population state for each year plotted at coordinates given by MMB at mating on the x axis and total fishing mortality on the y axis, as estimated from the author's preferred model, Model 01. The current year (2013/14) is highlighted in red text.

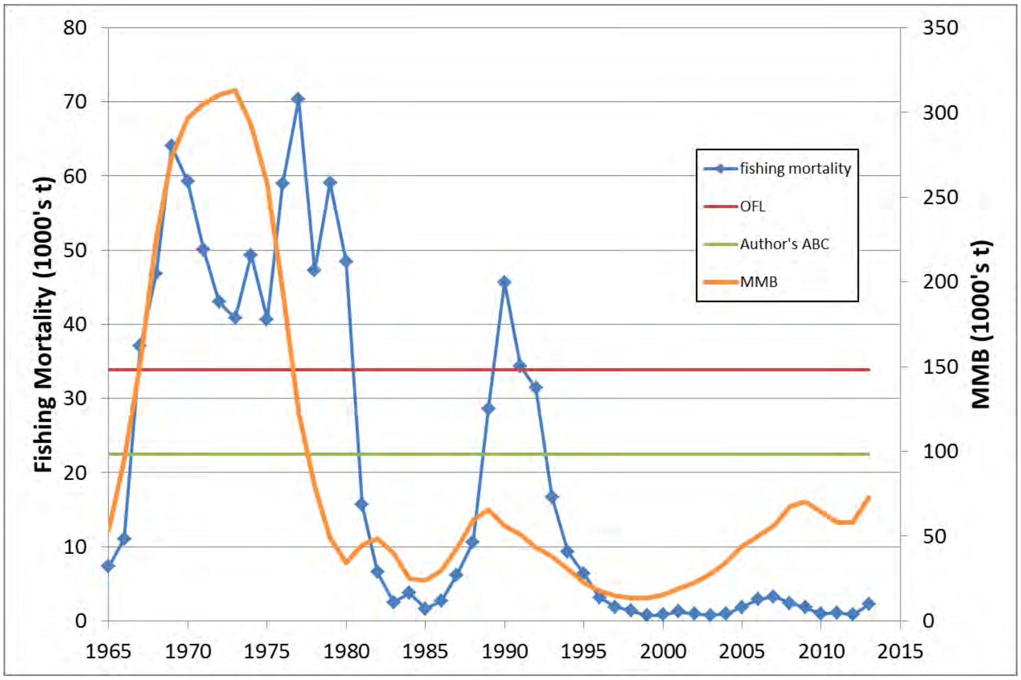


Figure 77. Comparison of the OFL from the author's preferred model and the author's recommended ABC with the time series of estimated total fishery-related mortality and MMB for the Tanner crab stock.

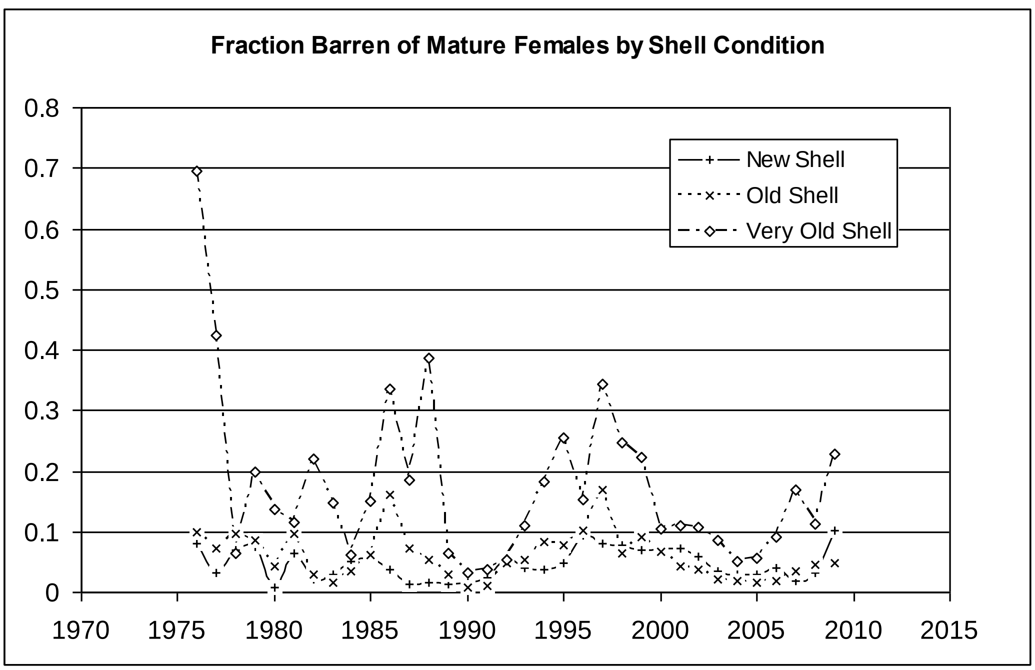


Figure 78. Proportion of female Tanner crab with barren clutches by shell condition from survey data for 1976/77 to 2009/10.

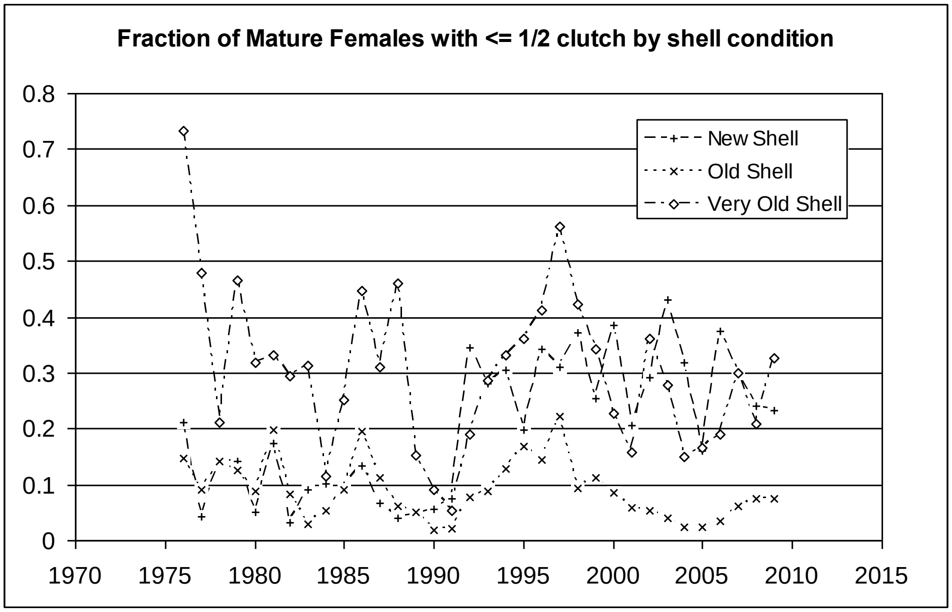


Figure 79. Proportion of female Tanner crab with less than or equal to one-half full clutch by shell condition from survey data 1976/77 to 2009/10.

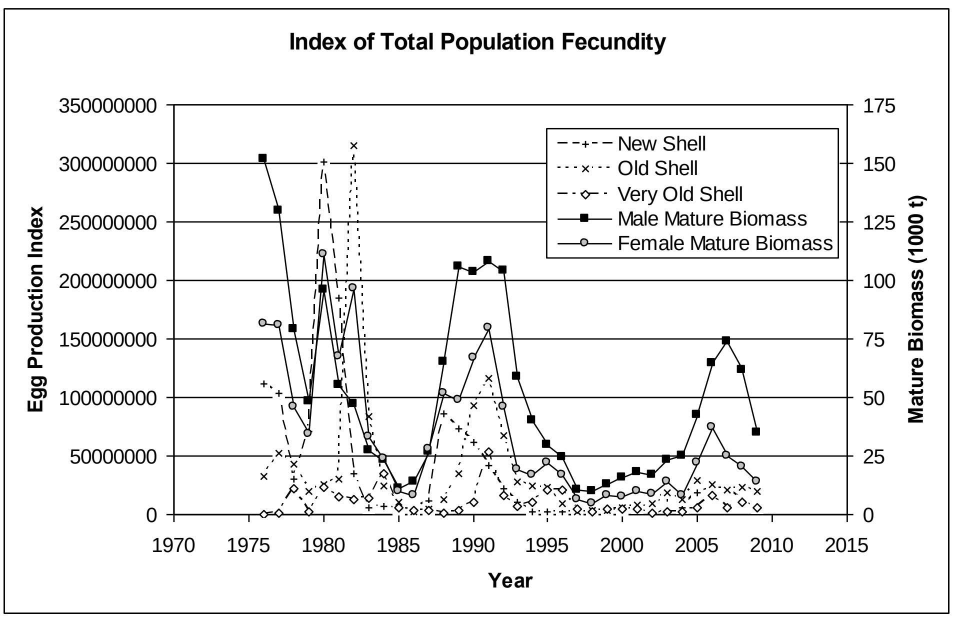


Figure 80. Tanner crab female egg production index (EPI) by shell condition, survey estimate of male mature biomass (1000 t), and survey estimate of female mature biomass (1000 t) from survey data for 1976/77 to 2009/10.

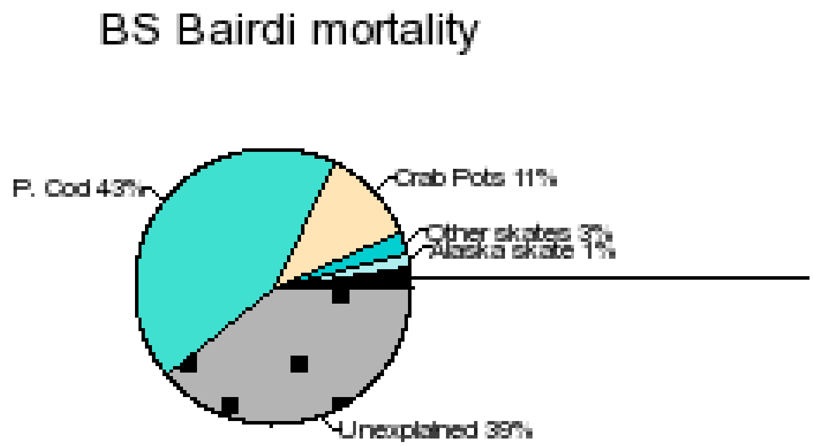


Figure 81. The fraction of annual mortality from major ecosystem components (including fisheries) on mature Tanner crab in the EBS, as estimated by a mass-balance ecosystem model for the EBS (Aydin et al., 2007).

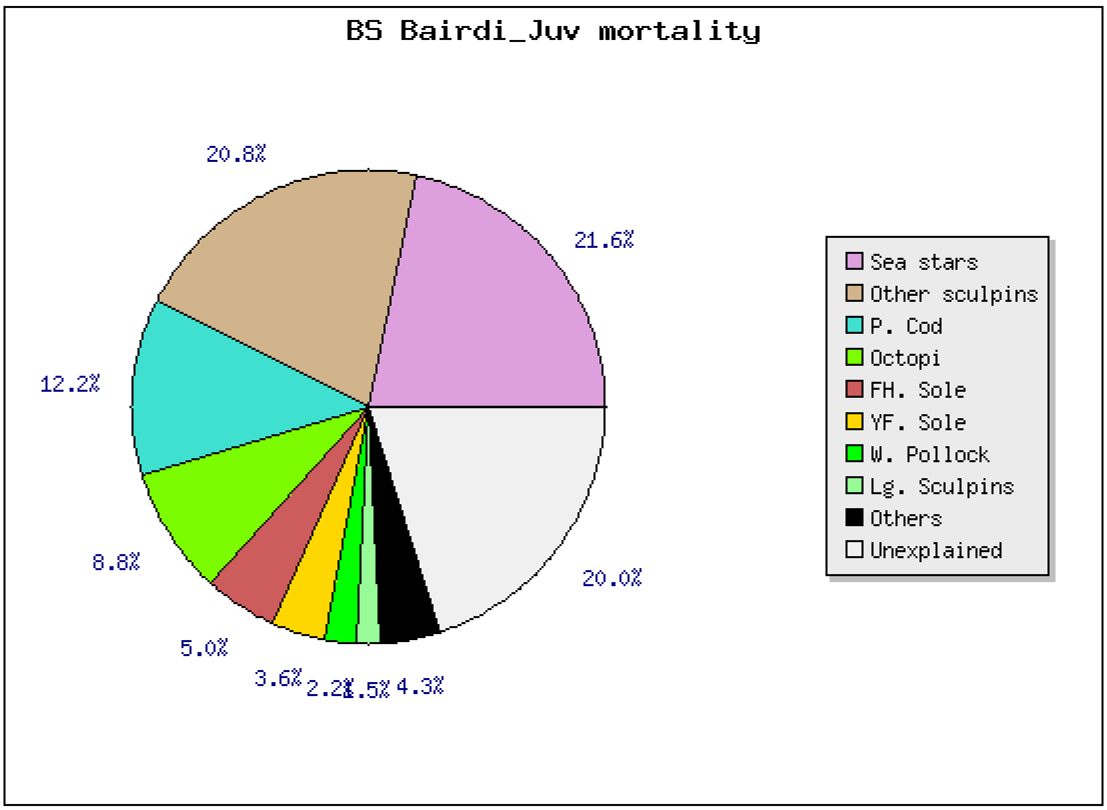


Figure 82. The fraction of annual mortality from major ecosystem components (including fisheries) on immature Tanner crab in the EBS, as estimated by a mass-balance ecosystem model for the EBS (Aydin et al., 2007).

Appendix 1: Changes to datasets since 2013 assessment

Introduction

This appendix addresses dataset issues in the Tanner crab stock assessment that have arisen subsequent to the Fall 2013 assessment. Following a discussion at the 2014 Crab Modeling Workshop (Crab Plan Team, 2014a), the Crab Plan Team (CPT) recognized that many crab assessments included "…'legacy' data, the origins of which are uncertain…", partly as a result of changes in analysts over time and partly a result of the length of some of the data time series. The CPT requested that W. Gaeuman (ADFG) provide assessment authors with updated information on crab fishery discards (total numbers discarded, length frequencies for discards and total observed catch). The updated information for Tanner crab is reviewed here, and changes to assessment model results in light of these changes are evaluated. In addition to the new information from W. Gaeuman, two other changes to the input data to the Tanner crab assessment are also evaluated. The first change addresses the correction of two inadvertent errors in the dataset used in the 2013 Tanner crab assessment, while the second incorporates updated information on bycatch size frequencies of Tanner crab in the groundfish fisheries provided to the author by R. Foy (NMFS/AFSC). The CPT reviewed this information at its May 2014 meeting and approved incorporation of the updated datasets into the September 2014 assessment.

Finally, based on a careful re-examination of fish ticket and logbook data, annual effort data (potlifts) in the directed Tanner crab fishery have been recalculated by D. Pengilly (ADFG). This revised data has been incorporated into the assessment in the Alt1a and Alt1b model scenarios.

Revisions to the data

Five revisions to the data used in the 2013 Tanner crab assessment are presented in this appendix. Data revision B corrects two errors in the 2013 assessment data (Dataset A) that were found after the 2013 assessment was completed. In the first of these errors, the size frequency for immature, new shell females from the 2013 AFSC trawl survey was incorrectly copied into the model data file. The corrected version shows two peaks in the size frequency (in the 27.5 and 62.5 mm CW size bins) of similar size, while the version used in the assessment is more reflective of a single peak in the smallest size bin (27.5 mm CW) (A1.Figure 1). Regarding the second error, the sex-specific sample sizes (A1.Figure 2) for bycatch size frequencies in the groundfish fisheries had been inadvertently switched between males and females. This error appears to have been introduced prior to the 2012 assessment.

Data revision C incorporates retained size frequencies from dockside observer sampling for male crabs by shell condition in the directed Tanner crab fishery from 1991-2009 as recalculated by W. Gaeuman (ADFG) and provided to the author (A1.Table 2, A1.Figure 4 and A1.Figure 5). This dataset does not include size frequencies for 1995, although these had been included in the 2013 assessment, due to difficulties in re-extracting this information from the ADFG crab observer database. Comparing the new data with the old, all years agree in terms of the number of measured crab (A1.Table 2, A1.Figure 4) except for new shell males in 2008 (429 fewer crab were included in the recalculated dataset) and both shell conditions in 2009 (almost 12,000 fewer crab were included in the recalculated dataset). The differences in the resulting size frequencies are small for the 2009 new shell males, but rather substantial for the old shell males. The sources for the rather large discrepancies in total numbers sampled for 2008 and 2009 are presently unknown.

Data revision D incorporates total catch size frequencies for Tanner crab from at-sea observer sampling in the crab fisheries starting in 1990, as recalculated by W. Gaeuman and provided to the author (Tables 3-5, Fig.s 5-10). The numbers of crab sampled are substantially different in the recalculated and assessment datasets in some circumstances (e.g., ~40,000 males for 1992 in the directed fishery, A1.Table 3) but are identical in others (e.g. 5,972 males in both datasets for 1994 in the directed fishery, A1.Table 3). On the whole, the changes in normalized size frequencies (examples of which are shown in Fig.s 6, 8, and 10) are relatively small. Where differences are more substantial (e.g., in 1999 for the BBRKC fishery, A1.Figure 10), the sample sizes are quite small (10-14 crabs, A1.Table 5). Once again, the sources for these large discrepancies are currently unknown.

Data revision E incorporates bycatch size frequencies for Tanner crab in the groundfish fisheries from at-sea observer sampling starting in 1973 from data files provided by R. Foy (NOAA/NMFS) that he extracted from AFSC's Groundfish Observer Program database. The numbers of crab sampled are again substantially different between the recalculated and assessment datasets (A1.Table 6, Figures 11-12). However, two sources for the differences are known. The first is that the recalculated dataset includes observer sampling from the joint venture fisheries in the late 1980s while the dataset used in the assessment does not. The second is that the recalculated dataset bases the size frequencies on the crab fishery year (July 1-June30) while the assessment dataset used the groundfish fishery year (Jan. 1-Dec. 31). The effects of the latter change can be seen in A1.Figure 12, which provides a comparison of example normalized size frequencies for measured female crab for 1985-87.

The impacts of these four changes on results from the 2013 assessment model are evaluated in a stepwise, cumulative fashion (Table 1) and discussed in the next section of this appendix.

Impacts on assessment results

Assessing the impacts of the four data revisions discussed above on the assessment was addressed by running the model used in the 2013 assessment (TCSAM2013) on each of the datasets and comparing time series of estimated mature male biomass (MMB) at mating (A1.Figure 14), recruitment (A1.Figure 15), and fully-selected fishing mortality in the directed fishery (A1.Figure 16). The resulting changes in the assessment model output are reasonably small across the time series for MMB, recruitment and directed fishing mortality. Correcting the errors to the assessment dataset (data revision B) resulted in a 12% increase in final (2012) MMB as well as 4% higher average recruitment (1982-2013), although the estimated final recruitment decreased (consistent with the correction to the 2013 trawl survey size frequency for immature, new shell females). Subsequent changes to the various size frequencies incorporated in the model data (revisions C-E) had smaller impacts on the model estimates in the terminal year of each time series.

Effort data revision

The final revision to the data used in the 2013 assessment is based on work conducted by D. Pengilly to re-calculate the time series of annual effort in the directed Tanner crab fishery (Table 7, Figure 17). This was based on a careful examination of fish ticket and logbook data. Apparently many potlifts targeting BBRKC or snow crab in their directed fisheries erroneously were assigned to the directed Tanner fishery, as well (i.e., double counted—the impact on effort in the BBRKC and snow crab fisheries was basically nonexistent). The re-calculated effort in the directed Tanner crab fishery was less than half the previously-calculated effort used in the 2013 assessment for 1991 and 1996, and still substantially different for 1990, 1992, 1993, and 2005. Because effort in the fishery is used to scale at-sea crab observer data from sampled pots up to the fishery itself, this revision had an identical (relative) impact on the time series of discard biomass in the directed fishery (Figure 17).

Recommendations

It would be worthwhile if the discrepancies (numbers of crab measured) between the size frequencies in the new datasets based on at-sea and dockside observer sampling in the various crab fisheries could be resolved with those used in previous assessments. If possible, computer codes (e.g., SQL scripts) used to generate the old and new datasets should be compared and differences identified. However, given changes in analysts over time, this may not be possible in some cases. In these cases, some double checking and vetting of the new data should occur in order to promote confidence in its reproducibility. The CPT should identify suitable procedures and a time frame for this vetting process. In particular, stock assessment analysts will need the vetted data much sooner than the fall assessment season in order to incorporate it into each assessment.

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Rugolo, L.J., and B.J. Turnock. 2012. 2012 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2012 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 267-416.

Stockhausen, W.T., B.J. Turnock and L. Rugolo. 2013. 2013 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2013 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 342-449.

Tables

A1.Table 1. Revisions to the input data for the Tanner crab model considered in the analysis.

ID	Description
A	2013 assessment data
B	A + corrected sample sizes for bycatch size frequencies in the groundfish fisheries + corrected size frequencies for immature, new shell females in the 2013 AFSC trawl survey + very minor correction to csample sizes used for discard size frequencies in the crab fisheries
C	B + recalculated retained size frequencies (1991-2009) based on new results from W. Gaeuman (ADFG)
D	C + recalculated total catch size frequencies (1992-2012) in all crab fisheries based on new results from W. Gaeuman (ADFG)
E	D + recalculated bycatch size frequencies (1973-2012) in the groundfish fisheries based on new results from R. Foy (NMFS)

A1.Table 2. Number of measured male crab in dockside sampling for retained size frequencies in the recalculated and 2013 datasets. W. Gaeuman (ADFG) did not provide recalculated size frequencies for 1995.

	Recalculated		2013 Assessment		Difference	
year	new shell	old shell	new shell	old shell	new shell	old shell
1991	117,630	8,669	117,630	8,669	0	0
1992	113,319	11,874	113,319	11,874	0	0
1993	67,264	4,358	67,264	4,358	0	0
1994	25,585	2,073	25,585	2,073	0	0
1995	0	0	495	1,030	-495	-1,030
1996	2,063	2,367	2,063	2,367	0	0
2005	649	56	649	56	0	0
2006	1,053	1,887	1,053	1,887	0	0
2007	3,662	2,165	3,662	2,165	0	0
2008	2,717	344	3,146	344	-429	0
2009	2,369	48	13,903	412	-11,534	-364

A1.Table 3. Number of Tanner crab measured by at-sea observers in the directed fishery in the recalculated and 2013 datasets.

Year	Recalc'd (all shell types)		2013 Assessment		Difference	
	Females	Males	Females	Males	Females	Males
1990	34	51				
1991	5,605	31,252	2,984	13,386	2,621	17,866
1992	8,755	54,836	1,374	15,007	7,381	39,829
1993	10,470	40,388	2,871	13,511	7,599	26,877
1994	2,132	5,792	2,132	5,792	0	0
1995	3,119	5,589	3,119	5,589	0	0
1996	168	352	168	352	0	0
2005	1,107	19,715	879	15,459	228	4,256
2006	4,432	24,226	4,432	24,226	0	0
2007	3,318	61,546	1,577	26,091	1,741	35,455
2008	646	29,166	294	19,797	352	9,369
2009	147	17,289	147	16,229	0	1,060

A1.Table 4. Number of Tanner crab measured by at-sea observers in the snow crab fishery for the recalculated and 2013 datasets.

Year	Recalc'd (all shell types)		2013 Assessment		Difference	
	Females	Males	Females	Males	Females	Males
1990	478	14,032				
1991	686	11,708				
1992	859	6,280	859	6,280	0	0
1993	1,542	6,969	1,542	6,969	0	0
1994	1,523	2,982	1,523	2,982	0	0
1995	428	1,898	428	1,898	0	0
1996	662	3,265	662	3,265	0	0
1997	657	3,970	515	2,747	142	1,223
1998	324	1,911	271	870	53	1,041
1999	82	976	22	103	60	873
2000	74	1,237	38	892	36	345
2001	160	3,113	140	2,086	20	1,027
2002	118	982	49	565	69	417
2003	152	688	21	162	131	526
2004	707	848	692	686	15	162
2005	368	9,792	368	9,212	0	580
2006	1,256	10,391	1,256	9,468	0	923
2007	728	13,797	728	13,113	0	684
2008	722	8,455	722	8,435	0	20
2009	474	11,057	474	11,014	0	43
2010	250	12,073	250	12,073	0	0
2011	189	9,453	189	9,453	0	0
2012	190	7,336	270	10,998	-80	-3,662

A1.Table 5. Number of Tanner crab measured by at-sea observers in the BBRKC fishery for the recalculated and 2013 datasets.

Year	Recalc'd (all shell types)		2013 Assessment		Difference	
	Females	Males	Females	Males	Females	Males
1990	43	1,580				
1991	89	2,273				
1992	105	2,056	105	1,662	0	394
1993	1,196	7,359	1,196	2,700	0	4,659
1996	5	114	5	190	0	-76
1997	41	1,030	41	272	0	758
1998	20	457	18	219	2	238
1999	14	207	10	183	4	24
2000	44	845	36	779	8	66
2001	39	456	26	496	13	-40
2002	50	750	43	528	7	222
2003	46	555	40	592	6	-37
2004	44	487	41	480	3	7
2005	70	983	70	1,072	0	-89
2006	76	798	68	780	8	18
2007	91	1,399	89	1,139	2	260
2008	121	3,797	98	2,389	23	1,408
2009	72	3,395	70	2,153	2	1,242
2010	30	595	28	510	2	85
2011	4	344	4	324	0	20
2012	48	618	48	503	0	115

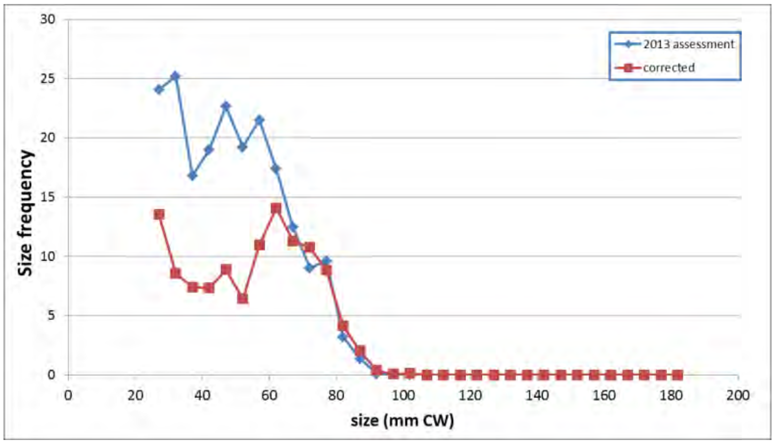
A1.Table 6. Number of Tanner crab measured by at-sea observers in the groundfish fisheries for the recalculated and 2013 datasets. The recalculated dataset is based on the crab fishery year (starting July 1), whereas the 2013 assessment dataset was based on the groundfish fishery year (starting Jan. 1).

Crab Fishery	Recalculated		2013 Assessment		Difference	
Year	Females	Males	Females	Males	Females	Males
1973	2,279	3,155	1,212	1,604	1,067	1,551
1974	1,624	2,500	2,789	4,155	-1,165	-1,655
1975	839	1,254	24	16	815	1,238
1976	6,709	6,984	2,526	2,928	4,183	4,056
1977	8,401	10,703	9,803	10,873	-1,402	-170
1978	13,801	18,699	8,105	11,724	5,696	6,975
1979	11,360	19,075	16,953	24,924	-5,593	-5,849
1980	5,984	12,890	5,598	10,424	386	2,466
1981	4,127	6,122	6,817	12,956	-2,690	-6,834
1982	8,161	13,681	5,694	7,690	2,467	5,991
1983	8,335	18,404	7,983	14,112	352	4,292
1984	14,288	27,849	10,589	24,303	3,699	3,546
1985	12,823	23,290	12,765	26,334	58	-3,044
1986	7,664	14,922	1,776	3,222	5,888	11,700
1987	15,967	23,620	1,689	3,308	14,278	20,312
1988	7,199	10,658	1,922	3,082	5,277	7,576
1989	41,315	60,089	2,190	2,814	39,125	57,275
1990	11,558	24,652	1,983	3,017	9,575	21,635
1991	3,494	6,828	6,155	14,432	-2,661	-7,604
1992	1,183	3,134	1,749	4,903	-566	-1,769
1993	369	1,258	279	1,148	90	110
1994	1,832	3,706	328	854	1,504	2,852
1995	2,675	3,946	2,248	4,404	427	-458
1996	3,410	8,370	2,364	3,458	1,046	4,912
1997	3,912	9,972	5,314	12,176	-1,402	-2,204
1998	4,448	12,150	4,282	10,139	166	2,011
1999	4,528	11,066	4,399	12,037	129	-971
2000	3,097	12,931	3,701	12,391	-604	540
2001	3,100	15,821	2,485	12,910	615	2,911
2002	3,252	15,418	3,232	15,498	20	-80
2003	2,763	9,613	3,292	13,542	-529	-3,929
2004	4,479	13,876	2,788	11,110	1,691	2,766
2005	3,711	17,796	4,097	13,424	-386	4,372
2006	3,050	15,916	3,498	17,129	-448	-1,213
2007	3,588	15,552	3,150	17,513	438	-1,961
2008	3,869	23,997	2,832	10,658	1,037	13,339
2009	2,493	17,642	1,973	6,435	520	11,207
2010	1,571	6,323	2,096	5,952	-525	371
2011	3,515	7,042	697	2,055	2,818	4,987
2012	1,850	3,538	1,845	3,478	5	60

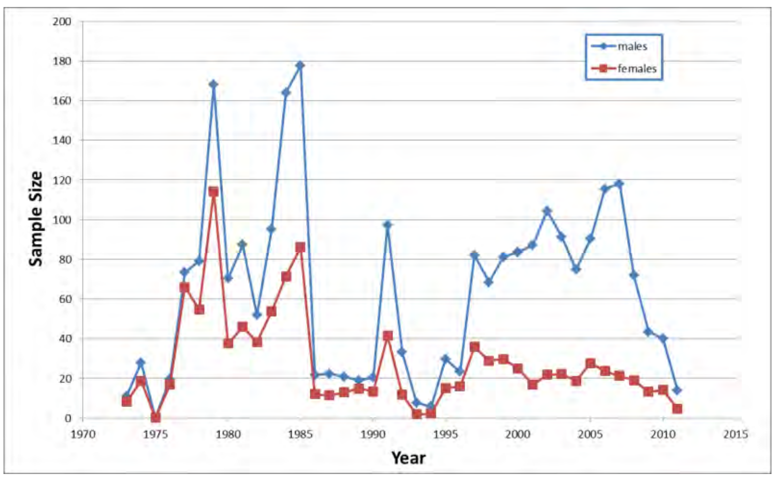
A1.Table 7. Comparison of the re-calculated annual effort (1000's of potlifts) time series in the directed Tanner crab fishery with the values used in the2013 assessment.

Year	re-calc'd effort	2013 effort	% difference
1990	494.299	883.441	-78.7
1991	500.914	1,224.959	-144.5
1992	675.592	1,201.900	-77.9
1993	326.720	576.662	-76.5
1994	249.536	249.536	0.0
1995	248.442	248.442	0.0
1996	73.522	149.289	-103.1
1997	0.000	0.000	0.0
1998	0.000	0.000	0.0
1999	0.000	0.000	0.0
2000	0.000	0.000	0.0
2001	0.000	0.000	0.0
2002	0.000	0.000	0.0
2003	0.000	0.000	0.0
2004	0.000	0.000	0.0
2005	6.346	3.926	38.1
2006	19.790	17.950	9.3
2007	33.709	34.689	-2.9
2008	21.737	21.737	0.0
2009	6.635	6.635	0.0
2010	0.000	0.000	0.0
2011	0.000	0.000	0.0
2012	0.000	0.000	0.0

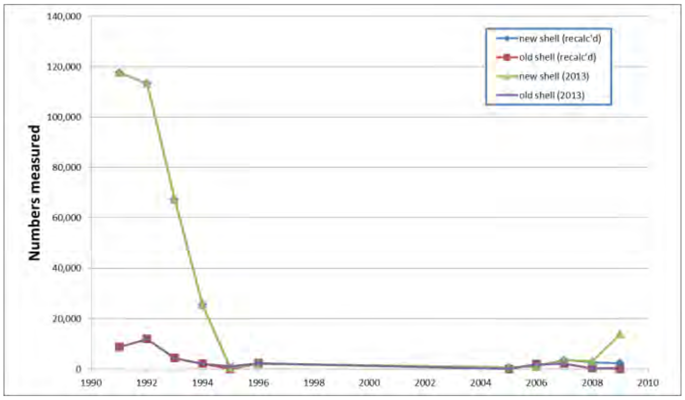
Figures



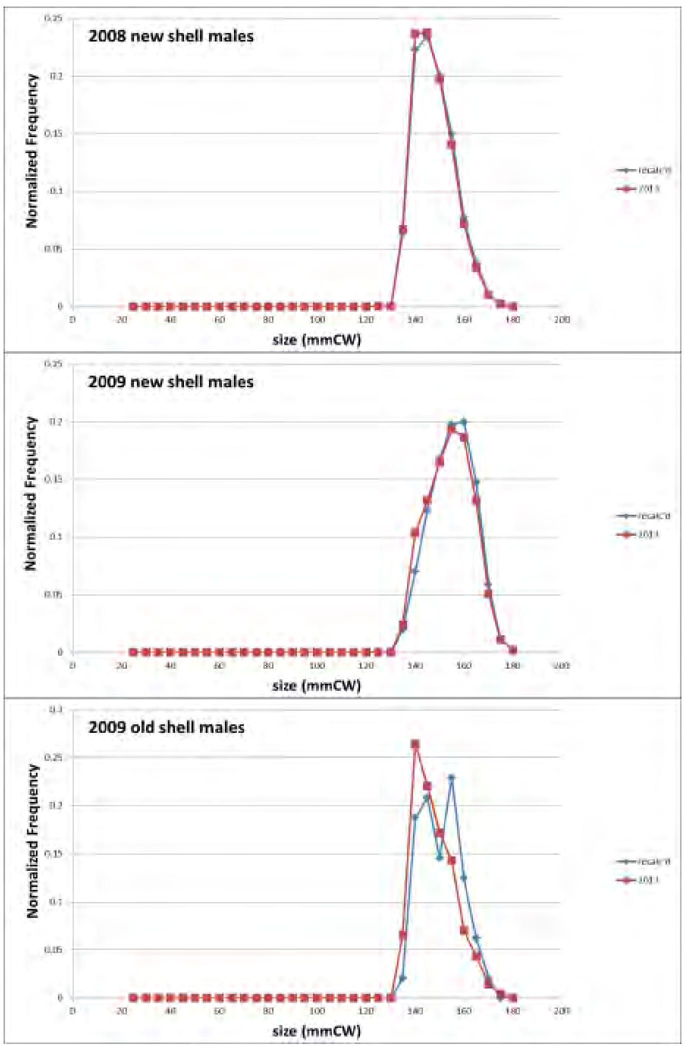
A1.Figure 1. Size frequencies for immature, new shell females from the 2013 AFSC trawl survey: the version used in the 2013 assessment (blue) and the corrected version (red).



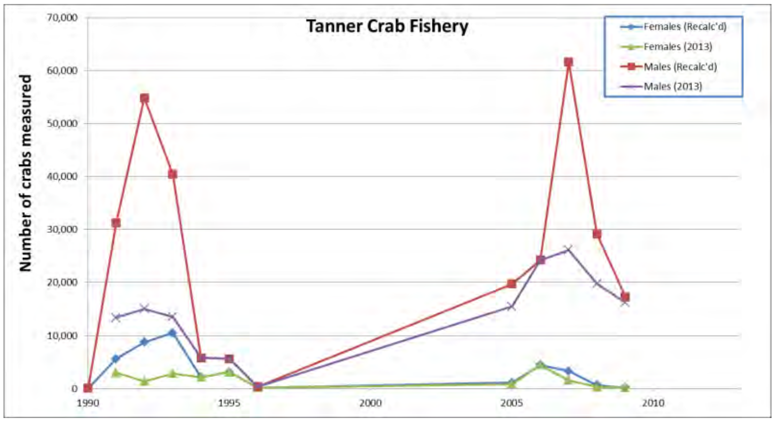
A1.Figure 2. Corrected sample sizes for sex-specific (males: blue; females: red) bycatch size frequencies in the groundfish fisheries. The sexes were switched in the 2013 (and 2012) assessments.



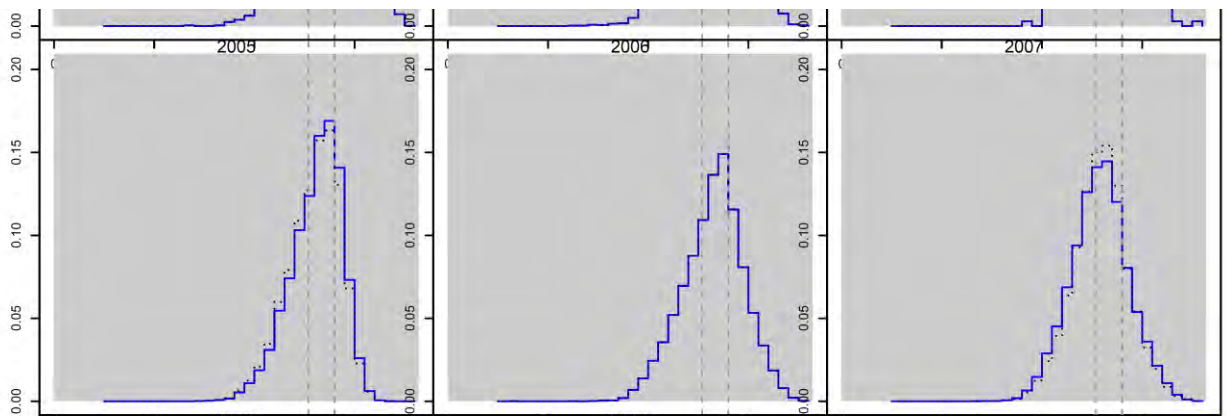
A1.Figure 3. Numbers of measured male crab in new/old shell categories in dockside sampling for retained Tanner crab in the updated dataset (red, blue lines) and the 2013 assessment dataset (green, purple lines).



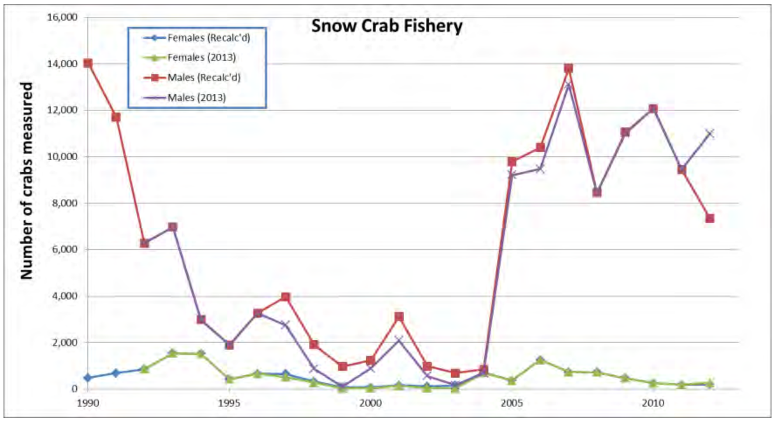
A1.Figure 4. Normalized dockside retained size frequencies from updated results (blue) and used in the 2013 assessment (red).



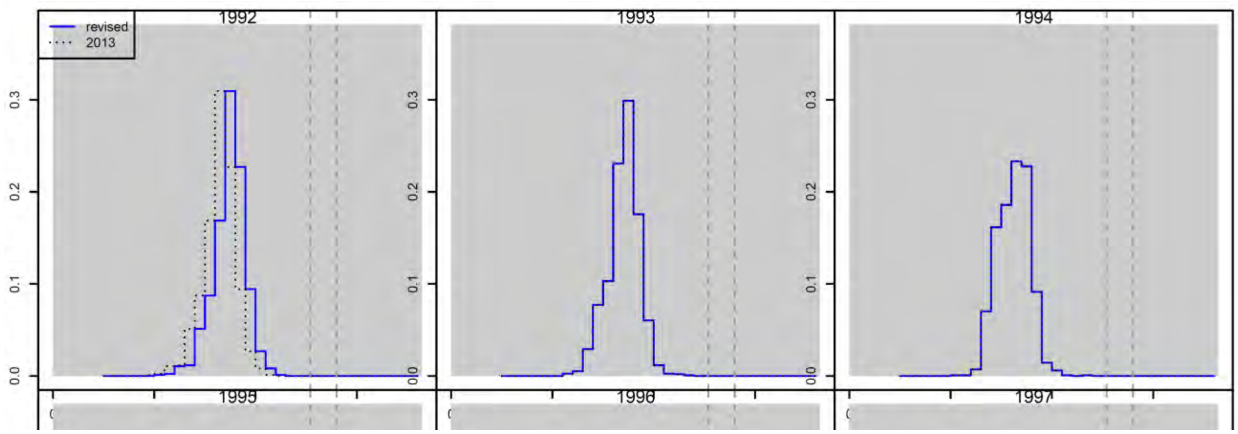
A1.Figure 5. Comparison of numbers of measured crab, by year and sex, in at-sea sampling in the directed Tanner crab fishery in the recalculated dataset (red and blue lines) and the 2013 assessment dataset (green and purple lines).



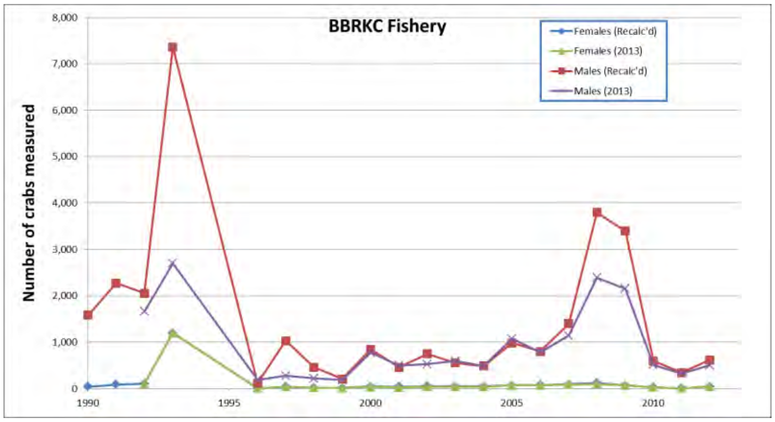
A1.Figure 6. Comparison of normalized size frequencies for measured male crab during selected years in at-sea sampling of the directed Tanner crab fishery in the recalculated dataset (blue lines) and the 2013 assessment dataset (dotted lines). Vertical dashed lines indicate the minimum legal sizes in the West and East regions.



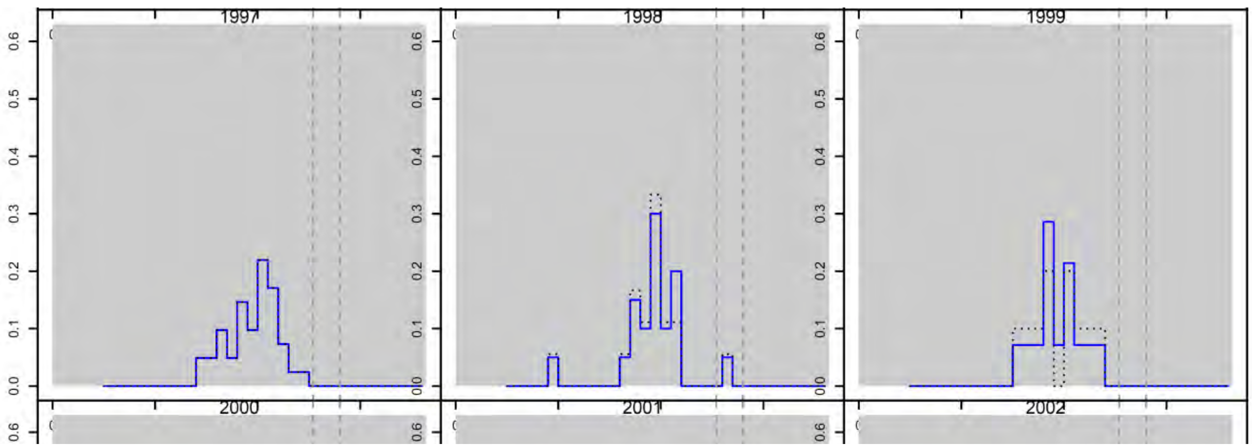
A1.Figure 7. Comparison of numbers of measured Tanner crab, by year and sex, in at-sea sampling in the snow crab fishery in the recalculated dataset (red, blue lines) and the 2013 assessment (green, purple lines).



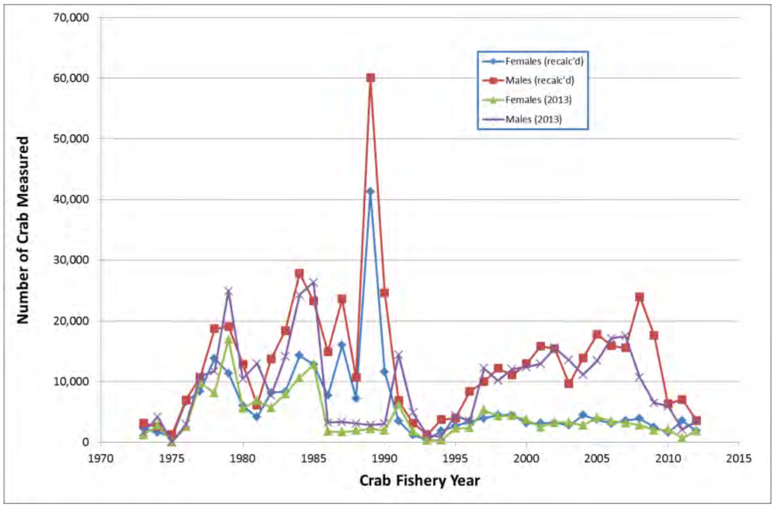
A1.Figure 8. Comparison of normalized size frequencies for measured female crab during selected years in at-sea sampling of the Tanner crab bycatch in the snow crab fishery in the recalculated dataset (blue lines) and the 2013 assessment dataset (dotted lines). Vertical dashed lines indicate the minimum legal sizes for Tanner crab in the West and East regions.



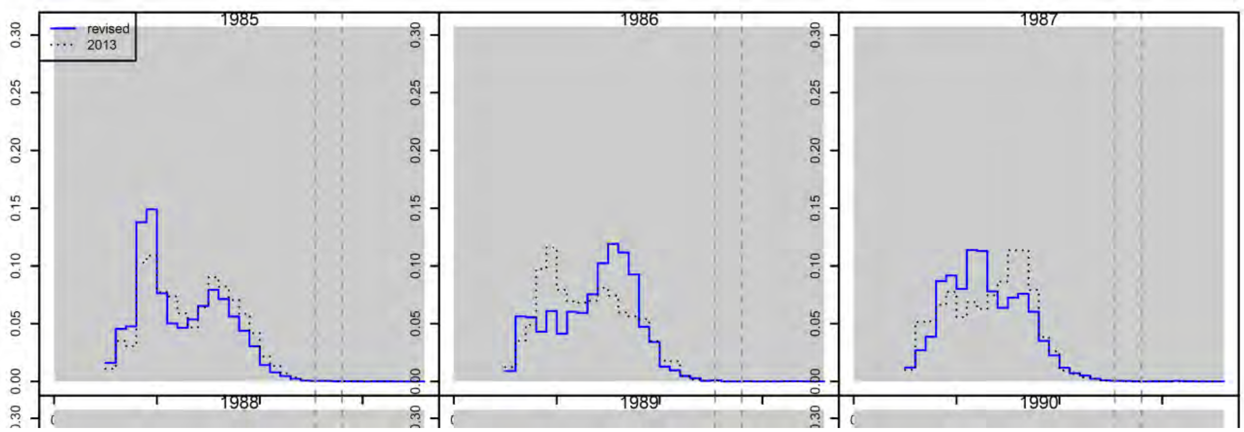
A1.Figure 9. Comparison of numbers of measured Tanner crab, by year and sex, in at-sea sampling in the BBRKC fishery in the recalculated dataset (red, blue lines) and the 2013 assessment (green, purple lines).



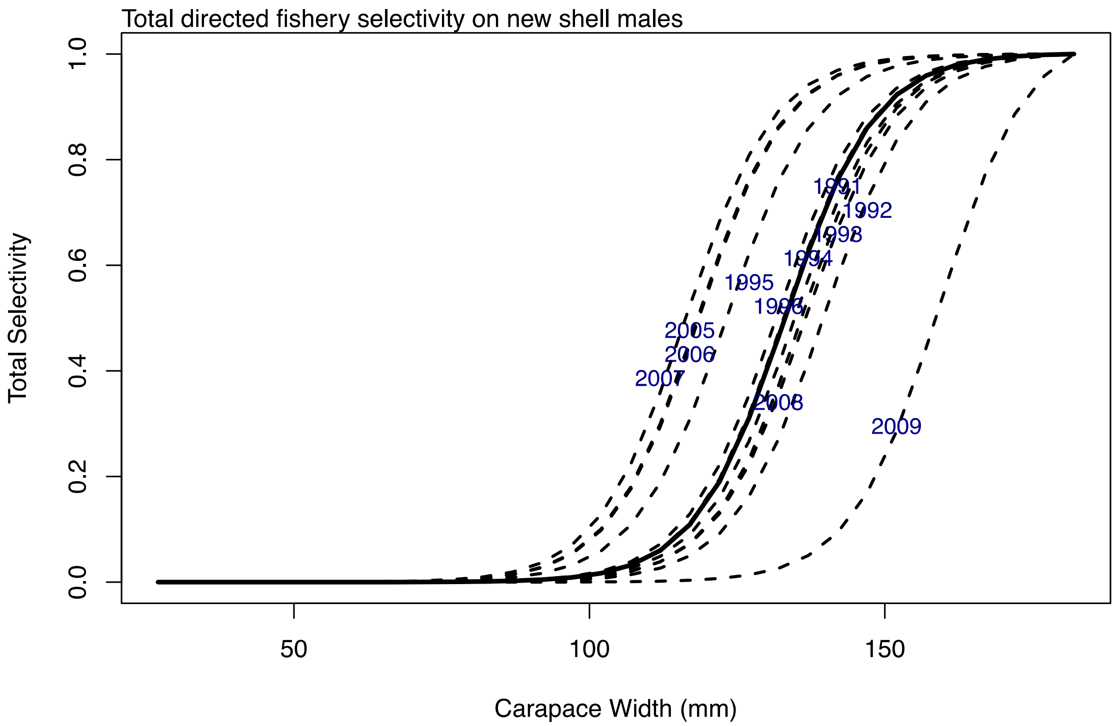
A1.Figure 10. Comparison of normalized size frequencies for measured female crab during selected years in at-sea sampling of the Tanner crab bycatch in the BBRKC fishery in the recalculated dataset blue lines) and the 2013 assessment dataset (dotted lines). Vertical dashed lines indicate the minimum legal sizes for Tanner crab in the West and East regions.

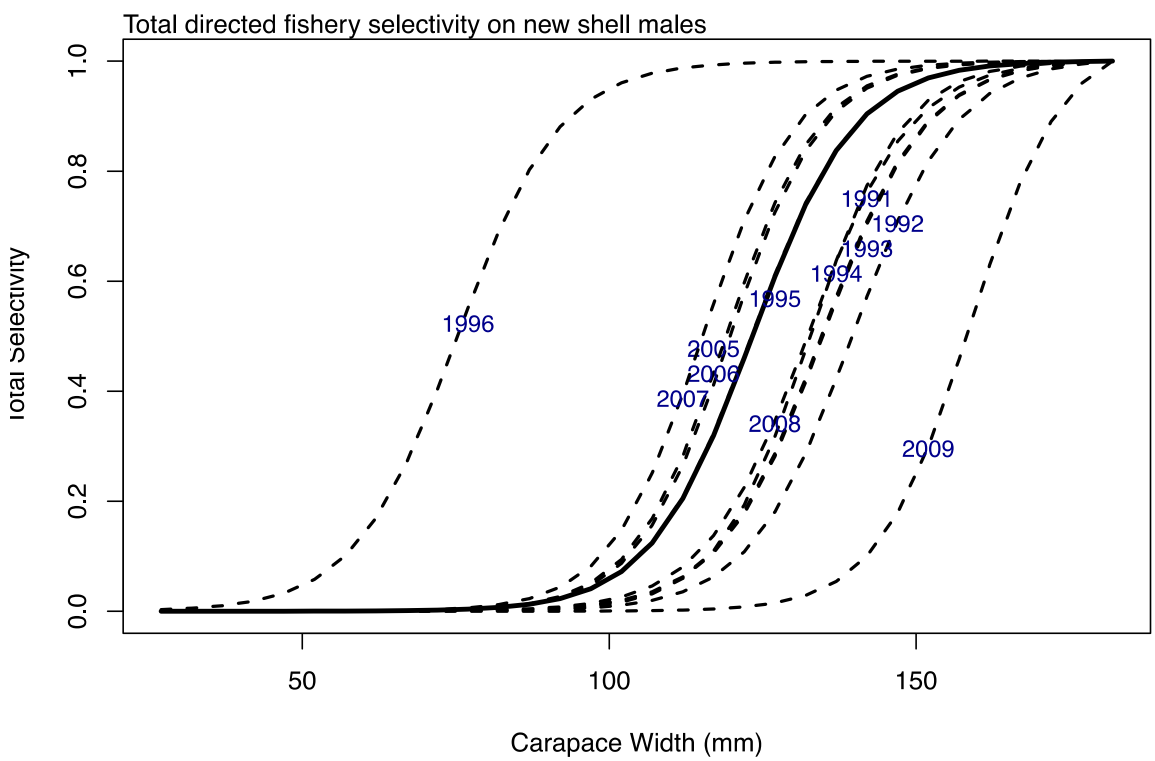


A1.Figure 11. Comparison of numbers of measured Tanner crab, by year and sex, in at-sea sampling in the groundfish fisheries in the recalculated dataset (red, blue lines) and the 2013 assessment (green, purple lines). The recalculated dataset is based on the crab fishery year (starting July 1), whereas the 2013 assessment dataset was based on the groundfish fishery year (starting Jan. 1).

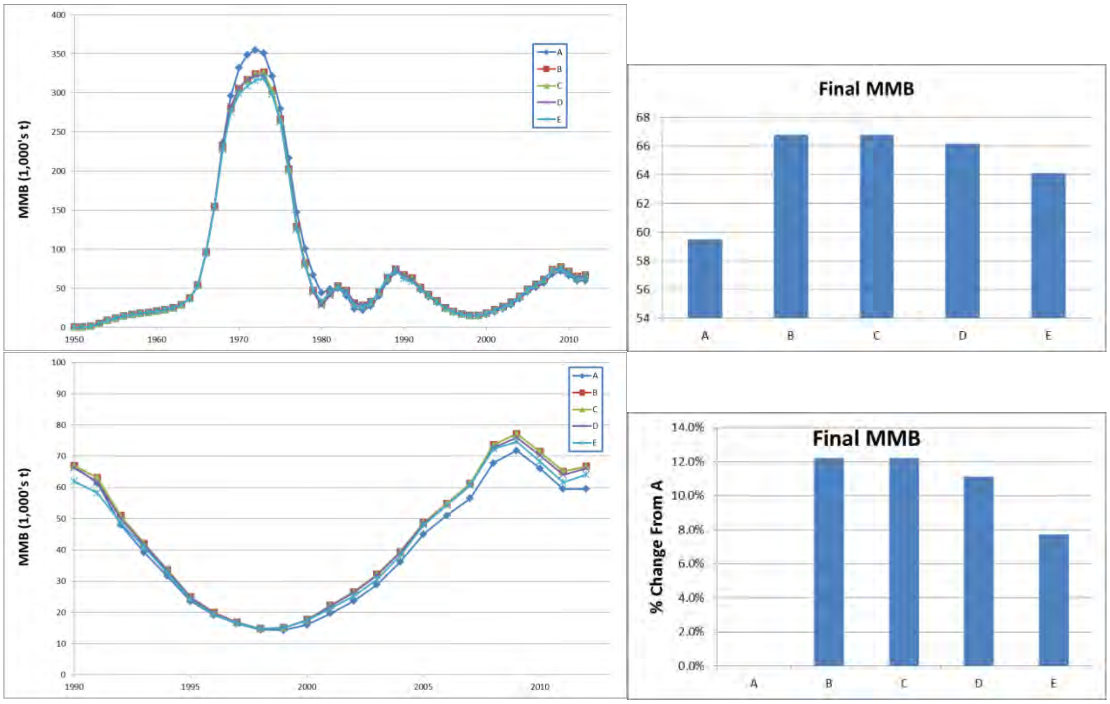


A1.Figure 12. Comparison of normalized size frequencies for measured female crab during selected years in at-sea sampling of the Tanner crab bycatch in the groundfish fisheries in the recalculated dataset blue lines) and the 2013 assessment dataset (dotted lines). Vertical dashed lines indicate the minimum legal sizes for Tanner crab in the West and East regions.

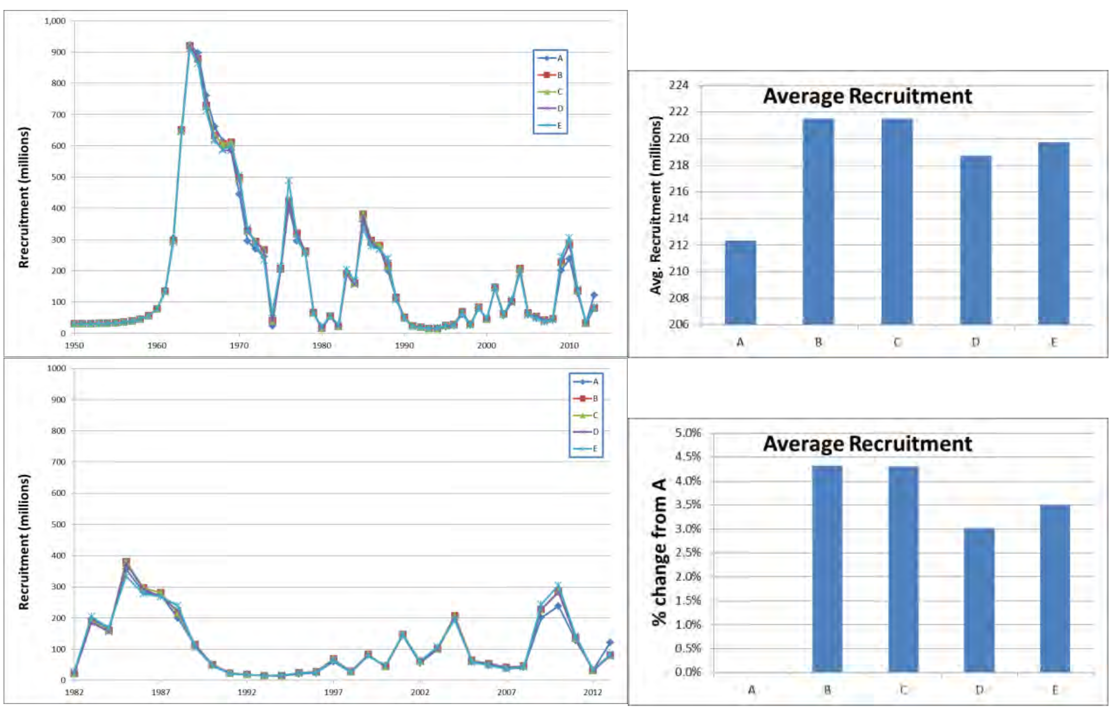




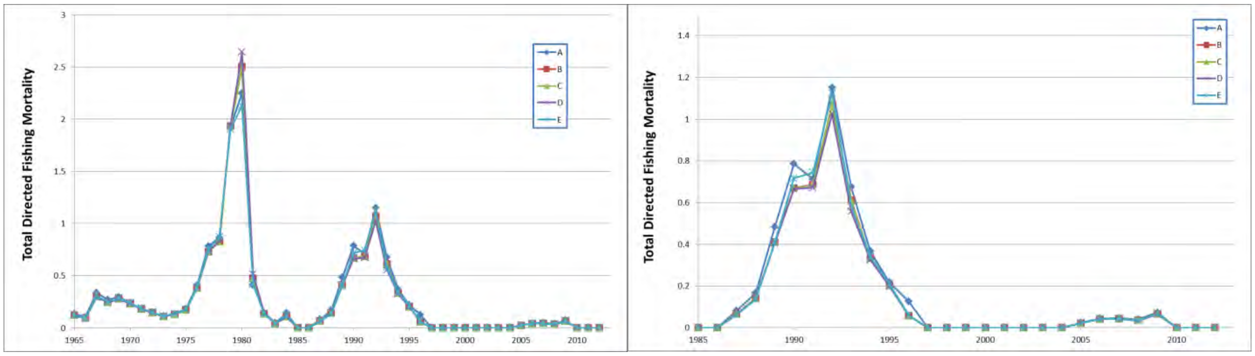
A1.Figure 13. Comparison of TCSAM2013-estimated selectivity on new shell males in the directed fishery for: 1) Dataset A, the2013 assessment data (upper graph) and 2) Dataset B, Dataset A with corrected sample sizes in the groundfish fisheries (lower graph).



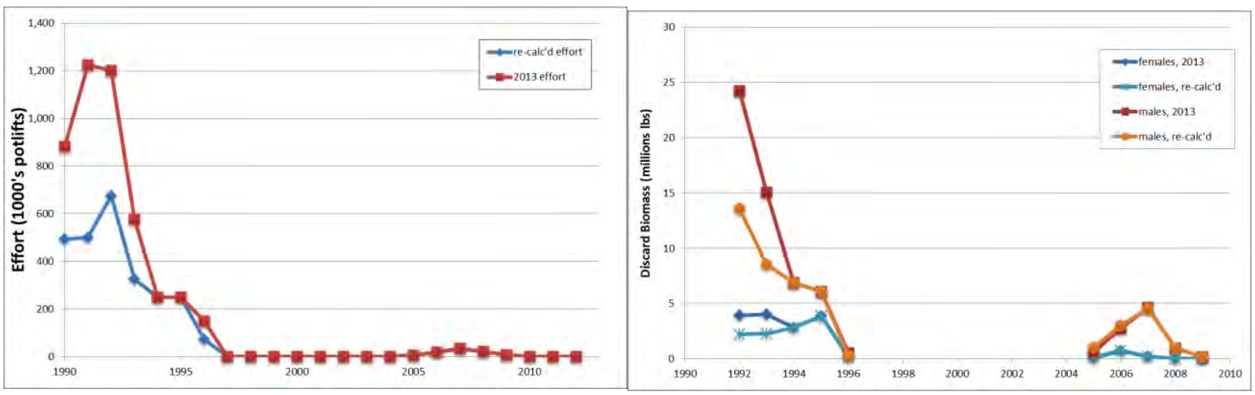
A1.Figure 14. Comparison of TCSAM2013-estimated MMB at mating time for the 5 datasets. Upper left: full time series. lower left: recent trends. Upper right: final (2012) estimates. Lower right: % change in final estimates relative to assessment dataset (A).



A1.Figure 15. Comparison of TCSAM2013-estimated recruitment for the 5 datasets. Upper left: full time series for males. Lower left: recent trends in males. Upper right: 1982-2013 average. Lower right: % change in 1982-2013 average relative to assessment dataset (A).



A1.Figure 16. Comparison of TCSAM2013-estimated directed fishing mortality for the 5 datasets. Left: full time series. Right: recent trends.



A1.Figure 17. Comparison of the re-calculated effort time series (left graph) and the resulting discard biomass (right graph) in the directed Tanner crab fishery with the values used in the 2013 assessment.

Appendix 2: Estimating crab bycatch in the groundfish fisheries

This appendix provides a brief overview regarding estimation of crab bycatch in the groundfish fisheries, as conducted by the NMFS Alaska Regional Office (AKRO) and the Alaska Fisheries Information Network (AKFIN). It represents a merging of two memos provided by J. Gaspar (AKRO) discussing these details.

Data availability:

Pre 1991: Data available in INPFC reports only.

1991-December 2002: Bycatch estimates use the “blend method”. The blend process combined data from industry production reports and observer reports to make the best, comprehensive accounting of groundfish catch. For shoreside processors, Weekly Production Reports (WPR) submitted by industry were the best source of data for retained groundfish landings. All fish delivered to shoreside processors were weighed on scales, and these weights were used to account for retained catch. Observer data from catcher vessels provided the best data on at-sea discards of groundfish by vessels delivering to shoreside processors. Discard rates from these observer data were applied to the shoreside groundfish landings to estimate total at-sea discards from both observed and unobserved catcher vessels. For observed catcher/processors and motherships, the WPR and the Observer Reports recorded estimates of total catch (retained catch plus discards). If both reports were available, one of them were selected during the “blend” process for incorporation into the catch database. If the vessel was unobserved, only the WPR was available.

January 2003 –December 2007: A new database structure named the Catch Accounting System (CAS) led to large method change. Bycatch estimates were derived from a combination of observer and landing (catcher vessels/production data). Production data included CPs and catcher vessels delivering to motherships. To obtain fishery level estimates, CAS uses a ratio estimator derived from observer data (counts of crab/kg groundfish) that is applied to production/landing information (see http://www.afsc.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-205.pdf). Estimates of crab are in numbers because the Prohibited Species Catch (PSC) is managed on numbers. There were two issues with this dataset that required estimation work outside of CAS:

1) The estimated number of crab had to be converted to weights. An average weight was calculated using groundfish observer data. This weight was specific to crab year, crab species, and fixed or trawl gear. This average was applied to the estimated number of crab for crab year by federal reporting area.

2) In some situations crab estimates were identified and grouped in the observed data to the genus level. These crabs were apportioned to the species level using the identified crab.

January 2008-2012: The observer program changed the method in which they speciate crab to better reflect their hierarchal sampling method and to account for broken crab that in the past were only identified to genus. In addition, haul-level weights collected by the observers were used to estimate the weight of crab through CAS instead of applying an annual (global) weight factor. Spatial resolution was at the federal reporting area.

NEW Data January 2009 – 2013: A new data set was made available in August 2013. The level of spatial resolution in CAS was formerly at the federal reporting area because this was the highest spatial resolution at which observer data was aggregated to create bycatch rates. The federal reporting area does not follow crab stock boundaries, particular for species with small stock areas such as the Pribilof Islands or St. Matthew Island stocks, so the new data was provided at the State reporting areas. This method uses a weight-based ratio estimator (wieght crab/weight groundfish) applied to groundfish reported on production/landing reports. Where possible, this dataset aggregates observer data to the stock area level to create bycatch estimates at the stock area. There are instances where no observer data is available and aggregation could go outside of a stock area, but this practice is greatly reduced compared with the pre-2009 data, which at-best was at the Federal reporting area level.

AKFIN/AKR created this new data set using observer data and eLandings information: landing reports and production reports. 2009 is the start of the data set because it is the first year that identification of state statistical areas was required on groundfish production reports. This allowed the use of a ratio estimator created from observer data to be applied to state statistical area landings/production.

Changes in 2014

Changes in estimates of crab bycatch in the groundfish fisheries, beginning in 2009, occurred between spring 2013 and fall of 2014 due to improvements made to the database and methods.

Background

The Alaska Region historically provided estimates of crab bycatch in groundfish fisheries at the federal reporting area level. Ratio estimation (weight of crab/total groundfish) methods were used to estimate crab catch by species. Generally speaking, there are two steps in this estimation method: 1) a ratio estimator is created by post-stratifying (aggregating) observer information; and 2) the ratio estimator is then applied to landings or production information that have the same post-strata characteristics as in 1 (e.g., both the landings and observer data were collected from area 541 for pot gear during the same week). Details on the estimation routines used in the Catch Accounting System (CAS) are in Cahalan et al. (2010), with an updated Technical Memorandum currently in review.

Spatial scale is an important component in the post-strata criteria. There are two spatial scales associated with industry reports of groundfish catch: 1) the federal reporting area and 2) the groundfish FMP area; the latter being an aggregation of federal reporting areas. Estimates of crab bycatch from CAS are specific to a federal reporting area if at-sea observer data is available; however, in federal reporting areas that have commercial landings and no corresponding observer data (defined by the post-stratification criteria), the ratio estimator is derived from an aggregation of observer information across the entire Bering Sea and Aleutian Islands FMP area. These post-stratification procedures result in bycatch estimates that may include at-sea observer information from outside a crab stock area[2].

Changes to estimation

In 2013, the NMFS Alaska Regional Office (AKRO) and Alaska Fisheries Information Network (AKFIN) created a new estimation method to generate estimates crab catch (in weight) in the groundfish fisheries by crab stock area. This required modifying the CAS Prohibited Species Catch (PSC) calculation methods so that the post-strata definitions were specific to a crab stock area and crab species (or state statistical area within a crab stock area). ***The stock-area specific estimates (in weight) are available through AKFIN starting in the 2009/2010 crab year.***

A flaw in the estimation method was identified in 2013 after the September Plan Team. This flaw allowed observer data from outside a stock area boundary to be used for stock-area specific estimation if there was little observer data available within the stock area. Correcting this issue was especially important for crab

[2] Note that post-strata definitions also including gear, vessel, week ending date, trip target, and observer selection method (based on deployment rates in the ADP). The intent of this appendix is not to provide detail on the estimation methods, but instead to highlight large changes in methodology.

stocks that bisect reporting areas, such as the Pribilof Islands, St. Mathews Islands, and Bristol Bay, but it also affected the estimates for most stocks throughout the Bering Sea and Aleutian Islands. As expected, large changes were observed for the St. Mathews and the Pribilof Islands stock areas since observer data had incorrectly been aggregated across these areas. For example, observer information from the St. Mathew stock area was used in the ratio estimators for the Pribilof Islands.

In 2014, AKFIN and AKRO staff conducted further review of the crab estimation routines. This review resulted in several programming changes that affected some estimates:

- There were errors in the mapping of State of Alaska statistical areas with the crab stock area boundaries that were found and corrected. This correction affected some estimates, particularly Pribilof Island estimates where the eastern extension of the stock area boundary for blue king crab was incorrectly applied to red and golden king crab (which also changed the Bristol Bay area slightly).

- The procedures used to determine if a trip has corresponding observer data were improved. This improvement results in a lower percentage of trips that are incorrectly marked as unobserved, which means more estimates are specific to observed trips. The impact on estimation due to this change was minor.

- A post stratum was added to the estimation process. This post stratum is only used when observer data are unavailable for landings of a specific gear type (with the exception of jig gear since it is never observed), stock area, and calendar year. The impact on crab estimates due to this change was minor (mainly a few vessels in the Aleutian Islands): nearly all ratio estimates use observer data that is of the same gear type as the vessels making a landing.

In addition, updates to observer information occur when observers are debriefed and data quality verified. Debriefings can result in changes to data values or cause deletions of incorrectly collected data.

References

Cahalan J., Mondragon J., and J. Gasper. 2010. Catch sampling and estimation in the federal groundfish fisheries off Alaska. NOAA Tech. Mem. NMFS AFSC-205. 42 pp.

Appendix 3: TCSAM (Tanner Crab Stock Assessment Model) 2013 Description

Introduction

The Tanner crab stock assessment model (TCSAM) is an integrated assessment model developed in C++ using AD Model Builder (Fournier et al., 2012) libraries that is fit to multiple data sources. The model described herein is the version used in the Sept. 2013 assessment (Stockhausen et al., 2013) and will be referred to as TCSAM2013. Except for some minor corrections to the code, this model was identical to that used in the Sept. 2012 assessment (Rugolo and Turnock, 2012).

Model parameters in TCSAM2013 are estimated using a maximum likelihood approach, with Bayesian-like priors on some parameters and penalties for smoothness and regularity on others. Data components entering the likelihood include fits to survey biomass, survey size compositions, retained catch, retained catch size compositions, discard mortality in the bycatch fisheries, and discard size compositions in the bycatch fisheries. Population abundance at the start of year *y* in the model, $n_{y,x,m,s,z}$, is characterized by sex *x* (male, female), maturity state *m* (immature, mature), shell condition *s* (new shell, old shell), and size *z* (carapace width, CW). Changes in abundance due to natural mortality, molting and growth, maturation, fishing mortality and recruitment are tracked on an annual basis. Because the principal crab fisheries occur during the winter, the model year runs from July 1 to June 30 of the following calendar year.

A. Calculation sequence

Step A1: Survival prior to fisheries

Natural mortality is applied to the population from the start of the model year (July 1) until just prior to prosecution of the pulse fisheries for year *y* at δt_y^F. The numbers surviving at δt_y^F in year *y* are given by:

$n^1_{y,x,m,s,z} = e^{-M_{y,x,m,s,z}\cdot\delta t_y^F} \cdot n_{y,x,m,s,z}$	A1

where *M* represents the annual rate of natural mortality in year *y* on crab classified as *x*, *m*, *s*, *z*.

Step A2: Prosecution of the fisheries

The directed fishery and bycatch fisheries are modeled as pulse fisheries occurring at δt_y^F in year *y*. The numbers that remain after the fisheries are prosecuted are given by:

$n^2_{y,x,m,s,z} = \left(1 - e^{-F^T_{y,x,m,s,z}}\right) \cdot n^1_{y,x,m,s,z}$	A2

where F^T represents total (across all fisheries) annual fishing mortality in year *y* on crab classified as *x*, *m*, *x*, *z*.

Step A3: Survival after fisheries to time of molting/mating

Natural mortality is again applied to the population from just after the fisheries to the time at which molting/mating occurs for year *y* at δt_y^m. The numbers surviving at δt_y^m in year *y* are then given by:

$n^3_{y,x,m,s,z} = e^{-M_{y,x,m,s,z}\cdot(\delta t_y^m - \delta t_y^F)} \cdot n^2_{y,x,m,s,z}$	A3

where, as above, *M* represents the annual rate of natural mortality in year *y* on crab classified as *x*, *m*, *s*, *z*. In the 2012 and 2013 assessments, molting and mating were taken to occur on Feb. 15 each year ($\delta t_y^m = 0.625$), and the pulse fisheries were taken to occur just prior to this ($\delta t_y^F = 0.625$, also), so the term in the exponent in eq. A3 was 0 for all years.

Step A4: Molting, growth, and maturation
The changes in population structure due to molting, growth and maturation of immature (new shell) crab, as well as the change in shell condition for new shell mature crab due to aging, are given by:

$n^4_{y,x,MAT,NS,z} = \sum_{z'} \Theta^{MAT}_{y,x,z,z'} \cdot \phi_{y,x,z'} \cdot n^3_{y,x,IMM,NS,z'}$	A4a
$n^4_{y,x,IMM,NS,z} = \sum_{z'} \Theta^{IMM}_{y,x,z,z'} \cdot (1-\phi_{y,x,z'}) \cdot n^3_{y,x,IMM,NS,z'}$	A4b
$n^4_{y,x,MAT,OS,z} = n^3_{y,x,MAT,OS,z} + n^3_{y,x,MAT,NS,z}$	A4c

where $\phi_{y,x,z}$ is the probability that an immature (new shell) crab of sex *x* and size *z* will undergo its terminal molt to maturity and $\Theta^{m}_{y,x,z,z'}$ is the growth transition matrix from size *z'* to *z* for that crab, which may depend on whether (*m*=*MAT*; eq. A.4a) or not (*m*=*IMM*; eq. A.4b) the terminal molt to maturity occurs. Additionally, crabs that underwent their terminal molt to maturity the previous year are assumed to change shell condition from new shell (*NS*) to old shell (*OS*; A.4c). Note that the numbers of immature, old shell crab are identically zero in the current model because immature crab are assumed to molt each year until they undergo the terminal molt to maturity; consequently, an equation for *m*=*IMM*, *s*=*NS* above is unnecessary.

Step A5: Survival to end of year, recruitment, and update to start of next year
Finally, population abundance at the start of year *y*+1 due to recruitment of immature new shell crab at the end of year *y* ($r_{y,x,z}$) and natural mortality on crab from the time of molting in year *y* until the end of the model year (June 30) are given by:

$r_{y,x,z} = R_y \cdot \rho_{y,x} \cdot \eta_z$	A5a
$n_{y+1,x,m,s,z} = \begin{cases} e^{-M_{y,x,IMM,NS,z} \cdot (1-\delta t^m_y)} \cdot n^4_{y,x,IMM,NS,z} + r_{y,x,z} & m = IMM, s = NS \\ e^{-M_{y,x,m,s,z} \cdot (1-\delta t^m_y)} \cdot n^4_{y,x,m,s,z} & otherwise \end{cases}$	A5b

B. Model processes: natural mortality

Natural mortality rates in TCSAM2013 vary across 3 year blocks (model start-1979, 1980-1984,1985-model end) within which they are sex- and maturity state-specific but do not depend on shell condition or size. They are parameterized in the following manner:

$M_{y,x,m,s,z} = \begin{cases} M^{base}_{x,m,s} \cdot \delta M_{x,m} & 1980 \le y \le 1984 \\ M^{base}_{x,m,s} \cdot \delta M_{x,m} \cdot \delta M^T_{x,m} & otherwise \end{cases}$	natural mortality rates	B1 B2

where *y* is year, *x* is sex, *m* is maturity state and *s* is shell condition, the $M^{base}_{x,m,s}$ are user constants (not estimated), and the $\delta M_{x,m}$ and $\delta M^T_{x,m}$ are parameters (although not all are estimated).

Priors are imposed on the $\delta M_{x,m}$ parameters in the likelihood using:

$\Pr(\delta M_{x,m}) = \cdot\, e^{-\frac{(\delta M_{x,m} - \mu_{x,m})}{2 \cdot \sigma_{x,m}^2}}$	Prior probability function for $\delta M_{x,m}$	B3

The μ's and σ^2 , along with bounds, initial values and estimation phases used for the parameters, as well as the values for the constants, used in the 2013 model are:

parameters/constants	$\mu_{x,m}$	$\sigma_{x,m}^2$	lower bound	upper bound	initial value	phase	code name
$M_{MALE,IMM,NS}^{base}$	--	--	--	--	0.23	NA	`M_in(MALE)`
$M_{FEMALE,IMM,NS}^{base}$	--	--	--	--	0.23	NA	`M_in(FEMALE)`
$M_{MALE,MAT,NS}^{base}$	--	--	--	--	0.23	NA	`M_matn_in(MALE)`
$M_{FEMALE,MAT,NS}^{base}$	--	--	--	--	0.23	NA	`M_matn_in(FEMALE)`
$M_{MALE,MAT,OS}^{base}$	--	--	--	--	0.23	NA	`M_mato_in(MALE)`
$M_{FEMALE,MAT,OS}^{base}$	--	--	--	--	0.23	NA	`M_mato_in(FEMALE)`
$\delta M_{x,IMM}$	1.0	0.05	0.2	2.0	1.1	7	`M_mult_imat`
$\delta M_{MALE,MAT}$	1.0	0.05	0.1	1.9	1.0	7	`Mmultm`
$\delta M_{FEMALE,MAT}$	1.0	0.05	0.1	1.9	1.0	7	`Mmultf`
$\delta M_{MALE,IMM}^{T}$	--	--	--	--	1.0	NA	`NA`
$\delta M_{FEMALE,IMM}^{T}$	--	--	--	--	1.0	NA	`NA`
$\delta M_{MALE,MAT}^{T}$			0.1	10.0	1.0	7	`mat_big(MALE)`
$\delta M_{FEMALE,MAT}^{T}$			0.1	10.0	1.0	7	`mat_big(FEMALE)`

where constants have phase = NA and estimated parameters have phase > 0. When no corresponding variable exists in the model (code name = NA), the effective value of the parameter/constant is given.

C. Model processes: growth

Growth of immature crab in the 2013 TCSAM model is based on sex-specific transition matrices that specify the probability that crab in pre-molt size bin z grow to post-molt size bin z'. The sex-specific growth matrix $\Theta_{x,z,z'}$ (i.e., the array `len_len[sex,ilen,ilen]` in the model code) is related to the sex-specific parameters a_x, b_x, and β_x by the following equations:

$\Theta_{x,z,z'} = c_{x,z} \cdot \Delta_{z,z'}{}^{\alpha_{x,z}-1} \cdot e^{-\frac{\Delta_{z,z'}}{\beta_x}}$	Sex-specific (x) transition matrix for growth from pre-molt z to post-molt z', with $z' \geq z$	C1
$c_{x,z} = \left[\sum_{z'} \Delta_{z,z'}{}^{\alpha_{x,z}-1} \cdot e^{-\frac{\Delta_{z,z'}}{\beta_x}}\right]^{-1}$	Normalization constant so $1 = \sum_{z'} \Theta_{x,z,z'}$	C2
$\Delta_{z,z'} = z' - z$	Actual growth increment	C3
$\alpha_{x,z} = \left[\bar{z}_{x,z} - z\right]/\beta_x$	Mean molt increment, scaled by β_x	C4
$\bar{z}_{x,z} = e^{a_x} \cdot z^{b_x}$	Mean size after molt, given pre-molt size z	C5

$\Theta_{x,z,z'}$ is used to update the numbers-at-size for immature crab following molting using:

$n^+_{x,z'} = \sum_z n_{x,z} \cdot \Theta_{x,z,z'}$		C6

where z is the pre-molt size and z' is the post-molt size.

Sex-specific priors are imposed on the estimated values $\hat{a}_x$ and $\hat{b}_x$ for the a_x and b_x parameters using:

$\Pr(\hat{a}_x) =\cdot\, e^{-\frac{(\hat{a}_x - \mu_{a_x})}{2\cdot\sigma^2_{a_x}}}$	Prior probability function for a's	C7
$\Pr(\hat{b}_x) =\cdot\, e^{-\frac{(\hat{b}_x - \mu_{b_x})}{2\cdot\sigma^2_{b_x}}}$	Prior probability function for b's	C8

The μ's and σ^2, along with the bounds, initial values and estimation phases used for the parameters in the 2013 TCSAM are:

parameter	sex (x)	μ_x	σ^2_x	lower bound	upper bound	initial value	phase	code name
a_x	female	0.56560241	0.100	0.4	0.7	0.55	8	`af1`

	male	0.43794100	0.025	0.3	0.6	0.45	8	`am1`
b_x	female	0.9132661	0.025	0.6	1.2	0.90	8	`bf1`
	male	0.9487000	0.100	0.7	1.2	0.95	8	`bm1`
β_x	both	NA	NA	0.75000	0.75001	0.750005	-2	`growth_beta`

Note that the β_x are treated as constants because the associated estimation phases are negative.

D. Model processes: maturity

Maturation of immature crab in TCSAM2013 is based on sex- and size-specific probabilities of maturation, $\phi_{x,z}$, where size *z* is pre-molt size. After molting, but before assessing growth, the numbers of crab remaining immature, $n^{+}_{x,IMM,NS,z}$, and those maturing, $n^{+}_{x,MAT,NS,z}$, at pre-molt size *z* are given by:

$n^{+}_{x,IMM,NS,z} = \quad (1-\phi_{x,z}) \cdot n_{x,IMM,NS,z}$ $n^{+}_{x,MAT,NS,z} = \quad \phi_{x,z} \cdot n_{x,IMM,NS,z}$		D1a D1b

where $n_{x,IMM,NS,z}$ is the number of immature, new shell crab of sex *x* at pre-molt size *z*.

The sex- and size-specific probabilities of maturing, $\phi_{x,z}$, are related to the model parameters $p^{mat}_{x,z}$ by:

$\phi_{FEMALE,z} = \begin{cases} e^{p^{mat}_{FEMALE,z}} & z \le 100\ mm\ CW \\ 1 & z > 100\ mm\ CW \end{cases}$	female probabilities of maturing at pre-molt size *z*	D2a
$\phi_{MALE,z} = e^{p^{mat}_{MALE,z}}$	male probabilities of maturing at pre-molt size *z*	D2b

where each $p^{mat}_{FEMALE,z}$ is an estimated parameter (16 parameters), as is each $p^{mat}_{MALE,z}$ (32 parameters).

Second difference penalties, P^{mat}_{x}, on the parameter estimates are applied in the model's objective function to promote relatively smooth changes with size. These penalties are of the form

$P^{m}_{x} = \sum_{z} \left[\nabla(\nabla p^{mat}_{x,z})\right]^2$	2nd-difference (smoothness) likelihood penalty	D3
$\nabla p^{mat}_{x,z} = p^{mat}_{x,z} - p^{mat}_{x,z-1}$	first difference	D4

The bounds, initial values and estimation phases used for the parameters in the 2013 model are:

parameters	lower bound	upper bound	initial value	phase	code name
$p^{mat}_{MALE,z}$	-16	0	-1.0	5	`matestm`

$p^{mat}_{FEMALE,z}$	-16	0	-1.0	5	`matestf`

E. Model processes: recruitment

Recruitment of immature (new shell) crab in TCSAM2013 has the functional form:

$R_{y,x,z} = \dot{R}_{y,x} \cdot \ddot{R}_z$	recruitment of immature, new shell crab	E1

where y is year, x is sex, and z is size. $\dot{R}_{y,x}$ represents total sex-specific recruitment in year y and $\ddot{R}_z$ represents the size distribution of recruits, which is assumed identical for males and females.

Sex-specific recruitment, $\dot{R}_{y,x}$, is parameterized as

$\dot{R}_{y,x} = \begin{cases} e^{pLnR^H + \delta R^H_y} & y \leq 1973 \\ e^{pLnR + \delta R_y} & 1974 \leq y \end{cases}$	sex-specific recruitment of immature, new shell crab	E2

where the sex ratio at recruitment is assumed to be 1:1 and the δR_y and δR^H_y are "devs" parameter vectors, with the constraint that the elements of a "devs" vector sums to zero. Independent parameter sets are used for the "historic" period during model spin-up (1949-1973) and the "current" period (1974-2013).

The size distribution for recruits, $\ddot{R}_z$, is based on a gamma-type distribution and is parameterized as

$\ddot{R}_z = c^{-1} \cdot \Delta_z^{\frac{\alpha}{\beta}-1} \cdot e^{-\frac{\Delta_z}{\beta}}$	size distribution of recruiting crab	E3

where α and β are parameters, $\Delta_z = z + 2.5 - z_{min}$, and $c = \sum_z \Delta_z^{\frac{\alpha}{\beta}-1} \cdot e^{-\frac{\Delta_z}{\beta}}$ is a normalization constant so that $1 = \sum_z \ddot{R}_z$. z_{min} is the smallest model size bin (27 mm) and the constant 2.5 represents one-half the size bin spacing.

Penalties are imposed on the "devs" parameter vectors δR_y and δR^H_y in the objective function as follows:

$\mathrm{P}(\delta R) = \sum_y \delta R_y{}^2$	Penalty function on δR_y	E4
$\mathrm{P}(\delta R^H) = \sum_y \left(\delta R^H_y - \delta R^H_{y-1}\right)^2$	1st difference penalty function on δR^H_y	E5

The bounds, initial values and estimation phases used for the parameters used in the 2013 model are:

parameters	lower bound	upper bound	initial value	phase	code name
$pLnR^H$	--	--	0.0	1	`pMnLnRecEarly`

$pLnR$	--	--	11.4	1	`pMnLnRec`
δR_y^H	-15	15	0	1	`pRecDevsEarly`
δR_y	-15	15	0	1	`pRecDevs`
α	11.49	11.51	11.50	-8	`alpha1_rec`
β	3.99	4.01	4.00	-8	`beta_rec`

where parameters with phase < 0 are not estimated (i.e., treated as constants).

F. Model processes: fisheries

Four fisheries that catch Tanner crab are included in TCSAM2013: 1) the directed Tanner crab fishery, 2) the snow crab fishery, 3) the BBRKC fishery and 4) the various groundfish fisheries (lumped as one bycatch fishery). Crab (males only) are assumed to be retained exclusively in the directed fishery. Bycatch of non-retained Tanner crab (males and females) is assumed to occur in all four fisheries; discard mortality fractions for the (discarded) bycatch are assumed to differ between the crab and groundfish fisheries due to the differences in gear used (pots vs. primarily bottom trawl).

The predicted number of crab killed in fishery *f* by year in TCSAM2013 model has the functional form:

$m_{y,x,m,s,z}^f = \dfrac{F_{y,x,m,s,z}^f}{F_{y,x,m,s,z}^T} \cdot \left[1 - e^{-F_{y,x,m,s,z}^T}\right] \cdot n_{y,x,m,s,z}^1$	estimated crab mortality in fishery *f*	F1

where *y* is year, *x* is sex, *m* is maturity state, *s* is shell condition and *z* is size, $F_{y,x,m,s,z}^f$ is sex/maturity state/shell condition/size-specific fishing mortality in year *y*, and $F_{y,x,m,s,z}^T = \sum_f F_{y,x,m,s,z}^f$ is total fishing mortality sex *x* crab in maturity state *m* and shell condition *s* at size *z* at the time the fisheries occur in year *y*. Note that $m_{y,x,m,s,z}^f$ represents the estimated *mortality* in numbers associated with fishery *f*, not the numbers *captured* (i.e., brought on deck). These differ because discard mortality is not 100% in the fisheries).

The total fishing mortality rate for each fishery is decomposed into two multiplicative components: 1) the mortality rate on fully-selected crab, FM_y^f, and 2) a size-specific selectivity function $S_{y,x,m,s,z}^f$, as follows:

$F_{y,x,m,s,z}^f = FM_y^f \cdot S_{y,x,m,s}^f$	fishing mortality rate in fishery *f*	F2

Fully-selected fishing mortality

The manner in which the fully-selected fishing mortality rate is further decomposed is time-dependent and specific to each fishery. Consequently, this decomposition is discussed below specific to each fishery.

Considering Tanner crab total fishing mortality (retained + discards) in the directed Tanner crab fishery (TCF) first, the fully-selected fishing mortality is modeled differently in three time periods:

$FM_y^{TCF} = \begin{cases} 0.05 & y < 1965 \\ 0 & 1965 \le y, fishery\ closed \\ e^{p\overline{LnF}^{TCF} + \delta F_y^{TCF}} & 1965 \le y, fishery\ open \end{cases}$	fully-selected fishing mortality rate in the directed Tanner crab fishery	F3

where $p\overline{LnF}^{TCF}$ is a parameter representing the mean ln-scale fishing mortality in the Tanner crab fishery since 1964 (catch data for this fishery begins in 1965) and δF_y^{TCF} represents a "devs" parameter vector with elements defined for each year the fishery was open. Prior to 1965, a small directed fishing mortality rate (0.05) is assumed.

For Tanner crab bycatch in the snow crab fishery (SCF), the fully-selected discard fishing mortality is modeled differently in three time periods using:

$FM_y^{SCF} = \begin{cases} 0.01 & y < 1978 \\ r^{SCF} \cdot E_y^{SCF} & 1978 \le y \le 1991 \\ e^{p\overline{LnF}^{SCF} + \delta F_y^{SCF}} & 1992 \le y \end{cases}$	fully-selected discard fishing mortality rate in the snow crab fishery	F4

where $p\overline{LnF}^{SCF}$ is a parameter representing the mean ln-scale bycatch fishing mortality in the snow crab fishery since 1992 (when reliable observer-based Tanner crab discard data in the snow crab fishery first became available) and δF_y^{SCF} represents a "devs" parameter vector with elements defined for each year in this time period. Prior to 1978, a small annual discard mortality rate associated with this fishery (0.01) is assumed. Annual effort data (total potlifts, E_y^{SCF}) is used to extend predictions of Tanner crab discard mortality in this fishery into the period 1978-1991. To do this, the assumption is made that effort in the snow crab fishery is proportional to Tanner crab discard fishing mortality and estimate the proportionality constant, r^{SCF}, using a ratio estimator between effort and discard mortality in the period 1992-present:

$r^{SCF} = \dfrac{\left\{\frac{1}{N}\sum_{y=1992}^{present} FM_y^{SCF}\right\}}{\left\{\frac{1}{N}\sum_{y=1992}^{present} E_y^{SCF}\right\}}$	ratio estimator relating fishing mortality rate to effort in the snow crab fishery	F5

where *N* is the number of years, 1992-present.

For Tanner crab bycatch in the BBRKC fishery (RKF), the fully-selected discard fishing mortality when the fishery was open is modeled differently in three time periods using:

$FM_y^{RKF} = \begin{cases} 0.02 & y < 1953 \\ max\{0.01, -ln[1 - r^{RKF} \cdot E_y^{RKF}]\} & 1953 \le y \le 1991 \\ e^{p\overline{LnF}^{RKF} + \delta F_y^{RKF}} & 1992 \le y \end{cases}$	fully-selected discard fishing mortality rate in the BBRKC fishery	F6

where $p\overline{LnF}^{RKF}$ is a parameter representing the mean ln-scale bycatch fishing mortality in the BBRKC fishery since 1992 (when observer-based Tanner crab discard data in the BBRKC fishery first became available) and δF_y^{RKF} represents a "devs" parameter vector with elements defined for each year in this period that the fishery was open. Prior to 1953, a small annual discard mortality rate associated with this fishery (0.02) was assumed. Annual effort data (total potlifts, E_y^{RKF}) was used to extend predictions of Tanner crab discard mortality in this fishery into the period 1953-1991. To do this, we made the assumption that effort in the BBRKC fishery is proportional to Tanner crab discard fishing mortality and estimate the proportionality constant, r^{RKF}, using a ratio estimator between effort and discard mortality in the period 1992-present:

$r^{RKF} = \dfrac{\left\{\frac{1}{N}\sum_{y=1992}^{present}\left[1 - e^{-FM_y^{RKF}}\right]\right\}}{\left\{\frac{1}{N}\sum_{y=1992}^{present} E_y^{RKF}\right\}}$	ratio estimator relating fishing mortality rate to effort in the BBRKC fishery	F7

where N is the number of years, 1992-present, when the BBRKC fishery was open. For any year that the BBRKC fishery was closed, FM_y^{RKF} was set to 0.

Finally, for Tanner crab bycatch in the groundfish fisheries (GTF), the fully-selected discard fishing mortality in the fishery was modeled differently in two time periods using:

$FM_y^{GTF} = \begin{cases} \frac{1}{N}\sum\limits_{y=1992}^{present} e^{p\overline{LnF}^{GTF}+\delta F_y^{GTF}} & y < 1973 \\ e^{p\overline{LnF}^{GTF}+\delta F_y^{GTF}} & 1973 \le y \end{cases}$	fully-selected discard fishing mortality rate in the groundfish trawl fisheries	F8

where $p\overline{LnF}^{GTF}$ is a parameter representing the mean fully-selected ln-scale bycatch fishing mortality in the groundfish fisheries since 1973 (when observer-based Tanner crab discard data in the groundfish fisheries first became available) and δF_y^{GTF} is a "devs" parameter vector with elements representing the annual ln-scale deviation from the mean. Prior to 1973, the fully-selected discard mortality rate associated with these fisheries was assumed to be constant and equal to the mean over the 1973-present period.

The bounds (when set), initial values and estimation phases used for the fully-selected fishing mortality parameters and devs vectors in the 2013 model were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\overline{LnF}^{TCF}$	--	--	-0.7	1	`pAvgLnFmTCF`
δF_y^{TCF}	-15	15	0	2	`pFmDevsTCF`
$p\overline{LnF}^{SCF}$	--	--	-3.0	3	`pAvgLnFmSCF`
δF_y^{SCF}	-15	15	0	4	`pFmDevsSCF`
$p\overline{LnF}^{RKF}$	-5.25	-5.25	-5.25	-4	`pAvgLnFmRKF`
δF_y^{RKF}	-15	15	0	-5	`pFmDevsRKF`
$p\overline{LnF}^{GTF}$	--	--	-4.0	2	`pAvgLnFmGTF`
δF_y^{GTF}	-15	15	0	3	`pFmDevsGTF`

where all parameters and parameter vectors were estimated (phase > 0), except for those associated with the BBRKC fishery.

Fishery selectivity

The manner in which fishery selectivity is parameterized is also time-dependent and specific to each fishery, as with the fully-selected fishing mortality. However, the time periods used to define selectivity are not necessarily those used for the fully-selected fishing mortality.

In the directed Tanner crab fishery (TCF), total selectivity (retained + discards) is modeled using sex-specific ascending logistic functions. For males, in addition, total selectivity is parameterized differently in three time periods, corresponding to differences in information about the fishery (pre-/post-1991) and differences in the fishery itself (pre-/post-rationalization in 2005):

$S_{y,FEMALE,m,s,z}^{TCF} = \left\{1 + e^{-p\beta_{FEMALE}^{TCF}\cdot\left(z - pz_{50}{}_{FEMALE}^{TCF}\right)}\right\}^{-1}$	total selectivity for females in the directed Tanner crab fishery	F9
$S_{y,MALE,m,s,z}^{TCF} = \begin{cases} \left\{1 + e^{-p\beta_{MALE}^{TCF(1)}\cdot\left(z - \overline{z_{50}}_{MALE}^{TCF}\right)}\right\}^{-1} & y \le 1990 \\ \left\{1 + e^{-p\beta_{MALE}^{TCF(1)}\cdot\left(z - z_{50}{}_{y,MALE}^{TCF}\right)}\right\}^{-1} & 1991 \le y \le 1996 \\ \left\{1 + e^{-p\beta_{MALE}^{TCF(2)}\cdot\left(z - z_{50}{}_{y,MALE}^{TCF}\right)}\right\}^{-1} & 2005 \le y \le 2009 \end{cases}$	total selectivity for males in the directed Tanner crab fishery	F10

where the $p\beta_x^{TCF(t)}$ are parameters controlling the slopes of the associated logistic selectivity curves, $pZ_{50}{}_{FEMALE}^{TCF}$ is the parameter controlling the size of females at 50% selection, $\overline{z_{50}}_{MALE}^{TCF}$ controls the size of 50%-selected males in the pre-1991 period, and $z_{50}{}_{y,MALE}^{TCF}$ controls the size of 50%-selected males in the post-1990 period. The latter three quantities are functions of estimable parameters as described in the following:

$\overline{z_{50}}_{MALE}^{TCF} = \frac{1}{6}\sum_{y=1991}^{1996} z_{50}{}_{y,MALE}^{TCF}$	male size at 50%-selected used in pre-1991 period	F11
$z_{50}{}_{y,MALE}^{TCF} = e^{pLnZ_{50}{}_{MALE}^{TCF} + \delta Z_{50}{}_{y,MALE}^{TCF}}$	male size at 50%-selected used in post-1990 period	F12

where $pLnZ_{50}{}_{MALE}^{TCF}$ is a parameter controlling the ln-scale mean male size at 50% selectivity post-1990 and $\delta Z_{50}{}_{y,MALE}^{TCF}$ is a parameter vector controlling annual ln-scale deviations in male size at 50% selectivity post-1990. As formulated, selectivity in the directed fishery is not a function of maturity state or shell condition.

The bounds, initial values and estimation phases used in the 2013 model for the 5 parameters describing total selectivity in the directed Tanner crab fishery were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta_{FEMALE}^{TCF}$	0.1	0.4	0.25	3	`fish_disc_slope_f`
$p{Z_{50}}_{FEMALE}^{TCF}$	80	150	115	3	`fish_disc_sel50_f`
$p\beta_{MALE}^{TCF(1)}$	0.05	0.75	0.4	3	`fish_slope_1`
$p\beta_{MALE}^{TCF(2)}$	0.1	0.4	0.25	3	`fish_slope_yr_3`
$pLn{Z_{50}}_{MALE}^{TCF}$	4.0	5.0	4.5	3	`log_avg_sel50_3`

where all parameters were estimated. The bounds, initial values and estimation phase used in the 2013 model for the ln-scale "devs" parameter vector $\delta {Z_{50}}_{y,MALE}^{TCF}$ describing annual deviations in male size at 50%-selected (1991-1996, 2005-2009) were:

parameters	lower bound	upper bound	initial value	phase	code name
$\delta {Z_{50}}_{y,MALE}^{TCF}$	-0.5	0.5	0	3	`log_sel50_dev_3`

In the snow crab fishery (SCF), bycatch (discard) selectivity is modeled using three time periods (model start to 1996, 1997-2004, 2005 to present). Male selectivity is described using dome-shaped (double logistic) functions in each period, with:

$S_{y,MALE,m,s,z}^{SCF} = \begin{cases} S_{MALE,z}^{SCF(1)} & y \le 1996 \\ S_{MALE,z}^{SCF(2)} & 1997 \le y \le 2004 \\ S_{MALE,z}^{SCF(3)} & 2005 \le y \end{cases}$	male selectivity in the snow crab fishery	F13

where the double logistic functions $S_{MALE,z}^{SCF(t)}$ are parameterized using:

$S_{MALE,z}^{SCF(t)} = \left\{1 + e^{-p\beta_{MALE}^{SCF(ta)} \cdot \left(z - p{Z_{50}}_{MALE}^{SCF(ta)}\right)}\right\}^{-1} \cdot \left\{1 + e^{+p\beta_{MALE}^{SCF(td)} \cdot \left(z - p{Z_{50}}_{MALE}^{SCF(td)}\right)}\right\}^{-1}$	dome-shaped selectivity	F14

where $p\beta_x^{SCF(ta)}$ and $p{Z_{50}}_x^{SCF(ta)}$ are the 6 parameters controlling the ascending limb of the double logistic function and $p\beta_x^{SCF(td)}$ and $p{Z_{50}}_x^{SCF(td)}$ are the 6 parameters controlling the descending limb for each period *t*.

Female selectivity is described using ascending logistic functions in each period, with:

$S_{y,FEMALE,m,s,z}^{SCF} = \begin{cases} S_{FEMALE,z}^{SCF(1)} & y \leq 1996 \\ S_{FEMALE,z}^{SCF(2)} & 1997 \leq y \leq 2004 \\ S_{FEMALE,z}^{SCF(3)} & 2005 \leq y \end{cases}$	female selectivity in the snow crab fishery	F15

where the ascending logistic functions $S_{FEMALE,z}^{SCF(t)}$ are parameterized using:

$S_{FEMALE,z}^{SCF(t)} = \left\{1 + e^{-p\beta_{FEMALE}^{SCF(t)} \cdot \left(z - pZ_{50}{}_{FEMALE}^{SCF(t)}\right)}\right\}^{-1}$	ascending logistic selectivity	F16

where the $p\beta_x^{SCF(p)}$ are the 3 parameters controlling the slopes of the associated logistic selectivity curves and the $pZ_{50}{}_x^{SCF(p)}$ are the 3 parameters controlling size at 50%-selection.

As formulated, selectivity in the snow crab fishery is not a function of maturity state or shell condition.

The bounds, initial values and estimation phases used in the 2013 model for the 12 parameters describing male selectivity in the snow crab fishery were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta_{MALE}^{SCF(1a)}$	0.01	0.50	0.255	4	`snowfish_disc_slope_m_1`
$pZ_{50}{}_{MALE}^{SCF(1a)}$	60	150	122.5	4	`snowfish_disc_sel50_m_1`
$p\beta_{MALE}^{SCF(1d)}$	0.01	0.50	0.255	4	`snowfish_disc_slope_m2_1`
$pZ_{50}{}_{MALE}^{SCF(1d)}$	40	200	120	4	`snowfish_disc_sel50_m2_1`
$p\beta_{MALE}^{SCF(2a)}$	0.01	0.50	0.255	4	`snowfish_disc_slope_m_2`
$pZ_{50}{}_{MALE}^{SCF(2a)}$	60	150	122.5	4	`snowfish_disc_sel50_m_2`
$p\beta_{MALE}^{SCF(2d)}$	0.01	0.50	0.255	4	`snowfish_disc_slope_m2_2`
$pZ_{50}{}_{MALE}^{SCF(2d)}$	40	200	120	4	`snowfish_disc_sel50_m2_2`
$p\beta_{MALE}^{SCF(3a)}$	0.01	0.50	0.255	4	`snowfish_disc_slope_m_3`
$pZ_{50}{}_{MALE}^{SCF(3a)}$	60	150	122.5	4	`snowfish_disc_sel50_m_3`
$p\beta_{MALE}^{SCF(3d)}$	0.01	0.50	0.255	4	`snowfish_disc_slope_m2_3`
$pZ_{50}{}_{MALE}^{SCF(3d)}$	40	200	120	4	`snowfish_disc_sel50_m2_3`

where all parameters were estimated.

The bounds, initial values and estimation phases used in the 2013 model for the 6 parameters describing female selectivity in the snow crab fishery were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta_{FEMALE}^{SCF(1)}$	0.05	0.5	0.275	4	`snowfish_disc_slope_f1`
$pZ_{50}{}_{FEMALE}^{SCF(1)}$	50	150	100	4	`snowfish_disc_sel50_f1`
$p\beta_{FEMALE}^{SCF(2)}$	0.05	0.5	0.275	4	`snowfish_disc_slope_f2`
$pZ_{50}{}_{FEMALE}^{SCF(2)}$	50	120	85	4	`snowfish_disc_sel50_f2`
$p\beta_{FEMALE}^{SCF(3)}$	0.05	0.5	0.275	4	`snowfish_disc_slope_f3`
$pZ_{50}{}_{FEMALE}^{SCF(3)}$	50	120	85	4	`snowfish_disc_sel50_f3`

where all parameters were estimated.

In the BBRKC fishery (RKF), bycatch (discard) selectivity is also modeled using the three time periods used to model selectivity in the snow crab fishery (model start to 1996, 1997-2004, 2005 to present), with sex-specific parameters estimated in each period. All sex/period combinations are modeled using ascending logistic functions:

$S_{y,x,m,s,z}^{RKF} = \begin{cases} \left\{1 + e^{-p\beta_x^{RKF(1)}\cdot(z - pZ_{50}{}_x^{RKF(1)})}\right\}^{-1} & y \le 1996 \\ \left\{1 + e^{-p\beta_x^{RKF(2)}\cdot(z - pZ_{50}{}_x^{RKF(2)})}\right\}^{-1} & 1997 \le y \le 2004 \\ \left\{1 + e^{-p\beta_x^{RKF(3)}\cdot(z - pZ_{50}{}_x^{RKF(3)})}\right\}^{-1} & 2005 \le y \end{cases}$	selectivity in the BBRKC fishery	F17

where the $p\beta_x^{RKF(p)}$ are 6 parameters controlling the slopes of the associated logistic selectivity curves and the $pZ_{50}{}_x^{RKF(p)}$ are 6 parameters controlling size at 50%-selection. As formulated, selectivity in the BBRKC fishery is not a function of maturity state or shell condition.

The bounds, initial values and estimation phases used in the 2013 model for the 12 parameters describing male selectivity in the BBRKC fishery were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta_{MALE}^{RKF(1)}$	0.01	0.50	0.255	3	`rkfish_disc_slope_m1`
$pZ_{50}{}_{MALE}^{RKF(1)}$	95	150	122.5	3	`rkfish_disc_sel50_m1`
$p\beta_{MALE}^{RKF(2)}$	0.01	0.50	0.255	3	`rkfish_disc_slope_m2`
$pZ_{50}{}_{MALE}^{RKF(2)}$	95	150	122.5	3	`rkfish_disc_sel50_m2`
$p\beta_{MALE}^{RKF(3)}$	0.01	0.50	0.255	3	`rkfish_disc_slope_m3`
$pZ_{50}{}_{MALE}^{RKF(3)}$	95	150	122.5	3	`rkfish_disc_sel50_m3`

where all parameters were estimated.

The bounds, initial values and estimation phases used in the 2013 model for the 6 parameters describing female selectivity in the BBRKC fishery were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta_{FEMALE}^{RKF(1)}$	0.005	0.50	0.2525	3	`rkfish_disc_slope_f1`
$pZ_{50}{}_{FEMALE}^{RKF(1)}$	50	150	100	3	`rkfish_disc_sel50_f1`
$p\beta_{FEMALE}^{RKF(2)}$	0.005	0.50	0.255	3	`rkfish_disc_slope_f2`
$pZ_{50}{}_{FEMALE}^{RKF(2)}$	50	150	100	3	`rkfish_disc_sel50_f2`
$p\beta_{FEMALE}^{RKF(3)}$	0.01	0.50	0.255	3	`rkfish_disc_slope_f3`
$pZ_{50}{}_{FEMALE}^{RKF(3)}$	50	170	110	3	`rkfish_disc_sel50_f3`

where all parameters were estimated.

In the groundfish fisheries (GTF), bycatch (discard) selectivity is also modeled using three time periods (model start to 1986, 1987-1996, 1997 to present), but these are different from those used in the snow crab and BBRKC fisheries. Sex-specific parameters are estimated in each period; all sex/period combinations are modeled using ascending logistic functions:

$S_{y,x,m,s,z}^{GTF} = \begin{cases} \left\{1 + e^{-p\beta_x^{GTF(1)} \cdot \left(z - pZ_{50}{}_x^{GTF(1)}\right)}\right\}^{-1} & y \le 1986 \\ \left\{1 + e^{-p\beta_x^{GTF(2)} \cdot \left(z - pZ_{50}{}_x^{GTF(2)}\right)}\right\}^{-1} & 1987 \le y \le 1996 \\ \left\{1 + e^{-p\beta_x^{GTF(3)} \cdot \left(z - pZ_{50}{}_x^{GTF(3)}\right)}\right\}^{-1} & 1997 \le y \end{cases}$	selectivity in the groundfish fisheries	F18

where the $p\beta_x^{GTF(p)}$ are 6 parameters controlling the slopes of the associated logistic selectivity curves and the $pZ_{50}{}_x^{GTF(p)}$ are 6 parameters controlling size at 50%-selection. As formulated, selectivity in the groundfish fisheries is not a function of maturity state or shell condition.

The bounds, initial values and estimation phases used in the 2013 model for the 12 parameters describing male selectivity in the groundfish fisheries were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta_{MALE}^{GTF(1)}$	0.01	0.50	0.255	3	`fish_disc_slope_tm1`
$pZ_{50}{}_{MALE}^{GTF(1)}$	40	120.01	80.005	3	`fish_disc_sel50_tm1`
$p\beta_{MALE}^{GTF(2)}$	0.01	0.50	0.255	3	`fish_disc_slope_tm2`
$pZ_{50}{}_{MALE}^{GTF(2)}$	40	120.01	80.005	3	`fish_disc_sel50_tm2`
$p\beta_{MALE}^{GTF(3)}$	0.01	0.50	0.255	3	`fish_disc_slope_tm3`
$pZ_{50}{}_{MALE}^{GTF(3)}$	40	120.01	80.005	3	`fish_disc_sel50_tm3`

where all parameters were estimated.

The bounds, initial values and estimation phases used in the 2013 model for the 6 parameters describing female selectivity in the groundfish fisheries were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta^{GTF(1)}_{FEMALE}$	0.01	0.50	0.255	3	`fish_disc_slope_tf1`
$pZ_{50}{}^{GTF(1)}_{FEMALE}$	40	125.01	82.505	3	`fish_disc_sel50_tf1`
$p\beta^{GTF(2)}_{FEMALE}$	0.005	0.50	0.255	3	`fish_disc_slope_tf2`
$pZ_{50}{}^{GTF(2)}_{FEMALE}$	40	250.01	145.005	3	`fish_disc_sel50_tf2`
$p\beta^{GTF(3)}_{FEMALE}$	0.01	0.50	0.255	3	`fish_disc_slope_tf3`
$pZ_{50}{}^{GTF(3)}_{FEMALE}$	40	150.01	95.005	3	`fish_disc_sel50_tf3`

where all parameters were estimated.

Retention in the directed fishery

Retention of male crab in the directed fishery is modeled as a multiplicative size-specific process "on top" of total (retention + discards) fishing selectivity. The number of crab (males only) retained in the directed Tanner crab fishery is given by

$r^{TCF}_{y,m,s,z} = \dfrac{R^{TCF}_{y,m,s,z}}{F^{T}_{y,MALE,m,s,z}} \cdot \left[1 - e^{-F^{T}_{y,MALE,m,s,z}}\right] \cdot n^{1}_{y,MALE,m,s,z}$	retained male crab (numbers) in the directed fishery	F19

where $R^{TCF}_{y,m,s,z}$ is the retained mortality rate associated with retention, which is related to the total fishing mortality rate on male crab in the directed fishery, $F^{TCF}_{y,MALE,m,s,z}$, by

$R^{TCF}_{y,m,s,z} = \rho^{TCF}_{y,m,s,z} \cdot F^{TCF}_{y,MALE,m,s,z} = FM^{TCF}_{y} \cdot \rho^{TCF}_{y,m,s,z} \cdot S^{TCF}_{y,MALE,m,s}$	retained mortality rate in the directed fishery	F20

where $\rho^{TCF}_{y,m,s,z}$ represents size-specific retention of male crab. Retention at size, $\rho^{TCF}_{y,m,s,z}$, in the directed fishery is modeled as an ascending logistic function, with different parameters in two time periods, as follows:

$\rho^{TCF}_{y,m,s,z} = \begin{cases} \left\{1 + e^{-p\beta^{TCFR(1)} \cdot (z - pZ_{50}{}^{TCFR(1)})}\right\}^{-1} & y \leq 1990 \\ \left\{1 + e^{-p\beta^{TCFR(2)} \cdot (z - pZ_{50}{}^{TCFR(2)})}\right\}^{-1} & 1991 \leq y \end{cases}$	size-specific retention in the directed fishery	F21

where $p\beta^{TCFR(t)}$ is the parameter controlling the slope of the function in the each period (*t*=1,2) and ${pZ_{50}}^{TCFR(t)}$ is the parameter controlling the size at 50%-selected. As formulated, retention is not a function of maturity state or shell condition.

The bounds, initial values and estimation phases used for the size-specific retention parameters in the 2013 model were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta^{TCFR(1)}$	0.25	1.01	0.63	3	`fish_fit_slope_mn1`
${pZ_{50}}^{TCFR(1)}$	85	160	122.5	3	`fish_fit_sel50_mn1`
$p\beta^{TCFR(2)}$	0.25	2.01	1.13	3	`fish_fit_slope_mn2`
${pZ_{50}}^{TCFR(2)}$	85	160	122.5	3	`fish_fit_sel50_mn2`

where all parameters were estimated.

G. Model indices: surveys

The predicted number of crab caught in the survey by year in the 2013 TCSAM model has the functional form:

$n^{srv}_{y,x,m,s,z} = q_{y,x} \cdot S_{y,x,z} \cdot n_{y,x,m,s,z}$	predicted number of crab caught in survey	G1

where *y* is year, *x* is sex, *m* is maturity state, *s* is shell condition and *z* is size, $q_{y,x}$is sex-specific survey catchability in year y, $S_{y,x,z}$ is sex-specific size selectivity in year y, and $n_{y,x,m,s,z}$ is the number of sex *x* crab in maturity state *m* and shell condition *s* at size *z* at the time of the survey in year *y*.

Three time periods that were used to test hypotheses regarding changes in catchability and selectivity in the survey over time are defined in the model. These periods are defined as: 1) $y < 1982$, 2) $1982 \leq y \leq 1987$, and 3) $1988 \leq y$. As parameterized in the 2013 model, catchabilities in periods 2 and 3 were assumed to be identical, so only two sets of sex-specific parameters reflecting catchability were used in the model. In terms of the three time periods, catchability was parameterized using the sex-specific parameters q_x^I and q_x^{II} in the following manner:

$q_{y,x} = \begin{cases} q_x^I & y < 1982 \\ q_x^{II} & 1982 \leq y \leq 1987 \\ q_x^{II} & 1988 \leq y \end{cases}$	survey catchability	G2

The bounds, initial values and estimation phases used for these parameters in the 2013 model were:

parameters	lower bound	upper bound	initial value	phase	code name

q^{I}_{MALE}	0.50	1.001	0.7505	4	`srv2_q`
q^{I}_{FEMALE}	0.50	1.001	0.7505	4	`srv2_femQ`
q^{II}_{MALE}	0.20	2.00	1.1	4	`srv3_q`
q^{II}_{FEMALE}	0.20	1.00	0.6	4	`srv3_femQ`

where all parameters were estimated (phase > 0).

Similarly, survey selectivity in periods 2 and 3 was assumed identical and only two sets of sex-specific parameters were used to describe survey selectivity using logistic functions:

$S_{y,z} = \begin{cases} \left\{1+e^{-\left[\ln(19)\cdot(z-z_{50}{}^{I}_{x})/\delta z_{95}{}^{I}_{x}\right]}\right\}^{-1} & y < 1982 \\ \left\{1+e^{-\left[\ln(19)\cdot(z-z_{50}{}^{II}_{x})/\delta z_{95}{}^{II}_{x}\right]}\right\}^{-1} & 1982 \le y \le 1987 \\ \left\{1+e^{-\left[\ln(19)\cdot(z-z_{50}{}^{II}_{x})/\delta z_{95}{}^{II}_{x}\right]}\right\}^{-1} & 1987 \le y \end{cases}$	survey selectivity	G3

where the z_{50}'s are parameters reflecting the inflection point of the logistic curve (i.e., size at 50% selected) and the δz_{95}'s are parameters reflecting the difference the sizes at 50% and 95% selected.

The bounds, initial values and estimation phases used for the selectivity parameters used in the 2013 model were:

parameters	lower bound	upper bound	initial value	phase	code name
${z_{50}}_{MALE}^{I}$	0	90	45	4	`srv2_sel50`
${z_{50}}_{FEMALE}^{I}$	-200	100.01	-49.005	4	`srv2_sel50_f`
$\delta {z_{95}}_{MALE}^{I}$	0	100	50	4	`srv2_seldiff`
$\delta {z_{95}}_{FEMALE}^{I}$	0	100	50	4	`srv2_seldiff_f`
${z_{50}}_{MALE}^{II}$	0	69	34.5	4	`srv3_sel50`
${z_{50}}_{FEMALE}^{II}$	-50	69	9.5	4	`srv3_sel50_f`
$\delta {z_{95}}_{MALE}^{II}$	0	100	50	4	`srv3_seldiff`
$\delta {z_{95}}_{FEMALE}^{II}$	0	100	50	4	`srv3_seldiff_f`

where all parameters were estimated (phase > 0).

H. Model fitting: objective function equations

The TCSAM2013 model is fit by minimizing an objective function, $\wp$, with additive components consisting of: 1) several penalty functions, 2) several negative log-likelihood functions based on assumed prior probability distributions for model parameters, and 3) several negative log-likelihood functions based on input data components, of the form:

$\mathcal{O} = \sum_f \lambda_f \cdot \mathcal{F}_f - 2\sum_p \lambda_p \cdot \ln(\wp_p) - 2\sum_l \lambda_l \cdot \ln(\mathcal{L}_l)$	model objective function	H1

where $\mathcal{F}_f$ represents the *f*th penalty function, $\wp_p$ represents the *p*th prior probability function, $\mathcal{L}_l$ represents the *l*th likelihood function, and the λ's represent user-adjustable weights for each component.

Penalty Functions

The penalty functions associated with various model quantities are identified in the section (B-F) concerning the associated process.

Prior Probability Functions

The prior probability functions associated with various model parameters are identified in the section (B-F) concerning the associated parameter.

Likelihood Functions

The model's objective function includes likelihood components based on 1) retained catch size frequencies (i.e., males only) in the directed fishery from dockside observer sampling; 2) total catch (retained + discarded) size frequencies by sex in each fishery from at-sea observer sampling; 3) size frequencies for immature males, mature males, immature females, and mature females, respectively, from trawl survey data; 4) dockside retained catch biomass (i.e., males only) in the directed fishery from fish ticket data; 5) estimated total catch (retained + discarded) mortality in biomass by sex in the crab and groundfish fisheries from at-sea observer sampling; and 6) estimated mature biomass by sex from trawl survey data. As discussed in more detail below, size frequency-related likelihood components are based on the multinomial distribution while those related to biomass are based on either the normal or lognormal distributions.

Size frequency components

Fishery-related (log-scale) likelihood components involving sex-specific size frequencies are based on the following equation for multinomial sampling:

$\ln(\mathcal{L}^M)_x^f = \sum_y n_{y,x}^f \cdot \sum_z p_{y,x,z}^{obs.f} \cdot \ln(p_{y,x,z}^{mod.f} + \delta) - p_{y,x,z}^{obs.f} \cdot \ln(p_{y,x,z}^{obs.f} + \delta)$	multinomial log-likelihood	H2

where *f* indicates the fishery, *x* indicates sex, the *y*'s are years for which data exists, $n_{y,x}^f$ is the sex-specific effective sample size for year y, $p_{y,x,z}^{obs.f}$ is the observed size composition in size bin *z* (i.e., the size frequency normalized to sum to 1 across size bins for each year), $p_{y,x,z}^{mod.f}$ is the corresponding model estimate, and δ is a small constant.

Size compositions for retained catch (male only) in the directed Tanner crab fishery are obtained from dockside observer sampling and calculated from shell condition-specific size frequencies $r_{y,MALE,s,z}^{obs.TCF}$ using:

$p_{y,MALE,z}^{obs.TCF} = \frac{\sum_s r_{y,MALE,s,z}^{obs.TCF}}{\sum_s \sum_z r_{y,MALE,s,z}^{obs.TCF}}$	retained size compositions for the directed fishery from dockside observer sammpling	H3

where *s* indicates shell condition (new shell, old shell) and *z* indicates the size bin. The corresponding model size compositions are calculated from the predicted numbers retained in the directed fishery $r_{y,MALE,m,s,z}^{mod.TCF}$ using

$p_{y,MALE,z}^{mod.TCF} = \frac{\sum_m \sum_s r_{y,MALE,m,s,z}^{mod.TCF}}{\sum_m \sum_s \sum_z r_{y,MALE,m,s,z}^{mod.TCF}}$	model-predicted retained catch size compositions for the directed fishery	H4

where, additionally, *m* is maturity state (immature, mature).

Size compositions for total (retained + discarded) catch in fishery *f* (*f* = 1-4) are sex-specific and are calculated from sex/shell condition-specific size frequencies $r_{y,x,s,z}^{obs.f} + d_{y,x,s,z}^{obs.f}$ obtained from at-sea observer sampling using:

$p_{y,x,z}^{obs.f} = \frac{\sum_s \left[r_{y,x,s,z}^{obs.f} + d_{f,y,x,s,z}^{obs.f}\right]}{\sum_s \sum_z \left[r_{y,x,s,z}^{obs} + d_{y,x,s,z}^{obs}\right]}$	sex-specific size compositions for total catch for fishery *f* from at-sea observer sampling	H5

where *s* indicates shell condition (new shell, old shell) and *z* indicates the size bin. In the above equation, $d^{obs.f}_{y,x,s,z}$ has *not* been discounted for discard survival (i.e., it's consistent with setting discard mortality to 100%). The corresponding model size compositions are calculated from the predicted total fishing *mortality* (numbers) in each fishery *f*, $m^{mod.f}_{y,x,m,s,z} (= r^{mod.f}_{y,x,m,s,z} + \delta_f \cdot d^{mod.f}_{y,x,m,s,z})$, using

$p^{mod.f}_{y,x,z} = \dfrac{\sum_m \sum_s m^{mod.f}_{y,x,m,s,z}}{\sum_m \sum_s \sum_z m^{mod.f}_{y,x,m,s,z}}$	model-predicted total catch mortality size compositions for fishery *f*	H6

where, again, the subscript *m* is maturity state (immature, mature). In eq. H6, $m^{mod.f}_{y,x,m,s,z}$ does not assume any particular value for discard mortality.

Log-scale likelihood components for the trawl survey involve size frequencies that are sex- and maturity state-specific, and thus are based on the following equation for multinomial sampling:

$\ln(\mathcal{L}^M)^{srv}_{x,m} = \sum_y n^{srv}_{y,x,m} \cdot \sum_z \{p^{obs.srv}_{y,x,m,z} \cdot \ln(p^{mod.srv}_{y,x,m,z} + \delta) - p^{obs.srv}_{y,x,mz} \cdot \ln(p^{obs.srv}_{y,x,mz} + \delta)\}$	multinomial log-likelihood	H7

where *x* indicates sex, the *y*'s are years for which data exists, $n^{srv}_{y,x,m}$ is the sex- and maturity-state specific effective sample size for year *y*, $p^{obs.srv}_{y,x,z}$ is the observed size composition in size bin *z* (i.e., the size frequency normalized to sum to 1 across size bins for each year), $p^{mod.srv}_{y,x,z}$ is the corresponding model estimate, and δ is a small constant.

Fishery biomass components
Likelihood components related to fishery biomass totals are based on the assumption of normally-distributed sampling, and generally have the simple form:

$\ln(\mathcal{L}^N)^f_x = -\sum_y [b^{obs.f}_{y,x} - b^{mod.f}_{y,x}]^2$	normal log-likelihood	H8

where $b^{obs.f}_{y,x}$ is the sex-specific catch *mortality* (as biomass) in fishery *f* for year *y* and $b^{mod.f}_{y,x}$ is the corresponding value predicted by the model. Components of this sort are calculated for retained biomass in the directed fishery, total (retained + discard) sex-specific fishery-related mortality in the model crab fisheries, and discard-related (not sex-specific) mortality in the groundfish fishery. The observed components of discard-related mortality for each fishery are obtained by multiplying the observed discard biomass by the assumed discard mortality fraction.

Survey biomass components
Likelihood components related to survey biomass are based on the assumption of lognormally-distributed sampling errors, and have the form:

$\ln(\mathcal{L}^N)^{srv}_x = -\sum_y \dfrac{[ln(b^{obs.srv}_{y,x} + \delta) - ln(b^{mod.srv}_{y,x} + \delta)]^2}{2 \cdot \ln(1 + cv^2_{y,x})}$	lognormal log-likelihood	H9

where $b^{obs.srv}_{y,x}$ is sex-specific mature biomass estimated from the trawl survey data for year *y*, $b^{mod.srv}_{y,x}$ is the corresponding value predicted by the model, and $cv_{y,x}$ is the cv of the observation. Survey numbers-at-size $n^{obs.srv}_{y,x,m,s,z}$, classified by sex, shell condition and maturity state, are combined with sex- and maturity state-specific weight-at-size relationships $w_{x,m,z}$ to estimate sex-specific mature biomass $b^{obs.srv}_{y,x}$ using

$b^{obs.srv}_{y,x} = \sum_s \sum_z n^{obs.srv}_{y,x,MATURE,s,z} \cdot w_{x,MATURE,z}$	mature biomass	H10

An equivalent equation is used to calculate $b^{mod.srv}_{y,x}$.

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Appendix 4: TCSAM-FRev revisions to TCSAM2013

Introduction

This appendix addresses an issue in the Tanner crab stock assessment that concerns a logical inconsistency in the manner in which fishing mortality was modeled in the 2013 stock assessment (hereafter referred to as TCSAM2013). As part of an effort to improve the assessment, I wrote a new description of the Tanner crab model used in the 2013 assessment (see Appendix 3). In the course of writing the new description, I realized that the equations used to estimate total fishing mortality and retained mortality were not consistent with those used in Gmacs (the Generic Model for Alaskan Crab Stocks), a generic modeling framework for crab assessments being developed by A. Whitten, J. Ianelli and A. Punt (Whitten et al., 2014). To resolve this, I derived a set of equations describing fishing mortality on crab stocks from first principles (see below). The resulting equations are the same that are used in Gmacs. These equations indicate that the interpretation of the estimated "retention curve" in TCSAM2013 as directly reflecting the on-deck process of sorting crab into retained and discarded components is incorrect. I have consequently revised the TCSAM2013 code to reflect the corrected equations (TCSAM-FRev).

Model revisions

The model used in the 2013 assessment, TCSAM2103, assumes that the rate of mortality on crab due to retaining them in the directed fishery is proportional to the rate of total fishing *mortality* (retained +discarded mortality) in that fishery (see Appendix 3 for details). Using a slightly simplified description, TCSAM2013 models the rate of fishing mortality on male crab of size z due to retention, $r_{y,z}$, as

$$r_{y,z} = r_z \cdot F_{y,z}$$

where $F_{y,z}$ is the total fishing mortality rate (retained + discard mortality) in year y on male crabs of size z and r_z is the size-specific "retention function", which takes values between 0 (no retention) and 1 (complete retention). In TCSAM2013, the retention function r_z is modeled using an increasing 2-parameter logistic function (retention is 0 for "small" crab and 100% for "large" crab) and the two parameters are estimated as part of the model fitting process. This is fine, as far as it goes, because it simply represents a somewhat non-standard model for retained fishing mortality. However, the expectation has been that r_z reflects the process of sorting and retaining legal crab on deck, and thus it represents the fraction of crab caught at size z that were retained. If this were the case, r_z would be independent of handling mortality because what's retained is not affected by what's discarded (rather it's the other way around: what's discarded is simply what's left over after crab to be retained have been selected). However, **this is not the correct interpretation of $\boldsymbol{r_z}$** as it is used in TCSAM2013 and the equation above. Rather, as illustrated in Fig. 1, r_z simply reflects the fraction of crab killed at size z that were killed because they were retained, as opposed to being killed as part of the discard process. As such, it is actually a function of the assumed handling mortality on discarded crab whereas the function that describes the on-deck sorting process is not. As an illustration to make this point, if handling mortality were 0 then all fishing mortality $F_{y,z}$ would be due to retention ($r_{y,z} = F_{y,z}$) and r_z would be identically 1 irrespective of any sorting process that occurred on deck (e.g., all sub-legals being discarded). In Fig. 1, this would be equivalent to the "fishing mortality pie" shrinking in size but turning completely red, while the only change to the "fishing capture pie" would be that the discard mortality slice turns blue (all discards survive). The fraction of the latter pie representing retention would not change.

In the Tanner crab assessment, we are concerned with fitting the *retained* (R_f) and *discarded* (D_f) components of the total catch ($C_f = R_f + D_f$) of Tanner crab on an annual basis in several fisheries (the directed Tanner crab fishery, the snow crab fishery, the Bristol Bay red king crab fishery, and the groundfish fisheries) , as well as accounting for the associated mortality in the population dynamics for the Tanner crab stock. As a clarification of terminology, C_f is the total number of crab *captured* (i.e., brought on board) in fishery *f*, and D_f is the number of crab discarded (i.e. released overboard), not the numbers killed. Unlike many fish species, crabs captured at sea and brought on deck experience little barotrauma and, while some fraction of those subsequently discarded overboard die as a result, the remaining discarded crab survive and continue to contribute to the stock. Experimental lab and observational field studies suggest that discard mortality on Tanner crab captured in the crab fisheries is moderate; a value of 50% has been used in past assessments as the discard mortality fraction for these fisheries. Discard mortality in the groundfish fisheries is assumed to be higher because of gear differences (trawl vs. pot); we use 80% as the discard mortality fraction for Tanner crab in the groundfish fisheries. Total *mortality*, M_f, of Tanner crab in fishery *f* is then given by $M_f = R_f + \delta_f \cdot D_f$, where δ_f is the discard (i.e., “handling”) mortality fraction in the fishery. So the number of crabs captured by a fishery is more than the number of crabs killed, because discard mortality is not 100%. Because capture, retention and discard processes in the fisheries are sex- and size-dependent, as well as being dependent on shell condition and maturity state, the TCSAM model applies these concepts to individual components of the population (e.g. mature, new shell males between 100 and 105 mm CW) and then sums up the individual contributions to obtain stock-level and fishery-level totals.

For some component (e.g. mature, new shell males between 100 and 110 mm CW) of a population experiencing mortality from several fisheries, the short term change in numbers, *N*, can be described by the following differential equation:

$\frac{dN}{dt} = -\left(m + \sum_f F_f\right) \cdot N(t)$	Rate of change of *N* over a short period of time	1

where *m* represents the rate of natural mortality and F_f represents the fishing *mortality rate* associated with the *f*th fishery on this component of the population (i.e., F_f includes size-dependent selectivity). The solution to this equation, assuming that *m* and the F_f’s are constant over the period, is

$N(t) = e^{-(m+F_T)\cdot t} \cdot N_0$	Change in *N* with time	2

where $F_T = \sum_f F_f$ is the rate of total fishing mortality experienced by population component. The cumulative numbers killed by each fishery, M_f, are described by the equation

$\frac{dM_f}{dt} = F_f \cdot N(t) = F_f \cdot e^{-(m+F_T)\cdot t} \cdot N_0$	Rate of change of the numbers killed by fishery *f*	3

which has the solution

$M_f(t) = \frac{F_f}{m + F_T} \cdot \left[1 - e^{-(m+F_T)\cdot t}\right] \cdot N_0$	Cumulative numbers killed by fishery *f*	4

As discussed above, in fisheries that discard part of the catch, and part of that discarded catch may survive, the numbers *captured* (i.e., brought on board) by the fishery are different from those actually *killed* by the fishery. Letting ϕ_f denote the *capture rate* associated with fishery *f*, the cumulative numbers captured in this fishery, C_f, are described by

$\frac{dC_f}{dt} = \phi_f \cdot N = \phi_f \cdot e^{-(m+F_T) \cdot t} \cdot N_0$	Rate of change of the numbers captured by fishery *f*	5

which has the solution

$C_f(t) = \frac{\phi_f}{m + F_T} \cdot \left[1 - e^{-(m+F_T) \cdot t}\right] \cdot N_0$	Numbers captured by fishery *f*	6

where ϕ_f is the fishery capture rate. Of course, $C_f(t) = R_f(t) + D_f(t)$ (number captured = number retained plus number discarded) and $M_f(t) = R_f(t) + \delta_f \cdot D_f(t)$ (number killed = number retained plus number discarded that die due to handling) for this component of the population.

Letting ρ_f denote the fraction of $C_f(t)$ that is retained, then

$R_f(t) = \rho_f \cdot C_f(t)$	Numbers retained by fishery *f*	7

and

$D_f(t) = (1 - \rho_f) \cdot C_f(t)$	Numbers discarded by fishery *f*	8

so, substituting eq.s 7 and 8 into the equation for M_f , one obtains

$M_f(t) = \rho_f \cdot C_f(t) + \delta_f \cdot (1 - \rho_f) \cdot C_f(t)$ $M_f(t) = \left[\rho_f + \delta_f \cdot (1 - \rho_f)\right] \cdot C_f(t)$	Numbers killed by fishery *f*	9

Substituting eq.s 4 and 6 into eq. 9 and eliminating similar terms from both sides, one finds that the fishing mortality rate in the *f*th fishery is related to the capture rate ϕ_f in that fishery by:

$F_f = \left[\rho_f + \delta_f \cdot \left(1 - \rho_f\right)\right] \cdot \phi_f$	Fishing mortality rate for fishery *f*	10

The above equations are based on continuous time models for the fishing and natural mortality processes. To convert these equations to those appropriate for a set of pulse fisheries conducted simultaneously (as used in the Tanner crab model), one takes the limit of the above equations as $t \to 0$ and the ϕ_f's gets large such that $\phi_f \cdot t$ and ϕ_f / F_T remains constant, for each *f*. Letting $\phi_f \equiv \lim_{\substack{t \to 0 \\ \phi_f \to \infty}} \left\{\phi_f \cdot t\right\}$ for all fisheries simultaneously, one obtains the following equations for a set of pulse fisheries in terms of ϕ_f, ρ_f, and δ_f:

$F_f = [\rho_f + \delta_f \cdot (1 - \rho_f)] \cdot \phi_f$	fishing *mortality* rate in fishery *f*	11
$F_T = \sum_f F_f$	Total fishing *mortality* rate	12
$N^+ = e^{-F_T} \cdot N_0$	Population numbers after fisheries	13
$C_f = \frac{\phi_f}{F_T} \cdot [1 - e^{-F_T}] \cdot N_0$	Numbers captured in fishery *f*	14
$R_f = \rho_f \cdot C_f = \frac{\rho_f \cdot \phi_f}{F_T} \cdot [1 - e^{-F_T}] \cdot N_0$	Numbers retained in fishery *f*	15
$D_f = (1 - \rho_f) \cdot C_f = \frac{(1 - \rho_f) \cdot \phi_f}{F_T} \cdot [1 - e^{-F_T}] \cdot N_0$	Numbers discarded in fishery *f*	16
$M_f = R_f + \delta_f \cdot D_f = [\rho_f + \delta_f \cdot (1 - \rho_f)] \cdot C_f$	Total mortality in fishery *f*	17
$DM_f = \delta_f \cdot (1 - \rho_f) \cdot C_f$	Discard mortality in fishery *f*	18

It is important to remember that all terms in eq.s 11-18 apply to individual components of the population, and not the entire population, on an annual basis. The TCSAM model decomposes the population by sex, maturity state, shell condition, and size. Thus, each of the quantities above, other than discard mortality δ_f (which is assumed to apply equally to all components of the discarded catch), can have additional subscripts *x* (sex), *m* (maturity), *s* (shell condition), *z* (size) (and *y*, year, to make the temporal component explicit).

On fitting the TCSAM2103 model

The TCSAM2013 model is parameterized, in part, based on annual fully-selected fishing mortality rates $F_{f,y,x,m,s}$, selectivity functions $S_{f,y,x,z}$, and retention functions $\rho_{f,y,x,z}$ (the latter non-zero only for males in the directed fishery, of course). The total (size selective) fishing mortality rate is given by

$F_{f,y,x,m,s,z} = F_{f,y,x,m,s} \cdot S_{f,y,x,z}$	Total mortality rate (retained+discard) for fishery *f*	19

from which total annual fishing mortality (in biomass) estimated by the model is compared to the observed total fishing mortality (observed discard biomass discounted by assumed discard mortality added to the retained biomass) in the model's objective function.

The retained mortality *rate* in the model is given by

$r_{f,y,x,m,s,z} = \rho_{f,y,x,z} \cdot F_{f,y,x,m,s,z}$	Total retained mortality rate for fishery *f* (TCSAM2013)	20

However, eq. 15 implies that the retained mortality rate is given by

$r_{f,y,x,m,s,z} = \rho_{f,y,x,z} \cdot \phi_{f,y,x,m,s,z}$	Total retained mortality rate for fishery f (TCSAM-FRev)	21

The simplest way to see that eq. 20 is inconsistent with the previous description of "retention" is to consider a fishery with no discard mortality, so that the only fishing mortality is due to retention. In this case, using eq. 11 with $\delta_f = 0$, one finds that the total fishing mortality rate is related to the capture rate by $F_{f,y,x,m,s,z} = \rho_{f,y,x,z} \cdot \phi_{f,y,x,m,s,z}$, so that applying eq. 20 to obtain the retention mortality rate yields $r_{f,y,x,m,s,z} = \rho^2_{f,y,x,z} \cdot \phi_{f,y,x,m,s,z}$ in eq. 21—the retention function is doubly-applied.

However, the overall effect in terms of model fit and parameter estimation is probably small. It depends on the steepness of the rise of the retention curve $\rho_{f,y,x,z}$, and is smaller for steeper curves. While not step functions, the retention curves for Tanner crab tend to be fairly steep.

TCSAM-FRev thus models the size-specific fishing mortality rate in the directed fishery using

$$F_{y,z} = (h \cdot [1 - \rho_z] + \rho_z) \cdot \phi_{y,z}$$

where h is handling mortality, ρ_z is the size-specific "retention function" that reflects the on-board sorting process, and $\phi_{y,z}$ is the fishery *capture rate* for crab of size z in year y. In this formulation, $\phi_{y,z}$ reflects the rate at which crab are brought on deck, ρ_z is the fraction of crab captured (not killed) that are retained (and thus die), and h is the fraction of discarded crab ($[1 - \rho_z]$) that die due to handling. The equation that describes the fishing mortality rate due to retention is simply

$$r_{y,z} = \rho_z \cdot \phi_{y,z}$$

The fishery capture rate $\phi_{y,z}$ in the revised model is treated with the same assumptions that $F_{y,z}$ is treated with in TCSAM2013: it is modeled as a separable function of size and year

$$\phi_{y,z} = \phi_y \cdot S_z$$

where ϕ_y is the "fully-selected" capture rate in year y and S_z is the size-specific capture selectivity. ϕ_y is parameterized in a similar fashion to the fully-selected fishing mortality rate F_y in TCSAM2013. The capture selectivity S_z and retention function ρ_z are also parameterized in the same way as selectivity and the retention function r_z in TCSAM2013.

Literature Cited

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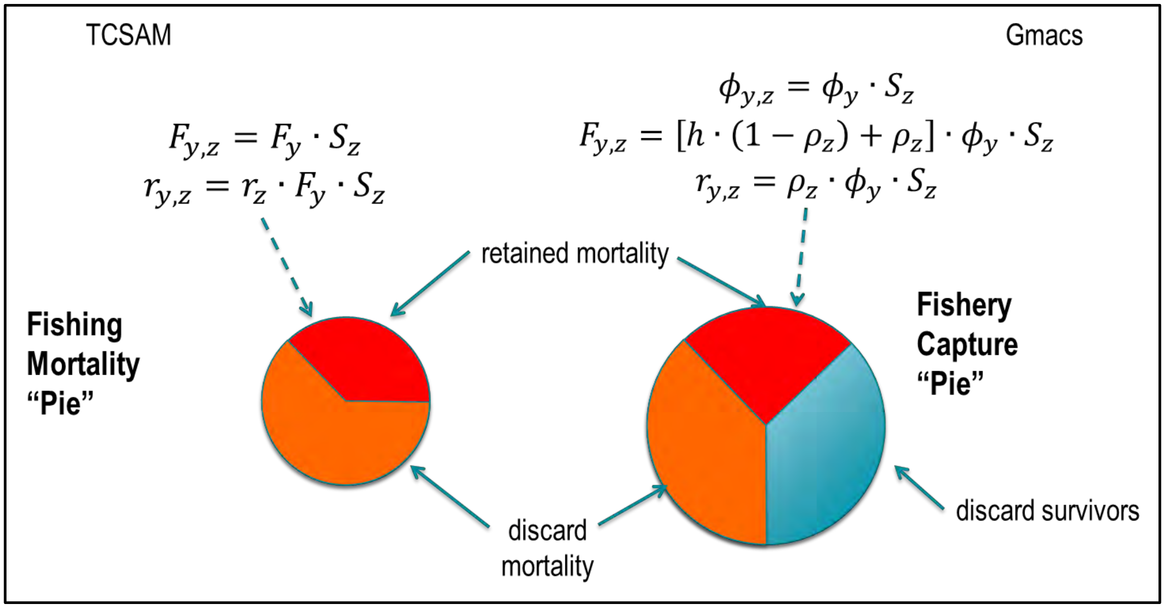
http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/crab/Whitten%20et%20al%202014%20-%20Gmacs%20Model%20Description.pdf

Figures



A4.Figure 1. Comparison of models for fishing mortality in TCSAM2013 (left) and Gmacs (right). The *areas* associated with retained mortality and discard mortality are the same in both pies. r_z is the fraction of the fishing mortality pie related to retained crab. ρ_z is the fraction of the fishery capture pie related to retained crab.

Appendix 5: Input sample sizes for size compositions

AFSC Trawl Survey data

Very large numbers of Tanner crab are measured for size during each AFSC Trawl Survey (Table 20 in the chapter). However, individual crabs do not represent truly independent samples from Tanner crab population because crab tend to be spatially aggregated by sex, size and maturity state. Consequently, using the actual numbers of measured crab from the trawl survey as the input sample sizes for any size composition components in the model (e.g., new shell males) vastly understates the actual variability in the observed size composition. Instead, an input sample size of 200 is used for all size compositions derived from AFSC Trawl Survey data.

Fishery data

Large numbers of Tanner crab are also typically measured by dockside observers during each directed fishery, while smaller numbers are measured by at-sea observers in the directed fishery and bycatch fisheries (Tables 4-8). However, the actual numbers measured can vary widely from year to year. It is thus not advisable to use a fixed input sample size for all fishery-related size compositions. Instead, a scaling factor ($\bar{n}_{TCFR}$ below) is derived from the average number (since 1981) of male crab measured by dockside observers in the directed fishery. As described in more detail below, this factor is then used to scale the sex-specific number of crab sampled by observers (dockside or at-sea) in a given year to obtain input sample sizes that reflect both the annual variability in the numbers of crab measured and the relative numbers sampled among the directed and bycatch fisheries.

To be more specific, if $n_{f,x}^{y}$ is the number of sex *x* crab measured in fishery *f* in year *y*, then the input sample size $s_{f,x}^{y}$ for the corresponding size composition is given by

$$s_{f,x}^{y} = \begin{cases} s_{min} & if \ \dfrac{n_{f,x}^{y}}{\bar{n}_{TCFR}} \le s_{min} \\ \dfrac{n_{f,x}^{y}}{\bar{n}_{TCFR}} & if \ s_{min} \le \dfrac{n_{f,x}^{y}}{\bar{n}_{TCFR}} \le s_{max} \\ s_{max} & if \ s_{max} \le \dfrac{n_{f,x}^{y}}{\bar{n}_{TCFR}} \end{cases}$$

where s_{min} is the minimum allowed sample size, s_{max} is the maximum allowed sample size, and

$$\bar{n}_{TCFR} = \frac{1}{N}\sum_{y} n_{TCFR}^{y}$$

is the average number of retained crab in the directed fishery measured by dockside observers, starting in 1981.

For the current assessment, $s_{min} = 0$ and $s_{max} = 200$.

Appendix 6: Additional Model Scenarios

Introduction

During the September 2014 Crab Plan Team (CPT) meeting to review the Tanner crab assessment, the CPT rejected the author's preferred model scenario (Alt1a; see Section 3 of the Tanner crab SAFE chapter) because it was based on the old pot fishery handling mortality rate (50%), but felt that none of the alternative models presented provided an adequate basis for status determination and OFL calculation. In particular, scenario Alt1b, the original scenario based on the CPT's new handling mortality rate for Tanner crab in pot fisheries (32.1%), was unable to estimate sensible parameter values to describe male bycatch selectivity in the snow crab fishery. Given the CPT's unwillingness to accept the author's recommendation of scenario Alt1a, the author proposed reparameterizing the selectivity functions used in TCSAM2013 to estimate and fit male bycatch in the snow crab fishery to avoid the problems encountered in Alt1b. This appendix presents results from three model scenarios (based on different handling mortality rates) the author ran using the reparamenterized model. Because of the compressed time frame required to prepare the Tanner crab chapter for the SSC, these results could not be integrated directly into the SAFE chapter and are instead presented here in abbreviated format as an appendix.

Author's note: Although the changes undertaken to the model code were relatively straightforward, the amount of work involved in testing the code, running the scenarios, analyzing the results, and compiling tables and figures to be reviewed by the CPT meeting and incorporated in this appendix was nearly overwhelming in the time frame of the meeting.

Changes to the model

In TCSAM2013, male bycatch in the snow crab fishery was modeled using a double-logistic function, with estimated slope (β) and size-at-50%-selected (z_{50}) parameters for both the ascending and descending limbs of the function (Appendix 3). Under "normal" circumstances (as for scenario Alt1a) illustrated in the lefthand column of Figure A6.1 below, z_{50} for the descending limb is greater than z_{50} for the ascending limb, the double logistic function has a "peak" between the two (left column, Figure A6.1) The problem encountered in scenario Alt1b was that z_{50} for the descending limb was less than z_{50} for the ascending limb, resulting in an almost-zero "flat" selectivity curve, as illustrated in the righthand column of Figure A6.1.

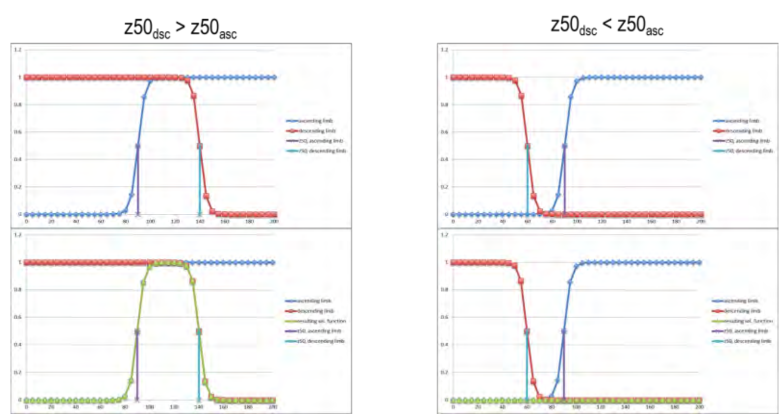


Figure A6.2. Example double logistic selectivity curves illustrating "normal" behavior (lefthand column) and problematic behavior (righthand column). Blue curve: ascending logistic; red curve: descending logistic; green curve: resulting double logistic function.

To eliminate the problematic behavior that occurred in scenario Alt1b (illustrated on the righthand side of Figure A6.1), the model was reparameterized so that z_{50} for the descending limb is always greater than z_{50}

for the ascending limb. In this case, the estimated parameter was the ln-scale offset lnZ_{50} between z_{50} for the ascending limb and z_{50} for the descending limb, so that $z_{50,dsc} = z_{50,asc} + \exp(lnZ_{50})$.

New Model Scenarios

Three new model scenarios were developed and run based on the reparameterized model, TCSAM_AltSCF (Table A6.1). The scenarios differed by the value used for handling mortality in the crab pot fisheries: Alt4a used HM=50%, the same as Alt1a; Alt4b used HM=32.1% (the CPT's preferred value); and Alt4c used HM=23.0% (a request by industry).

Table A6.8. New model scenarios.

Model Scenario	Model Converged?	Handling Mortality	Data	Model Type	Model Options
Alt4a	yes	50.0%	2014 revised data	TCSAM_AltSCF	reparameterized double logisitic selectivity functions
Alt4b	yes	32.1%	2015 revised data	TCSAM_AltSCF	reparameterized double logisitic selectivity functions
Alt4c	yes	23.0%	2016 revised data	TCSAM_AltSCF	reparameterized double logisitic selectivity functions

All three models converged, and the problematic behavior exhibited in Alt1b for male bycatch selectivity in the snow crab fishery was eliminated (Figure A6.2):

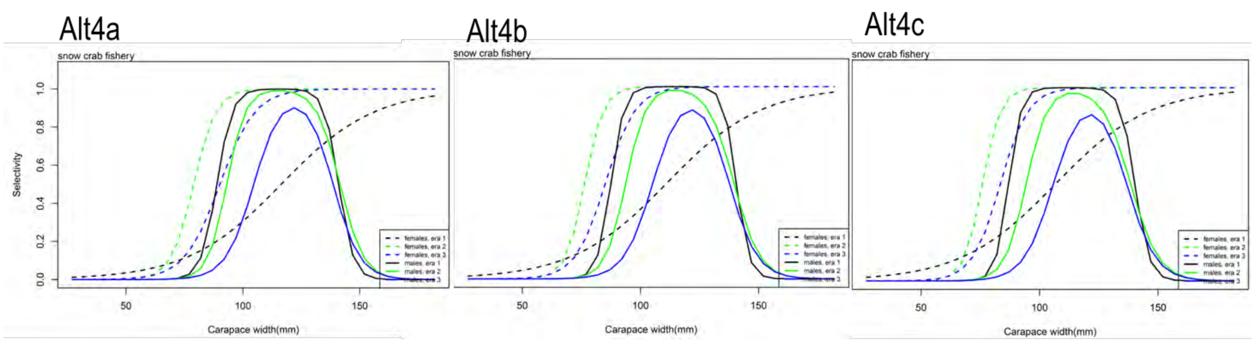


Figure A6.3. Estimated selectivity functions for bycatch in the snow crab fishery. Males: solid lines, females: dashed lines. Colors correspond to different time periods.

Model Selection and Evaluation

In the TCSAM models, handling mortality is applied to observed discard catches to obtain discard mortalities, which are then fit in the model. As a consequence, differences in handling mortality imply differences in the data that models are fit to. This, in turn, means that drawing inferences on model fit by comparing likelihood values is somewhat dubious for those components that involve fits to discard data. That said, the model achieving the overall lowest objective function value is Alt4b, although the difference between Alt1a and Alt4b is not substantial (Table A6.2, Figure A6.3). While not using the likelihood comparison as a strict measure of model fit, it appears that Alt4b fits "well enough" to base the assessment on, given that it uses the CPT-preferred pot fishery Tanner crab discard mortality rate (32.1%).

Estimated parameter values for Alt1a and the new scenarios are listed in Table A6.3. On the whole, the model estimates are fairly similar across models.

The time series of estimated recruitment are compared across Alt1a and the new scenarios in Table A6.3 and Figure A6.4. The time series of estimated MMB is similarly compared in Table A6.4 and Figure A6.5. On the whole, differences are small (<10%).

Fits to mature male and female survey biomass are nearly identical across model scenarios (Figure A6.6), as are model predictions of "legal" male biomass (taken as crabs with CW ≥ 138 mm; Table A6.6, Figure A6.6). Fits to retained catch, total male catch mortality in the directed fishery, and female discard mortality in the directed fishery follow similar trajectories across model scenarios, with differences in scale due to differences in assumed handling mortality rates. (Figure A6.7). Fits to bycatch mortalities in the snow crab fishery follow similar trends in the 2013 assessment model, Alt1a and Alt4b (Figure A6.8): fits to male bycatch are good, while fits to female bycatch are fairly poor (reflecting the much smaller biomass of females involved). Fits to bycatch mortalities in the groundfish fisheries are good in all three models examined (2013 assessment model, Alt1a, Alt4b; Figure A6.9).

Model fits of Alt4b to size compositions from the directed fishery (retained males, total male catch, and female bycatch; Figures A6.10-12) are identical in pattern and almost identical in scale to those of Alt1a (Figures 60-65). Marginal size compositions for the directed fishery are nearly identical between Alt1a and Alt4b, and very similar to those obtained from last year's assessment model (Figure A6.13), as are those estimated for bycatch in the snow crab and BBRKC fisheries (Figure A6.14). The marginal size compositions for bycatch in the groundfish fisheries are nearly identical for Alt1a and Alt4b, but differ dramatically from those obtained last year because of the corrected sample sizes (Figure A6.14).

As with most of the fits to fishery size compositions, model fits of Alt4b to size compositions from the NMFS trawl survey (males, females; Figures A6.15 and A6.16) are identical in pattern and almost identical in scale to those of Alt1a (Figures 66-69). Marginal size compositions for the NMFS trawl survey are also very similar between Alt1a and Alt4a (Figure A6.17).

Various estimated quantities for model scenarios Alt1a and Alt4b in are compared in Figures A6.19-24: exploitation in the directed fishery (A6.19), selectivity and retention curves in the directed fishery (A6.20), bycatch selectivity curves in the snow crab and BBRKC fisheries (A6.21), bycatch selectivity in the groundfish fisheries (A6.22), trawl survey selectivities (A6.23), and recruitment and MMB with estimated uncertainties (A6.24).

Population numbers-at-size for model Alt4b are given for males in Table A6.7 and for females in Table A6.8.

The selectivity functions used to calculate $B_{35\%}$, OFL and p^*-ABC for Alt4b are illustrated in Figure A6.25. The distribution of the OFL for Alt4b is shown in Figure A6.26. The resulting quad plots for Alt1a and Alt4b are shown for comparison in Figure A6.27.

The values of average recruitment, current B (MMB-at-mating in 2014/15), F_{msy}=$F_{35\%}$, B_{msy}=$B_{35\%}$, B/B_{msy}, OFL, the p^*-ABC, and the 10%-buffer ABC are given in Table A6.9 for all converged model scenarios considered in this assessment. Table 6.10 presents the basis for the OFL calculation using Alt4b, and Table 6.11 presents the management history based on Alt4b as the preferred model.

Tables

Table A6.2. Comparison of the final objective function components for Alt1a and the 3 new model scenarios (as differences from Alt1). A positive difference generally indicates a better fit by the new model scenario. Only Alt1a and Alt4a can be compared directly for all components. Alt4b and Alt4c cannot be directly compared with Alt1a for components involving fits to discard biomass. Thus, Alt4b does not necessarily provide a better overall fit to the data, even though its total objective function value is smaller than that for Alt1a.

sigma	Model Case				Description
	Alt1a	Alt1a-Alt4a	Alt1a-Alt4b	Alt1a-Alt4c	
1.000	2.19	0.00	-0.01	-0.02	recruitment penalty
NA	0.00	0.00	0.00	0.00	sex ratio penalty
1.000	0.85	0.00	-0.06	-0.08	immatures natural mortality penalty
1.000	1.44	0.00	-1.02	-2.05	mature male natural mortality penalty
1.000	42.70	0.02	3.73	6.01	mature female natural mortality penalty
1.000	6.17	0.00	2.95	3.84	survey q penalty
1.000	25.70	-0.01	5.25	7.09	female survey q penalty
1.000	0.90	0.00	0.00	0.00	prior on female growth parameter a
1.000	0.72	0.00	-0.01	-0.02	prior on female growth parameter b
1.000	0.09	0.00	-0.03	-0.03	prior on male growth parameter a
1.000	0.02	0.00	0.00	0.00	prior on male growth parameter b
1.000	1.26	0.00	0.00	0.00	smoothing penalty on female maturity curve
1.414	0.43	0.00	-0.01	-0.01	smoothing penalty on male maturity curve
NA	0.00	0.00	0.00	0.00	1st difference penalty on changes in male size at 50% selectivity in directed fishery
1.000	49.24	0.00	-2.17	-3.46	penalty on F-devs in directed fishery
1.414	10.02	0.00	1.73	2.95	penalty on F-devs in snow crab fishery
NA	0.00	0.00	0.00	0.00	penalty on F-devs in BBRKC fishery
1.414	13.12	0.00	0.12	0.25	penalty on F-devs in groundfish fishery
1.000	57.82	0.00	-6.83	-11.74	likelihood for directed fishery: retained males
1.000	93.14	0.00	-9.18	-13.65	likelihood for directed fishery: total males
1.000	13.53	-0.01	-0.41	-0.60	likelihood for directed fishery: discarded females
1.000	42.42	0.00	0.74	1.40	likelihood for snow crab fishery: discarded males
1.000	13.60	-0.01	0.67	0.84	likelihood for snow crab fishery: discarded females
1.000	22.23	0.00	-0.24	-0.42	likelihood for BBRKC fishery: discarded males
1.000	1.83	-0.07	-0.10	-0.11	likelihood for BBRKC fishery: discarded females
1.000	150.68	0.00	-2.93	-4.64	likelihood for groundfish fishery
1.000	289.76	-0.05	-9.64	-14.64	likelihood for survey: immature males
1.000	225.55	0.02	4.48	7.26	likelihood for survey: mature males
1.000	259.86	0.05	6.26	9.95	likelihood for survey: immature females
1.000	90.58	0.07	1.35	1.23	likelihood for survey: mature females
1.000	199.70	0.01	-1.06	-2.06	likelihood for survey: mature survey biomass
0.316	22.14	0.00	-9.94	-17.13	likelihood for directed fishery: male retained catch biomass
0.316	12.05	0.00	-6.69	-11.45	likelihood for directed fishery: male total catch biomass
0.316	12.57	-0.01	6.05	8.20	likelihood for directed fishery: female catch biomass
0.316	13.79	0.00	4.00	5.74	likelihood for snow crab fishery: total catch biomass
0.316	24.05	0.00	14.12	18.82	likelihood for BBRKC fishery: total catch biomass
0.316	2.07	0.00	-0.09	-0.14	likelihood for groundfish fishery: total catch biomass
	1,702.22	**0.01**	**1.06**	**-8.65**	**total**

Table A6.3. Comparison of parameter estimates and approximate standard deviations from Alt1a and the 3 new model scenarios. Parameter names, types, bounds, and associated indices are also given. Blue highlighting indicates the parameter estimate is at the lower bound set for the parameter, whereas red highlighting indicates the parameter estimate is at the upper bound.

Parameter characteristics					Model Scenarios							
					Alt1a		Alt4a		Alt4b		Alt4c	
name	type	min	max	index	value	std.dev	value	std.dev	value	std.dev	value	std.dev
af1	'param_init_bounded_number'	0.4	0.7	1	7.00E-01	7.93E-05	7.00E-01	7.97E-05	7.00E-01	7.73E-05	7.00E-01	7.71E-05
bf1	'param_init_bounded_number'	0.6	1.2	1	8.83E-01	1.23E-03	8.83E-01	1.23E-03	8.83E-01	1.24E-03	8.83E-01	1.24E-03
am1	'param_init_bounded_number'	0.3	0.6	1	4.27E-01	2.20E-02	4.27E-01	2.20E-02	4.26E-01	2.19E-02	4.26E-01	2.19E-02
bm1	'param_init_bounded_number'	0.7	1.2	1	9.71E-01	5.17E-03	9.71E-01	5.17E-03	9.71E-01	5.18E-03	9.71E-01	5.19E-03
Mmult_imat	'param_init_bounded_number'	0.2	2	1	1.07E+00	5.13E-02	1.07E+00	5.13E-02	1.07E+00	5.07E-02	1.07E+00	5.05E-02
Mmultm	'param_init_bounded_number'	0.1	1.9	1	1.08E+00	4.32E-02	1.08E+00	4.32E-02	1.11E+00	4.28E-02	1.13E+00	4.25E-02
Mmultf	'param_init_bounded_number'	0.1	1.9	1	1.46E+00	3.73E-02	1.46E+00	3.73E-02	1.44E+00	3.71E-02	1.43E+00	3.72E-02
mat_big	'param_init_bounded_vector'	0.1	10	1	1.07E+00	9.75E-02	1.07E+00	9.75E-02	1.12E+00	9.85E-02	1.15E+00	9.91E-02
mat_big	'param_init_bounded_vector'	0.1	10	2	2.59E+00	3.52E-01	2.59E+00	3.52E-01	2.59E+00	3.43E-01	2.58E+00	3.37E-01
pMnLnRec	'param_init_number'	-Inf	Inf	1	1.13E+01	7.11E-02	1.13E+01	7.11E-02	1.12E+01	7.08E-02	1.11E+01	7.10E-02
pRecDevs	'param_init_bounded_vector'	-15	15	1974	-1.94E-01	7.88E-01	-1.93E-01	7.88E-01	-1.50E-01	7.88E-01	-1.31E-01	7.89E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1975	1.03E+00	2.64E-01	1.03E+00	2.64E-01	1.09E+00	2.59E-01	1.11E+00	2.57E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1976	1.85E+00	1.27E-01	1.85E+00	1.27E-01	1.87E+00	1.27E-01	1.88E+00	1.27E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1977	1.36E+00	1.67E-01	1.36E+00	1.67E-01	1.37E+00	1.67E-01	1.37E+00	1.68E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1978	1.20E+00	1.58E-01	1.20E+00	1.58E-01	1.21E+00	1.58E-01	1.22E+00	1.59E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1979	-2.10E-01	3.75E-01	-2.10E-01	3.75E-01	-1.83E-01	3.72E-01	-1.74E-01	3.72E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1980	-1.16E+00	6.44E-01	-1.16E+00	6.44E-01	-1.14E+00	6.42E-01	-1.13E+00	6.41E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1981	-3.02E-01	2.50E-01	-3.02E-01	2.50E-01	-2.83E-01	2.49E-01	-2.73E-01	2.48E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1982	-1.00E+00	3.83E-01	-1.00E+00	3.83E-01	-9.93E-01	3.82E-01	-9.91E-01	3.83E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1983	9.66E-01	1.08E-01	9.66E-01	1.08E-01	9.66E-01	1.08E-01	9.66E-01	1.08E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1984	7.70E-01	1.59E-01	7.70E-01	1.59E-01	7.64E-01	1.58E-01	7.60E-01	1.57E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1985	1.43E+00	1.18E-01	1.43E+00	1.18E-01	1.40E+00	1.18E-01	1.38E+00	1.18E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1986	1.26E+00	1.33E-01	1.26E+00	1.33E-01	1.23E+00	1.32E-01	1.20E+00	1.32E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1987	1.19E+00	1.33E-01	1.19E+00	1.33E-01	1.13E+00	1.33E-01	1.09E+00	1.33E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1988	1.09E+00	1.25E-01	1.09E+00	1.25E-01	1.01E+00	1.26E-01	9.60E-01	1.26E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1989	2.61E-01	1.68E-01	2.61E-01	1.68E-01	1.94E-01	1.68E-01	1.53E-01	1.68E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1990	-5.51E-01	2.31E-01	-5.51E-01	2.31E-01	-6.02E-01	2.31E-01	-6.35E-01	2.31E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1991	-1.31E+00	3.08E-01	-1.31E+00	3.08E-01	-1.36E+00	3.09E-01	-1.39E+00	3.10E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1992	-1.48E+00	2.62E-01	-1.48E+00	2.62E-01	-1.50E+00	2.61E-01	-1.51E+00	2.61E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1993	-1.66E+00	2.56E-01	-1.66E+00	2.56E-01	-1.67E+00	2.56E-01	-1.68E+00	2.56E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1994	-1.53E+00	2.22E-01	-1.53E+00	2.22E-01	-1.53E+00	2.23E-01	-1.53E+00	2.23E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1995	-1.16E+00	1.74E-01	-1.16E+00	1.74E-01	-1.15E+00	1.74E-01	-1.14E+00	1.74E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1996	-1.19E+00	1.99E-01	-1.19E+00	1.99E-01	-1.17E+00	1.99E-01	-1.16E+00	1.99E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1997	-1.96E-01	1.04E-01	-1.96E-01	1.04E-01	-1.70E-01	1.04E-01	-1.53E-01	1.04E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1998	-1.13E+00	1.87E-01	-1.12E+00	1.87E-01	-1.10E+00	1.87E-01	-1.09E+00	1.88E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1999	1.35E-02	1.05E-01	1.35E-02	1.05E-01	3.65E-02	1.05E-01	5.36E-02	1.05E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2000	-4.84E-01	1.77E-01	-4.84E-01	1.77E-01	-4.67E-01	1.78E-01	-4.53E-01	1.78E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2001	6.45E-01	9.68E-02	6.45E-01	9.68E-02	6.65E-01	9.66E-02	6.81E-01	9.65E-02
pRecDevs	'param_init_bounded_vector'	-15	15	2002	-2.37E-01	1.87E-01	-2.37E-01	1.87E-01	-2.21E-01	1.87E-01	-2.09E-01	1.88E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2003	3.47E-01	1.36E-01	3.47E-01	1.36E-01	3.56E-01	1.36E-01	3.67E-01	1.36E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2004	9.46E-01	9.11E-02	9.46E-01	9.11E-02	9.62E-01	9.10E-02	9.73E-01	9.11E-02
pRecDevs	'param_init_bounded_vector'	-15	15	2005	-2.34E-01	1.95E-01	-2.34E-01	1.95E-01	-2.18E-01	1.94E-01	-2.07E-01	1.94E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2006	-4.20E-01	2.08E-01	-4.20E-01	2.08E-01	-4.06E-01	2.07E-01	-3.95E-01	2.07E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2007	-7.68E-01	2.57E-01	-7.68E-01	2.57E-01	-7.59E-01	2.57E-01	-7.52E-01	2.57E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2008	-6.21E-01	2.50E-01	-6.21E-01	2.50E-01	-6.21E-01	2.51E-01	-6.16E-01	2.51E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2009	1.05E+00	1.07E-01	1.05E+00	1.07E-01	1.06E+00	1.07E-01	1.07E+00	1.07E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2010	1.11E+00	1.14E-01	1.11E+00	1.14E-01	1.11E+00	1.14E-01	1.11E+00	1.14E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2011	4.25E-01	1.65E-01	4.25E-01	1.65E-01	4.21E-01	1.65E-01	4.18E-01	1.65E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2012	-1.17E+00	4.28E-01	-1.17E+00	4.28E-01	-1.18E+00	4.28E-01	-1.18E+00	4.28E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2013	-1.76E-01	2.30E-01	-1.76E-01	2.30E-01	-1.90E-01	2.30E-01	-1.97E-01	2.30E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2014	2.45E-01	2.38E-01	2.45E-01	2.38E-01	2.25E-01	2.38E-01	2.15E-01	2.38E-01

Table A6.1 (cont.)

Parameter characteristics					Model Scenarios							
					Alt1a		Alt4a		Alt4b		Alt4c	
name	type	min	max	index	value	std.dev	value	std.dev	value	std.dev	value	std.dev
pMnLnRecEarly	'param_init_number'	-Inf	Inf	1	1.19E+01	5.08E-01	1.19E+01	5.08E-01	1.18E+01	5.11E-01	1.18E+01	5.13E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1949	-1.50E+00	1.61E+00	-1.50E+00	1.61E+00	-1.49E+00	1.62E+00	-1.49E+00	1.62E+00
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1950	-1.49E+00	1.47E+00	-1.49E+00	1.47E+00	-1.49E+00	1.48E+00	-1.48E+00	1.48E+00
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1951	-1.49E+00	1.33E+00	-1.49E+00	1.33E+00	-1.48E+00	1.34E+00	-1.48E+00	1.34E+00
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1952	-1.47E+00	1.20E+00	-1.47E+00	1.20E+00	-1.47E+00	1.21E+00	-1.47E+00	1.21E+00
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1953	-1.46E+00	1.08E+00	-1.46E+00	1.08E+00	-1.45E+00	1.09E+00	-1.45E+00	1.09E+00
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1954	-1.43E+00	9.75E-01	-1.43E+00	9.75E-01	-1.43E+00	9.79E-01	-1.42E+00	9.81E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1955	-1.38E+00	8.85E-01	-1.38E+00	8.85E-01	-1.38E+00	8.87E-01	-1.38E+00	8.89E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1956	-1.32E+00	8.13E-01	-1.32E+00	8.13E-01	-1.32E+00	8.15E-01	-1.32E+00	8.16E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1957	-1.22E+00	7.61E-01	-1.22E+00	7.61E-01	-1.23E+00	7.62E-01	-1.23E+00	7.63E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1958	-1.08E+00	7.29E-01	-1.08E+00	7.29E-01	-1.09E+00	7.30E-01	-1.09E+00	7.30E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1959	-8.69E-01	7.13E-01	-8.69E-01	7.13E-01	-8.83E-01	7.14E-01	-8.88E-01	7.14E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1960	-5.34E-01	7.11E-01	-5.34E-01	7.11E-01	-5.53E-01	7.12E-01	-5.61E-01	7.13E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1961	1.36E-02	7.22E-01	1.35E-02	7.22E-01	-9.95E-03	7.23E-01	-2.00E-02	7.24E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1962	8.05E-01	7.25E-01	8.05E-01	7.25E-01	7.79E-01	7.27E-01	7.68E-01	7.27E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1963	1.57E+00	7.12E-01	1.57E+00	7.12E-01	1.55E+00	7.13E-01	1.54E+00	7.14E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1964	1.89E+00	6.90E-01	1.89E+00	6.90E-01	1.88E+00	6.91E-01	1.87E+00	6.92E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1965	1.82E+00	6.87E-01	1.82E+00	6.87E-01	1.82E+00	6.89E-01	1.81E+00	6.91E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1966	1.62E+00	6.88E-01	1.62E+00	6.88E-01	1.62E+00	6.91E-01	1.61E+00	6.92E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1967	1.46E+00	6.75E-01	1.46E+00	6.75E-01	1.47E+00	6.78E-01	1.48E+00	6.79E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1968	1.41E+00	6.58E-01	1.41E+00	6.58E-01	1.43E+00	6.59E-01	1.45E+00	6.59E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1969	1.42E+00	6.62E-01	1.42E+00	6.62E-01	1.46E+00	6.62E-01	1.49E+00	6.61E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1970	1.24E+00	6.11E-01	1.24E+00	6.11E-01	1.28E+00	6.12E-01	1.30E+00	6.13E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1971	8.36E-01	5.68E-01	8.36E-01	5.68E-01	8.54E-01	5.71E-01	8.60E-01	5.72E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1972	6.68E-01	5.51E-01	6.68E-01	5.51E-01	6.73E-01	5.54E-01	6.71E-01	5.56E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1973	4.68E-01	5.57E-01	4.68E-01	5.57E-01	4.66E-01	5.60E-01	4.58E-01	5.62E-01
pAvgLnFmTCF	'param_init_number'	-Inf	Inf	1	-1.66E+00	8.73E-02	-1.66E+00	8.73E-02	-1.62E+00	8.72E-02	-1.61E+00	8.72E-02
pFmDevsTCF	'param_init_bounded_vector'	-15	15	1	-5.21E-01	4.94E-01	-5.21E-01	4.94E-01	-5.17E-01	4.95E-01	-5.15E-01	4.95E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	2	-7.65E-01	3.82E-01	-7.65E-01	3.82E-01	-7.59E-01	3.83E-01	-7.56E-01	3.83E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	3	3.98E-01	3.37E-01	3.98E-01	3.37E-01	4.06E-01	3.39E-01	4.11E-01	3.40E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	4	2.10E-01	3.19E-01	2.10E-01	3.19E-01	2.17E-01	3.21E-01	2.21E-01	3.22E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	5	3.49E-01	3.08E-01	3.49E-01	3.08E-01	3.56E-01	3.11E-01	3.61E-01	3.13E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	6	1.69E-01	3.02E-01	1.69E-01	3.02E-01	1.76E-01	3.07E-01	1.81E-01	3.09E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	7	-6.51E-02	2.80E-01	-6.48E-02	2.80E-01	-6.08E-02	2.86E-01	-5.70E-02	2.89E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	8	-2.74E-01	2.28E-01	-2.74E-01	2.28E-01	-2.76E-01	2.34E-01	-2.76E-01	2.37E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	9	-5.46E-01	1.48E-01	-5.46E-01	1.48E-01	-5.59E-01	1.51E-01	-5.65E-01	1.53E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	10	-3.60E-01	9.65E-02	-3.60E-01	9.65E-02	-3.82E-01	9.75E-02	-3.93E-01	9.82E-02
pFmDevsTCF	'param_init_bounded_vector'	-15	15	11	-9.45E-02	8.79E-02	-9.46E-02	8.80E-02	-1.19E-01	8.90E-02	-1.31E-01	8.97E-02
pFmDevsTCF	'param_init_bounded_vector'	-15	15	12	6.99E-01	8.56E-02	6.99E-01	8.56E-02	6.78E-01	8.66E-02	6.69E-01	8.74E-02
pFmDevsTCF	'param_init_bounded_vector'	-15	15	13	1.36E+00	8.86E-02	1.36E+00	8.86E-02	1.35E+00	8.97E-02	1.34E+00	9.06E-02
pFmDevsTCF	'param_init_bounded_vector'	-15	15	14	1.49E+00	1.06E-01	1.49E+00	1.06E-01	1.50E+00	1.08E-01	1.50E+00	1.09E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	15	2.25E+00	1.60E-01	2.25E+00	1.60E-01	2.28E+00	1.64E-01	2.29E+00	1.67E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	16	2.35E+00	2.17E-01	2.35E+00	2.17E-01	2.36E+00	2.22E-01	2.35E+00	2.23E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	17	7.30E-01	1.54E-01	7.30E-01	1.54E-01	6.96E-01	1.50E-01	6.78E-01	1.47E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	18	-3.60E-01	1.28E-01	-3.60E-01	1.28E-01	-3.71E-01	1.28E-01	-3.77E-01	1.28E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	19	-1.52E+00	2.50E-01	-1.52E+00	2.50E-01	-1.51E+00	2.50E-01	-1.50E+00	2.50E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	20	-4.51E-01	1.81E-01	-4.51E-01	1.81E-01	-4.25E-01	1.81E-01	-4.13E-01	1.81E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	21	-1.08E+00	2.16E-01	-1.08E+00	2.16E-01	-1.07E+00	2.16E-01	-1.07E+00	2.16E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	22	-3.19E-01	1.10E-01	-3.19E-01	1.10E-01	-3.19E-01	1.10E-01	-3.14E-01	1.11E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	23	7.98E-01	8.67E-02	7.98E-01	8.67E-02	8.11E-01	8.72E-02	8.24E-01	8.75E-02

Table A6.1 (cont.).

Parameter characteristics					Model Scenarios							
					Alt1a		Alt4a		Alt4b		Alt4c	
name	type	min	max	index	value	std.dev	value	std.dev	value	std.dev	value	std.dev
pFmDevsTCF	'param_init_bounded_vector'	-15	15	24	1.37E+00	9.16E-02	1.37E+00	9.16E-02	1.40E+00	9.23E-02	1.42E+00	9.28E-02
pFmDevsTCF	'param_init_bounded_vector'	-15	15	25	1.39E+00	1.07E-01	1.39E+00	1.07E-01	1.40E+00	1.06E-01	1.41E+00	1.06E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	26	1.91E+00	1.41E-01	1.91E+00	1.41E-01	2.04E+00	1.56E-01	2.12E+00	1.66E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	27	1.14E+00	1.25E-01	1.14E+00	1.25E-01	1.23E+00	1.32E-01	1.28E+00	1.36E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	28	6.12E-01	1.45E-01	6.12E-01	1.45E-01	7.18E-01	1.55E-01	7.65E-01	1.59E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	29	1.18E-01	1.37E-01	1.17E-01	1.37E-01	8.89E-02	1.47E-01	5.96E-02	1.53E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	30	-1.16E+00	1.76E-01	-1.16E+00	1.76E-01	-1.15E+00	1.77E-01	-1.15E+00	1.77E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	31	-1.99E+00	2.10E-01	-1.99E+00	2.10E-01	-2.02E+00	2.17E-01	-2.05E+00	2.21E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	32	-1.47E+00	1.41E-01	-1.47E+00	1.41E-01	-1.55E+00	1.48E-01	-1.60E+00	1.53E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	33	-1.50E+00	1.30E-01	-1.50E+00	1.30E-01	-1.62E+00	1.39E-01	-1.69E+00	1.45E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	34	-1.69E+00	1.66E-01	-1.69E+00	1.66E-01	-1.73E+00	1.69E-01	-1.75E+00	1.71E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	35	-1.06E+00	2.89E-01	-1.06E+00	2.89E-01	-1.09E+00	2.86E-01	-1.11E+00	2.85E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	36	-2.12E+00	1.86E-01	-2.12E+00	1.86E-01	-2.15E+00	1.92E-01	-2.17E+00	1.95E-01
pAvgLnFmGTF	'param_init_number'	-Inf	Inf	1	-4.26E+00	7.66E-02	-4.26E+00	7.66E-02	-4.21E+00	7.47E-02	-4.19E+00	7.40E-02
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1973	8.07E-01	9.73E-02	8.07E-01	9.73E-02	7.90E-01	9.62E-02	7.83E-01	9.59E-02
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1974	1.22E+00	8.35E-02	1.22E+00	8.35E-02	1.20E+00	8.18E-02	1.19E+00	8.12E-02
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1975	4.15E-01	8.45E-02	4.15E-01	8.45E-02	3.98E-01	8.28E-02	3.91E-01	8.22E-02
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1976	-6.27E-02	9.66E-02	-6.27E-02	9.66E-02	-7.70E-02	9.50E-02	-8.15E-02	9.44E-02
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1977	-2.72E-01	1.24E-01	-2.72E-01	1.24E-01	-2.83E-01	1.22E-01	-2.86E-01	1.22E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1978	-4.03E-01	1.61E-01	-4.03E-01	1.61E-01	-4.12E-01	1.59E-01	-4.13E-01	1.59E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1979	3.12E-01	1.19E-01	3.12E-01	1.19E-01	3.08E-01	1.18E-01	3.09E-01	1.17E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1980	8.24E-02	1.55E-01	8.24E-02	1.55E-01	8.19E-02	1.54E-01	8.23E-02	1.54E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1981	-1.22E-01	1.95E-01	-1.22E-01	1.95E-01	-1.21E-01	1.94E-01	-1.22E-01	1.93E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1982	-9.02E-01	3.94E-01	-9.02E-01	3.94E-01	-8.96E-01	3.94E-01	-8.94E-01	3.94E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1983	-4.43E-01	3.57E-01	-4.43E-01	3.57E-01	-4.32E-01	3.58E-01	-4.27E-01	3.58E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1984	-2.24E-01	3.90E-01	-2.24E-01	3.90E-01	-2.05E-01	3.92E-01	-1.97E-01	3.93E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1985	-6.39E-01	4.77E-01	-6.39E-01	4.77E-01	-6.26E-01	4.81E-01	-6.18E-01	4.83E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1986	-5.92E-01	3.78E-01	-5.92E-01	3.78E-01	-5.78E-01	3.81E-01	-5.69E-01	3.82E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1987	-7.47E-01	3.81E-01	-7.47E-01	3.81E-01	-7.91E-01	3.80E-01	-8.10E-01	3.79E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1988	-1.18E+00	4.07E-01	-1.18E+00	4.07E-01	-1.21E+00	4.05E-01	-1.22E+00	4.04E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1989	-1.05E+00	3.45E-01	-1.05E+00	3.45E-01	-1.07E+00	3.43E-01	-1.08E+00	3.42E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1990	-7.12E-01	2.88E-01	-7.12E-01	2.88E-01	-7.30E-01	2.85E-01	-7.32E-01	2.83E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1991	4.13E-01	1.47E-01	4.13E-01	1.47E-01	4.07E-01	1.41E-01	4.09E-01	1.38E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1992	7.23E-01	1.37E-01	7.23E-01	1.37E-01	7.24E-01	1.31E-01	7.28E-01	1.28E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1993	5.85E-01	1.77E-01	5.85E-01	1.77E-01	5.77E-01	1.72E-01	5.71E-01	1.69E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1994	1.09E+00	1.55E-01	1.09E+00	1.55E-01	1.07E+00	1.50E-01	1.06E+00	1.47E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1995	1.13E+00	1.91E-01	1.13E+00	1.91E-01	1.10E+00	1.85E-01	1.08E+00	1.82E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1996	1.48E+00	1.82E-01	1.48E+00	1.82E-01	1.44E+00	1.77E-01	1.42E+00	1.74E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1997	1.51E+00	2.34E-01	1.51E+00	2.34E-01	1.53E+00	2.31E-01	1.54E+00	2.29E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1998	1.25E+00	3.22E-01	1.25E+00	3.22E-01	1.26E+00	3.20E-01	1.26E+00	3.19E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1999	7.31E-01	4.84E-01	7.31E-01	4.84E-01	7.29E-01	4.87E-01	7.24E-01	4.88E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2000	7.92E-01	3.94E-01	7.92E-01	3.94E-01	7.95E-01	3.96E-01	7.94E-01	3.98E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2001	1.11E+00	2.47E-01	1.10E+00	2.47E-01	1.12E+00	2.47E-01	1.12E+00	2.48E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2002	4.70E-01	3.66E-01	4.70E-01	3.66E-01	4.82E-01	3.67E-01	4.86E-01	3.68E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2003	-1.09E-01	4.73E-01	-1.09E-01	4.73E-01	-9.61E-02	4.75E-01	-9.16E-02	4.76E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2004	1.61E-02	3.61E-01	1.60E-02	3.61E-01	3.07E-02	3.61E-01	3.70E-02	3.62E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2005	-2.48E-01	3.69E-01	-2.48E-01	3.69E-01	-2.32E-01	3.70E-01	-2.25E-01	3.70E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2006	-2.34E-01	3.28E-01	-2.34E-01	3.28E-01	-2.16E-01	3.28E-01	-2.07E-01	3.28E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2007	-3.68E-01	3.27E-01	-3.68E-01	3.27E-01	-3.50E-01	3.26E-01	-3.41E-01	3.27E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2008	-6.69E-01	3.67E-01	-6.69E-01	3.67E-01	-6.51E-01	3.67E-01	-6.42E-01	3.68E-01

Table A6.1 (cont.).

	Parameter characteristics				Model Scenarios							
					Alt1a		Alt4a		Alt4b		Alt4c	
name	type	min	max	index	value	std.dev	value	std.dev	value	std.dev	value	std.dev
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2009	-8.91E-01	4.21E-01	-8.91E-01	4.21E-01	-8.73E-01	4.22E-01	-8.63E-01	4.23E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2010	-1.02E+00	4.73E-01	-1.02E+00	4.73E-01	-1.00E+00	4.75E-01	-9.91E-01	4.77E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2011	-1.01E+00	4.89E-01	-1.01E+00	4.89E-01	-9.92E-01	4.92E-01	-9.81E-01	4.94E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2012	-1.14E+00	4.95E-01	-1.14E+00	4.95E-01	-1.13E+00	4.97E-01	-1.12E+00	5.00E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2013	-1.10E+00	4.31E-01	-1.10E+00	4.31E-01	-1.08E+00	4.33E-01	-1.06E+00	4.35E-01
pAvgLnFmSCF	'param_init_number'	-Inf	Inf	1	-3.54E+00	1.12E-01	-3.54E+00	1.12E-01	-3.80E+00	1.32E-01	-4.00E+00	1.53E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1992	2.08E+00	1.07E-01	2.08E+00	1.07E-01	1.98E+00	1.30E-01	1.88E+00	1.54E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1993	1.84E+00	1.12E-01	1.84E+00	1.12E-01	1.72E+00	1.37E-01	1.61E+00	1.64E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1994	1.49E+00	1.25E-01	1.49E+00	1.25E-01	1.35E+00	1.59E-01	1.24E+00	1.97E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1995	1.48E+00	1.42E-01	1.48E+00	1.42E-01	1.35E+00	1.84E-01	1.24E+00	2.30E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1996	1.61E-01	4.10E-01	1.61E-01	4.10E-01	2.10E-01	4.97E-01	2.71E-01	5.54E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1997	8.03E-01	2.75E-01	8.03E-01	2.75E-01	7.56E-01	3.79E-01	7.31E-01	4.73E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1998	8.16E-01	3.00E-01	8.16E-01	3.00E-01	5.97E-01	4.74E-01	4.24E-01	6.37E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1999	-2.74E-01	5.90E-01	-2.74E-01	5.91E-01	-2.81E-01	6.91E-01	-2.51E-01	7.43E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2000	-7.65E-01	6.09E-01	-7.65E-01	6.09E-01	-5.69E-01	6.68E-01	-4.41E-01	7.11E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2001	-7.11E-01	5.65E-01	-7.11E-01	5.65E-01	-5.50E-01	6.34E-01	-4.39E-01	6.81E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2002	-6.19E-01	5.13E-01	-6.19E-01	5.13E-01	-5.22E-01	6.00E-01	-4.44E-01	6.53E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2003	-1.02E+00	5.29E-01	-1.02E+00	5.29E-01	-7.94E-01	5.86E-01	-6.48E-01	6.26E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2004	-1.32E+00	5.18E-01	-1.32E+00	5.18E-01	-1.07E+00	5.65E-01	-9.01E-01	6.00E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2005	-5.76E-01	3.99E-01	-5.76E-01	3.99E-01	-5.63E-01	5.08E-01	-5.31E-01	5.74E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2006	-2.57E-01	3.02E-01	-2.57E-01	3.02E-01	-2.99E-01	4.21E-01	-3.23E-01	5.09E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2007	-1.69E-01	2.49E-01	-1.69E-01	2.49E-01	-2.24E-01	3.55E-01	-2.66E-01	4.43E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2008	-7.40E-01	3.34E-01	-7.39E-01	3.34E-01	-7.01E-01	4.31E-01	-6.59E-01	4.96E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2009	-5.96E-01	3.17E-01	-5.96E-01	3.17E-01	-6.00E-01	4.26E-01	-5.89E-01	5.01E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2010	-5.00E-01	3.24E-01	-5.00E-01	3.24E-01	-5.23E-01	4.42E-01	-5.25E-01	5.22E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2011	1.70E-02	2.41E-01	1.71E-02	2.42E-01	-8.04E-02	3.59E-01	-1.68E-01	4.66E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2012	-6.37E-01	3.55E-01	-6.37E-01	3.55E-01	-6.50E-01	4.68E-01	-6.36E-01	5.39E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2013	-5.04E-01	2.58E-01	-5.04E-01	2.58E-01	-5.48E-01	3.60E-01	-5.73E-01	4.41E-01
fish_fit_slope_mn1	'param_init_bounded_number'	0.25	1.001	1	7.12E-01	1.26E-01	7.12E-01	1.26E-01	7.28E-01	1.31E-01	7.35E-01	1.33E-01
fish_fit_sel50_mn1	'param_init_bounded_number'	85	160	1	1.38E+02	4.15E-01	1.38E+02	4.15E-01	1.38E+02	3.94E-01	1.38E+02	3.86E-01
fish_fit_slope_mn2	'param_init_bounded_number'	0.25	2.001	1	8.44E-01	1.24E-01	8.44E-01	1.24E-01	8.41E-01	1.18E-01	8.43E-01	1.15E-01
fish_fit_sel50_mn2	'param_init_bounded_number'	85	160	1	1.37E+02	2.63E-01	1.37E+02	2.63E-01	1.37E+02	3.03E-01	1.37E+02	3.28E-01
fish_slope_1	'param_init_bounded_number'	0.05	0.75	1	1.23E-01	7.10E-03	1.23E-01	7.10E-03	1.24E-01	6.88E-03	1.25E-01	6.80E-03
fish_slope_yr_3	'param_init_bounded_number'	0.1	0.4	1	1.35E-01	8.36E-03	1.35E-01	8.36E-03	1.36E-01	8.51E-03	1.36E-01	8.59E-03
log_avg_sel50_3	'param_init_bounded_number'	4	5	1	4.82E+00	9.18E-03	4.82E+00	9.18E-03	4.83E+00	8.88E-03	4.83E+00	8.69E-03
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	1	5.63E-02	1.78E-02	5.63E-02	1.78E-02	4.70E-02	1.77E-02	4.14E-02	1.76E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	2	1.37E-01	1.48E-02	1.37E-01	1.48E-02	1.45E-01	1.53E-02	1.50E-01	1.56E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	3	9.63E-02	1.56E-02	9.63E-02	1.56E-02	1.05E-01	1.56E-02	1.09E-01	1.56E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	4	7.73E-02	2.30E-02	7.73E-02	2.30E-02	9.83E-02	2.14E-02	1.08E-01	2.05E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	5	-1.79E-02	3.09E-02	-1.78E-02	3.09E-02	-3.10E-03	2.98E-02	3.40E-03	2.93E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	6	-4.99E-01	2.02E-02	-4.99E-01	2.02E-02	-4.99E-01	1.78E-02	-4.99E-01	1.60E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	7	-3.93E-02	2.01E-02	-3.93E-02	2.01E-02	-4.65E-02	2.01E-02	-4.96E-02	2.00E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	8	-4.57E-02	2.00E-02	-4.56E-02	2.00E-02	-5.29E-02	2.00E-02	-5.62E-02	1.99E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	9	-7.62E-02	1.82E-02	-7.62E-02	1.82E-02	-8.20E-02	1.81E-02	-8.46E-02	1.80E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	10	6.42E-02	1.67E-02	6.42E-02	1.67E-02	5.63E-02	1.67E-02	5.27E-02	1.66E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	11	2.40E-01	2.09E-02	2.40E-01	2.09E-02	2.32E-01	2.07E-02	2.28E-01	2.05E-02
log_sel50_dev_3	'param_init_bounded_vector'	-0.5	0.5	12	7.53E-03	1.98E-02	7.53E-03	1.98E-02	5.25E-04	1.98E-02	-2.52E-03	1.97E-02
fish_disc_slope_f	'param_init_bounded_number'	0.1	0.4	1	1.41E-01	8.94E-03	1.41E-01	8.95E-03	1.38E-01	8.63E-03	1.36E-01	8.47E-03
fish_disc_sel50_f	'param_init_bounded_number'	80	150	1	1.17E+02	2.82E+00	1.17E+02	2.82E+00	1.20E+02	3.28E+00	1.23E+02	3.62E+00

Table A6.1 (cont.).

	Parameter characteristics				Model Scenarios							
					Alt1a		Alt4a		Alt4b		Alt4c	
name	type	min	max	index	value	std.dev	value	std.dev	value	std.dev	value	std.dev
snowfish_disc_slope_f_1	'param_init_bounded_number'	0.05	0.5	1	5.00E-02	1.56E-05	5.00E-02	1.56E-05	5.00E-02	2.29E-05	5.00E-02	3.39E-05
snowfish_disc_sel50_f_1	'param_init_bounded_number'	50	150	1	1.16E+02	3.62E+00	1.16E+02	3.62E+00	1.11E+02	4.71E+00	1.07E+02	5.95E+00
snowfish_disc_slope_f_2	'param_init_bounded_number'	0.05	0.5	1	2.09E-01	1.06E-01	2.08E-01	1.06E-01	2.48E-01	1.29E-01	2.60E-01	1.37E-01
snowfish_disc_sel50_f_2	'param_init_bounded_number'	50	120	1	7.89E+01	5.64E+00	7.89E+01	5.64E+00	7.65E+01	5.02E+00	7.59E+01	4.93E+00
snowfish_disc_slope_f_3	'param_init_bounded_number'	0.05	0.5	1	1.33E-01	4.18E-02	1.33E-01	4.18E-02	1.57E-01	5.28E-02	1.69E-01	5.78E-02
snowfish_disc_sel50_f_3	'param_init_bounded_number'	50	120	1	9.01E+01	7.95E+00	9.01E+01	7.95E+00	8.52E+01	6.35E+00	8.34E+01	5.76E+00
snowfish_disc_slope_m_1	'param_init_bounded_number'	0.1	0.5	1	3.01E-01	9.67E-02	3.01E-01	9.67E-02	3.56E-01	1.26E-01	3.77E-01	1.38E-01
snowfish_disc_sel50_m_1	'param_init_bounded_number'	60	150	1	8.88E+01	1.92E+00	8.88E+01	1.93E+00	8.75E+01	1.76E+00	8.69E+01	1.75E+00
snowfish_disc_slope_m2_1	'param_init_bounded_number'	0.1	0.5	1	3.22E-01	1.86E-01	3.22E-01	1.86E-01	3.73E-01	2.49E-01	3.29E-01	2.31E-01
snowfish_disc_sel50_m2_1	'param_init_bounded_number'	40	200	1	1.41E+02	2.17E+00	3.96E+00	6.14E-02	3.97E+00	5.28E-02	3.98E+00	6.00E-02
snowfish_disc_slope_m_2	'param_init_bounded_number'	0.1	0.5	1	2.52E-01	8.15E-02	2.52E-01	8.16E-02	2.34E-01	7.52E-02	2.25E-01	7.20E-02
snowfish_disc_sel50_m_2	'param_init_bounded_number'	60	150	1	9.31E+01	2.77E+00	9.31E+01	2.77E+00	9.38E+01	3.07E+00	9.43E+01	3.31E+00
snowfish_disc_slope_m2_2	'param_init_bounded_number'	0.1	0.5	1	1.99E-01	1.03E-01	1.99E-01	1.03E-01	1.83E-01	9.24E-02	1.70E-01	8.75E-02
snowfish_disc_sel50_m2_2	'param_init_bounded_number'	40	200	1	1.42E+02	4.18E+00	3.88E+00	1.14E-01	3.82E+00	1.32E-01	3.79E+00	1.51E-01
snowfish_disc_slope_m_3	'param_init_bounded_number'	0.1	0.5	1	1.68E-01	1.74E-02	1.68E-01	1.74E-02	1.65E-01	1.74E-02	1.63E-01	1.74E-02
snowfish_disc_sel50_m_3	'param_init_bounded_number'	60	150	1	1.05E+02	1.85E+00	1.05E+02	1.85E+00	1.05E+02	2.01E+00	1.06E+02	2.18E+00
snowfish_disc_slope_m2_3	'param_init_bounded_number'	0.1	0.5	1	1.76E-01	3.05E-02	1.76E-01	3.05E-02	1.70E-01	2.96E-02	1.65E-01	2.94E-02
snowfish_disc_sel50_m2_3	'param_init_bounded_number'	40	200	1	1.39E+02	1.85E+00	3.53E+00	9.84E-02	3.48E+00	1.15E-01	3.44E+00	1.33E-01
rkfish_disc_slope_f1	'param_init_bounded_number'	0.05	0.5	1	1.72E-01	3.98E-02	1.72E-01	3.98E-02	1.70E-01	4.00E-02	1.69E-01	4.01E-02
rkfish_disc_sel50_f1	'param_init_bounded_number'	50	150	1	1.50E+02	1.23E+00	1.50E+02	1.23E+00	1.50E+02	1.14E+00	1.50E+02	1.10E+00
rkfish_disc_slope_f2	'param_init_bounded_number'	0.05	0.5	1	1.51E-01	6.91E-02	1.79E-01	1.72E-01	1.78E-01	1.73E-01	1.79E-01	1.74E-01
rkfish_disc_sel50_f2	'param_init_bounded_number'	50	150	1	1.50E+02	2.31E+01	1.03E+02	4.51E+01	1.03E+02	4.57E+01	1.03E+02	4.50E+01
rkfish_disc_slope_f3	'param_init_bounded_number'	0.05	0.5	1	1.84E-01	5.58E-02	1.84E-01	5.58E-02	1.85E-01	5.63E-02	1.86E-01	5.66E-02
rkfish_disc_sel50_f3	'param_init_bounded_number'	50	170	1	1.57E+02	3.60E+02	1.57E+02	3.61E+02	1.57E+02	3.54E+02	1.57E+02	3.49E+02
rkfish_disc_slope_m1	'param_init_bounded_number'	0.01	0.5	1	1.03E-01	1.06E-02	1.03E-01	1.06E-02	1.06E-01	1.08E-02	1.08E-01	1.09E-02
rkfish_disc_sel50_m1	'param_init_bounded_number'	95	150	1	1.50E+02	1.52E-03	1.50E+02	1.52E-03	1.50E+02	8.90E-04	1.50E+02	7.17E-04
rkfish_disc_slope_m2	'param_init_bounded_number'	0.01	0.5	1	9.57E-02	2.82E-02	9.57E-02	2.82E-02	9.39E-02	2.73E-02	9.28E-02	2.66E-02
rkfish_disc_sel50_m2	'param_init_bounded_number'	95	150	1	1.31E+02	1.15E+01	1.31E+02	1.15E+01	1.32E+02	1.19E+01	1.33E+02	1.21E+01
rkfish_disc_slope_m3	'param_init_bounded_number'	0.01	0.5	1	8.27E-02	7.20E-03	8.27E-02	7.20E-03	8.14E-02	7.13E-03	8.08E-02	7.10E-03
rkfish_disc_sel50_m3	'param_init_bounded_number'	95	150	1	1.50E+02	7.86E-04	1.50E+02	7.89E-04	1.50E+02	8.57E-04	1.50E+02	8.82E-04
fish_disc_slope_tf1	'param_init_bounded_number'	0.01	0.5	1	2.69E-02	1.68E-03	2.69E-02	1.68E-03	2.67E-02	1.68E-03	2.66E-02	1.69E-03
fish_disc_sel50_tf1	'param_init_bounded_number'	40	125.01	1	1.25E+02	3.17E-04	1.25E+02	3.17E-04	1.25E+02	2.96E-04	1.25E+02	2.84E-04
fish_disc_slope_tf2	'param_init_bounded_number'	0.005	0.5	1	1.34E-02	5.31E-03	1.34E-02	5.31E-03	1.23E-02	5.43E-03	1.17E-02	5.51E-03
fish_disc_sel50_tf2	'param_init_bounded_number'	40	250.01	1	1.77E+02	4.77E+01	1.77E+02	4.78E+01	1.76E+02	5.20E+01	1.76E+02	5.52E+01
fish_disc_slope_tf3	'param_init_bounded_number'	0.01	0.5	1	5.48E-02	8.52E-03	5.48E-02	8.52E-03	5.43E-02	8.50E-03	5.41E-02	8.49E-03
fish_disc_sel50_tf3	'param_init_bounded_number'	40	150.01	1	1.48E+02	1.13E+01	1.48E+02	1.13E+01	1.48E+02	1.14E+01	1.49E+02	1.15E+01
fish_disc_slope_tm1	'param_init_bounded_number'	0.01	0.5	1	1.13E-01	1.24E-02	1.13E-01	1.24E-02	1.14E-01	1.26E-02	1.15E-01	1.27E-02
fish_disc_sel50_tm1	'param_init_bounded_number'	40	120.01	1	5.42E+01	2.00E+00	5.42E+01	2.00E+00	5.38E+01	1.97E+00	5.35E+01	1.96E+00
fish_disc_slope_tm2	'param_init_bounded_number'	0.01	0.5	1	4.34E-02	9.56E-03	4.34E-02	9.56E-03	4.80E-02	1.24E-02	5.16E-02	1.48E-02
fish_disc_sel50_tm2	'param_init_bounded_number'	40	120.01	1	7.11E+01	9.80E+00	7.11E+01	9.80E+00	6.47E+01	8.96E+00	6.13E+01	8.47E+00
fish_disc_slope_tm3	'param_init_bounded_number'	0.01	0.5	1	7.04E-02	3.65E-03	7.04E-02	3.65E-03	7.10E-02	3.67E-03	7.12E-02	3.67E-03
fish_disc_sel50_tm3	'param_init_bounded_number'	40	120.01	1	9.45E+01	2.37E+00	9.45E+01	2.37E+00	9.40E+01	2.32E+00	9.39E+01	2.30E+00
srv2_q	'param_init_bounded_number'	0.5	1.001	1	5.35E-01	3.21E-02	5.35E-01	3.21E-02	5.59E-01	3.33E-02	5.69E-01	3.39E-02
srv2_seldiff	'param_init_bounded_number'	0	100	1	2.33E+01	3.76E+00	2.33E+01	3.76E+00	2.30E+01	3.73E+00	2.29E+01	3.73E+00
srv2_sel50	'param_init_bounded_number'	0	90	1	4.72E+01	2.03E+00	4.72E+01	2.03E+00	4.69E+01	2.01E+00	4.67E+01	2.01E+00
srv3_q	'param_init_bounded_number'	0.2	2	1	7.04E-01	3.52E-02	7.04E-01	3.52E-02	7.53E-01	3.64E-02	7.72E-01	3.69E-02
srv3_seldiff	'param_init_bounded_number'	0	100	1	5.98E+01	8.52E+00	5.98E+01	8.52E+00	5.72E+01	8.05E+00	5.60E+01	7.91E+00
srv3_sel50	'param_init_bounded_number'	0	69	1	2.95E+01	3.36E+00	2.95E+01	3.36E+00	2.84E+01	3.29E+00	2.79E+01	3.28E+00

Table A6.1 (cont.).

Parameter characteristics					Model Scenarios							
					Alt1a		Alt4a		Alt4b		Alt4c	
name	type	min	max	index	value	std.dev	value	std.dev	value	std.dev	value	std.dev
matestf	'param_init_bounded_vector'	-15	0	1	-1.50E+01	2.63E-03	-1.50E+01	2.63E-03	-1.50E+01	2.62E-03	-1.50E+01	2.61E-03
matestf	'param_init_bounded_vector'	-15	0	2	-1.37E+01	7.78E-01	-1.37E+01	7.78E-01	-1.37E+01	7.78E-01	-1.37E+01	7.78E-01
matestf	'param_init_bounded_vector'	-15	0	3	-1.24E+01	1.17E+00	-1.24E+01	1.17E+00	-1.24E+01	1.17E+00	-1.24E+01	1.17E+00
matestf	'param_init_bounded_vector'	-15	0	4	-1.09E+01	1.27E+00	-1.09E+01	1.27E+00	-1.09E+01	1.27E+00	-1.09E+01	1.27E+00
matestf	'param_init_bounded_vector'	-15	0	5	-9.32E+00	1.13E+00	-9.32E+00	1.13E+00	-9.33E+00	1.12E+00	-9.34E+00	1.12E+00
matestf	'param_init_bounded_vector'	-15	0	6	-7.53E+00	8.34E-01	-7.53E+00	8.34E-01	-7.55E+00	8.33E-01	-7.56E+00	8.32E-01
matestf	'param_init_bounded_vector'	-15	0	7	-5.54E+00	4.99E-01	-5.54E+00	4.99E-01	-5.56E+00	4.99E-01	-5.57E+00	4.99E-01
matestf	'param_init_bounded_vector'	-15	0	8	-3.45E+00	2.24E-01	-3.45E+00	2.24E-01	-3.46E+00	2.24E-01	-3.47E+00	2.25E-01
matestf	'param_init_bounded_vector'	-15	0	9	-1.83E+00	1.01E-01	-1.83E+00	1.01E-01	-1.84E+00	1.01E-01	-1.85E+00	1.01E-01
matestf	'param_init_bounded_vector'	-15	0	10	-8.58E-01	5.76E-02	-8.58E-01	5.76E-02	-8.67E-01	5.80E-02	-8.74E-01	5.83E-02
matestf	'param_init_bounded_vector'	-15	0	11	-5.17E-01	4.13E-02	-5.17E-01	4.13E-02	-5.24E-01	4.15E-02	-5.28E-01	4.16E-02
matestf	'param_init_bounded_vector'	-15	0	12	-3.85E-01	4.07E-02	-3.85E-01	4.07E-02	-3.90E-01	4.08E-02	-3.94E-01	4.08E-02
matestf	'param_init_bounded_vector'	-15	0	13	-1.43E-01	3.65E-02	-1.43E-01	3.65E-02	-1.44E-01	3.69E-02	-1.45E-01	3.73E-02
matestf	'param_init_bounded_vector'	-15	0	14	-2.61E-09	1.01E-05	-2.63E-09	1.02E-05	-2.34E-09	9.08E-06	-2.25E-09	8.70E-06
matestf	'param_init_bounded_vector'	-15	0	15	-6.13E-03	1.10E-02	-6.28E-03	1.11E-02	-5.57E-03	1.05E-02	-5.23E-03	1.02E-02
matestf	'param_init_bounded_vector'	-15	0	16	-4.17E-04	8.20E-03	-2.72E-04	8.20E-03	-4.76E-04	7.91E-03	-5.77E-04	7.70E-03
matestm	'param_init_bounded_vector'	-15	0	1	-1.50E+01	6.41E-03	-1.50E+01	6.41E-03	-1.50E+01	6.42E-03	-1.50E+01	6.43E-03
matestm	'param_init_bounded_vector'	-15	0	2	-1.39E+01	1.10E+00	-1.39E+01	1.10E+00	-1.39E+01	1.10E+00	-1.39E+01	1.10E+00
matestm	'param_init_bounded_vector'	-15	0	3	-1.27E+01	1.65E+00	-1.27E+01	1.65E+00	-1.27E+01	1.65E+00	-1.27E+01	1.65E+00
matestm	'param_init_bounded_vector'	-15	0	4	-1.15E+01	1.78E+00	-1.15E+01	1.78E+00	-1.15E+01	1.79E+00	-1.15E+01	1.79E+00
matestm	'param_init_bounded_vector'	-15	0	5	-1.02E+01	1.59E+00	-1.02E+01	1.59E+00	-1.02E+01	1.60E+00	-1.01E+01	1.60E+00
matestm	'param_init_bounded_vector'	-15	0	6	-8.67E+00	1.22E+00	-8.67E+00	1.22E+00	-8.65E+00	1.22E+00	-8.63E+00	1.22E+00
matestm	'param_init_bounded_vector'	-15	0	7	-7.02E+00	8.34E-01	-7.02E+00	8.34E-01	-6.99E+00	8.32E-01	-6.96E+00	8.30E-01
matestm	'param_init_bounded_vector'	-15	0	8	-5.34E+00	6.00E-01	-5.34E+00	6.00E-01	-5.30E+00	5.94E-01	-5.27E+00	5.91E-01
matestm	'param_init_bounded_vector'	-15	0	9	-4.44E+00	3.49E-01	-4.44E+00	3.49E-01	-4.39E+00	3.45E-01	-4.35E+00	3.44E-01
matestm	'param_init_bounded_vector'	-15	0	10	-3.85E+00	2.53E-01	-3.85E+00	2.53E-01	-3.79E+00	2.51E-01	-3.75E+00	2.50E-01
matestm	'param_init_bounded_vector'	-15	0	11	-3.28E+00	1.94E-01	-3.28E+00	1.94E-01	-3.24E+00	1.93E-01	-3.21E+00	1.93E-01
matestm	'param_init_bounded_vector'	-15	0	12	-2.78E+00	1.53E-01	-2.78E+00	1.53E-01	-2.76E+00	1.53E-01	-2.74E+00	1.52E-01
matestm	'param_init_bounded_vector'	-15	0	13	-2.32E+00	1.26E-01	-2.32E+00	1.26E-01	-2.30E+00	1.25E-01	-2.29E+00	1.25E-01
matestm	'param_init_bounded_vector'	-15	0	14	-1.80E+00	1.01E-01	-1.80E+00	1.01E-01	-1.78E+00	9.98E-02	-1.77E+00	9.95E-02
matestm	'param_init_bounded_vector'	-15	0	15	-1.44E+00	8.41E-02	-1.44E+00	8.41E-02	-1.42E+00	8.31E-02	-1.41E+00	8.28E-02
matestm	'param_init_bounded_vector'	-15	0	16	-1.18E+00	7.44E-02	-1.18E+00	7.44E-02	-1.18E+00	7.35E-02	-1.19E+00	7.35E-02
matestm	'param_init_bounded_vector'	-15	0	17	-9.86E-01	6.60E-02	-9.86E-01	6.60E-02	-1.03E+00	6.64E-02	-1.05E+00	6.68E-02
matestm	'param_init_bounded_vector'	-15	0	18	-7.36E-01	5.66E-02	-7.36E-01	5.66E-02	-7.84E-01	5.82E-02	-8.11E-01	5.92E-02
matestm	'param_init_bounded_vector'	-15	0	19	-5.12E-01	5.14E-02	-5.12E-01	5.14E-02	-5.41E-01	5.34E-02	-5.57E-01	5.46E-02
matestm	'param_init_bounded_vector'	-15	0	20	-2.55E-01	4.34E-02	-2.55E-01	4.34E-02	-2.66E-01	4.47E-02	-2.74E-01	4.56E-02
matestm	'param_init_bounded_vector'	-15	0	21	-9.47E-02	2.88E-02	-9.47E-02	2.88E-02	-9.67E-02	2.92E-02	-9.91E-02	2.97E-02
matestm	'param_init_bounded_vector'	-15	0	22	-6.02E-09	2.25E-05	-6.01E-09	2.24E-05	-6.28E-09	2.35E-05	-7.42E-09	2.75E-05
matestm	'param_init_bounded_vector'	-15	0	23	-2.23E-09	8.56E-06	-2.23E-09	8.56E-06	-2.53E-09	9.69E-06	-2.87E-09	1.10E-05
matestm	'param_init_bounded_vector'	-15	0	24	-1.15E-09	4.47E-06	-1.15E-09	4.46E-06	-1.02E-09	4.02E-06	-9.57E-10	3.98E-06
matestm	'param_init_bounded_vector'	-15	0	25	-1.82E-09	7.02E-06	-1.82E-09	7.02E-06	-1.55E-09	6.00E-06	-1.43E-09	5.53E-06
matestm	'param_init_bounded_vector'	-15	0	26	-1.74E-09	6.71E-06	-1.74E-09	6.72E-06	-1.62E-09	6.26E-06	-1.57E-09	6.08E-06
matestm	'param_init_bounded_vector'	-15	0	27	-2.25E-09	8.71E-06	-2.25E-09	8.71E-06	-2.20E-09	8.49E-06	-2.19E-09	8.46E-06
matestm	'param_init_bounded_vector'	-15	0	28	-3.48E-09	1.35E-05	-3.48E-09	1.34E-05	-3.47E-09	1.34E-05	-3.49E-09	1.35E-05
matestm	'param_init_bounded_vector'	-15	0	29	-8.30E-09	3.21E-05	-8.30E-09	3.21E-05	-8.22E-09	3.18E-05	-8.24E-09	3.19E-05
matestm	'param_init_bounded_vector'	-15	0	30	-3.76E-08	1.45E-04	-3.76E-08	1.45E-04	-3.84E-08	1.49E-04	-3.94E-08	1.52E-04
matestm	'param_init_bounded_vector'	-15	0	31	-5.05E-02	2.80E-01	-5.05E-02	2.80E-01	-5.11E-02	2.82E-01	-5.09E-02	2.83E-01
matestm	'param_init_bounded_vector'	-15	0	32	-1.04E-01	1.16E+00	-1.04E-01	1.16E+00	-1.04E-01	1.16E+00	-1.04E-01	1.16E+00
srv2_femQ	'param_init_bounded_number'	0.5	1.001	1	6.65E-01	3.01E-01	6.62E-01	2.98E-01	6.10E-01	2.17E-01	5.83E-01	1.83E-01
srv2_seldiff_f	'param_init_bounded_number'	0	100	1	6.28E+01	3.13E+01	6.26E+01	3.12E+01	5.60E+01	2.96E+01	5.24E+01	2.88E+01
srv2_sel50_f	'param_init_bounded_number'	-200	100.01	1	6.38E+01	2.38E+01	6.36E+01	2.36E+01	5.76E+01	1.83E+01	5.47E+01	1.59E+01
srv3_femQ	'param_init_bounded_number'	0.2	1	1	5.22E-01	3.83E-02	5.21E-01	3.83E-02	5.60E-01	3.89E-02	5.75E-01	3.93E-02
srv3_seldiff_f	'param_init_bounded_number'	0	100	1	1.00E+02	6.88E-04	1.00E+02	6.89E-04	1.00E+02	8.03E-04	1.00E+02	8.69E-04
srv3_sel50_f	'param_init_bounded_number'	-50	69	1	-6.39E-01	1.49E+01	-6.94E-01	1.49E+01	-4.11E+00	1.55E+01	-6.16E+00	1.59E+01

Table A6.4. Comparison of estimated male recruitment (in millions) from the model scenarios.

year	Alt1a	Alt4a	Alt4b	Alt4c	2013 Model
1949	32.5	32.4	31.1	30.9	29.0
1950	32.5	32.5	31.2	31.0	29.1
1951	32.8	32.8	31.4	31.2	29.3
1952	33.2	33.1	31.7	31.5	29.7
1953	33.8	33.8	32.3	32.1	30.3
1954	34.8	34.8	33.2	33.0	31.2
1955	36.4	36.4	34.7	34.3	32.6
1956	38.8	38.8	36.9	36.5	34.8
1957	42.7	42.6	40.5	40.0	38.4
1958	49.1	49.1	46.4	45.8	44.3
1959	60.7	60.7	57.2	56.2	55.0
1960	84.9	84.8	79.6	78.1	77.4
1961	146.8	146.7	137.0	134.0	135.5
1962	324.0	323.9	301.5	294.6	302.0
1963	696.8	696.6	650.7	635.6	650.7
1964	961.4	961.1	903.8	883.4	915.3
1965	897.4	897.1	849.9	832.7	888.2
1966	732.3	732.1	698.8	687.3	752.6
1967	626.0	625.8	603.8	598.0	656.8
1968	592.4	592.3	580.6	580.7	615.8
1969	599.9	600.1	598.3	604.4	592.0
1970	500.3	500.4	498.9	502.4	448.7
1971	333.9	333.8	325.1	323.0	295.8
1972	282.5	282.4	271.3	267.4	269.7
1973	231.2	231.1	220.4	216.3	244.7
1974	64.4	64.4	61.1	59.8	23.3
1975	218.0	217.9	210.1	207.1	208.5
1976	494.6	494.5	459.7	445.1	403.6
1977	304.3	304.3	280.2	269.5	295.1
1978	258.3	258.2	238.7	230.5	260.5
1979	63.3	63.3	59.1	57.3	69.5
1980	24.5	24.5	22.7	22.0	14.8
1981	57.8	57.8	53.5	51.9	52.4
1982	28.7	28.7	26.3	25.3	21.0
1983	205.3	205.2	186.5	179.1	196.4
1984	168.8	168.8	152.3	145.8	165.7
1985	327.5	327.5	289.2	272.0	357.6
1986	274.5	274.4	241.8	227.4	283.3
1987	258.1	258.0	219.1	202.1	274.6
1988	231.3	231.3	194.2	178.0	199.8
1989	101.5	101.5	86.2	79.4	110.6
1990	45.0	45.0	38.9	36.1	47.3
1991	21.0	21.0	18.2	17.0	23.6
1992	17.8	17.8	15.9	15.1	18.5
1993	14.8	14.8	13.3	12.8	15.3
1994	16.9	16.9	15.3	14.7	14.8
1995	24.6	24.6	22.5	21.8	21.0
1996	23.8	23.8	22.0	21.4	23.6
1997	64.2	64.2	59.9	58.5	60.9
1998	25.4	25.4	23.6	23.0	25.8
1999	79.2	79.2	73.6	71.9	79.7
2000	48.2	48.2	44.5	43.3	46.5
2001	148.9	148.9	138.1	134.7	144.5
2002	61.7	61.7	56.9	55.3	55.9
2003	110.5	110.5	101.4	98.4	99.4
2004	201.2	201.2	185.7	180.4	198.9
2005	61.8	61.8	57.1	55.4	58.5
2006	51.3	51.3	47.3	45.9	47.8
2007	36.3	36.3	33.2	32.1	37.3
2008	42.0	42.0	38.2	36.8	41.5
2009	224.3	224.2	205.2	198.6	200.1
2010	237.1	237.1	216.0	207.8	238.4
2011	119.5	119.5	108.1	103.5	128.2
2012	24.2	24.2	21.9	20.9	33.8
2013	65.6	65.5	58.7	56.0	120.6
2014	99.8	99.8	88.9	84.5	

Table A6.5. Comparison of time series of estimated mature male biomass (1000's t) at mating from the four alternative 2014 models and the 2013 model.

year	Alt1a	Alt4a	Alt4b	Alt4c	2013 Model
1949	0.0	0.0	0.0	0.0	0.0
1950	0.0	0.0	0.0	0.0	0.0
1951	0.2	0.2	0.2	0.2	0.1
1952	1.3	1.3	1.2	1.2	1.1
1953	4.8	4.8	4.6	4.5	4.1
1954	9.2	9.2	8.8	8.7	8.1
1955	12.7	12.7	12.1	12.0	11.3
1956	15.4	15.4	14.6	14.4	13.7
1957	17.4	17.4	16.5	16.3	15.6
1958	19.1	19.1	18.1	17.8	17.2
1959	20.6	20.6	19.5	19.1	18.6
1960	22.2	22.2	20.9	20.5	20.0
1961	24.0	24.0	22.6	22.1	21.8
1962	26.6	26.6	25.0	24.5	24.2
1963	31.0	31.0	29.0	28.3	28.1
1964	39.7	39.7	37.1	36.1	36.1
1965	57.9	57.9	53.9	52.3	52.8
1966	102.1	102.1	94.8	92.0	93.3
1967	163.8	163.8	152.0	147.3	153.2
1968	242.9	242.8	225.9	219.2	233.8
1969	293.7	293.6	273.7	265.7	293.7
1970	317.3	317.2	296.5	288.0	328.8
1971	325.1	325.0	305.1	297.1	345.5
1972	328.2	328.1	310.4	303.4	352.5
1973	327.9	327.8	312.9	307.4	349.8
1974	304.7	304.7	292.5	288.3	321.2
1975	268.3	268.3	257.8	254.1	279.9
1976	203.8	203.8	195.3	192.1	216.6
1977	128.9	128.9	123.0	120.7	146.9
1978	82.9	82.9	79.2	77.8	100.4
1979	51.6	51.6	49.3	48.4	66.8
1980	35.8	35.7	34.5	34.2	44.1

year	Alt1a	Alt4a	Alt4b	Alt4c	2013 Model
1981	46.3669	46.3634	44.6	44.2	48.7
1982	51.35	51.3488	48.7	47.8	49.9
1983	43.0717	43.0712	40.3	39.3	40.2
1984	26.8963	26.8969	24.9	24.2	23.7
1985	25.4961	25.4963	23.8	23.2	21.7
1986	31.4177	31.4163	29.6	28.9	26.9
1987	45.4631	45.459	43.0	42.1	40.1
1988	63.1999	63.1925	59.7	58.3	59.0
1989	69.928	69.921	65.7	63.9	70.6
1990	59.6715	59.6652	56.0	54.5	66.7
1991	55.3995	55.3959	51.1	49.3	61.2
1992	46.9513	46.9508	43.5	42.4	48.0
1993	40.4347	40.435	38.1	37.6	39.2
1994	32.1013	32.1016	30.6	30.4	31.6
1995	23.4536	23.4542	22.7	22.8	23.5
1996	18.7306	18.7315	17.8	17.8	19.1
1997	15.813	15.8141	15.0	14.8	16.4
1998	14.1873	14.1885	13.4	13.3	14.5
1999	14.5719	14.5733	13.7	13.4	14.3
2000	16.67	16.672	15.5	15.1	16.0
2001	20.5581	20.5609	19.1	18.5	19.6
2002	24.5217	24.5246	22.7	22.0	23.6
2003	29.9425	29.9456	27.7	26.8	28.9
2004	37.5103	37.5133	34.6	33.5	36.1
2005	47.2549	47.2572	43.6	42.2	44.9
2006	53.9743	53.9745	49.9	48.4	50.9
2007	60.8287	60.8276	56.3	54.6	56.4
2008	72.9207	72.9182	67.3	65.1	67.6
2009	76.2319	76.2272	70.2	67.9	71.6
2010	70.0496	70.0444	64.4	62.1	65.9
2011	62.9475	62.9421	57.8	55.7	59.3
2012	63.5694	63.5636	58.2	56.0	59.4
2013	79.4674	79.4609	72.7	69.8	

Table A6.6. Comparison of time series of observed and estimated numbers of male crab ≥ 138 mmCW (millions) in the survey from the four alternative 2014 models and the 2013 model.

year	Observed	2014 Model Cases Alt1a	Alt4a	Alt4b	Alt4c	2013 Model
1949		0.00	0.00	0.00	0.00	0.00
1950		0.00	0.00	0.00	0.00	0.00
1951		0.00	0.00	0.00	0.00	0.00
1952		0.09	0.09	0.09	0.09	0.07
1953		0.77	0.77	0.80	0.82	0.63
1954		2.04	2.04	2.11	2.16	1.74
1955		3.08	3.08	3.17	3.24	2.66
1956		3.85	3.85	3.95	4.02	3.34
1957		4.43	4.43	4.53	4.61	3.86
1958		4.89	4.89	4.99	5.07	4.27
1959		5.28	5.28	5.38	5.46	4.63
1960		5.67	5.67	5.76	5.83	4.97
1961		6.10	6.10	6.19	6.26	5.36
1962		6.67	6.67	6.75	6.81	5.86
1963		7.54	7.54	7.61	7.67	6.62
1964		9.10	9.10	9.17	9.23	8.00
1965		12.52	12.52	12.59	12.65	11.00
1966		20.29	20.29	20.36	20.44	17.83
1967		38.14	38.14	38.29	38.42	33.72
1968		59.23	59.23	59.50	59.71	53.74
1969		79.02	79.01	79.41	79.68	73.82
1970		85.33	85.31	85.74	86.02	82.52
1971		85.41	85.39	85.99	86.35	85.17
1972		84.49	84.47	85.55	86.19	85.92
1973		84.55	84.54	86.45	87.59	86.17
1974	90.82	83.33	83.34	85.95	87.49	83.64
1975	153.74	74.25	74.26	76.72	78.14	73.24
1976	89.16	62.60	62.60	64.48	65.51	61.01
1977	69.32	44.89	44.90	46.00	46.59	44.20
1978	40.09	24.46	24.46	24.83	25.05	24.73
1979	22.39	15.30	15.30	15.53	15.67	14.88
1980	29.96	13.96	13.96	14.36	14.56	13.69
1981	10.83	14.07	14.07	14.65	14.99	14.3352
1982	7.75	22.59	22.58	23.70	24.22	23.5424
1983	5.01	20.95	20.95	21.60	21.90	21.4726
1984	6.60	14.34	14.34	14.56	14.66	14.0037
1985	3.71	9.11	9.11	9.18	9.21	8.088
1986	2.44	10.16	10.16	10.34	10.40	8.99951
1987	6.47	14.26	14.26	14.64	14.76	12.7366
1988	16.37	21.16	21.15	21.79	22.02	19.7785
1989	34.04	28.32	28.32	28.96	29.10	27.9265
1990	44.52	30.39	30.39	30.83	30.81	31.9349
1991	36.30	24.12	24.12	24.22	24.06	26.8509
1992	42.44	21.47	21.47	20.95	20.52	23.1869
1993	20.28	15.44	15.44	14.89	14.56	15.5813
1994	15.91	11.40	11.40	10.96	10.73	11.2771
1995	10.17	8.27	8.27	7.94	7.79	8.36462
1996	9.27	5.99	5.99	5.84	5.77	6.17713
1997	3.45	5.04	5.04	4.87	4.81	5.12244
1998	2.16	4.52	4.52	4.39	4.33	4.65216
1999	2.08	4.46	4.46	4.40	4.36	4.46927
2000	4.71	4.99	4.99	4.96	4.94	4.88238
2001	5.98	6.35	6.35	6.37	6.38	6.19705
2002	6.07	7.78	7.79	7.84	7.87	7.71162
2003	6.61	9.21	9.21	9.31	9.36	9.21249
2004	4.77	11.54	11.55	11.69	11.76	11.6134
2005	11.21	14.92	14.92	15.13	15.22	14.8417
2006	14.42	18.28	18.28	18.52	18.64	18.1377
2007	11.97	19.67	19.67	19.94	20.06	19.1568
2008	13.14	23.75	23.75	24.15	24.33	22.9342
2009	7.97	26.75	26.75	27.08	27.22	26.2613
2010	9.40	24.74	24.74	24.92	24.98	24.3725
2011	15.74	22.20	22.20	22.29	22.28	21.9077
2012	8.17	20.42	20.42	20.48	20.43	20.134
2013	9.02	24.14	24.14	24.26	24.20	23.1692
2014	19.55	32.56	32.56	32.73	32.68	

Table A6.7. Estimated population size (thousands) for females on July 1 from Alt4b.

year	Size bin 27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5	147.5	152.5	157.5	162.5	167.5	172.5	177.5	182.5
1949	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1950	4.78E+03	1.14E+04	1.12E+04	1.06E+04	7.80E+03	4.79E+03	2.60E+03	1.29E+03	6.02E+02	2.65E+02	1.12E+02	4.54E+01	1.79E+01	6.87E+00	2.57E+00	9.43E-01	3.39E-01	1.20E-01	4.16E-02	1.42E-02	4.80E-03	1.60E-03	5.23E-04	1.69E-04	5.41E-05	1.71E-05	5.38E-06	1.68E-06	5.18E-07	1.59E-07	4.94E-08	1.89E-08
1951	4.81E+03	1.15E+04	1.13E+04	1.10E+04	9.50E+03	8.14E+03	6.63E+03	4.84E+03	3.19E+03	1.92E+03	1.03E+03	4.89E+02	2.00E+02	7.22E+01	2.49E+01	7.82E+00	1.91E+00	3.74E-01	8.58E-02	2.54E-02	8.16E-03	2.67E-03	8.70E-04	2.81E-04	8.97E-05	2.84E-05	8.89E-06	2.77E-06	8.54E-07	2.62E-07	8.13E-08	3.12E-08
1952	4.86E+03	1.16E+04	1.14E+04	1.11E+04	9.59E+03	8.38E+03	7.38E+03	6.49E+03	5.86E+03	5.07E+03	3.74E+03	2.30E+03	1.18E+03	5.17E+02	2.08E+02	6.98E+01	1.59E+01	2.22E+00	2.64E-01	4.59E-02	1.14E-02	3.46E-03	1.11E-03	3.57E-04	1.14E-04	3.59E-05	1.12E-05	3.49E-06	1.08E-06	3.30E-07	1.03E-07	3.94E-08
1953	4.95E+03	1.18E+04	1.16E+04	1.13E+04	9.70E+03	8.47E+03	7.46E+03	6.70E+03	6.63E+03	6.83E+03	6.02E+03	4.49E+03	2.91E+03	1.62E+03	8.12E+02	3.22E+02	8.07E+01	1.14E+01	1.21E+00	1.49E-01	2.15E-02	4.46E-03	1.29E-03	4.10E-04	1.30E-04	4.10E-05	1.28E-05	3.98E-06	1.23E-06	3.76E-07	1.17E-07	4.49E-08
1954	5.10E+03	1.21E+04	1.19E+04	1.15E+04	9.89E+03	8.61E+03	7.57E+03	6.86E+03	7.08E+03	7.90E+03	7.44E+03	5.92E+03	4.27E+03	2.69E+03	1.52E+03	6.75E+02	1.84E+02	2.76E+01	3.33E+00	4.43E-01	5.09E-02	6.56E-03	1.48E-03	4.51E-04	1.43E-04	4.49E-05	1.40E-05	4.36E-06	1.35E-06	4.13E-07	1.28E-07	4.93E-08
1955	5.31E+03	1.26E+04	1.23E+04	1.19E+04	1.02E+04	8.83E+03	7.75E+03	7.04E+03	7.46E+03	8.71E+03	8.48E+03	6.93E+03	5.24E+03	3.48E+03	2.05E+03	9.50E+02	2.68E+02	4.12E+01	5.41E+00	7.72E-01	8.56E-02	9.00E-03	1.67E-03	4.84E-04	1.52E-04	4.80E-05	1.50E-05	4.67E-06	1.44E-06	4.42E-07	1.37E-07	5.28E-08
1956	5.66E+03	1.34E+04	1.31E+04	1.25E+04	1.06E+04	9.18E+03	8.01E+03	7.28E+03	7.82E+03	9.37E+03	9.29E+03	7.71E+03	5.96E+03	4.05E+03	2.44E+03	1.15E+03	3.28E+02	5.11E+01	6.93E+00	1.01E+00	1.11E-01	1.09E-02	1.82E-03	5.14E-04	1.62E-04	5.09E-05	1.59E-05	4.94E-06	1.52E-06	4.68E-07	1.45E-07	5.59E-08
1957	6.20E+03	1.47E+04	1.42E+04	1.35E+04	1.14E+04	9.72E+03	8.42E+03	7.62E+03	8.22E+03	9.98E+03	9.98E+03	8.35E+03	6.54E+03	4.50E+03	2.73E+03	1.30E+03	3.73E+02	5.83E+01	8.03E+00	1.19E+00	1.30E-01	1.22E-02	1.96E-03	5.47E-04	1.71E-04	5.40E-05	1.69E-05	5.25E-06	1.62E-06	4.97E-07	1.54E-07	5.94E-08
1958	7.12E+03	1.68E+04	1.61E+04	1.51E+04	1.25E+04	1.06E+04	9.07E+03	8.14E+03	8.74E+03	1.06E+04	1.06E+04	8.93E+03	7.03E+03	4.87E+03	2.97E+03	1.42E+03	4.08E+02	6.39E+01	8.86E+00	1.32E+00	1.44E-01	1.34E-02	2.12E-03	5.88E-04	1.84E-04	5.80E-05	1.81E-05	5.64E-06	1.74E-06	5.34E-07	1.66E-07	6.39E-08
1959	8.77E+03	2.07E+04	1.95E+04	1.78E+04	1.45E+04	1.20E+04	1.01E+04	8.95E+03	9.48E+03	1.14E+04	1.14E+04	9.54E+03	7.51E+03	5.21E+03	3.18E+03	1.52E+03	4.38E+02	6.87E+01	9.55E+00	1.42E+00	1.56E-01	1.46E-02	2.33E-03	6.48E-04	2.03E-04	6.40E-05	2.00E-05	6.22E-06	1.92E-06	5.89E-07	1.83E-07	7.05E-08
1960	1.22E+04	2.86E+04	2.64E+04	2.32E+04	1.83E+04	1.47E+04	1.20E+04	1.03E+04	1.06E+04	1.25E+04	1.24E+04	1.03E+04	8.07E+03	5.59E+03	3.41E+03	1.63E+03	4.68E+02	7.33E+01	1.02E+01	1.52E+00	1.67E-01	1.61E-02	2.66E-03	7.47E-04	2.35E-04	7.39E-05	2.31E-05	7.19E-06	2.22E-06	6.81E-07	2.12E-07	8.15E-08
1961	2.10E+04	4.88E+04	4.34E+04	3.58E+04	2.67E+04	2.02E+04	1.58E+04	1.30E+04	1.27E+04	1.43E+04	1.39E+04	1.14E+04	8.83E+03	6.06E+03	3.68E+03	1.75E+03	5.03E+02	7.88E+01	1.10E+01	1.64E+00	1.82E-01	1.85E-02	3.27E-03	9.37E-04	2.95E-04	9.30E-05	2.91E-05	9.05E-06	2.79E-06	8.58E-07	2.67E-07	1.03E-07
1962	4.62E+04	1.07E+05	9.16E+04	7.04E+04	4.91E+04	3.44E+04	2.49E+04	1.90E+04	1.70E+04	1.78E+04	1.65E+04	1.32E+04	1.00E+04	6.78E+03	4.08E+03	1.93E+03	5.52E+02	8.63E+01	1.20E+01	1.80E+00	2.07E-01	2.35E-02	4.67E-03	1.38E-03	4.36E-04	1.38E-04	4.31E-05	1.34E-05	4.14E-06	1.27E-06	3.96E-07	1.52E-07
1963	9.97E+04	2.30E+05	1.98E+05	1.53E+05	1.05E+05	7.09E+04	4.85E+04	3.43E+04	2.75E+04	2.56E+04	2.21E+04	1.69E+04	1.23E+04	8.06E+03	4.75E+03	2.22E+03	6.31E+02	9.86E+01	1.37E+01	2.09E+00	2.59E-01	3.59E-02	8.42E-03	2.58E-03	8.18E-04	2.59E-04	8.11E-05	2.52E-05	7.80E-06	2.39E-06	7.45E-07	2.86E-07
1964	1.39E+05	3.25E+05	2.99E+05	2.60E+05	1.95E+05	1.40E+05	9.93E+04	7.04E+04	5.35E+04	4.49E+04	3.57E+04	2.55E+04	1.73E+04	1.08E+04	6.11E+03	2.79E+03	7.83E+02	1.22E+02	1.69E+01	2.64E+00	3.67E-01	6.31E-02	1.68E-02	5.26E-03	1.67E-03	5.29E-04	1.66E-04	5.17E-05	1.60E-05	4.91E-06	1.53E-06	5.87E-07
1965	1.30E+05	3.12E+05	3.11E+05	3.08E+05	2.58E+05	2.10E+05	1.66E+05	1.29E+05	1.03E+05	8.65E+04	6.69E+04	4.61E+04	2.94E+04	1.72E+04	9.30E+03	4.09E+03	1.12E+03	1.72E+02	2.32E+01	3.59E+00	5.20E-01	9.67E-02	2.66E-02	8.39E-03	2.67E-03	8.45E-04	2.65E-04	8.25E-05	2.55E-05	7.84E-06	2.44E-06	9.38E-07
1966	1.07E+05	2.58E+05	2.67E+05	2.80E+05	2.52E+05	2.28E+05	2.02E+05	1.74E+05	1.58E+05	1.47E+05	1.20E+05	8.52E+04	5.45E+04	3.13E+04	1.66E+04	7.12E+03	1.91E+03	2.87E+02	3.63E+01	5.24E+00	7.03E-01	1.19E-01	3.12E-02	9.71E-03	3.07E-03	9.65E-04	3.02E-04	9.37E-05	2.89E-05	8.87E-06	2.76E-06	1.06E-06
1967	9.25E+04	2.23E+05	2.28E+05	2.36E+05	2.16E+05	2.02E+05	1.89E+05	1.78E+05	1.83E+05	1.95E+05	1.75E+05	1.33E+05	9.11E+04	5.49E+04	2.99E+04	1.30E+04	3.51E+03	5.24E+02	6.45E+01	8.83E+00	1.05E+00	1.42E-01	3.28E-02	9.95E-03	3.14E-03	9.84E-04	3.07E-04	9.53E-05	2.94E-05	9.02E-06	2.80E-06	1.08E-06
1968	8.90E+04	2.13E+05	2.12E+05	2.11E+05	1.88E+05	1.73E+05	1.61E+05	1.57E+05	1.76E+05	2.12E+05	2.07E+05	1.68E+05	1.24E+05	8.00E+04	4.58E+04	2.06E+04	5.67E+03	8.51E+02	1.06E+02	1.44E+01	1.55E+00	1.60E-01	2.90E-02	8.22E-03	2.54E-03	7.87E-04	2.43E-04	7.51E-05	2.31E-05	7.07E-06	2.20E-06	8.44E-07
1969	9.17E+04	2.18E+05	2.14E+05	2.08E+05	1.80E+05	1.59E+05	1.44E+05	1.38E+05	1.62E+05	2.08E+05	2.14E+05	1.82E+05	1.42E+05	9.67E+04	5.79E+04	2.70E+04	7.59E+03	1.15E+03	1.50E+02	2.10E+01	2.20E+00	1.95E-01	2.84E-02	7.51E-03	2.29E-03	7.05E-04	2.17E-04	6.69E-05	2.05E-05	6.28E-06	1.95E-06	7.49E-07
1970	7.65E+04	1.84E+05	1.90E+05	1.97E+05	1.75E+05	1.56E+05	1.39E+05	1.31E+05	1.53E+05	2.01E+05	2.11E+05	1.82E+05	1.47E+05	1.03E+05	6.33E+04	3.01E+04	8.55E+03	1.31E+03	1.75E+02	2.51E+01	2.60E+00	2.16E-01	2.79E-02	7.00E-03	2.11E-03	6.47E-04	1.98E-04	6.09E-05	1.87E-05	5.71E-06	1.77E-06	6.81E-07
1971	4.98E+04	1.22E+05	1.35E+05	1.54E+05	1.47E+05	1.40E+05	1.32E+05	1.27E+05	1.50E+05	1.98E+05	2.07E+05	1.79E+05	1.46E+05	1.04E+05	6.42E+04	3.08E+04	8.78E+03	1.35E+03	1.83E+02	2.64E+01	2.73E+00	2.19E-01	2.65E-02	6.46E-03	1.94E-03	5.94E-04	1.82E-04	5.59E-05	1.71E-05	5.24E-06	1.63E-06	6.25E-07
1972	4.16E+04	1.00E+05	1.04E+05	1.10E+05	1.05E+05	1.06E+05	1.06E+05	1.10E+05	1.39E+05	1.91E+05	2.03E+05	1.76E+05	1.44E+05	1.03E+05	6.36E+04	3.05E+04	8.71E+03	1.34E+03	1.82E+02	2.63E+01	2.70E+00	2.09E-01	2.34E-02	5.51E-03	1.65E-03	5.05E-04	1.55E-04	4.76E-05	1.46E-05	4.46E-06	1.39E-06	5.32E-07
1973	3.38E+04	8.16E+04	8.47E+04	8.96E+04	8.27E+04	7.86E+04	7.68E+04	8.27E+04	1.15E+05	1.72E+05	1.89E+05	1.68E+05	1.40E+05	1.00E+05	6.26E+04	3.01E+04	8.60E+03	1.32E+03	1.80E+02	2.60E+01	2.65E+00	2.00E-01	2.10E-02	4.81E-03	1.44E-03	4.41E-04	1.36E-04	4.17E-05	1.28E-05	3.91E-06	1.22E-06	4.67E-07
1974	9.36E+03	2.56E+04	3.85E+04	5.65E+04	5.99E+04	6.09E+04	6.03E+04	6.43E+04	9.21E+04	1.45E+05	1.65E+05	1.50E+05	1.28E+05	9.40E+04	5.94E+04	2.89E+04	8.30E+03	1.28E+03	1.76E+02	2.56E+01	2.61E+00	1.93E-01	1.90E-02	4.20E-03	1.25E-03	3.86E-04	1.19E-04	3.66E-05	1.12E-05	3.44E-06	1.07E-06	4.10E-07
1975	3.22E+04	7.36E+04	6.06E+04	4.44E+04	3.68E+04	3.87E+04	4.21E+04	4.89E+04	7.50E+04	1.22E+05	1.40E+05	1.28E+05	1.11E+05	8.29E+04	5.29E+04	2.60E+04	7.51E+03	1.16E+03	1.62E+02	2.37E+01	2.40E+00	1.70E-01	1.46E-02	2.93E-03	8.58E-04	2.63E-04	8.09E-05	2.48E-05	7.61E-06	2.32E-06	7.21E-07	2.77E-07
1976	7.05E+04	1.63E+05	1.40E+05	1.07E+05	7.20E+04	4.70E+04	3.39E+04	3.39E+04	5.62E+04	9.89E+04	1.17E+05	1.09E+05	9.53E+04	7.17E+04	4.59E+04	2.26E+04	6.52E+03	1.01E+03	1.41E+02	2.07E+01	2.09E+00	1.50E-01	1.36E-02	2.86E-03	8.46E-04	2.60E-04	8.01E-05	2.47E-05	7.56E-06	2.31E-06	7.17E-07	2.75E-07
1977	4.29E+04	1.06E+05	1.19E+05	1.34E+05	1.15E+05	8.91E+04	6.58E+04	5.05E+04	5.53E+04	8.26E+04	9.51E+04	8.84E+04	7.89E+04	6.01E+04	3.87E+04	1.90E+04	5.43E+03	8.22E+02	1.12E+02	1.60E+01	1.61E+00	1.25E-01	1.47E-02	3.53E-03	1.05E-03	3.18E-04	9.71E-05	2.97E-05	9.06E-06	2.77E-06	8.57E-07	3.29E-07
1978	3.66E+04	8.81E+04	9.06E+04	9.58E+04	9.25E+04	9.29E+04	8.78E+04	7.85E+04	7.93E+04	9.38E+04	9.40E+04	7.99E+04	6.70E+04	4.96E+04	3.14E+04	1.51E+04	4.20E+03	6.06E+02	7.85E+01	1.06E+01	1.02E+00	7.94E-02	9.75E-03	2.32E-03	6.64E-04	1.95E-04	5.82E-05	1.75E-05	5.30E-06	1.61E-06	4.98E-07	1.91E-07
1979	9.06E+03	2.53E+04	3.99E+04	6.01E+04	6.39E+04	6.51E+04	6.55E+04	6.90E+04	8.44E+04	1.07E+05	1.07E+05	8.85E+04	6.87E+04	4.71E+04	2.82E+04	1.29E+04	3.40E+03	4.62E+02	5.49E+01	6.84E+00	6.33E-01	5.07E-02	6.64E-03	1.58E-03	4.39E-04	1.26E-04	3.66E-05	1.09E-05	3.27E-06	9.88E-07	3.05E-07	1.17E-07
1980	3.48E+03	9.04E+03	1.22E+04	1.83E+04	2.56E+04	3.56E+04	4.25E+04	4.90E+04	6.72E+04	9.69E+04	1.05E+05	9.12E+04	7.28E+04	4.97E+04	2.90E+04	1.27E+04	3.17E+03	4.05E+02	4.24E+01	4.71E+00	4.07E-01	2.65E-02	2.03E-03	3.28E-04	7.90E-05	2.08E-05	5.75E-06	1.65E-06	4.87E-07	1.46E-07	4.47E-08	1.70E-08
1981	8.20E+03	1.89E+04	1.61E+04	1.28E+04	1.10E+04	1.22E+04	1.59E+04	2.44E+04	4.54E+04	7.70E+04	8.85E+04	7.97E+04	6.62E+04	4.67E+04	2.78E+04	1.23E+04	3.09E+03	4.01E+02	4.49E+01	5.60E+00	5.19E-01	3.19E-02	1.53E-03	1.11E-04	1.95E-05	4.72E-06	1.24E-06	3.47E-07	1.00E-07	2.97E-08	9.05E-09	3.37E-09
1982	4.03E+03	1.02E+04	1.22E+04	1.47E+04	1.30E+04	1.04E+04	8.95E+03	1.15E+04	2.55E+04	5.23E+04	6.56E+04	6.26E+04	5.54E+04	4.09E+04	2.53E+04	1.16E+04	3.06E+03	4.26E+02	5.40E+01	7.50E+00	7.35E-01	4.74E-02	2.70E-03	3.24E-04	8.19E-05	2.40E-05	7.19E-06	2.17E-06	6.58E-07	2.00E-07	6.17E-08	2.36E-08
1983	2.86E+04	6.48E+04	5.07E+04	3.19E+04	1.97E+04	1.42E+04	1.16E+04	1.15E+04	1.95E+04	3.76E+04	4.68E+04	4.51E+04	4.15E+04	3.20E+04	2.05E+04	9.82E+03	2.69E+03	3.91E+02	5.35E+01	7.86E+00	7.90E-01	5.15E-02	2.95E-03	3.62E-04	9.46E-05	2.84E-05	8.67E-06	2.65E-06	8.10E-07	2.47E-07	7.65E-08	2.91E-08
1984	2.33E+04	5.63E+04	5.82E+04	5.90E+04	4.60E+04	3.10E+04	2.01E+04	1.52E+04	1.91E+04	3.12E+04	3.67E+04	3.42E+04	3.10E+04	2.39E+04	1.54E+04	7.45E+03	2.07E+03	3.09E+02	4.46E+01	6.87E+00	7.22E-01	5.45E-02	5.50E-03	1.25E-03	3.84E-04	1.21E-04	3.77E-05	1.17E-05	3.62E-06	1.11E-06	3.46E-07	1.33E-07
1985	4.43E+04	1.03E+05	9.01E+04	7.33E+04	5.69E+04	4.73E+04	3.91E+04	3.09E+04	2.80E+04	3.23E+04	3.29E+04	2.87E+04	2.47E+04	1.85E+04	1.17E+04	5.61E+03	1.55E+03	2.30E+02	3.29E+01	5.01E+00	5.33E-01	4.48E-02	5.92E-03	1.53E-03	4.74E-04	1.49E-04	4.63E-05	1.44E-05	4.44E-06	1.36E-06	4.24E-07	1.63E-07
1986	3.71E+04	8.93E+04	9.18E+04	9.37E+04	7.78E+04	6.08E+04	4.78E+04	4.01E+04	3.96E+04	4.35E+04	4.06E+04	3.22E+04	2.46E+04	1.69E+04	1.03E+04	4.80E+03	1.32E+03	1.97E+02	2.79E+01	4.25E+00	4.76E-01	4.94E-02	9.02E-03	2.61E-03	8.26E-04	2.61E-04	8.20E-05	2.56E-05	7.90E-06	2.43E-06	7.57E-07	2.92E-07
1987	3.36E+04	8.05E+04	8.13E+04	8.29E+04	7.48E+04	6.86E+04	6.11E+04	5.26E+04	4.99E+04	5.30E+04	4.94E+04	3.95E+04	2.95E+04	1.94E+04	1.13E+04	5.12E+03	1.39E+03	2.06E+02	2.76E+01	4.04E+00	4.59E-01	5.17E-02	1.04E-02	3.08E-03	9.76E-04	3.09E-04	9.69E-05	3.02E-05	9.33E-06	2.87E-06	8.92E-07	3.43E-07
1988	2.98E+04	7.15E+04	7.26E+04	7.43E+04	6.65E+04	6.08E+04	5.62E+04	5.35E+04	5.75E+04	6.53E+04	6.15E+04	4.86E+04	3.57E+04	2.33E+04	1.36E+04	6.19E+03	1.70E+03	2.55E+02	3.33E+01	4.74E+00	5.23E-01	5.58E-02	1.06E-02	3.09E-03	9.73E-04	3.06E-04	9.58E-05	2.98E-05	9.18E-06	2.82E-06	8.76E-07	3.37E-07
1989	1.32E+04	3.37E+04	4.22E+04	5.40E+04	5.38E+04	5.21E+04	4.93E+04	4.79E+04	5.47E+04	6.78E+04	6.80E+04	5.65E+04	4.31E+04	2.86E+04	1.67E+04	7.65E+03	2.11E+03	3.18E+02	4.13E+01	5.81E+00	6.23E-01	6.01E-02	1.00E-02	2.81E-03	8.77E-04	2.74E-04	8.53E-05	2.64E-05	8.13E-06	2.49E-06	7.74E-07	2.98E-07
1990	5.96E+03	1.52E+04	1.90E+04	2.54E+04	2.92E+04	3.42E+04	3.72E+04	3.97E+04	4.95E+04	6.58E+04	6.84E+04	5.83E+04	4.61E+04	3.17E+04	1.90E+04	8.85E+03	2.46E+03	3.68E+02	4.73E+01	6.50E+00	6.57E-01	5.28E-02	6.54E-03	1.62E-03	4.86E-04	1.49E-04	4.59E-05	1.41E-05	4.32E-06	1.32E-06	4.09E-07	1.57E-07
1991	2.79E+03	7.08E+03	8.76E+03	1.15E+04	1.32E+04	1.59E+04	1.89E+04	2.42E+04	3.76E+04	5.77E+04	6.35E+04	5.58E+04	4.54E+04	3.18E+04	1.93E+04	8.97E+03	2.46E+03	3.59E+02	4.55E+01	6.14E+00	5.92E-01	4.08E-02	3.39E-03	6.44E-04	1.81E-04	5.38E-05	1.62E-05	4.91E-06	1.49E-06	4.54E-07	1.40E-07	5.38E-08
1992	2.44E+03	5.85E+03	5.99E+03	6.39E+03	6.56E+03	7.46E+03	8.80E+03	1.23E+04	2.37E+04	4.33E+04	5.15E+04	4.76E+04	4.07E+04	2.95E+04	1.82E+04	8.50E+03	2.32E+03	3.32E+02	4.17E+01	5.56E+00	5.25E-01	3.35E-02	2.06E-03	2.79E-04	7.17E-05	2.07E-05	6.14E-06	1.84E-06	5.55E-07	1.68E-07	5.19E-08	1.98E-08
1993	2.04E+03	4.92E+03	5.06E+03	5.27E+03	4.81E+03	4.58E+03	4.77E+03	6.79E+03	1.52E+04	3.09E+04	3.82E+04	3.61E+04	3.21E+04	2.39E+04	1.48E+04	6.87E+03	1.81E+03	2.45E+02	2.95E+01	3.82E+00	3.50E-01	2.14E-02	1.08E-03	9.77E-05	2.06E-05	5.47E-06	1.54E-06	4.45E-07	1.32E-07	3.95E-08	1.21E-08	4.60E-09
1994	2.35E+03	5.55E+03	5.31E+03	5.01E+03	4.32E+03	3.92E+03	3.77E+03	4.85E+03	1.08E+04	2.24E+04	2.80E+04	2.67E+04	2.41E+04	1.83E+04	1.14E+04	5.31E+03	1.39E+03	1.88E+02	2.35E+01	3.16E+00	2.96E-01	1.83E-02	9.56E-04	9.49E-05	2.16E-05	6.02E-06	1.74E-06	5.15E-07	1.54E-07	4.65E-08	1.43E-08	5.45E-09
1995	3.45E+03	8.08E+03	7.36E+03	6.36E+03	5.00E+03	4.07E+03	3.55E+03	4.12E+03	8.40E+03	1.69E+04	2.09E+04	1.98E+04	1.79E+04	1.36E+04	8.51E+03	3.95E+03	1.03E+03	1.38E+02	1.76E+01	2.39E+00	2.25E-01	1.42E-02	8.58E-04	1.15E-04	2.99E-05	8.75E-06	2.61E-06	7.86E-07	2.38E-07	7.24E-08	2.24E-08	8.55E-09
1996	3.37E+03	8.04E+03	7.95E+03	7.75E+03	6.41E+03	5.15E+03	4.23E+03	4.20E+03	7.08E+03	1.32E+04	1.60E+04	1.50E+04	1.34E+04	1.01E+04	6.31E+03	2.92E+03	7.59E+02	1.02E+02	1.30E+01	1.77E+00	1.68E-01	1.13E-02	9.03E-04	1.71E-04	4.91E-05	1.49E-05	4.53E-06	1.39E-06	4.23E-07	1.29E-07	4.01E-08	1.54E-08
1997	9.18E+03	2.11E+04	1.77E+04	1.30E+04	9.09E+03	6.85E+03	5.52E+03	5.03E+03	6.86E+03	1.12E+04	1.30E+04	1.19E+04	1.04E+04	7.80E+03	4.84E+03	2.24E+03	5.87E+02	8.00E+01	1.03E+01	1.43E+00	1.39E-01	1.00E-02	1.01E-03	2.30E-04	6.91E-05	2.14E-05	6.61E-06	2.04E-06	6.27E-07	1.92E-07	5.96E-08	2.28E-08
1998	3.61E+03	9.36E+03	1.22E+04	1.56E+04	1.39E+04	1.08E+04	8.05E+03	6.55E+03	7.45E+03	1.05E+04	1.14E+04	9.98E+03	8.44E+03	6.15E+03	3.78E+03	1.75E+03	4.61E+02	6.41E+01	8.40E+00	1.19E+00	1.22E-01	1.09E-02	1.69E-03	4.66E-04	1.46E-04	4.60E-05	1.44E-05	4.47E-06	1.38E-06	4.23E-07	1.31E-07	5.04E-08
1999	1.13E+04	2.59E+04	2.14E+04	1.58E+04	1.23E+04	1.16E+04	1.08E+04	9.66E+03	9.74E+03	1.15E+04	1.13E+04	9.38E+03	7.54E+03	5.32E+03	3.22E+03	1.48E+03	3.96E+02	5.61E+01	7.36E+00	1.04E+00	1.09E-01	9.98E-03	1.59E-03	4.43E-04	1.39E-04	4.38E-05	1.37E-05	4.26E-06	1.31E-06	4.02E-07	1.25E-07	4.77E-08
2000	6.82E+03	1.69E+04	1.90E+04	2.13E+04	1.79E+04	1.35E+04	1.04E+04	9.25E+03	1.06E+04	1.32E+04	1.30E+04	1.05E+04	7.94E+03	5.34E+03	3.15E+03	1.44E+03	3.88E+02	5.63E+01	7.42E+00	1.07E+00	1.17E-01	1.25E-02	2.40E-03	7.09E-04	2.25E-04	7.14E-05	2.24E-05	6.99E-06	2.16E-06	6.63E-07	2.06E-07	7.92E-08
2001	2.12E+04	4.85E+04	4.02E+04	2.91E+04	2.11E+04	1.74E+04	1.49E+04	1.25E+04	1.20E+04	1.37E+04	1.35E+04	1.12E+04	8.78E+03	5.97E+03	3.53E+03	1.61E+03	4.40E+02	6.51E+01	8.47E+00	1.20E+00	1.32E-01	1.37E-02	2.55E-03	7.46E-04	2.37E-04	7.51E-05	2.36E-05	7.35E-06	2.27E-06	6.97E-07	2.17E-07	8.32E-08
2002	8.73E+03	2.25E+04	2.88E+04	3.63E+04	3.20E+04	2.44E+04	1.83E+04	1.49E+04	1.50E+04	1.69E+04	1.60E+04	1.27E+04	9.56E+03	6.43E+03	3.84E+03	1.80E+03	5.04E+02	7.68E+01	1.04E+01	1.53E+00	1.75E-01	2.04E-02	4.22E-03	1.27E-03	4.05E-04	1.29E-04	4.05E-05	1.26E-05	3.90E-06	1.20E-06	3.72E-07	1.43E-07
2003	1.55E+04	3.61E+04	3.21E+04	2.74E+04	2.46E+04	2.51E+04	2.43E+04	2.14E+04	1.99E+04	2.06E+04	1.89E+04	1.51E+04	1.13E+04	7.52E+03	4.43E+03	2.05E+03	5.73E+02	8.77E+01	1.19E+01	1.75E+00	1.98E-01	2.14E-02	4.09E-03	1.21E-03	3.84E-04	1.22E-04	3.83E-05	1.19E-05	3.69E-06	1.13E-06	3.53E-07	1.36E-07
2004	2.85E+04	6.61E+04	5.82E+04	4.69E+04	3.40E+04	2.49E+04	2.01E+04	1.90E+04	2.19E+04	2.58E+04	2.45E+04	1.92E+04	1.40E+04	9.07E+03	5.30E+03	2.45E+03	6.91E+02	1.07E+02	1.44E+01	2.12E+00	2.38E-01	2.55E-02	4.82E-03	1.42E-03	4.51E-04	1.44E-04	4.52E-05	1.41E-05	4.37E-06	1.34E-06	4.18E-07	1.61E-07
2005	8.75E+03	2.35E+04	3.37E+04	4.67E+04	4.39E+04	3.65E+04	2.89E+04	2.30E+04	2.21E+04	2.58E+04	2.58E+04	2.18E+04	1.69E+04	1.14E+04	6.73E+03	3.11E+03	8.73E+02	1.34E+02	1.80E+01	2.64E+00	3.02E-01	3.40E-02	6.77E-03	2.02E-03	6.45E-04	2.06E-04	6.48E-05	2.03E-05	6.27E-06	1.93E-06	6.02E-07	2.32E-07
2006	7.25E+03	1.75E+04	1.82E+04	2.06E+04	2.38E+04	2.92E+04	3.13E+04	2.99E+04	2.99E+04	3.23E+04	3.00E+04	2.39E+04	1.83E+04	1.25E+04	7.60E+03	3.63E+03	1.04E+03	1.63E+02	2.23E+01	3.28E+00	3.61E-01	3.53E-02	5.99E-03	1.71E-03	5.43E-04	1.73E-04	5.43E-05	1.70E-05	5.25E-06	1.61E-06	5.03E-07	1.94E-07
2007	5.09E+03	1.24E+04	1.34E+04	1.49E+04	1.42E+04	1.43E+04	1.57E+04	1.94E+04	2.71E+04	3.60E+04	3.61E+04	2.94E+04	2.20E+04	1.45E+04	8.59E+03	4.02E+03	1.14E+03	1.78E+02	2.46E+01	3.64E+00	3.94E-01	3.52E-02	5.20E-03	1.42E-03	4.48E-04	1.42E-04	4.46E-05	1.39E-05	4.29E-06	1.32E-06	4.11E-07	1.58E-07
2008	5.85E+03	1.38E+04	1.33E+04	1.26E+04	1.13E+04	1.07E+04	1.05E+04	1.15E+04	1.74E+04	2.81E+04	3.23E+04	2.92E+04	2.40E+04	1.68E+04	1.02E+04	4.81E+03	1.37E+03	2.12E+02	2.84E+01	4.09E+00	4.30E-01	3.53E-02	4.47E-03	1.15E-03	3.60E-04	1.14E-04	3.57E-05	1.11E-05	3.43E-06	1.06E-06	3.28E-07	1.26E-07
2009	3.15E+04	7.15E+04	5.67E+04	3.66E+04	2.20E+04	1.42E+04	1.05E+04	9.81E+03	1.40E+04	2.28E+04	2.64E+04	2.43E+04	2.12E+04	1.58E+04	1.02E+04	5.01E+03	1.47E+03	2.33E+02	3.26E+01	4.83E+00	5.05E-01	3.91E-02	4.26E-03	1.02E-03	3.16E-04	9.99E-05	3.13E-05	9.75E-06	3.01E-06	9.24E-07	2.88E-07	1.10E-07
2010	3.31E+04	7.87E+04	7.65E+04	7.18E+04	5.43E+04	3.63E+04	2.32E+04	1.58E+04	1.53E+04	2.07E+04	2.29E+04	2.07E+04	1.80E+04	1.36E+04	8.80E+03	4.40E+03	1.30E+03	2.09E+02	3.07E+01	4.75E+00	5.20E-01	4.61E-02	6.64E-03	1.79E-03	5.61E-04	1.77E-04	5.57E-05	1.73E-05	5.36E-06	1.65E-06	5.13E-07	1.97E-07
2011	1.66E+04	4.17E+04	5.01E+04	6.13E+04	5.85E+04	5.28E+04	4.46E+04	3.50E+04	2.89E+04	2.79E+04	2.52E+04	2.03E+04	1.64E+04	1.19E+04	7.59E+03	3.77E+03	1.12E+03	1.80E+02	2.68E+01	4.23E+00	4.82E-01	4.88E-02	8.54E-03	2.46E-03	7.79E-04	2.47E-04	7.79E-05	2.43E-05	7.53E-06	2.32E-06	7.22E-07	2.78E-07
2012	3.35E+03	9.78E+03	1.69E+04	2.78E+04	3.35E+04	3.90E+04	4.11E+04	4.05E+04	4.16E+04	4.33E+04	3.80E+04	2.84E+04	1.99E+04	1.28E+04	7.53E+03	3.56E+03	1.03E+03	1.63E+02	2.37E+01	3.68E+00	4.21E-01	4.39E-02	7.96E-03	2.32E-03	7.36E-04	2.34E-04	7.36E-05	2.30E-05	7.11E-06	2.19E-06	6.82E-07	2.63E-07
2013	9.00E+03	2.07E+04	1.75E+04	1.40E+04	1.39E+04	1.74E+04	2.15E+04	2.65E+04	3.57E+04	4.65E+04	4.65E+04	3.79E+04	2.78E+04	1.77E+04	1.01E+04	4.58E+03	1.27E+03	1.95E+02	2.59E+01	3.73E+00	4.06E-01	3.86E-02	6.27E-03	1.77E-03	5.61E-04	1.78E-04	5.59E-05	1.74E-05	5.39E-06	1.66E-06	5.17E-07	1.99E-07
2014	1.36E+04	3.18E+04	2.89E+04	2.44E+04	1.79E+04	1.29E+04	1.09E+04	1.29E+04	2.20E+04	3.67E+04	4.21E+04	3.79E+04	3.09E+04	2.15E+04	1.30E+04	6.10E+03	1.73E+03	2.67E+02	3.51E+01	4.96E+00	5.19E-01	4.37E-02	5.90E-03	1.56E-03	4.91E-04	1.56E-04	4.90E-05	1.53E-05	4.72E-06	1.45E-06	4.52E-07	1.74E-07

Table A6.8. Estimated population size (thousands) for males on July 1 from Alt4b.

year	Size bin 27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5	147.5	152.5	157.5	162.5	167.5	172.5	177.5	182.5
1949	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1950	4.78E+03	1.12E+04	1.07E+04	9.61E+03	7.32E+03	5.07E+03	3.12E+03	1.76E+03	9.51E+02	4.94E+02	2.47E+02	1.21E+02	5.77E+01	2.71E+01	1.25E+01	5.73E+00	2.58E+00	1.15E+00	5.10E-01	2.23E-01	9.71E-02	4.19E-02	1.80E-02	7.69E-03	3.26E-03	1.37E-03	5.67E-04	2.32E-04	9.32E-05	3.68E-05	1.48E-05	7.40E-06
1951	4.81E+03	1.12E+04	1.08E+04	9.84E+03	8.17E+03	6.87E+03	5.95E+03	4.85E+03	3.77E+03	2.81E+03	1.98E+03	1.32E+03	8.51E+02	5.33E+02	3.26E+02	1.94E+02	1.13E+02	6.49E+01	3.63E+01	1.98E+01	1.05E+01	5.51E+00	2.86E+00	1.47E+00	7.36E-01	3.53E-01	1.58E-01	6.36E-02	2.17E-02	5.67E-03	9.26E-04	1.32E-05
1952	4.86E+03	1.14E+04	1.09E+04	9.92E+03	8.24E+03	6.93E+03	6.11E+03	5.26E+03	4.54E+03	4.00E+03	3.57E+03	3.10E+03	2.61E+03	2.14E+03	1.70E+03	1.31E+03	9.70E+02	6.98E+02	4.86E+02	3.28E+02	2.15E+02	1.38E+02	8.67E+01	5.39E+01	3.24E+01	1.85E+01	9.76E+00	4.56E+00	1.80E+00	5.38E-01	9.79E-02	4.95E-05
1953	4.95E+03	1.16E+04	1.11E+04	1.01E+04	8.34E+03	7.01E+03	6.16E+03	5.32E+03	4.61E+03	4.11E+03	3.75E+03	3.41E+03	3.10E+03	2.86E+03	2.63E+03	2.37E+03	2.09E+03	1.82E+03	1.55E+03	1.27E+03	1.01E+03	7.74E+02	5.79E+02	4.25E+02	3.00E+02	1.99E+02	1.21E+02	6.44E+01	2.88E+01	9.79E+00	2.00E+00	3.51E-03
1954	5.10E+03	1.19E+04	1.13E+04	1.03E+04	8.51E+03	7.14E+03	6.26E+03	5.40E+03	4.70E+03	4.20E+03	3.86E+03	3.55E+03	3.28E+03	3.13E+03	2.99E+03	2.81E+03	2.59E+03	2.42E+03	2.23E+03	2.05E+03	1.80E+03	1.52E+03	1.25E+03	1.01E+03	7.86E+02	5.78E+02	3.89E+02	2.30E+02	1.14E+02	4.25E+01	9.41E+00	7.19E-02
1955	5.31E+03	1.24E+04	1.18E+04	1.07E+04	8.77E+03	7.33E+03	6.42E+03	5.53E+03	4.80E+03	4.30E+03	3.97E+03	3.68E+03	3.44E+03	3.35E+03	3.27E+03	3.14E+03	2.94E+03	2.83E+03	2.70E+03	2.60E+03	2.37E+03	2.09E+03	1.75E+03	1.45E+03	1.17E+03	8.89E+02	6.17E+02	3.77E+02	1.93E+02	7.45E+01	1.69E+01	3.41E-01
1956	5.66E+03	1.32E+04	1.25E+04	1.12E+04	9.19E+03	7.64E+03	6.66E+03	5.72E+03	4.96E+03	4.44E+03	4.11E+03	3.82E+03	3.60E+03	3.55E+03	3.50E+03	3.41E+03	3.23E+03	3.15E+03	3.07E+03	3.02E+03	2.80E+03	2.50E+03	2.12E+03	1.79E+03	1.45E+03	1.12E+03	7.84E+02	4.84E+02	2.51E+02	9.80E+01	2.22E+01	6.19E-01
1957	6.20E+03	1.44E+04	1.36E+04	1.21E+04	9.84E+03	8.13E+03	7.03E+03	6.01E+03	5.20E+03	4.64E+03	4.29E+03	3.99E+03	3.77E+03	3.74E+03	3.72E+03	3.64E+03	3.47E+03	3.42E+03	3.36E+03	3.35E+03	3.14E+03	2.82E+03	2.40E+03	2.03E+03	1.67E+03	1.29E+03	9.08E+02	5.63E+02	2.93E+02	1.15E+02	2.62E+01	8.22E-01
1958	7.12E+03	1.65E+04	1.54E+04	1.35E+04	1.09E+04	8.90E+03	7.62E+03	6.46E+03	5.56E+03	4.94E+03	4.54E+03	4.22E+03	3.98E+03	3.96E+03	3.95E+03	3.88E+03	3.71E+03	3.67E+03	3.63E+03	3.63E+03	3.42E+03	3.08E+03	2.63E+03	2.23E+03	1.83E+03	1.42E+03	1.00E+03	6.25E+02	3.26E+02	1.29E+02	2.92E+01	9.72E-01
1959	8.77E+03	2.03E+04	1.87E+04	1.61E+04	1.27E+04	1.02E+04	8.60E+03	7.21E+03	6.13E+03	5.40E+03	4.93E+03	4.56E+03	4.28E+03	4.25E+03	4.23E+03	4.15E+03	3.96E+03	3.93E+03	3.88E+03	3.90E+03	3.67E+03	3.32E+03	2.83E+03	2.41E+03	1.98E+03	1.53E+03	1.09E+03	6.76E+02	3.54E+02	1.39E+02	3.17E+01	1.09E+00
1960	1.22E+04	2.82E+04	2.54E+04	2.10E+04	1.61E+04	1.26E+04	1.04E+04	8.50E+03	7.12E+03	6.18E+03	5.57E+03	5.08E+03	4.73E+03	4.65E+03	4.61E+03	4.50E+03	4.28E+03	4.23E+03	4.18E+03	4.19E+03	3.94E+03	3.55E+03	3.03E+03	2.57E+03	2.12E+03	1.64E+03	1.16E+03	7.24E+02	3.79E+02	1.49E+02	3.40E+01	1.18E+00
1961	2.10E+04	4.83E+04	4.21E+04	3.29E+04	2.39E+04	1.78E+04	1.40E+04	1.11E+04	8.98E+03	7.60E+03	6.69E+03	5.99E+03	5.48E+03	5.31E+03	5.18E+03	5.01E+03	4.73E+03	4.65E+03	4.56E+03	4.55E+03	4.26E+03	3.83E+03	3.26E+03	2.77E+03	2.27E+03	1.76E+03	1.25E+03	7.76E+02	4.05E+02	1.60E+02	3.63E+01	1.26E+00
1962	4.62E+04	1.06E+05	8.93E+04	6.55E+04	4.48E+04	3.13E+04	2.29E+04	1.71E+04	1.32E+04	1.07E+04	9.02E+03	7.79E+03	6.91E+03	6.49E+03	6.19E+03	5.88E+03	5.47E+03	5.30E+03	5.14E+03	5.07E+03	4.72E+03	4.22E+03	3.58E+03	3.03E+03	2.48E+03	1.92E+03	1.35E+03	8.41E+02	4.39E+02	1.73E+02	3.93E+01	1.35E+00
1963	9.97E+04	2.28E+05	1.93E+05	1.42E+05	9.68E+04	6.63E+04	4.66E+04	3.31E+04	2.43E+04	1.85E+04	1.48E+04	1.21E+04	1.02E+04	9.08E+03	8.29E+03	7.61E+03	6.89E+03	6.51E+03	6.17E+03	5.97E+03	5.48E+03	4.85E+03	4.08E+03	3.44E+03	2.80E+03	2.15E+03	1.51E+03	9.38E+02	4.88E+02	1.92E+02	4.35E+01	1.46E+00
1964	1.39E+05	3.20E+05	2.89E+05	2.38E+05	1.77E+05	1.30E+05	9.58E+04	6.96E+04	5.12E+04	3.86E+04	2.98E+04	2.33E+04	1.87E+04	1.57E+04	1.35E+04	1.18E+04	1.02E+04	9.20E+03	8.38E+03	7.81E+03	6.99E+03	6.06E+03	5.03E+03	4.18E+03	3.37E+03	2.57E+03	1.79E+03	1.10E+03	5.71E+02	2.23E+02	5.05E+01	1.62E+00
1965	1.30E+05	3.05E+05	2.97E+05	2.75E+05	2.27E+05	1.83E+05	1.50E+05	1.20E+05	9.42E+04	7.49E+04	5.99E+04	4.79E+04	3.84E+04	3.17E+04	2.65E+04	2.23E+04	1.86E+04	1.60E+04	1.39E+04	1.23E+04	1.06E+04	8.89E+03	7.21E+03	5.86E+03	4.63E+03	3.47E+03	2.39E+03	1.45E+03	7.41E+02	2.87E+02	6.45E+01	1.87E+00
1966	1.07E+05	2.52E+05	2.53E+05	2.47E+05	2.14E+05	1.87E+05	1.68E+05	1.46E+05	1.24E+05	1.07E+05	9.24E+04	7.92E+04	6.75E+04	5.83E+04	5.03E+04	4.31E+04	3.63E+04	3.11E+04	2.65E+04	2.28E+04	1.90E+04	1.55E+04	1.23E+04	9.74E+03	7.51E+03	5.49E+03	3.70E+03	2.20E+03	1.10E+03	4.18E+02	9.30E+01	2.23E+00
1967	9.25E+04	2.18E+05	2.16E+05	2.08E+05	1.81E+05	1.61E+05	1.50E+05	1.35E+05	1.22E+05	1.11E+05	1.04E+05	9.52E+04	8.67E+04	8.02E+04	7.37E+04	6.68E+04	5.91E+04	5.29E+04	4.67E+04	4.12E+04	3.50E+04	2.89E+04	2.31E+04	1.84E+04	1.42E+04	1.03E+04	6.93E+03	4.10E+03	2.04E+03	7.68E+02	1.70E+02	3.28E+00
1968	8.90E+04	2.08E+05	2.01E+05	1.87E+05	1.59E+05	1.39E+05	1.27E+05	1.15E+05	1.04E+05	9.79E+04	9.42E+04	9.02E+04	8.62E+04	8.48E+04	8.28E+04	7.93E+04	7.36E+04	6.92E+04	6.38E+04	5.85E+04	5.09E+04	4.29E+04	3.48E+04	2.82E+04	2.21E+04	1.63E+04	1.10E+04	6.55E+03	3.27E+03	1.23E+03	2.73E+02	4.88E+00
1969	9.17E+04	2.14E+05	2.04E+05	1.85E+05	1.54E+05	1.30E+05	1.16E+05	1.03E+05	9.20E+04	8.54E+04	8.22E+04	7.95E+04	7.76E+04	7.93E+04	8.04E+04	7.97E+04	7.63E+04	7.45E+04	7.15E+04	6.84E+04	6.15E+04	5.33E+04	4.42E+04	3.67E+04	2.94E+04	2.22E+04	1.53E+04	9.29E+03	4.71E+03	1.81E+03	4.05E+02	8.21E+00
1970	7.65E+04	1.80E+05	1.80E+05	1.74E+05	1.50E+05	1.29E+05	1.14E+05	9.98E+04	8.81E+04	8.05E+04	7.64E+04	7.33E+04	7.15E+04	7.39E+04	7.60E+04	7.62E+04	7.36E+04	7.32E+04	7.15E+04	6.98E+04	6.35E+04	5.56E+04	4.65E+04	3.89E+04	3.16E+04	2.42E+04	1.69E+04	1.04E+04	5.34E+03	2.07E+03	4.67E+02	1.18E+01
1971	4.98E+04	1.19E+05	1.27E+05	1.34E+05	1.22E+05	1.12E+05	1.05E+05	9.53E+04	8.60E+04	7.93E+04	7.53E+04	7.19E+04	6.99E+04	7.20E+04	7.40E+04	7.42E+04	7.15E+04	7.13E+04	6.99E+04	6.87E+04	6.27E+04	5.50E+04	4.61E+04	3.87E+04	3.16E+04	2.44E+04	1.72E+04	1.06E+04	5.50E+03	2.15E+03	4.86E+02	1.43E+01
1972	4.16E+04	9.79E+04	9.79E+04	9.59E+04	8.64E+04	8.07E+04	8.00E+04	7.63E+04	7.23E+04	6.99E+04	6.93E+04	6.84E+04	6.79E+04	7.09E+04	7.33E+04	7.37E+04	7.11E+04	7.09E+04	6.95E+04	6.83E+04	6.23E+04	5.47E+04	4.57E+04	3.85E+04	3.14E+04	2.43E+04	1.71E+04	1.06E+04	5.52E+03	2.16E+03	4.90E+02	1.57E+01
1973	3.38E+04	7.96E+04	8.01E+04	7.86E+04	6.93E+04	6.20E+04	5.84E+04	5.48E+04	5.25E+04	5.23E+04	5.42E+04	5.60E+04	5.80E+04	6.33E+04	6.77E+04	6.97E+04	6.84E+04	6.93E+04	6.86E+04	6.80E+04	6.25E+04	5.50E+04	4.61E+04	3.88E+04	3.18E+04	2.45E+04	1.73E+04	1.07E+04	5.59E+03	2.20E+03	4.98E+02	1.65E+01
1974	9.36E+03	2.40E+04	3.47E+04	4.76E+04	4.89E+04	4.75E+04	4.65E+04	4.38E+04	4.14E+04	4.04E+04	4.12E+04	4.25E+04	4.49E+04	5.08E+04	5.61E+04	5.94E+04	5.96E+04	6.19E+04	6.28E+04	6.38E+04	5.96E+04	5.33E+04	4.51E+04	3.83E+04	3.16E+04	2.45E+04	1.74E+04	1.09E+04	5.67E+03	2.23E+03	5.08E+02	1.71E+01
1975	3.22E+04	7.32E+04	5.94E+04	4.08E+04	2.97E+04	2.67E+04	2.88E+04	3.00E+04	3.05E+04	3.13E+04	3.28E+04	3.44E+04	3.65E+04	4.15E+04	4.61E+04	4.89E+04	4.92E+04	5.16E+04	5.30E+04	5.46E+04	5.16E+04	4.65E+04	3.96E+04	3.39E+04	2.81E+04	2.20E+04	1.57E+04	9.87E+03	5.19E+03	2.06E+03	4.68E+02	1.68E+01
1976	7.05E+04	1.61E+05	1.36E+05	9.98E+04	6.69E+04	4.46E+04	3.03E+04	2.25E+04	1.96E+04	1.98E+04	2.22E+04	2.50E+04	2.83E+04	3.38E+04	3.86E+04	4.16E+04	4.21E+04	4.43E+04	4.55E+04	4.67E+04	4.39E+04	3.93E+04	3.33E+04	2.84E+04	2.36E+04	1.85E+04	1.32E+04	8.31E+03	4.38E+03	1.74E+03	3.97E+02	1.54E+01
1977	4.29E+04	1.03E+05	1.12E+05	1.18E+05	1.02E+05	8.23E+04	6.38E+04	4.78E+04	3.61E+04	2.83E+04	2.37E+04	2.17E+04	2.20E+04	2.56E+04	2.96E+04	3.25E+04	3.33E+04	3.54E+04	3.62E+04	3.66E+04	3.35E+04	2.93E+04	2.43E+04	2.05E+04	1.68E+04	1.31E+04	9.31E+03	5.82E+03	3.05E+03	1.21E+03	2.74E+02	1.06E+01
1978	3.66E+04	8.60E+04	8.57E+04	8.35E+04	7.56E+04	7.12E+04	7.05E+04	6.47E+04	5.69E+04	4.92E+04	4.26E+04	3.71E+04	3.31E+04	3.21E+04	3.17E+04	3.09E+04	2.89E+04	2.82E+04	2.67E+04	2.48E+04	2.10E+04	1.71E+04	1.36E+04	1.12E+04	9.06E+03	6.98E+03	4.93E+03	3.06E+03	1.59E+03	6.24E+02	1.41E+02	5.01E+00
1979	9.06E+03	2.36E+04	3.58E+04	5.05E+04	5.23E+04	5.07E+04	4.96E+04	4.71E+04	4.52E+04	4.47E+04	4.52E+04	4.47E+04	4.34E+04	4.30E+04	4.19E+04	3.95E+04	3.53E+04	3.18E+04	2.73E+04	2.27E+04	1.75E+04	1.31E+04	9.73E+03	7.47E+03	5.67E+03	4.12E+03	2.77E+03	1.65E+03	8.29E+02	3.16E+02	7.01E+01	2.28E+00
1980	3.48E+03	8.62E+03	1.10E+04	1.46E+04	1.80E+04	2.26E+04	2.85E+04	3.11E+04	3.18E+04	3.23E+04	3.32E+04	3.40E+04	3.48E+04	3.73E+04	3.89E+04	3.87E+04	3.59E+04	3.26E+04	2.76E+04	2.23E+04	1.71E+04	1.30E+04	9.89E+03	7.50E+03	5.44E+03	3.67E+03	2.23E+03	1.17E+03	5.15E+02	1.70E+02	3.35E+01	3.96E-01
1981	8.20E+03	1.87E+04	1.57E+04	1.16E+04	8.89E+03	8.14E+03	9.02E+03	1.06E+04	1.28E+04	1.56E+04	1.88E+04	2.12E+04	2.30E+04	2.51E+04	2.63E+04	2.61E+04	2.43E+04	2.20E+04	1.89E+04	1.58E+04	1.30E+04	1.07E+04	8.91E+03	7.30E+03	5.66E+03	4.02E+03	2.54E+03	1.37E+03	6.09E+02	2.02E+02	3.97E+01	1.46E-01
1982	4.03E+03	9.79E+03	1.14E+04	1.29E+04	1.15E+04	9.36E+03	7.44E+03	6.18E+03	5.74E+03	6.02E+03	7.00E+03	8.35E+03	9.96E+03	1.23E+04	1.44E+04	1.57E+04	1.58E+04	1.56E+04	1.47E+04	1.37E+04	1.23E+04	1.08E+04	9.37E+03	8.05E+03	6.60E+03	5.05E+03	3.49E+03	2.11E+03	1.06E+03	4.04E+02	9.10E+01	1.00E+00
1983	2.86E+04	6.46E+04	5.02E+04	3.06E+04	1.78E+04	1.16E+04	9.30E+03	7.87E+03	6.80E+03	6.00E+03	5.52E+03	5.33E+03	5.45E+03	6.23E+03	7.10E+03	7.77E+03	7.97E+03	8.39E+03	8.60E+03	8.92E+03	8.75E+03	8.34E+03	7.60E+03	6.88E+03	5.94E+03	4.77E+03	3.46E+03	2.18E+03	1.15E+03	4.56E+02	1.06E+02	3.09E+00
1984	2.33E+04	5.50E+04	5.52E+04	5.30E+04	4.24E+04	3.11E+04	2.10E+04	1.38E+04	9.55E+03	7.29E+03	6.27E+03	5.75E+03	5.46E+03	5.52E+03	5.61E+03	5.59E+03	5.35E+03	5.35E+03	5.35E+03	5.56E+03	5.52E+03	5.34E+03	4.90E+03	4.49E+03	3.95E+03	3.24E+03	2.41E+03	1.56E+03	8.50E+02	3.47E+02	8.15E+01	4.01E+00
1985	4.43E+04	1.02E+05	8.76E+04	6.71E+04	4.95E+04	3.92E+04	3.38E+04	2.81E+04	2.26E+04	1.77E+04	1.35E+04	1.02E+04	7.88E+03	6.54E+03	5.78E+03	5.29E+03	4.84E+03	4.61E+03	4.39E+03	4.29E+03	4.02E+03	3.70E+03	3.27E+03	2.91E+03	2.50E+03	2.00E+03	1.47E+03	9.42E+02	5.08E+02	2.06E+02	4.79E+01	2.94E+00
1986	3.71E+04	8.72E+04	8.71E+04	8.37E+04	6.92E+04	5.48E+04	4.32E+04	3.38E+04	2.74E+04	2.34E+04	2.08E+04	1.85E+04	1.61E+04	1.41E+04	1.22E+04	1.03E+04	8.62E+03	7.34E+03	6.33E+03	5.68E+03	5.03E+03	4.43E+03	3.80E+03	3.33E+03	2.82E+03	2.24E+03	1.62E+03	1.03E+03	5.48E+02	2.20E+02	5.08E+01	2.73E+00
1987	3.36E+04	7.88E+04	7.72E+04	7.33E+04	6.32E+04	5.56E+04	5.10E+04	4.45E+04	3.78E+04	3.20E+04	2.73E+04	2.33E+04	2.01E+04	1.82E+04	1.67E+04	1.53E+04	1.38E+04	1.25E+04	1.12E+04	1.00E+04	8.64E+03	7.31E+03	6.02E+03	5.02E+03	4.04E+03	3.05E+03	2.11E+03	1.29E+03	6.62E+02	2.58E+02	5.84E+01	2.63E+00
1988	2.98E+04	6.99E+04	6.89E+04	6.56E+04	5.64E+04	4.92E+04	4.50E+04	4.03E+04	3.63E+04	3.36E+04	3.18E+04	2.95E+04	2.70E+04	2.50E+04	2.30E+04	2.09E+04	1.85E+04	1.68E+04	1.51E+04	1.38E+04	1.21E+04	1.04E+04	8.75E+03	7.41E+03	6.04E+03	4.59E+03	3.18E+03	1.94E+03	9.89E+02	3.82E+02	8.60E+01	2.60E+00
1989	1.32E+04	3.23E+04	3.89E+04	4.63E+04	4.47E+04	4.16E+04	3.94E+04	3.58E+04	3.24E+04	3.01E+04	2.88E+04	2.75E+04	2.63E+04	2.59E+04	2.55E+04	2.47E+04	2.31E+04	2.19E+04	2.03E+04	1.88E+04	1.66E+04	1.42E+04	1.18E+04	9.95E+03	8.04E+03	6.06E+03	4.16E+03	2.52E+03	1.28E+03	4.93E+02	1.11E+02	3.22E+00
1990	5.96E+03	1.46E+04	1.75E+04	2.12E+04	2.25E+04	2.42E+04	2.68E+04	2.72E+04	2.65E+04	2.59E+04	2.56E+04	2.50E+04	2.43E+04	2.44E+04	2.45E+04	2.41E+04	2.29E+04	2.21E+04	2.09E+04	1.96E+04	1.73E+04	1.49E+04	1.24E+04	1.06E+04	8.60E+03	6.50E+03	4.47E+03	2.69E+03	1.36E+03	5.18E+02	1.15E+02	2.93E+00
1991	2.79E+03	6.80E+03	8.06E+03	9.66E+03	1.02E+04	1.09E+04	1.24E+04	1.35E+04	1.46E+04	1.61E+04	1.80E+04	1.93E+04	2.00E+04	2.10E+04	2.18E+04	2.19E+04	2.10E+04	2.02E+04	1.86E+04	1.69E+04	1.44E+04	1.20E+04	9.87E+03	8.36E+03	6.79E+03	5.10E+03	3.47E+03	2.07E+03	1.03E+03	3.89E+02	8.57E+01	2.07E+00
1992	2.44E+03	5.72E+03	5.66E+03	5.53E+03	5.17E+03	5.22E+03	5.75E+03	6.31E+03	7.05E+03	8.07E+03	9.52E+03	1.10E+04	1.22E+04	1.40E+04	1.57E+04	1.68E+04	1.69E+04	1.69E+04	1.61E+04	1.49E+04	1.28E+04	1.06E+04	8.61E+03	7.24E+03	5.86E+03	4.40E+03	3.00E+03	1.79E+03	8.91E+02	3.35E+02	7.37E+01	1.50E+00
1993	2.04E+03	4.81E+03	4.80E+03	4.65E+03	4.05E+03	3.60E+03	3.42E+03	3.48E+03	3.80E+03	4.37E+03	5.32E+03	6.34E+03	7.17E+03	8.44E+03	9.79E+03	1.08E+04	1.12E+04	1.17E+04	1.16E+04	1.13E+04	9.94E+03	8.26E+03	6.57E+03	5.33E+03	4.11E+03	2.98E+03	2.00E+03	1.20E+03	6.12E+02	2.35E+02	5.33E+01	6.22E-01
1994	2.35E+03	5.46E+03	5.09E+03	4.48E+03	3.68E+03	3.15E+03	2.91E+03	2.81E+03	2.87E+03	3.11E+03	3.63E+03	4.25E+03	4.70E+03	5.50E+03	6.44E+03	7.22E+03	7.51E+03	8.03E+03	8.16E+03	8.10E+03	7.18E+03	5.95E+03	4.69E+03	3.84E+03	3.00E+03	2.21E+03	1.52E+03	9.36E+02	4.87E+02	1.92E+02	4.39E+01	1.04E+00
1995	3.45E+03	7.97E+03	7.11E+03	5.79E+03	4.40E+03	3.45E+03	2.90E+03	2.60E+03	2.52E+03	2.63E+03	2.98E+03	3.38E+03	3.61E+03	4.09E+03	4.68E+03	5.19E+03	5.35E+03	5.73E+03	5.84E+03	5.84E+03	5.17E+03	4.27E+03	3.35E+03	2.75E+03	2.17E+03	1.61E+03	1.12E+03	6.94E+02	3.65E+02	1.45E+02	3.33E+01	1.12E+00
1996	3.37E+03	7.88E+03	7.59E+03	6.94E+03	5.64E+03	4.52E+03	3.70E+03	3.09E+03	2.74E+03	2.61E+03	2.73E+03	2.92E+03	2.99E+03	3.24E+03	3.62E+03	3.94E+03	4.00E+03	4.21E+03	4.21E+03	4.12E+03	3.60E+03	2.96E+03	2.35E+03	1.99E+03	1.61E+03	1.21E+03	8.46E+02	5.27E+02	2.78E+02	1.11E+02	2.53E+01	1.03E+00
1997	9.18E+03	2.09E+04	1.73E+04	1.21E+04	8.13E+03	5.84E+03	4.67E+03	3.88E+03	3.36E+03	3.05E+03	2.94E+03	2.90E+03	2.78E+03	2.85E+03	3.01E+03	3.16E+03	3.14E+03	3.25E+03	3.24E+03	3.19E+03	2.83E+03	2.37E+03	1.92E+03	1.64E+03	1.34E+03	1.02E+03	7.18E+02	4.48E+02	2.36E+02	9.42E+01	2.15E+01	9.01E-01
1998	3.61E+03	8.93E+03	1.12E+04	1.36E+04	1.24E+04	1.01E+04	7.73E+03	5.81E+03	4.55E+03	3.81E+03	3.48E+03	3.29E+03	3.09E+03	3.04E+03	3.07E+03	3.07E+03	2.94E+03	2.95E+03	2.87E+03	2.79E+03	2.48E+03	2.10E+03	1.72E+03	1.47E+03	1.21E+03	9.23E+02	6.50E+02	4.06E+02	2.14E+02	8.51E+01	1.94E+01	8.11E-01
1999	1.13E+04	2.57E+04	2.10E+04	1.46E+04	1.03E+04	8.63E+03	8.45E+03	7.87E+03	7.00E+03	6.09E+03	5.28E+03	4.57E+03	3.96E+03	3.63E+03	3.43E+03	3.28E+03	3.07E+03	2.99E+03	2.87E+03	2.77E+03	2.46E+03	2.11E+03	1.74E+03	1.48E+03	1.21E+03	9.25E+02	6.49E+02	4.03E+02	2.11E+02	8.34E+01	1.89E+01	7.43E-01
2000	6.82E+03	1.63E+04	1.78E+04	1.88E+04	1.61E+04	1.27E+04	9.51E+03	7.26E+03	6.03E+03	5.56E+03	5.54E+03	5.48E+03	5.24E+03	5.03E+03	4.76E+03	4.42E+03	3.98E+03	3.70E+03	3.42E+03	3.20E+03	2.82E+03	2.41E+03	1.99E+03	1.67E+03	1.36E+03	1.04E+03	7.28E+02	4.50E+02	2.34E+02	9.23E+01	2.09E+01	7.40E-01
2001	2.12E+04	4.82E+04	3.94E+04	2.72E+04	1.84E+04	1.40E+04	1.23E+04	1.06E+04	9.02E+03	7.60E+03	6.44E+03	5.55E+03	4.95E+03	4.78E+03	4.74E+03	4.69E+03	4.52E+03	4.45E+03	4.28E+03	4.11E+03	3.69E+03	3.18E+03	2.63E+03	2.19E+03	1.75E+03	1.32E+03	9.17E+02	5.60E+02	2.88E+02	1.12E+02	2.53E+01	8.13E-01
2002	8.73E+03	2.15E+04	2.65E+04	3.17E+04	2.86E+04	2.30E+04	1.74E+04	1.30E+04	1.02E+04	8.68E+03	7.95E+03	7.39E+03	6.82E+03	6.44E+03	6.04E+03	5.58E+03	5.05E+03	4.78E+03	4.55E+03	4.44E+03	4.09E+03	3.64E+03	3.08E+03	2.62E+03	2.15E+03	1.66E+03	1.17E+03	7.28E+02	3.79E+02	1.49E+02	3.38E+01	9.66E-01
2003	1.55E+04	3.57E+04	3.10E+04	2.46E+04	1.99E+04	1.85E+04	1.90E+04	1.79E+04	1.58E+04	1.35E+04	1.13E+04	9.51E+03	8.17E+03	7.49E+03	7.06E+03	6.71E+03	6.26E+03	6.04E+03	5.78E+03	5.59E+03	5.11E+03	4.50E+03	3.77E+03	3.15E+03	2.55E+03	1.95E+03	1.37E+03	8.45E+02	4.39E+02	1.72E+02	3.91E+01	1.32E+00
2004	2.85E+04	6.53E+04	5.65E+04	4.33E+04	3.08E+04	2.22E+04	1.69E+04	1.36E+04	1.21E+04	1.17E+04	1.19E+04	1.18E+04	1.13E+04	1.08E+04	1.02E+04	9.31E+03	8.32E+03	7.69E+03	7.16E+03	6.84E+03	6.25E+03	5.52E+03	4.65E+03	3.92E+03	3.20E+03	2.46E+03	1.74E+03	1.08E+03	5.60E+02	2.20E+02	4.99E+01	1.55E+00
2005	8.75E+03	2.22E+04	3.07E+04	4.01E+04	3.83E+04	3.28E+04	2.68E+04	2.11E+04	1.66E+04	1.34E+04	1.14E+04	1.01E+04	9.46E+03	9.60E+03	9.86E+03	9.97E+03	9.73E+03	9.66E+03	9.40E+03	9.16E+03	8.40E+03	7.41E+03	6.20E+03	5.16E+03	4.15E+03	3.15E+03	2.20E+03	1.35E+03	6.97E+02	2.72E+02	6.15E+01	1.97E+00
2006	7.25E+03	1.71E+04	1.71E+04	1.74E+04	1.78E+04	1.98E+04	2.30E+04	2.32E+04	2.15E+04	1.94E+04	1.72E+04	1.50E+04	1.32E+04	1.22E+04	1.14E+04	1.07E+04	9.87E+03	9.64E+03	9.52E+03	9.62E+03	9.16E+03	8.35E+03	7.19E+03	6.15E+03	5.07E+03	3.94E+03	2.80E+03	1.74E+03	9.08E+02	3.57E+02	8.12E+01	2.37E+00
2007	5.09E+03	1.21E+04	1.26E+04	1.30E+04	1.18E+04	1.08E+04	1.06E+04	1.08E+04	1.16E+04	1.29E+04	1.45E+04	1.52E+04	1.54E+04	1.55E+04	1.52E+04	1.44E+04	1.32E+04	1.25E+04	1.18E+04	1.14E+04	1.05E+04	9.35E+03	7.91E+03	6.66E+03	5.44E+03	4.20E+03	2.98E+03	1.86E+03	9.72E+02	3.84E+02	8.76E+01	3.07E+00
2008	5.85E+03	1.36E+04	1.27E+04	1.12E+04	9.41E+03	8.33E+03	7.98E+03	7.57E+03	7.28E+03	7.28E+03	7.69E+03	8.33E+03	9.24E+03	1.08E+04	1.22E+04	1.31E+04	1.33E+04	1.36E+04	1.37E+04	1.36E+04	1.28E+04	1.15E+04	9.72E+03	8.16E+03	6.62E+03	5.07E+03	3.55E+03	2.19E+03	1.14E+03	4.44E+02	1.00E+02	3.35E+00
2009	3.15E+04	7.12E+04	5.61E+04	3.51E+04	2.05E+04	1.26E+04	8.84E+03	6.93E+03	6.05E+03	5.81E+03	6.01E+03	6.36E+03	6.88E+03	8.05E+03	9.10E+03	9.82E+03	1.01E+04	1.09E+04	1.16E+04	1.25E+04	1.24E+04	1.17E+04	1.02E+04	8.87E+03	7.40E+03	5.82E+03	4.17E+03	2.62E+03	1.38E+03	5.44E+02	1.24E+02	3.86E+00
2010	3.31E+04	7.72E+04	7.33E+04	6.51E+04	5.01E+04	3.60E+04	2.44E+04	1.61E+04	1.10E+04	8.14E+03	6.72E+03	6.13E+03	6.13E+03	6.94E+03	7.78E+03	8.37E+03	8.56E+03	9.27E+03	9.99E+03	1.10E+04	1.11E+04	1.05E+04	9.29E+03	8.10E+03	6.80E+03	5.37E+03	3.87E+03	2.44E+03	1.29E+03	5.17E+02	1.19E+02	4.63E+00
2011	1.66E+04	4.02E+04	4.65E+04	5.30E+04	4.95E+04	4.43E+04	3.95E+04	3.30E+04	2.65E+04	2.09E+04	1.63E+04	1.27E+04	1.03E+04	9.32E+03	8.85E+03	8.55E+03	8.18E+03	8.48E+03	8.93E+03	9.72E+03	9.78E+03	9.33E+03	8.24E+03	7.21E+03	6.08E+03	4.82E+03	3.48E+03	2.20E+03	1.17E+03	4.69E+02	1.07E+02	4.75E+00
2012	3.35E+03	9.00E+03	1.50E+04	2.28E+04	2.58E+04	2.80E+04	3.06E+04	3.01E+04	2.83E+04	2.64E+04	2.46E+04	2.23E+04	1.99E+04	1.80E+04	1.62E+04	1.43E+04	1.24E+04	1.14E+04	1.06E+04	1.05E+04	9.88E+03	9.05E+03	7.80E+03	6.70E+03	5.58E+03	4.38E+03	3.14E+03	1.98E+03	1.05E+03	4.20E+02	9.59E+01	4.32E+00
2013	9.00E+03	2.05E+04	1.70E+04	1.25E+04	1.04E+04	1.10E+04	1.34E+04	1.51E+04	1.65E+04	1.78E+04	1.93E+04	2.00E+04	2.01E+04	2.04E+04	2.03E+04	1.96E+04	1.82E+04	1.72E+04	1.61E+04	1.52E+04	1.37E+04	1.20E+04	1.00E+04	8.29E+03	6.64E+03	5.04E+03	3.51E+03	2.15E+03	1.11E+03	4.35E+02	9.81E+01	3.86E+00
2014	1.36E+04	3.14E+04	2.79E+04	2.24E+04	1.63E+04	1.18E+04	8.71E+03	7.27E+03	7.16E+03	8.00E+03	9.53E+03	1.11E+04	1.27E+04	1.48E+04	1.66E+04	1.76E+04	1.77E+04	1.81E+04	1.82E+04	1.83E+04	1.72E+04	1.55E+04	1.32E+04	1.11E+04	9.00E+03	6.88E+03	4.81E+03	2.95E+03	1.52E+03	5.92E+02	1.34E+02	3.84E+00

Table A6.9. OFLs and ABCs for the 2013 assessment and all the alternative 2014 model scenarios. The author's preferred model was Alt1a. The CPT's preferred model is Alt4b.

Model Case	average recruitment (millions)	B (1000's t)	Fmsy	Bmsy (1000's t)	B/Bmsy	OFL (1000's t)	ABC (p*) (1000's t)	ABC (10% buffer) (1000's t)
2013	211.9	59.35	0.73	33.54	1.77	25.35	25.31	22.82
Alt0a	206.6	63.91	0.69	32.95	1.94	32.84	32.78	29.55
Alt0b	185.4	59.65	0.61	29.12	2.05	30.04	30.00	27.04
Alt1a	209.7	70.77	0.58	33.95	2.08	33.81	33.76	30.43
Alt1b	187.0	63.37	0.61	29.51	2.15	31.35	31.30	28.21
Alt4a	209.7	70.76	0.58	33.95	2.08	33.81	33.76	30.43
Alt4b	187.9	63.80	0.61	29.82	2.14	31.48	31.43	28.33
Alt4c	179.1	60.68	0.62	27.90	2.17	30.58	30.53	27.52

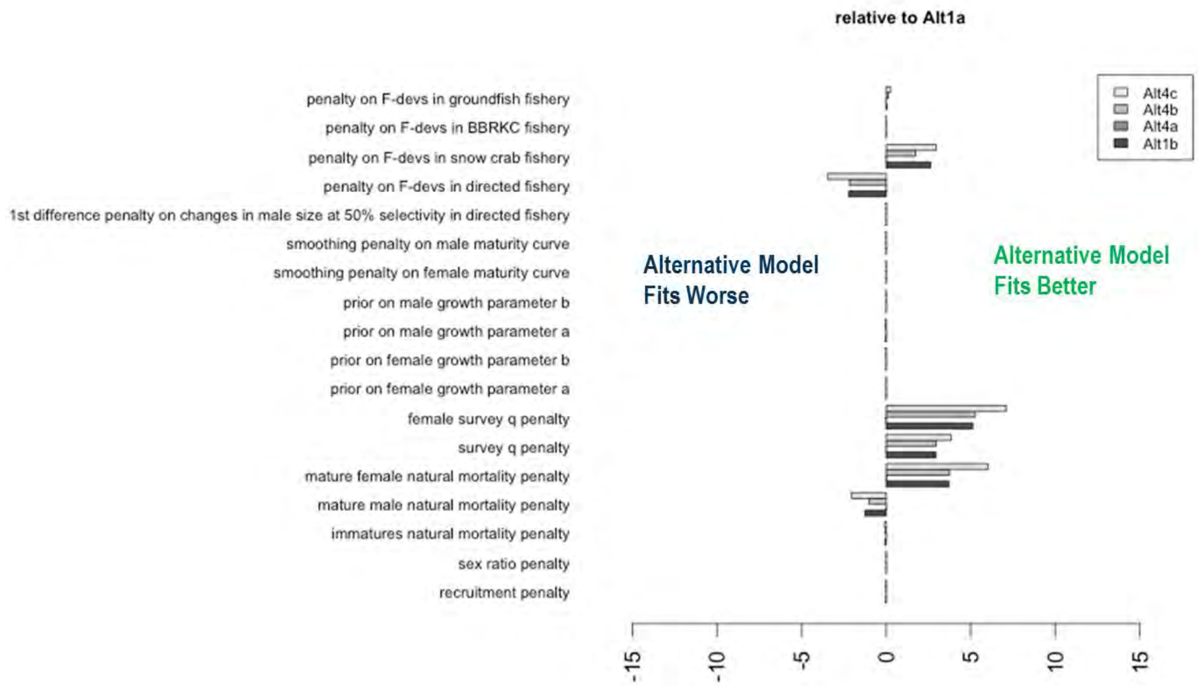
Table A6.10. Basis for the OFL from Alt4b (in 1000's t).

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2012/13	3a	33.45	58.59	1.75	0.61 yr^{-1}	1982-2012	0.23 yr^{-1}
2013/14	3a	33.54	59.35	1.77	0.73 yr^{-1}	1982-2013	0.23 yr^{-1}
2014/15	3a	33.95	70.77	2.08	0.58 yr^{-1}	1982-2014	0.23 yr^{-1}

Table A6.11. OFL table for Alt4b (in 1000's t).

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2010/11	41.67	26.73	0.00	0.00	0.87	1.45	
2011/12	11.40	58.59	0.00	0.00	1.24	2.75	2.48
2012/13	16.77	59.35	0.00	0.00	0.71	19.02	8.17
2013/14	14.91	72.70	1.41	1.26	2.78	25.35	17.82
2014/15		63.80				31.48	28.33

Figures



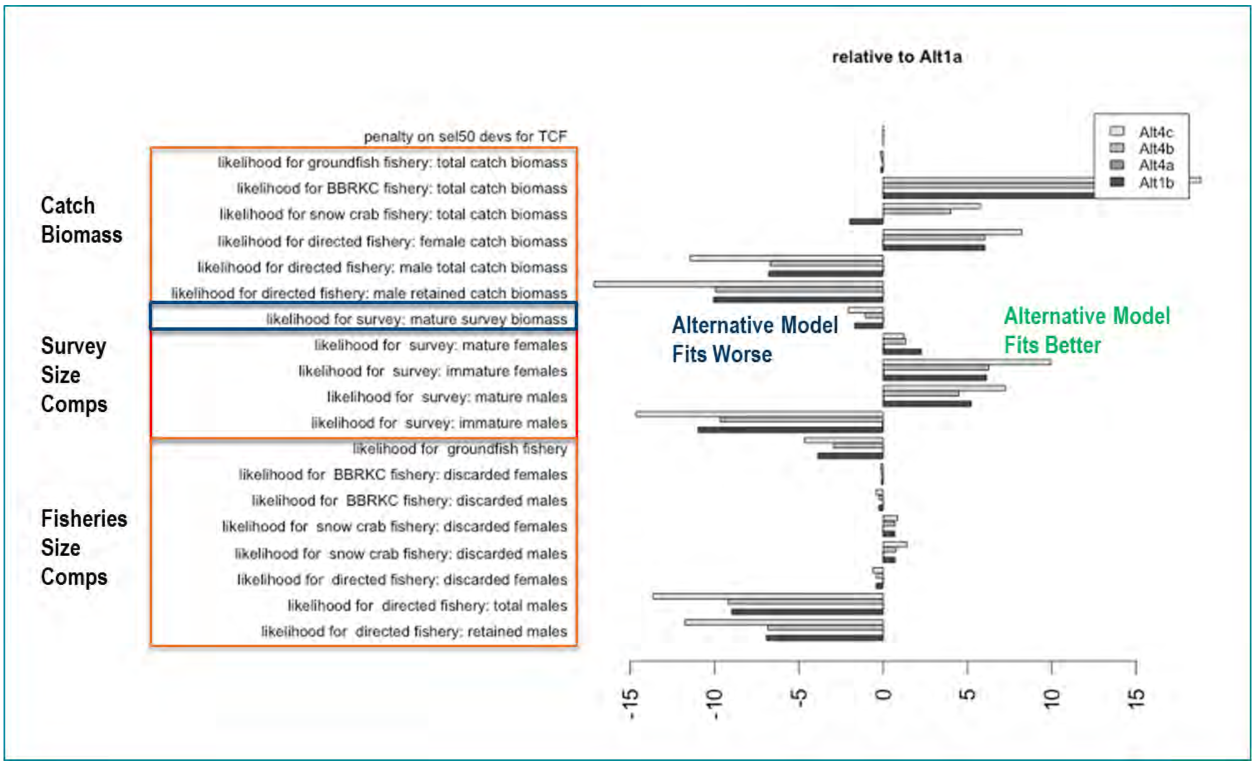


Figure A6.3. Comparison of model-estimated time series for (male) recruitment from the four alternative models and the 2013 model.

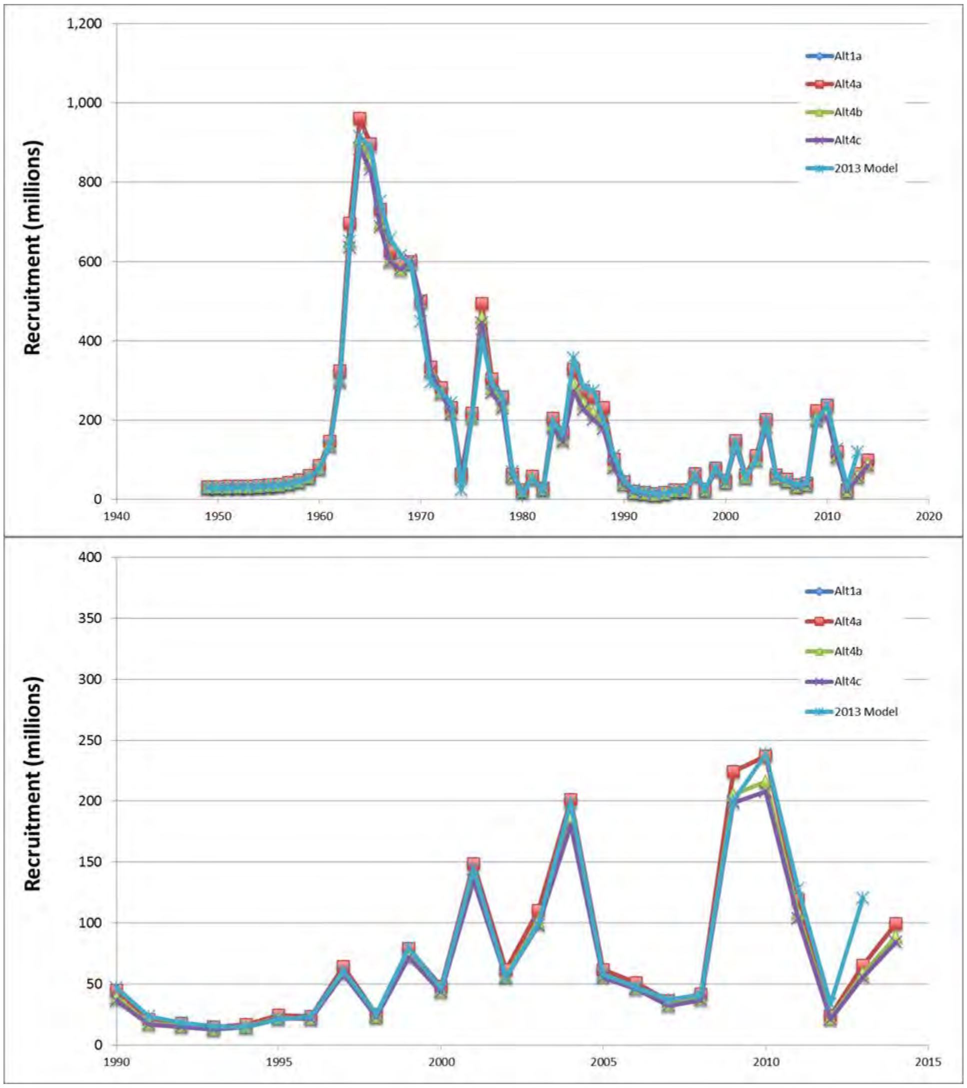


Figure A6.4. Comparison of model-estimated time series for (male) recruitment from the four alternative models and the 2013 model.

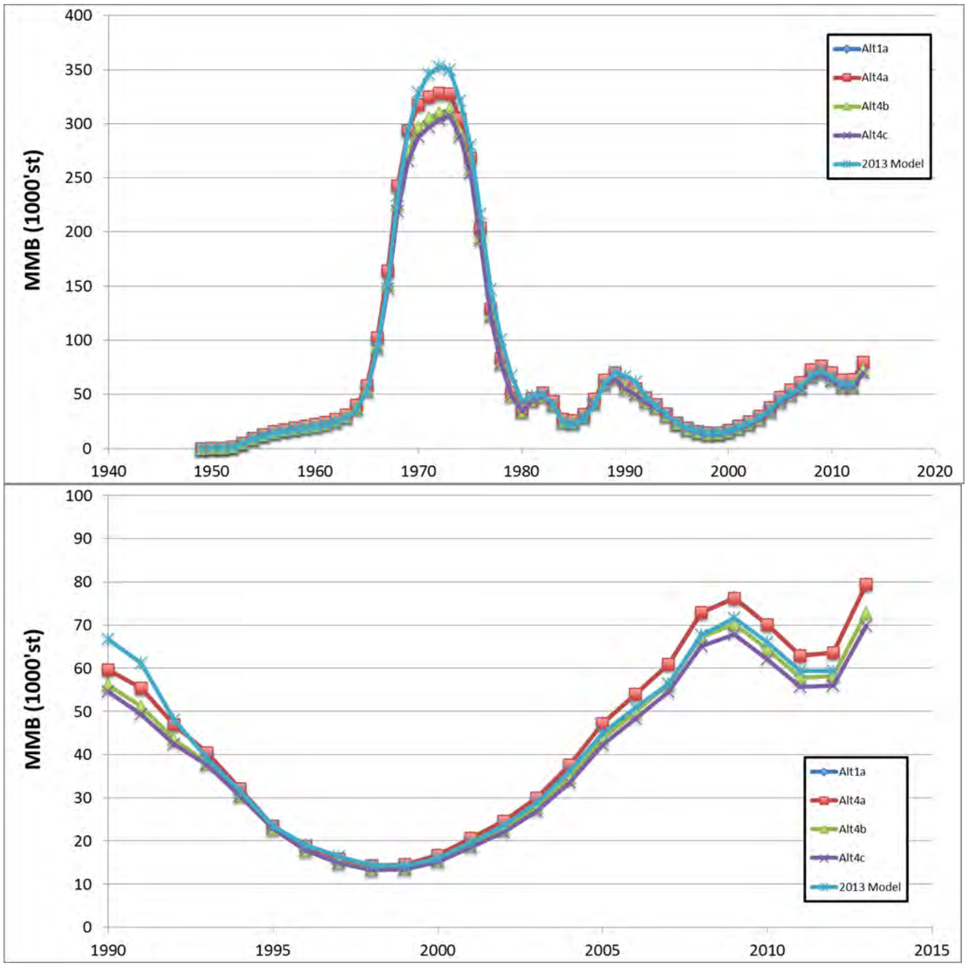


Figure A6.5. Comparison of estimated time series for mature male biomass at mating time from the four alternative models and the 2013 model.

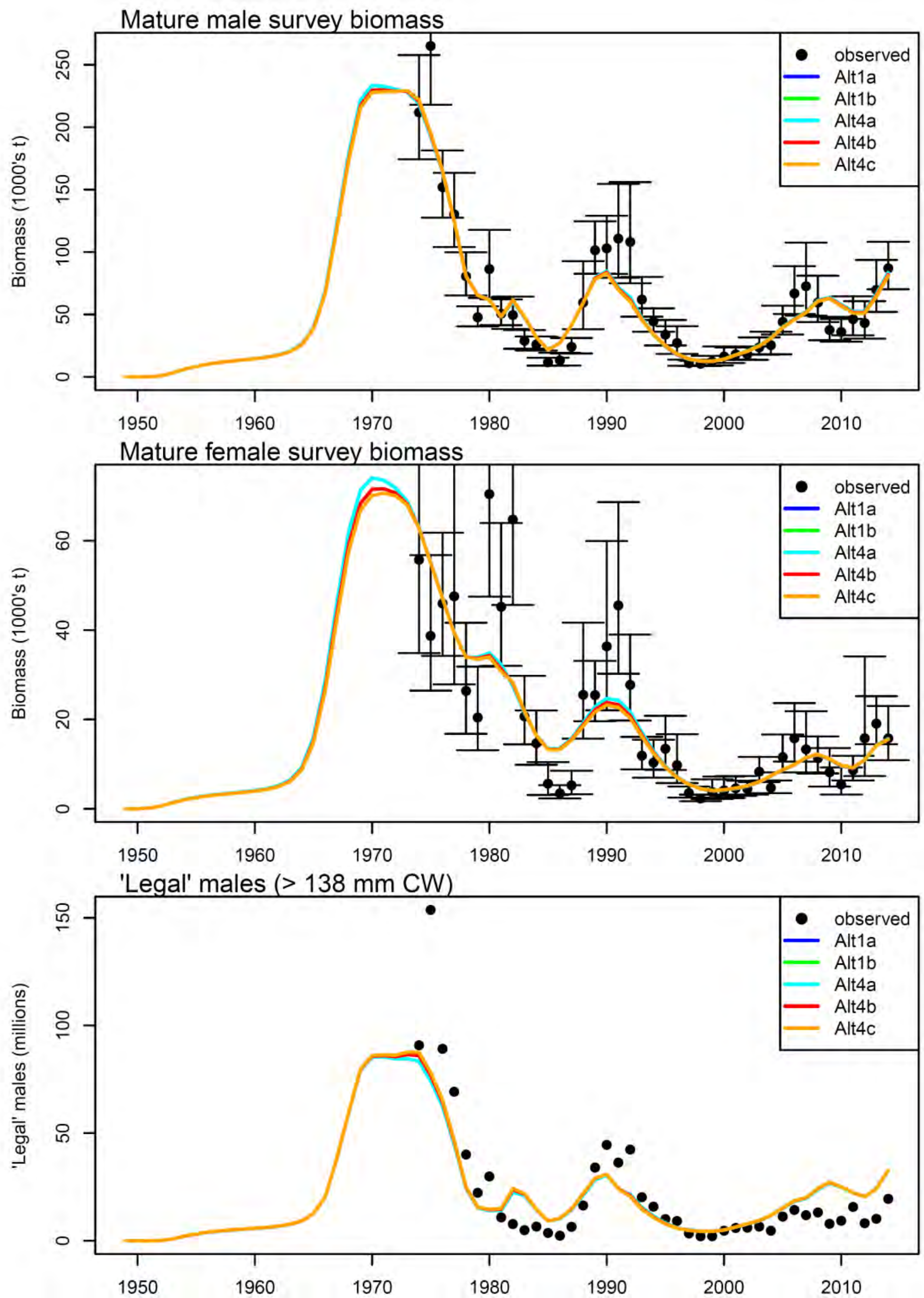


Figure A6.6. Comparison of observed and estimated survey time series for model scenarios Alt1a, Alt1b, Alt4a, Alt4b, and Alt4c:1) mature male biomass (top graph); 2) mature female biomass (middle graph), and 3) the number of males ≥ 138 mm CW (lower graph)from the four alternative models and the 2013 model.

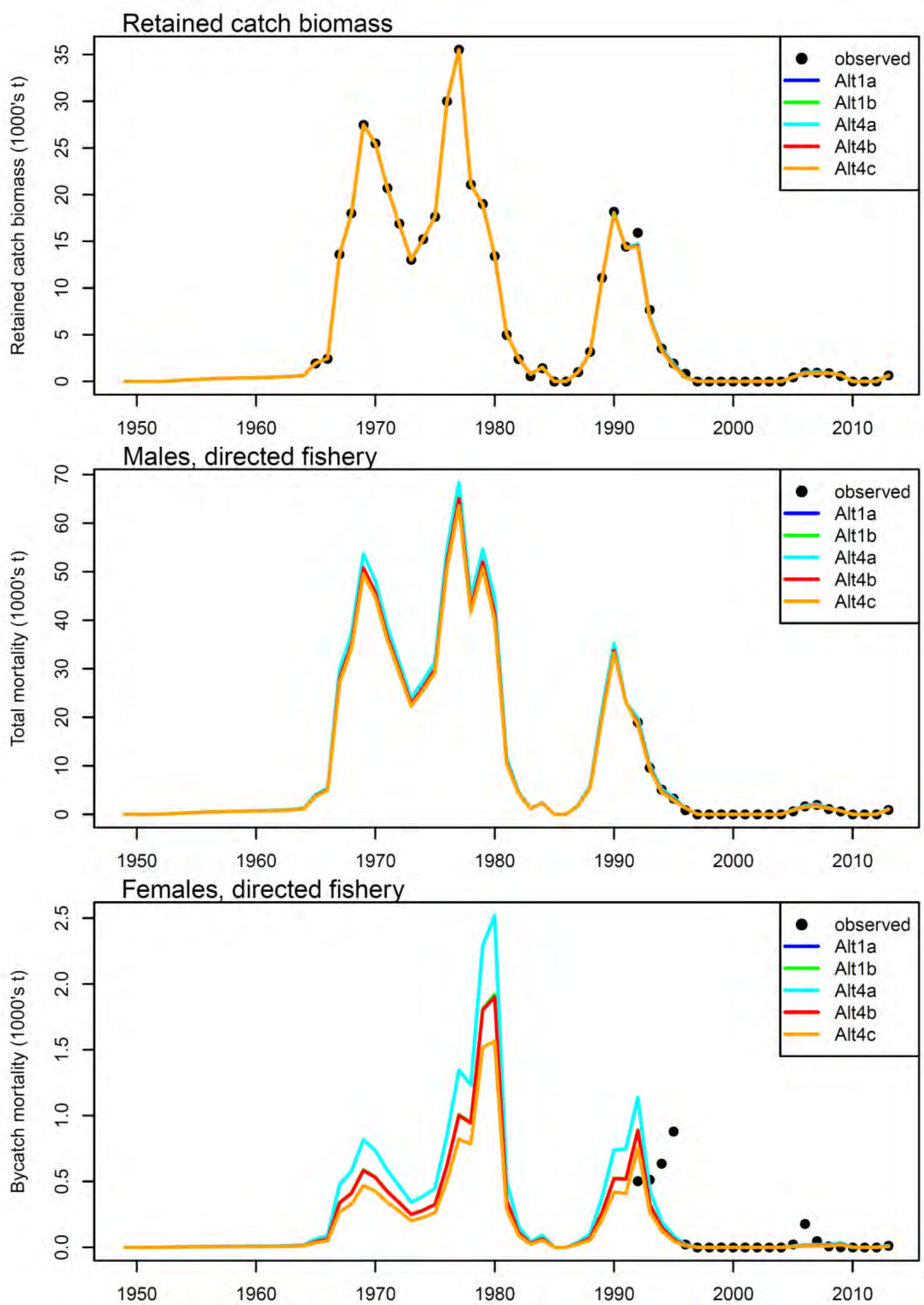


Figure A6.7. Comparison of model-estimated time series for fits to data from the directed fishery: 1) retained catch (upper graph), 2) total male mortality (retained + discard), and 3) female discard mortality (lower graph). "Observed" data is shown only for the pot fishery handling mortality = 50%..

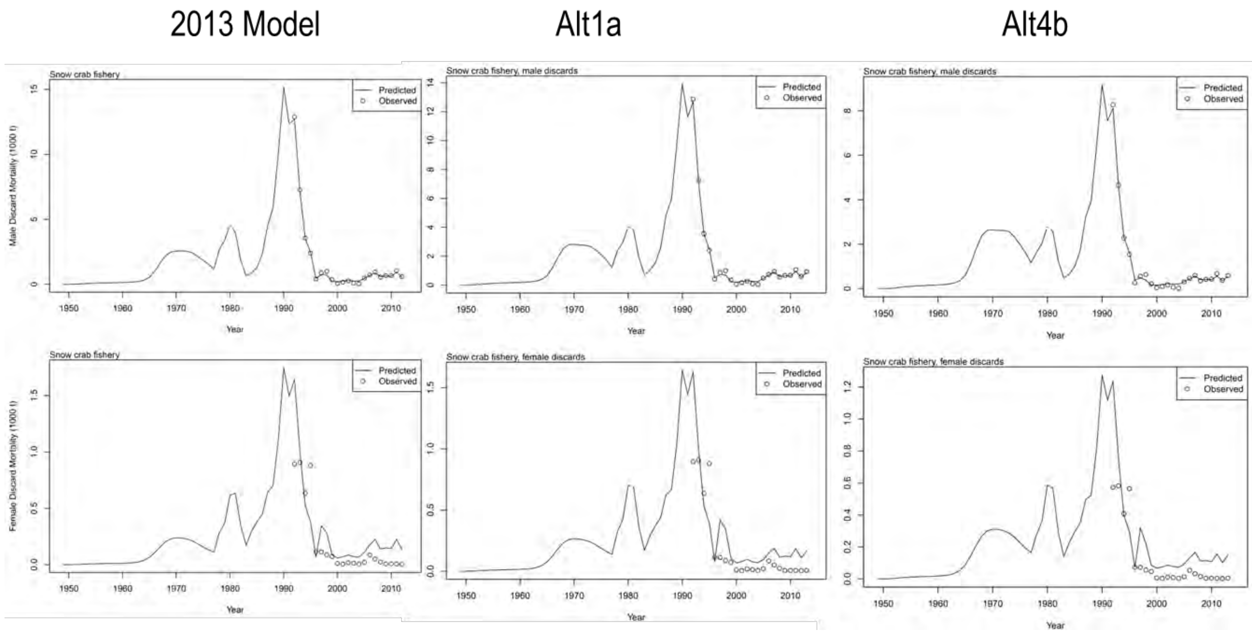
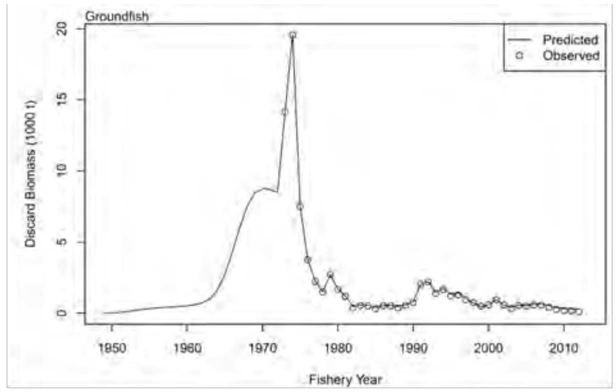
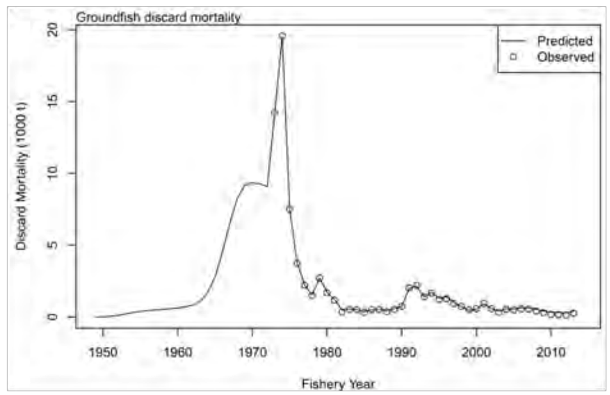


Figure A6.8. Comparison of model-estimated time series for fits to data for bycatch mortality in the snow crab fishery for the 2013 assessment model (leftmost column), Alt1a (middle column), and Alt14b (rightmost column). "Observed" discards are scaled by assumed handling mortality.

2013 Model



Alt1a



Alt4b

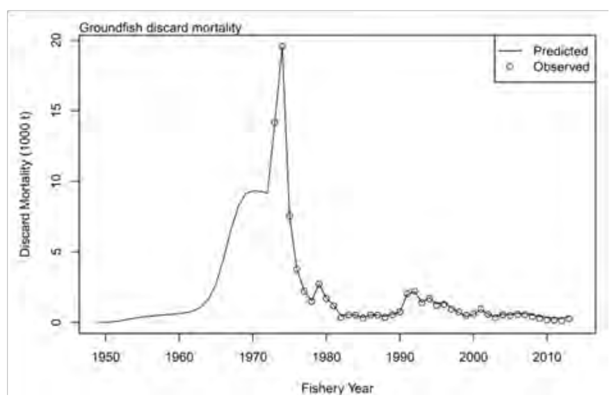


Figure A6.9. Comparison of estimated time series for fits to discard mortality in the groundfish fisheries: 1) the 2013 assessment model (upper graph), 2) Alt1a, and 3) Alt4b.

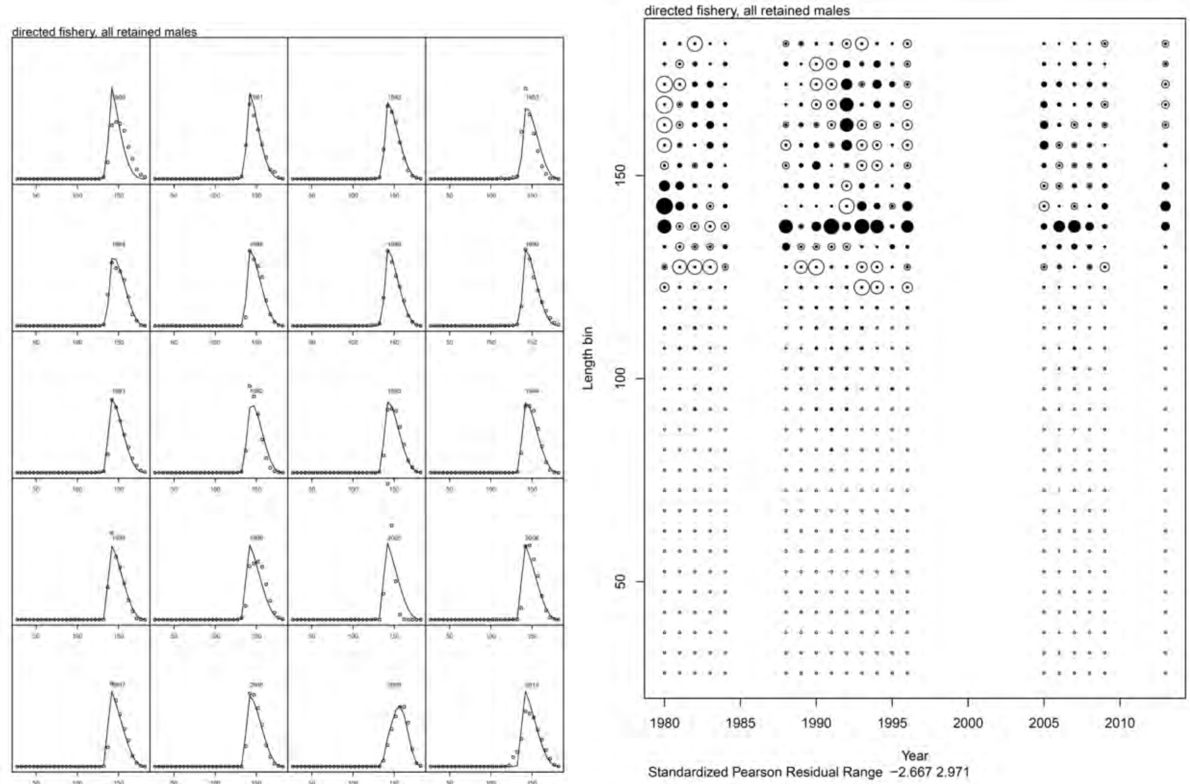


Figure A6.10. Alt4b model fits to retained catch size compositions.

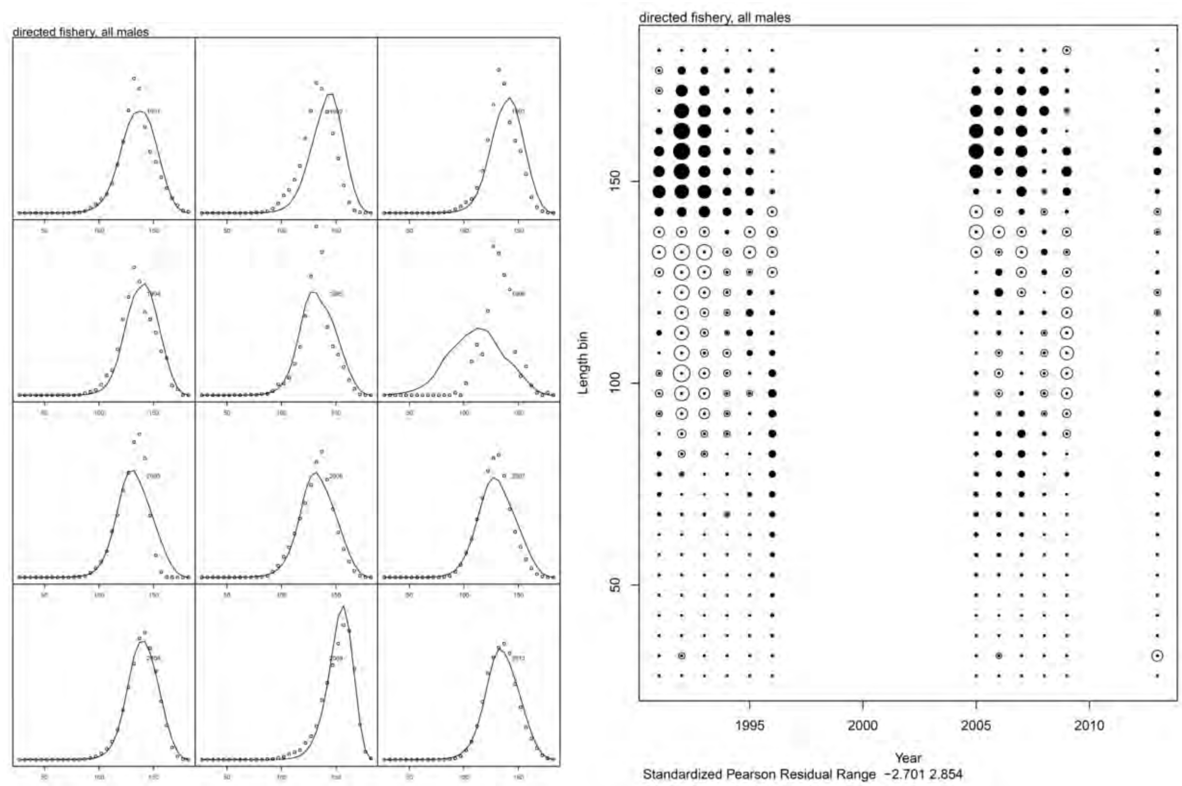


Figure A6.11. Alt4b model fits to total male catch size compositions in the directed fishery.

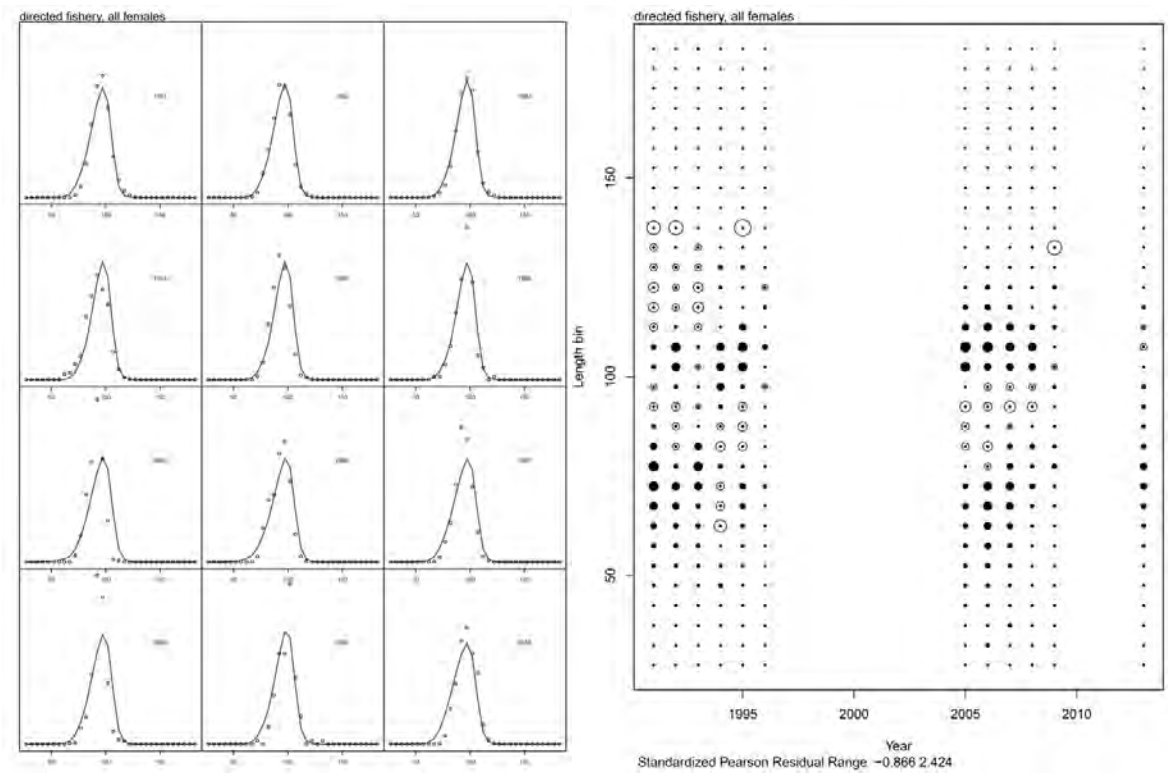


Figure A6.12. Alt4b model fits to female bycatch size compositions in the directed fishery.

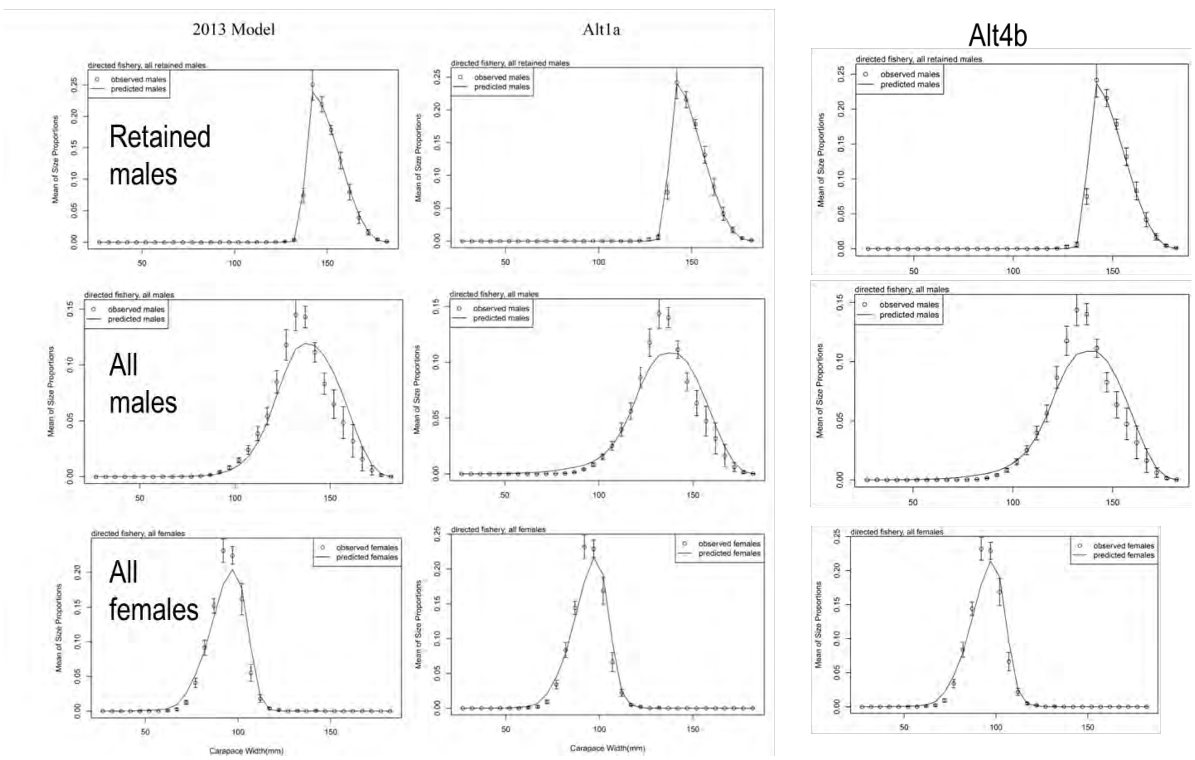


Figure A6.13. Comparison of marginal size compositions in the directed fishery. Circles with error bars are based on observer sampling.

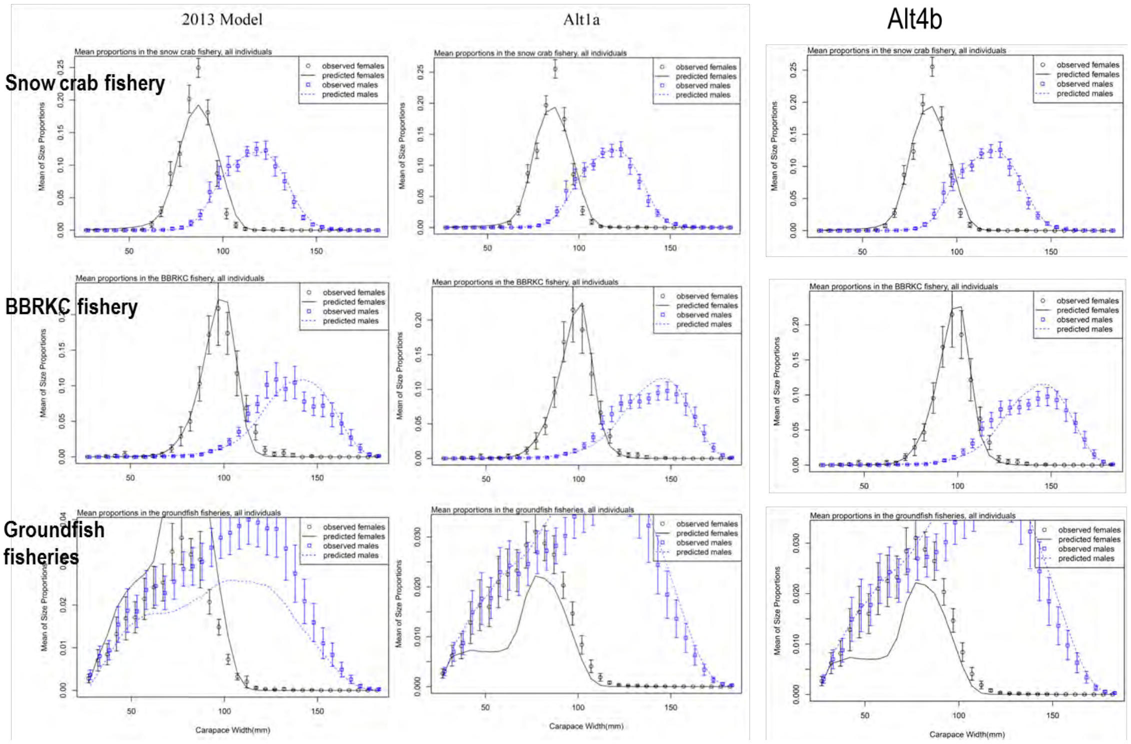


Figure 14. Comparison of marginal size compositions in the bycatch fisheries. Circles with error bars are based on observer sampling.

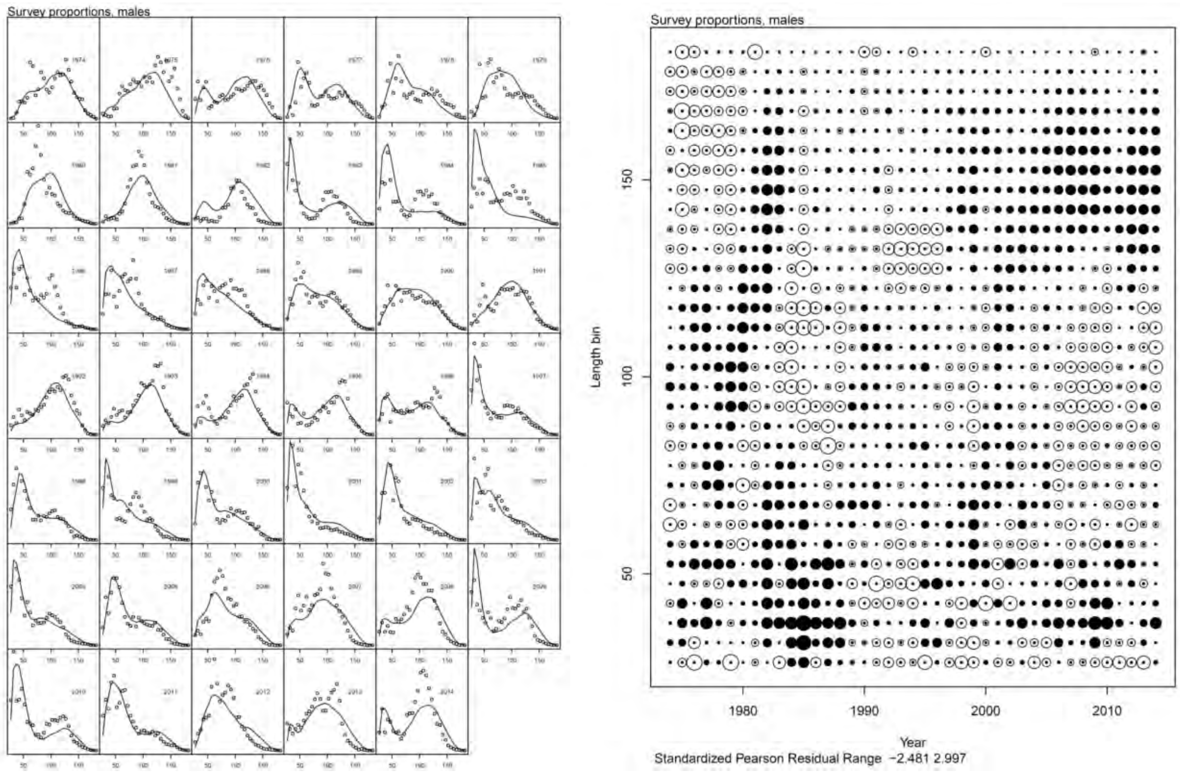


Figure 15. Alt4b model fits to male size compositions in the NMFS trawl survey.

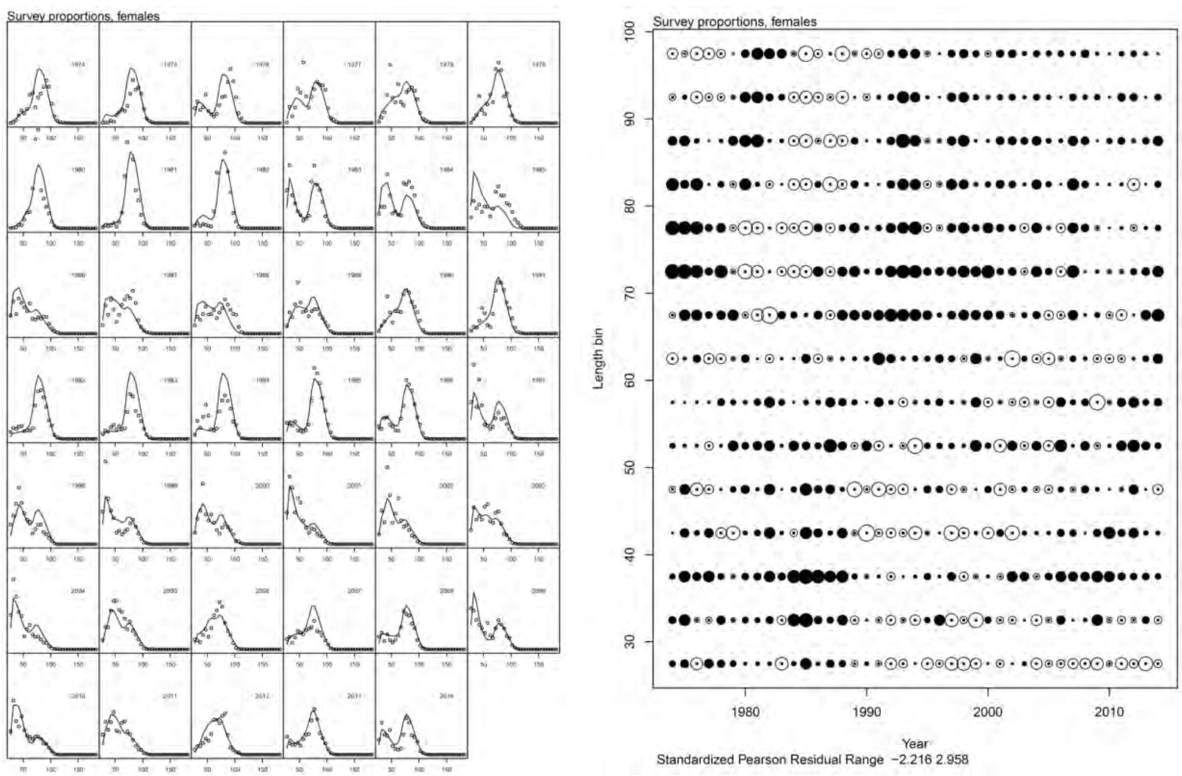


Figure 16. Alt4b model fits to female size compositions in the NMFS trawl survey.

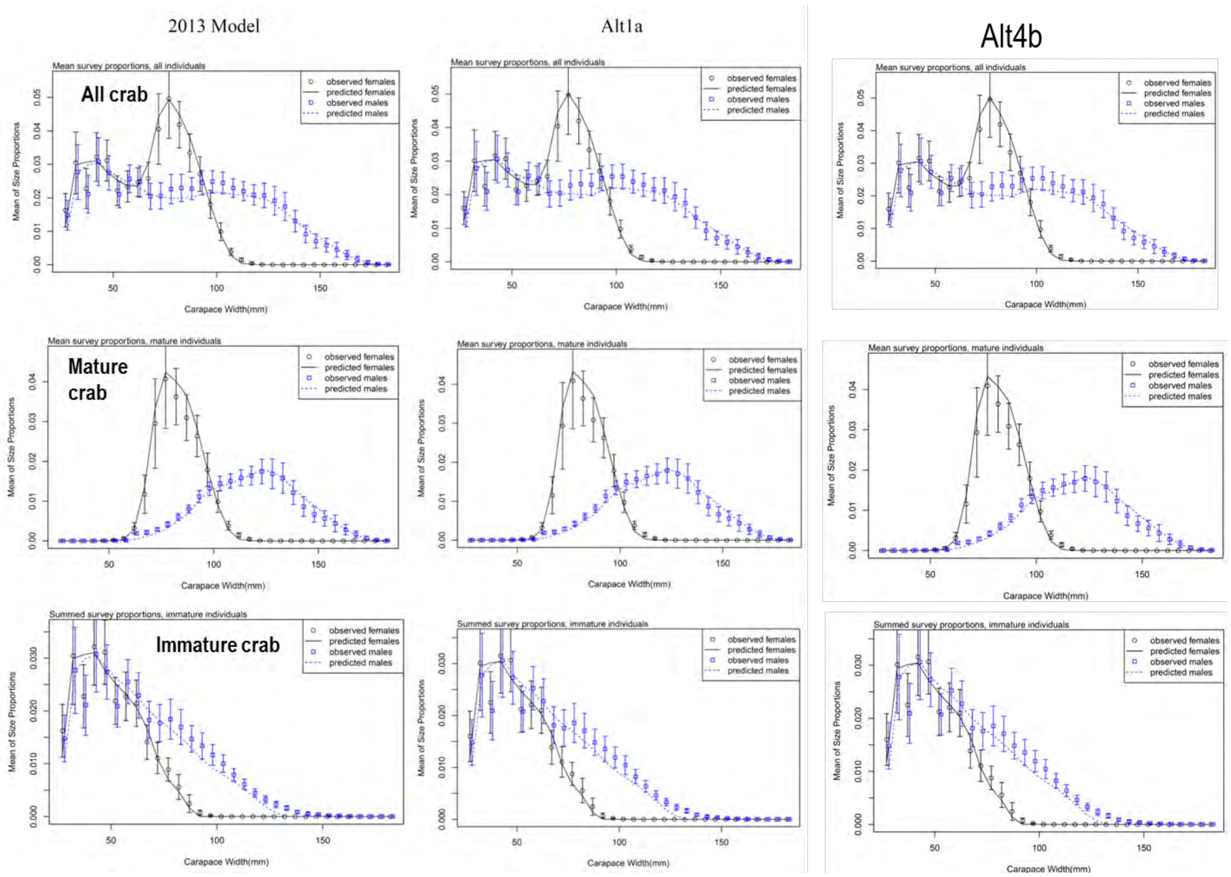


Figure A6.17. Comparison of marginal size compositions in the NMFS trawl survey. Circles with error bars are based on observer sampling.

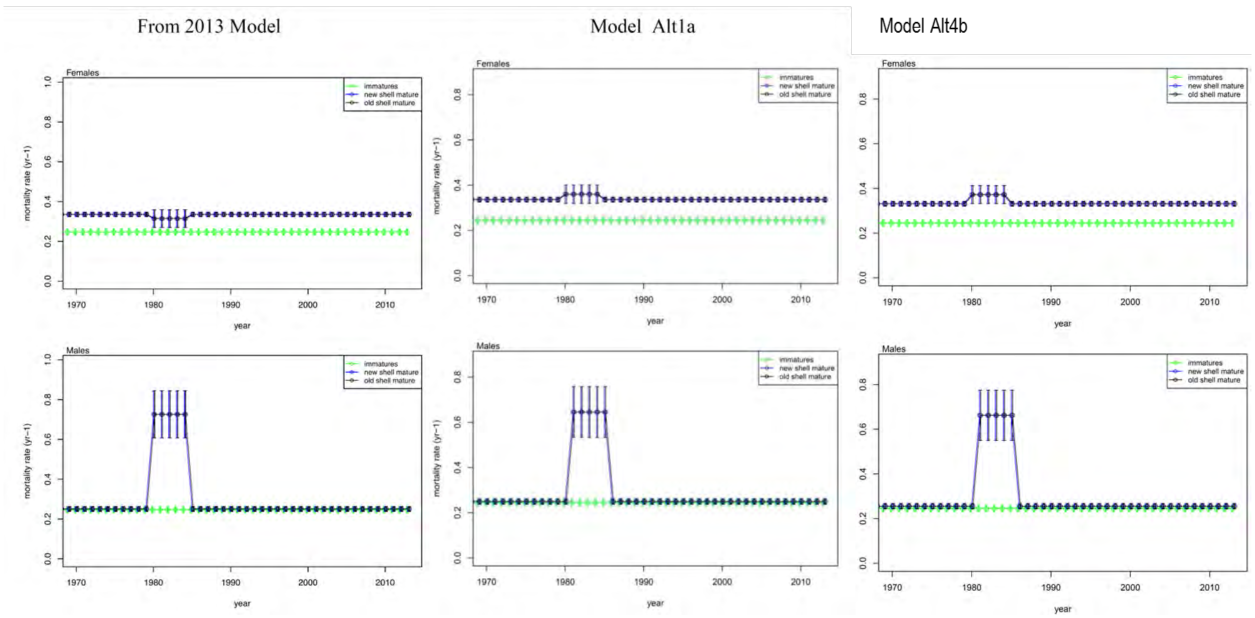


Figure A6.18. Estimated natural mortality for immature (single time period: 1949-2013) and mature (two time periods: 1949-1979+2005-2013 and 1980-1984) crab by sex (upper graph: females; lower graph: males).

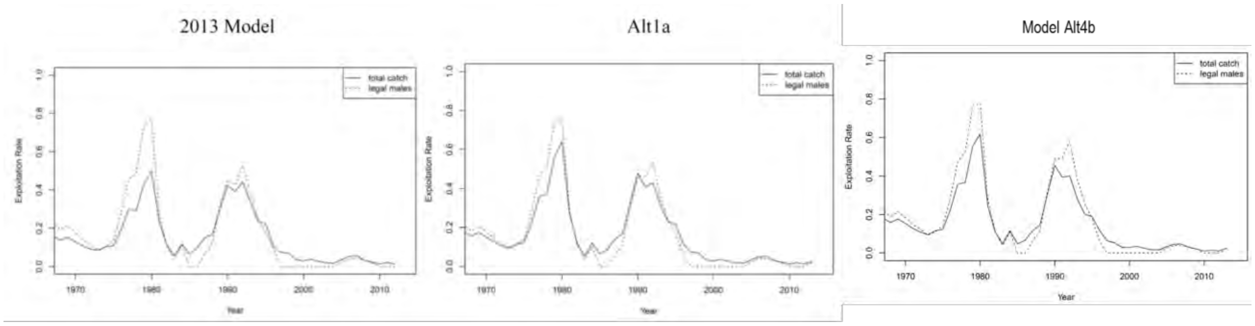


Figure A6.19. Estimated exploitation rates in the directed fishery for total catch and legal-sized males (≥ 138 mm CW).

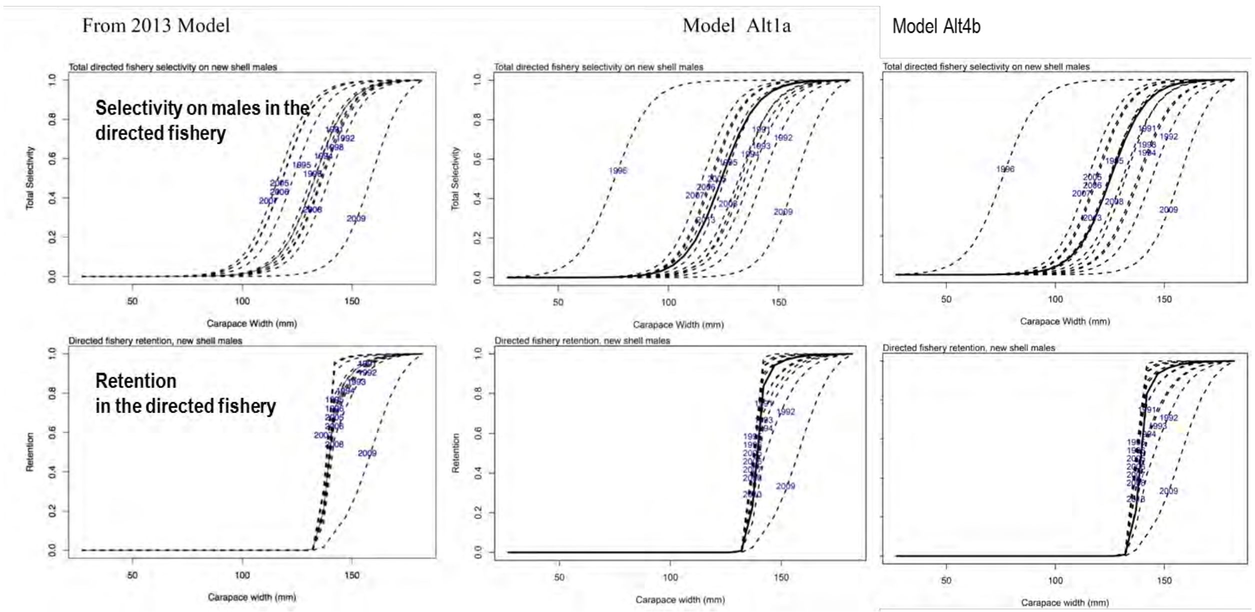


Figure A6.20. Comparison of estimated selectivity and retention functions in the directed fishery.

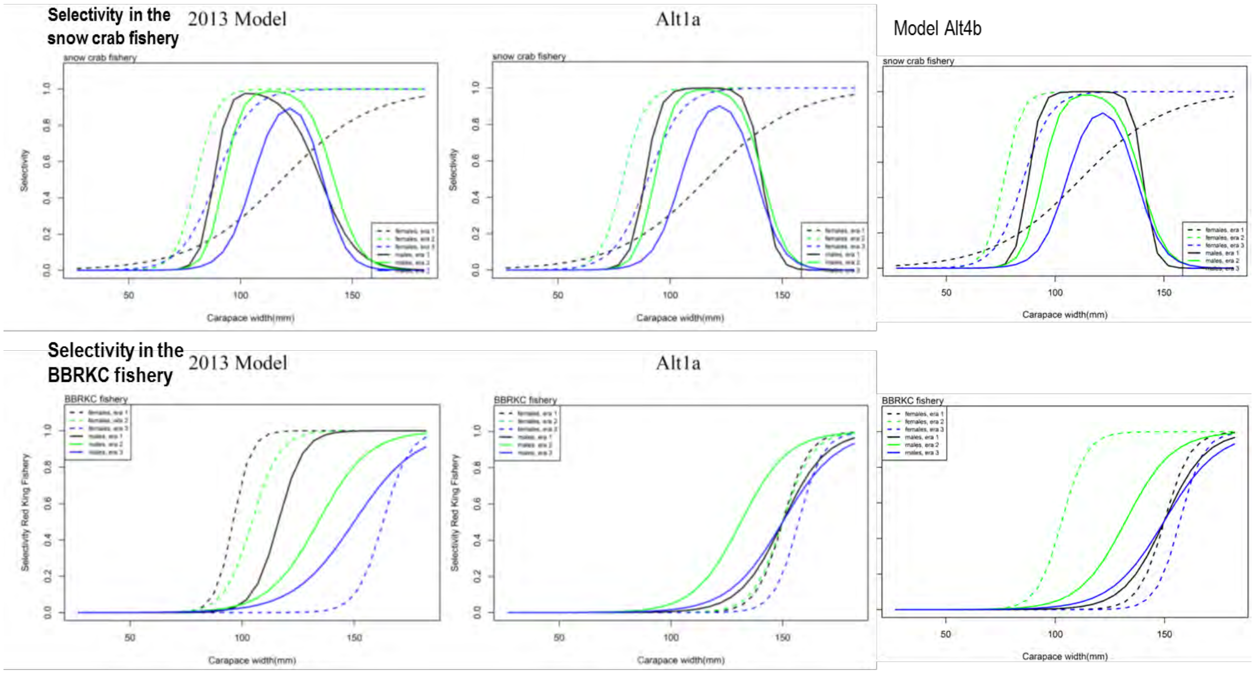


Figure A6.21. Comparison of estimated bycatch selectivity functions in the other crab fisheries.

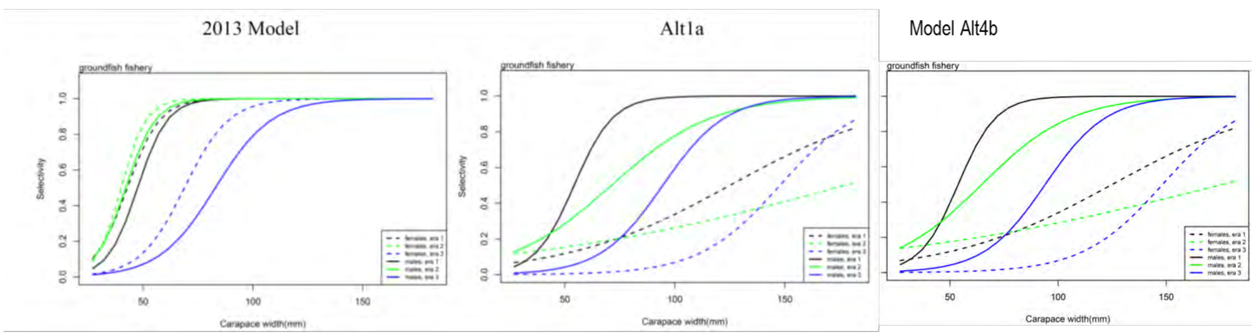


Figure A6.22. Comparison of estimated bycatch selectivity functions in the groundfish fisheries.

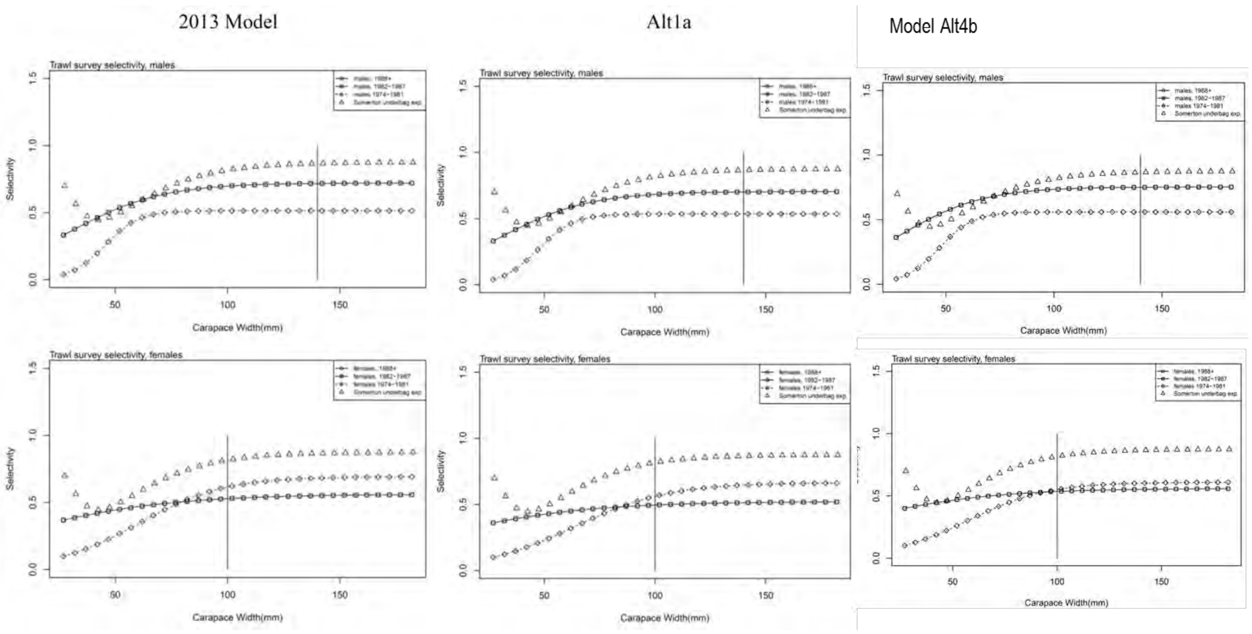


Figure A6.23. Comparison of estimated selectivity functions in the NMFS trawl survey.

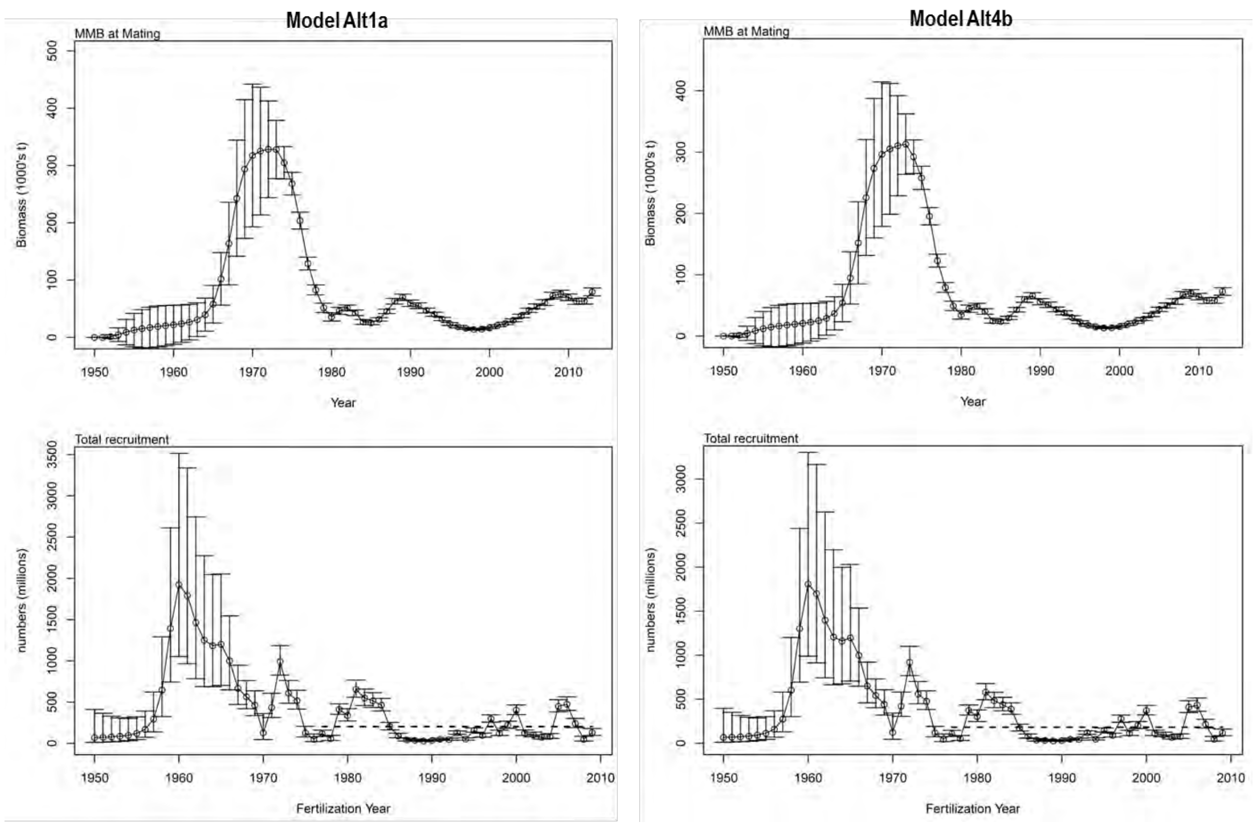


Figure A6.24. Comparison of estimated MMB (upper row) and recruitment (lower row) time series with approximate 80% confidence intervals (based on standard deviations estimated from inverting the model hessian).

220

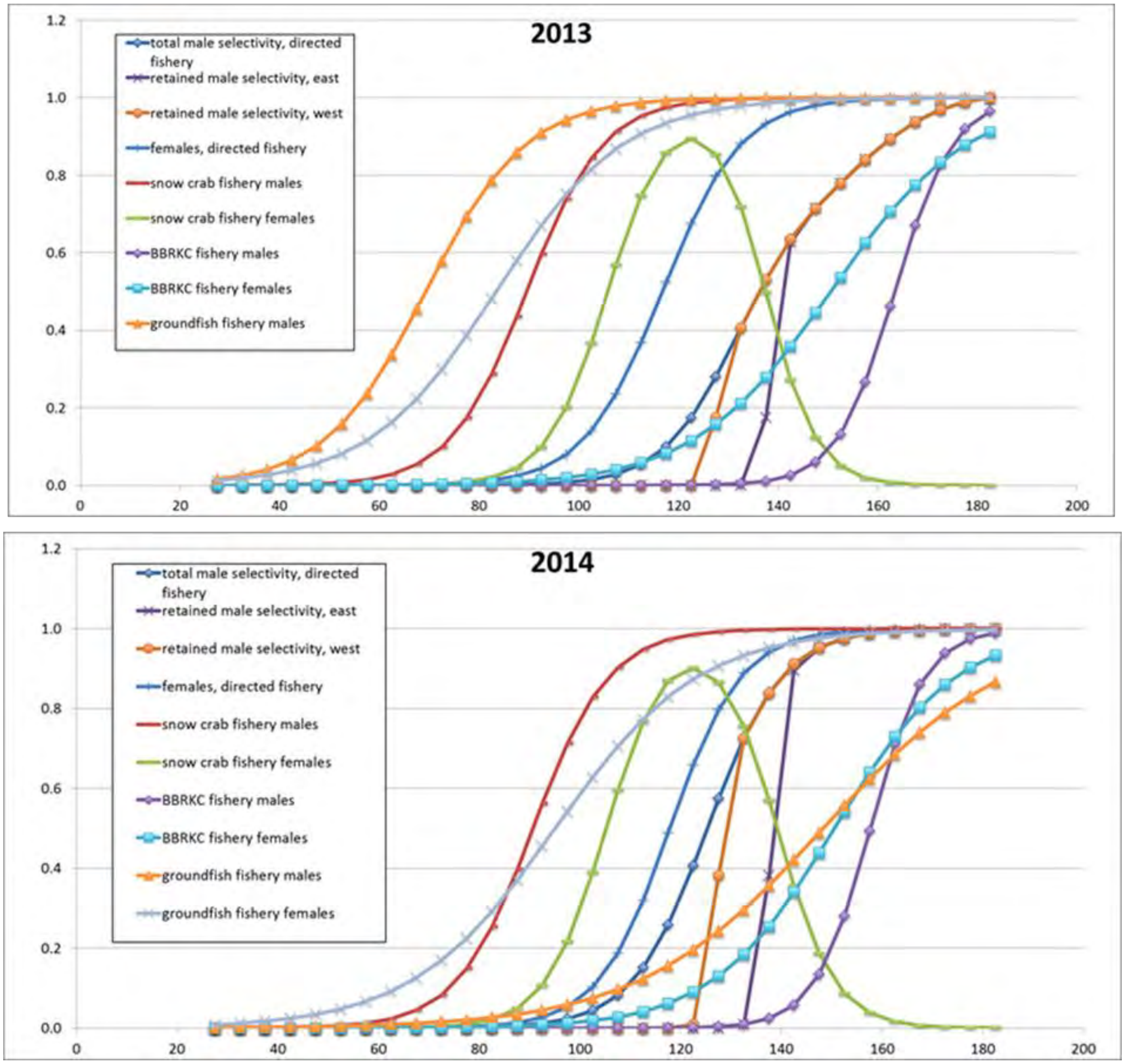


Figure A6.25. Comparison of selectivity and retention curves for the directed fishery and bycatch fisheries used to compute the OFL. Curves in the lower graph are from scenario Alt4b.

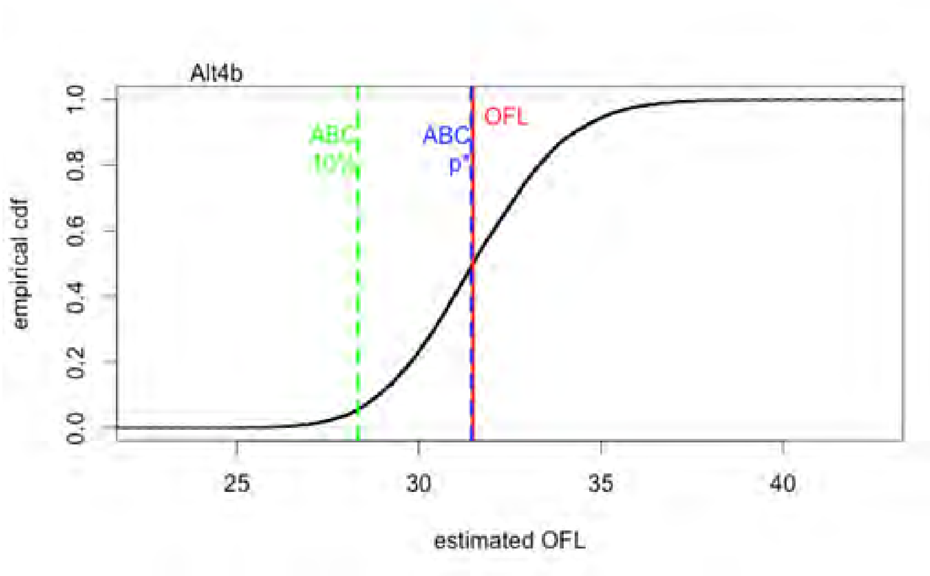


Figure A6.26. Distribution of OFL, illustrating the estimated p* ABC and 10-buffer ABC, for scenario Alt4b.

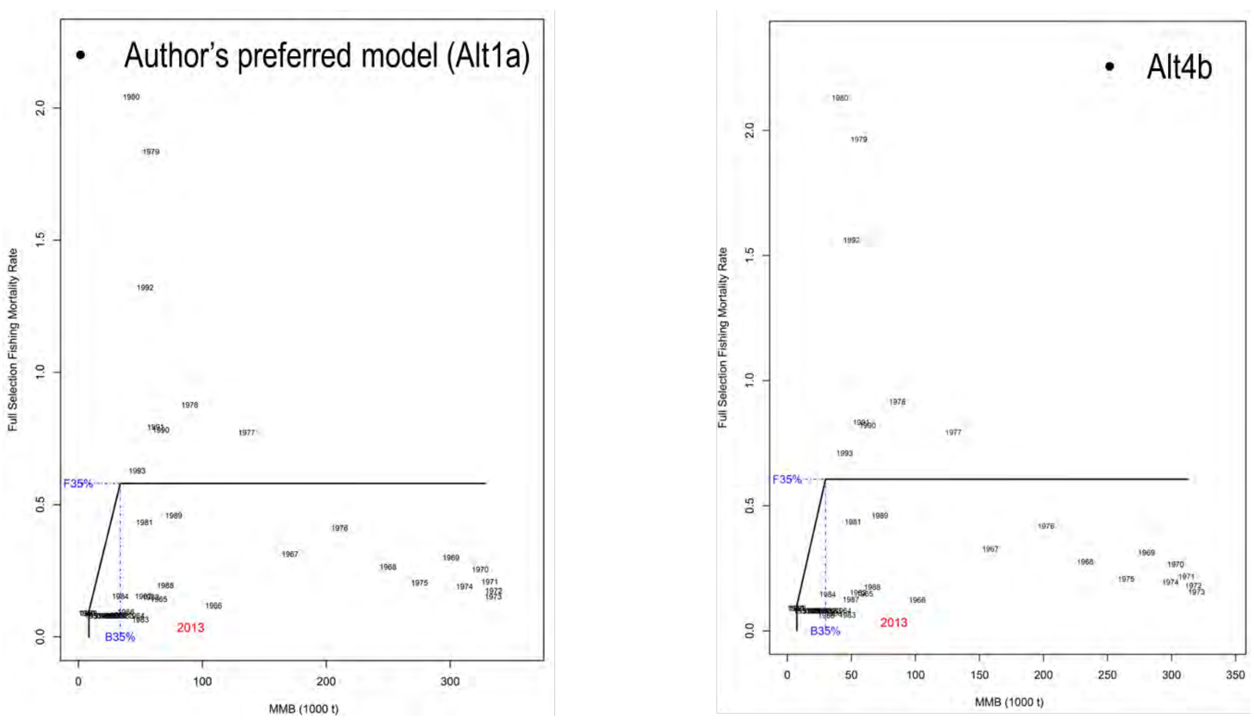


Figure A6.27. Tier 3 quad plots for the author's preferred model scenario (Alt1a) and Alt4b.

2014 Stock assessment and fishery evaluation report for the Pribilof Island red king crab fishery of the Bering Sea and Aleutian Islands regions

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Executive summary

1. Stock: Pribilof Islands red king crab, *Paralithodes camtschaticus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch and discards have been increasing in recent years, but are still low relative to the OFL.
3. Stock biomass:
    a. According to a 3-year running average, mature male biomass decreased from 2007 to 2010 and increased during 2011 through 2014.
    b. According to an integrated length-based assessment, mature male biomass increased from 2007 to 2009 and decreased from 2010 through 2014.
4. Recruitment: Recruitment is episodic for PIRKC and has been very low recently.
5. Recent management statistics:

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	2,255	2,754[A]	0	0	4.2	349	
2011/12	2,571	2,775[B*]	0	0	5.4	393	307
2012/13	2,609	4,025[C**]	0	0	13.1	569	455
2013/14	2,582	4,679 [D**]	0	0	2.25	903	718

Units are in tonnes.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	4.97	6.07[A]	0	0	0.009	0.77	
2011/12	5.67	6.12[B*]	0	0	0.011	0.87	0.68
2012/13	5.75	8.87[C**]	0	0	0.029	1.25	1.00
2013/14	5.66	10.32[D**]	0	0	0.005	1.99	1.58

Unita are in millions of lbs. The OFL is the total catch OFL for each year. The stock was above MSST in 2013/2014 according to both a 3-year average and a length-based assessment method and is hence not overfished.

Notes:

A – Based on survey data available to the Crab Plan Team in September 2010 and updated with 2010/2011 catches
B – Based on survey data available to the Crab Plan Team in September 2011 and updated with 2011/2012 catches
C – Based on survey data available to the Crab Plan Team in September 2012 and updated with 2012/2013 catches
D – Based on survey data available to the Crab Plan Team in September 2013
* – 2011/12 estimates based on 3 year running average
** –estimates based on weighted 3 year running average using inverse variance

6. Basis for 2014/2015 OFL projection:

Tier	Assessment Method	OFL	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	γ	Years to define B_{MSY}	F_{MSY}	P*	ABC
4	Running Average	1359	5742	8894	1.55	1.0	1991/1992-2013/2014 (MMB)	0.18	0.49	1338
3	Integrated assessment	801	1034	2239	2.16	1.0	1983-present (recruitment)	0.53	0.49	771
4	Integrated assessment	320	2754	2239	0.81	1.0	1991/1992-2013/2014 (MMB)	0.18	0.49	311

Units are in tonnes

Tier	Assessment Method	OFL	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	γ	Years to define B_{MSY}	F_{MSY}	P*	ABC
4	Running Average	3.00	12.66	19.60	1.55	1.0	1991/1992-2013/2014 (MMB)	0.18	0.49	2.95
3	Integrated assessment	1.77	2.28	4.94	2.16	1.0	1983-present (recruitment)	0.53	0.49	1.70
4	Integrated assessment	0.71	6.07	4.94	0.81	1.0	1991/1992-2013/2014 (MMB)	0.18	0.49	0.69

Units are in millions of pounds.

7. Probability distributions of the OFL for tier 4 methods were generated by bootstrapping values of MMB in the current year with an additional sigma of 0.3. The posterior of the OFL from the integrated assessment was used as the distribution for the OFL from which ABCs were calculated.
8. Basis for ABC: ABCs were identified as the 49th percentile of the distributions of the OFL given a p-star of 0.49.

Summary of Major Changes:

1. Management: None.
2. Input data: The crab fishery retained, bycatch, and discard catch time series were updated with 2013/2014 data. The survey data were updated with 2014/2015 data. A new methodology for estimating discard catch was used for 2009/10-2013/14 replacing the previous estimates.
3. Assessment methodology: Both a 3-year running average and an integrated assessment were used to estimate mature male biomass and Tier 3 and 4 harvest control rules were compared.
4. Assessment results: Results presented in this assessment differ from the May draft due to changes in the integrated assessment (e.g. estimating growth and changing length frequency likelihoods).

CPT May 2014 Comments specific to PIRKC assessment

Add likelihood profile for survey catchability
Done (Figure 18).

Initialize the model before the first year of data to reduce the number of parameters used
The model was initialized in 1970; the first year of data is 1975.

Consider a more generalized growth model.

The primary impetus behind the suggestion of more generalized model was the use of data from a study that showed large, non-linear changes in growth per molt for females after maturity around Kodiak Island (Stevens and Swiney, 2007b). However, a single cohort that established the commercial population in the 1980s provided an opportunity to estimate growth. There appears to be a linear relationship between pre- and post-molt length for females (Figure 13), so a more complicated model was not used.

Do not calculate likelihood contributions for length-bins with very low frequency (~0)
Done (equation A18).

Explore sensitivities to the size of length bin
The assessment was performed with data files prepared using 10mm length bins. The change in bin size did influence the estimates of some quantities important in management, so this question requires further study.

Include 3-year averages on plots
Done.

Include lognormal confidence intervals for the survey estimates of numbers and biomass
Lognormal confidence intervals back-calculated from the CVs provided by the Kodiak lab (and used in the integrated assessment) were included (Figure 6). Bootstrapped CIs were also included as the author thinks they are a more transparent method for representing the uncertainty around estimates of survey numbers.

Consider ADFG pot survey data and retained catch size frequency data
These data area not yet incorporated (or located).

Include more detail on the model
More details on the model were provided in the appendix and associated tables. The code will be made available on Github.

1. Introduction

1.1 Distribution
Red king crabs, *Paralithodes camtschaticus,* (Tilesius, 1815) are anomurans in the family lithodidae and are distributed from the Bering Sea south to the Queen Charlotte Islands and to Japan in the western Pacific (Jensen 1995; Figure 1). Red king crabs have also been introduced and become established in the Barents Sea (Jørstad et al. 2002). The Pribilof Islands red king crab stock is located in the Pribilof District of the Bering Sea Management Area Q. The Pribilof District is defined as Bering Sea waters south of the latitude of Cape Newenham (58° 39’ N lat.), west of 168° W long., east of the United States – Russian convention line of 1867 as amended in 1991, north of 54° 36’ N lat. between 168° 00’ N and 171° 00’ W long and north of 55° 30’N lat. between 171° 00’ W. long and the U.S.-Russian boundary (Figure 2).

1.2 Stock structure
Populations of red king crab in the eastern Bering Sea (EBS) for which genetic studies have been performed appear to be composed of four stocks: Aleutian Islands, Norton Sound, Southeast Alaska, and the rest of the EBS. Seeb and Smith (2005) reported micro-satellite samples from Bristol Bay, Port Moller, and the Pribilof Islands were divergent from the Aleutian Islands and Norton Sound. A more recent study describes the genetic distinction of Southeast Alaska red king crab compared to Kodiak and the Bering Sea; the latter two being similar (Grant and Cheng 2012).

1.3 Life history

Red king crabs reproduce annually and mating occurs between hard-shelled males and soft-shelled females. Red king crabs do not have spermathecae and cannot store sperm, therefore a female must mate every year to produce a fertilized clutch of eggs (Powell and Nickerson 1965). A pre-mating embrace is formed 3-7 days prior to female ecdysis, the female molts, and copulation occurs within hours. The male inverts the female so they are abdomen to abdomen and then the male extends his fifth pair of periopods to deposit sperm on the female's gonopores. Eggs are fertilized after copulation as they are extruded through the gonopores located at the ventral surface of the coxopides of the third periopods. The eggs form a spongelike mass, adhering to the setae on the pleopods where they are brooded until hatching (Powell and Nickerson 1965). Fecundity estimates are not available for Pribilof Islands red king crab, but range from 42,736 to 497,306 for Bristol Bay red king crab (Otto et al. 1990). The estimated size at 50 percent maturity of female Pribilof Islands red king crabs is approximately 102 mm carapace length (CL) which is larger than 89 mm CL reported for Bristol Bay and 71 mm CL for Norton Sound (Otto et al. 1990). Size at maturity has not been determined specifically for Pribilof Islands red king crab males, however, approximately 103 mm CL is reported for eastern Bering Sea male red king crabs (Somerton 1980). Early studies predicted that red king crab become mature at approximately age 5 (Powell 1967; Weber 1967); however, Stevens (1990) predicted mean age at recruitment in Bristol Bay to be 7 to 12 years, and Loher et al. (2001) predicted age to recruitment to be approximately 8 to 9 years after settlement. Based upon a long-term laboratory study, longevity of red king crab males is approximately 21 years and less for females (Matsuura and Takeshita 1990).

Natural mortality of Bering Sea red king crab stocks is poorly known (Bell 2006). Siddeek et al. (2002) reviewed natural mortality estimates from various sources. Natural mortality estimates based upon historical tag-recapture data range from 0.001 to 0.93 for crabs 80-169 mm CL with natural mortality increasing with size. Natural mortality estimates based on more recent tag-recovery data for Bristol Bay red king crab males range from 0.54 to 0.70, however, the authors noted that these estimates appear high considering the longevity of red king crab. Natural mortality estimates based on trawl survey data vary from 0.08 to 1.21 for the size range 85-169 mm CL, with higher mortality for crabs <125 mm CL. In an earlier analysis that utilized the same data sets, Zheng et al. (1995) concluded that natural mortality is dome shaped over length and varies over time. Natural mortality was set at 0.2 for Bering Sea king crab stocks (NPFMC 1998) and was changed to 0.18 with Amendment 24.

The reproductive cycle of Pribilof Islands red king crabs has not been established, however, in Bristol Bay, timing of molting and mating of red king crabs is variable and occurs from the end of January through the end of June (Otto et al. 1990). Primiparous (i.e. brooding their first egg clutch) Bristol Bay red king crab females extrude eggs on average 2 months earlier in the reproductive season and brood eggs longer than multiparous (i.e. brooding their second or subsequent egg clutch) females (Stevens and Swiney 2007a, Otto et al. 1990), resulting in incubation periods that are approximately eleven to twelve months in duration (Stevens and Swiney 2007a, Shirley et al. 1990). Larval hatching among red king crabs is relatively synchronous among stocks and in Bristol Bay occurs March through June with peak hatching in May and June (Otto et al. 1990), however larvae of primiparous females hatch earlier than multiparous females (Stevens and Swiney 2007b, Shirley and Shirley 1989). As larvae, red king crabs exhibit four zoeal stages and a glaucothoe stage (Marukawa 1933).

Growth parameters have not been examined for Pribilof Islands red king crabs; however they have been studied for Bristol Bay red king crab. A review by the Center for Independent Experts (CIE) reported that growth parameters are poorly known for all red king crab stocks (Bell 2006). Growth increments of immature southeastern Bering Sea red king crabs are approximately: 23% at 10 mm CL, 27% at 50 mm CL, 20% at 80 mm CL and 16 mm for immature crabs over 69 mm CL (Weber 1967). Growth of males and females is similar up to approximately 85 mm CL, thereafter females grow more slowly than males (Weber 1967; Loher et al. 2001). In a laboratory study, growth of female red king crabs was reported to vary with age; during their pubertal molt (molt to maturity) females grew on average 18.2%, whereas primiparous females grew 6.3% and multiparous females grew 3.8% (Stevens and Swiney, 2007a). Similarly, based upon tag-recapture data from 1955-1965 researchers observed that adult female growth per molt decreases with increased size (Weber 1974). Adult male growth increment averages 17.5 mm irrespective of size (Weber 1974).

Molting frequency has been studied for Alaskan red king crabs, but Pribilof Islands specific studies have not been conducted. Powell (1967) reports that the time interval between molts increases from a minimum of approximately three weeks for young juveniles to a maximum of four years for adult males. Molt frequency for juvenile males and females is similar and once mature, females molt annually and males molt annually for a few years and then biennially, triennially and quadrennial (Powell 1967). The periodicity of mature male molting is not well understood and males may not molt synchronously like females who molt prior to mating (Stevens 1990).

1.4 Management history

Red king crab stocks in the Bering Sea and Aleutian Islands are managed by the State of Alaska through the federal Fishery Management Plan (FMP) for Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 1998). The Alaska Department of Fish and Game (ADF&G) has not published harvest regulations for the Pribilof district red king crab fishery. The king crab fishery in the Pribilof District began in 1973 with blue king crab *Paralithodes platypus* being targeted (Figure 3). A red king crab fishery in the Pribilof District opened for the first time in September 1993. Beginning in 1995, combined red and blue king crab GHLs were established. Declines in red and blue king crab abundance from 1996 through 1998 resulted in poor fishery performance during those seasons with annual harvests below the fishery GHL. The North Pacific Fishery Management Council (NPFMC) established the Bering Sea Community Development Quota (CDQ) for Bering Sea fisheries including the Pribilof Islands red and blue king crab fisheries which was implemented in 1998. From 1999 to present the Pribilof Islands fishery was not open due to low blue king crab abundance, uncertainty with estimated red king crab abundance, and concerns for blue king crab bycatch associated with a directed red king crab fishery. Pribilof Islands blue king crab was declared overfished in September of 2002 and is still considered overfished (see Bowers et al. 2011 for complete management history).

Amendment 21a to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 4) which prohibits the use of trawl gear in a specified area around the Pribilof Islands year round (NPFMC 1994). The amendment went into effect January 20, 1995 and protects the majority of crab habitat in the Pribilof Islands area from impacts from trawl gear.

Pribilof Islands red king crab often occur as bycatch in the eastern Bering Sea snow crab (*Chionoecetes opilio*), eastern Bering Sea Tanner crab (*Chionoecetes bairdi*), Bering Sea hair crab (*Erimacrus isenbeckii*), and Pribilof Islands blue king crab fisheries (when there is one). Limited non-directed catch exists in crab fisheries and groundfish pot and hook and line fisheries (see bycatch and discards section below). However, bycatch is currently very low compared to historical levels.

2. Data

The standard survey time series data updated through 2014 and the standard groundfish discards time series data updated through 2014 were used in this assessment. The crab fishery retained and discard catch time series were updated with 2013/2014 data. The following sources and years of data are available:

Data source	Years available	Used in integrated assessment?
NMFS trawl survey	1975-2014	Yes
Retained catch	1993-2013	Yes

Trawl bycatch	1991-2013	Yes
Fixed gear bycatch	1991-2013	No
Pot discards	1998-2013	No

2.1 Retained catch

Red king crab were targeted in the Pribilof Islands District from the 1993/1994 season to 1998/1999. Live and deadloss landings data and effort data are available during that time period (Tables 1 and 2), but no retained catch has been allowed since 1999.

2.2 Bycatch and discards

Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers. Catch weight was calculated by first determining the mean weight (g) for crabs in each of three categories: legal non-retained, sublegal, and female. Length to weight parameters were available for two time periods: 1973 to 2009 (males: A=0.000361, B=3.16; females: A=0.022863, B=2.23382) and 2010 to 2013 (males: A=0.000403, B=3.141; ovigerous females: A=0.003593, B=2.666; non-ovigerous females: A=0.000408, B=3.128). The average weight for each category was multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 2).

$$\text{Weight (g)} = A * CL(\text{mm})^B \qquad (1)$$

$$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \qquad (2)$$

Finally, weights, discards, and bycatch were the product of average weight, CPUE, and total pot lifts in the fishery. A 50% handling mortality rate was applied to these estimates.

Historical non-retained catch data are available from 1998/1999 to present from the snow crab, golden king crab (*Lithodes aequispina*), and Tanner crab fisheries (Table 3) although data may be incomplete for some of these fisheries. Limited observer data exists prior to 1998 for catcher-processor vessels only so non-retained catch before this date is not included here. In 2013/2014, there were no Pribilof Islands red king crab incidentally caught in the crab fisheries (Table 3).

2.3 Groundfish pot, trawl, and hook and line fisheries

The 2013/2014 NOAA Fisheries Regional Office (J. Gasper, NMFS, personal communication) assessments of non-retained catch from all groundfish fisheries are included in this SAFE report. Groundfish catches of crab are reported for all crab combined by federal reporting areas and by State of Alaska reporting areas since 2009/2010. Catches from observed fisheries were applied to non-observed fisheries to estimate a total catch. Catch counts were converted to biomass by applying the average weight measured from observed tows from July 2011 to June 2012. Prior to 2011/2012, Areas 513 and 521 were included in the estimate, a practice that likely resulted in an overestimate of the catch of Pribilof Islands red king crab due to the extent of Area 513 into the Bristol Bay District. In 2012/2013 these data were available in State of Alaska reporting areas that overlap specifically with stock boundaries so that the management unit for each stock can be more appropriately represented. To estimate sex ratios for 2012/2013 catches, it was assumed that the male to female ratio was one. To assess crab mortalities in these groundfish fisheries a 50% handling mortality rate was applied to pot and hook and line estimates and an 80% handling mortality rate was applied to trawl estimates.

Historical non-retained groundfish catch data are available from 1991/1992 to present (J. Mondragon, NMFS, personal communication) although sex ratios have not been determined (Table 3). Prior to 1991data are only available in INPFC reports. Between 1991 and December 2001 bycatch was estimated using the “blend method”. The blend method combined data from industry production reports and observer reports to make the best, comprehensive accounting of groundfish catch. For shoreside processors, Weekly Production Reports (WPR) submitted by industry were the best source of data for retained groundfish landings. All fish delivered to shoreside processors were weighed on scales, and these weights were used to account for retained catch. Observer data from catcher vessels provided the best data on at-sea discards of groundfish by vessels delivering to shoreside processors. Discard rates from these observer data were applied to the shoreside groundfish landings to estimate total at-sea discards from both observed and unobserved catcher vessels. For observed catcher/processors and motherships, the WPR and the Observer Reports recorded estimates of total catch (retained catch plus discards). If both reports were available, one of them was selected during the "blend method" for incorporation into the catch database. If the vessel was unobserved, only the WPR was available. From January 2003 to December 2007, a new database structure named the Catch Accounting System (CAS) led to large method change. Bycatch estimates were derived from a combination of observer and landing (catcher vessels/production data). Production data included CPs and catcher vessels delivering to motherships. To obtain fishery level estimates, CAS used a ratio estimator derived from observer data (counts of crab/kg groundfish) that is applied to production/landing information. (See http://www.afsc.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-205.pdf). Estimates of crab are in numbers because the PSC is managed on numbers. There were two issues with this dataset that required estimation work outside of CAS:

1) The estimated number of crab had to be converted to weights. An average weight was calculated using groundfish observer data. This weight was specific to crab year, crab species, and fixed or trawl gear. This average was applied to the estimated number of crab for crab year by federal reporting area.
2) In some situations, crab estimates were identified and grouped in the observed data to the genus level. These crabs were apportioned to the species level using the identified crab.

From January 2008 to 2012 the observer program changed the method in which they speciate crab to better reflect their hierarchal sampling method and to account for broken crab that in the past were only identified to genus. In addition, haul-level weights collected by the observers were used to estimate the weight of crab through CAS instead of applying an annual (global) weight factor. Spatial resolution was at federal reporting area.

Starting in 2013, a new data set based on the CAS system was made available for January 2009 to present. In 2009 reporting State statistical areas was required on groundfish production reports. The level of spatial resolution in CAS was formally federal reporting area since this the highest spatial resolution at which observer data is aggregated to create bycatch rates. The federal reporting area does not follow crab stock boundaries, in particular for species with small stock areas such as Pribilof Islands or St. Matthew Island stocks, so the new data was provided at the State reporting areas. This method uses ratio estimator (weight crab/weight groundfish) applied to the weight of groundfish reported on production/landing reports. Where possible, this dataset aggregates observer data to the stock area level to create bycatch estimates by stock area. There are instances where no observer data is available and aggregation may go outside of a stock area, but this practice is greatly reduced compared with the pre-2009 data, which at best was at the Federal reporting area level.

The new time series resulted in different estimates of red king crab bycatch biomass in 2009/2010-2012/2013 (Table 3). In 2012/2013, using the new database estimation, 16.46 t of male and female red king crab were caught in fixed gear (0.23 t) and trawl gear (16.23 t) groundfish fisheries which is 51% greater than was caught in 2011/2012 pot, trawl, and hook and line groundfish fisheries. The catch was mostly in non-pelagic trawls (99%) followed by longline (1%), and pot (<1%) fisheries (Table 4). The targeted species in these fisheries were Pacific cod (3%), flathead sole (18%), yellowfin sole (77%), and traces <1% found in the rockfish fisheries. Unlike previous years no bycatch was observed in Alaska plaice fisheries in 2011/2012 or 2012/2013.

2.4 Catch-at-length
Catch-at-length data are not available for this fishery.

2.5 Survey biomass and length frequencies
The 2014 NOAA Fisheries EBS bottom trawl survey results (Daly et al. in press) are included in this SAFE report. Data available for estimating the abundance of crab around the Pribilof Islands are relatively sparse. Red king crab have been observed at 35 unique stations in the Pribilof District (22 stations on the 400 nm^2 grid). The number of stations at which at least one crab was observed in a given year ranges from 0-14 over the period from 1975-present (Figure 5). Weight (equation 1) and maturity (equation 3) schedules are applied to calculated abundances and summed to calculate mature male, female, and legal male biomass for the Tier 4 analysis.

$$\text{Proportion mature male} = 1/(1 + (5.842 * 10^{14}) * e^{((CL(mm)+2.5) * -0.288)})$$
$$\text{Proportion mature female} = 1/(1 + (1.416 * 10^{13}) * e^{((CL(mm)+2.5) * -0.297)}) \qquad (3)$$

Historical survey data are available from 1975 to the present (Tables 5 and 6), and survey data analyses were standardized in 1980 (Stauffer, 2004). Male and female abundance varies widely over the history of the survey time series' (Figure 6) and uncertainty around area-swept estimates of abundance are large due to relatively low sample sizes (Figure 5). Male crabs were observed at 4 of 35 stations in the Pribilof District during the 2014 NMFS survey (Figure 7); female crabs were observed at 3 (Figure 8). Two (possibly three) cohorts can be seen moving through the length-classes over time (Figure 9 and Figure 10). Numbers at length vary dramatically from year to year, but the cohorts can nonetheless also be discerned in these data (Figure 11 and Figure 12).

The centers of distribution for both males and females have moved within a 40 nm by 40 nm region around St. Paul Island. The center of the red king crab distribution moved to within 20 nm of the northeast side of St. Paul Island as the population abundance increased in the 1980's and remained in that region until the 1990's. Since then, the centers of distribution have been located closer to St. Paul Island the exception of 2000-2003 located towards the north east.

Survey length frequencies were calculated from the survey data for use in the integrated assessment. Occasionally, several hauls were taken at a single survey station (here a 'haul' does not refer to the high density sampling in which the 'corners' of a station are trawled—'haul' refers to multiple samples from a given location). Treating multiple hauls as independent measurements may introduce bias when calculating the population-wide length frequencies. Therefore, whenever multiple hauls were taken at a station, their contribution to the overall length frequency was weighted by the average number of individuals caught in a haul at that station.

3. Analytical approaches
3.1 History of modeling
An inverse-variance weighted 3-year running average of mature male biomass based on densities estimated from the NMFS summer trawl survey has been used in recent years to set allowable catches. The natural mortality rate has been used as a proxy for the fishing mortality at which maximum sustainable yield occurs (Fmsy) and target biomasses are set by identifying a range of years over which the stock was thought to be near B_{MSY} (i.e. a tier 4 control rule). A catch survey analysis has been used for assessing the stock in the past, although the data are not currently used in this assessment. This year (2014), biomass and derived management quantities are estimated both by a running-average method and by an integrated length-based assessment method (developed in 2014). Tier 3 and tier 4 harvest control

rules (HCRs) are applied to the integrated assessment output and are compared to the OFLs calculated by a tier 4 HCR applied to the running-average estimates of MMB.

3.2 Model descriptions

3.2.1. Running average

A 3 year running average of mature male biomass (runAvg) was calculated using the function 'weighted.mean' in the R programming languages as:

```
for(t in 2:(length(MMB)-1))
 runAvg[t]<-weighted.mean(MMB[(t-1):(t+1)],w=1/σ2[(t-1):(t+1)])          (4)
```

Where,

MMB	Estimated mature male biomass from the survey data
σ^2	The variance associated with the estimate of MMB at time t

σ_t^2 is calculated from the CVs of the estimates of MMB from the survey provided by the Kodiak lab as:

$$\sigma_t^2 = \ln(\mu_t^{MMB} * CV_t^{MMB})^2 \tag{5}$$

Where,

μ_t^{MMB}	estimated mature male biomass from the survey at time t
CV_t^{MMB}	Coefficient of variation associated with the estimate of MMB at time t

3.2.2 Integrated assessment

A length-based integrated assessment method was coded in ADMB (Fournier et al. 2012) to estimate trends in recruitment, fishing mortality (directed and bycatch in the non-pelagic trawl fishery) and mature male biomass (see appendix A for the model description, likelihood weightings, and estimated and fixed parameters). The assessment is initiated 5 years before data are available to avoid estimating initial numbers at length for both sexes. Males and females are tracked by 5 mm length bins ranging from 37.5-207.5mm. Sensitivities to the size of bin with were performed by repeating the analysis with 10 mm length bins. A likelihood profile for survey catchability was performed to explore the influence of fixing survey catchability at 1 on the objective function. Fishing mortality from the directed fishery during 1993-1998 and bycatch in the non-pelagic trawl fishery from 1991-2013 were accounted for in the model, but discards from the pot fisheries for crab and the fixed gear fishery for cod are not incorporated into the model. The magnitude of the mortality imposed by discards on the population is very small compared to the directed fishery, so the impact of excluding them from the model should be relatively small. Samples were drawn from the posterior distributions for some quantities important in management (e.g. the OFL and MMB) using MCMC to characterize the uncertainty in parameter estimates and derived quantities. This involved conducting 10,000,000 cycles of the MCMC algorithm, implementing a 20% burn-in period and saving every 3000th draw for the assessments in which growth was estimated (when growth was fixed, fewer cycles were required). Several diagnostic statistics (e.g. checking for lack of autocorrelation and calculating Geweke statistics) were used to check for evidence of non-convergence of the MCMC algorithm. MCMC was performed while estimating all parameters in table A1 and while fixing the parameters associated with growth.

Growth was estimated within the integrated assessment because there are no targeted studies on growth of Pribilof Island red king crab. The presence of a single, large cohort that established the population during the mid-1980s and then was subsequently relatively lightly fished (or not at all in the case of females) makes estimating growth tractable. The modes of the length frequency distributions over this period should be indicative of the growth per molt and, when translated to growth per molt, were well fit by a linear relationship (Figure 13).

4. Model Selection and Evaluation

Three assessment methods are presented for evaluation: a running average with a tier 4 HCR, an integrated assessment with tier 3 HCR, and an integrated assessment with a tier 4 HCR. This is the first comparison of estimates from an integrated assessment to estimates from a running average model for this stock, so alternative weighting schemes, alternate specifications of non-estimated parameters, or alternative functional forms of population processes were not explored.

There are trade-offs between using the running average method and the integrated assessment to estimated MMB. The running average methodology is simple to perform and interpret, but estimates of biomass can be sensitive to measurement errors, particularly when relatively few stations report observations of crab. An integrated assessment can smooth over some of the error introduced by imperfect measurement, but it also smoothes over process error (e.g. time-varying natural mortality) that may be captured by a running average. Integrated assessments are also relatively data-hungry and some assumptions must be made about the underlying population processes like selectivity of the different fleets.

Non-convergence of the integrated models was checked for by examining the maximum gradient components and the ability to invert the Hessian matrix.

5. Results

5.1 Mature biomass

Estimated MMB from the integrated assessment peaked during 1992 at 4071 t; estimates of MMB from a 3-year moving average peaked during 1994 at 18203 t (Figure 14; table 7 and 8). Female mature biomass peaked during 2001 at 1541 t; whereas estimates of FMB from the 3-year moving average peaked during 1994 at 5112 t. Estimated trajectories of the two models are similar in that a large pulse of recruitment in the early 1980s translates to an initial rise in biomass which is fished down through the 1990s. However, estimates of biomass from the integrated assessment rebound to levels as high as or higher than the early 1990s levels after fishing pressure is ceased. Estimates from the 3-year moving average for both MMB and FMB do not return to the levels estimated during the early 1990s. The integrated assessment estimated mature male biomass for 2014 at 2239 t; the running average method estimated MMB at 9303 (t).

5.2 Integrated assessment model fits

Estimated male survey numbers peaked during 1991 at 1.49 million, corresponding to an estimated mature male biomass at 3954 t (Figure 14). Estimated female survey numbers peaked during 1992 at 1.22 million, corresponding to an estimated mature female biomass of 1525 t (Figure 14). Catch and bycatch in the non-pelagic trawl fishery are well fit by the assessment method (Figure 15). Given a relatively low natural mortality, a short series of years in which there was a directed fishery, and the selectivity of the fishery, the assessment method was unable to track large year-to-year swings in estimated survey abundance. It is possible that swings in estimates of abundance were attributable to sampling error, given the few data points available to inform these estimates. This is somewhat corroborated by noting the number of observations available to inform the estimates increases over time (Figure 5) and the extreme estimates of biomass are less often observed after the 2000. The differences in interannual variability of estimates of mature biomass between the integrated assessment and running average represent a tradeoff between following data influenced by low sample sizes (running average) and the smoothing effects of assuming a constant natural mortality (integrated assessment).

Large estimated recruitment events during the mid-1980s translated to a large increase in mature biomass, but estimated recruitment events since that period have been much smaller (Figure 16). Estimated recruitment is very poor during recent years (2003-present) and there does not seem to be a relationship between female mature biomass and recruitment at 4, 5, or 6 year lags (Figure 17). Estimated fishing mortality peaks in 1998 (the last year of the directed fishery) at 0.62, which exceeds the calculated F35% of 0.53. Estimated survey selectivity is gradually increases until ~141 mm length at which point 95% of crab are selected in the survey gear (Figure 16) and survey catchability is fixed at 1. The negative log likelihood decreases as survey catchability (q) increases, even beyond a value of 1 (Figure 18). However, catchability higher than 1 is difficult to justify, so fixing q at 1 is a reasonable practice here. Fishery selectivity is not estimated as there are no catch at length or discard at length data available.

Two (possibly three) cohorts are seen to move through the male size classes throughout the history of the fishery and the resulting survey length frequencies are better fit in the 1980s than during the late 1990s and early 2000s (Figure 19). During 1999 and 2001, two large peaks in small crab appear but do not carry through to larger size classes. The appearance (1999), disappearance (2000), and reappearance (2001) of a "cohort" influenced the ability of the assessment method to fit the length frequencies in the 2000s. These data conflicts are not resolved by increasing the size bin to 10mm (see below). Capping the samples sizes at 200 provided slightly better fits to the length frequencies, but did not completely eliminate the poor fits. Female length frequencies are fit better than the male frequencies (table A3, Figure 20), but also display 'disappearing' crab (e.g. the year 2000).

The estimated growth relationships are similar to estimates for other red king crab in the EBS. For example, a 50 mm female would molt to 68 mm on average given the estimates produced here. Weber (1967) estimated the post-molt length for a 50 mm female at 63.5 and then 67.5 in 1974. An 80 mm female would molt to 94.2 mm given estimates from the integrated assessment which is less than Weber's estimates (96m m and 97.5 mm), but corroborates the observation that female growth increment decreases compared to males as size increases. A 50 mm male would molt to 66 mm given the estimates from the assessment and an 80 mm male would molt to 100.2 mm. Posteriors for the growth parameters suggest growth is relatively well estimated (but this is also likely influenced by specifying a constant natural mortality; Figure 21). Estimated variability around the growth curve is larger for males than it is for females (.72 vs. .52) and is apparent in the spread of the length frequencies throughout the 1990s (Figure 19 vs. Figure 20).

Estimates of quantities important in management and model fits were not identical when calculating data inputs to the integrated assessment using 10 mm size bins instead of 5 mm (Table A2). Fits to numbers at length and length frequencies were visually similar (Figure 22 and Figure 23), but estimated MMB for 2014 was 16% higher when using the 10mm data (2239 vs. 2588 t). The direction of change in estimated biomass when aggregating length bins depends on the tradeoff between the rate of increase in the probability of maturity, the relationship between weight and length, and natural mortality. For red king crab, the increase in estimated biomass from 'promoting' smaller crab to a higher probability of maturity due to increasing the length bin size outweighed the decrease in estimated biomass from 'demoting' larger crab to a smaller length bin. Differences in estimated growth may also influence the observed discrepancy between estimates of mature male biomass and this issue should be pursued in future assessments.

6. Calculation of reference points

6.1 Tier 4 OFL and B_{MSY}

Natural mortality was used as a proxy for F_{MSY} and a proxy for B_{MSY} was calculated by averaging the biomass of a predetermined period of time thought to represent the a time when the stock was at B_{MSY} in the tier 4 HCR. The OFL is calculated by applying a fishing mortality determined by equation 4 to the mature male biomass at the time of fishing.

$$F_{OFL} = \begin{cases} Bycatch\ only & if\ \dfrac{B_{cur}}{B_{MSY\ proxy}} \le \beta \\ \dfrac{\gamma M \left(\dfrac{B_{cur}}{B_{MSY\ proxy}} - \alpha\right)}{1-\alpha} & if\ \beta < \dfrac{B_{cur}}{B_{MSY\ proxy}} < 1 \\ \gamma M & if\ B_{cur} > B_{MSY\ proxy} \end{cases} \quad (4)$$

Where,

B_{cur}	Current estimated mature male biomass
$B_{MSY\ proxy}$	Average mature male biomass over the years 1991-present
M	Natural mortality
α	Determines the slope of the descending limb of the HCR (0.05)
β	Fraction of $B_{MSY\ proxy}$ below which directed fishing mortality is zero (here set to 0.25)

The F_{OFL} calculated from equation 4 is applied to the legal male population surviving to the time of the fishery (October 15).

6.2 Tier 3 OFL, $F_{35\%}$, and $B_{35\%}$

Proxies for biomass and fishing mortality reference points were calculated using spawner-per-recruit methods (e.g. Clarke, 1991) in the tier 3 HCR. After fitting the assessment model to the data and estimating population parameters, the model was projected forward 100 years using the estimated parameters under no exploitation to find virgin mature male biomass per recruit. Projections were repeated (again for 100 years) to determine the level of fishing mortality that reduced the mature male biomass per recruit to 35% of the virgin level (i.e. $F_{35\%}$ and $B_{35\%}$, respectively) by using the bisection method for identifying the target fishing mortality.

Calculated values of $F_{35\%}$ and $B_{35\%}$ are used in conjunction with a control rule to adjust the proportion of $F_{35\%}$ that is applied based on the status of the population relative to $B_{35\%}$ (Amendment 24, NPFMC).

$$F_{OFL} = \begin{cases} Bycatch\ only & if\ \dfrac{B_{cur}}{B_{35\%}} \le \beta \\ \dfrac{F_{35\%} \left(\dfrac{B_{cur}}{B_{35\%}} - \alpha\right)}{1-\alpha} & if\ \beta < \dfrac{B_{cur}}{B_{35\%}} < 1 \\ F_{35\%} & if\ B_{cur} > B_{35\%} \end{cases} \quad (5)$$

Where,

B_{cur}	current estimated mature male biomass
$B_{35\%}$	mature male biomass at the time of mating resulting from fishing at $F_{35\%}$
$F_{35\%}$	Fishing mortality that reduce the spawners per recruit (measured here as mature male biomass at the time of mating) to 35% of the unfished level
α	Determines the slope of the descending limb of the HCR (0.05)
β	Fraction of $B_{35\%}$ below which directed fishing mortality is zero (here set to 0.25)

6.3 Acceptable biological catches

An acceptable biological catch (ABC) is set below the OFL by a proportion based a predetermined probability that the ABC would exceed the OFL (P*). Currently, P* is set at 0.49 and represents a proportion of the OFL distribution that accounts for within assessment uncertainty (σ_w) in the OFL to establish the maximum permissible ABC (ABC_{max}). Any additional uncertainty outside of the assessment methods (σ_b) will be considered as a recommended ABC below ABC_{max}. Additional uncertainty will be included in the application of the ABC by adding the uncertainty components as $\sigma_{\text{total}} = \sqrt{\sigma_b^2 + \sigma_w^2}$.

6..4 Specification of the distributions of the OFL used in the ABC

A distribution for the OFL associated with estimates of MMB from the running average method was constructed by bootstrapping values of MMB_{mating} (assuming that MMB is log-normally distributed) and calculating the OFL according to equation 4. Additional uncertainty (σ_b) equal to 0.3 was added when bootstrapping values of MMB while calculating the distribution for the OFL for the tier 4 HCR. The posterior distribution for the OFL generated from the integrated assessment was used for determining the ABC.

6.5 Tier 3 and integrated assessment: Reference points and OFL

A large year class recruited to the survey gear during 1985 and, lagged to the year of fertilization, would have been produced near the timing of the late 1970s shift in environmental conditions in the North Pacific (Overland et al., 2008). Consequently, $B_{35\%}$ was calculated using only estimates of recruitment from 1983 forward to reflect current environmental conditions (DOC, 2007) and corresponds to a MMB of 1034 t. The corresponding $F_{35\%}$ is 0.53 and, given a ratio of the current biomass to $B_{35\%}$ of 2.16, the calculated F_{OFL} is also 0.54 which results in an OFL of 801 t. $F_{35\%}$ is relatively high compared to natural mortality because a large fraction of MMB is protected by the 138mm size limit.

The traces of the MCMCs performed when growth was estimated were highly autocorrelated, but stationary when thinned sufficiently. Thinning is often used to reduce autocorrelation, but provided the trace is stationary and chains are long, the utility of thinning is debated in the literature (Link and Eaton, 2011). Given this debate, the posteriors derived from the unthinned chains are shown here. Fixing growth at the estimated values and rerunning the MCMC improved mixing and produced more normally distributed and narrow posteriors.

The 90% credibility interval of the posterior distribution of $B_{current}/B_{35\%}$ when growth was estimated ranged from 1.81 to 2.47; the 90% credibility interval for the posterior for $F_{35\%}$ ranged from .522 to .539; and the 90% credibility interval for the OFL ranged from 640 to 1016 t (Figure 24). The 90% credibility interval of the posterior distribution of $B_{current}/B_{35\%}$ when growth was fixed ranged from 2.08 to 2.72; the 90% credibility interval for the posterior for $F_{35\%}$ ranged from .529 to .531; and the 90% credibility interval for the OFL ranged from 636 to 997 t (Figure 25).

Management quantities calculated using 10mm length bins (and estimating growth) differed slightly from the management quantities using 5 mm length bins (Figure 26). $B_{35\%}$ was calculated as 952 t. The corresponding $F_{35\%}$ is 0.56 and, given a ratio of the current biomass to $B_{35\%}$ of 2.72, the calculated F_{OFL} is also 0.56, which resulted in an OFL of 948 t. The 90% credibility interval of the posterior distribution of $B_{current}/B_{35\%}$ ranged from 2.50 to 3.31; the 90% credibility interval for the posterior for $F_{35\%}$ ranged from .547 to .560; and the 90% credibility interval for the OFL ranged from 800 to 1273 t (Figure 26).

5.4 Tier 4 Reference points and OFL

Tier 4 reference points and management quantities were calculated simultaneously in the integrated assessment with the tier 3 reference points. When estimating growth, B_{MSY} (based on the MMB over the years 1991-present) was calculated as 2754 t. F_{MSY} was set equal to natural mortality (0.18) and the resulting OFL was 320 t. The 90% credibility interval of the posterior distribution of B_{MSY} for the tier 4 control rule ranged from 2268 to 3435 t, and the 90% credibility interval for the OFL ranged from 256 to 404 t (Figure 27). When not estimating growth, B_{MSY} and the OFL were identical, but the posteriors narrowed and appeared more normally distributed. The 90% credibility interval of the posterior distribution of B_{MSY} for the tier 4 control rule ranged from 2344 to 3327 t, and the 90% credibility interval for the OFL ranged from 256 to 398 t (Figure 28). Tier 4 management quantities were not calculated using 10mm length bins.

B_{MSY} and current MMB calculated from the 3-year running averages were substantially higher than the estimates from the integrated assessment (5742 and 8894 t, respectively). Consequently, the calculated OFL was also much higher—1359 t. The 90th quantiles of the bootstrapped distribution for the OFL ranged from 464 to 3978 t (Figure 29).

5.5 Recommended ABCs

Based on the distributions of the OFL calculated using the running-average method and a p-star of 0.49, the ABC for the tier 4 HCR is 1338 t. The ABC for the tier 4 HCR using the posterior of the OFL from the integrated assessment and a p-star of 0.49 is 311 t; the ABC for the tier 3 HCR is 771 t.

5.6 Variables related to scientific uncertainty in the OFL probability distribution

Uncertainty in estimates of stock size and OFL for Pribilof Islands red king crab is relatively high due to small sample sizes. The coefficient of variation for the estimate of male abundance for the most recent year is 0.78 and has ranged between 0.36 and 0.79 since the 1991 peak in numbers. Growth and survey selectivity are estimated within the integrated assessment (and therefore uncertainty in both processes is accounted for in the posterior distributions), but maturity, survey catchabillity, fishery selectivity, and natural mortality were fixed. F_{MSY} is assumed to be equal to natural mortality and B_{MSY} is somewhat arbitrarily set to the average MMB over a predetermined range of years for tier 4 HCRs; both of which are assumptions that have a direct impact on the calculated OFL. Sources of mortality from discard in the crab pot fishery and the fixed gear fishery were not included in the integrated assessment because of a lack of length data to apportion removals correctly. Including these sources of mortality may alter the estimated MMB.

Retrospective analyses and simulation testing have not yet been performed for the presented integrated assessment, but should be considered.

6. Author Recommendation

In the foreseeable future, low sample size will be a problem for the Pribilof Island red king crab, so extra precaution should be taken given the uncertainty associated with MMB estimates. In this respect, the tier 4 HCR is more precautionary in that it sets a higher MSST and a lower $F_{OFL,}$ OFL, and ABC for a given MMB. However, when used in concert with a running average method to estimate MMB, it can be less conservative than the tier 3 HCR that uses estimates from the integrated assessment. If there is a particularly high estimate of MMB from the survey (which are often uncertain–see this year for an example), the OFL can be much higher for the tier 4/running average combination than the tier3/integrated assessment combination. The integrated assessment can be useful in these years because it smoothes over fluctuations in estimates of biomass and numbers, which often appear to be the result of measurement error. The integrated assessment method also provides increased biological realism, allows for the incorporation of multiple data streams into the assessment, and facilitates the use of MCMC to characterize uncertainty in management quantities. MCMC is a cleaner way to account for uncertainty than arbitrarily inflating the variance around survey estimates, particularly when data are available to inform estimation of important population processes.

7. Data gaps and research priorities

Catch-at-length data for the fishery would allow fishery selectivity to be estimated and discards to be incorporated into the model. Further research on the impact of different size bins is warranted given the impact of changing the bin size on management quantities. Simulation studies designed to prioritize research on population processes for which additional information would be beneficial in achieving more accurate estimates of management quantities could be useful for this stock (e.g. Szuwalski and Punt, 2012).

7. Ecosystem Considerations

The impact of a directed fishery for Pribilof Islands red king crab on the population of Pribilof island blue king crab will likely continue to be the largest ecosystem consideration facing this fishery and preclude the possibility of a directed fishery for red king crab. Linking changes in productivity as seen in the 1980s with environmental influences is a potential avenue of research useful in selecting management strategies for crab stocks around the Pribilof Islands (e.g. Szuwalski and Punt, 2013a). It is possible that the large year class in the mid-1980s reflected changing environmental conditions, similar to proposed relationships between the Pacific Decadal Oscillation snow crab recruitment in the EBS (Szuwalski and Punt, 2013b).

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8. Appendix 1: Population dynamics model for the integrated assessment

An integrated length-based assessment that tracks biannual dynamics of numbers of male and female Pribilof Island red king crabs is used here to provide estimates for quantities used in management. See table A1 for a list of estimated and fixed parameters, table A2 for a list of estimates of parameters, and table A3 for contributions of likelihood components to the objective function and their relative weights. The mode date of the hauls performed in the NMFS trawl survey was June 15th, so this date is used as the beginning of the 'model year'. Survey to fishery dynamics are described by equation A1:

$$N_{s,y,l} = N_{s,y,l}e^{-3M/12} \tag{A1}$$

where $N_{s,y,l}$ is the number of animals of sex *s* in length-class *l* at time step *y,* and –3*M/12* decrements the population by three months of natural mortality. A pulse fishery is modeled three month after the survey (the fishery lasted on average two weeks, so a pulse fishery is a reasonable assumption) in which numbers are updated as in equation A2. Historically, the fishery occurred in September, but the opening day for all crab fisheries is October 15th now. Consequently, the calculated OFL is based on numbers at length decremented by 4 months of natural mortality.

$$N_{s,y,l} = N_{s,y,l}e^{-(F_{dir,y,l}+F_{trawl,y,l})} \tag{A2}$$

Molting, growth, and recruitment occur after the fishery (in that order, equation A3):

$$N_{s,y,l} = \begin{cases} \Omega_l N_{s,y,l} X_{l,l'} \\ (1-\Omega_l)N_{s,y,l} + Pr_l R_y \end{cases} \tag{A3}$$

Where Ω_l is the probability of an animal molting at length l, $N_{s,y,l}$, is the number of animals in sex s in length-class l at time step y, $X_{l,l'}$ is the size transition matrix, R_y is recruitment during year y and Pr_l is the proportion recruiting to length-class l.

Mature biomass at the time of mating (which is used in calculation of reference points) is calculated by decrementing the population by 5 months of natural mortality after the fishery. The remaining 4 months of natural mortality are applied to the population between the mating and the survey:

$$N_{s,y+1,l} = N_{s,y,l}e^{-4M/12} \tag{A4}$$

Fishing mortality and selectivity

Historical fishing mortality was primarily caused by landings in the directed fishery. No length frequency data are available to allocate discards from the directed fishery, so discard mortality is assumed to be zero and knife-edge selectivity is specified for the fishery with the 'edge' occurring at the minimum legal size—138mm carapace length (Figure 30). Fishing mortality is calculated by:

$$F_{dir,y,l} = S_{l,dir}e^{\overline{F_{dir}}+n_y} \tag{A5}$$

where $S_{l,dir}$ is the selectivity of the fishery on animals in length-class l, $\overline{F_{dir}}$ is the average (over time) ln-scale fully-selected fishing mortality, and n_y is the ln-scale deviation in fishing mortality for year y from the average fishing mortality. Average fishing mortality and the yearly deviations are estimated parameters.

Fishery selectivity is assumed to be a logistic function of size and constant over time:

$$S_{l,dir} = \left(1 + \exp\left(-\frac{\log(19)\left(\bar{L}_l - L_{50,dir}\right)}{L_{95,dir} - L_{50,dir}}\right)\right)^{-1} \tag{A6}$$

where $L_{50,dir}$ is the length at which 50% of animals are selected, $\bar{L}_l$ is the midpoint of length-class l, and $L_{95,dir}$ is the length at which 95% of animals are selected.

Bycatch in the non-pelagic trawl for groundfish is the second largest historical source of mortality, but it only comprised 3% (on average) of the catch when the directed fishery was operating. Fishing mortality at length attributed to bycatch in the trawl fishery is modeled by equation A7:

$$F_{trawl,y,l} = S_{l,trawl}e^{\overline{F_{trawl}}+n_y} \tag{A7}$$

Selectivity, $S_{l,trawl}$, in the non-pelagic trawl fishery for groundfish is assumed to be a logistic function of size and constant over time:

$$S_{l,trawl} = \left(1 + \exp\left(-\frac{\log(19)\left(\bar{L}_l - L_{50,trawl}\right)}{L_{95,trawl} - L_{50,trawl}}\right)\right)^{-1} \tag{A8}$$

where $L_{50,trawl}$ is the length at which 50% of animals are selected, $\bar{L}_l$ is the midpoint of length-class l, and $L_{95,trawl}$ is the length at which 95% of animals are selected. Parameters are fixed to those reported in the Bristol Bay red king crab assessment because there are no length frequency data available to inform estimation for Pribilof Island red king crab (Figure 30).

Survey selectivity is assumed to be a logistic function of size and constant over time. :

$$S_{l,surv} = Surv_q * \left(1 + \exp\left(-\frac{\log(19)\left(\bar{L}_l - L_{50,surv}\right)}{L_{95,surv} - L_{50,surv}}\right)\right)^{-1} \tag{A9}$$

where $Surv_q$, is the catchability coefficient for the survey gear, $L_{50,\mathrm{surv}}$ is the length at which 50% of animals are selected, $\bar{L}_l$ is the midpoint of length-class l, and $L_{95,\mathrm{surv}}$ is the length at which 95% of animals are selected. Survey selectivity parameters are estimated, except for $Surv_q$, which is fixed to a value of 1.

Survey numbers at length

The model prediction of the number of male crab at length at the time of the survey, $\widehat{N}_{s,y,l}^{surv}$, is given by:

$$\widehat{N}_{s,y,l}^{surv} = S_{l,surv} N_{s,y,l} \tag{A10}$$

Catch

The model prediction of the directed catch at length is given by:

$$\hat{C}_{y,l}^{dir} = S_{l,dir} N_{s,y=fishtime,l} (1 - e^{-F_{y,l}}) \tag{A11}$$

where $\hat{C}_{y,l}^{dir}$ is the model estimate of the total catch of animals in length-class l during year y in numbers, $N_{s,y=fishtime,l}$ is the number of animals of sex s in length-class l when the fishery occurs during year y. ($1-e^{-F_{y,l}}$) is the proportion of crab taken by the fishery during year y.

Growth

Molting and growth occur before the survey. Female crab are assumed to molt every year, but the probability of molting for male crab is a declining logistic function of length. The parameters are fixed based on Wendel (1969) such that the probability of molting is 1 until approximately the age of maturity at which time it steadily declines (Figure 30):

$$P_l = 1 - \left(1 + \exp\left(-\frac{\log(19)\left(\bar{L}_l - L_{50,molt}\right)}{L_{95,molt} - L_{50,molt}}\right)\right)^{-1} \tag{A12}$$

where $L_{50,\mathrm{molt}}$ is the length at which 50% of animals molt, and $L_{95,\mathrm{molt}}$ is the length at which 95% of animals molt. The growth increment for animals that do molt is based on a gamma distribution, i.e.:

$$X_{l,l'} = Y_{l,l'} / \sum_{l'} Y_{l,l'} \tag{A13}$$

$$Y_{l,l'} = (\Delta_{l,l'})^{(L_l - (\bar{L}_l - 2.5))/\beta} e^{-\Delta_{l,l'}/\beta} \tag{A14}$$

where L_l is the expected length for an animal in length-class l given that it moults:

$$L_l = \delta_1 + \delta_2 \bar{L}_l \tag{A15}$$

δ_1, δ_2 are the parameters of the relationship between length and growth increment, $\Delta_{l,l'}$ is the difference in length between midpoints of length-classes i and j:

$$\Delta_{l,l'} = \bar{L}_{l'} + 2.5 - \bar{L}_l \tag{A16}$$

β is the parameter which defines the variability in growth increment and was set to 0.75 for this analysis. The constant "2.5" is half a length bin's length. The size transition matrix can be seen in Figure 30.

Recruitment

The fraction of the annual recruitment in an area which recruits to length-class l is based on a gamma function, i.e.:

$$Pr_l = (\Delta_{l,l'})^{\mu_1/\mu_2} e^{-\Delta_{l,l'}/\mu_2} / \sum_{l'} (\Delta_{l,l'})^{\mu_1/\mu_2} e^{-\Delta_{l,l'}/\mu_2} \tag{A17}$$

Where μ_1 and μ_2 are the parameters that define the recruitment fractions. Mean recruitment, annual recruitments and fraction recruiting are treated as estimable parameters, resulting 42 total estimated parameters related to recruitment (Table A1). The fraction recruiting was estimated such that all recruitment enters the model in the first size bin (Figure 31).

Likelihood components

The model is fit to survey length frequencies (L1, A18), a survey index of abundance (L2, A19), directed catch (L3, A20) and non-pelagic trawl bycatch (L4, A21).

$$L_1 = \begin{cases} \sum_s \sum_y \sum_l -\gamma_y p_{surv,l,y,s}^{obs} \ln\left(p_{surv,l,y,s}^{pred} + \kappa\right) & if\ p_{surv,l,y,s}^{obs} \geq 0.01 \\ 0 & if\ p_{surv,l,y,s}^{obs} < 0.01 \end{cases} \quad \text{(A18)}$$

where L_l is the contribution to the objective function of the fit to survey length frequencies; γ_y is the sample size for year y, $p_{surv,l,y,s}^{pred}$ is the model-estimate of the length-frequency for sex s for length-class l in year y; $p_{surv,l,y,s}^{obs}$ is the observed survey length-frequency for sex s for length-class l during year y; κ is a small number (0.001 here) added to all log calculations. Fits to the observed length frequencies only contribute to the objective function if the observed proportion is greater than 0.01. The reported number of samples used to calculate the length frequencies were used to weight the survey length frequency likelihoods unless they exceeded 200, at which point they were set to 200.

$$L_2 = \sum_s \sum_y \frac{\left(\ln\left(N_{y,s}^{pred} + \kappa\right) - \ln\left(N_{y,s}^{obs} + \kappa\right)\right)^2}{\sqrt{\ln\left(CV_{y,s}\right)^2 + 1}} \quad \text{(A19)}$$

where $N_{y,s}^{pred}$ is the model-estimate of the number of crab of sex s caught in the survey in during year y, $N_{y,s}^{obs}$ is the observed number of crab of sex s in the survey in during year y, and $CV_{y,s}$ is the observed coefficient of variation for $N_{y,s}^{obs}$. κ is a small number (equal to 0.001 here) added to avoid taking the log of zero. Historically calculated CVs were used to fit the survey numbers

$$L_3 = \sum_y \frac{\left(\ln\left(C_y^{pred} + \kappa\right) - \ln\left(C_y^{obs} + \kappa\right)\right)^2}{\sqrt{\ln\left({CV_y}^{cat}\right)^2 + 1}} \quad \text{(A20)}$$

where C_y^{pred} is the catch in numbers predicted by the model for year y, C_y^{obs} is the observed catch in numbers for year y, ${CV_y}^{cat}$ is the assumed coefficient of variation for the observed data for year y, and κ is a small number added to avoid taking the log of zero when catches do not occur (here 0.001 is used).

$$L_3 = \sum_y \frac{\left(\ln\left(\sum_s byC_{y,s}^{pred} + \kappa\right) - \ln\left(byC_{y,s}^{obs} + \kappa\right)\right)^2}{\sqrt{\ln\left({CV_y}^{bycatch}\right)^2 + 1}} \quad \text{(A21)}$$

where $byC_{y,s}^{pred}$ is the bycatch in tonnes of sex s from the non-pelagic trawl fishery predicted by the model for year y, byC_y^{obs} is the observed bycatch in tonnes for during year y, ${CV_y}^{bycatch}$ is the assumed coefficient of variation for the observed data for year y, and κ is a small number added to avoid taking the log of zero when catches do not occur (here 0.001 is used).

Penalty components

A penalty is placed on the between year deviations in estimated recruitment deviates and fishing mortality deviates (both directed and trawl) of the form:

$$P_2 = \gamma_w \sum_l (\ln(\eta_l) - \ln(\eta_{l-1}))\ \hat{}2 \quad \text{(A22)}$$

where, η_l, is the quantity in question (e.g. recruitment deviations) and γ_w is the weighting factor (equal to 1 in the assessment presented for all quantities).

9. Tables

Table 1. Total retained catches from directed fisheries for Pribilof Islands District red king crab (Bowers et al. 2011; D. Pengilly, ADF&G, personal communications).

Year	Catch (count)	Catch (t)	Avg CPUE (legal crab count pot^{-1})
1973/1974	0	0	0
1974/1975	0	0	0
1975/1976	0	0	0
1976/1977	0	0	0
1977/1978	0	0	0
1978/1979	0	0	0
1979/1980	0	0	0
1980/1981	0	0	0
1981/1982	0	0	0
1982/1983	0	0	0
1983/1984	0	0	0
1984/1985	0	0	0
1985/1986	0	0	0
1986/1987	0	0	0
1987/1988	0	0	0
1988/1989	0	0	0
1989/1990	0	0	0
1990/1991	0	0	0
1991/1992	0	0	0
1992/1993	0	0	0
1993/1994	380,286	1183.02	11
1994/1995	167,520	607.34	6
1995/1996	110,834	407.32	3
1996/1997	25,383	90.87	<1
1997/1998	90,641	343.29	3
1998/1999	68,129	246.91	3
1999/2000 to 2013/2014	0	0	0

Table 2. Fishing effort during Pribilof Islands District commercial red king crab fisheries, (Bowers et al. 2011).

Season	Number of Vessels	Number of Landings	Number of Pots Registered	Number of Pots Pulled
1993	112	135	4,860	35,942
1994	104	121	4,675	28,976
1995	117	151	5,400	34,885
1996	66	90	2,730	29,411
1997	53	110	2,230	28,458
1998	57	57	2,398	23,381
1999-2013/14		Fishery Closed		

Table 3. Non-retained total catch mortalities from directed and non-directed fisheries for Pribilof Islands District red king crab. Handling mortalities (pot and hook/line= 0.5, trawl = 0.8) were applied to the catches. (Bowers et al. 2011; D. Pengilly, ADF&G; J. Mondragon, NMFS). **** NEW 2013 calculation of bycatch using AKRO Catch Accounting System with data reported from State of Alaska reporting areas that encompass the Pribilof Islands red king crab district.**

	Crab pot fisheries			Groundfish fisheries	
Year	Legal male (t)	Sublegal male (t)	Female (t)	All fixed (t)	All trawl (t)
1991/1992				0.48	45.71
1992/1993				16.12	175.93
1993/1994				0.60	131.87
1994/1995				0.27	15.29
1995/1996				4.81	6.32
1996/1997				1.78	2.27
1997/1998				4.46	7.64
1998/1999	0.00	0.91	11.34	10.40	6.82
1999/2000	1.36	0.00	8.16	12.40	3.13
2000/2001	0.00	0.00	0.00	2.08	4.71
2001/2002	0.00	0.00	0.00	2.71	6.81
2002/2003	0.00	0.00	0.00	0.50	9.11
2003/2004	0.00	0.00	0.00	0.77	9.83
2004/2005	0.00	0.00	0.00	3.17	3.52
2005/2006	0.00	0.18	1.81	4.53	24.72
2006/2007	1.36	0.14	0.91	6.99	21.35
2007/2008	0.91	0.05	0.09	1.92	2.76
2008/2009	0.09	0.00	0.00	1.64	6.94
2009/2010	0.00	0.00	0.00	0.33	2.45
****2009/2010**				**0.19**	**1.05**
2010/2011	0.00	0.00	0.00	0.30	3.87
****2010/2011**				**0.45**	**6.25**
2011/2012	0.00	0.00	0.00	0.62	4.78
****2011/2012**				**0.35**	**4.47**
****2012/2013**	0.00	0.00	0.00	**0.12**	**12.98**
2013/2014	0.00	0.00	0.00	**0.25**	**1.99**

Table 4. Proportion by weight of the Pribilof Islands red king crab bycatch using the new 2014 calculation of bycatch using AKRO Catch Accounting System with data reported from State of Alaska reporting areas that encompass the Pribilof Islands red king crab district.

Crab fishing season	hook and line %	non-pelagic trawl %	pot %	pelagic trawl %	TOTAL (# crabs)
2009/10	19	77	3	1	813
2010/11	10	90	<1	<1	3,026
2011/12	10	89	1		2,167
2012/13	1	99	<1		4,517
2013/14	11	89	0	0	640

Table 5. Pribilof Islands District red king crab male abundance, male biomass, and female biomass estimated based on the NMFS annual EBS bottom trawl survey with no running average.

Year	Total Male Abundance	Total males at survey (t)	Total females at survey (t)
1975/1976	0	0	10
1976/1977	50778	162	80
1977/1978	228477	253	120
1978/1979	367140	1228	42
1979/1980	279707	859	76
1980/1981	400513	1317	195
1981/1982	80928	299	97
1982/1983	352166	1458	673
1983/1984	144735	544	216
1984/1985	64331	261	67
1985/1986	16823	60	0
1986/1987	38419	135	57
1987/1988	18611	53	25
1988/1989	1963775	797	732
1989/1990	1844076	2154	1846
1990/1991	6354076	6815	1775
1991/1992	3100675	4959	3860
1992/1993	1861538	3505	2612
1993/1994	3787997	9962	4837
1994/1995	3669755	9600	3397
1995/1996	7693368	24854	6199
1996/1997	683611	2389	1456
1997/1998	3155556	7528	1442
1998/1999	1192015	2688	1262
1999/2000	9102898	8682	4762
2000/2001	1674067	4393	734
2001/2002	6157584	10714	4333
2002/2003	1910263	6923	571
2003/2004	1506201	5280	1644
2004/2005	2196795	3710	983
2005/2006	302997	1272	2207
2006/2007	1459278	6859	1406
2007/2008	1883489	7378	2534
2008/2009	1721467	5698	2099
2009/2010	923133	2498	546
2010/2011	927825	3137	468
2011/2012	1052228	3878	817
2012/2013	1609444	4813	663
2013/2014	1831377	7854	169
2014/2015	3036807	12129	1093

Table 6. Pribilof Islands District male red king crab abundance CV and total male and female biomass CVs estimated from the NMFS annual EBS bottom trawl survey data with no running average.

Year	Total Male Abundance CV	Total male at survey (t) CV	Total female at survey (t) CV
1975/1976	0.00	0.00	1.00
1976/1977	1.00	1.00	0.76
1977/1978	1.00	1.00	1.00
1978/1979	0.83	0.83	1.00
1979/1980	0.37	0.39	0.72
1980/1981	0.47	0.52	0.64
1981/1982	0.57	0.58	0.78
1982/1983	0.70	0.70	0.76
1983/1984	0.64	0.55	0.48
1984/1985	0.48	0.55	0.57
1985/1986	1.00	1.00	0.00
1986/1987	0.70	0.70	1.00
1987/1988	1.00	1.00	1.00
1988/1989	0.74	0.56	0.65
1989/1990	0.69	0.77	0.69
1990/1991	0.87	0.88	0.69
1991/1992	0.78	0.80	0.60
1992/1993	0.68	0.61	0.91
1993/1994	0.93	0.92	0.72
1994/1995	0.75	0.74	0.76
1995/1996	0.42	0.43	0.51
1996/1997	0.37	0.37	0.74
1997/1998	0.56	0.54	0.57
1998/1999	0.42	0.37	0.76
1999/2000	0.79	0.58	0.86
2000/2001	0.40	0.38	0.63
2001/2002	0.90	0.83	0.99
2002/2003	0.67	0.69	0.51
2003/2004	0.66	0.66	0.91
2004/2005	0.83	0.60	0.53
2005/2006	0.53	0.57	0.78
2006/2007	0.37	0.36	0.61
2007/2008	0.47	0.40	0.52
2008/2009	0.52	0.50	0.70
2009/2010	0.70	0.64	0.55
2010/2011	0.37	0.38	0.41
2011/2012	0.63	0.64	0.73
2012/2013	0.65	0.59	0.55
2013/2014	0.58	0.61	0.58
2014/2015	0.71	0.78	0.94

Table 7. Estimated recruitment (numbers), female mature biomass (t), male mature biomass (t), total female abundance and total male abundance (1000s) from the integrated assessment method with 5 mm length bins and estimated growth.

Year	Recruitment	FMB (t)	MMB (t)	Female abundance	Male abundance
1975	7526	67	119	62	64.7
1976	5610	101	210	83.1	93.1
1977	4906	124	304	97	114.1
1978	3989	130	349	101	118.4
1979	3651	127	351	97.1	109.8
1980	5091	121	331	88.8	96.8
1981	12099	112	303	79.1	83.9
1982	62349	103	272	69.4	72.5
1983	262232	93	241	61	62.9
1984	107431	84	213	56.2	56.9
1985	3913786	77	189	58.1	55.4
1986	549495	82	176	96.1	89
1987	160787	120	208	194.4	157.4
1988	165716	236	344	405.8	317.5
1989	116638	780	749	725.9	667.1
1990	56976	1354	2766	1032.4	1195.6
1991	71925	1532	3954	1203.3	1488.3
1992	896675	1525	4071	1221.6	1427.1
1993	478441	1412	2457	1145.2	1239.7
1994	331502	1246	1722	1017.6	725.1
1995	2169231	1000	1192	901.7	523
1996	801165	983	1091	799.4	468.4
1997	49808	807	1103	830.8	588.5
1998	23719	764	1259	806.8	675.4
1999	37128	1085	1704	909.7	833
2000	173801	1432	2872	1081	1129.8
2001	309382	1541	3706	1154.1	1291.1
2002	1028556	1493	3837	1125.3	1229.3
2003	538631	1398	3613	1046.1	1086.2
2004	237795	1312	3293	971.1	962.8
2005	98802	1266	3014	938.5	903.5
2006	90511	1328	2911	950.6	924.4
2007	146090	1420	3211	976.2	1009.1
2008	131534	1426	3448	976.4	1056.6
2009	32195	1361	3440	935.2	1011.6
2010	17845	1263	3241	866.5	917.1
2011	14552	1169	2976	787.5	816.5
2012	13463	1080	2723	708.1	729.7
2013	13053	985	2495	628.5	648.6
2014	12925	881	2239	550.9	566.7

Table 8. Estimates of female and male abundance (1000s individuals) and female and male biomass (t) from a 3-year running average.

Year	Female abundance	Male abundance	Female biomass	Male biomass
1977	106	203	72	420
1978	95	281	71	756
1979	100	325	106	1035
1980	103	249	121	798
1981	192	246	252	879
1982	180	155	251	592
1983	140	143	196	555
1984	94	82	128	305
1985	47	44	59	171
1986	39	26	33	89
1987	408	489	108	101
1988	1112	1009	430	317
1989	2495	3107	1220	651
1990	3374	3859	2355	2192
1991	3460	3412	2769	2863
1992	4231	2551	3847	4682
1993	3639	2704	3714	5992
1994	4622	6080	5112	18203
1995	3549	2906	4053	8991
1996	2694	2867	3102	8503
1997	1205	1211	1394	2752
1998	3518	2779	1592	3439
1999	3224	2298	1253	3413
2000	4071	3730	1677	5018
2001	879	2310	951	5280
2002	1020	2820	1169	6643
2003	1029	1907	803	4990
2004	1520	1205	1277	2946
2005	1354	1285	1267	4489
2006	1320	1329	2055	5579
2007	1420	1667	2032	6598
2008	1061	1615	1522	5557
2009	477	1138	701	3579
2010	315	951	543	3102
2011	351	1112	576	3568
2012	275	1498	454	5236
2013	260	1966	453	7092
2014	152	2267	328	9303

Table A1. List of estimated and fixed parameters.

Fixed parameters (11)	Number
Natural mortality	1
Molting probability	3
Fishery selectivity	2
Weight	4
Survey catchability	1
Estimated parameters (87)	
Growth	6
Proportion recruiting	2
Log recruitment deviations	45
Log average fishing mortality (directed)	1
Log fishing mortality deviations (directed)	6
Log average fishing mortality (trawl)	1
Log fishing mortality deviations (trawl)	23
Survey selectivity	2

Table A2. List of estimated parameter values for models using 5 and 10 mm length bins.

Parameter	5 mm	10 mm
srv_q	1	1
fish_sel50	138	138
fish_sel95	138.05	138.05
srv_sel50	102.15	106.86
srv_sel95	141.06	155.6
log_avg_fmort_dir	-0.98	-0.89
log_avg_fmort_trawl	-4.88	-4.69
mean_log_rec	11.21	11.56
A_f (growth)	25.42	19.95
A_m (growth)	9.77	6.79
B_f (growth)	0.86	0.9
B_m (growth)	1.13	1.14
growth_beta_males	0.72	1.04
alpha_rec	0.86	1.6
beta_rec	0.16	0.37

Table A3. Likelihood component contribution to the likelihood and associated weights.

Likelihood component	negLogLike	Weighting
Survey numbers (males)	63.5	.36 -1 (CVs)
Survey numbers (females)	46.6	.36-1 (CVs)
Survey length frequencies (male)	7943.0	18-200 (sample size)
Survey length frequencies (female)	5032.2	18-200 (sample size)
Catch	2.2	.005(CV)
Trawl	0.97	.05 (CV)
Smoothness penalties		
Trawl fishing mortality	26.7	1 (CV)
Fishing mortality	4.4	1 (CV)
Recruitment	57.2	1 (CV)

10. Figures

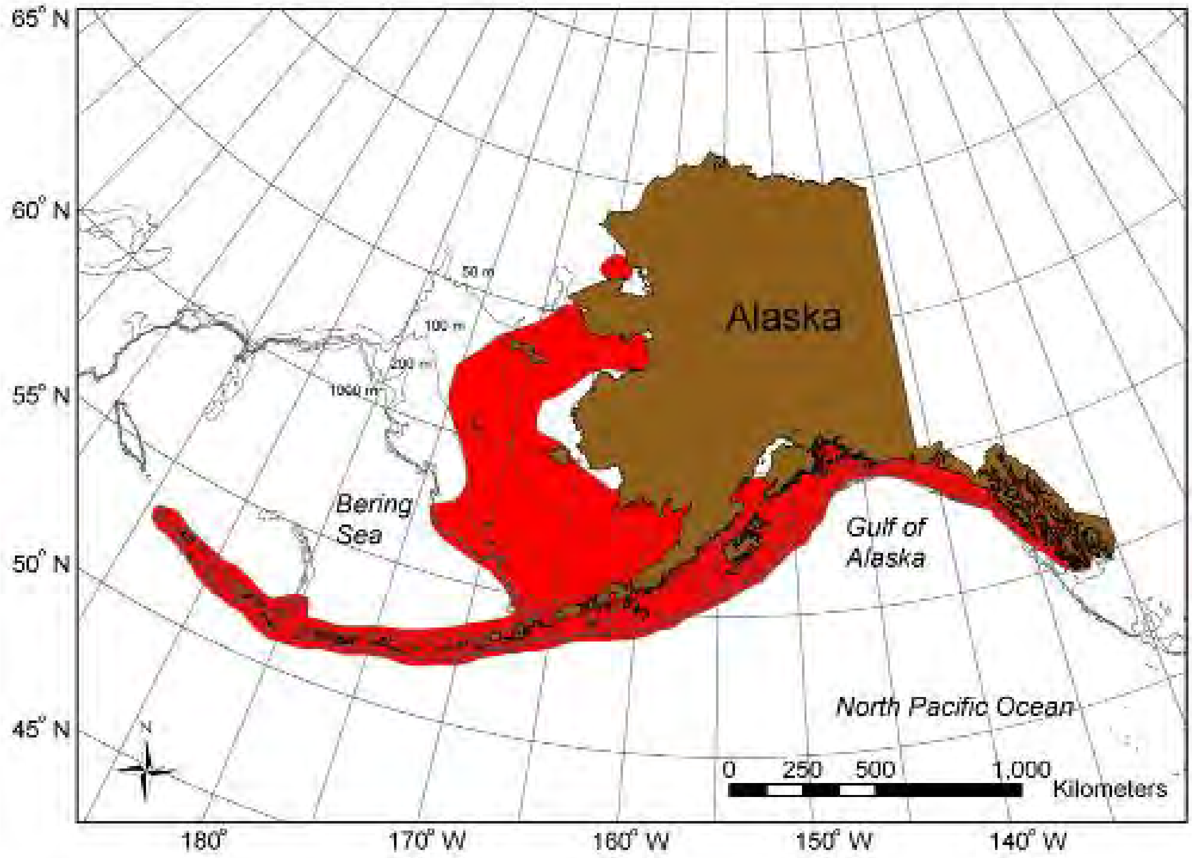

Figure 1. Red king crab distribution.

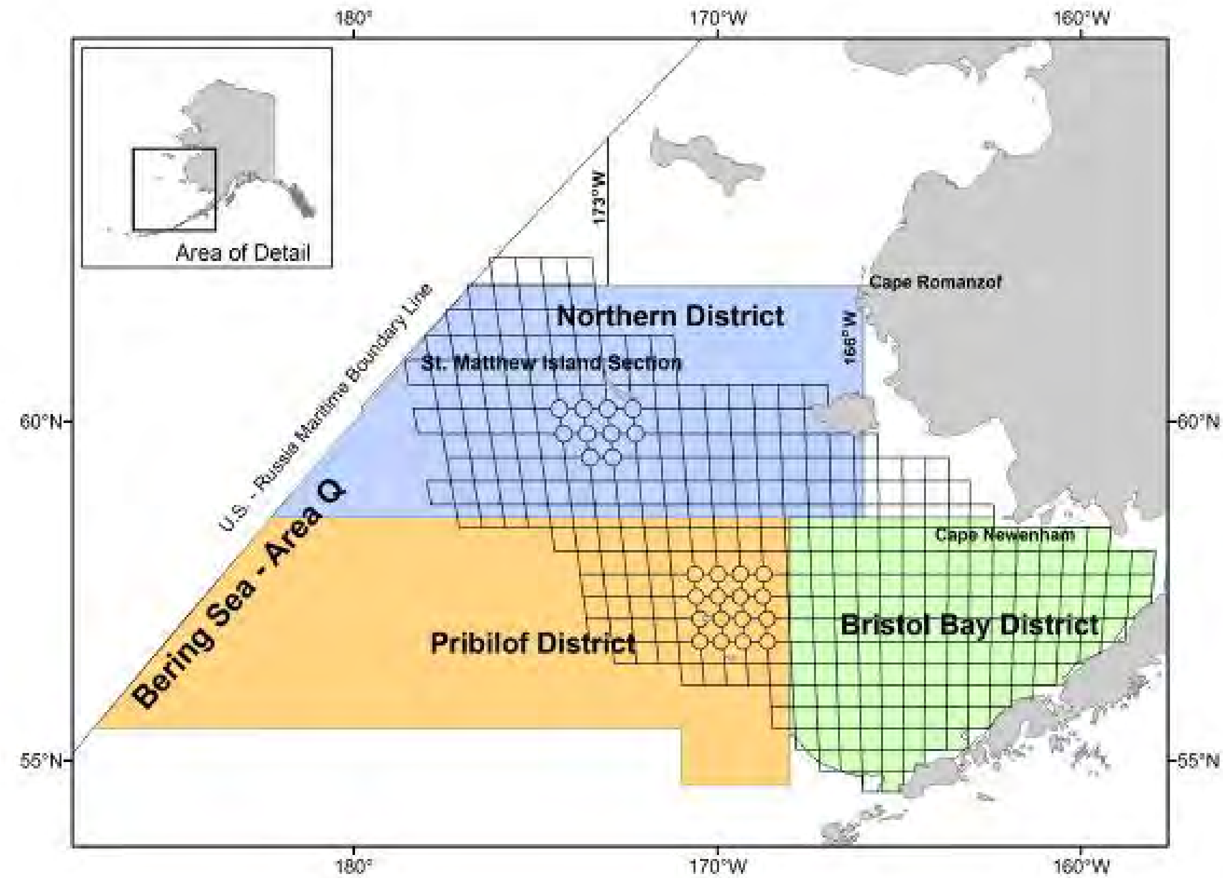

Figure 2. King crab registration area Q (Bering Sea) showing the Pribilof District.

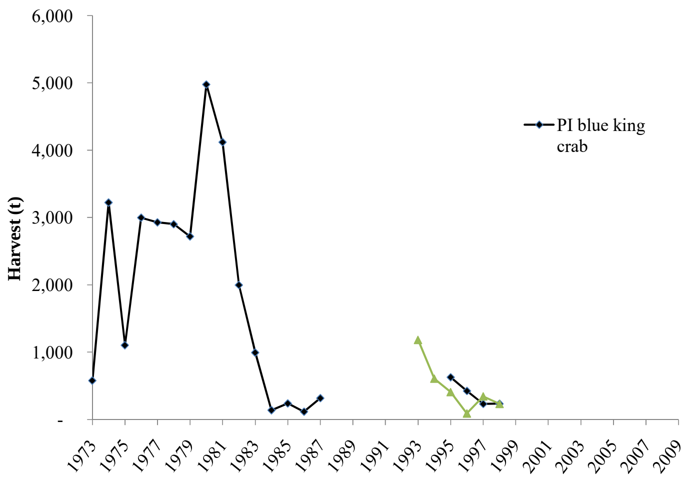

Figure 3. Historical harvests and GHLs for Pribilof Island blue (diamonds) and red king crab (triangles) (Bowers et al. 2011).

Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation area.

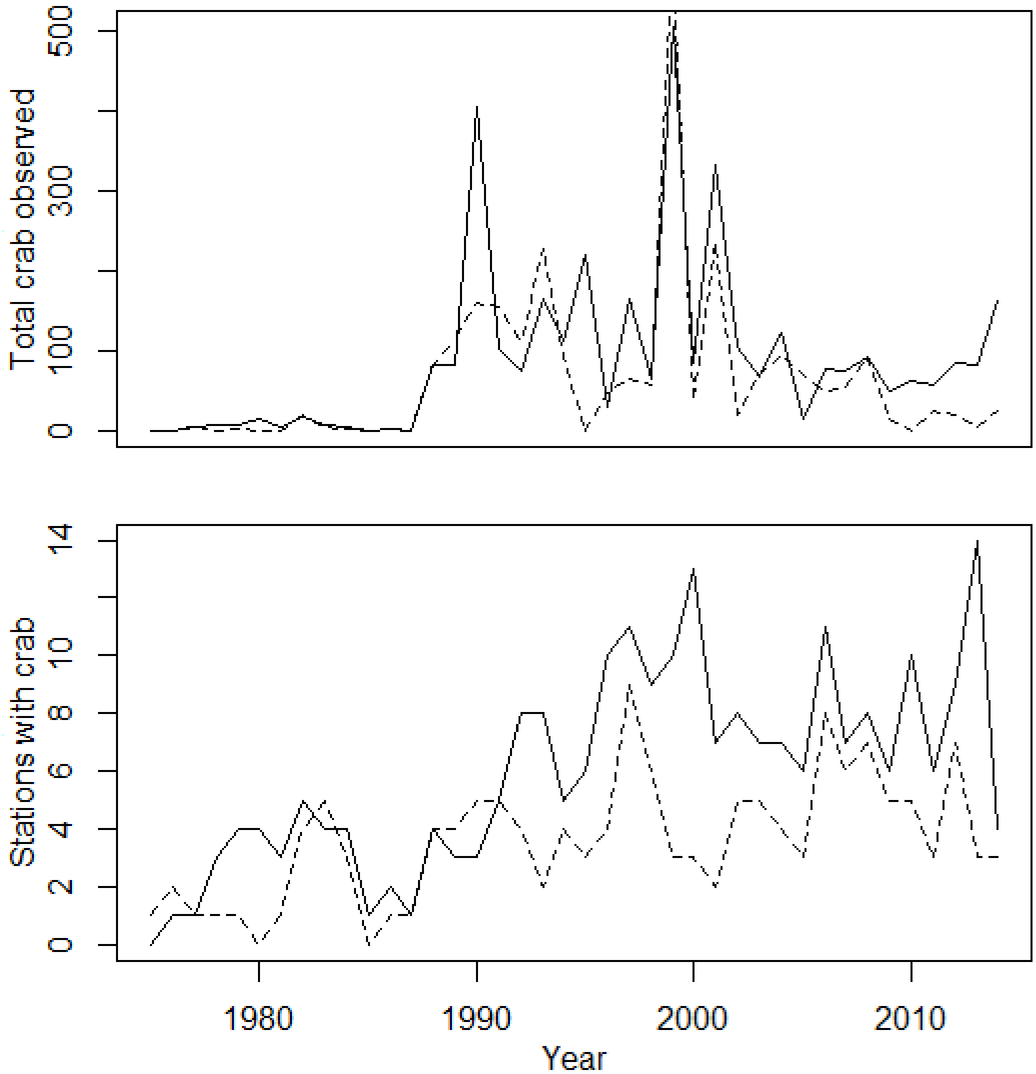

Figure 5. Total number of observed crab (top) and the number of stations that reported observations of crab (female = dashed line, male = solid line) from 1975-2014.

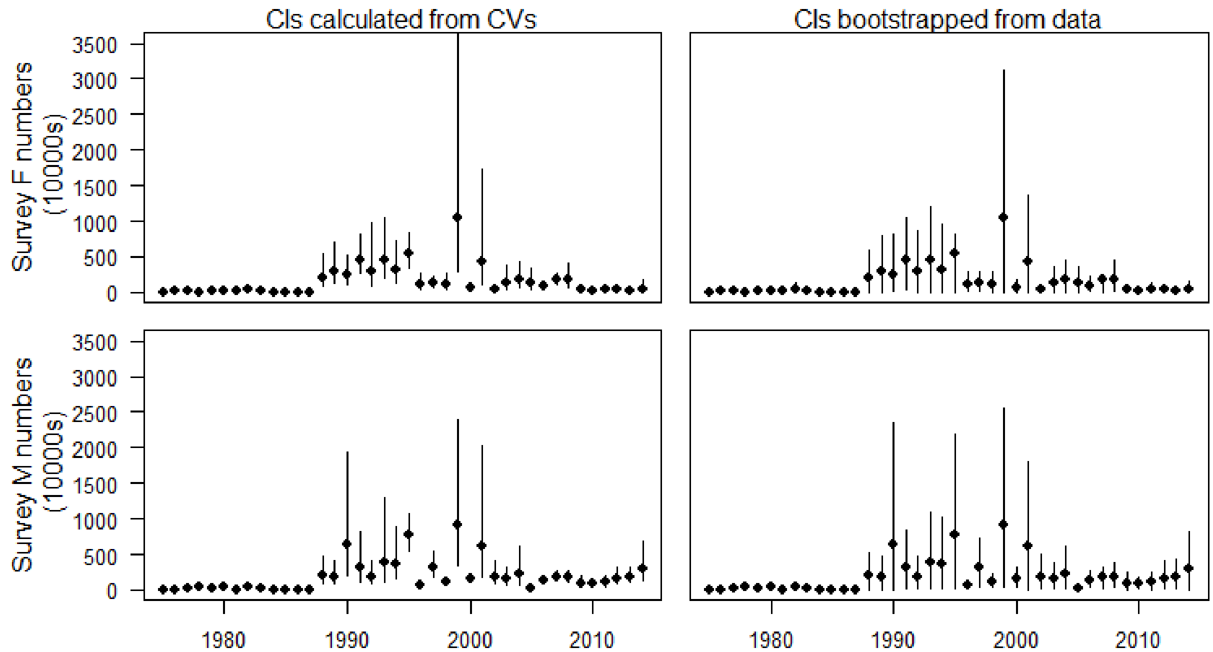

Figure 6. Time series of Pribilof Islands red king crab estimated from the NMFS annual EBS bottom trawl survey. CIs for the left column are based on back calculations from the CVs provided from Kodiak, CIs in the right column are based on bootstraps from the NMFS.

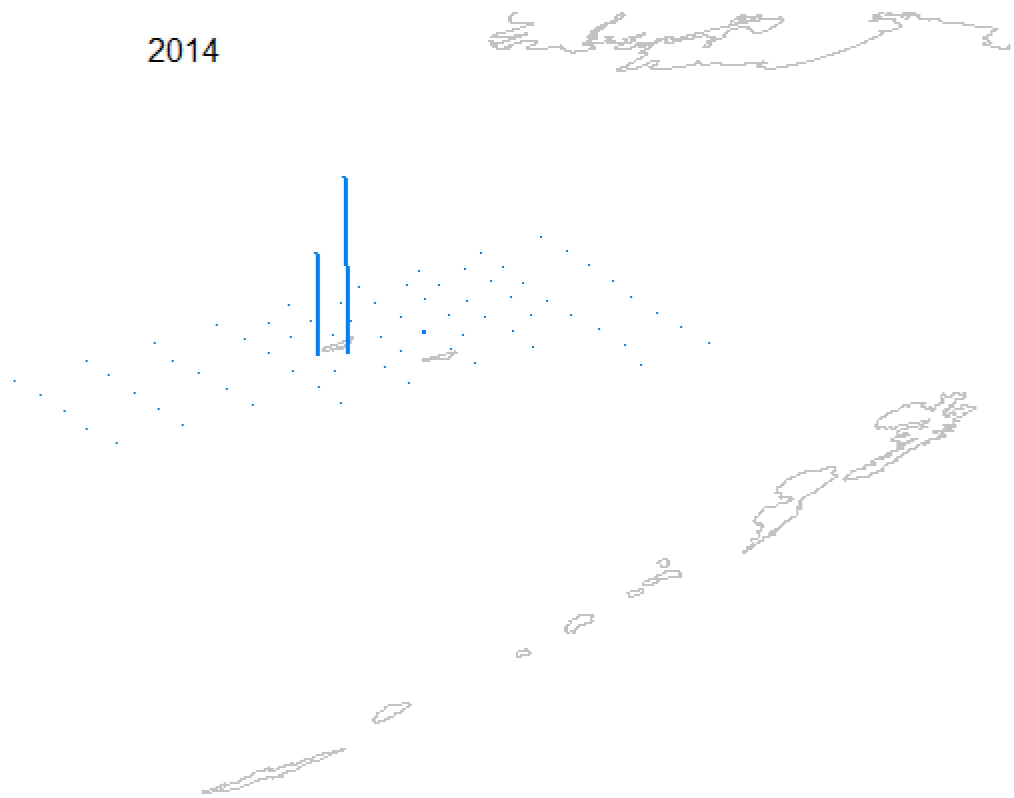

Figure 7. Male red king crab relative density by station in the Pribilof Island district in 2014. Blue bars represent the relative magnitude of the density calculated from the NMFS trawl survey.

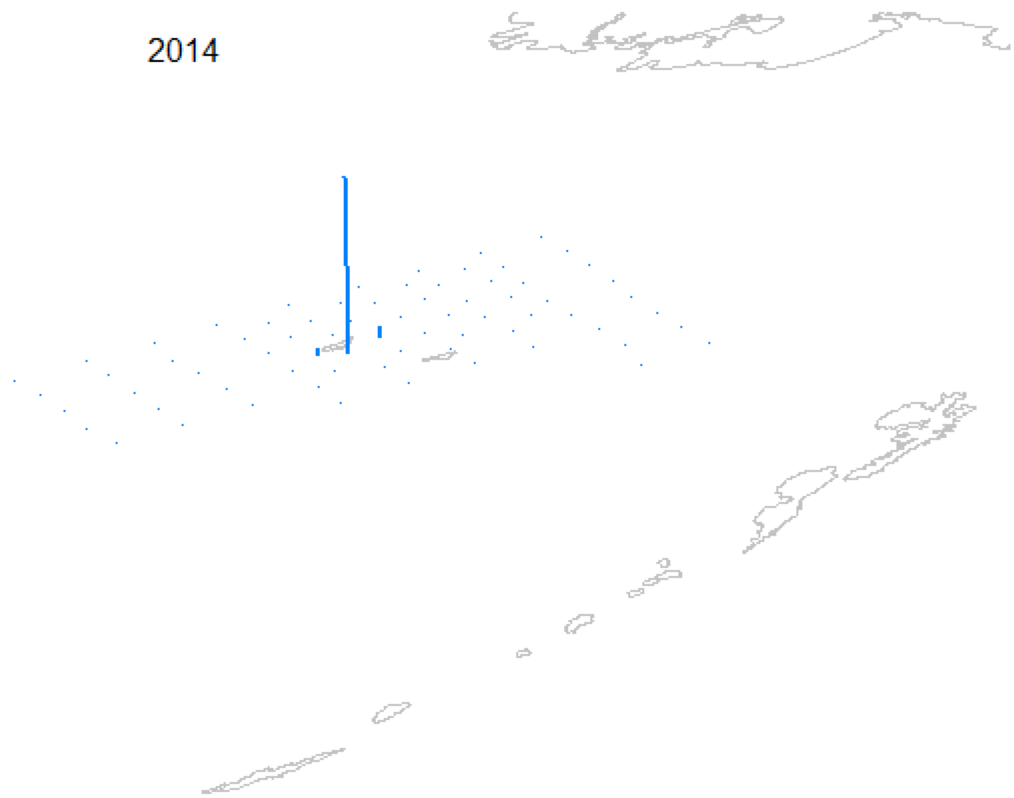

Figure 8. Female red king crab relative density by station in the Pribilof Island district in 2014. Blue bars represent the relative magnitude of the density calculated from the NMFS trawl survey.

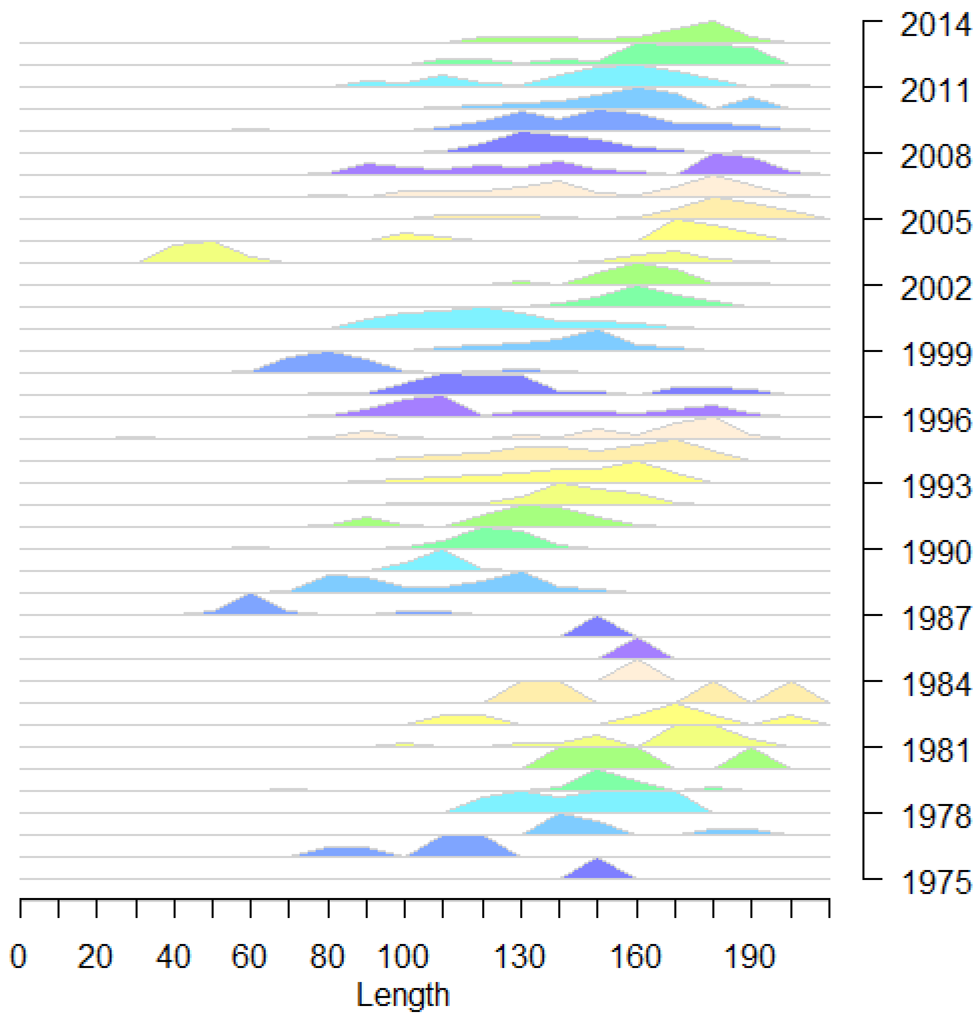

Figure 9. Observed length frequencies by 5 mm length classes of Pribilof Islands male red king crab (Paralithodes camtschaticus) from 1975 to 2014.

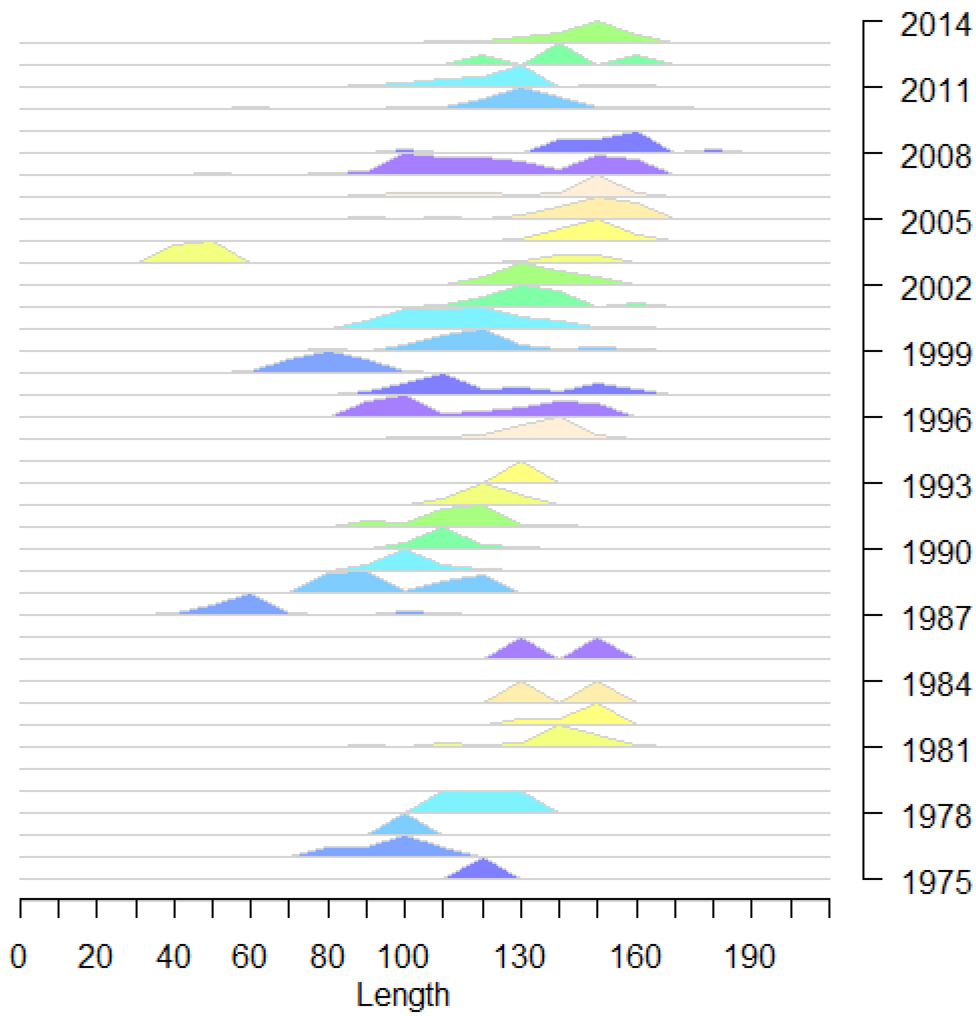

Figure 10. Observed length frequencies by 5 mm length classes of Pribilof Islands female red king crab (Paralithodes camtschaticus) from 1975 to 2014.

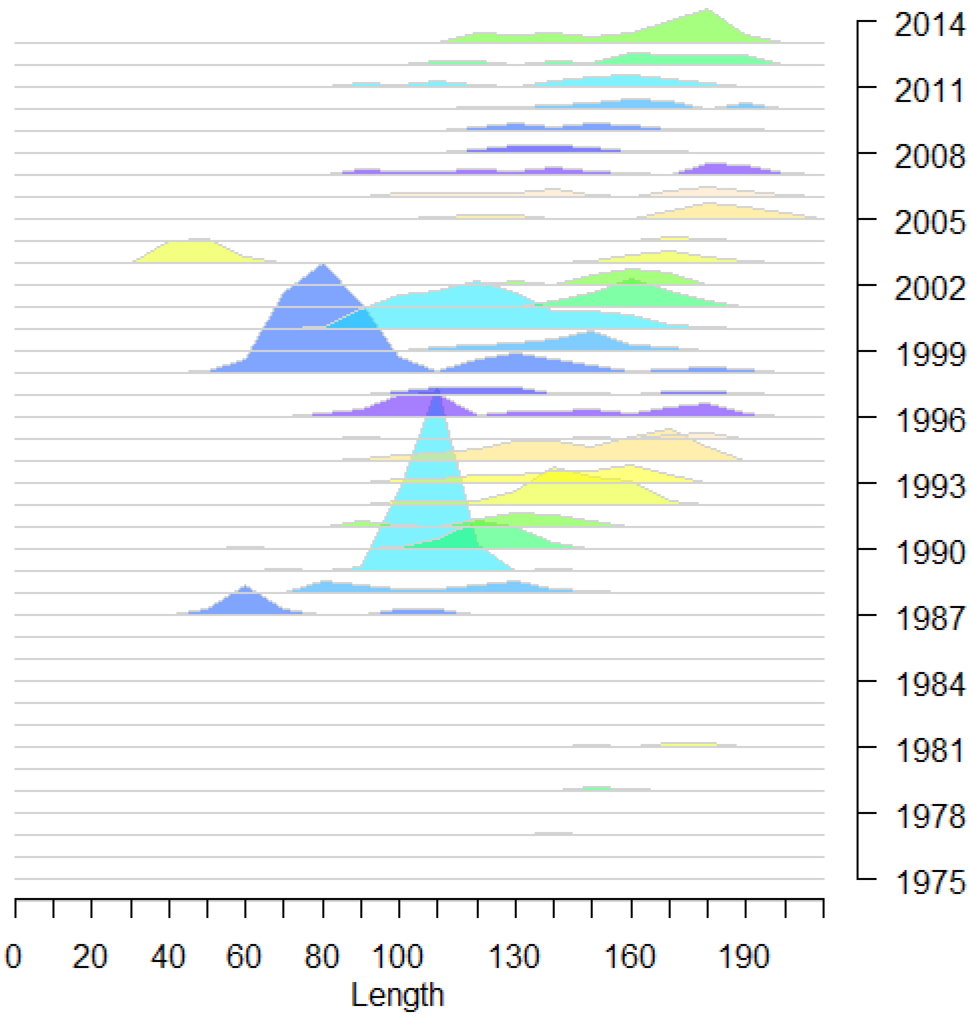

Figure 11. Observed numbers at length by 5 mm length classes of Pribilof Islands male red king crab (Paralithodes camtschaticus) from 1975 to 2014.

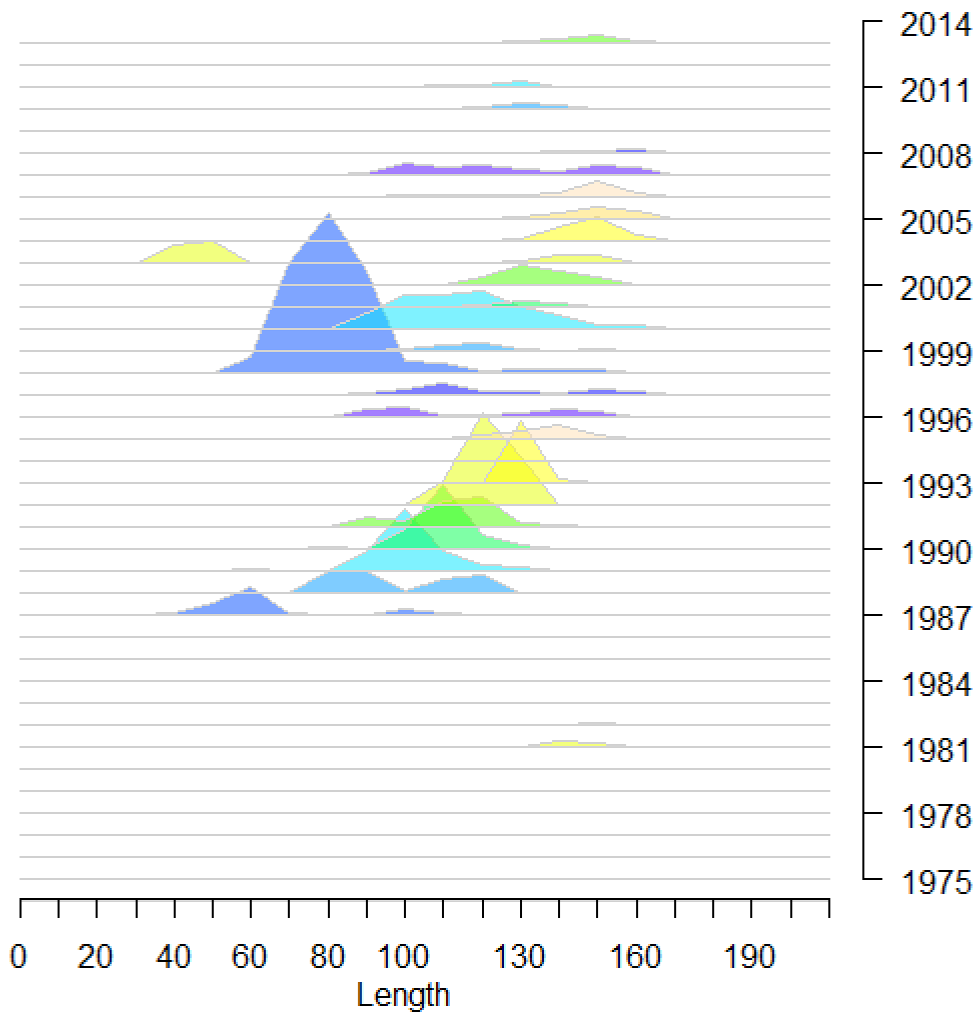

Figure 12. Observed numbers at length by 5 mm length classes of Pribilof Islands female red king crab (Paralithodes camtschaticus) from 1975 to 2014.

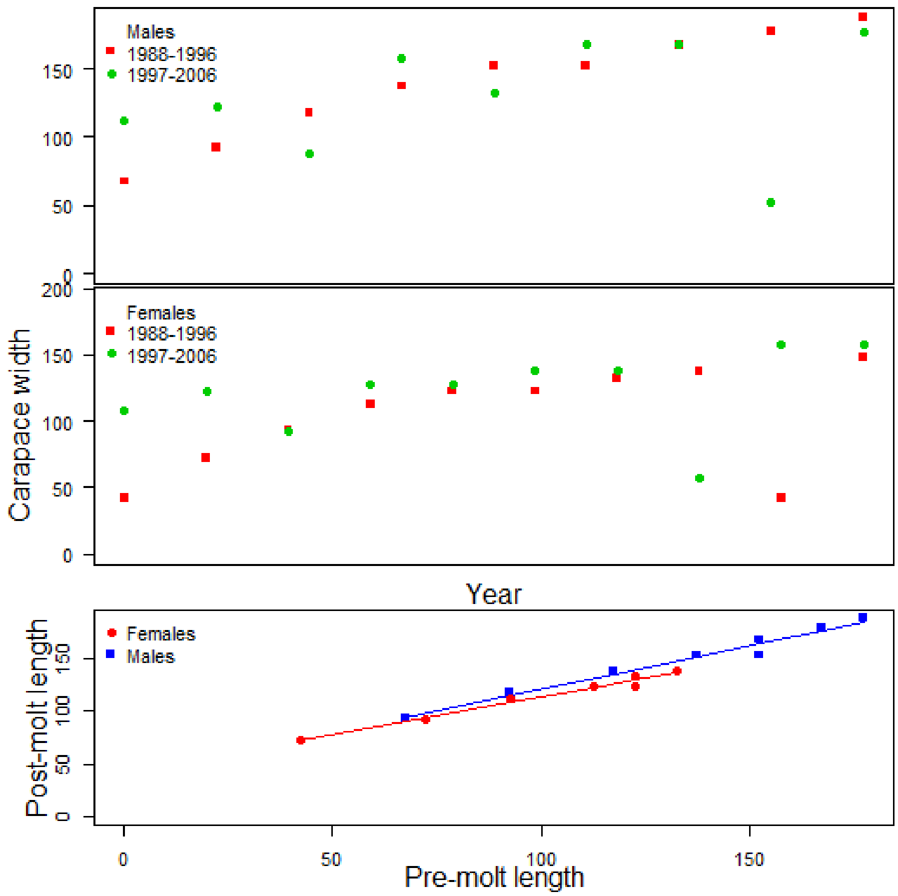

Figure 13. Modes of the length frequency distribution for males and females plotted for two time periods over which two cohorts were observed to move through the population. Growth per molt calculated from the modes from the length frequencies with fitted linear relationship (bottom).

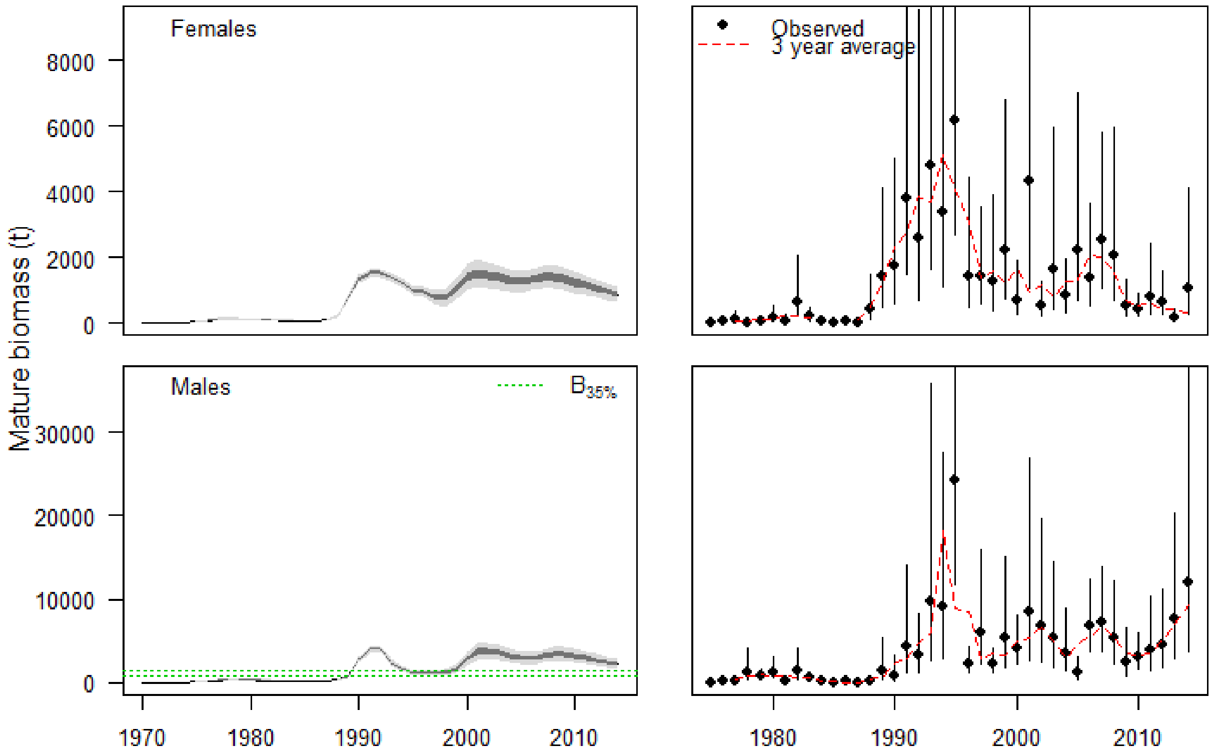

Figure 14. Estimated mature female and male biomass from the integrated assessment (left column) and a 3 year running average from the survey estimates (right column). Scale is different for males and females.

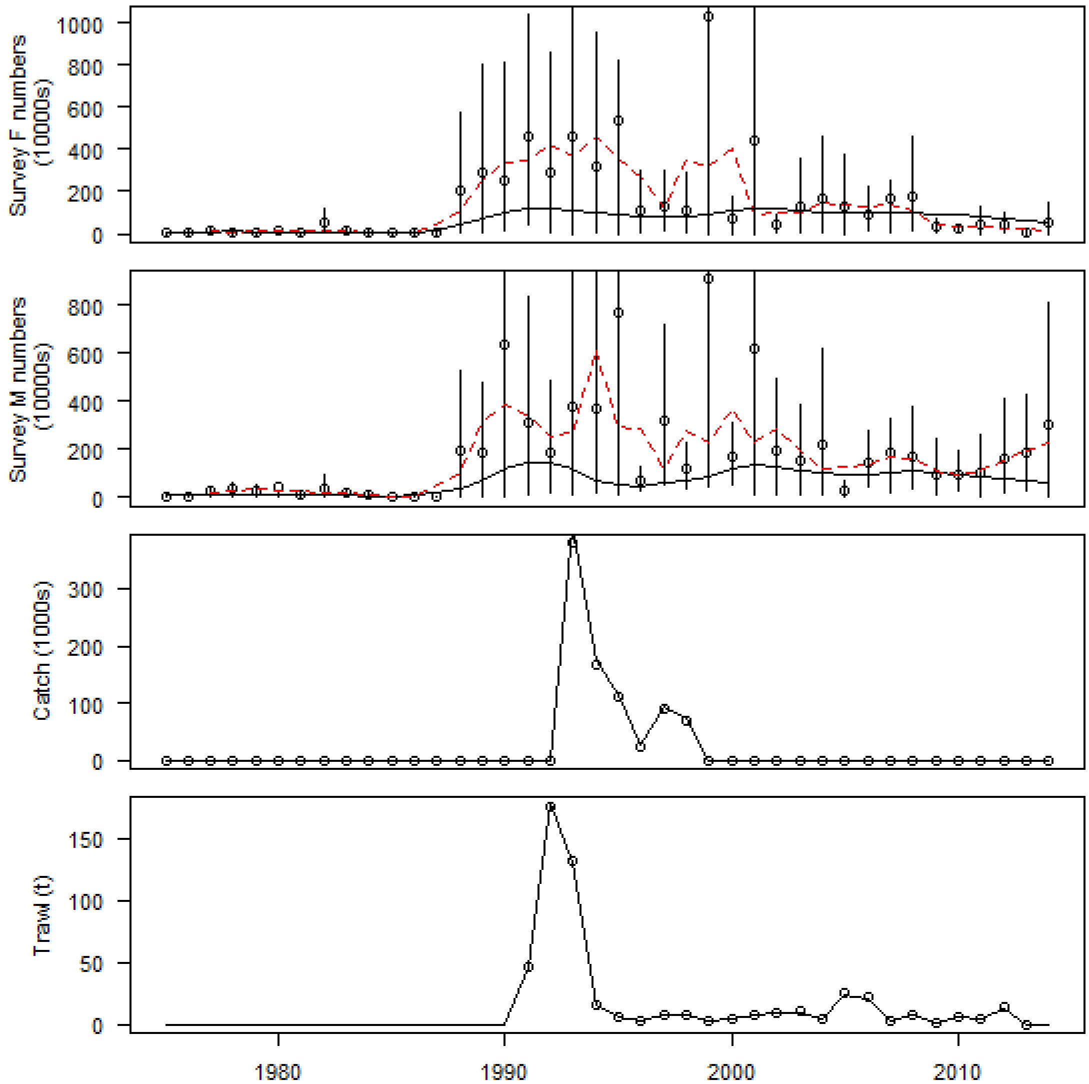

Figure 15. Model fits (black line) to observed survey numbers (black dots) with 95% bootstrapped CIs for females (top) and males (2nd row). Dashed red line is the three year running average. Model fits (black line) to observed catches in the directed fishery (dots) in numbers caught (3rd row) and bycatch in the non-pelagic trawl fishery (4th row).

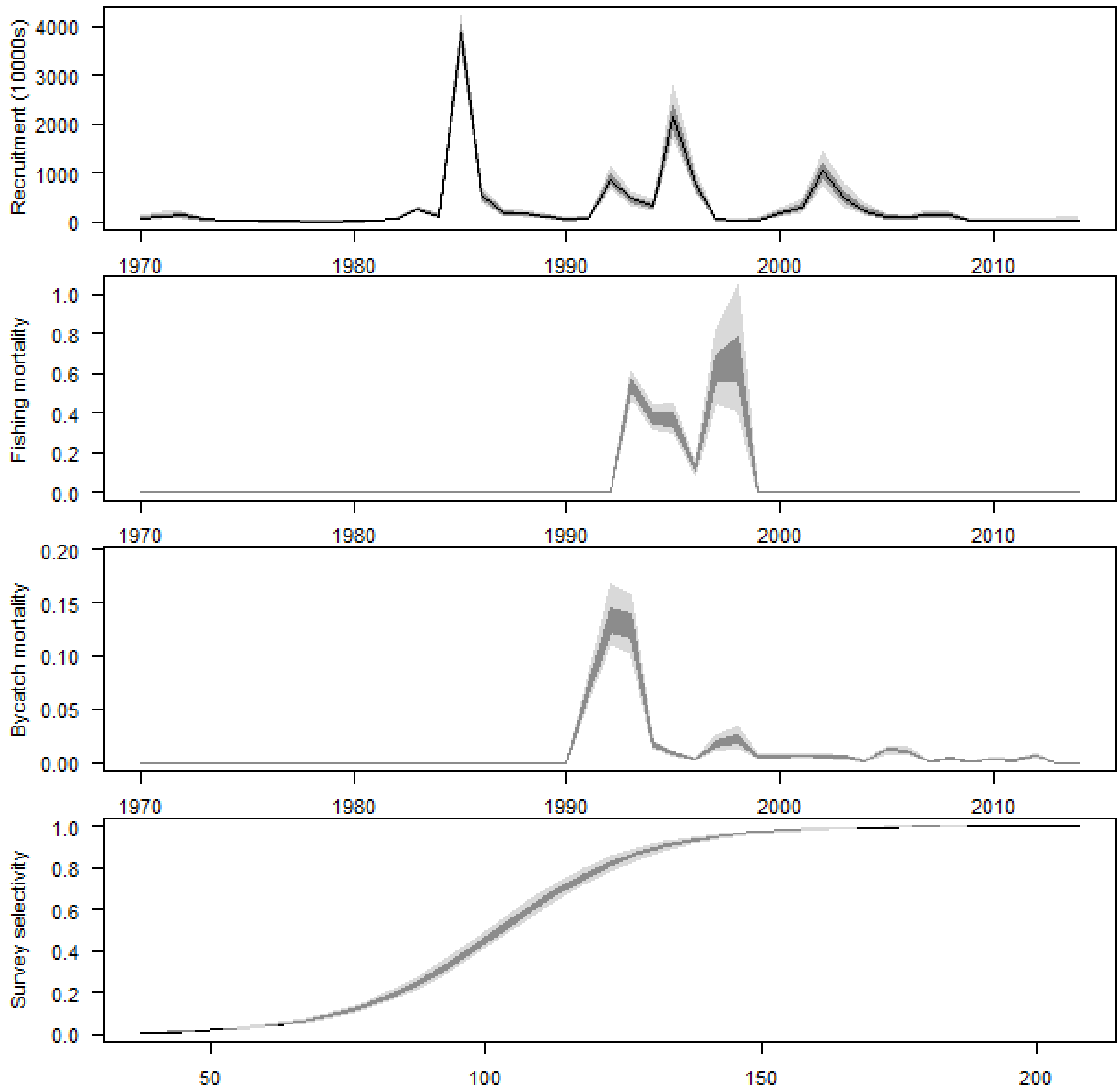

Figure 16. Estimated recruitment (top), fishing mortality in the directed fishery (2nd row), fishing mortality in the non-pelagic trawl (3rd row) and survey selectivity (bottom). Light grey areas indicate the 90% credibility interval and darker grey are the 50% credibility interval.

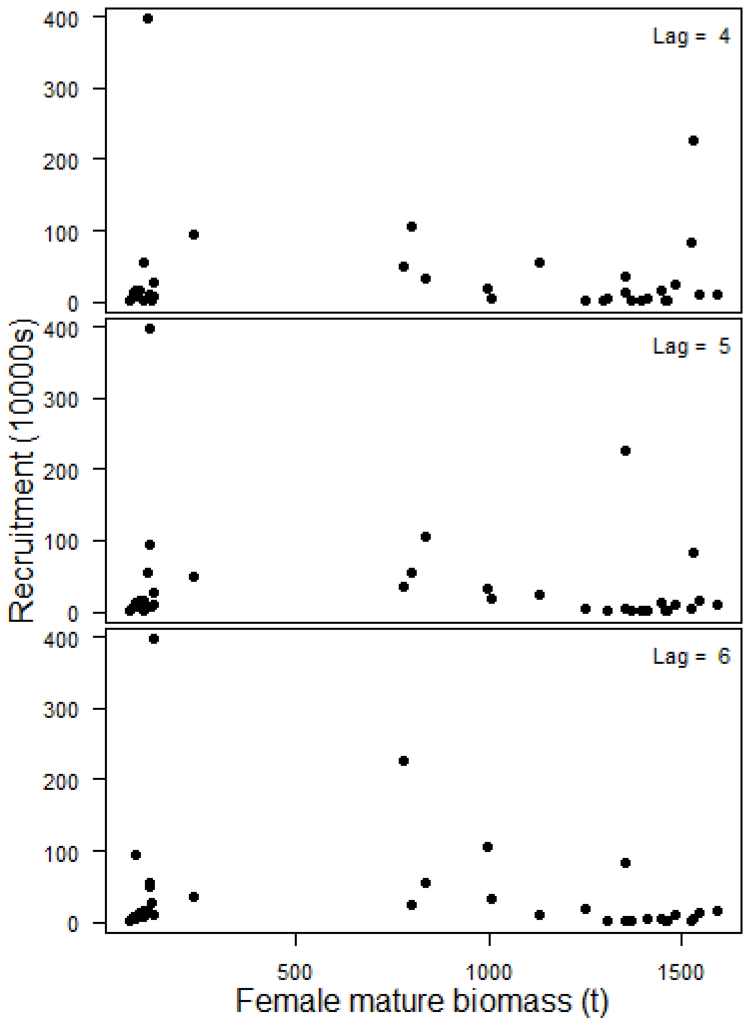

Figure 17. Recruitment vs. estimated female mature biomass at lags of 4, 5, and 6 years.

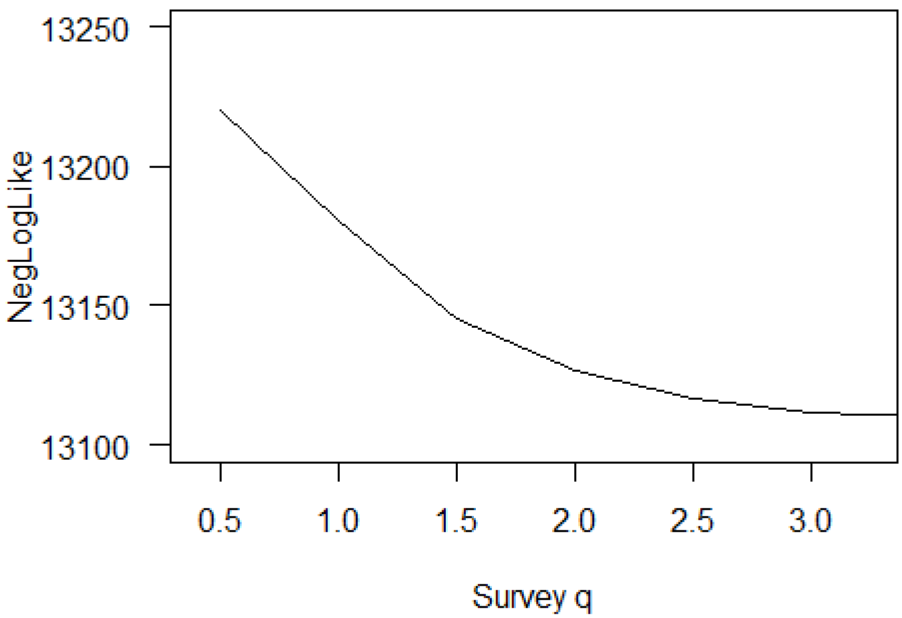

Figure 18. Likelihood profile for survey catchabillity (q).

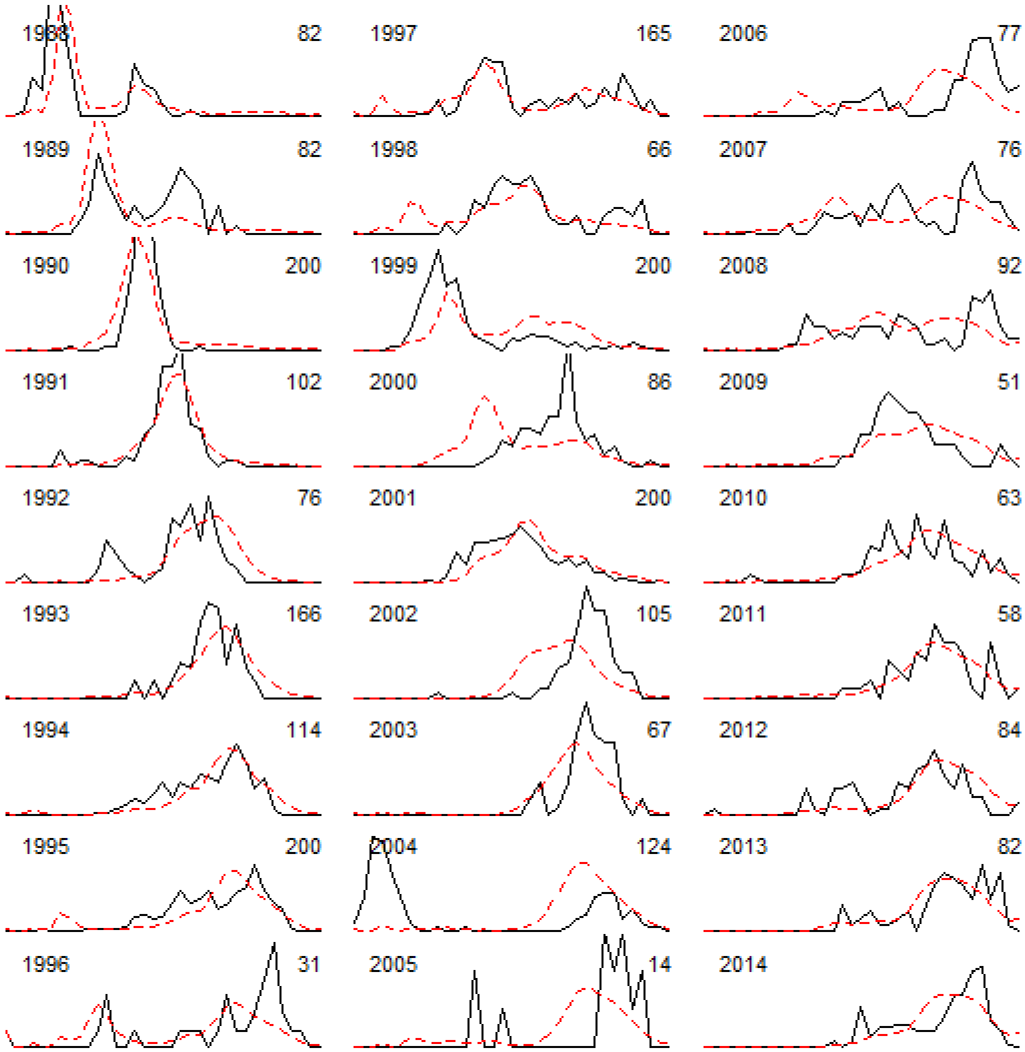

Figure 19. Model fits (red dashed line) to observed male length frequencies in the survey (solid line) by year using 5 mm length bins. Sample size is noted in the top right hand corner of each plot. Length frequencies for the years 1975-1987 are not shown because the associated sample sizes were <=18 and therefore held very little information.

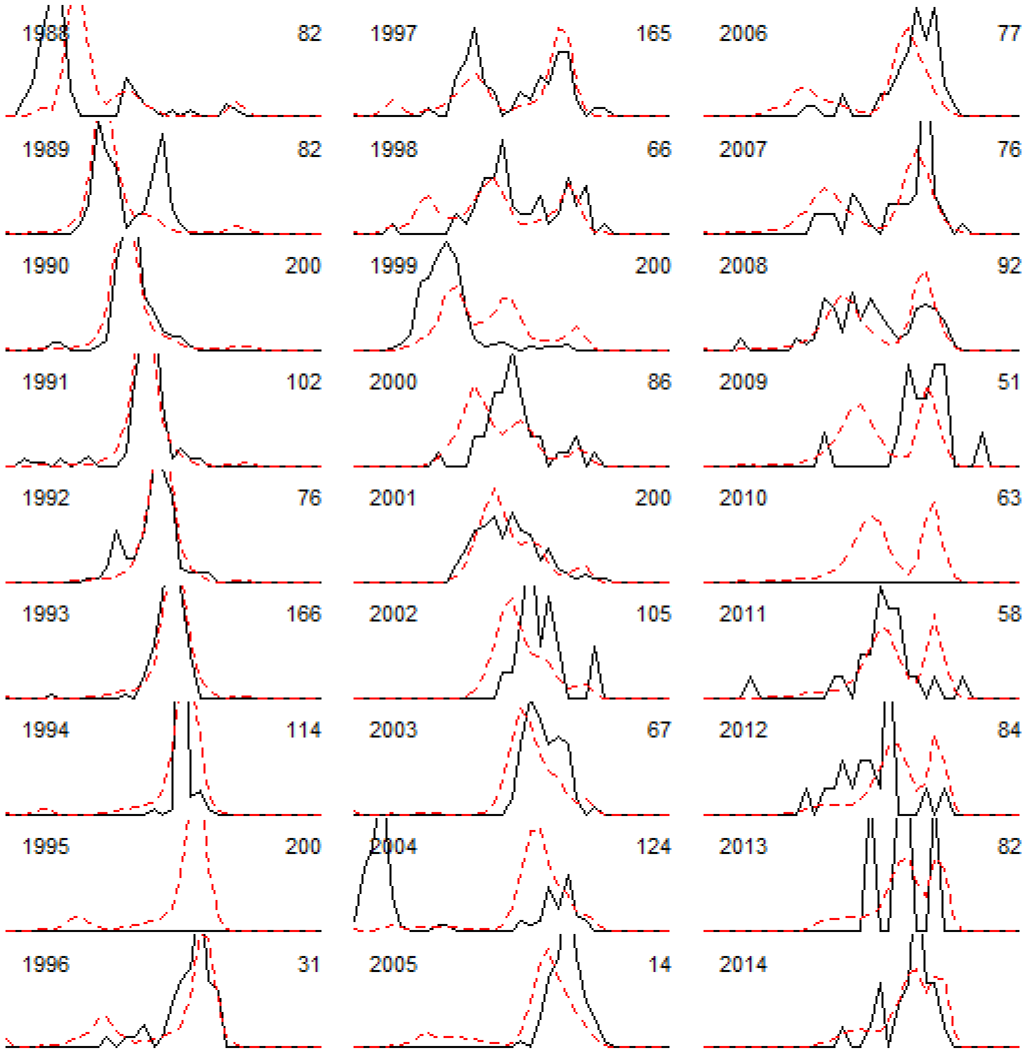

Figure 20. Model fits (red dashed line) to observed female length frequencies in the survey (solid line) by year using 5 mm length bins. Sample size is noted in the top right hand corner of each plot. Length frequencies for the years 1975-1987 are not shown because the associated sample sizes were <=18 and therefore held very little information.

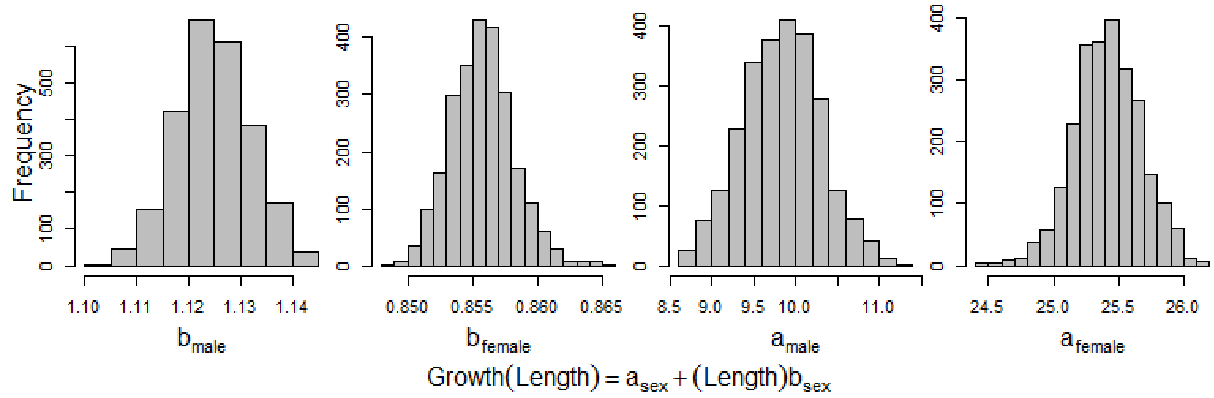

Figure 21. Posterior distributions of estimated growth parameters.

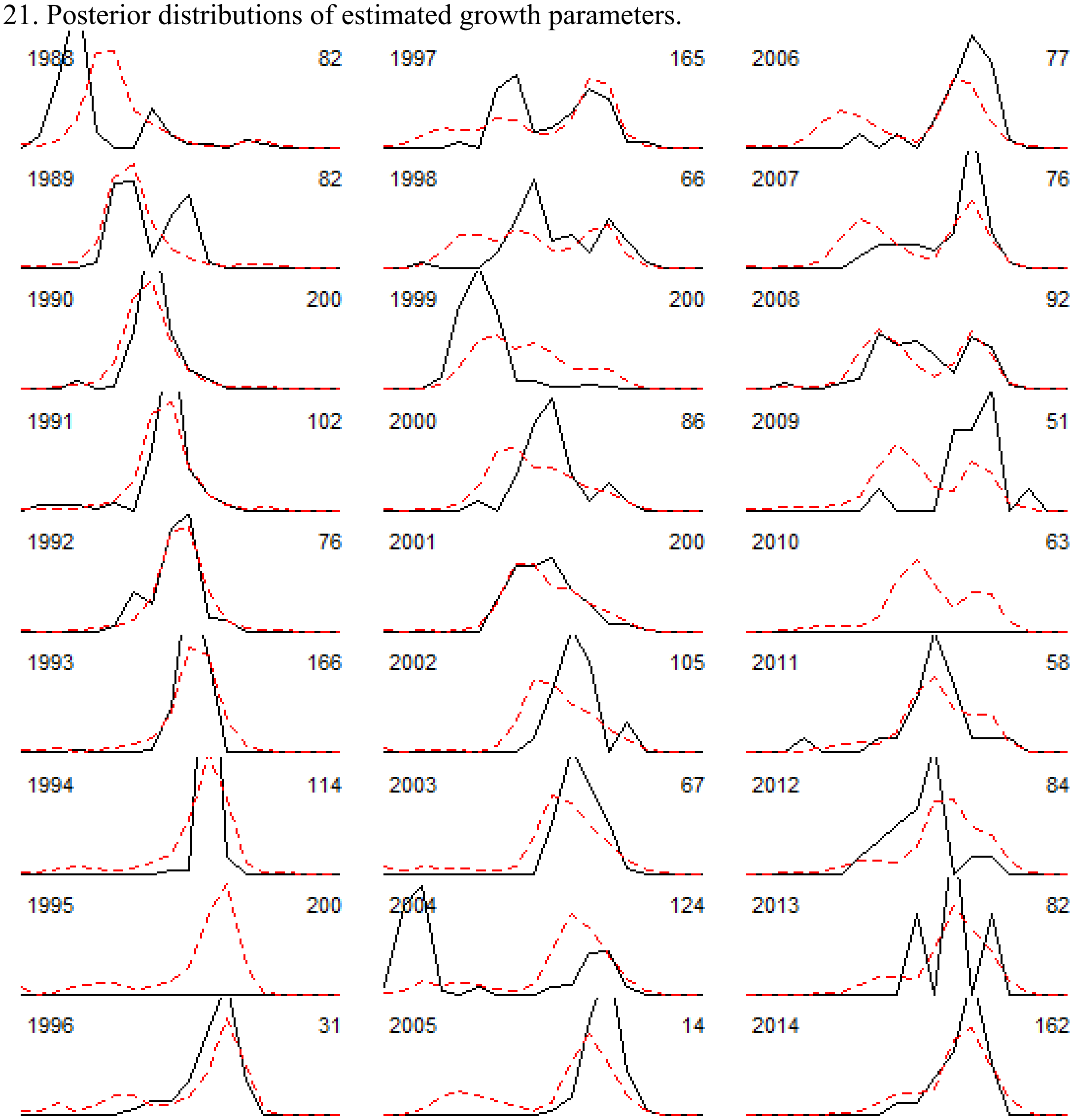

Figure 22. Model fits (red dashed line) to observed female length frequencies in the survey (solid line) by year using 10 mm length bins. Sample size is noted in the top right hand corner of each plot. Length frequencies for the years 1975-1987 are not shown because the associated sample sizes were <=18 and

therefore held very little information.

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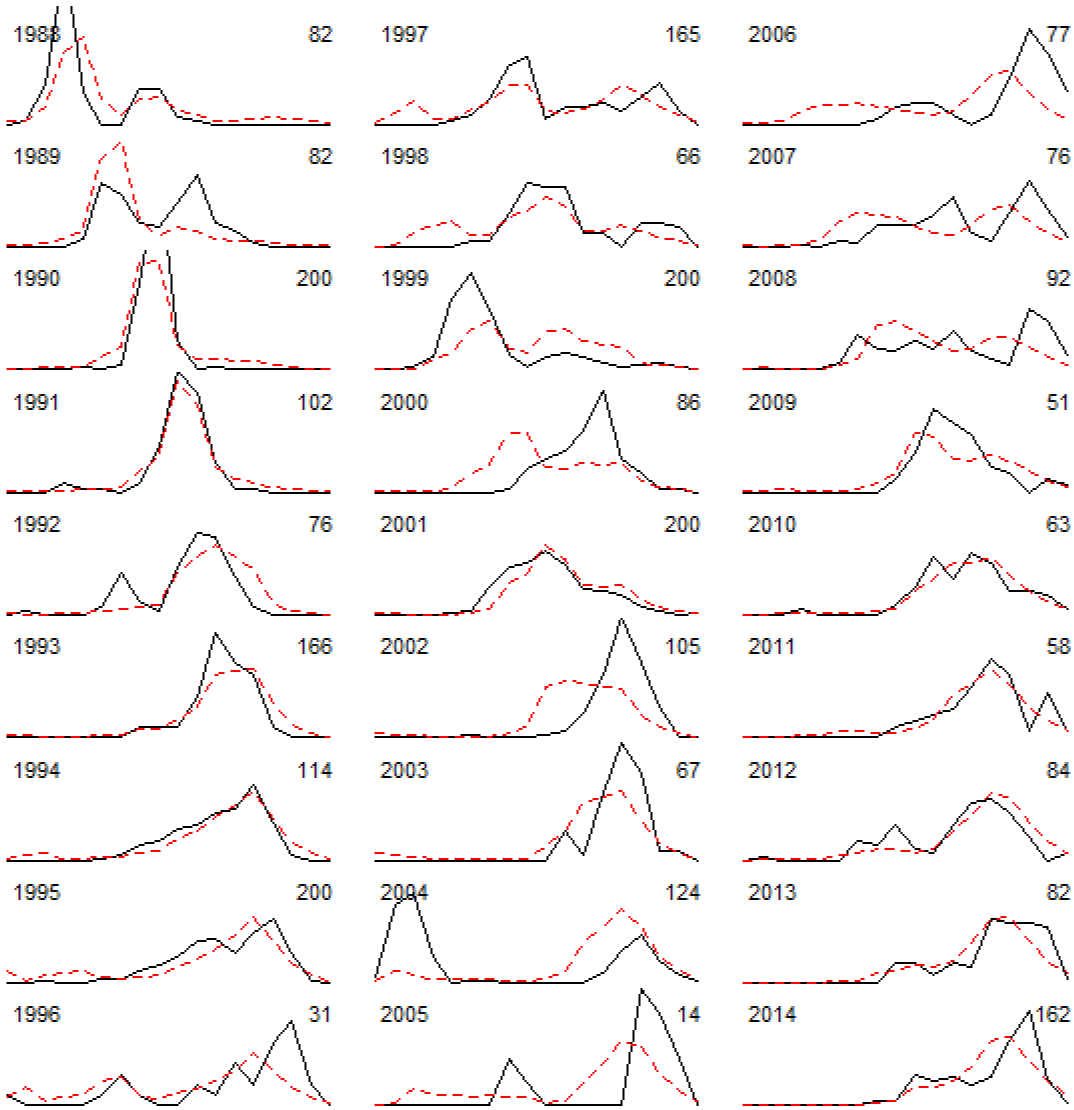

Figure 23. Model fits (red dashed line) to observed male length frequencies in the survey (solid line) by year using 10 mm length bins. Sample size is noted in the top right hand corner of each plot. Length frequencies for the years 1975-1987 are not shown because the associated sample sizes were <=18 and therefore held very little information.

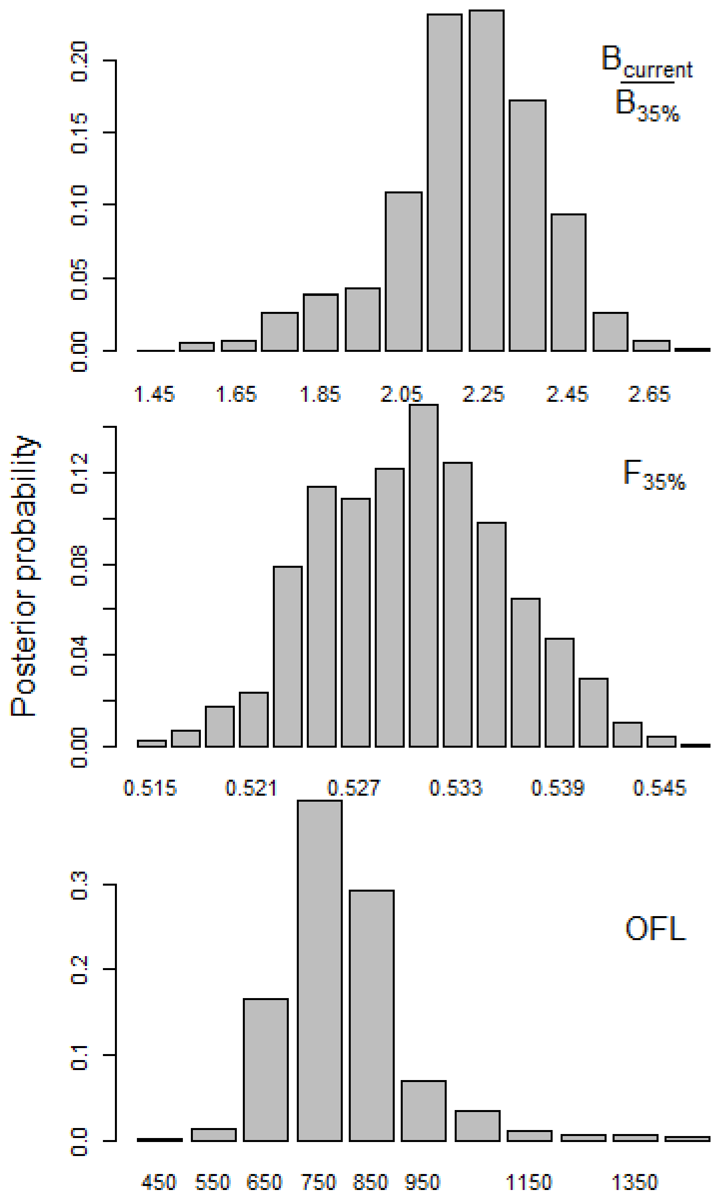

Figure 24. Posterior distributions for the ratio of the current biomass to the target biomass (top), F35% (middle) and the overfishing level (bottom) for an MCMC in which growth and associated parameters were estimated.

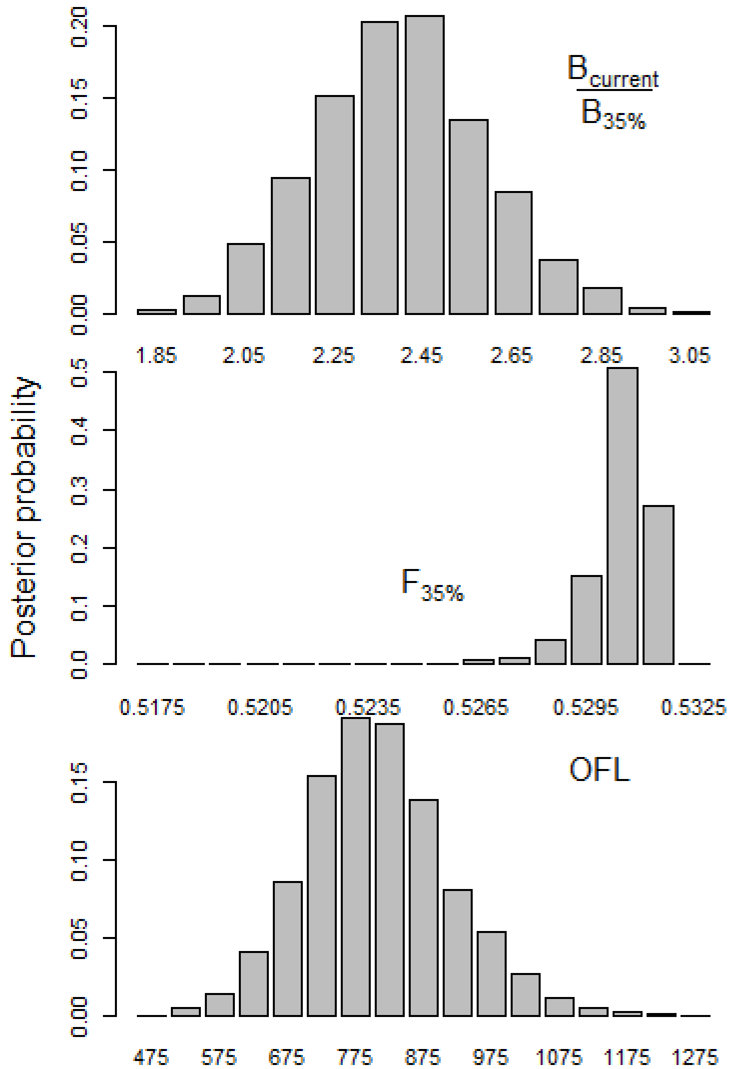

Figure 25. Posterior distributions for the ratio of the current biomass to the target biomass (top), $F_{35\%}$ (middle) and the overfishing level (bottom) for an MCMC in which growth and associated parameters were not estimated.

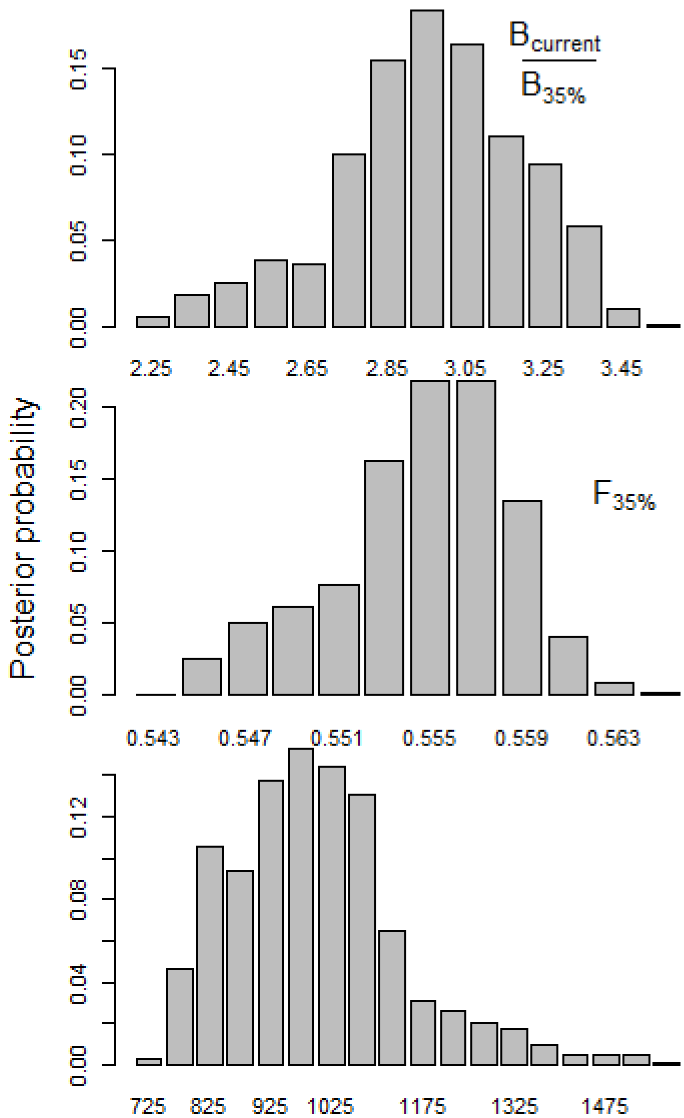

Figure 26. Posterior distributions for the ratio of the current biomass to the target biomass (top), F35% (middle) and the overfishing level (bottom) for an MCMC in which growth and associated parameters were estimated and length bins were in 10 mm intervals.

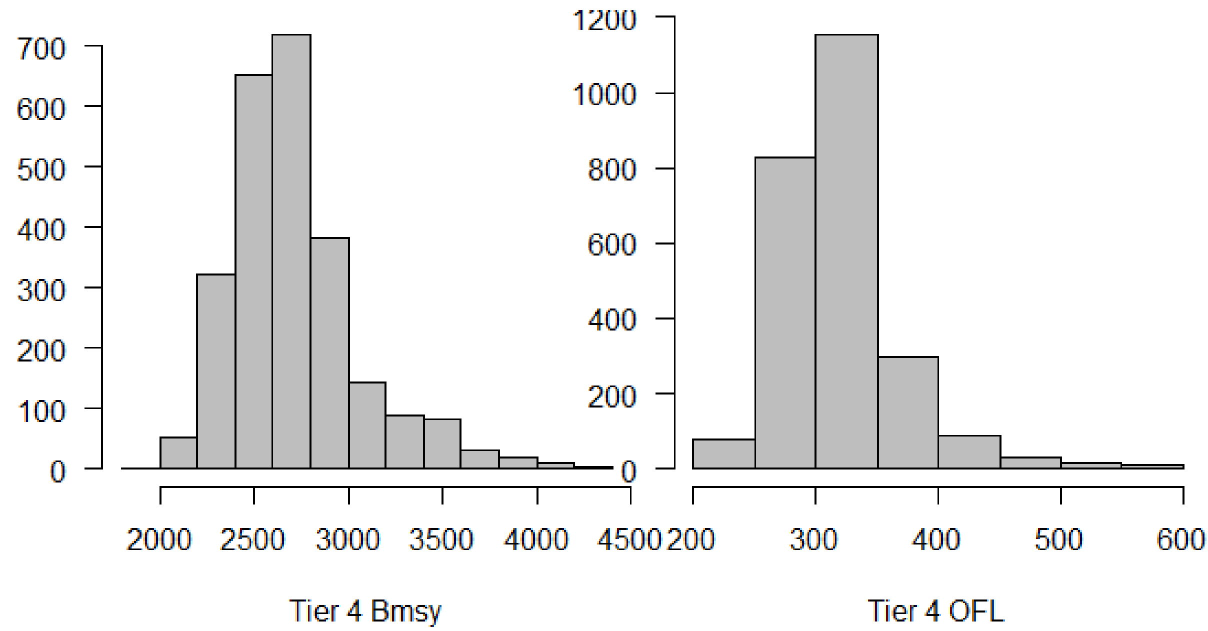

Figure 27. Posterior distribution for Tier 4 BMSY and OFL (in tonnes) from the integrated assessment when growth and associated parameters were estimated.

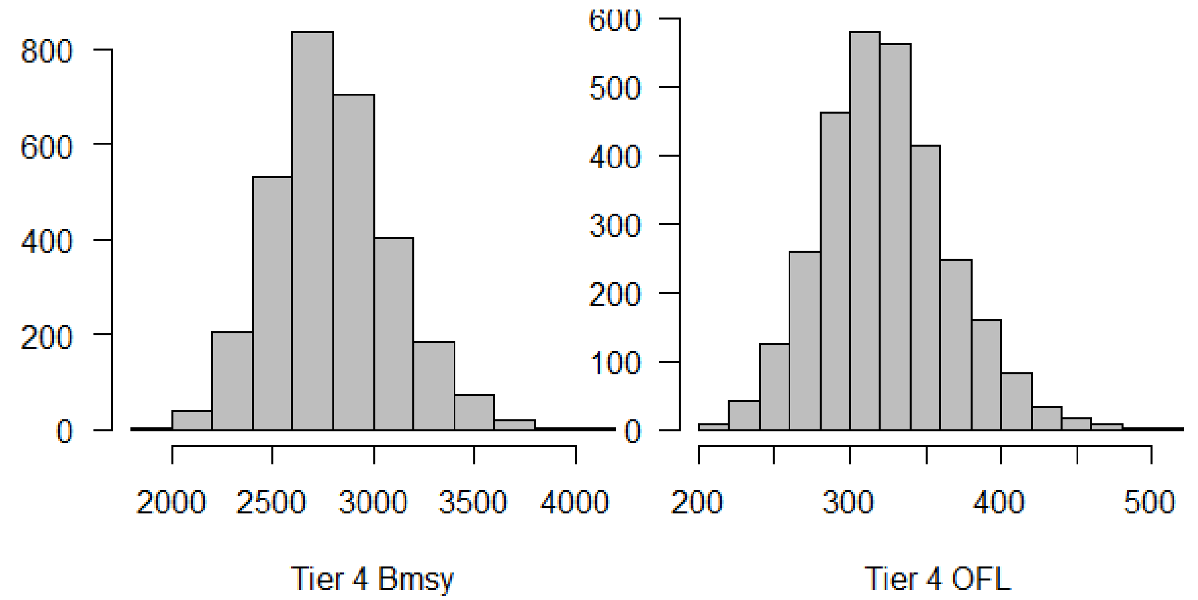

Figure 28. Posterior distribution for Tier 4 BMSY and OFL (in tonnes) from the integrated assessment when growth and associated parameters were fixed.

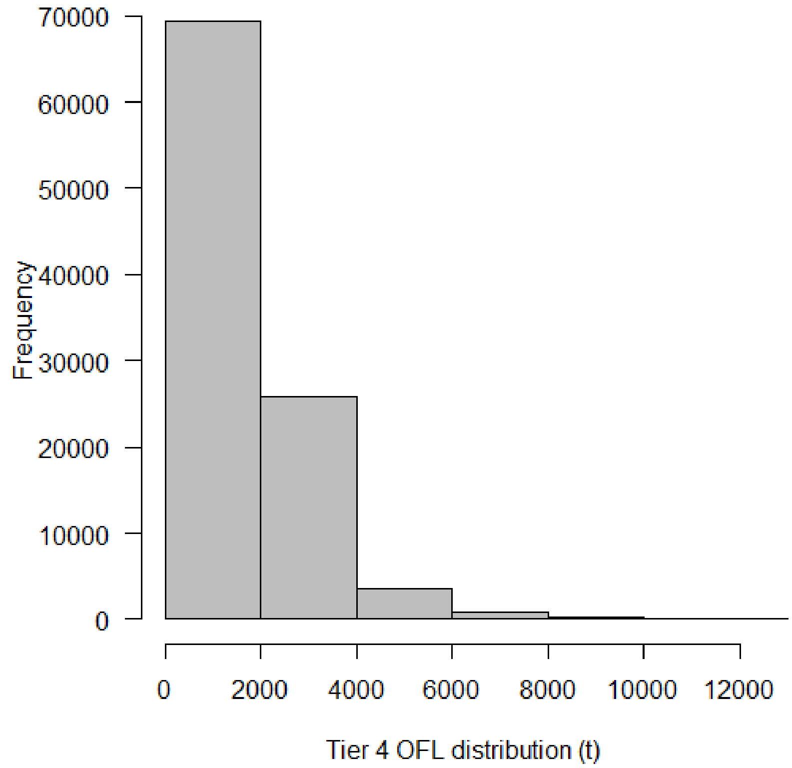

Figure 29. Distribution of tier 4 OFL generated by bootstrapping values of MMB with an additional sigma of 0.3.

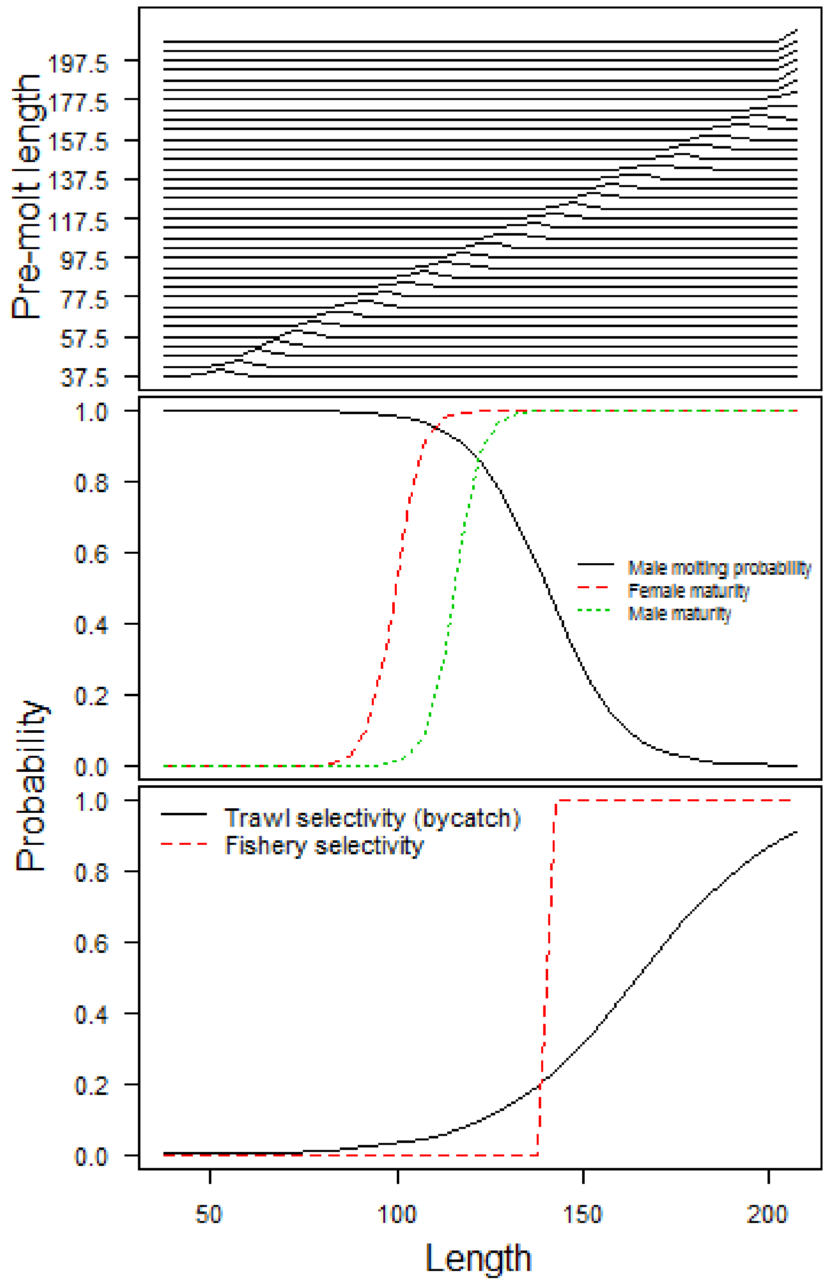

Figure 30. Size transition matrix (top), probability of molting (males only) and maturing (females and males; middle), probability of being selected in the directed and trawl fisheries (bottom).

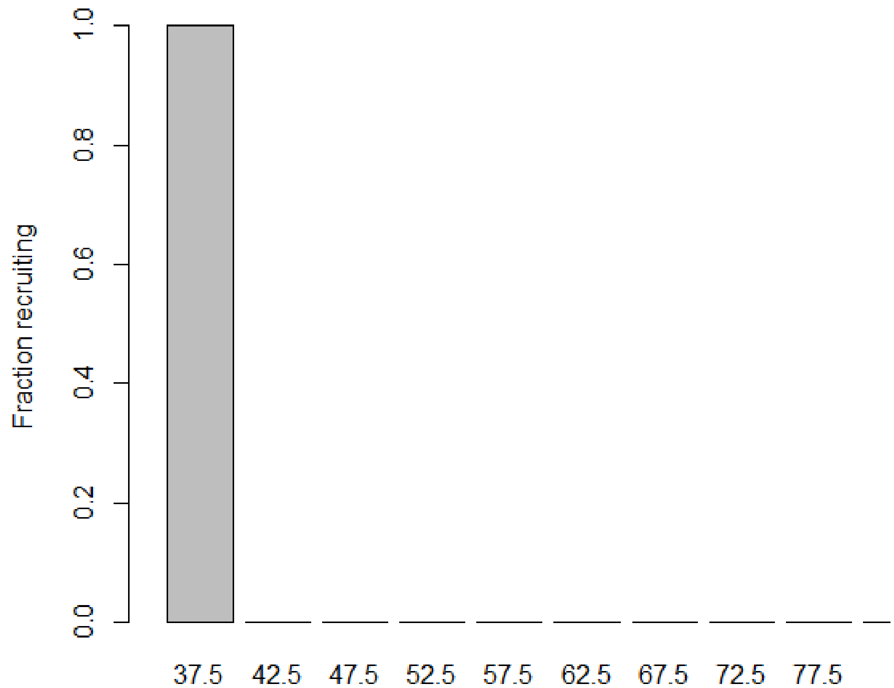

Figure 31. Estimated fraction of incoming recruitment allocated to a given length bin.

Draft 2014 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

W.T. Stockhausen
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Executive Summary

1. Stock: Pribilof Islands blue king crab (PIBKC), *Paralithodes platypus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch and discards have been relatively small in recent years, with most bycatch mortality occurring in the BSAI groundfish trawl fisheries (5-year average: 0.12 t [0.0003 million lbs]) and pot fisheries (5-year average: 0.03 t [0.0001 million lbs]). In 2013/14, the estimated crab bycatch mortality was zero in the groundfish trawl fisheries and 0.03 t (0.0001 million lbs) in the groundfish pot fisheries. The estimated bycatch mortality for Pribilof Islands blue king crab in other crab fisheries was zero in 2013/14.
3. Stock biomass: Stock biomass in recent years decreased between the 1995 and 2008 surveys, and continues to fluctuate at low abundance in all size classes. Any short term trends are questionable given the high uncertainty associated with recent survey results.
4. Recruitment: Recruitment indices are not well understood for Pribilof blue king crab. Pre-recruits have remained consistently low in the past 10 years, although these may not be well assessed with the survey.
5. Management performance: The stock is below MSST and consequently is overfished. Overfishing did not occur during the 2013/2014 fishing year.

All units are tons of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2010/11	4,420 [A]	286 [A]	0	0	0.18	1.81	
2011/12	2,247 [A]	365 [A]	0	0	0.36	1.16	1.04
2012/13	1,994 [A]	579 [A]	0	0	0.61	1.16	1.04
2013/14	2,001 [A]	225 [A]	0	0	0.03	1.16	1.04
2014/15	--	218 [B]	--	--	--	1.16	1.04

All units are million pounds of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2010/11	9.74 [A]	0.63 [A]	0	0	0.0004	0.004	
2011/12	4.95 [A]	0.80 [A]	0	0	0.0008	0.003	0.002
2012/13	4.39 [A]	1.09 [A]	0	0	0.0013	0.003	0.002
2013/14	4.41 [A]	0.50 [A]	0	0	0.0001	0.003	0.002
2014/15	--	0.48 [B]	--	--	--	0.003	0.002

Notes:

A – Based on data available to the Crab Plan Team at the time of the assessment following the end of the crab fishing year.
B – Based on data available to the Crab Plan Team at the time of the assessment for the crab fishing year.

6. Basis for the 2014/2015 OFL: The OFL was set following Tier 4 considerations. The ratio of the estimate of current (2014/15) MMB at mating to B_{MSY} is less than 0.25, so directed fishing is not allowed. As a consequence, the OFL is based on a Tier 5 calculation of average bycatch mortalities between 1999/2000 and 2005/2006 to adequately reflect the conservation needs with this stock and to acknowledge existing non-directed catch mortality. Using this approach, the OFL was determined to be 1.16 t (0.0003 million lbs) for 2014/15.

All weights in t.

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2010/11	4c	4,209	286	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2011/12	4c	4,209	365	0.09	1	1975/76-1984/85 &1990/91-1997/98	0.18	10% buffer
2012/13	4c	4,494	496	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	3,988	278	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	4,002	218	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer

All weights in million lbs.

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2010/11	4c	9.28	0.63	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2011/12	4c	9.28	0.80	0.09	1	1975/76-1984/85 &1990/91-1997/98	0.18	10% buffer
2012/13	4c	9.91	1.09	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	8.79	0.61	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	8.82	0.48	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer

7. Probability density function for the OFL: Not applicable for this stock.
8. The ABC_{max} was calculated using a 10% buffer similar to that of the Tier 5 ABC control rule. The ABC_{max} was thus estimated to be 1.04 t.
9. Rebuilding analyses results summary: Proposed Crab FMP and regulatory amendments were submitted for review by the Secretary in early 2013 because NMFS determined that the stock was not rebuilding in a timely manner and would not meet the rebuilding horizon of 2014. These amendments are still under review.

A. Summary of Major Changes:

1. Management: There were no major changes to the 2013/2014 management of the fishery.
2. Input data: Retained and discard catch time series were updated with 2013/2014 data from the crab and groundfish fisheries. A new methodology for estimating discard catch for the groundfish fisheries based on ADF&G state statistical areas was used for 2009/10-2013/14, replacing the previous estimates. This new methodology corrected some deficiencies in a similar approach used in the previous assessment. Abundance, biomass and size frequencies were estimated from the 2014 NMFS crab and groundfish summer bottom trawl survey data using the same methodology as in 2013, as well.
3. Assessment methodology: The time series of MMB-at-mating to determine B_{MSY} for this stock was estimated using a 3-year centered, running average, weighted by the inverse variance. The MMB-at-mating for 2014/15 was calculated by projecting a simple average of MMB-at-survey for this year and last year forward to mating, using a 3-year average estimator for the ratio of bycatch mortality to MMB-at-fishery to estimate the projected bycatch mortality for 2014/15.
4. Assessment results: The projected MMB decreased somewhat from that in 2013/14 and remained below the MSST. Consequently, the OFL remains low with no directed fishery. Total catch mortality in 2013/2014 was 0.03 t.

B. Responses to SSC and CPT Comments

SSC comments October 2013:

Specific remarks pertinent to this assessment

The SSC recommends a modified Tier 5 calculation of average catch mortalities between 1999/2000 and 2005/2006, resulting in a total catch OFL of 0.00116 kt.

The SSC supports using a 10% buffer for the ABC calculation, resulting in an ABC_{max} of 0.00104 kt.

Responses to SSC Comments: The authors have followed the SSC's recommendations for OFL and ABC calculations. Because these are based on catch mortalities over a fixed time period, the resulting OFL and ABC values are identical to those the SSC recommended last year.

SSC comments June 2014:

Specific remarks pertinent to this assessment

none

CPT comments September 2013:

Specific remarks pertinent to this assessment

The CPT expressed interest in seeing information about whether the amount of observer coverage has changed since the new groundfish observer program was implemented in 2013.

The CPT would like to see the spatial distribution of bycatch by State statistical area.

Responses to CPT Comments: This will be addressed at the May 2015 CPT meeting.

CPT comments May 2014:

Specific remarks pertinent to this assessment

none

C. Introduction

1. **Blue king crabs,** *Paralithodes platypus*
2. **Distribution -** Blue king crab are anomurans in the family Lithodidae which also includes the red king crab (*Paralithodes camtschaticus*) and golden or brown king crab (*Lithodes aequispinus*) in Alaska. Blue king crabs are found in widely-separated populations that are frequently associated with fjord-like bays (Figure 1). In the western Pacific, blue king crabs occur off Hokkaido in Japan, and isolated populations have been observed n the Sea of Okhotsk and along the Siberian coast to the Bering Straits. In North America, they are found in the Diomede Islands, Point Hope, outer Kotzebue Sound, King Island, and the outer parts of Norton Sound. In the remainder of the Bering Sea, they are found in the waters off St. Matthew Island and the Pribilof Islands. In more southerly areas, blue king crabs are found in the Gulf of Alaska in widely-separated populations that are frequently associated with fjord-like bays (Figure 1). The insular distribution of blue king crab relative to the similar but more broadly distributed red king crab is likely the result of post-glacial-period increases in water temperature that have limited the distribution of this cold-water adapted species (Somerton 1985). Factors that may be directly responsible for limiting the distribution include the physiological requirements for reproduction, competition with the more warm-water adapted red king crab, exclusion by warm-water predators, or habitat requirements for settlement of larvae (Somerton 1985; Armstrong et al 1985, 1987).

   During the years when the fishery was active (1973-1989, 1995-1999), the Pribilof Islands blue king crab were managed under the Bering Sea king crab Registration Area Q Pribilof District, which has as its southern boundary a line from 54° 36’ N lat., 168° W long., to 54° 36’ N lat., 171° W long., to 55° 30’ N lat., 171° W. long., to 55° 30’ N lat., 173° 30’ E long., as its northern boundary the latitude of Cape Newenham (58° 39’ N lat.), as its eastern boundary a line from 54° 36’ N lat., 168° W long., to 58° 39’ N lat., 168° W long., to Cape Newenham (58° 39’ N lat.), and as its western boundary the United States-Russia Maritime Boundary Line of 1991 (ADF&G 2008) (Figure 2). In the Pribilof District, blue king crab occupied the waters adjacent to and northeast of the Pribilof Islands (Armstrong et al. 1987).

3. **Stock structure** - Stock structure of blue king crabs in the North Pacific is largely unknown. Samples were collected in 2009-2011 to support a genetic study on blue king crab population structure by a graduate student at the University of Alaska. Aspects of blue king crab harvest and abundance trends, phenotypic characteristics, behavior, movement, and genetics will also be evaluated by the authors following the guidelines in the AFSC report entitled “Guidelines for determination of spatial management units for exploited populations in Alaskan groundfish fishery management plans” by P. Spencer.

   The potential for species interactions between blue king crab and red king crab as a potential reason for PIBKC shifts in abundance and distribution were addressed in the previous assessment (Foy, 2013). R. Foy compared the spatial extent of both speices in the Pribilof Islands from 1975 to 2009 and found that, in the early 1980’s when red king crab first became abundant, blue king crab males and females dominated the 1 to 7 stations where the species co-occurred in the Pribilof Islands District. Spatially, the stations with co-occurance were all dominated by blue king crab and broadly distributed around the Pribilof Islands. In the 1990’s, the red king crab population biomass increased substantially as the blue king crab population biomass decreased. During this time period, the number of stations with co-occurance remained around a maximum of 8, but they were equally dominated by both blue king crab ands red king crab—sugggesting a direct overlap in distribution at the scale of a survey station. During this time period, the stations dominated by red king crab were dispersed around the Pribilof Islands. Between 2001 and 2009 the blue king crab population decreased dramatically while the red king crab fluctuated. The number of stations dominated by blue king crab i 2001-2009 was similar to that for stations dominated by red king crab for both males and females, suggesting continued competition for similar habitat. The only stations dominated by blue king crab in the latter period exist to the north and east of St. Paul Island. Although blue king crab protection measures also afford protection for the red king crab in this region, red king crab stocks continue to fluctuate (more so than simply accounted for by the uncertainty in the survey).

4. **Life History** - Blue king crab are similar in size and appearance, except for color, to the more widespread red king crab, but are typically biennial spawners with lesser fecundity and somewhat larger sized (*ca.* 1.2 mm) eggs (Somerton and Macintosh 1983; 1985; Jensen et al. 1985; Jensen and Armstrong 1989; Selin and Fedotov 1996). Blue king crab fecundity increases with size, from approximately 100,000 embryos for a 100-110 mm CL female to approximately 200,000 for a female >140-mm CL (Somerton and MacIntosh 1985). Blue king crab have a biennial ovarian cycle with embryos developing over a 12 or 13-month period depending on whether or not the female is primiparous or multiparous, respectively (Stevens 2006a). Armstrong et al. (1985, 1987), however, estimated the embryonic period for Pribilof blue king crab at 11-12 months, regardless of previous reproductive history. Somerton and MacIntosh (1985) placed development at 14-15 months. It may not be possible for large female blue king crabs to support the energy requirements for annual ovary development, growth, and egg extrusion due to limitations imposed by their habitat, such as poor quality or low abundance of food or reduced feeding activity due to cold water (Armstrong et al. 1987, Jensen and Armstrong 1989). Both the large size reached by Pribilof Islands blue king crab and the generally high productivity of the Pribilof area, however, argue against such environmental constraints. Development of the fertilized embryos occurs in the egg cases attached to the pleopods beneath the abdomen of the female crab and hatching occurs February through April (Stevens 2006b). After larvae are released, large female Pribilof blue king crab will molt, mate, and extrude their clutches the following year in late March through mid April (Armstrong et al. 1987).

   Female crabs require an average of 29 days to release larvae, and release an average of 110,033 larvae (Stevens 2006b). Larvae are pelagic and pass through four zoeal larval stages which last about 10 days each, with length of time being dependent on temperature: the colder the temperature the slower the development and vice versa (Stevens et al 2008). Stage I zoeae must find food within 60 hours as starvation reduces their ability to capture prey (Paul and Paul 1980) and successfully molt. Zoeae consume phytoplankton, the diatom *Thalassiosira* spp. in particular, and zooplankton. The fifth larval stage is the non-feeding (Stevens et al. 2008) and transitional glaucothoe stage in which the larvae take on the shape of a small crab but retain the ability to swim by using their extended abdomen as a tail. This is the stage at which the larvae searches for appropriate settling substrate, and upon finding it, molts to the first juvenile stage and henceforth remains benthic. The larval stage is estimated to last for 2.5 to 4 months and larvae metamorphose and settle during July through early September (Armstrong et al. 1987, Stevens et al. 2008).

   Blue king crab molt frequently as juveniles, growing a few mm in size with each molt. Unlike red king crab juveniles, blue king crab juveniles are not known to form pods. Female king crabs typically reach sexual maturity at approximately five years of age while males may reach maturity one year later, at six years of age (NPFMC 2003). Female size at 50% maturity for Pribilof blue king crab is estimated at 96-mm carapace length (CL) and size at maturity for males, as estimated from size of chela relative to CL, is estimated at 108-mm CL (Somerton and MacIntosh 1983). Skip molting occurs with increasing probability for those males larger than 100 mm CL (NMFS 2005).

   Longevity is unknown for this species due to the absence of hard parts retained through molts with which to age crabs. Estimates of 20 to 30 years in age have been suggested (Blau 1997). Natural mortality for male Pribilof blue king crabs has been estimated at 0.34-0.94 with a mean of

0.79 (Otto and Cummiskey 1990) and a range of 0.16 to 0.35 for Pribilof and St. Matthew Island stocks combined (Zheng et al. 1997). An annual natural mortality of 0.2 for all king crab species was adopted in the federal crab fishery management plan for the BSAI areas (Siddeek et. al 2002).

5. **Management history -** The king crab fishery in the Pribilof District began in 1973 with a reported catch of 590 t by eight vessels (Figure 3). Landings increased during the 1970s and peaked at a harvest of 5,000 t in the 1980/81 season, with an associated increase in effort to 110 vessels (ADF&G 2008). The fishery occurred September through January, but usually lasted less than 6 weeks (Otto and Cummiskey 1990, ADF&G 2008). The fishery was male only, and legal size was >16.5 cm carapace width (NOAA 1995). Guideline harvest level (GHL) was 10 percent of the abundance of mature male or 20 percent of the number of legal males (ADF&G 2006). Following 1995, declines in the stock resulted in a closure of directed fishing from 1999 to present. The Pribilof Islands blue king crab stock was declared overfished in September, 2002 and the Alaska Department of Fish and Game (ADFG) developed a rebuilding harvest strategy as part of the North Pacific Fishery Management Council's (NPFMC) comprehensive rebuilding plan for the stock.

   Amendment 21a to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 4) which prohibits the use of trawl gear in a specified area around the Pribilof Islands year round. The amendment went into effect January 20, 1995 and protects the majority of crab habitat in the Pribilof Islands area from impacts from trawl gear.

   Blue king crab in the Pribilof District can occur as bycatch in the following crab fisheries: the eastern Bering Sea snow crab (*Chionoecetes opilio*), the eastern Bering Sea Tanner crab (*Chionoecetes bairdi*), the Bering Sea hair crab (*Erimacrus isenbeckii*), and the Pribilof red and blue king crab. In addition, blue king crab are caught in flatfish, sablefish, halibut, pollock, and Pacific cod fisheries.

D. Data

1. *Summary of new information:* The standard survey time series data, including an additional (as of 2013) 20 nm strip on the eastern portion of the Pribilof District, was recalculated and updated through 2014. The time series of discards in the groundfish pot and trawl fisheries was recalculated and updated through the 2013/14 crab fishery season (July 1-June 30). The time series of retained and discarded catch in the crab fisheries was also updated with 2013/2014 data.

2. *a. Total catch:*

   <u>Crab pot fisheries</u>

   Retained pot fishery catches (live and deadloss landings data) are provided for 1973/1974 to 2012/2013 (Table 1), including the 1973/1974 to 1987/1988 and 1995/1996 to 1998/1999 seasons when blue king crab were targeted in the Pribilof Islands District. In the 1995/1996 to 1998/1999 seasons, blue king crab and red king crab were fished under the same GHL. Total allowable catch (TAC) for a directed fishery was set at zero in 2013/14 and there was consequently no retained catch in the 2013/2014 crab fishing season *b. Bycatch and discards:*

Crab pot fisheries

Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers in the crab fisheries. Catch weight was calculated by first determining the mean weight (in grams) for crabs in each of three categories: legal non-retained, sublegal, and female. The average weight for each category was then calculated from length frequency tables, where the carapace length (CL; in mm) was converted to weight (W; in g) using the following equation:

$$W = \alpha \cdot CL^{\beta} \tag{1}$$

Values for the length-to-weight conversion parameters α and β were available for two time periods: 1973-2009 (males: α =0.000329, β =3.175; females: α =0.114389, β =1.9192) and 2010-2011 (both sexes: α =0.000508, β =3.106). Average weights ($\overline{W}$) for each category were calculated using the following equation:

$$\overline{W} = \frac{\sum_z W_z \cdot n_z}{\sum_z n_z} \tag{2}$$

where W_z is crab weight-at-size z (i.e., carapace length) using Eq. 1 and n_z is the number of crabs observed at that size in the category.

Finally, estimated total non-retained weights for each crab fishery were the product of average weight ($\overline{W}$), CPUE based on observer data, and total effort (pot lifts) in each fishery. A 50% handling mortality rate was applied to these bycatch estimates to estimate crab mortality in these pot fisheries.

Historical non-retained catch data are available from 1996/1997 to present from the snow crab general, snow crab CDQ, and Tanner crab fisheries (Table 2, Bowers et al. 2011), although data may be incomplete for some of these fisheries. Prior to 1998, limited observer data exists (for catcher-processor vessels only), so non-retained catch before this date is not included here.

In 2013/2014, there were no Pribilof Islands blue king crab incidentally caught in the crab fisheries (Table 2).

Groundfish pot, trawl, and hook and line fisheries

NOAA Fisheries Alaska Regional Office (AKRO; J. Gasper, NMFS, pers. comm.) estimates of non-retained catch from all groundfish fisheries in 2013/14 are included in this SAFE report. Revised estimates for 2009/10-2012/13, based on an improved approach to handling unobserved catches, are also included (Table 2 and 3).

Prior to 1991, groundfish bycatch data are available only in INPFC reports and are not included in this assessment. Historical non-retained groundfish catch data are available from 1991/1992 to present (J. Mondragon, NMFS, personal communication). Between 1991 and December 2001, bycatch was estimated using the “blend method”. From January 2003 to December 2007, bycatch was estimated using the Catch Accounting System (CAS), based on substantially different methods than the “blend”. Starting in January 2008, the groundfish observer program changed the method in which they speciate crab to better reflect their hierarchal sampling method and to account for broken crab that in the past were only identified to genus. In addition, the haul-level weights collected by observers were used to estimate the crab weights through CAS instead of applying an annual (global) weight factor to convert numbers to biomass. Spatial resolution was at federal reporting area. Starting in January 2009, ADF&G (state) statistical areas were included in groundfish production reports and allowed an increase in the spatial resolution of bycatch estimates from the federal reporting areas to the state statistical areas. Bycatch estimates (2009-present) based on the state statistical areas were first provided in the 2013 assessment. For this assessment (2014), these estimates have been recalculated based on improved methods for aggregating observer data. More information on crab bycatch estimates in the groundfish fisheries, and changes between 2013 and 2014, is provided in Appendix A.

To assess crab mortalities in the groundfish fisheries, an 80% handling mortality rate was applied to estimates of bycatch using trawl fisheries and a 50% handling mortality rate was applied to fisheries using pot and hook and line gear (Table 2, 3). Changes in these results from the 2013 assessment for 2009/10-2012/13 are summarized in the following table (units are t):

year	2013 estimates		2014 estimates		% change	
	fixed gear	trawl gear	fixed gear	trawl gear	fixed gear	trawl gear
2009/10	1.04	0.17	0.11	0.17	-89	0
2010/11	0.05	0.05	0.02	0.05	-60	0
2011/12	0.06	0.01	0.06	0.01	0	0
2012/13	0.08	0.54	0.08	0.54	0	0

While changes in estimates from fixed gear were substantial in a relative sense for 2009/10 and 2010/11, they were small in an absolute sense (< 1 t).

In 2013/14, bycatch of Pribilof Islands blue king crab occurred almost exclusively in fisheries targeting Pacific cod (*Gadus macrocephalus*; 99.2% by weight, Table 3). In 2012/13, fisheries targeting Pacific cod accounted for 20% of the bycatch while those targeting yellowfin sole (*Limanda aspera*) accounted for 77.2%. The flathead sole (*Hippoglossoides elasodon*) fishery also accounted for a substantial fraction of the bycatch in 2010/11 (26%).

Since the 2009/10 crab fishing season, Pribilof Islands blue king crab have been taken as bycatch in the groundfish fisheries only by hook and line and non-pelagic trawl gear (Table 4). In 2013/14, hook and line gear accounted for the total bycatch of Pribilof Islands blue king crab. In the previous year, it accounted for only 20% of the bycatch (by weight) whereas non-pelagic trawl gear accounted for 80%.

c. Catch-at-length: NA

d. Survey biomass:

The 2014 NMFS EBS bottom trawl survey results (Daly et al. in press) included in this SAFE report are based on the new Pribilof Islands blue king crab stock area definition first used in the 2013 assessment. This stock area definition includes the Pribilof District and a 20 nm strip adjacent to the eastern edge of the District. This new area was defined as a result of the new rebuilding plan and the concern that crab outside of the Pribilof District were not being accounted for in the assessment. The addition of the 20 nm strip resulted in a small effect on the time series (Foy, 2013). Annual differences between the previous time series and the new time series ranged from 0 to 9% (Foy, 2013). Historical survey data were available from 1975 to the present (Tables 6 and 7).

Abundance estimates for male and female crab were calculated by shell condition using 5 mm size (CL) bins. Weight-at-size (Eq. 1) schedules and cutpoint maturity criteria (females: immature < 90 mm CL, mature ≥ 90 mmCL; males: immature < 120 mm CL, mature ≥ 120 mm CL) were applied to these abundance-at-size estimates and summed across relevant sizes to calculate mature male, female, and legal male biomass.

A total of 15 blue king crab were caught at 6 of the 86 stations in the Pribilof District; 10 males were caught at 4 stations and 5 females were caught at 4 stations (Table 5). Males and females were caught together at two of these stations.

Five mature males were caught at 2 stations. All were legal-sized. The 2014 area-swept biomass estimate (± 95% CI) for mature/legal-sized males was 233 ± 320 t, while the 2014 abundance estimate was 0.09 ± 0.13 million crab (Table 6, Figure 5). Also, five immature males were caught at 3 stations. The 2014 biomass estimate for immature males was 83 ± 102 t, while the 2014 abundance estimate was 0.09 ± 0.11 million crab (Table 6, Figure 5).

For mature males, the 2014 survey represents a 7% decrease in biomass and a 12% decrease in abundance over 2013; both are well below the 1990-2013 averages of 1,888 t for biomass and 0.81 million for abundance. For legal males, the changes represent a 22% increase in biomass and a 34% increase in abundance over 2013, but both are well below the 1990-2013 averages of 1,456 t for biomass and 0.53 million for abundance. For immature males, the changes represent a 472% increase in biomass and a 19% increase in abundance over 2013, but both are well below the 1990-2013 averages of 445 t for biomass and 0.69 million for abundance.

Four mature females were caught at 3 stations. The 2014 area-swept biomass estimate (± 95% CI) for mature females was 91 ± 108 t, while the 2014 abundance estimate was 0.07 ± 0.09 million crab (Table 6, Figure 5). One immature female was caught. The 2014 area-swept biomass estimate (± 95% CI) for immature females was 16 ± 32 t, while the 2014 abundance estimate was 0.03 ± 0.05 million crab (Table 6, Figure 5).

For mature females, the 2014 survey represents a 30% decrease in biomass and a 12% decrease in abundance over 2013; both are well below the 1990-2013 averages of 1,590 t for biomass and 1.5 million for abundance. For immature females, the changes represent a 53% decrease in biomass and a 69% increase in abundance over 2013, but both are well below the 1990-2013 averages of 270 t for biomass and 0.68 million for abundance.

Given the large confidence intervals and CVs involved in these area-swept biomass and abundance estimates (Table 7), none of the changes from 2013 to 2014 is statistically significant. To smooth out some of the interannual variability in survey results associated with sampling uncertainty, a centered 3-year running average with inverse variance weighting was applied to the time series of abundance and biomass estimates in Table 6 (Table 8). The smoothed trends suggest that mature male biomass (MMB; Figure 6) and male recruit biomass (Figure 7) trends have been relatively stable since 2010.

Size frequencies for males by shell condition from the 3 most recent surveys (2012-2014) are illustrated in Figure 8, while size frequencies for all males are shown in Figure 9.

Size frequencies for females by shell condition, egg condition, and clutch fullness are illustrated in Figure 10 for the 2014 survey. Size frequencies for all females are shown in Figure 11.

Spatial patterns found in the 2014 survey are contrasted with those from the 2013 survey in Figures 12-14.

E. Analytic Approach

1. *History of modeling approaches*

   A catch survey analysis has been used for assessing the stock in the past, although it is not currently in use. In October 2013, the SSC concurred with the CPT that the PIBKC stock falls under Tier 4 for status determination but it recommended that the OFL be calculated using a Tier 5 approach, with ABC based on a 10% buffer.

2. *Model Desciption: Not applicable.*

3. *Model Selection and Evaluation: Not applicable*
4. *Results: Not applicable*

F. Calculation of the OFL

1. *Tier Level:*

Based on available data, the ***author recommended classification for this stock is Tier 4*** for stock status level determination defined by Amendment 24 to the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 2008).

In Tier 4, stock status is based on the ratio of current B to B_{MSY} (or a proxy thereof, B_{MSY}^{proxy}, also referred to as B_{REF}). MSY is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions. The fishing mortality that, if applied over the long-term, would result in MSY is F_{MSY}. The MSY stock size (B_{MSY}) is based on mature male biomass at the time of mating (MMB_{mating}), which serves as an approximation for egg production. MMB_{mating} is used as a basis for B_{MSY} because of the complicated female crab life history, unknown sex ratios, and male only fishery. Although B_{MSY} cannot be calculated for a Tier 4 stock, a proxy value (B_{MSY}^{proyx} or B_{REF}) is defined as the average biomass over a specified period that satisfies the conditions under which B_{MSY} would occur (i.e., equilibrium biomass yielding MSY by an applied F_{MSY}).

The time period for establishing B_{MSY}^{proxy} is assumed to be representative of the stock being fished at an average rate near F_{MSY} fluctuating around B_{MSY}. The SSC has endorsed using the time periods 1980-84 and 1990-97 to calculate B_{MSY}^{proxy} for Pribilof Islands blue king crab to avoid time periods of low abundance possibly caused by high fishing pressure. Alternative time periods (e.g., 1975 to 1979) have also been considered but rejected. Considerations for choosing the current time periods included:

A. Production potential

1) Between 2006 and 2013 the stock does appears to be below a threshold for responding to increased production based on the lack of response of the adult stock biomass to slight fluctuations in recruitment (male crab 120-134 mm) (Figure 20).
2) An estimate of surplus production (ASP = $MMB_{t+1} - MMB_t$ + total $catch_t$) suggested that only meaningful surplus existed in the late 1970s and early 1980s while minor surplus production in the early 1990s may have led to the increases in biomass observed in the late 1990s.
3) Although a climate regime shift where temperature and current structure changes are likely to impact blue king crab larval dispersal and subsequent juvenile crab distribution, no apparent trends in production before and after 1978 were observed. There are few empirical data to identify trends that may allude to a production shift. However, further analysis is warranted given the paucity of surplus production and recruitment subsequent to 1981 and the spikes in recruits (male crab 120-134 mm) /spawner (MMB) observed in the early 1990s and 2009 (Figure 21).

B. Exploitation rates fluctuated during the open fishery periods from 1975 to 1987 and 1995 to 1998 (Figure 20) while total catch increased until 1980 before the fishery was closed in 1987 and increased again in 1995 before again closing in 1999 (Figure 22). The current $F_{\mathrm{MSY}}^{\mathrm{proxy}}$ assume F=M is 0.18 so time periods with greater exploitation rates should not be considered to represent a period with an average rate of fishery removals.

C. Subsequent to increases in exploitation rates in the late 1980s and 1990s, the ln (recruits/MMB) dropped, suggesting that exploitation rates at the levels of MMB present were not sustainable.

Thus, MMB_{mating} is the basis for calculating $B_{MSY}{}^{proxy}$. The formulas used to calculate MMB_{mating} from MMB at the time of the survey (MMB_{survey}) are documented in Appendix B. For this stock, $B_{MSY}{}^{proxy}$ was calculated using "raw" (unsmoothed) estimates for MMB_{survey} in the formula for MMB_{mating}. $B_{MSY}{}^{proxy}$ is the average of MMB_{mating} for the years 1980-84 and 1990-97 (see Table 6) and was calculated as 4002 t.

In this assessment, "current B" is the MMB_{mating} projected for 2014/15. Details of this calculation are provided in Appendix B. For 2014/15, current B =

Overfishing is defined as any amount of fishing in excess of a maximum allowable rate, F_{OFL}, which would result in a total catch greater than the OFL. For Tier 4 stocks, a minimum stock size threshold (MSST) is specified as 0.5 $B_{\mathrm{MSY}}{}^{\mathrm{proxy}}$ and if the current MMB (projected to the time of mating) drops below the MSST, the stock is considered to be overfished.

2. *List of parameter and stock sizes:*

- $B_{MSY}{}^{proxy}$ (B_{REF}) = 4,002 t
- M = 0.18 yr^{-1}

3. *OFL specification:*

a. In the Tier 4 OFL-setting approach, the "total catch OFL" and the "retained catch OFL" are calculated by applying the F_{OFL} to all crab at the time of the fishery (total catch OFL) or to the mean retained catch determined for a specified period of time (retained catch OFL). The Tier 4 F_{OFL} Control Rule is illustrated in Figure 15.

The Tier 4 F_{OFL} is derived using the F_{OFL} Control Rule (Figure 15), where Stock Status Level (level a, b or c; equations 6-8) is based on the relationship of current MMB (B) to $B_{MSY}{}^{proxy}$:

Stock Status Level:	F_{OFL}:	
a. $B/B_{\mathrm{MSY}}{}^{\mathrm{prox}} > 1.0$	$F_{\mathrm{OFL}} = \gamma \cdot M$	(4)
b. $\beta < B/B_{\mathrm{MSY}}{}^{\mathrm{prox}} \leq 1.0$	$F_{\mathrm{OFL}} = \gamma \cdot M\,[(B/B_{\mathrm{MSY}}{}^{\mathrm{prox}} - \alpha)/(1 - \alpha)]$	(5)
c. $B/B_{\mathrm{MSY}}{}^{\mathrm{prox}} \leq \beta$	$F_{\mathrm{directed}} = 0$; $F_{\mathrm{OFL}} \leq F_{\mathrm{MSY}}$	(6)

When $B/B_{\mathrm{MSY}}{}^{\mathrm{proxy}}$ is greater than 1 (Stock Status Level a), $F_{OFL}{}^{proxy}$ is given by the product of a scalar (γ=1.0, nominally) and M. The scalar α (= 0.1) determines the slope of the non-constant portion of the control rule for $F_{OFL}{}^{proxy}$ when $B/B_{\mathrm{MSY}}{}^{\mathrm{proxy}}$ is less than 1 and greater than the critical threshold β (= 0.25) (Stock Status Level b). Directed fishing mortality is set to zero when the ratio $B/B_{MSY}{}^{proxy}$ drops below β (Stock Status Level c). Values for α and β are based on a sensitivity analysis of the effects on $B/B_{MSY}{}^{proxy}$ (NPFMC 2008).

b. The basis for projecting MMB from the survey to the time of mating is discussed in detail in Appendix B.

c. Specification of F_{OFL}, OFL and other applicable measures:

All weights in t.

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2010/11	4c	4,209	286	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2011/12	4c	4,209	365	0.09	1	1975/76-1984/85 &1990/91-1997/98	0.18	10% buffer
2012/13	4c	4,494	496	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	3,988	278	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	4,002	218	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer

All weights in million lbs.

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2010/11	4c	9.28	0.63	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2011/12	4c	9.28	0.80	0.09	1	1975/76-1984/85 &1990/91-1997/98	0.18	10% buffer
2012/13	4c	9.91	1.09	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	8.79	0.61	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	8.82	0.48	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer

4. *Specification of the retained catch portion of the total catch OFL:*

   a. The retained portion of the catch for this stock is zero (0 t).

5. *Recommendations:*

   For 2014/2015, B_{MSY}^{proxy} *= 4002 t, derived as the mean MMB_{mating} from 1980 to 1984 and 1990 to 1997*. The stock demonstrated highly variable levels of MMB during both of these periods likely leading to uncertain approximations of B_{MSY}. Crabs were highly concentrated during the EBS bottom trawl surveys and male biomass estimates were characterized by poor precision due to a limited number of tows with crab catches.

   MMB_{mating} for 2014/15 was estimated at 218 t for B_{MSY}^{prxyy}. The B/B_{MSY}^{proxy} ratio corresponding to the biomass reference is 0.05. B/B_{MSY}^{proxy} is < β, therefore the ***stock status level is c, $F_{directed}$ = 0, and $F_{OFL} \leq F_{MSY}$*** (as determined in the Pribilof Islands District blue king crab rebuilding plan). Total catch OFL calculations were explored in 2008 to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality (NPFMC 2008). The preferred method was a total catch OFL equivalent to the average catch mortalities between 1999/2000 and 2005/2006. This period was after the targeted fishery was closed and did not include recent changes to the groundfish fishery that led to increased blue king crab bycatch. ***The author recommended OFL for 2014/15, based on an average catch mortality, is 1.16 t***.

G. Calculation of the ABC

To calculate an Annual Catch Limit (ACL) to account for scientific uncertainty in the OFL, an acceptable biological catch (ABC) control rule was developed such that ACL=ABC. For Tier 3 and 4 stocks, the ABC is set below the OFL by a proportion based a predetermined probability that the ABC would exceed the OFL (P*). Currently, P* is set at 0.49 and represents a proportion of the OFL distribution that accounts for within assessment uncertainty (σ_w) in the OFL to establish the maximum permissible ABC (ABC_{max}). Any additional uncertainty to account for uncertainty outside of the assessment methods (σ_b) is considered as a recommended ABC below ABC_{max}. Additional uncertainty is included in the application of the ABC by adding the uncertainty components as $\sigma_{\text{total}} = \sqrt{\sigma_b^2 + \sigma_w^2}$. For a Tier 5 stock a constant buffer of 10% is applied to the OFL.

1. *Specification of the probability distribution of the OFL used in the ABC:* The OFL was set based on a Tier 5 calculation of average catch mortalities between 1999/2000 and 2005/2006 to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality. As such, the OFL does not have an associated probability distribution.
2. *List of variables related to scientific uncertainty considered in the OFL probability distribution:* None. The OFL is based on a Tier 5 calculation and does not have an associated probability distribution. However, compared to other BSAI crab stocks, the uncertainty associated with the estimates of stock size and OFL for Pribilof Islands blue king crab is very high due to insufficient data and the small spatial extent of the stock relative to the survey sampling density. The coefficient of variation for the estimate of mature male biomass from the surveys for the most recent year is 0.70 and has ranged between 0.17 and 0.80 since the 1980 peak in biomass.
3. *List of additional uncertainties considered for alternative σ_b applications to the ABC.*

   Several sources of uncertainty are not included in the measures of uncertainty reported as part of the stock assessment:

   • Survey catchability and natural mortality uncertainties are not estimated but are rather pre-specified.

   • F_{msy} is assumed to be equal to γM when applying the OFL control rule while γ is assumed to be equal to 1 and M is assumed to be known.

   • The coefficients of variation for the survey estimates of abundance for this stock are very high.

   • B_{msy} is assumed to be equivalent to average mature male biomass. However, stock biomass has fluctuated greatly and targeted fisheries only occurred from 1973-1987 and 1995-1998 so considerable uncertainty exists with this estimate of B_{msy}.
4. *Recommendations:*

   For 2014/2015, $F_{directed} = 0$ and the total catch OFL based on catch biomass would maintain the conservation needs with this stock and acknowledge the existing non-directed catch mortality. In this case, the ***ABC_{max}* based on a 10% buffer of the average catch between 1999/2000 and 2005/2006 would be 1.04 t.**

All units are tons of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2010/11	4,420 [A]	286 [A]	0	0	0.18	1.81	
2011/12	2,247 [A]	365 [A]	0	0	0.36	1.16	1.04
2012/13	1,994 [A]	579 [A]	0	0	0.61	1.16	1.04
2013/14	2,001 [A]	225 [A]	0	0	0.03	1.16	1.04
2014/15	--	218 [B]	--	--	--	1.16	1.04

All units are million pounds of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2010/11	9.74 [A]	0.63 [A]	0	0	0.0004	0.004	
2011/12	4.95 [A]	0.80 [A]	0	0	0.0008	0.003	0.002
2012/13	4.39 [A]	1.09 [A]	0	0	0.0013	0.003	0.002
2013/14	4.41 [A]	0.50 [A]	0	0	0.0001	0.003	0.002
2014/15	--	0.48 [B]	--	--	--	0.003	0.002

Notes:
A – Based on data available to the Crab Plan Team at the time of the assessment following the end of the crab fishing year.
B – Based on data available to the Crab Plan Team at the time of the assessment for the crab fishing year.

H. Rebuilding Analyses

Rebuilding analyses results summary: A revised rebuilding plan analysis was submitted to the Secretary of Commerce in2014 as NMFS determined that the stock was not rebuilding in a timely manner and would not meet the rebuilding horizon of 2014. The preferred alternative imposes a closure to all fishing for Pacific cod with pot gear in the Pribilof Islands Habitat Conservation Area. This measure would protect the main concentration of the stock from the fishery with the highest observed rates of bycatch. As noted the area is already closed to trawling. Pending secretarial approval of the rebuilding plan, the BSAI Crab FMP and BSAI Groundfish FMP will be amended accordingly and regulations published to implement the groundfish fishery closure.

I. Data Gaps and Research Priorities

Given the large CVs associated with the survey abundance and biomass estimates for the Pribilof Islands blue king crab stock, assessment of this species might benefit from additional surveys using alternative gear at finer spatial resolution. Further data gaps include a lack of understanding regarding processes apparently preventing successful recruitment to the Pribilof District.

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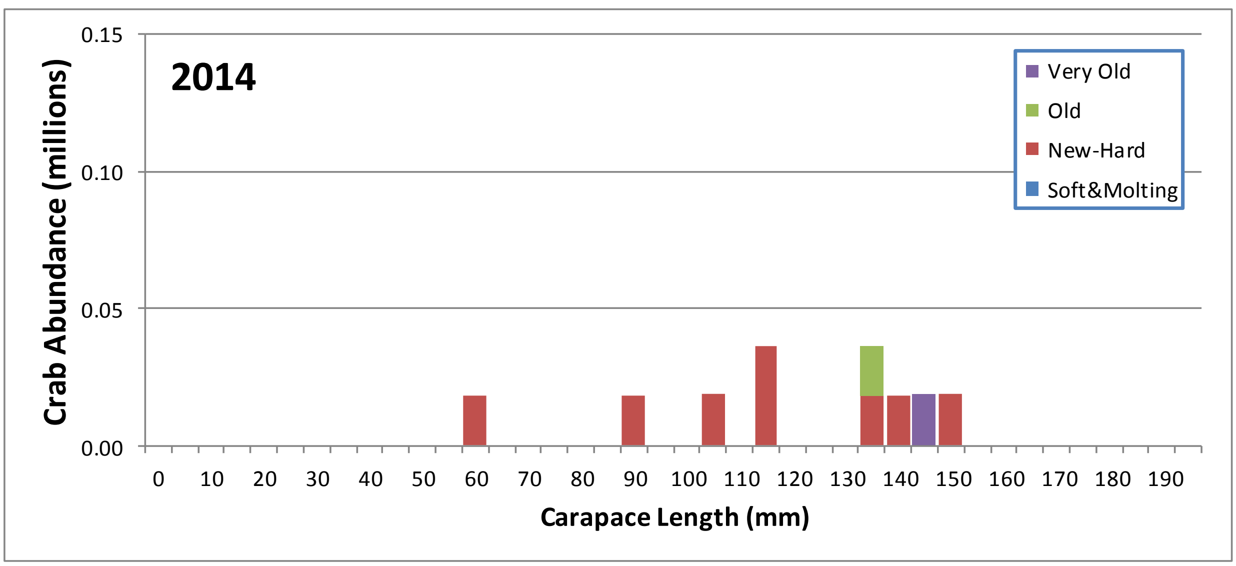


Figure 13. 2013 (left) and 2014 (right) EBS bottom trawl survey size class distribution of blue king crab in the Pribilof District.

Figure 14. 2013 (left) and 2014 (right) EBS bottom trawl survey frequency of occurrence of mature male blue king crab in the Pribilof District.

Figure 15. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β (= 0.25).

Tables

Table 1. Total retained catches from directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2011; D. Pengilly, ADF&G, personal communications).

Year	Retained Catch		Avg. CPUE
	Abundance	Biomass (t)	legal crabs/pot
1973/1974	174,420	579	26
1974/1975	908,072	3224	20
1975/1976	314,931	1104	19
1976/1977	855,505	2999	12
1977/1978	807,092	2929	8
1978/1979	797,364	2901	8
1979/1980	815,557	2719	10
1980/1981	1,497,101	4976	9
1981/1982	1,202,499	4119	7
1982/1983	587,908	1998	5
1983/1984	276,364	995	3
1984/1985	40,427	139	3
1985/1986	76,945	240	3
1986/1987	36,988	117	2
1987/1988	95,130	318	2
1988/1989	0	0	0
1989/1990	0	0	0
1990/1991	0	0	0
1991/1992	0	0	0
1992/1993	0	0	0
1993/1994	0	0	0
1994/1995	0	0	0
1995/1996	190,951	628	5
1996/1997	127,712	425	4
1997/1998	68,603	232	3
1998/1999	68,419	234	3
1999/2000 - 2013/2014	0	0	0

Table 2. Total non-retained catch (bycatch/discard) mortalities from directed and non-directed fisheries for Pribilof Islands District blue king crab. Handling mortalities (pot and hook/line= 0.5, trawl = 0.8) were applied to estimates of non-retained catch based on observer data in the crab and groundfish fisheries. Crab bycatch data is not available prior to 1996/1997 (Bowers et al. 2011; D. Pengilly ADF&G). Gear-specific groundfish fishery data is not available prior to 1991/1992 (J. Mondragon, NMFS).

Year	Crab pot fisheries			Groundfish fisheries	
	Non-retained legal male (t)	Sublegal male (t)	Female (t)	Fixed gear (t)	Trawl gear (t)
1991/1992	NA	NA	NA	0.03	4.96
1992/1993	NA	NA	NA	0.44	48.63
1993/1994	NA	NA	NA	0.00	27.39
1994/1995	NA	NA	NA	0.02	5.48
1995/1996	NA	NA	NA	0.05	1.03
1996/1997	0	0.4	0	0.02	0.05
1997/1998	0	0	0	0.73	0.10
1998/1999	1.15	0.23	1.86	9.90	0.06
1999/2000	1.75	2.15	0.99	0.40	0.02
2000/2001	0	0	0	0.06	0.02
2001/2002	0	0	0	0.42	0.02
2002/2003	0	0	0	0.04	0.24
2003/2004	0	0	0	0.17	0.18
2004/2005	0	0	0	0.41	0.00
2005/2006	0	0	0.05	0.18	1.07
2006/2007	0	0	0.05	0.07	0.06
2007/2008	0	0	0.05	2.00	0.11
2008/2009	0	0	0	0.07	0.38
2009/2010	0	0	0	0.11	0.17
2010/2011	0	0.09	0	0.02	0.05
2011/2012	0	0	0	0.06	0.01
2012/2013	0	0	0	0.08	0.54
2013/2014	0	0	0	0.03	0.00

Table 3. Proportion by weight of the Pribilof Islands blue king crab bycatch in the groundfish fisheries among trip targets For the 2003/2004-2008/2009 crab fishing seasons, these were calculated using bycatch from NMFS Statistical Area 513. For 2009/10-2013/14, these were calculated using the AKRO Catch Accounting System, with data reported from State of Alaska statistical areas that encompass the newly-defined Pribilof Islands Blue King Crab District. Groundfish fishery target species that caught blue king crab but made up less than 1% of the blue king crab bycatch across all years are not shown in the table. These include pollock-bottom trawl, pollock-midwater trawl, halibut, Greenland halibut, and arrowtooth flounder.

Crab Fishery Year	% bycatch by trip target					total bycatch (# crabs)
	yellowfin sole %	Pacific cod %	flathead sole %	rocksole %	sablefish %	
2003/2004	47.0	22.0	31.0	0.0	0.0	252
2004/2005	0.0	100.0	0.0	0.0	0.0	259
2005/2006	0.0	97.0	3.0	0.0	0.0	757
2006/2007	54.0	20.0	0.0	26.0	0.0	96
2007/2008	3.0	96.0	1.0	0.0	0.0	2,950
2008/2009	77.0	23.0	0.0	0.0	0.0	295
2009/2010	30.5	51.1	16.8	0.0	<1	281
2010/2011	<1	38.5	59.0	0.0	<1	48
2011/2012	<1	99.8	<1	0.0	<1	63
2012/2013	77.2	20.0	2.9	0.0	<1	410
2013/2014	<1	99.2	<1	0.0	<1	26

Table 4. Proportion by weight of the Pribilof Islands blue king crab bycatch in the groundfish fisheries among gear types. For the 2003/2004-2008/2009 crab fishing seasons, these were calculated using bycatch from NMFS Statistical Area 513. For 2009/10-20134/14, these were calculated using the AKRO Catch Accounting System, with data reported from State of Alaska statistical areas that encompass the newly-defined Pribilof Islands Blue King Crab District.

Crab Fishery Year	% bycatch by gear type				total bycatch (# crabs)
	hook and line %	non-pelagic trawl %	pot %	pelagic trawl %	
2003/04	21	79	0	0	252
2004/05	99	1	0	0	259
2005/06	18	3	79	0	757
2006/07	20	20	0	0	96
2007/08	1	3	95	0	2,950
2008/09	23	77	0	0	295
2009/10	7	49	44	0	281
2010/11	41	59	0	0	48
2011/12	94	6	0	0	63
2012/13	20	80	0	0	410
2013/14	100	0	0	0	26

Table 5. Summary of 2014 NMFS annual EBS bottom trawl survey for Pribilof Islands District blue king crab by stock component.

Stock Component	Number of tows in District 2014	Tows with crab 2014	Number of crab measured 2014	Number of crab crab caught 2014	Abundance (millions)	Biomass (mt)
Immature male	86	3	5	5	0.091	83
Mature male	86	2	5	5	0.092	233
Legal male	86	2	5	5	0.092	233
Immature female	86	1	1	1	0.028	16
Mature female	86	3	4	4	0.074	91

Table 6. Pribilof Islands District blue king crab abundance, mature biomass, legal male biomass, and totals estimated based on the NMFS annual EBS bottom trawl survey. These data are estimated using the new stock boundaries established in 2012, which included a 20 nm column to the east of the previous stock boundary definition. Running averages were not done. NA = Not Available.

Year	@ time of survey					@ mating time
	Mature male abundance	Mature male biomass (t)	Legal male biomass (t)	Total male biomass (t)	Total female biomass (t)	Mature male biomass (t)
1975/1976	14,955,818	33,862	24,037	41,292	12,172	29,447
1976/1977	3,568,103	9,573	8,585	13,333	5,770	5,795
1977/1978	13,043,983	38,756	36,706	42,137	13,573	32,135
1978/1979	6,140,638	15,798	12,291	18,315	6,492	11,491
1979/1980	5,232,918	12,974	10,843	14,275	4,097	9,119
1980/1981	5,432,065	14,253	12,163	16,050	63,713	8,146
1981/1982	3,921,734	10,744	9,686	13,014	9,911	5,794
1982/1983	2,344,203	6,691	6,241	7,740	9,376	4,142
1983/1984	1,851,301	4,919	4,069	5,795	10,248	3,492
1984/1985	674,376	1,761	1,446	1,860	2,580	1,454
1985/1986	428,076	959	687	995	523	638
1986/1987	480,198	1,368	1,340	1,372	2,431	1,121
1987/1988	903,180	2,659	2,529	2,833	913	2,094
1988/1989	237,868	766	766	921	717	690
1989/1990	239,948	752	752	1,914	1,745	677
1990/1991	1,738,237	3,259	1,549	5,376	3,811	2,934
1991/1992	2,014,086	4,266	3,025	5,521	2,776	3,839
1992/1993	1,935,278	3,995	2,761	5,635	2,649	3,574
1993/1994	1,875,500	4,144	2,913	5,136	2,092	3,718
1994/1995	1,263,447	3,028	2,491	3,578	4,858	2,724
1995/1996	3,139,328	7,753	6,365	8,616	4,844	6,388
1996/1997	1,712,015	4,221	3,522	4,899	5,585	3,400
1997/1998	1,201,296	2,940	2,515	3,288	3,028	2,428
1998/1999	967,097	2,545	2,283	3,175	2,182	2,065
1999/2000	617,258	1,573	1,297	1,719	2,868	1,414
2000/2001	725,050	1,902	1,588	2,005	1,462	1,712
2001/2002	522,239	1,454	1,329	1,533	1,817	1,309
2002/2003	225,476	618	588	618	1,401	557
2003/2004	228,897	638	610	656	1,307	575
2004/2005	47,905	97	44	130	123	87
2005/2006	91,932	313	313	610	847	281
2006/2007	50,638	137	115	210	558	124
2007/2008	100,295	254	170	417	257	228
2008/2009	18,256	42	42	235	672	37
2009/2010	248,626	452	170	684	625	407
2010/2011	138,787	322	202	420	440	290
2011/2012	165,525	461	399	461	37	415
2012/2013	272,233	644	459	809	237	579
2013/2014	104,361	250	190	265	166	225
2014/2015	91,856	233	233	317	108	NA

Table 7. CVs for Pribilof Islands District blue king crab abundance, mature biomass, legal male biomass, and totals estimated based on the NMFS annual EBS bottom trawl survey. These data are estimated using the new stock boundaries established in 2012 which included a 20 nm column to the east of the previous stock boundary definition. Running averages were not done.

Year	@ time of survey				
	Mature male abundance	Mature male biomass	Legal male biomass	Total male biomass	Total female biomass
1975/1976	0.503	0.501	0.500	0.476	0.637
1976/1977	0.418	0.413	0.421	0.468	0.893
1977/1978	0.743	0.768	0.784	0.729	0.874
1978/1979	0.496	0.558	0.643	0.506	0.717
1979/1980	0.266	0.256	0.247	0.275	0.441
1980/1981	0.319	0.300	0.285	0.310	0.894
1981/1982	0.173	0.168	0.169	0.173	0.452
1982/1983	0.181	0.187	0.192	0.175	0.669
1983/1984	0.186	0.178	0.175	0.187	0.781
1984/1985	0.229	0.233	0.254	0.227	0.385
1985/1986	0.281	0.267	0.283	0.263	0.446
1986/1987	0.305	0.303	0.307	0.302	0.896
1987/1988	0.414	0.411	0.414	0.397	0.526
1988/1989	0.509	0.529	0.529	0.457	0.473
1989/1990	0.624	0.637	0.637	0.551	0.497
1990/1991	0.439	0.425	0.381	0.433	0.375
1991/1992	0.363	0.385	0.450	0.373	0.376
1992/1993	0.420	0.423	0.446	0.432	0.463
1993/1994	0.310	0.307	0.301	0.305	0.399
1994/1995	0.341	0.346	0.352	0.344	0.436
1995/1996	0.540	0.539	0.544	0.564	0.423
1996/1997	0.281	0.269	0.265	0.279	0.491
1997/1998	0.294	0.276	0.271	0.294	0.407
1998/1999	0.246	0.249	0.255	0.252	0.392
1999/2000	0.334	0.337	0.347	0.333	0.467
2000/2001	0.296	0.296	0.305	0.304	0.460
2001/2002	0.710	0.735	0.759	0.733	0.722
2002/2003	0.473	0.506	0.525	0.506	0.775
2003/2004	0.389	0.400	0.411	0.390	0.734
2004/2005	0.563	0.583	1.000	0.455	0.504
2005/2006	0.712	0.710	0.710	0.589	0.606
2006/2007	0.565	0.604	0.700	0.462	0.671
2007/2008	0.854	0.799	0.734	0.662	0.708
2008/2009	1.000	1.000	1.000	0.797	0.705
2009/2010	0.732	0.713	0.604	0.698	0.818
2010/2011	0.484	0.459	0.481	0.521	0.604
2011/2012	0.792	0.843	0.886	0.843	0.674
2012/2013	0.797	0.735	0.643	0.786	0.637
2013/2014	0.862	0.797	0.752	0.754	0.654
2014/2015	0.710	0.699	0.699	0.567	0.529

Table 8. Three-year weighted (inverse variance), centered running averages of Pribilof Islands District blue king crab mature male abundance and biomass, legal male biomass, total male biomass, total female biomass, and mature male biomass at mating time based on the NMFS annual EBS bottom trawl survey. NA = Not Available.

Year	@ time of survey					@ mating time
	Mature male abundance	Mature male biomass (t)	Legal male biomass (t)	Total male biomass (t)	Total female biomass (t)	Mature male biomass (t)
1975/1976	NA	NA	NA	NA	NA	NA
1976/1977	4,200,609	11,280	10,247	16,841	8,410	6,633
1977/1978	4,234,074	11,020	9,579	15,638	6,747	6,699
1978/1979	5,517,339	13,598	11,191	15,260	4,592	9,575
1979/1980	5,404,179	13,645	11,402	15,289	4,463	8,838
1980/1981	4,311,444	11,615	10,304	13,691	4,960	6,507
1981/1982	2,898,311	8,353	7,783	9,494	9,950	4,980
1982/1983	2,300,630	6,214	5,253	7,353	9,819	4,152
1983/1984	1,017,736	2,686	2,291	2,792	2,857	2,209
1984/1985	614,303	1,401	1,030	1,420	639	955
1985/1986	508,803	1,223	925	1,266	650	856
1986/1987	475,461	1,133	853	1,167	614	776
1987/1988	369,370	1,165	1,153	1,259	809	1,011
1988/1989	278,353	901	902	1,249	872	818
1989/1990	261,166	879	931	1,176	992	792
1990/1991	362,449	1,250	1,206	3,042	2,461	1,126
1991/1992	1,897,982	3,766	1,941	5,508	2,980	3,385
1992/1993	1,930,678	4,139	2,897	5,351	2,422	3,713
1993/1994	1,550,754	3,575	2,714	4,372	2,516	3,210
1994/1995	1,547,448	3,632	2,816	4,342	2,762	3,265
1995/1996	1,521,470	3,713	3,085	4,321	5,015	3,188
1996/1997	1,428,799	3,480	2,952	3,947	3,779	2,855
1997/1998	1,136,930	2,943	2,590	3,505	2,650	2,399
1998/1999	838,049	2,166	1,848	2,414	2,546	1,867
1999/2000	752,767	1,948	1,639	2,135	1,890	1,714
2000/2001	648,723	1,696	1,422	1,815	1,758	1,526
2001/2002	336,836	954	905	944	1,504	859
2002/2003	237,187	658	628	668	1,457	592
2003/2004	72,140	138	71	172	132	124
2004/2005	67,024	134	70	168	138	120
2005/2006	52,721	119	68	161	144	107
2006/2007	60,960	171	147	256	364	154
2007/2008	29,890	67	67	233	353	60
2008/2009	23,986	57	70	329	342	51
2009/2010	28,621	69	80	343	518	61
2010/2011	154,495	357	195	465	42	322
2011/2012	153,347	364	238	461	45	327
2012/2013	139,469	337	259	342	48	304
2013/2014	105,996	267	238	315	132	NA
2014/2015	NA	NA	NA	NA	NA	NA

Figures

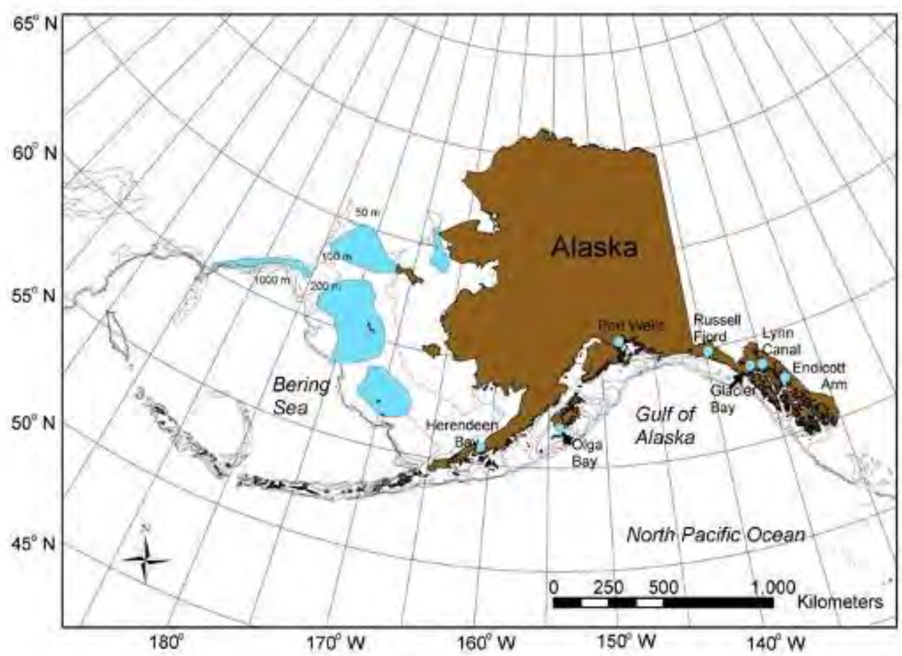


Figure 1. Distribution of blue king crab (*Paralithodes platypus*) in Alaskan waters.

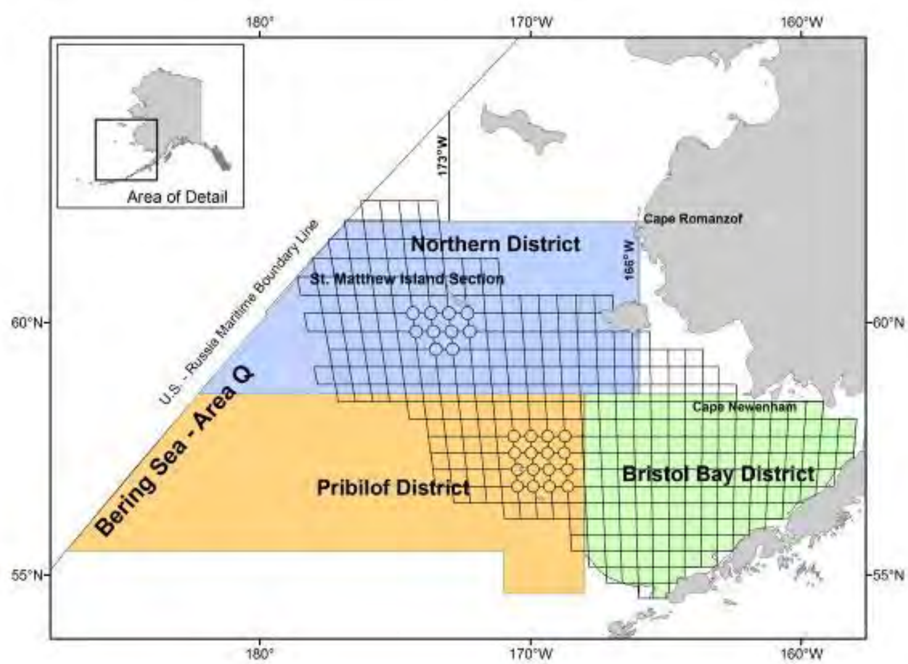


Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District. This figure does not show the additional 20 nm strip considered starting in 2013 year for biomass and catch data in the Pribilof District.

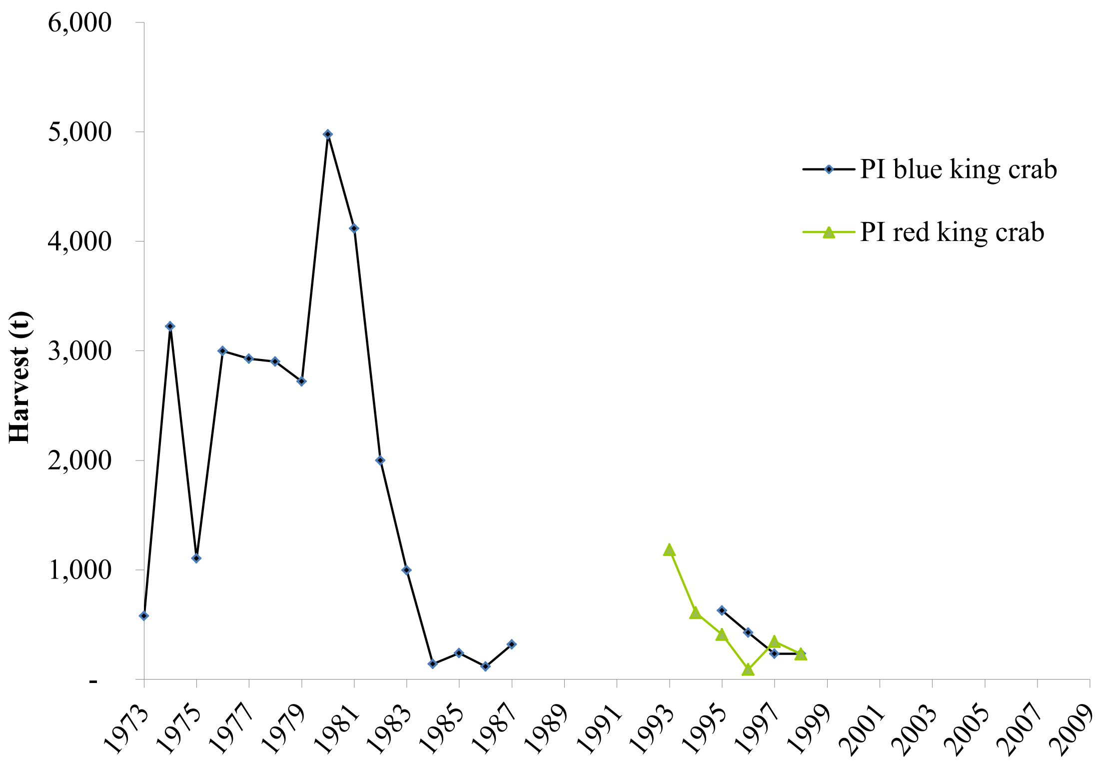


Figure 3. Historical harvests (t) and GHLs for Pribilof Island blue and red king crab (Bowers et al. 2011).

Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation area. Trawl fishing is prohibited year-round in this zone.

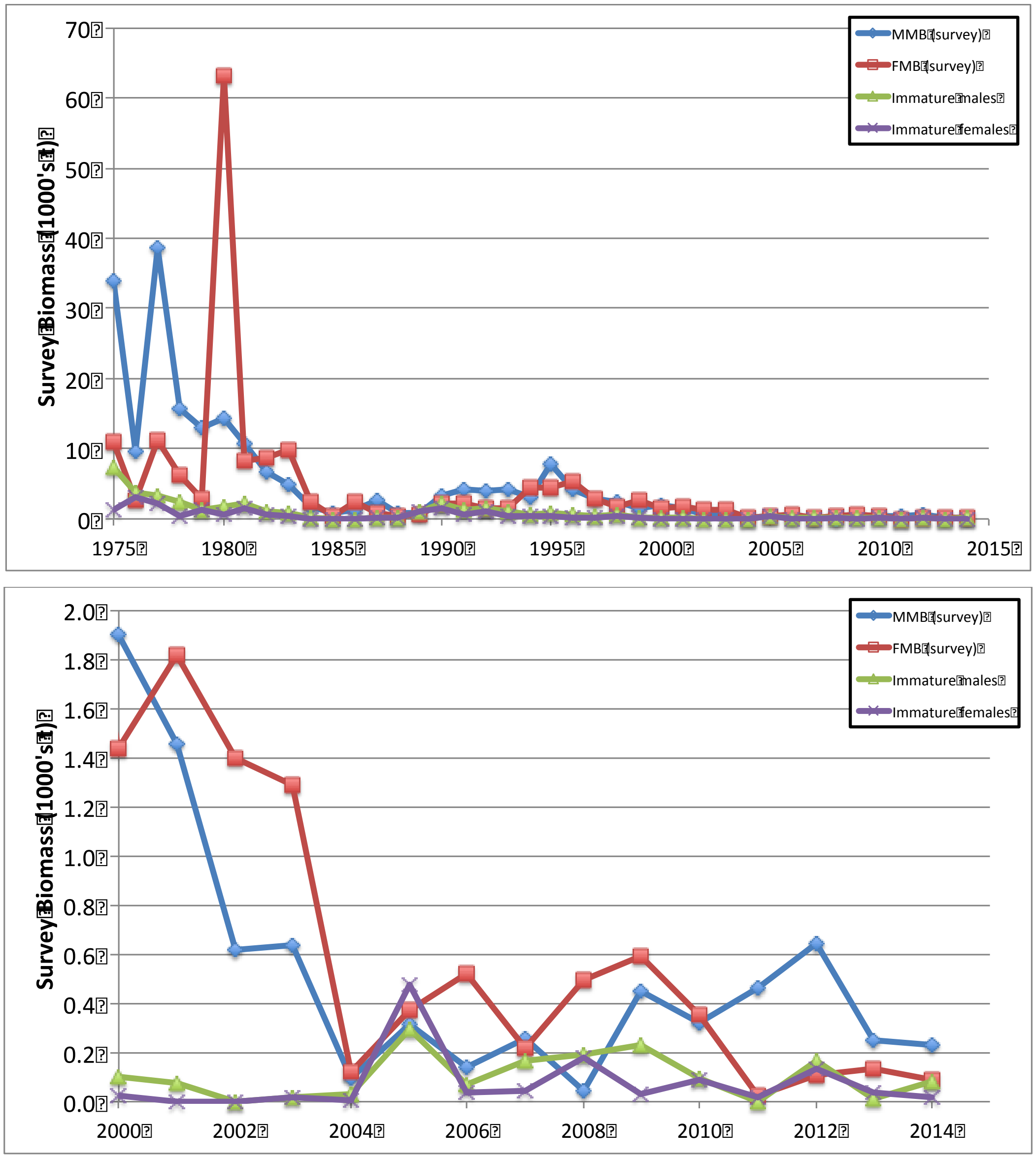


Figure 5. Time series for various stock components of Pribilof Islands blue king crab estimated from the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2014. Lower graph: 2000-2014.

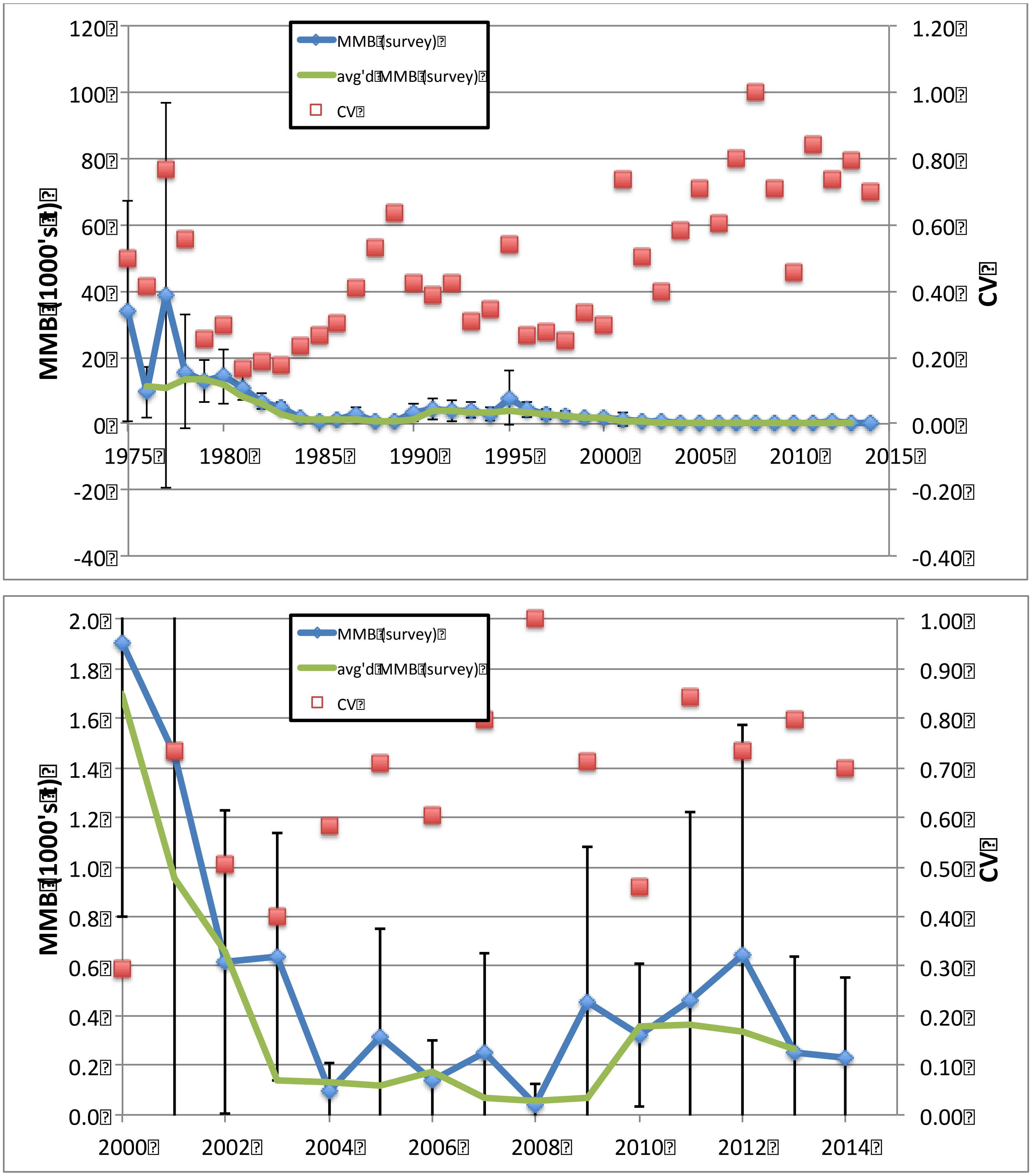
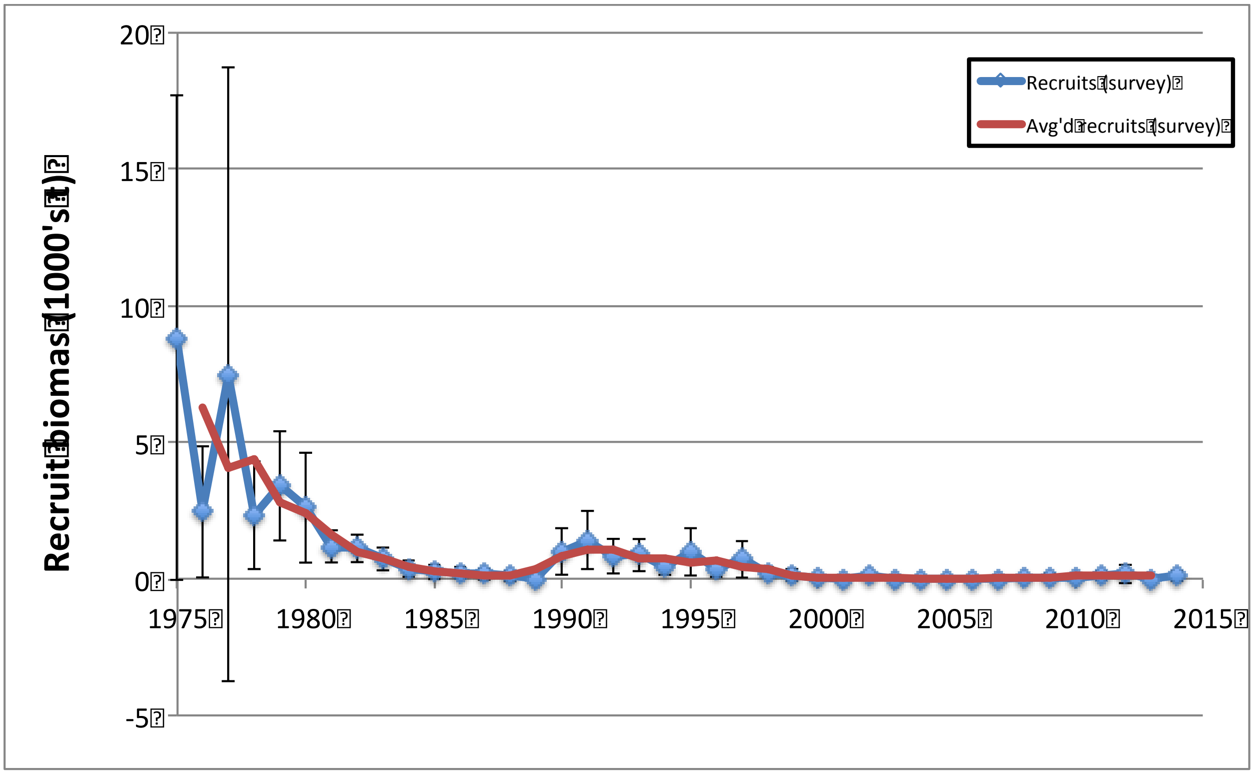


Figure 6. Time series for mature male biomass (MMB) estimated from the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2014. Lower graph: 2000-2014. Blue line: “raw” time series. Red line: 3-year center-averaged using inverse-variance weighting. Error bars are 95% CIs.



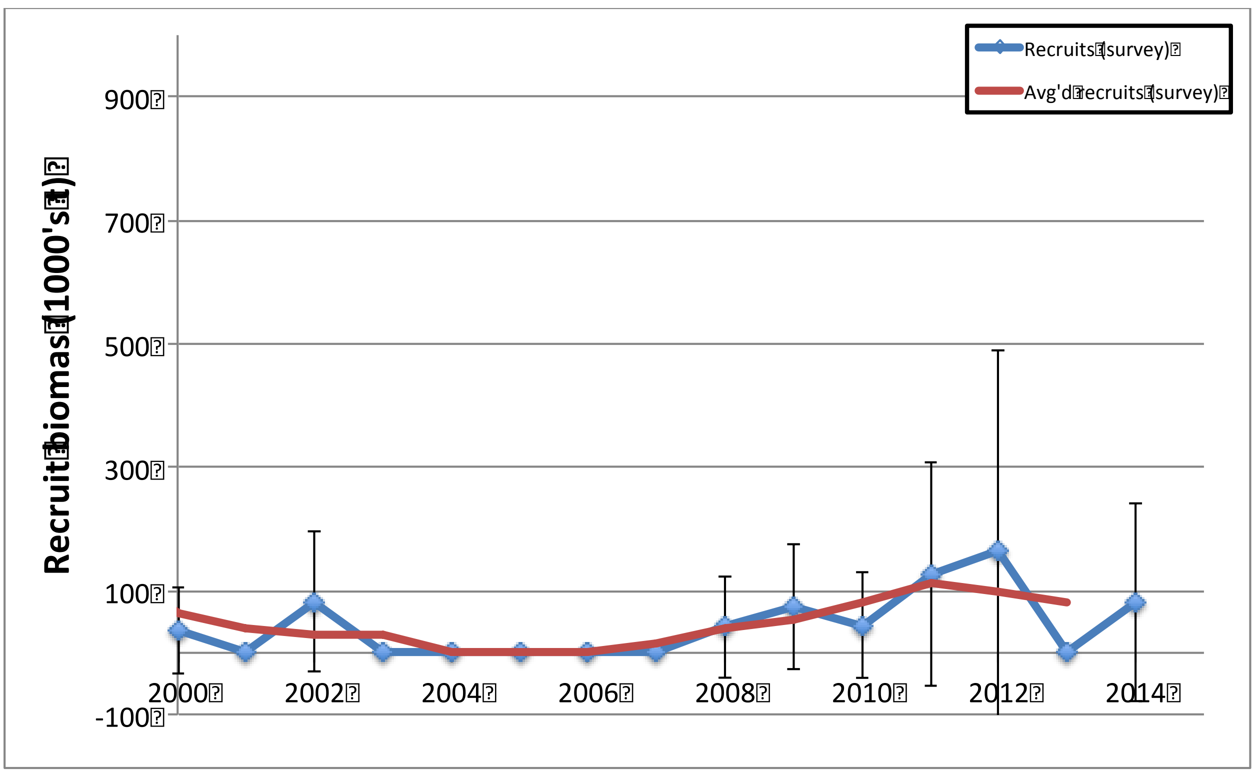


Figure 7. Time series for male recruits (120-134 mm CL) estimated from the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2014. Lower graph: 2000-2014. Blue line: "raw" time series. Red line: 3-year center-averaged using inverse-variance weighting. Error bars are 95% CIs.

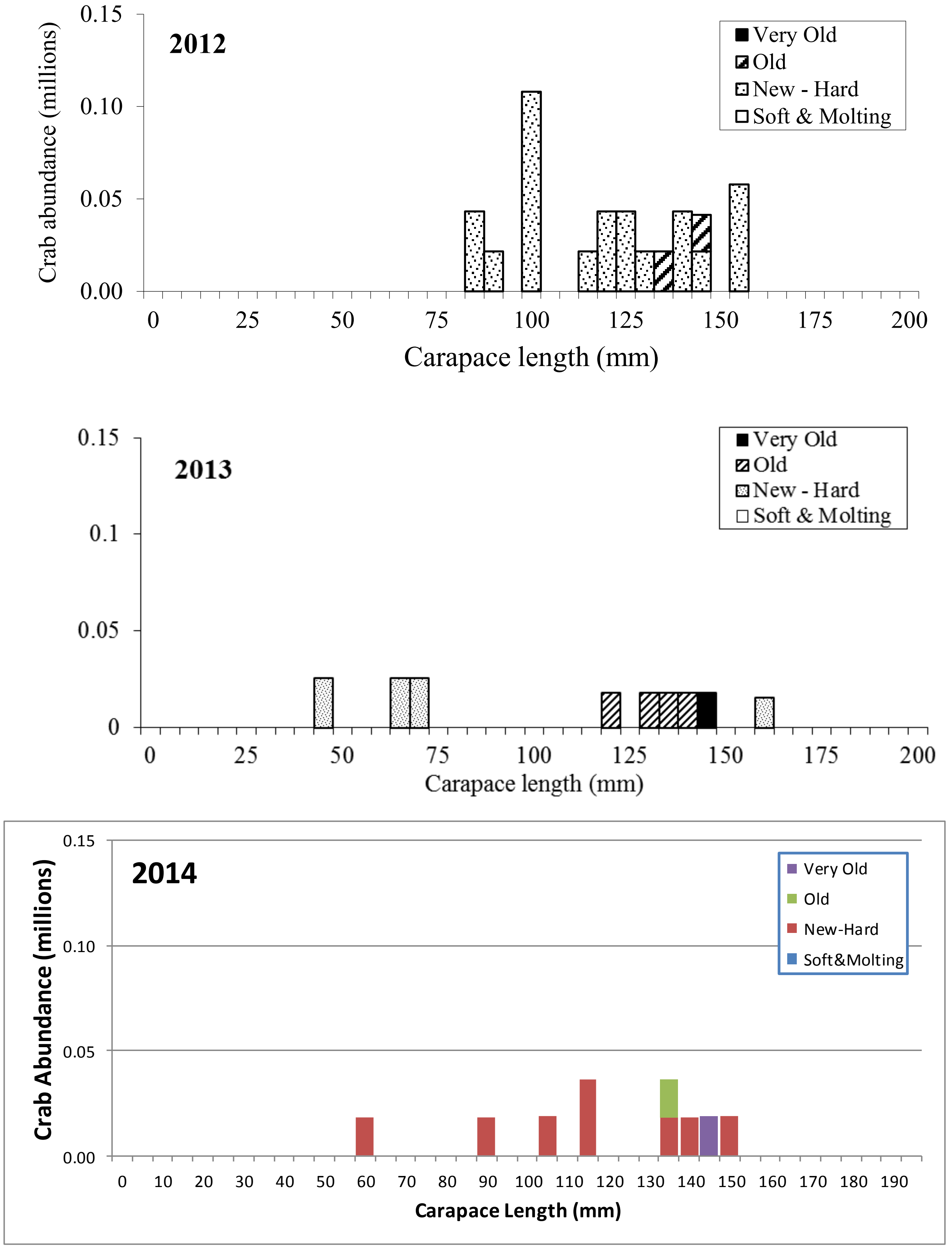
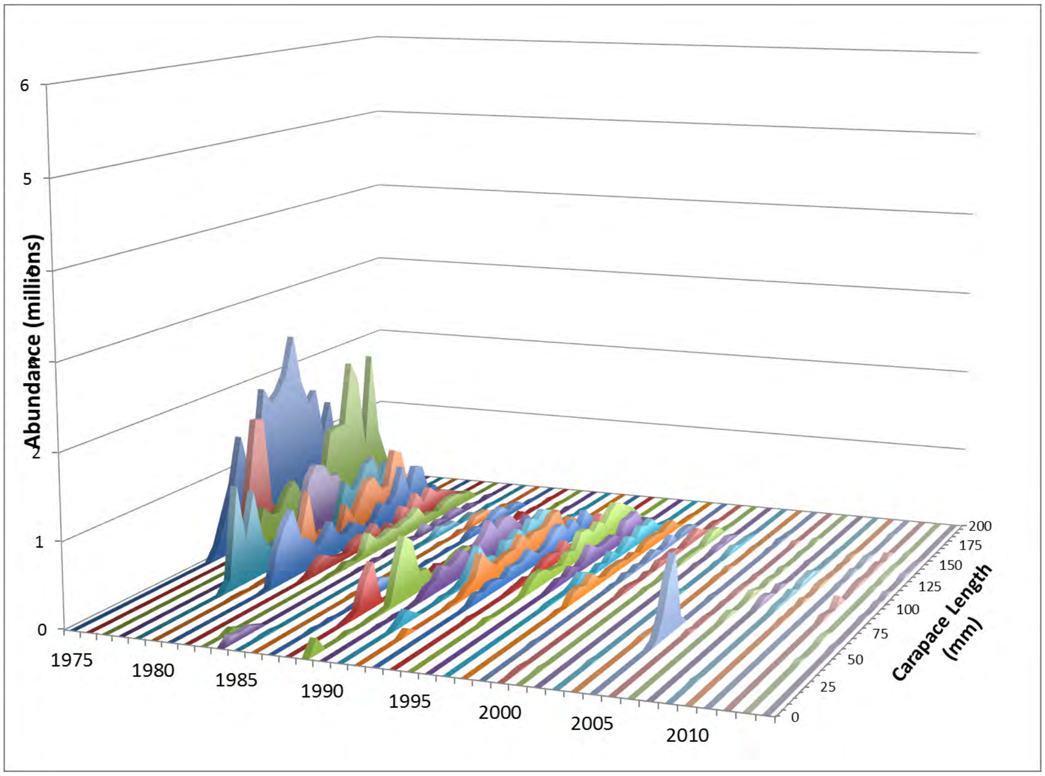


Figure 8. Size frequencies by shell condition for male Pribilof Island blue king crab in 5 mm length bins from the last 3 surveys.



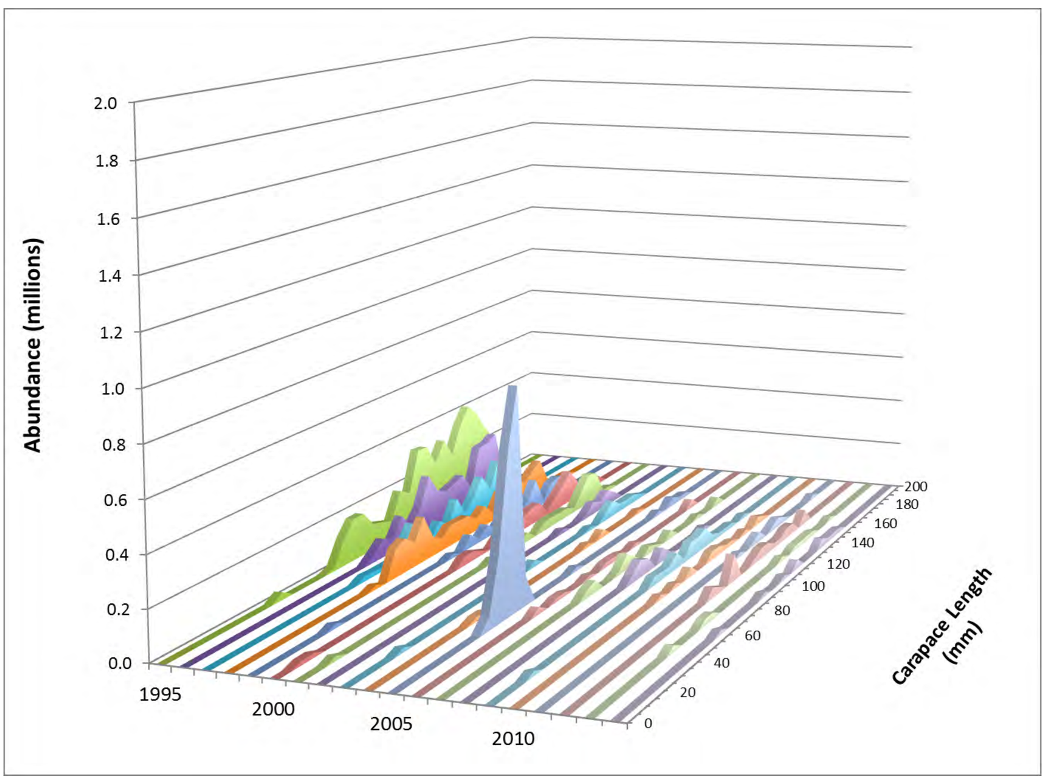


Figure 9. Size frequencies from the annual NMSF bottom trawl survey for male Pribilof Islands blue king crab from 1975 to 2014 (upper graph) and from 1995 to 2014 (lower graph) by 5 mm length classes.

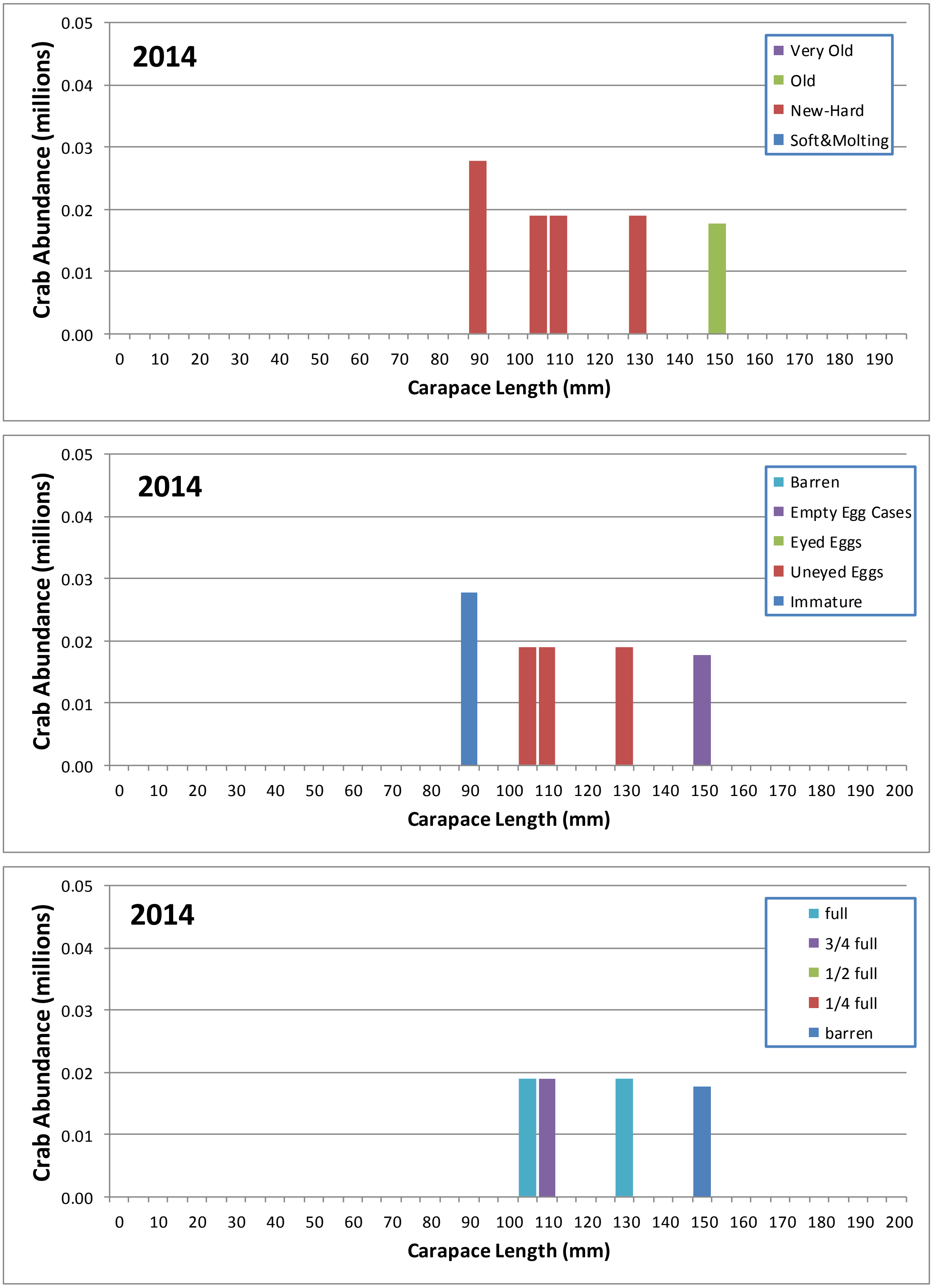


Figure 10. Size-frequencies by shell condition, egg condition, and clutch fullness for female Pribilof Island blue king crab by 5 mm length bins from the 2014 NMFS bottom trawl survey.

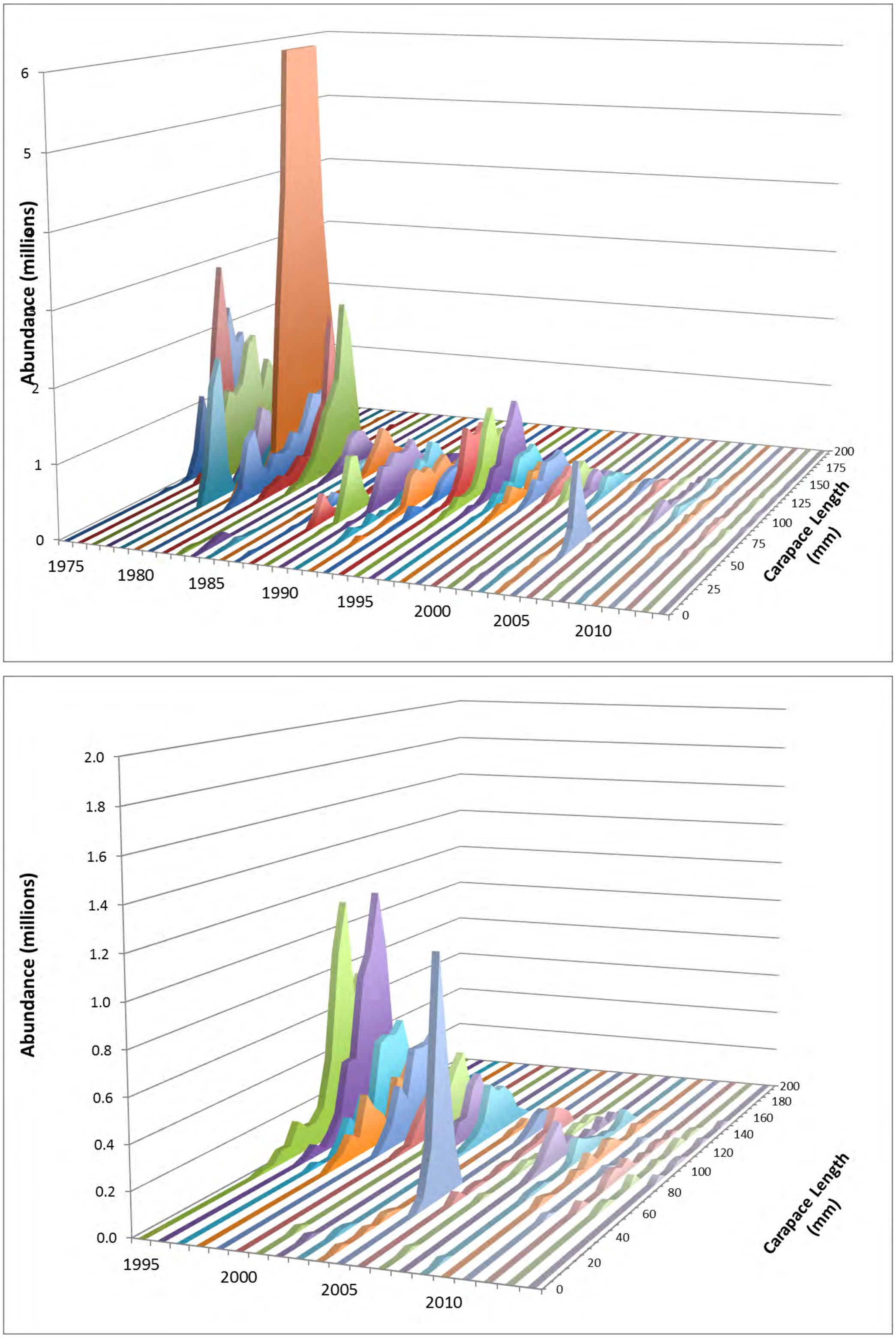
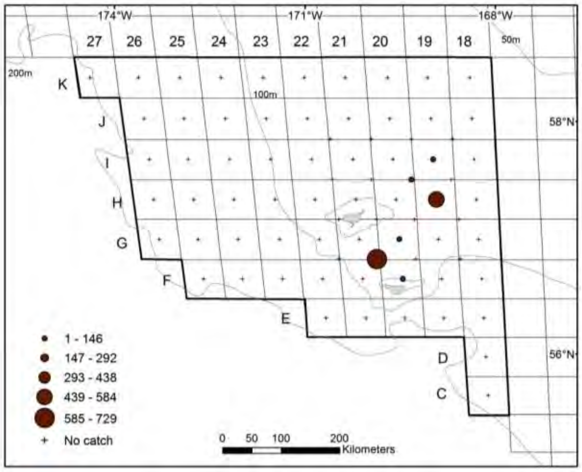


Figure 11. Size frequencies from the annual NMSF bottom trawl survey for female Pribilof Islands blue king crab from 1975 to 2014 (upper graph) and from 1995 to 2014 (lower graph) by 5 mm length classes.

2013 2014



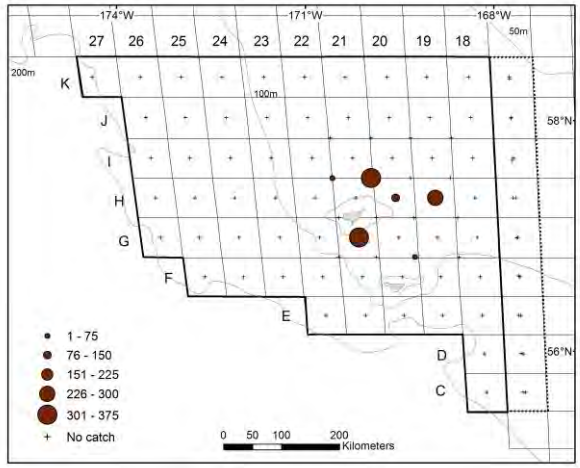
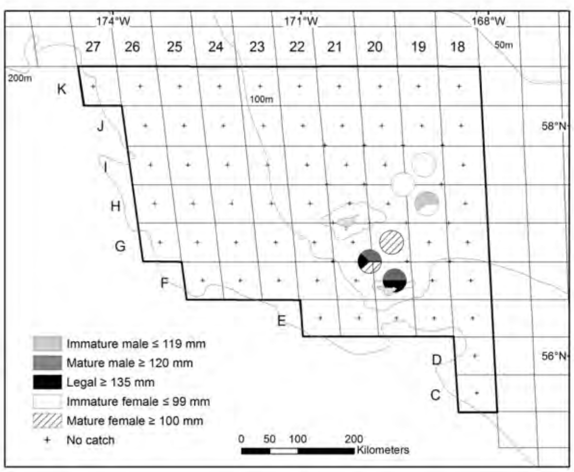


Figure 12. Total density (number/nm^2) of blue king crab in the Pribilof District in the 2013 (left) and 2014 (right) EBS bottom trawl survey.

2013 2014



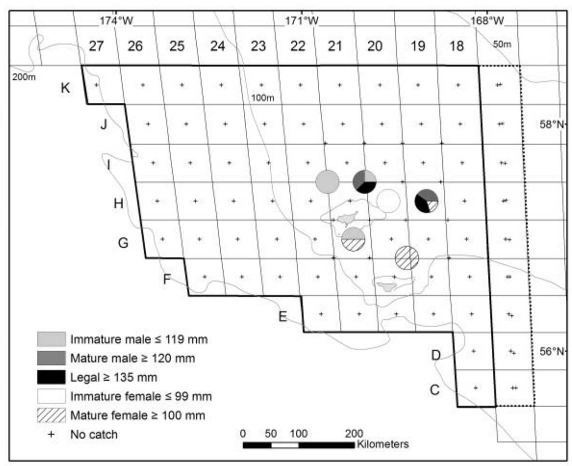
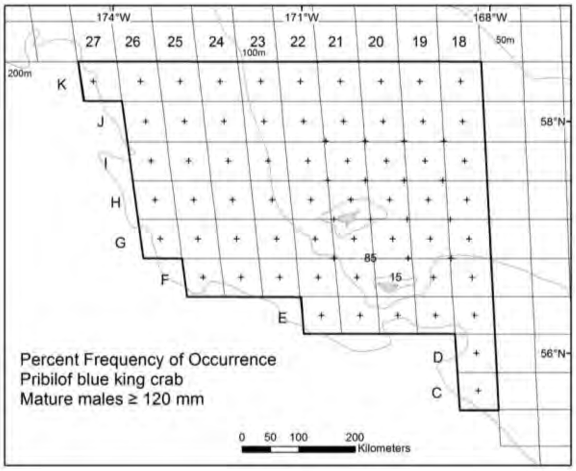


Figure 13. 2013 (left) and 2014 (right) EBS bottom trawl survey size class distribution of blue king crab in the Pribilof District.

2013



2014

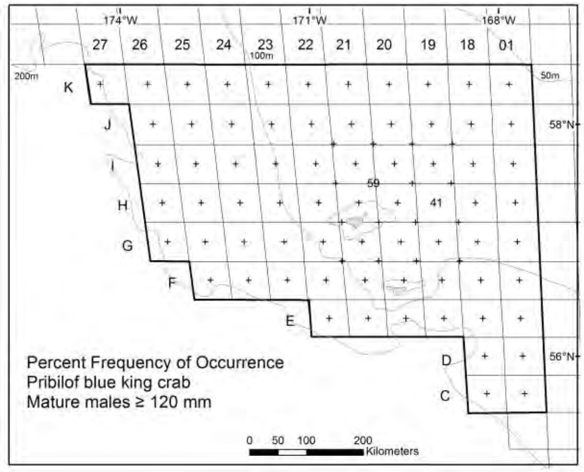


Figure 14. 2013 (left) and 2014 (right) EBS bottom trawl survey frequency of occurrence of mature male blue king crab in the Pribilof District.

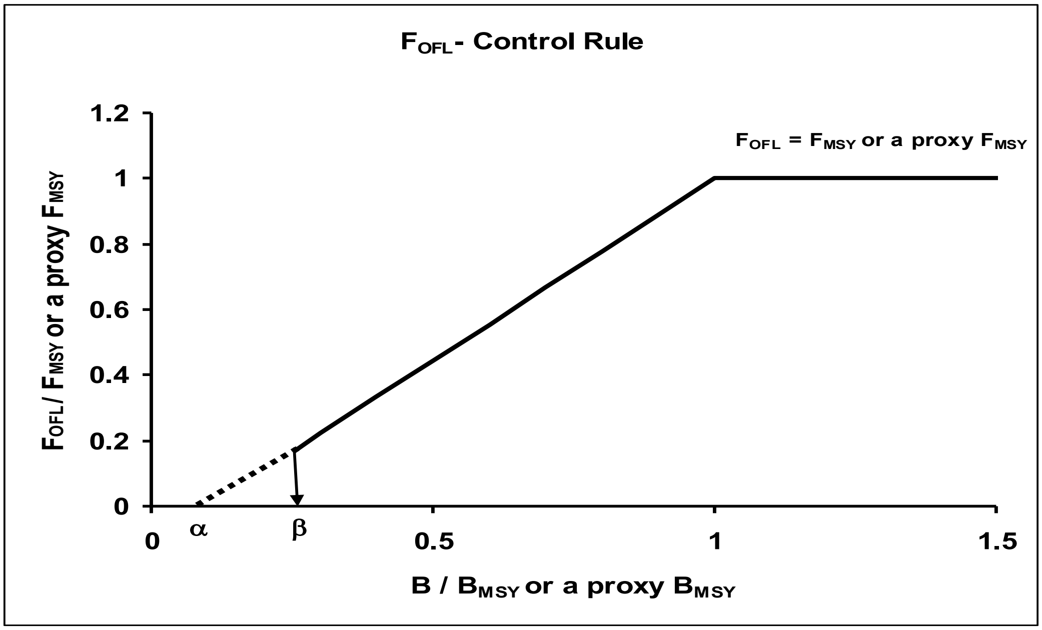


Figure 15. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β (= 0.25).

Appendix A: Estimating crab bycatch in the groundfish fisheries

This appendix provides a brief overview regarding estimation of crab bycatch in the groundfish fisheries, as conducted by the NMFS Alaska Regional Office (AKRO) and the Alaska Fisheries Information Network (AKFIN). It represents a merging of two memos provided by J. Gaspar (AKRO) discussing these details.

Data availability:

Pre 1991: Data available in INPFC reports only.

1991-December 2002: Bycatch estimates use the "blend method". The blend process combined data from industry production reports and observer reports to make the best, comprehensive accounting of groundfish catch. For shoreside processors, Weekly Production Reports (WPR) submitted by industry were the best source of data for retained groundfish landings. All fish delivered to shoreside processors were weighed on scales, and these weights were used to account for retained catch. Observer data from catcher vessels provided the best data on at-sea discards of groundfish by vessels delivering to shoreside processors. Discard rates from these observer data were applied to the shoreside groundfish landings to estimate total at-sea discards from both observed and unobserved catcher vessels. For observed catcher/processors and motherships, the WPR and the Observer Reports recorded estimates of total catch (retained catch plus discards). If both reports were available, one of them were selected during the "blend" process for incorporation into the catch database. If the vessel was unobserved, only the WPR was available.

January 2003 –December 2007: A new database structure named the Catch Accounting System (CAS) led to large method change. Bycatch estimates were derived from a combination of observer and landing (catcher vessels/production data). Production data included CPs and catcher vessels delivering to motherships. To obtain fishery level estimates, CAS uses a ratio estimator derived from observer data (counts of crab/kg groundfish) that is applied to production/landing information (see http://www.afsc.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-205.pdf). Estimates of crab are in numbers because the Prohibited Species Catch (PSC) is managed on numbers. There were two issues with this dataset that required estimation work outside of CAS:

1) The estimated number of crab had to be converted to weights. An average weight was calculated using groundfish observer data. This weight was specific to crab year, crab species, and fixed or trawl gear. This average was applied to the estimated number of crab for crab year by federal reporting area.

2) In some situations crab estimates were identified and grouped in the observed data to the genus level. These crabs were apportioned to the species level using the identified crab.

January 2008-2012: The observer program changed the method in which they speciate crab to better reflect their hierarchal sampling method and to account for broken crab that in the past were only identified to genus. In addition, haul-level weights collected by the observers were used to estimate the weight of crab through CAS instead of applying an annual (global) weight factor. Spatial resolution was at the federal reporting area.

NEW Data January 2009 – 2013: A new data set was made available in August 2013. The level of spatial resolution in CAS was formerly at the federal reporting area because this was the highest spatial resolution at which observer data was aggregated to create bycatch rates. The federal reporting area does not follow crab stock boundaries, particular for species with small stock areas such as the Pribilof Islands or St. Matthew Island stocks, so the new data was provided at the State reporting areas. This method uses a weight-based ratio estimator (wieght crab/weight groundfish) applied to groundfish reported on production/landing reports. Where possible, this dataset aggregates observer data to the stock area level to create bycatch estimates at the stock area. There are instances where no observer data is available and aggregation could go outside of a stock area, but this practice is greatly reduced compared with the pre-2009 data, which at-best was at the Federal reporting area level.

AKFIN/AKR created this new data set using observer data and eLandings information: landing reports and production reports. 2009 is the start of the data set because it is the first year that identification of state statistical areas was required on groundfish production reports. This allowed the use of a ratio estimator created from observer data to be applied to state statistical area landings/production.

Changes in 2014

Changes in estimates of crab bycatch in the groundfish fisheries, beginning in 2009, occurred between spring 2013 and fall of 2014 due to improvements made to the database and methods.

Background

The Alaska Region historically provided estimates of crab bycatch in groundfish fisheries at the federal reporting area level. Ratio estimation (weight of crab/total groundfish) methods were used to estimate crab catch by species. Generally speaking, there are two steps in this estimation method: 1) a ratio estimator is created by post-stratifying (aggregating) observer information; and 2) the ratio estimator is then applied to landings or production information that have the same post-strata characteristics as in 1 (e.g., both the landings and observer data were collected from area 541 for pot gear during the same week). Details on the estimation routines used in the Catch Accounting System (CAS) are in Cahalan et al. (2010), with an updated Technical Memorandum currently in review.

Spatial scale is an important component in the post-strata criteria. There are two spatial scales associated with industry reports of groundfish catch: 1) the federal reporting area and 2) the groundfish FMP area; the latter being an aggregation of federal reporting areas. Estimates of crab bycatch from CAS are specific to a federal reporting area if at-sea observer data is available; however, in federal reporting areas that have commercial landings and no corresponding observer data (defined by the post-stratification criteria), the ratio estimator is derived from an aggregation of observer information across the entire Bering Sea and Aleutian Islands FMP area. These post-stratification procedures result in bycatch estimates that may include at-sea observer information from outside a crab stock area[1].

Changes to estimation

In 2013, the NMFS Alaska Regional Office (AKRO) and Alaska Fisheries Information Network (AKFIN) created a new estimation method to generate estimates crab catch (in weight) in the groundfish fisheries by crab stock area. This required modifying the CAS Prohibited Species Catch (PSC) calculation methods so that the post-strata definitions were specific to a crab stock area and crab species (or state statistical area within a crab stock area). ***The stock-area specific estimates (in weight) are available through AKFIN starting in the 2009/2010 crab year.***

A flaw in the estimation method was identified in 2013 after the September Plan Team. This flaw allowed observer data from outside a stock area boundary to be used for stock-area specific estimation if there was little observer data available within the stock area. Correcting this issue was especially important for crab stocks that bisect reporting areas, such as the Pribilof Islands, St. Mathews Islands, and Bristol Bay, but it also affected the estimates for most stocks throughout the Bering Sea and Aleutian Islands. As expected, large changes were observed for the St. Mathews and the Pribilof Islands stock areas since observer data had incorrectly been aggregated across these areas. For example, observer information from the St.

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[1] Note that post-strata definitions also including gear, vessel, week ending date, trip target, and observer selection method (based on deployment rates in the ADP). The intent of this appendix is not to provide detail on the estimation methods, but instead to highlight large changes in methodology.

Mathew stock area was used in the ratio estimators for the Pribilof Islands.

In 2014, AKFIN and AKRO staff conducted further review of the crab estimation routines. This review resulted in several programming changes that affected some estimates:

- There were errors in the mapping of State of Alaska statistical areas with the crab stock area boundaries that were found and corrected. This correction affected some estimates, particularly Pribilof Island estimates where the eastern extension of the stock area boundary for blue king crab was incorrectly applied to red and golden king crab (which also changed the Bristol Bay area slightly).

- The procedures used to determine if a trip has corresponding observer data were improved. This improvement results in a lower percentage of trips that are incorrectly marked as unobserved, which means more estimates are specific to observed trips. The impact on estimation due to this change was minor.

- A post stratum was added to the estimation process. This post stratum is only used when observer data are unavailable for landings of a specific gear type (with the exception of jig gear since it is never observed), stock area, and calendar year. The impact on crab estimates due to this change was minor (mainly a few vessels in the Aleutian Islands): nearly all ratio estimates use observer data that is of the same gear type as the vessels making a landing.

In addition, updates to observer information occur when observers are debriefed and data quality verified. Debriefings can result in changes to data values or cause deletions of incorrectly collected data.

References

Cahalan J., Mondragon J., and J. Gasper. 2010. Catch sampling and estimation in the federal groundfish fisheries off Alaska. NOAA Tech. Mem. NMFS AFSC-205. 42 pp.

Appendix B: MMB Calculations

MMBsurvey

MMB at the time of each survey (MMB_{survey}; Figure 6, Table 6) is calculated from NMFS trawl survey estimates of male numbers-at-size z (n_z) by summing the product of weight-at-size (W_z, Eq. 1), maturity-at-size ($P_z = 0\ or\ 1$, depending on whether z<120 mm CL or z≥120 mm CL), and n_z over all sizes, as in:

$$MMB_{survey} = \sum_z P_z \cdot W_z \cdot n_z \qquad \text{(B1)}$$

To reduce the effects of large uncertainty in these survey-based estimates, the time series of MMB_{survey} is also smoothed using a 3-year centered, inverse variance-weighted, running average (denoted $\langle MMB_{survey} \rangle$, Table 8). The "raw" and 3-year running average estimates for MMB are compared in Figure 14.

MMB_{mating}

The estimates for MMB_{survey} ("raw" or averaged) are projected forward to mating time each year (MMB_{mating}; Table 8) based on an assumed rate for natural mortality (M = 0.18 yr^{-1}), retained (R) and non-retained (NR) fishing mortalities for that year (based on Tables 1 and 2), and assumed time intervals between the survey and fishing activity (t_{sf} = 3 months) and between the fishing activity and mating (t_{fm} = 5 months) using the following equation:

$$MMB_{mating} = \left(MMB_{survey} \cdot e^{-M \cdot t_{sf}} - R - NR\right) \cdot e^{-M \cdot t_{fm}} \qquad \text{(B2)}$$

Current B: Projected MMB_{mating}

The "current B" used in status determination and OFL setting is the projected MMB_{mating} for the current year (2014/15 for the 2014 assessment) calculated using Eq. B2. To reduce year-to-year variability in this quantity due simply to sampling uncertainty in the survey, the value used in the equation for MMB_{survey} is the average of MMB_{survey} from the last two surveys (2013 and 2014, denoted here as $\langle MMB_{survey} \rangle$). For this year, $\langle MMB_{survey} \rangle$ = 241.76 t. Note that the projected MMB_{mating} (= current B) is necessarily less than or equal to $\langle MMB_{survey} \rangle$. Consequently, because B_{MSY}^{proxy} (B_{REF}) = 4002 t, $B/\ B_{MSY}^{proxy} \leq 0.06 < \beta$ = 0.25, the stock is in Tier 4c, and directed fishing in 2014/15 will not be allowed under any circumstances and R in Eq. B2 is zero.

An estimate of the projected NR (non-retained mortality, NR_p) to use in eq. B2 for the projected MMB_{mating} is based on multiplying an estimator (θ) for the ratio of bycatch mortality to MMB just prior to fishing ($MMB_{fishing}$). Thus, $NR_p = \theta \cdot MMB_{fishing}$, where $MMB_{fishing} = \langle MMB_{survey} \rangle \cdot e^{-M \cdot t_{sf}}$. The estimator θ is taken as the ratio of the average mature male bycatch mortality to the average actual MMB_{mating}, where the averages are taken over the last 3 years (i.e., 2011/12-2013/14).

Putting this all together,

$$Projected\ MMB_{mating} = \left(\langle MMB_{survey} \rangle \cdot e^{-M \cdot t_{sf}} - R - NR_P\right) \cdot e^{-M \cdot t_{fm}}$$

$$Projected\ MMB_{mating} = \left(\langle MMB_{survey} \rangle \cdot e^{-M \cdot t_{sf}} - 0 - \theta \cdot \langle MMB_{survey} \rangle \cdot e^{-M \cdot t_{sf}}\right) \cdot e^{-M \cdot t_{fm}}$$

$$Projected\ MMB_{mating} = \left(\langle MMB_{survey} \rangle \cdot e^{-M \cdot t_{sf}}\right)(1 - \theta) \cdot e^{-M \cdot t_{fm}} \qquad \text{(B3)}$$

2014 Saint Matthew Island Blue King Crab Stock Assessment

William Gaeuman, ADF&G, Kodiak
Sept 2014

Executive Summary

1. Stock: Blue king crab, *Paralithodes platypus,* Saint Matthew Island, Alaska.

2. Catches: Peak historical harvest was 9.454 million pounds (4,288 t) in 1983/84. The fishery was closed for 10 years after the stock was declared overfished in 1999. Fishing resumed in 2009/10 with a fishery-reported retained catch of 0.461 million pounds (209 t), less than half the 1.167 million pound (529.3 t) TAC. Following three more years of modest harvests supported by a fishery CPUE of around 10 crab per pot lift, the fishery was again closed in 2013/14 due to declining trawl-survey estimates of abundance and concerns about the health of the stock. Non-negligible male bycatch mortality resulting from other fisheries with potential to impact the stock in 2013/14 consist only in an estimated 0.0006 million pounds (0.3 t) in the Bering Sea groundfish fisheries.

3. Stock biomass: Following a period of low numbers after the stock was declared overfished in 1999, trawl-survey indices of SMBKC stock abundance and biomass generally increased in subsequent years, with survey estimated mature male biomass reaching 21.07 million pounds (9,557 t; CV 0.53) in 2011, the second highest in the 36-year time series used in this assessment. Survey mature male biomass then declined to 12.46 million pounds (5,652 t; CV 0.33) in 2012 and to 4.459 million pounds (2,203 t; CV 0.22) in 2013 before going back up to 12.06 million pounds (5,443 t; CV 0.44) in 2014.

4. Recruitment: Because little information about the abundance of small crab is available for this stock, recruitment has been assessed in terms of the number of male crab entering the 90-104 mm CL size class in each year. The 2013 trawl-survey area-swept estimate of 0.335 million male SMBKC in this size class marked a three-year exponential decline and was the lowest since 2005. That decline came to an end with the 2014 survey, however, with an estimate of 0.723 million, more than double the previous year's value and very close to what it was in 2012.

5. Management performance: In recent assessments, estimated total male catch has been determined as the sum of fishery-reported retained catch, estimated male discard mortality in the directed fishery, and estimated male bycatch mortality in the groundfish fisheries, as these have been the only sources of non-negligible fishing mortality to consider. Because the directed fishery was closed in 2013/14, estimated total male fishing mortality consists only in an estimated male bycatch mortality of 0.0006 million pounds (0.3 t) in the Bering Sea groundfish fisheries, so that overfishing did not occur in 2013/2014. And while the available evidence suggests that stock biomass remains depressed, there is little basis for believing that the stock is overfished or nearing an overfished condition. See table below. (Biomass measures in millions of pounds with metric ton equivalents in parentheses.)

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Male Catch	OFL[a]	ABC
2010/11	3.4 (1,500)	14.77 (6,700)	1.600 (725.7)	1.264 (573)	1.41 (639)	2.29 (1,040)	-
2011/12	3.4 (1,500)	11.09 (5,030)	2.539 (1,151)	1.881 (853)	2.10 (953)	3.74 (1,700)	3.40 (1,540)
2012/13	4.0 (1,800)	6.29 (2,850)	1.630 (739.4)	1.616 (733)	1.81 (821)	2.24 (1,020)	2.02 (916)
2013/14	3.4 (1,500)	6.64 (3,010)	0	0	0.0006 (0.3)	1.24 (562)	0.99 (450)
2014/15	3.6[b] (1,600)	5.98[c] (2,710)	TBD	TBD	TBD	0.82[d] (370)	0.65[d,e] (290)

[a] Total male catch OFL.
[b] Fall 2014 model ST estimate using the reference period 1978/79 – 2013/14.
[c] Fall 2014 model ST projection assuming OFL catch.
[d] From Fall 2014 model ST.
[e] As described in §G with P* = 0.49 and 20% buffer.

6. <u>Basis for the OFL</u>: Estimated Feb 15 mature-male biomass (MMB_{mating}) is used as the measure of biomass for this Tier 4 stock, with males measuring 105 mm CL or more considered mature. The B_{MSY} proxy is obtained by averaging estimated MMB_{mating} over a specific reference period, and current CPT/SSC guidance recommends using the the full assessment time frame as the default reference period. Under the author-recommended model configuration ST that procedure results in an estimated 2014/15 B_{MSY} proxy of 7.24 million pounds (3,280 t). The F_{MSY} proxy is taken equal to the assumed 0.18 yr^{-1} instantaneous natural mortality (NPFMC 2007). See table below. (Biomass measures in millions of pounds with metric ton equivalents in parentheses.)

Year	Tier	B_{MSY}	B (MMB_{mating})	B/B_{MSY}	F_{OFL}	γ	Basis for B_{MSY}	Natural Mortality	P^*
2010/11	4a	6.86 (3,110)	15.29 (6,940)	2.23	$0.18yr^{-1}$	1	1989/90-2009/10	$0.18yr^{-1}$	-
2011/12	4a	6.85 (3,110)	15.80 (7,167)	2.31	$0.18yr^{-1}$	1	1989/90-2009/10	$0.18yr^{-1}$	0.49
2012/13	4a	7.93 (3,560)	12.41 (5,629)	1.56	$0.18yr^{-1}$	1	1978/79-2011/12	$0.18yr^{-1}$	0.49
2013/14	4b	6.76 (3,060)	6.64 (3,010)	0.98	$0.18yr^{-1}$	1	1978/79-2012/13	$0.18yr^{-1}$	0.49
2014/15	4b	7.24 (3,280)	5.98[a] (2,710)	0.82	$0.14yr^{-1}$	1	1978/79-2013/14	$0.18yr^{-1}$	0.49

[a] Fall 2014 model ST projection assuming OFL catch.

7. <u>Distribution of the OFL</u>: It is recognized that the use of the assessment methodology to compute the OFL involves substantial inherent uncertainty by virtue of, among other things, its dependence on estimated quantities as key inputs. Accordingly, the calculated OFL may be viewed as a random variable with an associated probability distribution. Following recommendations developed during the Jan 2012 NPFMC crab modeling workshop, the model associated standard error of the logarithm of the estimated OFL is used to specify a probability distribution to quantify some of this uncertainty and to facilitate determination of the absolute biological catch (ABC). Details are provided in §G of this document.

8. <u>Basis for the ABC</u>: For determining an acceptable ABC and hence the annual catch limit (ACL), current instructions are to require that P[ABC > OFL] = P* with P* = 0.49. Implementation of this requirement to determine a maximum ABC relies on the assigned OFL probability distribution and is described in §G. To account for additional sources of uncertainty, and in keeping with past CPT and SSC guidance, the author recommends that the ABC be set at no more than 80% of the maximum value. Note that use of a 20% buffer rather than the previous default 10% value was proposed during the Fall 2013 CPT meeting as a result of concern about possible model misspecification. The author shares that concern.

9. Summary of rebuilding analyses: NA

A. Summary of Major Changes

Changes in Management of The Fishery
There are no new changes in management of the fishery.

Changes to The Input Data
All time series used in the assessment have been updated to include the most recent fishery and survey results, including those from the 2013 ADF&G triennial SMBKC pot survey, which were not yet available at the time of last year's assessment. This assessment also makes use of an updated full trawl-survey time series supplied by R. Foy in August 2014, as well as updated groundfish bycatch estimates based on 1999-2013 AKRO data also supplied by R. Foy.

Changes in Assessment Methodology
This assessment employs the 3-stage length-based assessment model first presented in May 2011 and accepted by the CPT in May 2012. The model was developed to replace a similar 4-stage model used prior to 2011. During each of the last two assessment cycles, a number of alternative model configurations have been considered and rejected in favor of the base-model configuration documented in Appendix A to this report. For this assessment the author is recommending use of a new alternative model configuration that is described in what follows.

Changes in Assessment Results
There are no major changes in assessment results at this time.

B. Responses to SSC and CPT Comments

CPT and SSC Comments on Assessments in General

Fall 2013 CPT
Comments: No new recommendations.

Fall 2013 SSC
Comments: No new recommendations.

Spring 2014 CPT
Comments: No new recommendations.

Spring 2015 SSC
Comments: No new recommendations relevant to this assessment.

CPT and SSC Comments Specific to SMBKC Stock Assessment

Fall 2013 CPT
Comments: *The Team recommends the author continue to develop a biologically plausible transition matrix.*

The Team also discussed the large retrospective pattern in the base model fit to the trawl data as shown in Figure 20 of the [2013] SAFE. While retrospective issue occurred throughout the time series, the last decade shows a pattern of the model retrospectively indicating lower biomass than the assessment during the year in which the estimate is made. This period also corresponds to natural mortality having increased variation around its mean for both hybrid models presented in this assessment. The Team noted that the retrospective patterns indicate a large amount of uncertainty in model projections that should be considered in setting the ABC.

Response: See Spring 2014 CPT/SCC comments and author's responses.

Fall 2013 SSC
Comments: *For next year's assessment, the SSC encourages the stock assessment author to focus on addressing the retrospective bias in the current assessment and offers the following recommendations:*

• Develop a likelihood profile over a large range of Ms and provide diagnostics on model fits. Misspecification of M can lead to biases in abundance estimates.

• As suggested by the team, further work on a biologically defensible age-transition matrix may be fruitful. Alternative models should be developed using this approach.

• Investigate all other model assumptions to evaluate their potential contribution to the retrospective pattern.

Response: See Spring 2014 CPT/SSC comments and author's responses.

Spring 2014 CPT
Comments: *The CPT previously requested the author "continue to develop a biologically plausible transition matrix" for use in the SMBKC assessment model . The author has acquired growth data from crab tagged during the 1995 ADF&G pot survey and recaptured during subsequent commercial seasons. He plans to use these data, along with earlier results from Otto and Cummiskey (1990), to develop a more "biologically plausible" stage-transition matrix/population dynamics model for use in September 2014 model configurations. Plots of individual growth increment vs. size-at-release were presented for recaptures from four fishing seasons. CPT members expressed concern over data quality and potential measurement errors. The author noted that the growth increments appeared constant (~15 mm CL, consistent with Otto and Cummisky) for crab in the 110-160 mm CL release size range, and CPT members raised the possibility that this was due to quantization (e.g., to 1 cm) in the measurements. In addition, the author noted that, these data would not be terribly informative to the model transition matrix in any case because almost all tagged crab fall into the largest size class in the mode.*

The SSC in October 2013 requested that the author address the "retrospective bias" in the current assessment. In an effort to obtain clarification on this issue, the author presented a ten-year retrospective plot of model-predicted 90+ mm CL male survey biomass. The CPT regarded the plot as indicating a substantial retrospective problem. Potential sources suggested for the bias included time-varying selectivity or growth. It was recommended that the author examine whether there are retrospective patterns in other model output (e.g., recruitment, fishing mortality), as well as residuals for evidence of time-varying growth or selectivity.

Response: See following author response to Spring 2014 SSC comments.

Spring 2014 SSC
Comments: *The Saint Matthew Island blue king crab stock is currently managed under Tier 4 using biomass estimates from a three-stage catch-survey analysis first approved by the CPT and SSC in 2012. While the model was judged adequate for setting reference points, some concerns with the model structure and performance were highlighted in the 2013 assessment cycle, including uncertainty in natural mortality, the use of an appropriate stage-transition matrix and a strong retrospective pattern. No document was available for review, but the author, at the CPT meeting, discussed efforts to improve the stage-transition matrix using growth data from crab tagged during the 1995 ADF&G pot survey and presented an updated ten-year retrospective plot. The SSC encourages these explorations and also re-iterates its request from the October 2013 minutes to explore the effects of varying natural mortality in the model, for example using a likelihood profile on M.*

Response: In accordance with NPFMC (2007), under all model configurations used for this and recent assessments natural mortality has been fixed at 0.18 yr^{-1} overall years except 1998/99, for which year it is model estimated to account for a hypothesized anomalous fatality event (Zheng and Kruse 2002). The "true" value likely differs from this. Global natural mortality can in fact be estimated in the base model, but the estimate unrealistically high at 1.29 yr^{-1} and, moreover, leads to nonsensical model behavior. On the other hand, as is clear from the associated ADMB profile likelihood, the assumed 0.18 yr^{-1} value is itself implausible within the base model framework (Figure 1). The author is unclear about what to make of this state of affairs.

For this assessment the author has again investigated use of a more biologically plausible stage-transition matrix based, as before, on Otto and Cummiskey (2002). It turns out that ADF&G tagging data, as noted at the 2014 Spring CPT meeting, have little to offer here because they are based almost entirely on animals measuring 120 mm CL or larger, model stage 3, at the time of release. The author has come to believe that, as so much is unknown, it is best to make use of any biologically meaningful information that can reasonably inform model structure and attempt to configure other model components around it so as to achieve reasonable model behavior. In keeping with that belief, the author-recommended model configuration for the 2014 assessment includes the more biologically plausible stage-transition matrix.

The base-model retrospective pattern of concern in 2013 (Figure 2) is associated with increasing retrospective estimates of stage-1 and stage-2 trawl-survey selectivity (Figure 3). In the base model, these two estimated parameters are treated as invariant in time whereas stage-3 trawl-survey selectivity is additionally set equal to catchability, which in turn is assumed equal to 1. These conventions are clearly simplifications: catchability is almost certainly not 1 and both it and relative stage selectivity undoubtedly vary over time. But all this is especially likely to be the case for the SMBKC stock given its proximity to Saint Matthew Island and the fact that the trawl survey does not and cannot survey areas in the vicinity of the island that are known to play a roll in seasonal movement of the population (Figure 4). It is to be expected that trawl-survey results could be greatly affected and potentially biased as a meaningful population index as crab move in and out of the surveyed area at different times, both within and across years. Such a mechanism may well underlie, for example, the sporadically large catches that have occurred in recent years at survey station R-24 near Hall Island to the north of Saint Matthew Island, which in 2014 accounted for more than a third (67) of the 181 model-size male SMBKC captured at the 56 stations comprising the SMBKC survey area (Figure 5). To address these issues, for this assessment the author has investigated the utility of time-varying trawl-survey selectivity, and the author-recommended model configuration includes this feature.

C. Introduction

Scientific Name
The blue king crab is a lithodid crab, *Paralithodes platypus* (Brant 1850).

Distribution
Blue king crab are sporadically distributed throughout the North Pacific Ocean from Hokkaido, Japan, to southeastern Alaska (Figure 6). In the eastern Bering Sea small populations are distributed around St. Matthew Island, the Pribilof Islands, St. Lawrence Island, and Nunivak Island. Isolated populations also exist in some other cold water areas of the Gulf of Alaska (NPFMC 1998). The St. Matthew Island Section for blue king crab is within Area Q2 (Figure 7), which is the Northern District of the Bering Sea king crab registration area and includes the waters north of of Cape Newenham (58°39' N. lat.) and south of Cape Romanzof (61°49' N. lat.).

Stock Structure
The Alaska Department of Fish and Game (ADF&G) Gene Conservation Laboratory division has detected regional population differences between blue king crab collected from St. Matthew Island and the Pribilof Islands[1]. NMFS tag-return data from studies on blue king crab in the Pribilof Islands and St. Matthew Island support the idea that legal-sized males do not migrate between the two areas (Otto and Cummiskey 1990). St. Matthew Island blue king crab tend to be smaller than their Pribilof conspecifics, and the two stocks are managed separately.

Life History
Like the red king crab, *Paralithodes camtshaticus*, the blue king crab is considered a shallow water species by comparison with its lithodid cousins the golden or brown king crab, *Lithodes aequispinus,* and the scarlet king crab, *Lithodes couesi* (Donaldson and Byersdorfer 2005). Adult male blue king crab are found at an average depth of 70m (NPFMC 1998). Mature females have a biennial ovarian cycle (cf. Jensen and Armstrong, 1989) and seasonally migrate inshore where they molt and mate. Unlike red king crab, juvenile blue king crab do not form pods but instead rely on cryptic coloration for protection from predators and require suitable habitat such as cobble and shell hash. Somerton and MacIntosh (1983) estimated SMBKC male size at sexual maturity to be 77.0 mm CL. Paul et al. (1991) found that spermatophores were present in the vas deferens of 50% of the St. Matthew Island blue king crab males examined with sizes of 40–49 mm CL and in 100% of the males at least 100 mm CL. They noted, however, that although spermataphore presence indicates physiological sexual maturity it may not be an indicator of functional sexual maturity. For purposes of management of the St. Matthew Island blue king crab fishery, the State of Alaska uses 105 mm CL to define the lower size bound of functionally mature males (Pengilly and Schmidt 1995). Otto and Cummiskey (1990) report an average growth increment of 14.1 mm CL for adult SMBKC males.

Management History
The SMBKC fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990). Ten U.S. vessels harvested 1.202 million pounds in 1977, and harvests

[1] NOAA grant Bering Sea Crab Research II, NA16FN2621, 1997.

peaked in 1983 when 164 vessels landed 9.454 million pounds (Fitch et al. 2012; Table 1). The fishing seasons were generally short, often lasting only a few days. The fishery was declared overfished and closed in 1999 when the stock biomass estimate was below the minimum stock-size threshold (MSST) of 11.0 million pounds as defined by the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner crabs (NPFMC 1999). Zheng and Kruse (2002) hypothesized a high level of SMBKC natural mortality from 1998 to 1999 as an explanation for the low catch per unit effort (CPUE) in the 1998/99 commercial fishery and 1999 ADF&G pot survey, as well as the low numbers across all male crab size groups caught in the annual NMFS eastern Bering Sea trawl survey from 1999 to 2005 (Table 2). In Nov 2000, Amendment 15 to the FMP for Bering Sea/Aleutian Islands king and Tanner crabs was approved to implement a rebuilding plan for the SMBKC stock (NPFMC 2000). The rebuilding plan included a regulatory harvest strategy (5 AAC 34.917), area closures, and gear modifications. In addition, commercial crab fisheries near St. Matthew Island were scheduled in fall and early winter to reduce the potential for bycatch mortality of vulnerable molting and mating crab.

NMFS declared the stock rebuilt on Sept 21, 2009, and the fishery was reopened after a 10-year closure on Oct 15, 2009 with a TAC of 1.167 million pounds, closing again by regulation on Feb 1, 2010. Seven participating vessels landed a catch of 460,859 pounds with a reported effort of 10,697 pot lifts and an estimated CPUE of 9.9 retained crab per pot lift. The fishery remained open the next three years with modest harvests and similar CPUE, but large declines in the NMFS trawl-survey estimate of stock abundance raised concerns about the health of the stock, prompting ADF&G to close the fishery again for the 2013/14 season.

Though historical observer data are limited, bycatch of female and sublegal male crab from the directed blue king crab fishery off St. Matthew Island was relatively high in past years, with estimated total bycatch in terms of number of crab captured sometimes twice or more as high as the catch of legal crab (Moore et al. 2000; ADF&G Crab Observer Database). Pot-lift sampling by ADF&G crab observers (Gaeuman 2013; ADF&G Crab Observer Database) indicates similar bycatch rates of discarded male crab since the reopening of the fishery (Table 3), with total male discard mortality in the 2012/13 directed fishery estimated at about 12% (0.193 million pounds) of the reported retained catch weight, assuming 20% handling mortality. On the other hand, these same data suggest a significant reduction in the bycatch of females, which may be attributable to the later timing of the contemporary fishery[2]. Some bycatch of discarded blue king crab has also been observed historically in the eastern Bering Sea snow crab fishery, but in recent years it has generally been negligible, and observers recorded no bycatch of blue king crab in sampled pot lifts during 2013/14. The St. Matthew Island golden king crab fishery, the third commercial crab fishery to have taken place in the area, typically occurred in areas with depths exceeding blue king crab distribution. NMFS observer data suggest that variable but mostly limited SMBKC bycatch has also occurred in the eastern Bering Sea groundfish fisheries (Table 4).

[2] D. Pengilly, ADF&G, pers. comm.

D. Data

Summary of New Information

Data used in this assessment have been updated to include the most recently available fishery and survey numbers, including results from the 2013 ADF&G triennial SMBKC pot survey, which were not yet available in Fall 2013. In addition, this assessment makes use an updated trawl-survey time series provided by R. Foy in August 2014, as well as updated 1993-2013 groundfish bycatch estimates based on AKRO data also supplied by R. Foy.

Major Data Sources

Major data sources used in this assessment are annual directed-fishery retained-catch statistics from fish tickets (1978/79-1998/99, 2009/10-2012/13; Table 1); results from the annual NMFS eastern Bering Sea trawl survey (1978-2014; Table 2); results from the triennial ADF&G SMBKC pot survey (every third year 1995-2013; Table 3); size-frequency information from ADF&G crab-observer pot-lift sampling (1990/91-1998/99, 2009/10-2012/13; Table 4); and NMFS groundfish-observer bycatch biomass estimates (1992/93-2013/14; Table 5). Figure 3 maps stations from which SMBKC trawl-survey and pot-survey data were obtained. Further information concerning the NMFS trawl survey as it relates to commercial crab species is available in Daly et al. (2014); see Gish et al. (2012) for a description of ADF&G SMBKC pot-survey methods. It should be noted that the two surveys cover different geographic regions and that each has in some years encountered proportionally large numbers of male blue king crab in areas where the other is not represented (Figure 4). Crab-observer sampling protocols are detailed in the crab-observer training manual (ADF&G 2013). Groundfish SMBKC bycatch data come from NMFS Bering Sea reporting areas 521 and 524 (Figure 8). Note that for this assessment the newly available NMFS groundfish observer data reported by ADF&G statistical area was not used.

Other Data Sources

The alternative model configuration developed for this assessment makes use of a growth transition matrix based on Otto and Cummiskey (1990). Other relevant data sources, including assumed population and fishery parameters, are presented in Appendix A, which provides a detailed description of the base-model configuration used for the 2012 and 2013 assessments.

Major Excluded Data Sources

Groundfish bycatch size-frequency data available for selected years, though used in the model-based assessment in place prior to 2011, play no direct role in this analysis. This is because these data tend to be severely limited: for example, 2012/13 data include a total of just 4 90-mm+ CL male blue king crab from reporting areas 521 and 524.

E. Analytic Approach

History of Modeling Approaches for this Stock

A four-stage catch-survey-analysis (CSA) assessment model was used before 2011 to estimate abundance and biomass and prescribe fishery quotas for the SMBKC stock (2010 SAFE; Zheng et al. 1997). The four-stage CSA is similar to a full length-based analysis, the major difference being coarser length groups, which are more suited to a small stock with consistently low survey catches. In this approach, the abundance of male crab with a CL of 90 mm or more is modeled in terms of four crab stages: stage 1 (90-104 mm CL); stage 2 (105-119 mm CL); stage 3 (newshell 120-133 mm CL); and stage 4 (oldshell $\geq$ 120 mm CL and newshell $\geq$ 134 mm CL). Motivation for these stage definitions comes from the fact that for management of the SMBKC stock, male crab measuring at least 105 mm CL are considered mature, whereas 120 mm CL is considered a proxy for the legal size of 5.5 in carapace width, including spines. Additional motivation for these stage definitions derives from an estimated average growth increment of about 14 mm per molt for SMBKC (Otto and Cummiskey 1990), with the slightly narrower stage-3 size range intended to buttress the model assumption that all stage-3 crab transition to stage 4 after one year[3].

Concerns about the pre-2011 assessment model led to CPT and SSC recommendations that included development of an alternative model with provisional assessment based on survey biomass or some other index of abundance. The author proposed an alternative 3-stage model to the CPT in May 2011 but was requested to proceed with a survey-based approach for the Fall 2011 assessment. In May 2012 the CPT approved for use a slightly revised and better documented version of the alternative model.

Assessment Methodology

The current SMBKC stock assessment model, first used in Fall 2012, is a variant of the previous four-stage SMBKC CSA model (2010 SAFE; Zheng et al. 1997) and similar in complexity to that described by Collie et al. (2005). Like the earlier model, it considers only male crab at least 90 mm in CL, but it combines stages 3 and 4 of the earlier model resulting in just three stages (male size classes) determined by carapace length measurements of (1) 90-104 mm, (2) 105-119 mm, and (3) 120 mm+. This consolidation was heavily driven by concern about the accuracy and consistency of shell-condition information, which had been used in distinguishing stages 3 and 4 of the earlier model. A detailed description of the base model and its implementation in the software AD Model Builder (ADMB Project 2009) is presented in technical Appendix A to this report. Basic model code was previously provided to the CPT in May 2012 and is available upon request from the author[4].

Model Selection and Evaluation

The base model described in Appendix A to this report was used for the 2012 and 2013 SMBKC assessments after comparison with a number of alternative model configurations, including ten in 2013 (2013 SAFE). Most of the alternative model configurations were designed to address previous CPT and SSC requests and recommendations. To address the most recent CPT and SSC

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[3] J. Zheng, ADF&G, pers. comm.
[4] william.gaeuman@alaska.gov

concerns, for this assessment the author has chosen to consider three alternative model configurations in addition to the base model. The alternative models, here denoted S, T and ST, differ from the base model in one or both of two ways. In contrast to the base model, which estimates separate time-invariant stage-1 and stage-2 trawl-survey selectivity parameters, model S estimates only the geometric mean of stage-1 trawl-survey selectivity, with the geometric mean of stage-2 trawl-survey selectivity set equal to the average of it and 1 (Q), the default assumed stage-3 value in all models. Year-t stage-j selectivity is then given by $s_{j,t} = \bar{s}_j \exp(\epsilon_{j,t})$, where $\bar{s}_j$ is the geometric mean $\bar{s}_1$, $\bar{s}_2 = (\bar{s}_1 + 1)/2$ or $\bar{s}_3 = 1$ and $\epsilon_{j,t}$ are estimated zero-sum deviations subject to a first-difference smoothing penalty $\frac{\lambda}{0.5}\sum_t(\epsilon_{j,t-1} - \epsilon_{j,t})^2$. This specification enforces overall monotonicity on the geometric mean values of the three trawl-survey stage selectivity parameters while allowing them to vary individually across years (Figure 9a).

Model configuration T differs from the base model in that it employs a presumably more biologically realistic stage-transition matrix $\begin{bmatrix} 0.2 & 0.7 & 0.1 \\ 0 & 0.4 & 0.6 \\ 0 & 0 & 1 \end{bmatrix}$ in place of the matrix $\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \end{bmatrix}$ used in the base model. So, for example, in any given year, instead of 100%, only 70% of stage-1 crab molt and grow into stage-2 crab, with 10% molting and growing into stage 3 and the remaining 20% staying in stage 1, whether or not they molt. The alternative transition matrix was developed based on the work of Otto and Cummiskey (1990) on Pribilof and St. Matthew Island blue king crab molting and growth. They report estimated molting probabilities of about 95% and 70% for crab measuring 97.5 and 112.5 mm CL, respectively, and model CL molt increment using a normal probability density function with mean 14.1 mm and standard deviation 3.1 mm.

The third alternative model configuration considered for this assessment, model ST, combines the defining features of configurations S and T. Use of the alternative model T stage-transition matrix evidently dampens some of the more extreme behavior displayed by model S estimates of trawl-survey selectivity parameters (Figure 9b). In all other respects the three alternative model configurations are identical to that of the base-model with, for example, natural mortality assumed equal to 0.18 yr^{-1} in all years except 1998/99, for which it is model estimated to account for a hypothesized anomalous fatality event in that year (Zheng and Kruse, 2002). Further details about the base model are provided in Appendix A.

Choice of the three alternative model configurations examined for this assessment was largely driven by CPT and SSC concerns about the biological implausibility of the base model transition matrix, on the one hand, and, on the other, about the retrospective pattern previously observed in the base-model fit to the trawl-survey biomass index data (Figure 2). Another concern about the base model was its very poor fit to the trawl-survey composition data, particularly in the last third of the 37-year time series (2013 SAFE).

Table 6 and Figures 8-13 facilitate basic comparison of the different model configurations with respect to these concerns and in terms of important measures of model behavior. Allowing trawl-survey selectivity to vary with time, model configurations S and ST, provides a substantially better fit to both the trawl-survey index (Table 6; Figure 10) with little impact on the fit to the pot-survey index data (Table 6; Figure 11). As is clear from Figures 12a-c, these models also provide a much better fit to the trawl-survey composition data. Fits to the pot-survey and observer composition data differ little across models and so are not considered further here. On the other hand, models T and ST, which make use of the alternative transition matrix, perform more similarly in terms of estimation of population abundance (Figure 13) and biomass (Figure 14), though model T estimates of these quantities are perhaps improbably large in the early years of the time series. Apparent deficiencies in model S include the extremely low estimates of abundance and biomass in the early years of the time series by comparison with the other three model configurations, resulting in implausibly high estimates of directed-fishery fishing mortality (Figure 15d), and there is some evidence in the likelihoods for preferring model ST to model S (Table 6). For these reasons the author recommends use of model ST for the 2014 assessment.

Results

Additional results are presented for model configuration ST, as the author-recommended choice for use in the Fall 2014 SMBKC stock assessment (Tables 7-9; Figures 16-20). Primary parameter estimates are all sensible and within the parameter space (Table 7), which is not the case for some of the competing model configurations, and there are no particularly worrisome correlations (Table 8). All in all, model ST offers the best overall fit to the data, is arguably the most biologically defensible, and shows no egregiously pathological behavior. Management implications of the model are presented in the next two sections.

F. Calculation of The OFL

The overfishing level (OFL) is the fishery-related mortality biomass associated with fishing mortality F_{OFL}. The SMBKC stock is currently managed as Tier 4 (2013 SAFE), and only a Tier 4 analysis is presented here. Thus given stock estimates or suitable proxy values of B_{MSY} and F_{MSY}, along with two additional parameters α and β, F_{OFL} is determined by the control rule

$$a) \quad F_{OFL} = F_{MSY}, \; when \;\; B/B_{MSY} > 1;$$

$$b) \quad F_{OFL} = F_{MSY}\,(B/B_{MSY} - \alpha)/(1-\alpha), \; when \;\; \beta < B/B_{MSY} \le 1;$$

$$c) \quad F_{OFL} < F_{MSY} \;\; with \; directed \;\; fishery \; F = 0, \; when \;\; B/B_{MSY} \le \beta,$$

where B is quantified as mature-male biomass at mating MMB_{mating}, with time of mating assigned a nominal date of Feb 15. Note that as B is itself a function of the fishing mortality F_{OFL}, in case b) numerical approximation of F_{OFL} is required. As implemented for this assessment, all calculations proceed according to the model equations given in Appendix A. In particular, the OFL catch is computed using equations [A3], [A4], and [A5], given model configuration ST modifications, with F_{OFL} taken to be full-selection fishing mortality in the directed pot fishery and groundfish trawl and fixed-gear fishing mortalities set at their model geometric mean values over years for which there are data-based estimates of bycatch-mortality biomass.

The currently recommended Tier 4 convention is to use the full assessment period, currently 1978/79 -2013/14, to define a B_{MSY} proxy in terms of average estimated MMB_{mating} and to put $\gamma = 1.0$ with assumed stock natural mortality $M = 0.18$ yr^{-1} in setting the F_{MSY} proxy value γM. The parameters α and β are assigned their default values $\alpha = 0.10$ and $\beta = 0.25$. With these specifications and letting F_{OFL} determine directed-fishery fishing mortality, under the author recommended model configuration ST the B_{MSY} proxy is 7.24 million pounds, and case b) of the control rule obtains, with $F_{OFL} = 0.14$ yr^{-1} and a Tier 4b 2014/15 total male catch OFL of 0.82 million pounds. The retained catch component of the OFL is 0.79 million pounds. Complete partitioning of the OFL under model configuration ST is given in Table 10.

G. Calculation of The ABC

For determining an acceptable biological catch (ABC), and hence the annual catch limit (ACL), current recommendations are to require that $P[ABC > OFL] = P^*$, with P^* = 0.49. As implemented here, the maximum ABC is set equal to $\lambda \times ofl$, where *ofl* is the Tier 4 model-calculated overfishing level from the control rule and the multiplier λ is determined by the probability statement $P[\lambda\widehat{OFL} > OFL]$ = P^*, under the assumptions that OFL = *median*$(\widehat{OFL})$ and $\log(\widehat{OFL}) \sim N(\log(OFL), \sigma)$, where σ is the ADMB-reported standard error of $\log(\widehat{OFL})$ from the model. With this set up, $P^* = P\left[\lambda\widehat{OFL} > OFL\right] = 1 - \Phi(-\frac{\log(\lambda)}{\sigma})$, so that

$\log(\lambda) = -\sigma\Phi^{-1}(1 - P^*)$ and $\lambda = \exp(\sigma\Phi^{-1}(P^*))$.

For the recommended model, this procedure yields $\lambda = \exp\left(0.3379\Phi^{-1}(0.49)\right) = 0.99$ and a maximum ABC of $\lambda \times ofl$ = 0.99 × 0.82 = 0.81million pounds. To account for additional sources of uncertainly and in keeping with current CPT and SSC guidance, the author recommends that the ABC be set at no more than 80% of the maximum value. In this instance, the use of an additional 20% buffer leads to a provisional author-recommended ABC of 0.65 million pounds.

H. Rebuilding Analysis

This stock is not currently subject to a rebuilding plan.

I. Data Gaps and Research Priorities

The CPT and SSC have identified as an important research need to investigate SMBKC annual molting frequency (and growth increment) as a function of pre-molt size. As the currently specified base-model transition matrix, requiring all stage-1 and 2 crab to transition in each year to stages 2 and 3, respectively, is likely unrealistic, the author concurs with this recommendation. For this assessment he has explored the use of a more biologically plausible transition matrix based on his review of Otto and Cummiskey's 1990 work on molting frequency and growth increment of Pribilof and St. Matthew Island blue king crab. Currently available ADF&G SMBKC tagging data are limited to larger crab, making them mostly uninformative in this regard. Additional specifically SMBKC tagging data covering a broader range of sizes would be useful.

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Table 1. The 1978/79 – 2013/14 directed St. Matthew Island blue king crab pot fishery. Source: Fitch et al. 2012; ADF&G Dutch Harbor staff, pers. comm.

			Harvest[b]					
season	dates	GHL/TAC[a]	crab	pounds	pot lifts	CPUE[c]	avg wt[d]	avg CL[e]
1978/79	07/15-09/03		436,126	1,984,251	43,754	10	4.5	132.2
1979/80	07/15-08/24		52,966	210,819	9,877	5	4.0	128.8
1980/81	07/15-09/03			**CONFIDENTIAL**				
1981/82	07/15-08/21		1,045,619	4,627,761	58,550	18	4.4	NA
1982/83	08/01-08/16		1,935,886	8,844,789	165,618	12	4.6	135.1
1983/84	08/20-09/06	8	1,931,990	9,454,323	133,944	14	4.9	137.2
1984/85	09/01-09/08	2.0-4.0	841,017	3,764,592	73,320	11	4.5	135.5
1985/86	09/01-09/06	0.9-1.9	436,021	2,175,087	46,988	9	5.0	139.0
1986/87	09/01-09/06	0.2-0.5	219,548	1,003,162	22,073	10	4.6	134.3
1987/88	09/01-09/05	0.6-1.3	227,447	1,039,779	28,230	8	4.6	134.1
1988/89	09/01-09/05	0.7-1.5	280,401	1,236,462	21,678	13	4.4	133.3
1989/90	09/01-09/04	1.7	247,641	1,166,258	30,803	8	4.7	134.6
1990/91	09/01-09/07	1.9	391,405	1,725,349	26,264	15	4.4	134.3
1991/92	09/16-09/20	3.2	726,519	3,372,066	37,104	20	4.6	134.1
1992/93	09/04-09/07	3.1	545,222	2,475,916	56,630	10	4.5	134.1
1993/94	09/15-09/21	4.4	630,353	3,003,089	58,647	11	4.8	135.4
1994/95	09/15-09/22	3.0	827,015	3,764,262	60,860	14	4.9	133.3
1995/96	09/15-09/20	2.4	666,905	3,166,093	48,560	14	4.7	135.0
1996/97	09/15-09/23	4.3	660,665	3,078,959	91,085	7	4.7	134.6
1997/98	09/15-09/22	5.0	939,822	4,649,660	81,117	12	4.9	139.5
1998/99	09/15-09/26	4.0	635,370	2,968,573	91,826	7	4.7	135.8
1999/00-2008/09				**FISHERY CLOSED**				
2009/10	10/15-02/01	1.17	103,376	460,859	10,697	10	4.5	134.9
2010/11	10/15-02/01	1.60	298,669	1,263,982	29,344	10	4.2	129.3
2011/12	10/15-02/01	2.54	437,862	1,881,322	48,554	9	4.3	130.0
2012/13	10/15-02/01	1.63	379,386	1,616,054	37,065	10	4.3	129.8
2013/14				**FISHERY CLOSED**				

[a] Guideline Harvest Level/Total Allowable Catch in millions of pounds.
[b] Includes deadloss.
[c] Harvest number/pot lift.
[d] Harvest weight/harvest number, in pounds.
[e] Average CL of retained crab in millimeters, from dockside sampling of delivered crab.

Table 2. NMFS EBS trawl-survey area-swept estimates of male crab abundance (10^6 crab) and of mature male biomass (10^6 lb). Total number of captured male crab $\geq$ 90 mm CL is also given. Source: J.Zheng, ADF&G; R.Foy, NMFS.

	abundance					biomass		
year	stage 1 (90-104mm CL)	stage 2 (105-119mm CL)	stage 3 (120mm+ CL)	Total	CV	mature male (105mm+ CL)	cv	number of crab
1978	2.421	2.227	1.702	6.350	0.41	11.574	0.39	163
1979	3.013	2.276	2.196	7.485	0.42	12.918	0.39	187
1980	2.931	2.630	2.608	8.169	0.57	16.141	0.47	188
1981	0.495	1.245	2.323	4.064	0.37	12.779	0.40	140
1982	1.713	2.495	5.987	10.194	0.38	30.748	0.32	269
1983	1.078	1.663	3.363	6.104	0.33	17.921	0.28	231
1984	0.447	0.499	1.478	2.424	0.18	7.684	0.19	104
1985	0.381	0.376	1.124	1.881	0.22	5.750	0.22	93
1986	0.206	0.457	0.377	1.039	0.43	2.579	0.39	46
1987	0.325	0.631	0.715	1.671	0.30	4.060	0.29	71
1988	0.410	0.816	0.957	2.183	0.29	5.693	0.24	81
1989	2.169	1.159	1.786	5.109	0.31	9.639	0.25	211
1990	1.053	1.031	2.338	4.422	0.30	11.955	0.26	170
1991	1.147	1.665	2.233	5.045	0.26	12.208	0.25	198
1992	1.074	1.382	2.291	4.746	0.21	12.649	0.20	220
1993	1.521	1.828	3.276	6.626	0.19	16.959	0.16	324
1994	0.883	1.298	2.257	4.438	0.19	11.696	0.18	211
1995	1.025	1.188	1.741	3.953	0.19	9.844	0.17	178
1996	1.238	1.891	3.064	6.193	0.26	17.111	0.24	285
1997	1.165	2.228	3.789	7.182	0.37	20.143	0.33	296
1998	0.660	1.661	2.849	5.170	0.37	15.054	0.36	243
1999	0.223	0.222	0.558	1.003	0.19	2.871	0.18	52
2000	0.282	0.285	0.740	1.307	0.30	3.794	0.31	61
2001	0.419	0.502	0.938	1.859	0.24	5.064	0.26	91
2002	0.111	0.230	0.640	0.981	0.31	3.311	0.32	38
2003	0.449	0.280	0.465	1.194	0.40	2.483	0.32	65
2004	0.247	0.184	0.562	0.993	0.37	2.705	0.29	48
2005	0.319	0.310	0.501	1.130	0.40	2.812	0.36	42
2006	0.917	0.642	1.240	2.798	0.34	6.494	0.36	126
2007	2.518	2.020	1.193	5.730	0.42	9.157	0.35	250
2008	1.352	0.801	1.457	3.609	0.29	7.353	0.29	167
2009	1.573	2.161	1.410	5.144	0.26	10.189	0.26	251
2010	3.937	3.253	2.458	9.648	0.54	17.949	0.37	385
2011	1.800	3.255	3.207	8.263	0.59	20.979	0.53	315
2012	0.705	1.967	1.808	4.483	0.36	12.461	0.33	193
2013	0.335	0.452	0.807	1.593	0.22	4.459	0.22	74
2014	0.723	1.627	1.809	4.160	0.50	12.063	0.44	181

Table 3. Observed proportion of crab by size class during ADF&G crab observer pot-lift sampling. Source: ADF&G Crab Observer Database.

year	pot lifts (sampled/total)	number of crab (90 mm+ CL)	stage 1 (90-104 mm CL)	stage 2 (105-119 mm CL)	stage 3 (120 mm+ CL)
1990/91	10/26,264	150	0.113	0.393	0.493
1991/92	125/37,104	3,393	0.133	0.177	0.690
1992/93	71/56,630	1,606	0.191	0.268	0.542
1993/94	84/58,647	2,241	0.281	0.210	0.510
1994/95	203/60,860	4,735	0.294	0.271	0.434
1995/96	47/48,560	663	0.148	0.212	0.640
1996/97	96/91,085	489	0.160	0.223	0.618
1997/98	133/81,117	3,195	0.182	0.205	0.613
1998/99	135/91,826	1,322	0.193	0.216	0.591
1999-2008			**FISHERY CLOSED**		
2009/10	989/10,484	19,802	0.141	0.324	0.535
2010/11	2,419/29,356	45,466	0.131	0.315	0.553
2011/12	3,359/48,554	58,666	0.131	0.305	0.564
2012/13	2,841/37,065	57,298	0.141	0.318	0.541
2013/14			**FISHERY CLOSED**		

Table 4. Size-class and total CPUE (90 mm+ CL) and estimated CV and total number of captured crab (90 mm+ CL) from the 96 common stations surveyed during the six triennial ADF&G SMBKC pot surveys. Source: D.Pengilly and R.Gish, ADF&G.

year	stage 1 (90-104mm CL)	stage 2 (105-119mm CL)	stage 3 (120mm+ CL)	CPUE	CV	number of crab
1995	1.919	3.198	6.922	12.042	0.13	4,624
1998	0.964	2.763	8.804	12.531	0.06	4,812
2001	1.266	1.737	5.487	8.477	0.08	3,255
2004	0.112	0.414	1.141	1.667	0.15	640
2007	1.086	2.721	4.836	8.643	0.09	3,319
2010	1.326	3.276	5.607	10.209	0.13	3,920
2013	0.878	1.398	3.367	5.643	0.19	2,167

Table 5. Groundfish SMBKC male bycatch biomass (10^3 pounds) estimates. Source: J. Zheng, ADF&G, and author estimates based on data from R. Foy, NMFS. AKRO estimates used after 2008/09.

	bycatch		
year	trawl[a]	fixed gear	total mortality[b]
1991/92	7.8	0.1	6.3
1992/93	4.4	5.0	6.0
1993/94	3.4	0.0	2.7
1994/95	0.7	0.2	0.7
1995/96	1.4	0.3	1.3
1996/97	0.0	0.1	0.1
1997/98	0.0	0.4	0.2
1998/99	0.0	2.0	1.0
1999/00	0.0	3.0	1.5
2000/01	0.0	0.0	0.0
2001/02	0.0	1.9	1.0
2002/03	1.6	0.9	1.7
2003/04	2.2	2.5	3.0
2004/05	0.2	1.4	0.9
2005/06	0.0	1.3	0.7
2006/07	6.2	3.2	6.6
2007/08	0.1	153.7	76.9
2008/09	0.6	14.6	7.8
2009/10	1.4	16.6	9.4
2010/11	0.8	21.1	11.2
2011/12	0.4	1.3	1.0
2012/13	1.3	0.0	1.1
2013/14	0.4	0.6	0.6

[a] Trawl, pelagic trawl, and non-pelagic trawl gear types.
[b] Assuming handling mortalities of 0.8 for trawl and 0.5 for fixed gear.

Table 6. Key base and alternative model quantities.

	model estimated trawl-survey selectivity			survey-index RMSE		objective function		management quantities (10^6 lb)		
model	stage 1	stage 2	stage 3	trawl	pot	min[a]	K[b]	Bmsy[c]	OFL[d]	MMB[e]
base	0.98	1.44	1 (Q)	1.43	6.12	3,888	122 - 4	6.656	0.943	5.906
ST	0.60[f]	0.80[f]	1[f]	1.10	6.29	3,845	232 - 7	7.243	0.820	5.968
S	0.89[f]	0.95[f]	1[f]	1.08	6.06	3,858	232 - 7	6.139	1.303	6.846
T	0.62	0.86	1 (Q)	1.47	6.33	3,890	122 - 4	7.781	0.940	6.711

[a] ADMB minimized objective function value.
[b] Number of model "parameters" – number of zero-sum constraints.
[c] Average 1978-2013 model MMBmating.
[d] Tier 4 assuming Fmsy = 0.18 yr^{-1}.
[e] Model projected 2015 MMBmating assuming OFL catch.
[f] Geometric mean value.

Table 7. Model ST ADMB parameter estimates and standard errors. Ranges are given for log recruit, log fishing mortality and log trawl-survey selectivity deviations.

parameter	estimate	standard error
1998/99 natural mortality	0.86	0.136
pot-survey proportionality constant	4.34	0.434
geometric mean trawl-survey stage-1 selectivity	0.60	0.053
pot-survey stage-1 selectivity	0.31	0.048
pot-survey stage-2 selectivity	0.71	0.077
pot-fishery stage-1 selectivity	0.33	0.038
pot-fishery stage-2 selectivity	0.50	0.047
log initial stage-1 abundance	7.96	0.238
log initial stage-2 abundance	7.56	0.290
log initial stage-3 abundance	6.67	0.449
mean log recruit abundance	6.83	0.073
mean log recruit abundance deviations (36)	[-1.96, 1.36]	[0.156, 0.530]
mean log pot-fishery fishing mortality	-1.08	0.102
log pot-fishery fishing mortality deviations (25)	[-3.03, 1.75]	[0.146, 0.647]
mean log GF trawl-gear fishing mortality	-10.39	0.233
log GF trawl-gear fishing mortality deviations (23)	[-1.76, 1.63]	[0.695, 0.713]
mean log GF fixed-gear fishing mortality	-9.61	0.230
log GF fixed-gear fishing mortality deviations (23)	[-2.25, 2.57]	[0.688, 0.702]
log trawl-survey s1 selectivity deviations (37)	[-0.59, 0.57]	[0.142, 0.225]
log trawl-survey s2 selectivity deviations (37)	[-0.37, 0.59]	[0.133, 0.224]
log trawl-survey s3 selectivity deviations (37)	[-0.33, 0.27]	[0.131, 0.302]

Table 8. Model ST ADMB primary parameter correlations. Does not include those for recruitment, fishing mortality and trawl-survey selectivity deviations.

index	parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1998/99 M	1													
2	pot-survey proportionality constant	-0.18	1												
3	geometric mean trawl-survey s1 selectivity	-0.27	0.45	1											
4	pot-survey s1 selectivity	-0.15	-0.26	0.06	1										
5	pot-survey s2 selectivity	-0.18	-0.42	-0.02	0.22	1									
6	pot-fishery s1 selectivity	-0.17	-0.10	0.02	0.17	0.22	1								
7	pot-fishery s2 selectivity	-0.07	-0.21	-0.08	0.13	0.19	0.59	1							
8	log initial s1 abundance	-0.01	0.21	0.20	-0.03	-0.06	-0.04	-0.06	1						
9	log initial s2 abundance	-0.02	0.32	0.40	-0.05	-0.09	-0.09	-0.13	0.07	1					
10	log initial s3 abundance	0.00	0.39	0.45	-0.08	-0.13	-0.16	-0.20	0.20	0.22	1				
11	mean log pot-fishery F	-0.05	-0.32	-0.53	0.02	0.05	-0.11	-0.08	-0.33	-0.44	-0.57	1			
12	mean log recruit abundance	0.37	-0.74	-0.63	-0.05	0.08	0.04	0.21	-0.29	-0.39	-0.44	0.36	1		
13	mean log groundfish trawl-gear F	-0.06	0.33	0.20	-0.03	-0.07	-0.04	-0.09	0.09	0.14	0.17	-0.14	-0.33	1	
14	mean log groundfish fixed-gear F	-0.06	0.34	0.21	-0.03	-0.07	-0.04	-0.09	0.09	0.14	0.17	-0.14	-0.34	0.15	1

Table 9. Contribution of negative loglikelihood and penalty components to minimized value of the objective function under model configuration ST. Relative contributions include weights.

Negative Loglikelihood Component	Weight	Contribution (%)
retained catch number	1,000	0.00
trawl-survey biomass	1	0.56
pot-survey CPUE	1	1.39
trawl-survey stage composition	1	47.98
pot-survey stage composition	1	15.95
directed pot-fishery stage composition	1	31.94
groundfish trawl mortality biomass	1	0.42
groundfish fixed-gear mortality biomass	1	0.46
log recruit deviations	1.25	0.33
log directed pot fishery fishing mortality deviations	0.001	0.00
log groundfish trawl fishing mortality deviations	1	0.33
log groundfish fixed-gear fishing mortality deviations	1	0.41
log trawl-survey selectivity deviation first differences	64	0.24

Table 10. Partitioning of the OFL. Catches are in millions of pounds, with metric ton equivalents in parentheses.

			OFL				
			directed fishery		groundfish bycatch mortality		
year	tier	F_{OFL} (yr^{-1})	retained	discard mortality	trawl	fixed gear	total male
2011/12	4a	0.18	3.36 (1,520)	0.296 (134)	0.001 (0.5)	0.009 (4)	3.74 (1,700)
2012/13	4a	0.18	2.14 (971)	0.095 (43)	0.0002 (0.1)	0.0009 (0.4)	2.24 (1,020)
2013/14	4b	0.18	1.20 (544)	0.044 (20)	0.0002 (0.09)	0.0007 (0.3)	1.24 (562)
2014/15[a]	4b	0.14	0.79 (360)	0.031 (14)	0.0002 (0.1)	0.0005 (0.2)	0.820 (370)

[a] From Fall 2014 model configuration ST.

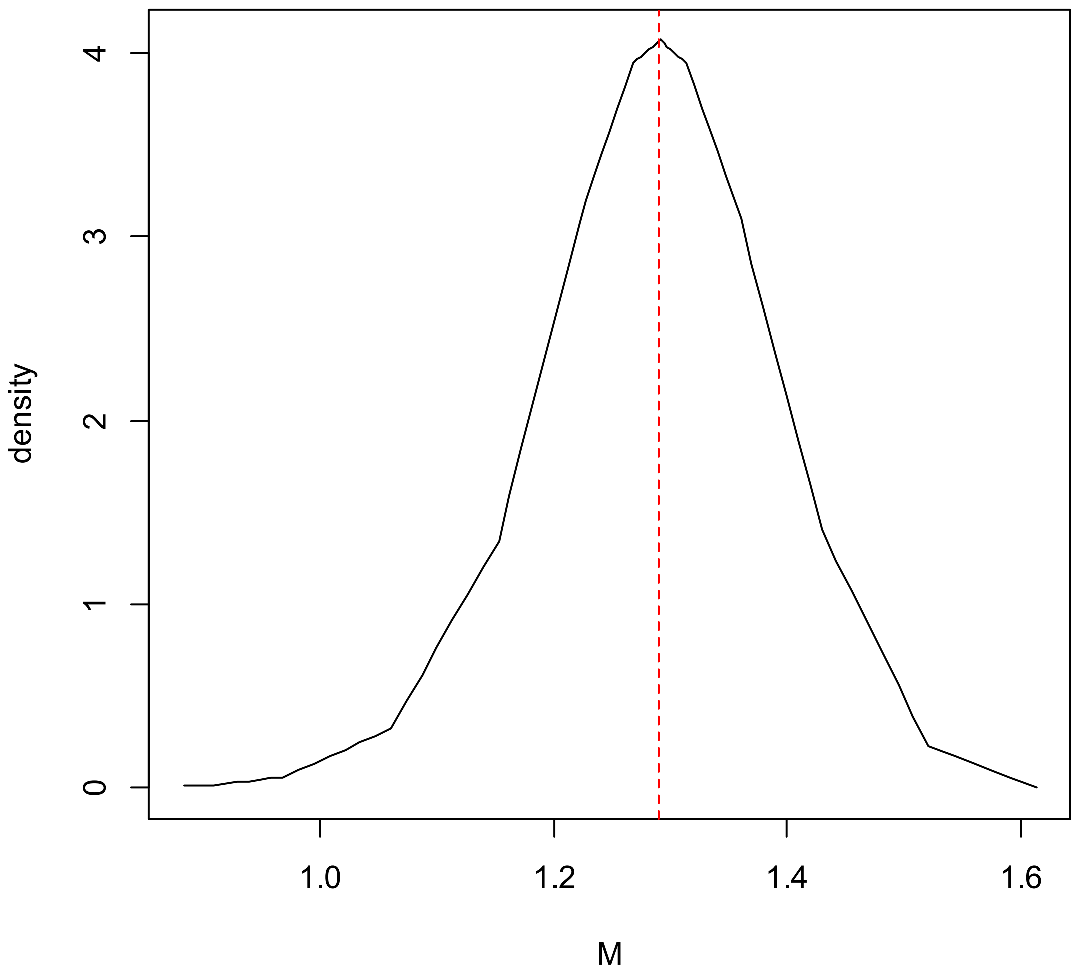

Figure 1. Base-model ADMB profile likelihood for estimated natural mortality parameter M with 2014 dataset. M = 0.18 yr^{-1} is assumed for assessment.

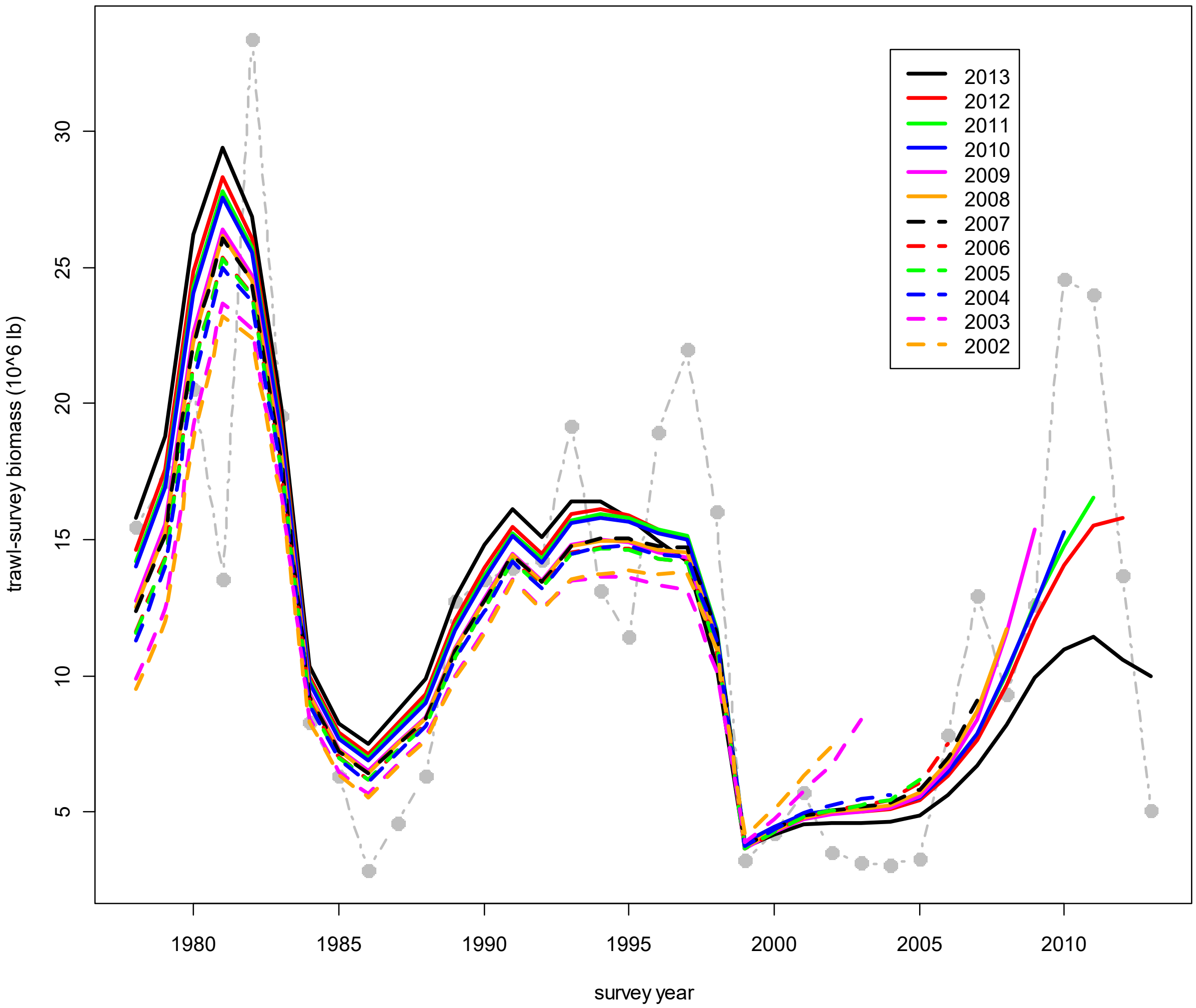

Figure 2. Retrospective plot of trawl-survey model-male (90mm+ CL) biomass for 2013 base-model configuration and terminal years 2002 – 2013. Estimates are based on all available data up to and including terminal-year trawl and pot surveys. Grey dotted line and points represent trawl-survey area-swept estimates. (From 2013 SAFE.)

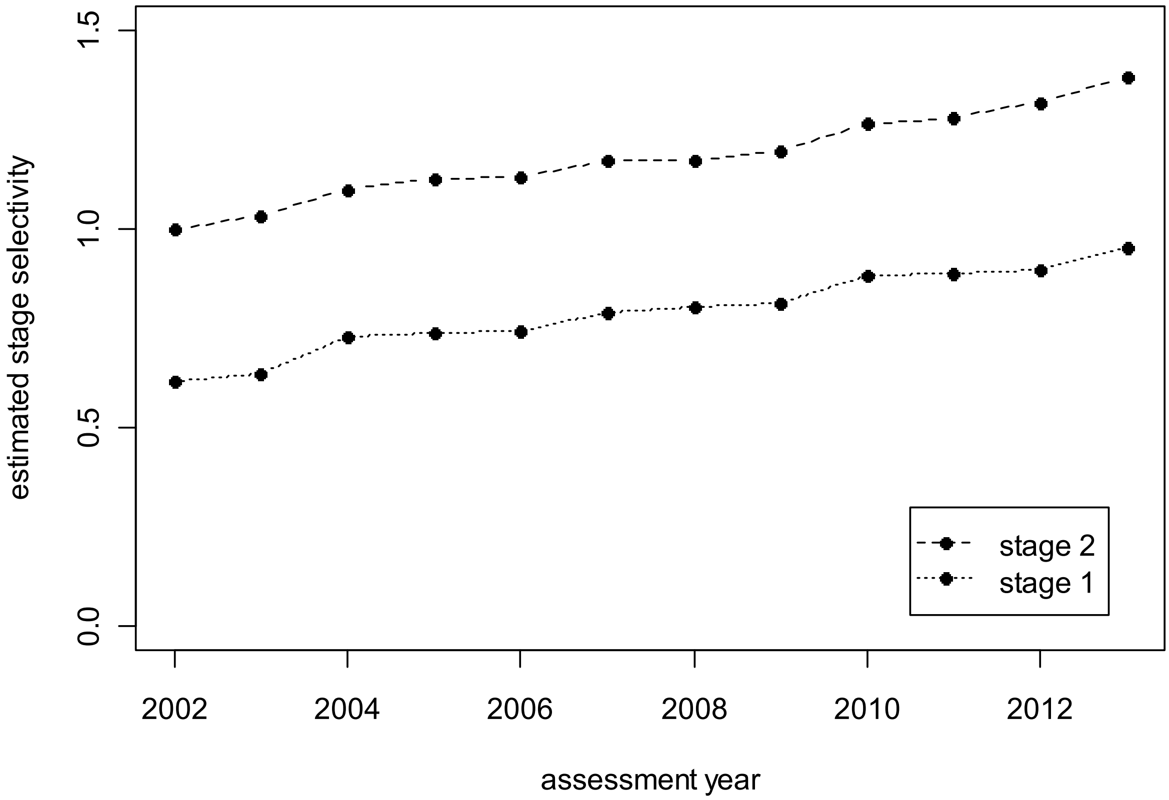

Figure 3. Base-model retrospective estimates of stage-1 and stage-2 trawl-survey selectivity for terminal years 2002/02-2013/14. Estimates are based on all available data up to and including terminal-year trawl and pot surveys.

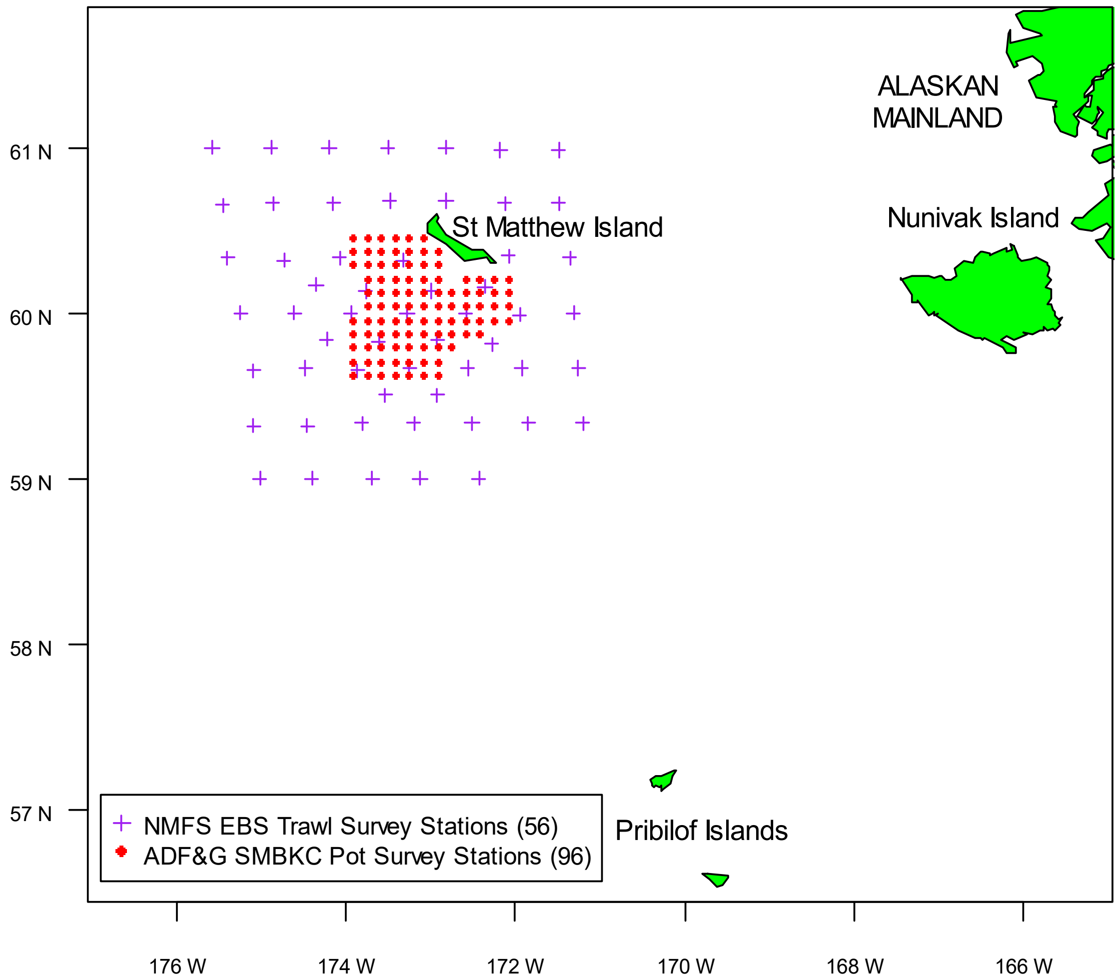

Figure 4. Trawl and pot-survey stations used in the SMBKC stock assessment.

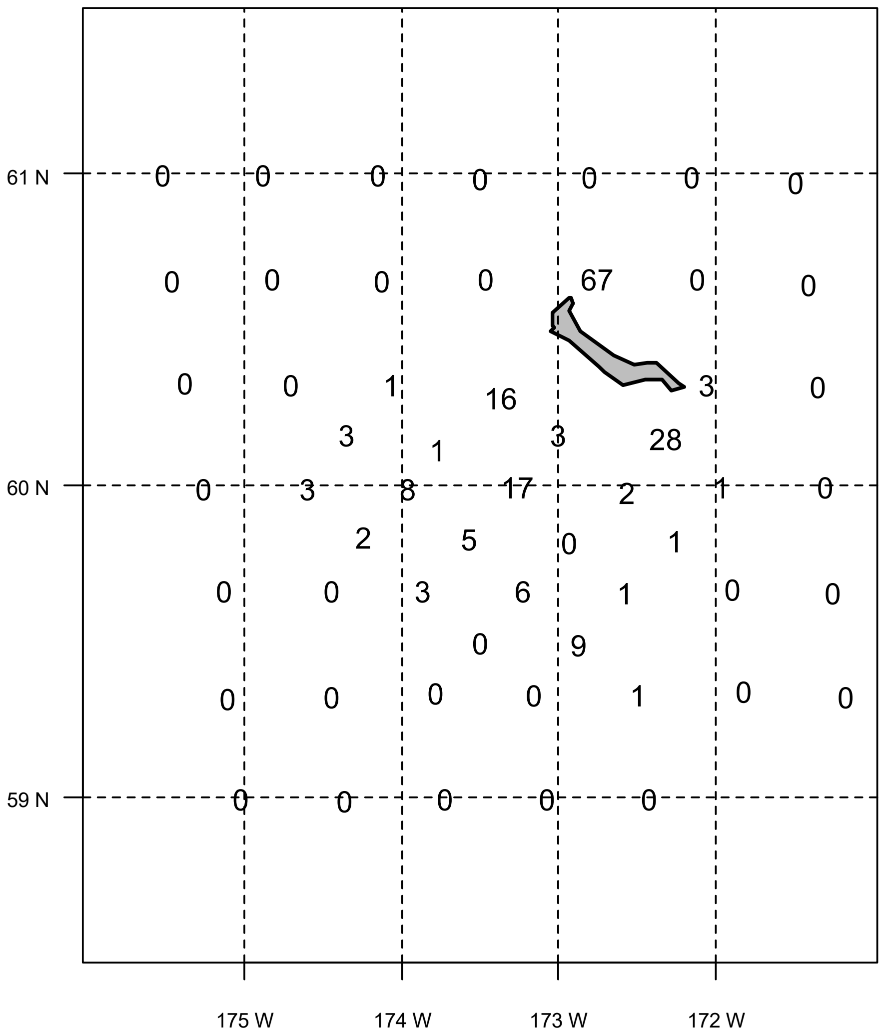

Figure 5. Catches of 181 male blue king crab measuring at least 90 mm CL from the 2014 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock. Note that the area north of St. Matthew Island, which includes the large catch of 67 crab at station R-24, is not represented in the ADF&G pot-survey data used in the assessment (cf. Figure 3).

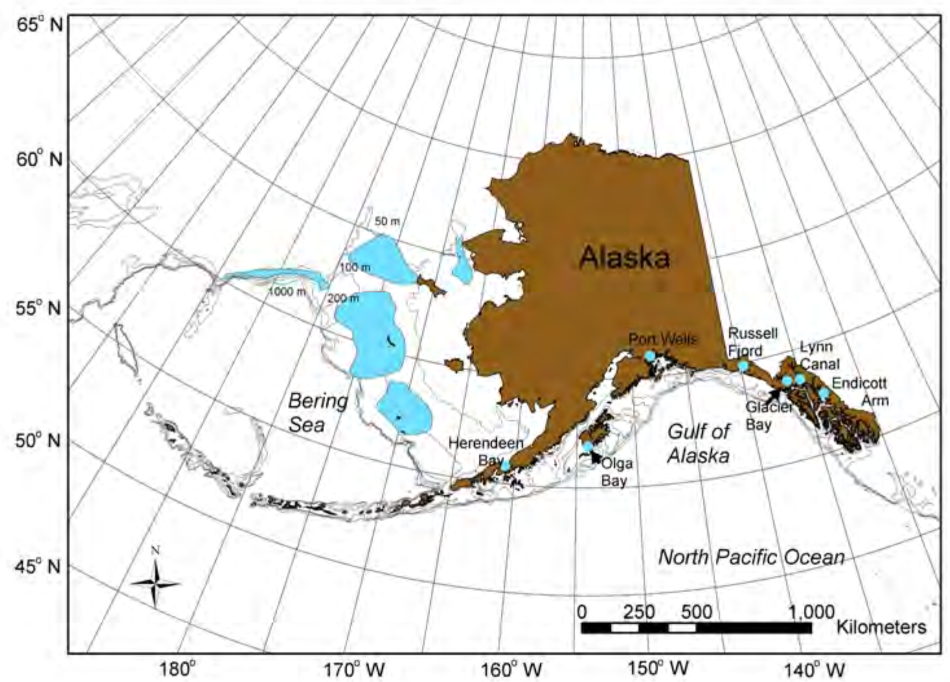

Figure 6. Distribution of blue king crab *Paralithodes platypus* in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters. Shown in blue.

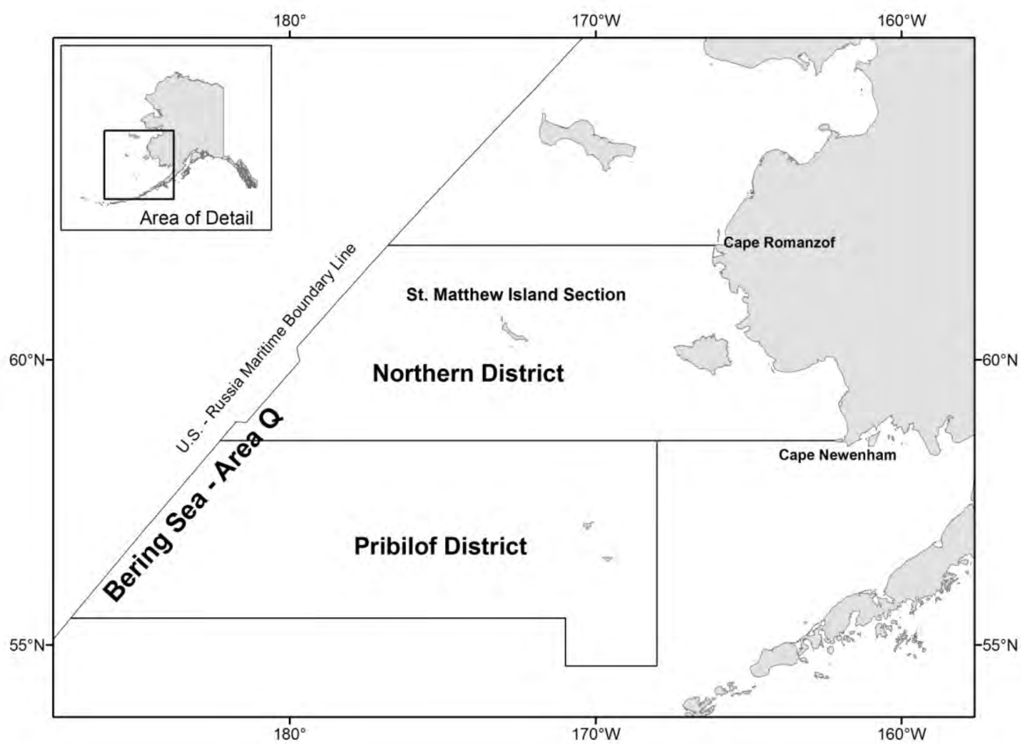

Figure 7. King crab Registration Area Q (Bering Sea).

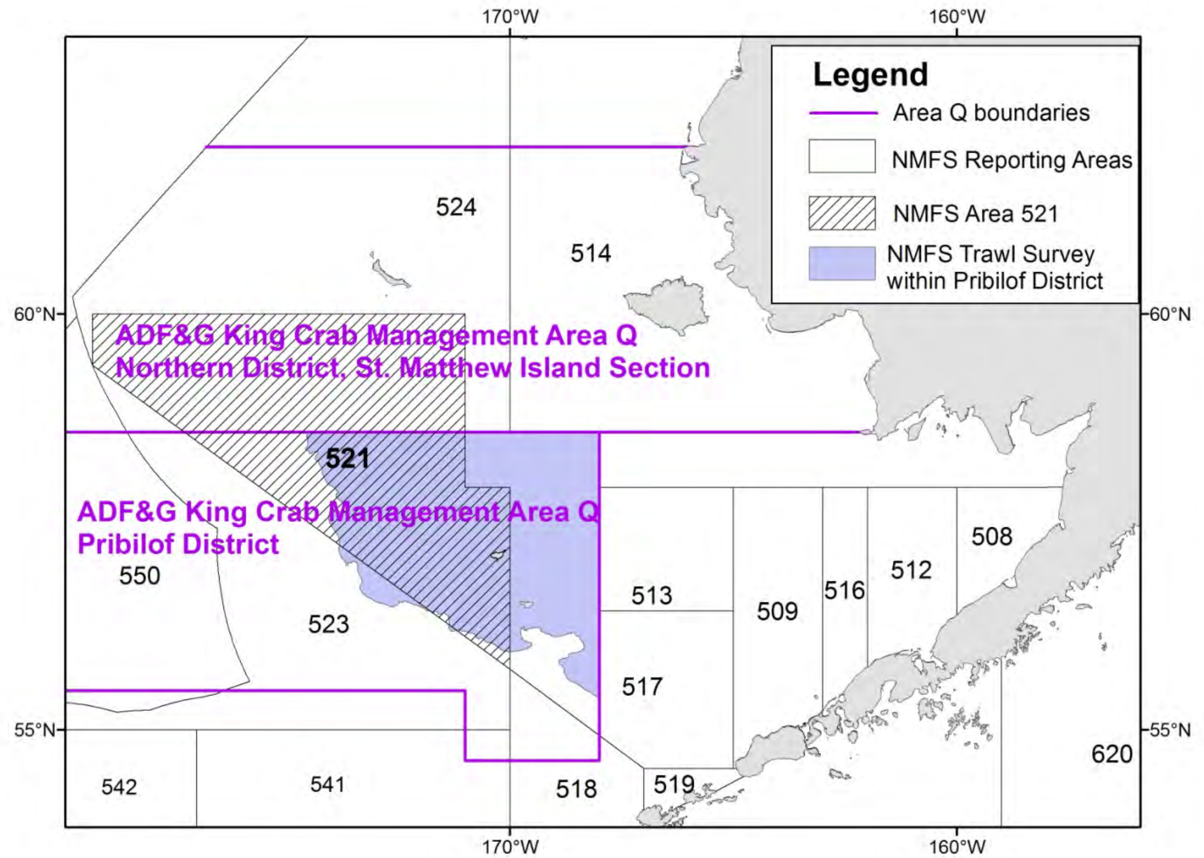

Figure 8. NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521.

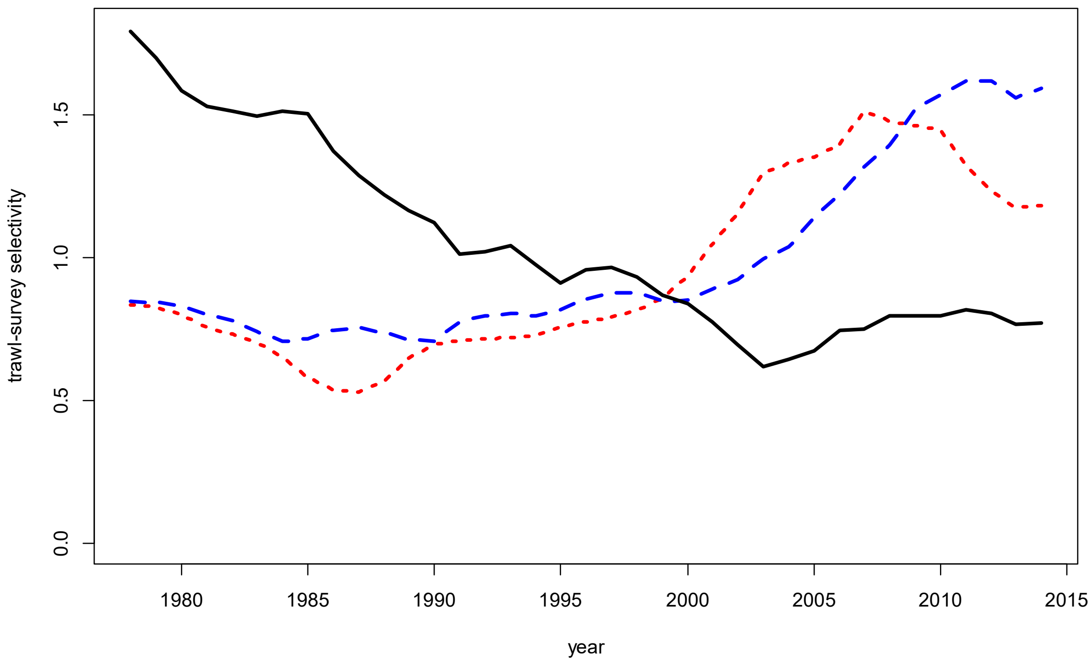

Figure 9a. Model S stage-1(dotted red curve), stage-2 (dashed blue curve) and stage-3 (solid black curve) trawl-survey selectivities. Geometric means are respectively 0.89, 0.95 = (0.89 + 1)/2 and 1 (Q).

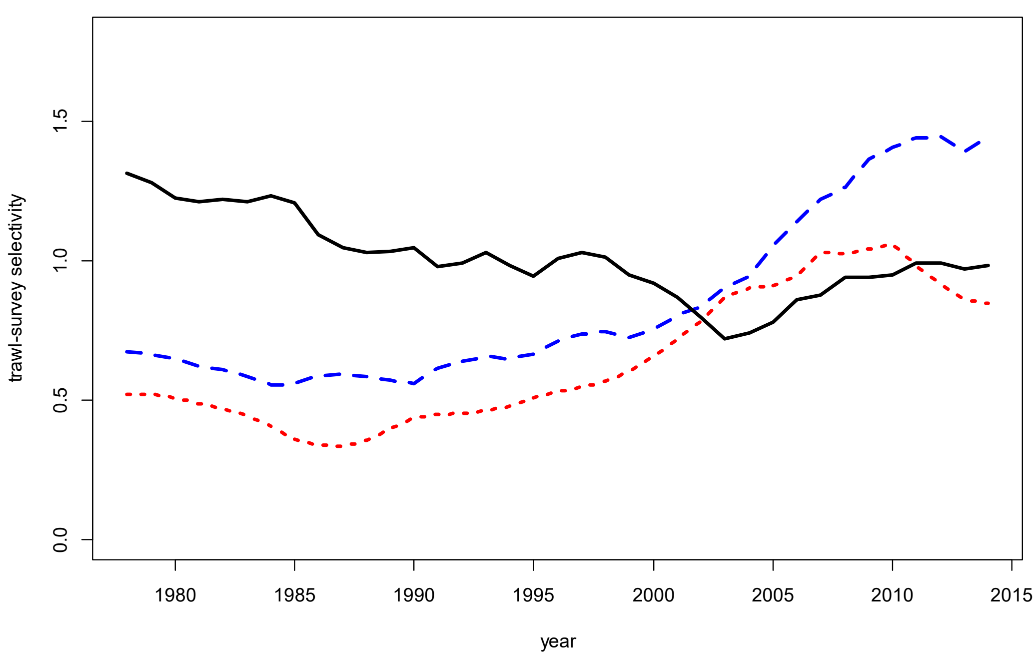

Figure 9b. Model ST stage-1(dotted red curve), stage-2 (dashed blue curve) and stage-3 (solid black curve) trawl-survey selectivities. Geometric means are respectively 0.60, 0.80 = (0.60 + 1)/2 and 1 (Q).

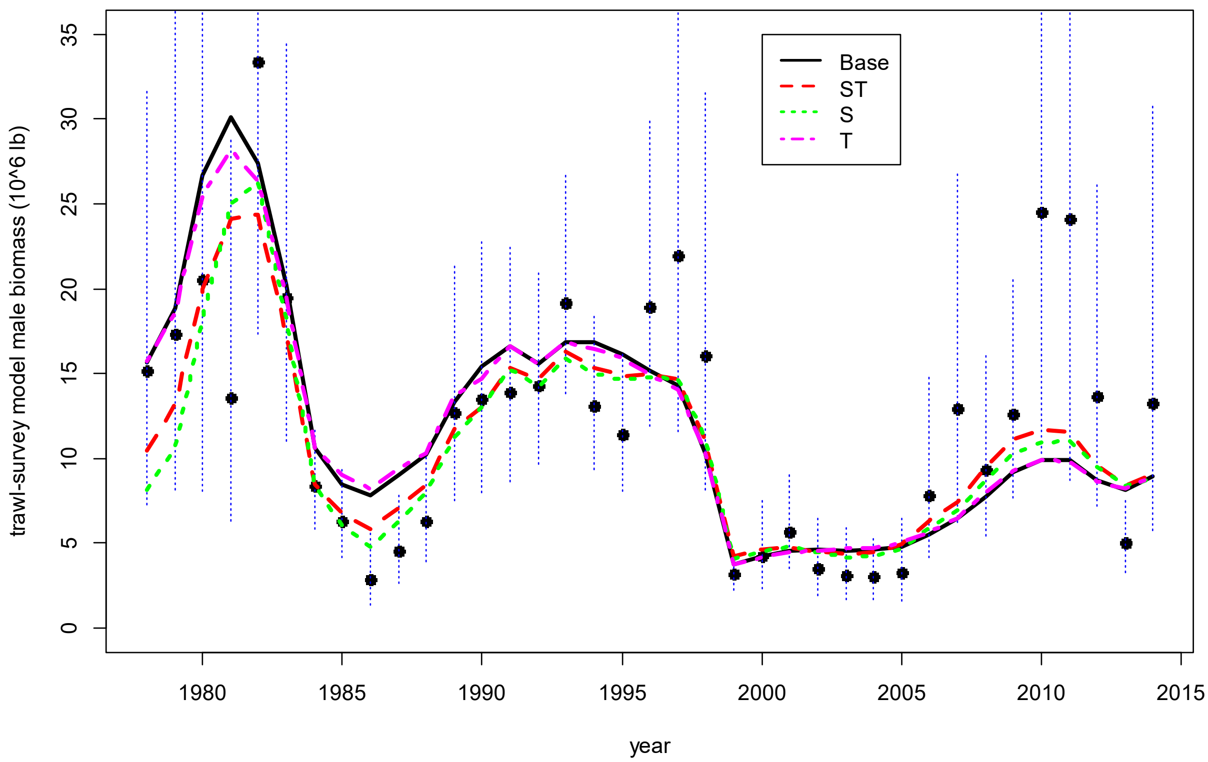

Figure 10. Plots of base and alternative model estimated trawl-survey model male (90+ mm CL) biomass with area-swept estimates (points).

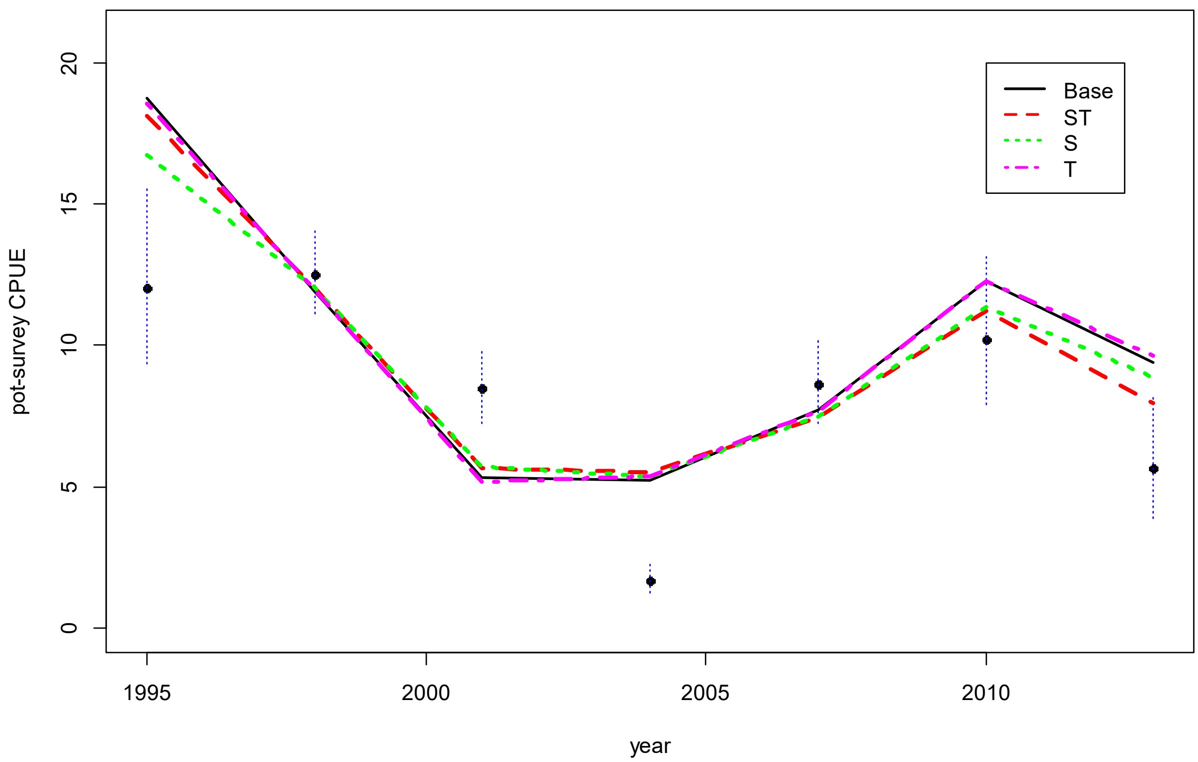

Figure 11. Plots of base and alternative model estimated pot-survey model male (90+ mm CL) CPUE.

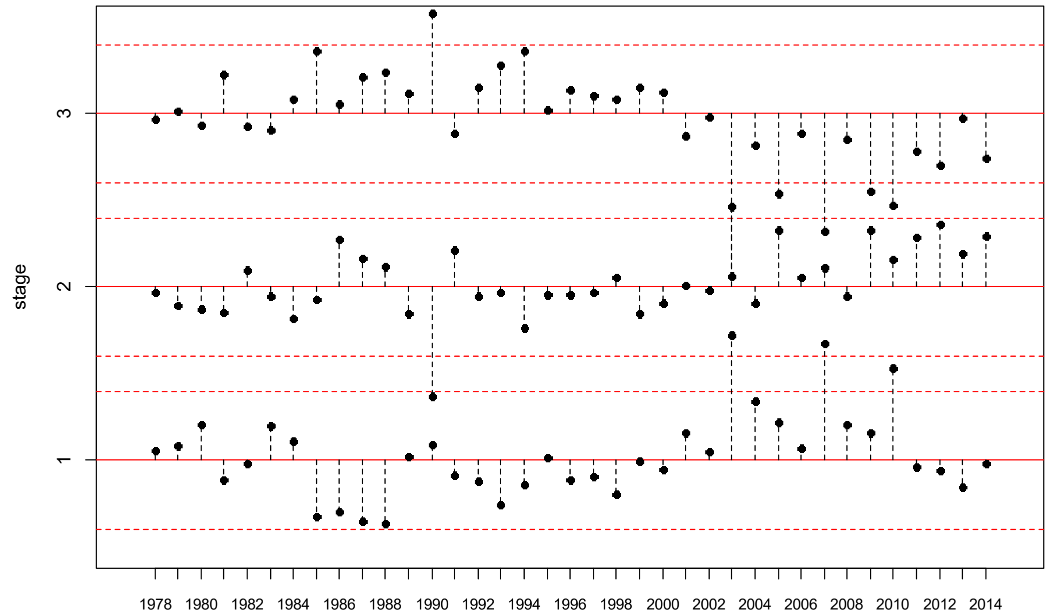

Figure 12a. Base-model fits to trawl-survey composition data.

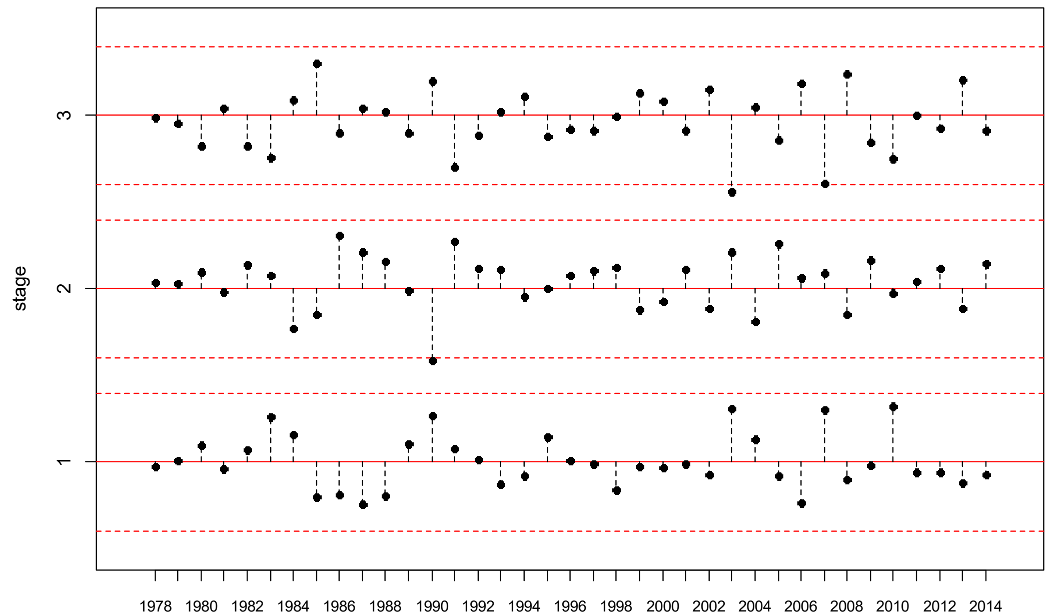

Figure 12b. Model ST fits to trawl-survey composition data.

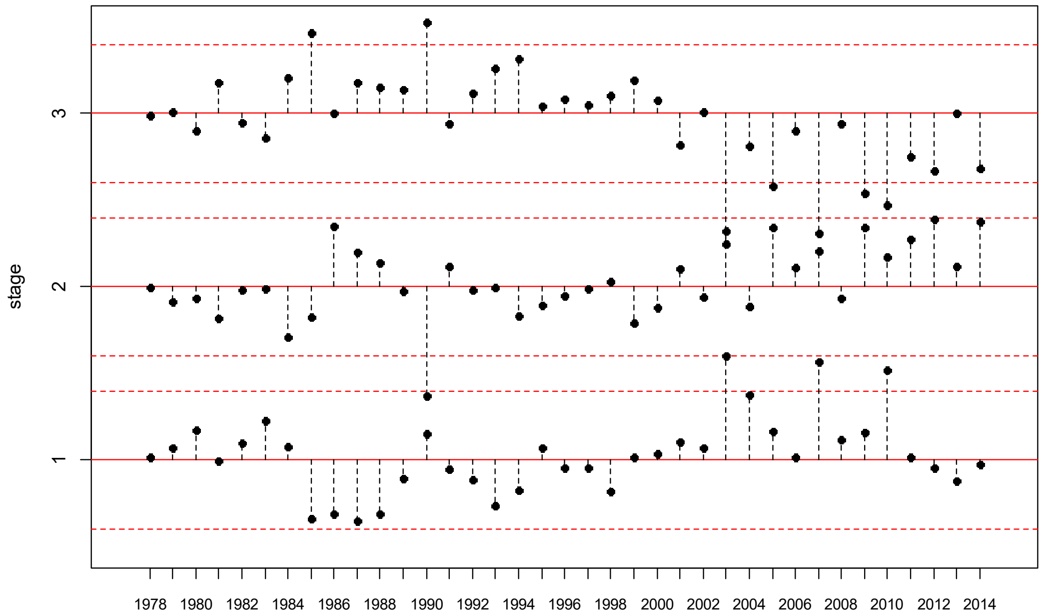

Figure 12c. Model T fits to trawl-survey composition data.

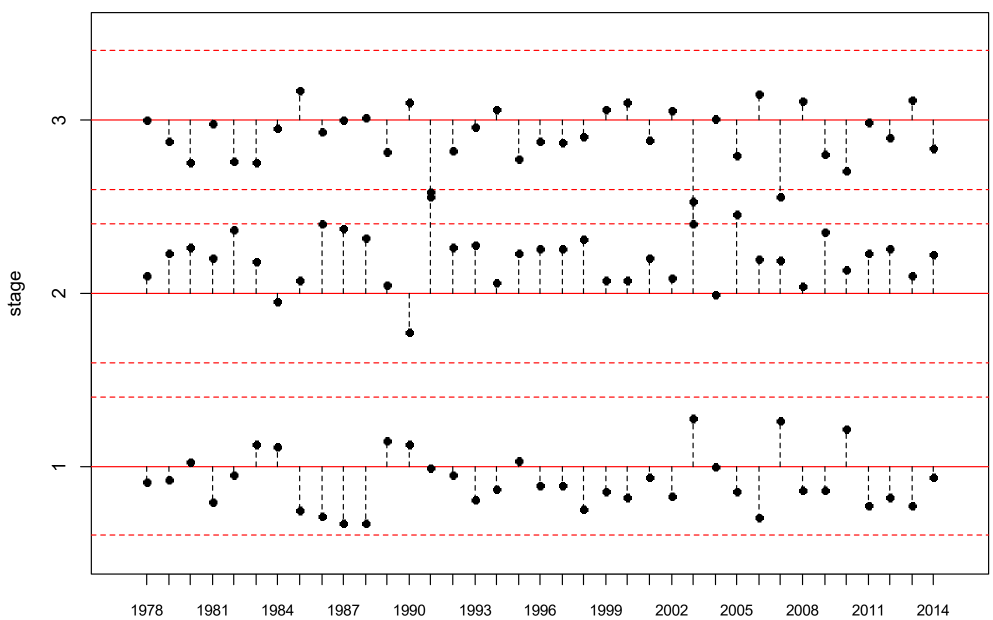

Figure 12d. Model S fits to trawl-survey composition data.

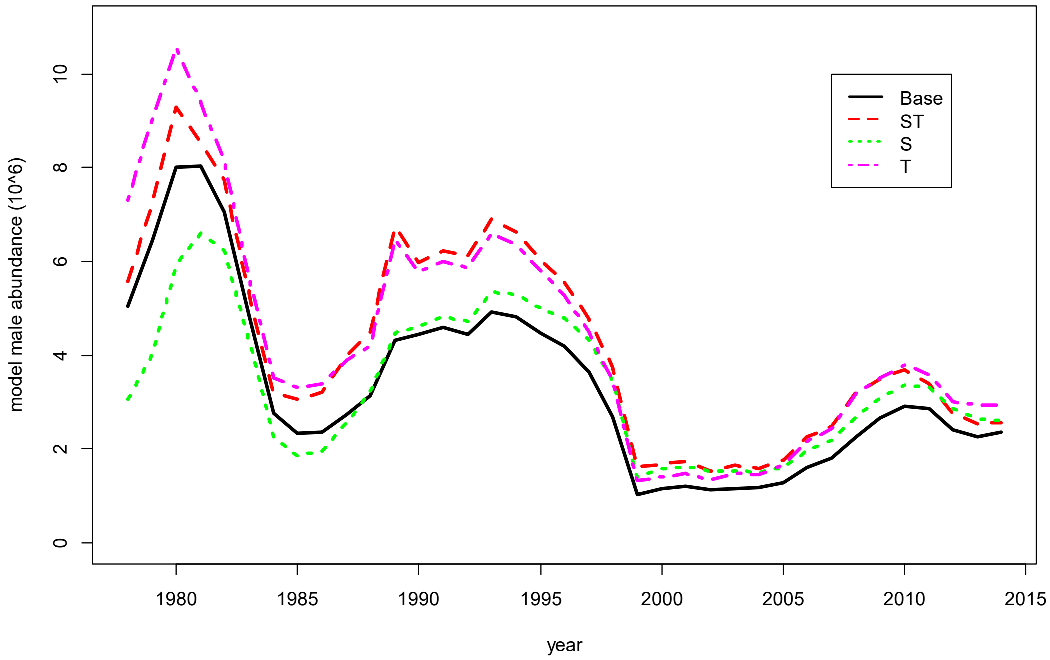

Figure 13. Plots of base and alternative model estimated model male (90+ mm CL) abundance.

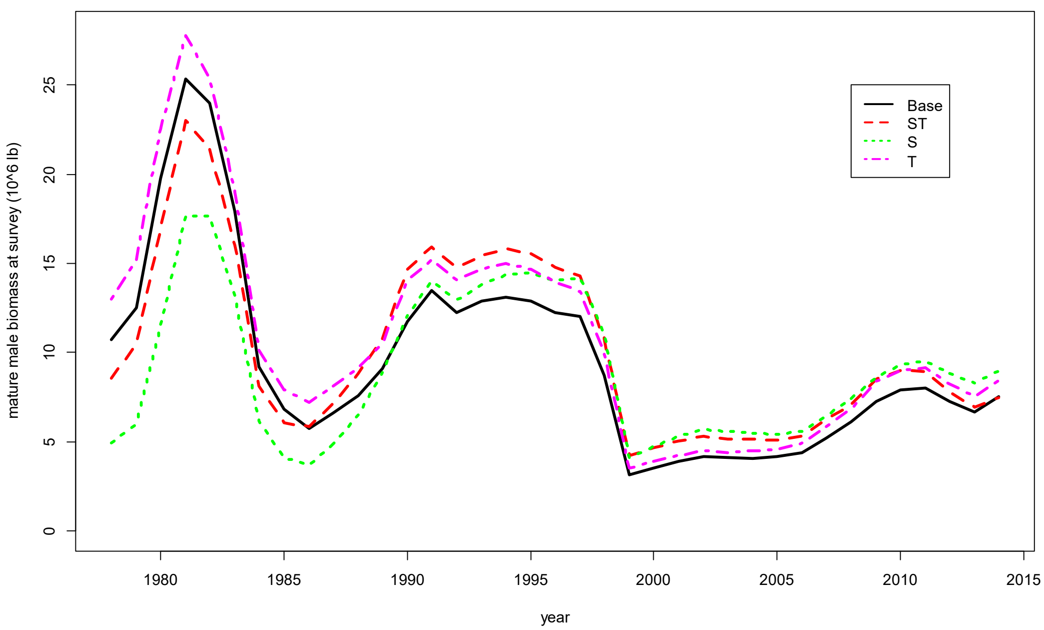

Figure 14. Plots of base and alternative model estimated mature-male biomass at time of survey.

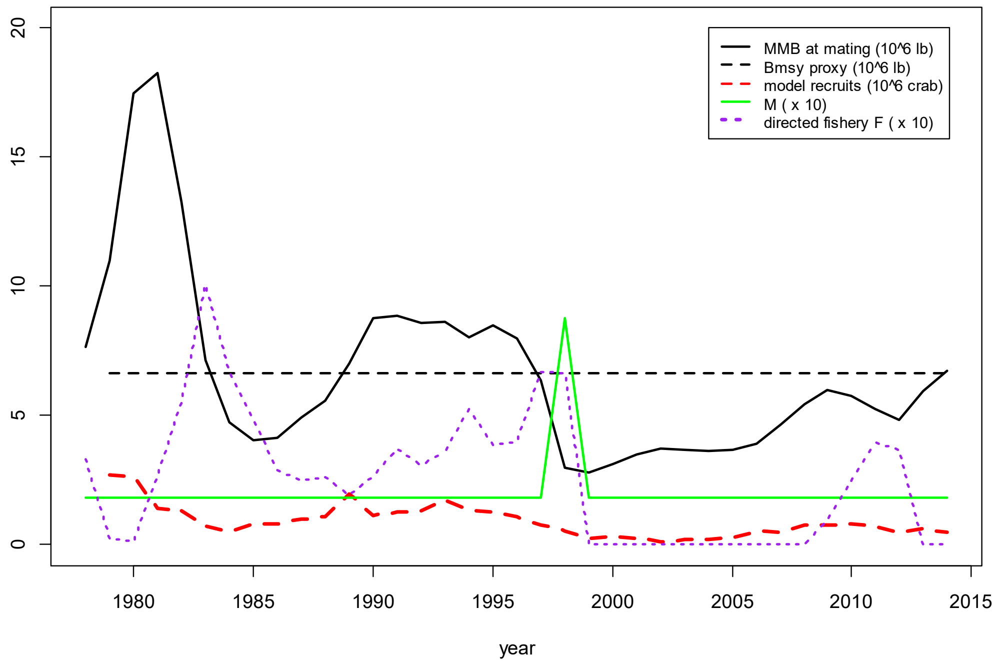

Figure 15a. Base-model estimates of important SMBKC management quantities.

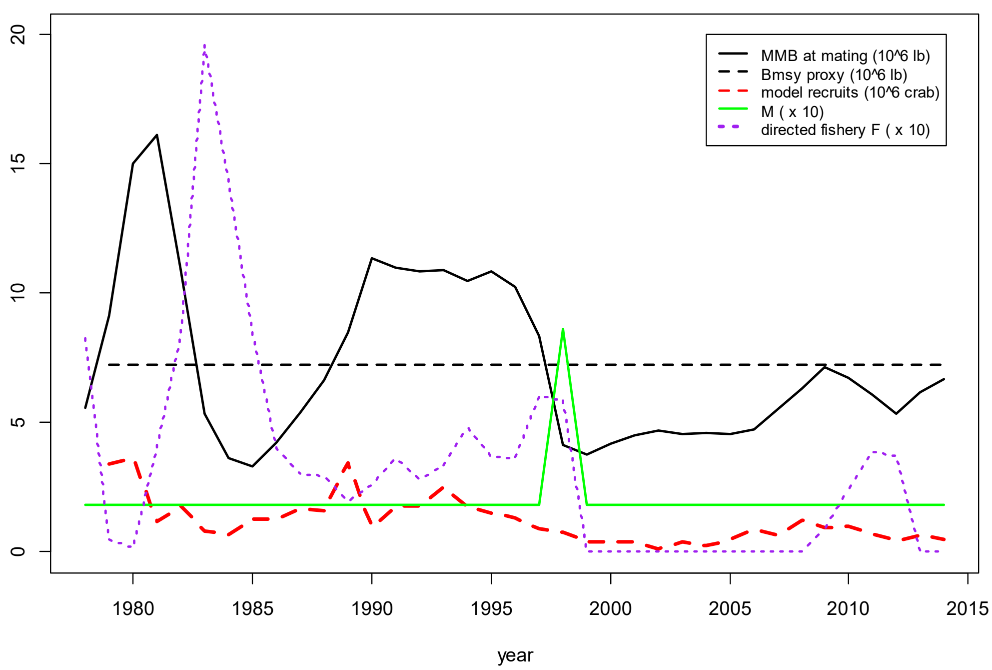

Figure 15b. Model ST estimates of important SMBKC management quantities.

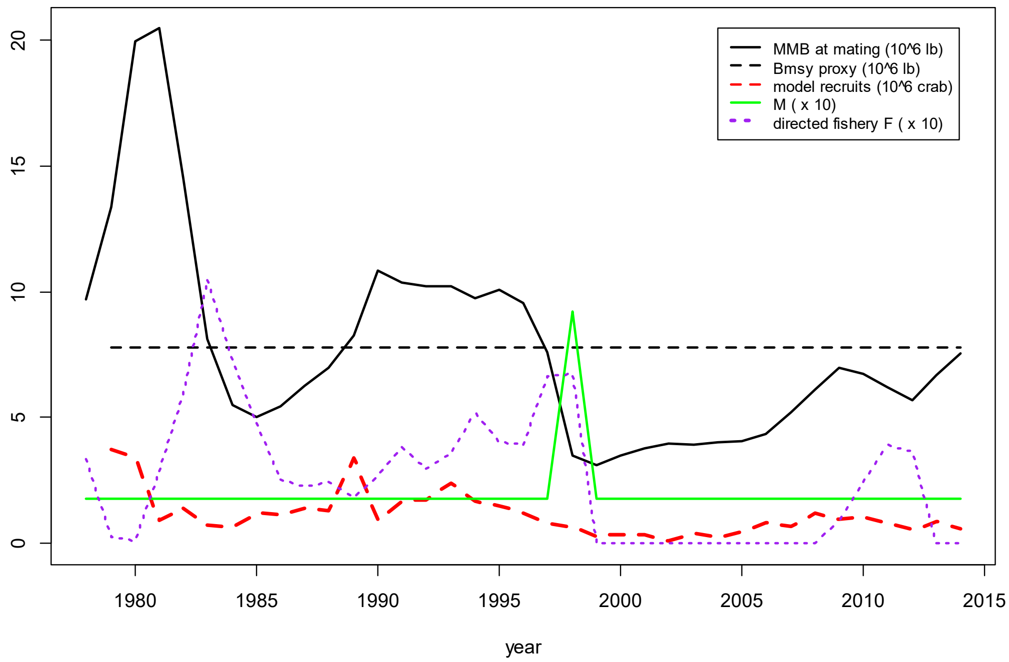

Figure 15c. Model T estimates of important SMBKC management quantities.

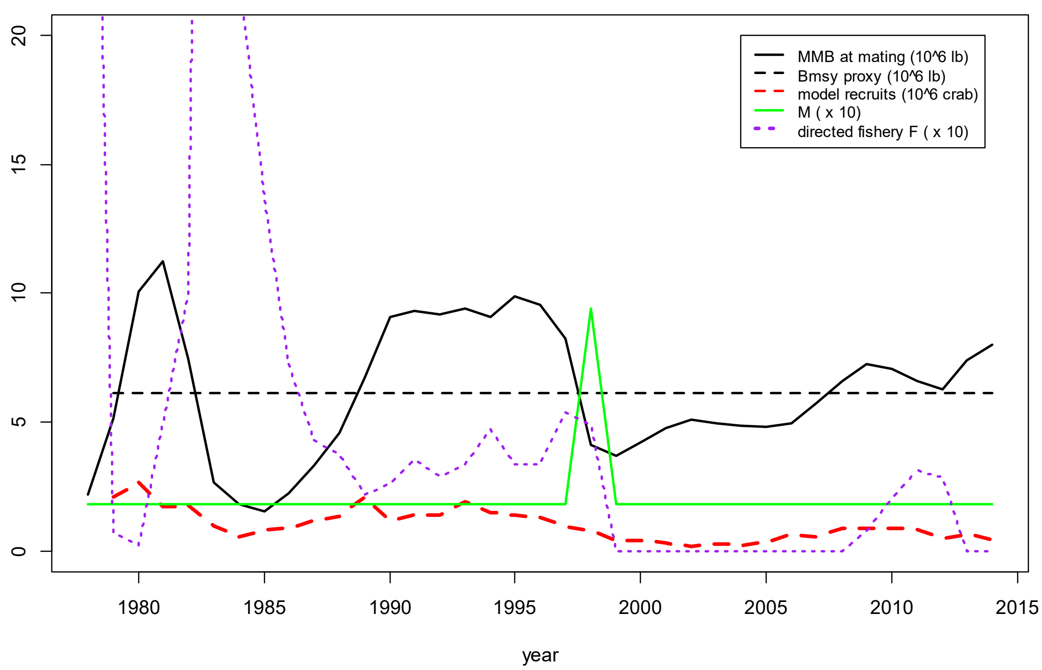

Figure 15d. Model S estimates of important SMBKC management quantities.

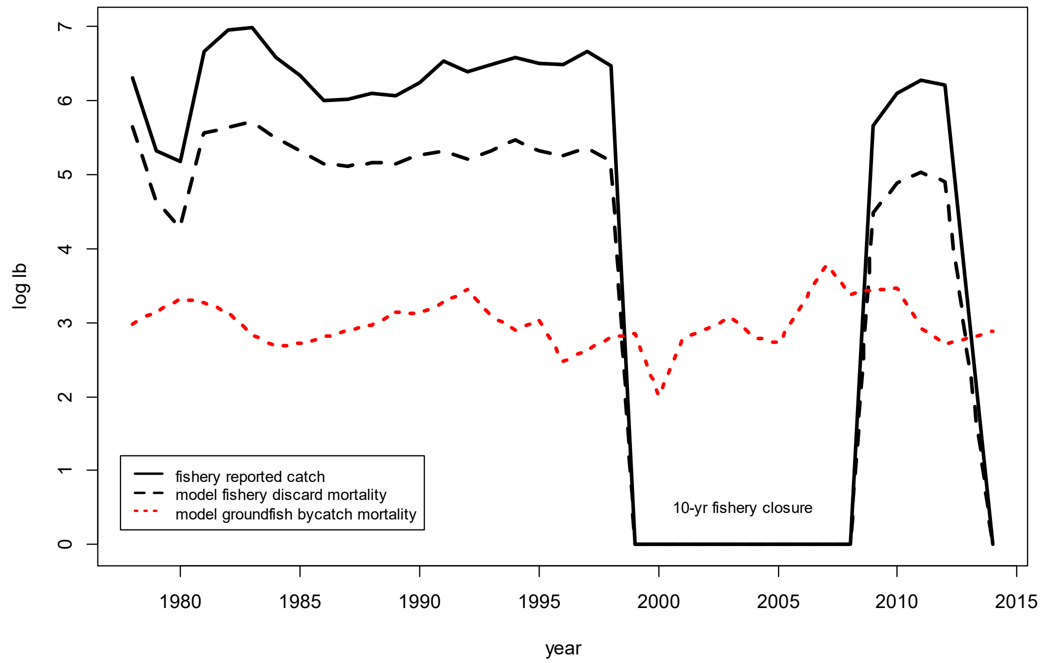

Figure 16. Model ST SMBKC fishing mortality.

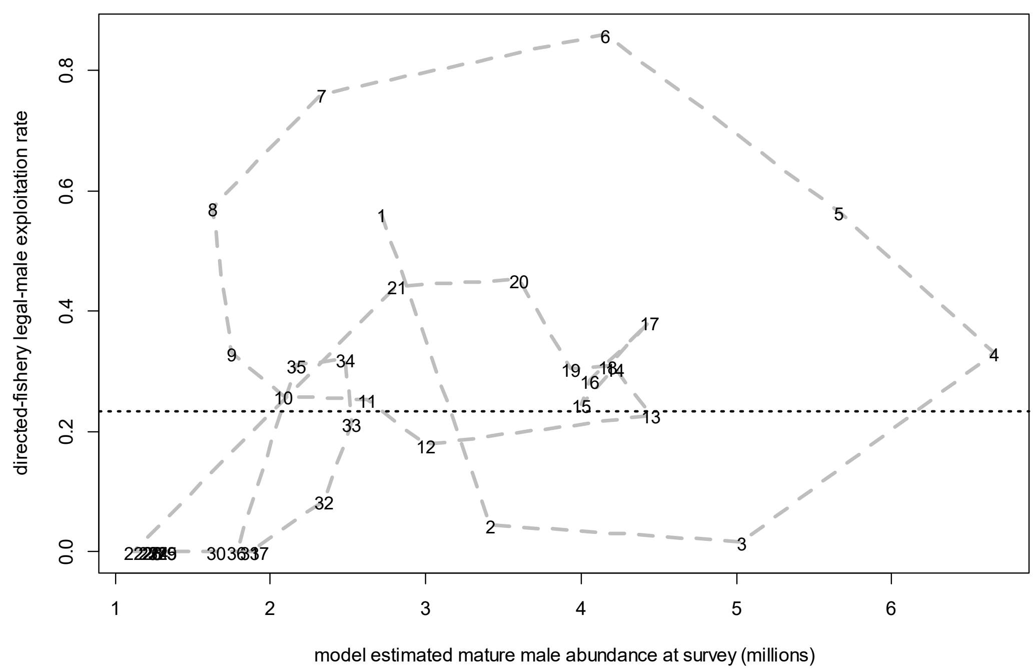

Figure 17. Model ST SMBKC exploitation rate versus mature male abundance.

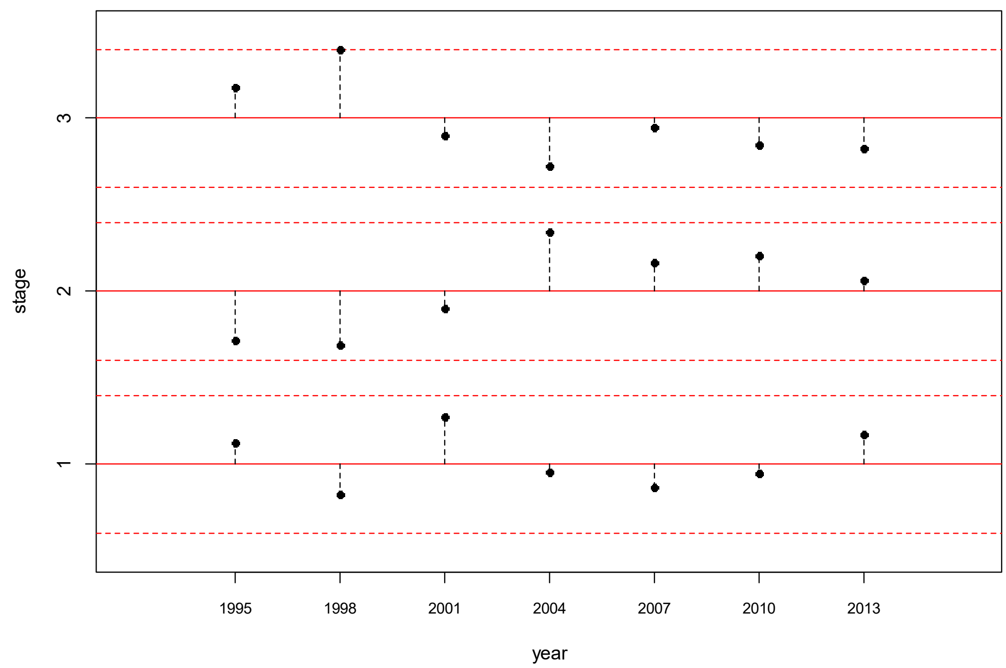

Figure 18. Model ST fits to SMBKC triennial pot-survey composition data.

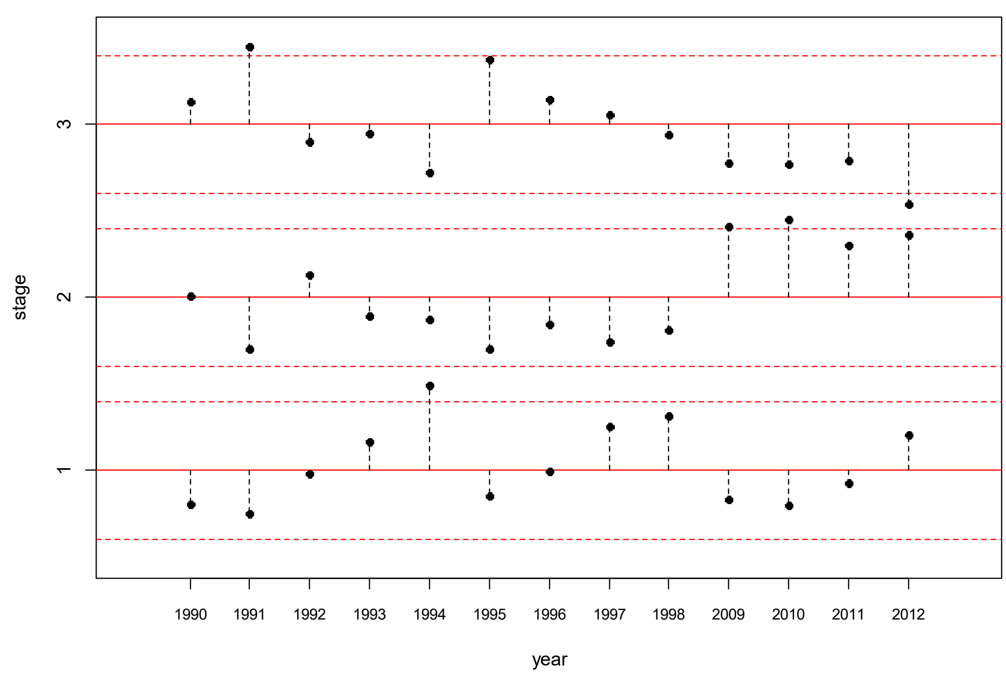

Figure 19. Model ST fits to SMBKC pot-fishery observer composition data.

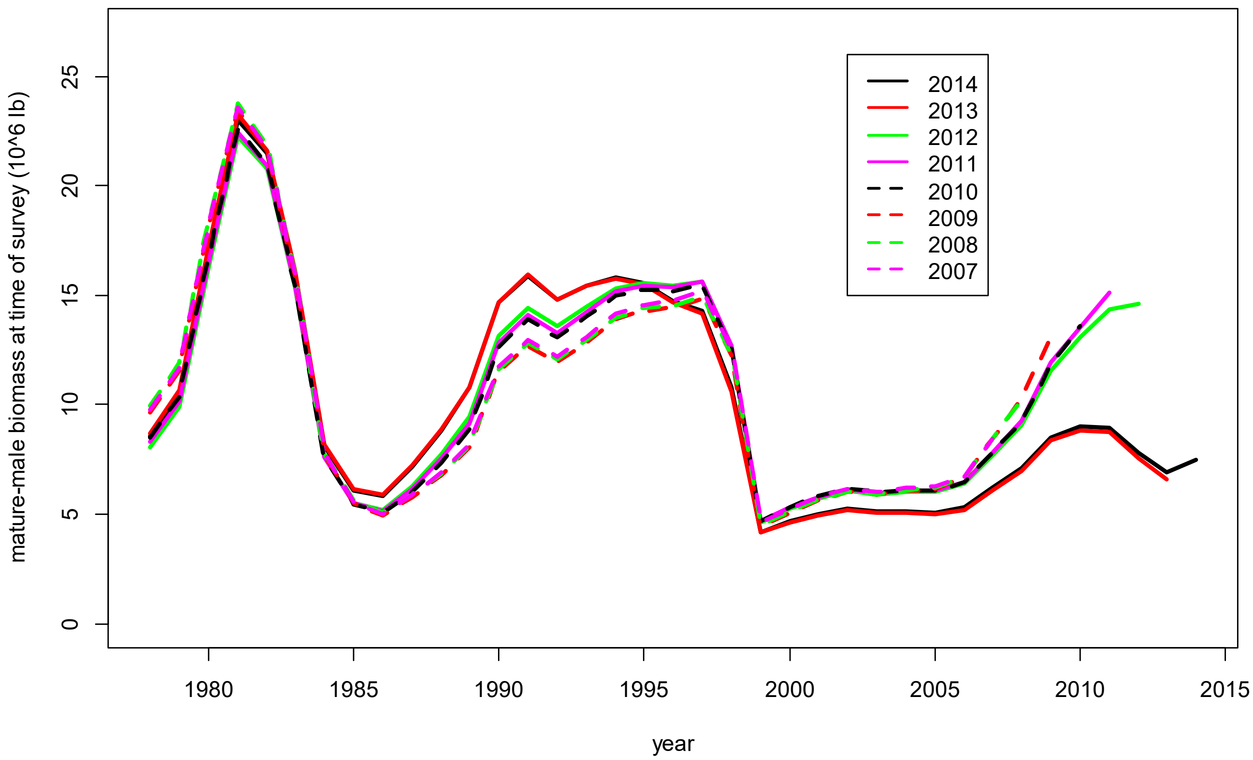

Figure 20. Retrospective plot of model-estimated mature male biomass at time of survey for 2014 model configuration ST and terminal years 2007-2014. Estimates are based on all available data up to and including terminal-year trawl and pot surveys.

Appendix A: SMBKC Base Model Description

1. Introduction

The model accounts only for male crab at least 90 mm in carapace length (CL). These are partitioned into three stages (male size classes) determined by CL measurements of (1) 90-104 mm, (2) 105-119 mm, and (3) 120 mm+. For management of the St. Matthew Island blue king crab (SMBKC) fishery, 120 mm CL is used as the proxy value for the legal measurement of 5.5 in carapace width (CW), whereas 105mm CL is the management proxy for mature-male size (5 AAC 34.917 (d)). Accordingly, within the model only stage-3 crab are retained in the directed fishery, and stage-2 and stage-3 crab together comprise the collection of mature males. Some justification for the 105 mm value is presented in Pengilly and Schmidt (1995), who used it in developing the current regulatory SMBKC harvest strategy. The term “recruit” here designates recruits to the model, i.e. annual new stage-1 crab, rather than recruits to the fishery. The following description of model structure reflects the base-model configuration.

2. Model Population Dynamics

Within the model framework, the beginning of the crab year is assumed contemporaneous with the NMFS trawl survey, nominally assigned a date of July 1. With boldface letters indicating vector quantities, let $\boldsymbol{N}_t = [\, N_{1,t}, N_{2,t}, N_{3,t}\,]^T$ designate the vector of stage abundances at the start of year t. Then the basic population dynamics underlying model construction are described by the linear equation

$$\boldsymbol{N}_{t+1} = \boldsymbol{G}e^{-M_t}\boldsymbol{N}_t + \boldsymbol{N}^{new}{}_{t+1}, \qquad \text{[A1]}$$

where the scalar factor e^{-M_t} accounts for the effect of year-t natural mortality M_t and the hypothesized transition matrix $\boldsymbol{G}$ has the simple structure

$$\boldsymbol{G} = \begin{bmatrix} 1-\pi_{12} & \pi_{12} & 0 \\ 0 & 1-\pi_{23} & \pi_{23} \\ 0 & 0 & 1 \end{bmatrix}, \qquad \text{[A2]}$$

with π_{jk} equal to the proportion of stage-j crab that molt and grow into stage k from any one year to the next. The vector $\boldsymbol{N}^{new}{}_{t+1} = [\, N^{new}{}_{1,t+1},\, 0\,,0\,]^T$ registers the number $N^{new}{}_{1,\,t+1}$ of new crab, or “recruits,” entering the model at the start of year $t + 1$, all of which are assumed to go into stage 1. Aside from natural mortality and molting and growth, only the directed fishery and some limited bycatch mortality in the groundfish fisheries are assumed to affect the stock. (In the event of nontrivial bycatch mortality with another fishery, as in 2012/13, it is accounted for in the model in the estimate of groundfish bycatch mortality.) The directed fishery is modeled as a mid-season pulse occurring at time τ_t with full-selection fishing mortality F_t^{df} relative to stage-3 crab. Year-t directed-fishery removals from the stock are computed as

$$\boldsymbol{R}_t^{df} = \boldsymbol{H}^{df}\boldsymbol{S}^{df}(1-e^{-F_t^{df}})e^{-\tau_t M}\boldsymbol{N}_t, \qquad \text{[A3]}$$

where the diagonal matrices $\boldsymbol{S}^{df} = \begin{bmatrix} s_1^{df} & 0 & 0 \\ 0 & s_2^{df} & 0 \\ 0 & 0 & 1 \end{bmatrix}$ and $\boldsymbol{H}^{df} = \begin{bmatrix} h^{df} & 0 & 0 \\ 0 & h^{df} & 0 \\ 0 & 0 & 1 \end{bmatrix}$ account for stage selectivities s_1^{df} and s_2^{df} and discard handling mortality h^{df} in the directed fishery, both assumed constant over time. Yearly stage removals resulting from bycatch mortality in the groundfish trawl and fixed-gear fisheries are calculated as Feb 15 (0.63 yr) pulse effects in terms of the respective fishing mortalities F_t^{gt} and F_t^{gf} by

$$\boldsymbol{R}_t^{gt} = \frac{F_t^{gt}}{F_t^{gt}+F_t^{gf}} e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})(1-e^{-(F^{gt}+F^{gf})})h^{gt} \quad \text{[A4]}$$

$$\boldsymbol{R}_t^{gf} = \frac{F_t^{gf}}{F_t^{gt}+F_t^{gf}} e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})(1-e^{-(F^{gt}+F^{gf})})h^{gf}. \quad \text{[A5]}$$

These last two computations assume that the groundfish fisheries affect all stages proportionally, i.e. that all stage selectivities equal one, and that handling mortalities h^{gt} and h^{gf} are constant across both stages and years. The author believes that the available composition data from these fisheries are of such dubious quality as to preclude meaningful use in estimation. Moreover, evidently with the exception of 2007/08, which in the author's view is suspiciously anomalous, the impact of these fisheries on the stock has typically been small. These considerations suggest that more elaborate efforts to model that impact are unwarranted. Model population dynamics are thus completely determined by the equation

$$\boldsymbol{N}_{t+1} = \boldsymbol{G}e^{-0.37M_t}(e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df}) - (\boldsymbol{R}_t^{gt} + \boldsymbol{R}_t^{gf})) + \boldsymbol{N}^{new}{}_{t+1}, \quad \text{[A6]}$$

for $t \geq 1$ and initial stage abundances $\boldsymbol{N}_1$.

Necessary biomass computations, such as required for management purposes or for integration of groundfish bycatch biomass data into the model, are based on application of the SMBKC length-to-weight relationship of Chilton and Foy (2010) to the stage-1 and stage-2 CL interval midpoints and use fishery reported average retained weights for stage-3 ("legal") crab. In years with no fishery, including the current assessment year, the time average value over years with a fishery is used. The author believes this approach to be an appropriate simplification given the data limitations associated with the stock.

3. Model Data

Data inputs used in model estimation are listed in Table 1. All quantities relate to male SMBKC ≥ 90mm CL.

Table 1. Data inputs used in model estimation.

Data Quantity	Years	Source
Directed pot-fishery retained-catch number	1978/79-1998/99 2009/10-2012/13	Fish tickets (fishery closed 1999/00-2008/09)
NMFS trawl-survey biomass index (area-swept estimate) and CV	1978-2014	NMFS EBS trawl survey
ADFG pot-survey abundance index (CPUE) and CV	Triennial 1995-2013	ADF&G SMBKC pot survey
NMFS trawl-survey stage proportions and total number of measured crab	1978-2014	NMFS EBS trawl survey
ADFG pot-survey stage proportions and total number of measured crab	Triennial 1995-2013	ADF&G SMBKC pot survey
Directed pot-fishery stage proportions and total number of measured crab	1990/91-1998/99 2009/10-2012/13	ADF&G crab observer program (fishery closed 1999/00-2008/09)
Groundfish trawl bycatch biomass	1992/93-2013/14	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93-2013/14	NMFS groundfish observer program

Model-predicted retained-catch number C_t is calculated assuming catch consists precisely of those stage-three crab captured in the directed fishery so that

$$C_t = e^{-\tau_t M_t} N_{3,t}(1 - e^{-F^{df}}), \quad \text{[A7]}$$

which is just the third component of [3]. In fact, in the actual pot fishery a small number of captured stage-3 males are discarded, whereas some captured stage-2 males are legally retained, but data from onboard observers and dockside samplers suggest that [7] here provides a serviceable approximation (ADF&G Crab Observer Database). Model analogs of trawl-survey biomass and pot-survey abundance indices are given by

$$B_t^{ts} = Q^{ts}(s_1^{ts} N_{1,t} w_1 + s_2^{ts} N_{2,t} w_2 + N_{3,t} w_{3,t}) \quad \text{[A8]}$$

$$A_t^{ps} = Q^{ps}(s_1^{ps} N_{1,t} + s_2^{ps} N_{2,t} + N_{3,t}), \quad \text{[A9]}$$

these being year-*t* trawl-survey area-swept biomass and year-*t* pot-survey CPUE, respectively, both with respect to 90 mm+ CL males. In these expressions, Q^{ts} and Q^{ps} denote model proportionality constants, assumed independent of year and with $Q^{ts} = 1.0$ under all scenarios considered for this assessment, and s_j^{ts} and s_j^{ps} denote corresponding stage-*j* survey selectivities, also assumed independent of year. Model trawl-survey, pot-survey, and directed-fishery stage proportions $\boldsymbol{P}_t^{ts}$, $\boldsymbol{P}_t^{ps}$, and $\boldsymbol{P}_t^{df}$ are then determined by

$$\boldsymbol{P}_t^{ts} = \frac{Q^{ts}}{A_t^{ts}} \begin{bmatrix} s_1^{ts} & 0 & 0 \\ 0 & s_2^{ts} & 0 \\ 0 & 0 & 1 \end{bmatrix} \boldsymbol{N}_t \quad \text{[A10]}$$

$$\boldsymbol{P}_t^{ps} = \frac{Q^{ps}}{A_t^{ps}} \begin{bmatrix} s_1^{ps} & 0 & 0 \\ 0 & s_2^{ps} & 0 \\ 0 & 0 & 1 \end{bmatrix} \boldsymbol{N}_t \quad \text{[A11]}$$

$$\boldsymbol{P}_t^{df} = \frac{1}{\langle (\boldsymbol{H}^{df})^{-1} \boldsymbol{R}_t^{df},\ \boldsymbol{1} \rangle} (\boldsymbol{H}^{df})^{-1} \boldsymbol{R}_t^{df}. \quad \text{[A12]}$$

Letting $\boldsymbol{w}_t = [w_1, w_2, w_{3,t}]^T$ be an estimate of stage mean weights in year *t* as described above, model predicted groundfish bycatch mortality biomasses in the trawl and fixed-gear fisheries are given by

$$B_t^{gt} = \boldsymbol{w}_t{}^T \boldsymbol{R}_t^{gt} \text{ and } B_t^{gf} = \boldsymbol{w}_t{}^T \boldsymbol{R}_t^{gf}. \quad \text{[A13]}$$

Recall that stage-1 and stage-2 mean weights do not depend on year, being based on the length-to-weight relationship of Chilton and Foy (2010), whereas stage-3 mean weight is set equal to year-*t* fishery reported average retained weight or its time average for years with no fishery.

4. Model Parameters

Base-model estimated parameters are listed in Table 2 and include an estimated parameter for natural mortality in 1998/99 on the assumption of an anomalous mortality event in that year, as hypothesized by Zheng and Kruse (2002), with natural mortality otherwise fixed at 0.18 yr^{-1}. In any year with no directed fishery, and hence zero retained catch, F_t^{df} is set to zero rather than model estimated. Similarly, for years in which no groundfish bycatch data are available, F_t^{gf} and

F_t^{gt} are imputed to be the geometric means of the estimates from years for which there are data. Table 3 lists additional externally determined parameters used in model computations.

Both surveys are assigned a nominal date of July 1, the start of the crab year. The directed fishery is treated as a season midpoint pulse. Groundfish bycatch is likewise modeled as a pulse effect, occurring at the nominal time of mating, Feb 15, which is also the reference date for calculation of federal management biomass quantities.

Table 2. Base-model estimated parameters.

Parameter	Number
Log initial stage abundances	3
1998/99 natural mortality	1
Pot-survey “catchability”	1
Stage 1 and 2 Trawl-survey selectivities	2
Stage 1 and 2 Pot-survey selectivities	2
Stage 1 and 2 Directed-fishery selectivities	2
Mean log recruit abundance	1
Log recruit abundance deviations	36[a]
Mean log directed-fishery mortality	1
Log directed-fishery mortality deviations	25[a]
Mean log groundfish trawl fishery mortality	1
Log groundfish trawl fishery mortality deviations	23[a]
Mean log groundfish fixed-gear fishery mortality	1
Log groundfish fixed-gear fishery mortality deviations	23[a]
Total	122

[a] Subject to zero-sum constraint.

Table 3. Base-model fixed parameters.

Parameter	Value	Source/Rationale
Trawl-survey "catchability", i.e. abundance-index proportionality constant	1.0	Default
Natural mortality (except 1998/99)	0.18 yr^{-1}	NPFMC (2007)
Stage 1 and 2 transition probabilities	1.0, 1.0	Default
Stage-1 and 2 mean weights	1.65, 2.57 lb	Chilton and Foy (2010) length-weight equation applied to stage size-interval midpoints.
Stage-3 mean weight	depends on year	Fishery-reported average retained weight from fish tickets, or its average.
Directed-fishery handling mortality	0.20	2010 Crab SAFE
Groundfish trawl handling mortality	0.80	2010 Crab SAFE
Groundfish fixed-gear handling mortality	0.50	2010 Crab SAFE

5. Model Objective Function and Weighting Scheme

The objective function consists of a sum of eight "negative loglikelihood" terms characterizing the hypothesized error structure of the principal data inputs with respect to their true, i.e. model-predicted, values and four "penalty" terms associated with year-to-year variation in model recruit abundance and fishing mortality in the directed fishery and groundfish trawl and fixed-gear fisheries. See Table 4, where upper and lower case letters designate model-predicted and data-computed quantities, respectively, and boldface letters again indicate vector quantities. Sample sizes n_t (observed number of male SMBKC $\geq$ 90mm CL) and estimated coefficients of variation $\widehat{cv}_t$ were used to develop appropriate variances for stage-proportion and abundance-index components. The weights λ_j appearing in the objective function component expressions in Table 4 play the role of "tuning" parameters in the modeling procedure.

Table 4. Loglikelihood and penalty components of base-model objective function. The λ_k are weights, described in text; the $neff_t$ are effective sample sizes, also described in text. All summations are with respect to years over each data series.

Component		Form
Legal retained-catch number	Lognormal	$-\lambda_1 0.5\sum[\log(c_t+0.001)-\log(C_t+0.001)]^2$
Trawl-survey biomass index	Lognormal	$-\lambda_2 0.5\sum[\frac{\ln(b_t^{ts})-\ln(B_t^{ts})}{\ln(1+\widehat{cv_t^{ts}}^2)}]^2$
Pot-survey abundance index	Lognormal	$-\lambda_3 0.5\sum[\frac{\ln(a_t^{ps})-\ln(A_t^{ps})}{\ln(1+\widehat{cv_t^{ps}}^2)}]^2$
Trawl-survey stage proportions	Multinomial	$\lambda_4\sum neff_t^{ts}(\boldsymbol{p}_t^{ts})^T\ln(\boldsymbol{P}_t^{ts}+0.01)$
Pot-survey stage proportions	Multinomial	$\lambda_5\sum neff_t^{ps}(\boldsymbol{p}_t^{ps})^T\ln(\boldsymbol{P}_t^{ps}+0.01)$
Directed-fishery stage proportions	Multinomial	$\lambda_6\sum neff_t^{df}(\boldsymbol{p}_t^{df})^T\ln(\boldsymbol{P}_t^{df}+0.01)$

Groundfish trawl mortality biomass	Lognormal	$-\lambda_7 \sum [\ln(b_t^{gt}) - \ln(B_t^{gt})]^2$
Groundfish fixed-gear mortality biomass	Lognormal	$-\lambda_8 \sum [\ln(b_t^{gf}) - \ln(B_t^{gf})]^2$
$\ln(N_{1,t}^{new})$ deviations	Quadratic/Normal	$\lambda_9 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{df})$ deviations	Quadratic/Normal	$\lambda_{10} 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{gft})$ deviations	Quadratic/Normal	$\lambda_{11} 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{gff})$ deviations	Quadratic/Normal	$\lambda_{12} 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$

Determination of the weighting scheme involved a great deal of trial and error with respect to graphical and other diagnostic tools; however, the author's basic strategy was to begin with a baseline weighting scheme that was either unity or otherwise defensible in terms of plausible variances and then proceed in the spirit of Francis (2011). The CPT noted in May 2012 that survey weights should generally not exceed unity, and the author has complied with that advice for this assessment.

Table 5 shows the weighting scheme used for the base-model scenario. The weight of 1,000 applied to the lognormal fishery catch-number component (λ_1) corresponds to a coefficient of variation of approximately 3% for the fishery estimate of catch number. The weights λ_2 and λ_3 on the lognormal trawl-survey and pot-survey abundance components are set at 1.0, allowing the yearly conventional survey-based CV estimates to govern the terms contributed by these two series. The default 1.0 weights on the lognormal groundfish bycatch mortality biomass components (λ_7 and λ_8) correspond to implied CVs of about 130%, which this author judges probably appropriate given the nature of the data. The weight of 1.25 applied to the quadratic/normal recruit-deviation penalty (λ_9) is approximately the inverse of the sample variance of trawl-survey time-series estimates of 90-104 mm male crab ("recruit") abundance. With λ_4, λ_5, and λ_6 equal to 1.0, the factors denoted by $neff_t$ appearing in the multinomial loglikelihood expressions of the objective function represent effective sample sizes describing observed survey and fishery stage-proportion error structure with respect to model predicted values. Each set is determined by a single set-specific parameter N_{max} such that the effective sample size in any given year $neff_t$ is equal to the observed number of crab n_t if $n_t < N_{max}$ and otherwise equal to N_{max}. For the base-model configuration, N_{max} was assigned a value of 50 for trawl-survey composition data and 100 for both pot-survey and fishery observer composition data. Graphical displays of the standardized residuals, including normal Q-Q plots, provided some guidance in making this choice, although model fit to the composition data tends to be rather poor under all scenarios.

Table 5. Base-model objective-function weighting scheme.

Objective-Function Component	Weight λ_j
Legal retained-catch number	1000
Trawl-survey abundance index	1.0
Pot-survey abundance index	1.0
Trawl-survey stage proportions	1.0
Pot-survey stage proportions	1.0
Directed-fishery stage proportions	1.0
Groundfish trawl mortality biomass	1.0
Groundfish fixed-gear mortality biomass	1.0
Log model recruit-abundance deviations	1.25
Log directed fishing mortality deviations	0.001
Log groundfish trawl fishing mortality deviations	1.0
Log groundfish fixed-gear fishing mortality deviations	1.0

6. Estimation

The model was implemented using the software AD Model Builder (ADMB Project 2009), with parameter estimation by minimization of the model objective function using automatic differentiation. Standard errors and estimated parameter correlations provided in this document are AD Model Builder reported values assuming maximum likelihood theory asymptotics.

Norton Sound Red King Crab Stock Assessment for the fishing year 2014/15

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Executive Summary

1. Stock. Red king crab, *Paralithodes camtschaticus*, in Norton Sound, Alaska.

2. Catches. This stock supports three main fisheries: summer commercial, winter commercial, and winter subsistence fisheries. Of those, the summer commercial fishery accounts for more than 90% of total harvest. Summer commercial fishery started in 1977, and its catch quickly reached a peak in the late 1970s with retained catch of over 2.9 million pounds. Since 1982, retained catches have been below 0.5 million pounds, averaging 0.275 million pounds, including several low years in the 1990s. As the crab population rebounds, retained catches have been increasing. For past several years, retained catch is around 0.4 million pounds.

3. Stock Biomass. Estimated mature male biomass (MMB) shows an increasing trend since 1997 following the dramatic decrease in abundance from a peak in 1977 to a historic low in 1982. However, estimates of historical biomass are highly uncertain due in part to infrequent trawl surveys (every 3 to 5 years) and limited geographic coverage of the winter pot survey.

4. Recruitment. Model estimated recruitment was weak during the late 1970s, high during the early 1980s, and showed a slight decreasing trend from 1983 to 1993. Estimated recruitment has been highly variable but with an increasing trend in recent years.

5. Management performance.

Status and catch specifications (million lb)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2010/11	1.56[A]	5.44	0.40	0.42	0.46	0.73[A]	
2011/12	1.56[B]	4.70	0.36	0.40	0.43	0.66[B]	0.59
2012/13	1.78[C]	4.59	0.47	0.47	0.47	0.53[C]	0.48
2013/14	2.06[D]	5.00	0.50	0.35	0.35	0.58[D]	0.52
2014/15	2.11[E]	3.71	TBD	TBD	TBD	0.46[E]	0.42

Status and catch specifications (1000t)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2010/11	0.71[A]	2.47	0.18	0.19	0.21	0.33[A]	
2011/12	0.71[B]	2.13	0.16	0.18	0.20	0.30[B]	0.27
2012/13	0.80[C]	2.08	0.21	0.21	0.21	0.24[C]	0.22
2013/14	1.02[D]	2.16	0.23	0.16	0.16	0.26[D]	0.24
2014/15	1.04[E]	1.83	TBD	TBD	TBD	0.23[E]	0.21

Notes:
MSST was calculated as $B_{MSY}/2$
A-Calculated from the assessment reviewed by the Crab Plan Team in May 2010
B-Calculated from the assessment reviewed by the Crab Plan Team in May 2011
C-Calculated from the assessment reviewed by the Crab Plan Team in May 2012
D-Calculated from the assessment reviewed by the Crab Plan Team in May 2013
E-Calculated from the assessment reviewed by the Crab Plan Team in May 2014
Conversion to Metric ton: 1 Metric ton = 2.024 × 1000 lb

Biomass in millions of pounds

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	ABC
2010/11	4a	3.12	5.44	1.7	0.18	1983-2010	0.18		
2011/12	4a	2.97	4.70	1.6	0.18	1983-2011	0.18	0.9	0.59
2012/13	4a	3.51	4.25	1.2	0.18	1980-2012	0.18	0.9	0.48
2013/14	4a	4.12	5.00	1.2	0.18	1980-2013	0.18	0.9	0.52
2014/15	4b	4.19	3.71	0.9	0.16	1980-2014	0.18	0.9	0.42

Biomass in 1000t

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	ABC
2010/11	4a	1.42	2.47	1.7	0.18	1983-2010	0.18		
2011/12	4a	1.35	2.18	1.6	0.18	1983-2011	0.18	0.9	0.27
2012/13	4a	1.59	1.93	1.2	0.18	1980-2012	0.18	0.9	0.22
2013/14	4a	1.86	2.27	1.2	0.18	1980-2013	0.18	0.9	0.24
2014/15	4b	2.07	1.83	0.9	0.16	1980-2014	0.18	0.9	0.21

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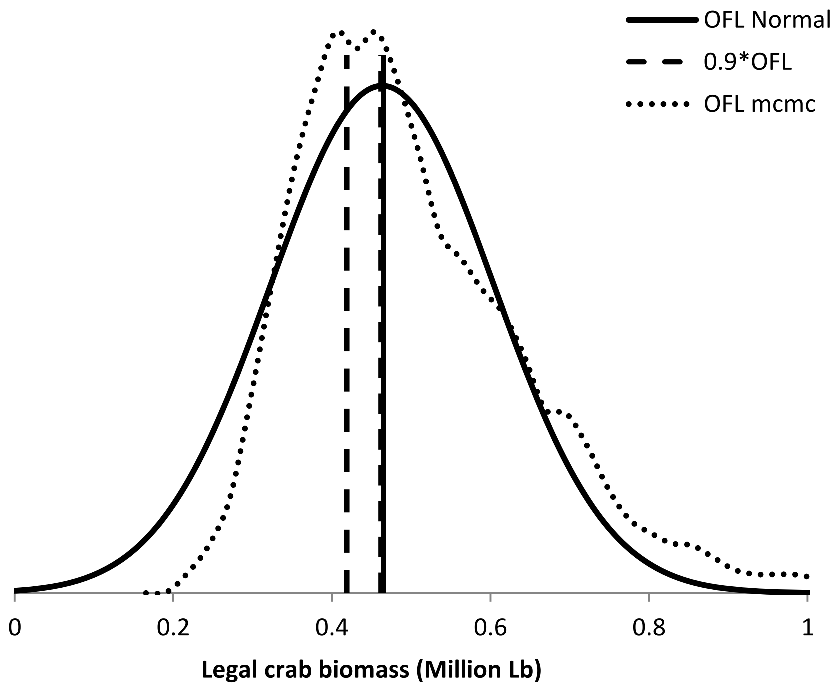
6. Probability Density Function of the OFL



OFL profile. Model estimated CV 0.3 and mcmc estimates.

7. The basis for the ABC recommendation

For Tier 4 stocks, the default maximum ABC P*=49% that is essentially identical to the OFL. Accounting for uncertainties in assessment and model results, the SSC chose to use 90% OFL (10% Buffer) for the Norton Sound red king crab stock in 2011.

For 2014 fishery, we chose 90% OFL (10% Buffer)

8. A summary of the results of any rebuilding analyses.
   N/A

A. Summary of Major Changes in 2013

1. Changes to the management of the fishery**:**

   None

2. Changes to the input data

   Updated

   a. 2013 summer commercial fishery, 2012/2013 winter commercial and subsistence catch.

   New Data included into the assessment model

b. 2013 summer commercial fishery observer data, standardized commercial catch CPUE and CV.

c. Winter pot survey CPUE 1980-2011

Revised Data

d. 1976-1991 NMFS survey NSRKC crab abundance estimates were revised based on original survey data.

3. Changes to the assessment methodology:

   None

4. Changes to the assessment results.

   None

B. Response to SSC and CPT Comments

CPT Review Sept 17 – 20, 2013

The team had the following comments:

- The model incorporating 2013 observer length frequency data led to an unusually high terminal year mature male abundance whereas the model that disregarded the 2013 observer data led to a reasonable estimate of terminal stock abundance. Therefore, the OFL estimate based on the biomass determined by the model that excluded the 2013 observer data should be considered for developing harvest specifications for 2014.

  Author response:
  The model estimates using all finalized data did not show observable discrepancies when including or excluding observer data.

- The authors assumed a constant M value of $0.18yr^{-1}$ to exclude the possibility of confounding with molting. Show the likelihood profile of M.

  Author response:
  Profile of M was provided. In this, all estimated parameters, except ms6 (mortality multiplier for the last length class), changed depending on value of M. The parameter ms6 was set to 1.0, which assumes constant mortality for all length classes as opposed to the original assumption that mortality of the last length class is 3.6 times higher (M = 0.648) than other length classes. The profile analysis showed that M = 0.42 generated the lowest negative log likelihood.

- Calculate the non-retained OFL as well as the total OFL.

Author response: Implemented.

- Report the estimate of the additional variance that is added to the variance assumed for the CPUE data.

Author response: The variance has been reported on table 11 (log_w^2_t). We also show this in Figures 9a and 9b.

- Estimate separate selectivity patterns for the NMFS and ADFG trawl surveys and evaluate whether the assumption that they are the same can be justified.

Author response:
The analysis shows that trawl selectivity of the ADF&G differed from NMFS survey. However, standard error of the selectivity function parameter was very high (CV 2-5 $\times 10^5$ %). Selectivity both surveys was 0.999 for all length classes.

- Increase weight of recruit penalty from 0.01 to 0.5

Author response:
Implemented.

Recruit penalty was described as standard deviation (sd) (i.e., sd = 0.5) converted from the original multiplier (W_R) form

$$W_R \sum_{t=1} \tau_t^2 \Rightarrow \sum_{t=1} \frac{\tau_t^2}{2sd^2}$$

With sd = 0.5, the conversion increased weight from W_R = 0.01 to = 4.75. ($W_R = 1/2sd^2$).

The effects of this weight change were reported at the 2014 workshop, and the proposed weight was considered appropriate.

SSC Review on September 30-October1, 2013

- Conduct sensitivity analyses on weighting.
  See January 14-17 modeling workshop report.

Crab modeling workshop on January 14-17, 2014

- A full assessment should be conducted with a range of suggested scenarios so the May CPT can recommend an OFL and an ABC for the 2014-15 management cycle. The assessment will need to be revised again for the September 2014 CPT meeting and the September specification cycle.

Author response:

2014 summer commercial harvest season also coincides with triennial assessment. It is unlikely that both commercial harvest assessment and triennial survey assessment will be finalized before the September 2014 CPT meeting. Similar to 2013 CPT meeting, it is possible that summer commercial fishery is not finished.

- Provide alternative model runs where selectivity for the ADFG and NMFS trawl surveys are assumed the same, and where different selectivity patterns are estimated for each survey.

  Author response:
  In the revised model, selectivity for ADFG and NMFS trawl surveys were identical, so that combining or not combining the two did not change model outcomes (c.f. alternative models 0 and 1). However, we separate the two selectivity because the selectivity may differ in alternative models and the assumption of identical selectivity will most likely be challenged in the future.

- Provide alternative model runs in which the growth transition matrix incorporates both growth and molting probabilities. If possible, develop a model that incorporates the growth data and in which the growth transition matrix is estimated.

  Author response:

  Three models (2.i, 2.io, 2.ii) estimated the growth transition matrix from tagging data.

- Provide alternative model runs in which: 1) the size-composition data from the winter pot survey are excluded, and 2) the CPUE data for the winter pot survey are included.

  Author response:
  Inclusion of the winter pot CPUE decreased model fit, and exclusion of winter pot data did not improve model fit. Further, removing the winter pot data resulted in the loss of the model's ability to estimate winter pot selectivity.

- Review the data used to calculate the growth transition matrix, and provide an overview of the new tagging program and the data that it is expected to provide.

  Author response:
  A growth transition matrix was developed using historical tag recovery data. In this assessment we combined all historical tag recovery data (through recoveries in 2013). The Tagging study is ongoing as a NPRB funded projects (2013-14) and we expect recovery of tagged crabs for coming years.

C. Introduction

Species: red king crab (*Paralithodes camtschaticus*) in Norton Sound, Alaska.

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1. General Distribution: Norton Sound red king crab is one of the northernmost red king crab populations that can support a commercial fishery (Powell et al. 1983). It is distributed throughout Norton Sound with a westward limit of 167-168^{o} W. longitude with depths less than 30 m and summer bottom temperatures above 4^{o}C. The Norton Sound red king crab management area consists of two units: Norton Sound Section (Q3) and Kotzebue Section (Q4) (Menard et al. 2011). The Norton Sound Section (Q3) consists of all waters in Registration Area Q north of the latitude of Cape Romanzof, east of the International Dateline, and south of 66°N latitude (Figure 1). The Kotzebue Section (Q4) lies immediately north of the Norton Sound Section and includes Kotzebue Sound. Commercial fisheries have not occurred regularly in the Kotzebue Section. This report deals with the Norton Sound Section of the Norton Sound red king crab management area.
2. Evidence of stock structure: Thus far, no studies have been made on possible stock separation within the putative stock known as Norton Sound red king crab.
3. Life history characteristics relevant to management: One of the unique life-history traits of Norton Sound red king crab is that they spend their entire lives in shallow water since Norton Sound is generally less than 40 m in depth. Distribution and migration patterns of Norton Sound red king crab have not been well studied. Based on the 1976-2006 trawl surveys, red king crab in Norton Sound are found in areas with a mean depth range of 19 ± 6 (SD) m and bottom temperatures of 7.4 ± 2.5 (SD) ^{o}C during summer. Norton Sound red king crab are consistently abundant offshore of Nome.

   Norton Sound red king crab migrate between deeper offshore waters during molting/feeding and inshore shallow waters during the mating period. Timing of the inshore mating migration is unknown; but is assumed to be during March-June. Offshore migration likely occurs in May-July. Trawl surveys show that crab distribution is dynamic. Recent surveys show high abundance on the southeast side of the Sound, offshore of Stebbins and Saint Michael. There is limited information on the timing of male molting, but at least some males likely molt late August – September based on increased catches of post-molt crabs in the fishery.
4. Brief management history: Norton Sound red king crab fisheries consist of commercial and subsistence fisheries. The commercial red king crab fishery started in 1977 and occurs in summer (June – August) and in winter (December – May) (Menard et al. 2011). The majority of red king crab are harvested by the summer commercial fisheries, whereas the majority of the winter harvest is in the subsistence fishery occurring near the coast (Table 2).

<u>Summer Commercial Fishery</u>

Summer commercial crab fishery started in 1977 (Table 1). A large-vessel summer commercial crab fishery existed in the Norton Sound Section from 1977 through 1990. No summer commercial fishery occurred in 1991 because there was no staff to manage the fishery. In March 1993, the Alaska Board of Fisheries (BOF) limited participation in the fishery to small boats. Then on June 27, 1994, a super-exclusive designation went into effect for the fishery. This designation stated that a vessel registered for the Norton Sound crab fishery may not be used to take king crabs in any other registration areas during that registration year. A vessel moratorium was put into place before the 1996 season. This was intended to precede a license limitation program. In 1998, Community Development Quota

(CDQ) groups were allocated a portion of the summer harvest; however, no CDQ harvest occurred until the 2000 season. On January 1, 2000 the North Pacific License Limitation Program (LLP) went into effect for the Norton Sound crab fishery. The program dictates that a vessel which exceeds 32 feet in length overall must hold a valid crab license issued under the LLP by the National Marine Fisheries Service. Regulation changes and location of buyers resulted in harvest distribution moving eastward in Norton Sound in the mid-1990s. In the Norton Sound, a legal crab is defined as ≥ 4-3/4 inch carapace width (Menard et al. 2011). Since 2005, commercial buyers started accepting only legal crabs of ≥ 5 inch carapace.

Not all Norton Sound area is open for commercial fisheries. Since the beginning of the commercial fisheries in 1977, nearshore areas near Nome area have been closed during the summer commercial crab fishery, possibly to protect crab nursery grounds (Figure 2). The spatial extent of closed area has varied through time.

CDQ Fishery

The Norton Sound and Lower Yukon CDQ groups divide the CDQ allocation. Only fishers designated by the Norton Sound and Lower Yukon CDQ groups are allowed to participate in this portion of the king crab fishery. Fishers are required to have a CDQ fishing permit from the Commercial Fisheries Entry Commission (CFEC) and register their vessel with the Alaska Department of Fish and Game (ADF&G) before they make their first delivery. Fishers operate under authority of the CDQ group and each CDQ group decides how their crab quota is to be harvested. During the March 2002 BOF meeting, new regulations were adopted that affected the CDQ crab fishery and relaxed closed-water boundaries in eastern Norton Sound and waters west of Sledge Island. At its March 2008, the BOF changed the start date of the Norton Sound open-access portion of the fishery to be opened by emergency order and as early as June 15. The CDQ fishery may open at any time (as soon as ice is out), by emergency order. It is possible that the fishery starts BEFORE determination of OFL and ABC.

Winter Commercial Fishery

Winter commercial crab fishery is a small fishery using hand lines and pots through the nearshore ice. Approximately 10 permit holders participated in this fishery harvesting, on average, 2,500 crabs during 1978-2009 (Table 2). During 2006-2013 the winter commercial catch increased to 3,000 – 23,000. The winter commercial fishery catch is influenced not only by crab abundance, but also by changes in nearshore crab distribution, sea ice conditions, number of participants, and market condition.

Subsistence Fishery

Harvest statistics are available for the winter subsistence fishery since 1977/78 (Table 2). The majority of harvest occurs during winter using hand lines and pots through the nearshore ice. Average annual winter subsistence harvest was 5,400 crabs (1977-2010). Subsistence harvesters are required to obtain a permit before fishing and record daily effort and catch. There is no size limit in the subsistence fishery. The subsistence fishery catch is influenced

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not only by crab abundance, but also by changes in crab distribution, changes in gear (e.g., more use of pots instead of hand lines since 1980s), and ice conditions (e.g., reduced catch due to unstable ice conditions in 1987-88, 1988-89, 1992-93, 2000-01, 2003-04, 2004-05, and 2006-07).

The summer subsistence crab fishery harvest has been monitored since 2004 with an average harvest of 712 crabs per year. Since this harvest is very small, summer subsistence fishery was not included in the assessment model.

5. Brief description of the annual ADF&G harvest strategy

beginning in Norton Sound red king crab was managed based on a guideline harvest limit (GHL) since 1997. Detailed historical methods of GHL determination are unknown. From 1999 to 2011, GHL was determined by a prediction model and the model estimated predicted biomass: (1) 0% harvest rate of legal crab when estimated legal biomass < 1.5 million lb.; (2) ≤ 5% of legal male abundance when the estimated legal biomass falls within the range 1.5-2.5 million lb.; and (3) ≤ 10% of legal male when estimated legal biomass >2.5 million lb.

has been The method of GHL determination was revised in 2012 to: (1) 0% harvest rate of legal crab when estimated legal biomass < 1.25 million lb.; (2) ≤ 7% of legal male abundance when the estimated legal biomass falls within the range 1.25-2.0 million lb.; (3) ≤ 13% of legal male abundance when the estimated legal biomass falls within the range 2.0-3.0 million lb.; and (4) ≤ 15% of legal male when estimated legal biomass >3.0 million lb.

Year	Notable historical management changes
1976	Periodic fishery-independent surveys began
1977	Large vessel commercial fisheries began
1991	Fishery closed due to staff constraints
1994	Participation of large vessels in the commercial fishery ended by super exclusive designation. Fishery effectively becomes small-vessel only. The majority of commercial fishery effort and catch subsequently shifted to east of 164°W line.
1998	Community Development Quota (CDQ) allocation into effect
1999	Guideline Harvest Level (GHL) into effect
2000	North Pacific License Limitation Program (LLP) into effect.
2002	Change in closed water boundaries (Figure 2)
2005	Commercially accepted legal crab size changed from ≥ 4-3/4 inch CW to ≥ 5 inch CW
2006	The Statistical area Q3 section expanded (Figure 1)
2008	Start date of the open access fishery changed from July1 to after June 15 by emergency order. Pot configuration requirement: at least 4 escape rings (>4½ inch diameter) per pot located within one mesh of the bottom of the pot, or at least ½ of the vertical surface of a square pot or sloping side-wall surface of a conical or pyramid pot with mesh size > 6½ inches.
2012	Board of fisheries adopted a revised GHL

6. Summary of the history of the B_{MSY}.

NSRKC is a Tier4a crab stock. Direct estimation of the B_{MSY} is not possible. B_{MSY} is calculated as mean model estimated mature male biomass (MMB) from 1980 to present. Choice of this period was based on the possibility that a regime shift in ocean-atmosphere circulation dynamics indexed by the Pacific Decadal Ocscillation (PDO) occurred in 1976-77 may have influenced stock productivity.

D. Data

1. Summary of new information:
    1. Winter pot survey CPUE. Data have been available but have not previously been incorporated into the model.
    2. **2.** 2014 winter commercial and subsistence catches (Model year 2013). **Because these data are not available at the time of assessment values were assumed to be the same as 2013.**

2. Available survey, catch, and tagging data:

Data Source	Years	Data Types	Representation
Summer trawl survey*	76,79,82,85,88,91,96, 99, 02,06,08,10,11	Abundance Length proportion	Table 3 Table 5, Figure 3
Winter pot survey	81-87, 89-91,93,95-00,02-12	CPUE Length proportion	Table 2 Table 6, Figure 3
Summer commercial fishery	76-90,92-13	Retained catch number Standardized CPUE, Length proportion	Table 1 Table 1 Table 4, Figure 3
Summer commercial Observer	87-90,92,94, 2012-2013	Length proportion (sub-legal only)	Table 7, Figure 3
Winter subsistence fishery	76-13	Number of crab caught Retained catch number	Table 2 Table 2
Winter commercial fishery	78-13	Retained catch number	Table 2
Tagging recovery	80-13	Recovered tagged crab	Table 9

*: Triennial trawl surveys were conducted by the NMFS (1976-1991, 2010) and by the ADF&G (1996-2011) (Table 3). The NMFS survey was conducted using the 83-112 Eastern Otter Trawl, whereas the ADF&G survey was conducted using the 400 Eastern Otter Trawl (Soong 2008). In both surveys, survey design was based on 10×10nm square, except for the NMFS survey in 2010 where survey grid was 20×20nm. Abundance of crabs were estimated by area-swept methods (Alverson and Pereyra 1969). Historical NMFS trawl survey abundance (Schwarz 1984, Stevens and MaIntosh 1986, Stevens 1989, 1992; Wolotira et al 1977) was re-estimated from the original raw data in 2013 (Robert Foy, NMFS personal communication).

Data available but not used for assessment

Data Source	Years	Data Types	Reason not used
Summer pot survey	80-82,85	Abundance Length proportion	Uncertainties on how estimates were made.
Summer preseason survey	95	Length proportion	Just one year of data
Summer subsistence fishery	2005-2013	retained catch	Too few catches compared to commercial

4. Catches in other fisheries: None.

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3. Other miscellaneous data: None.

Data aggregated

Growth-per-molt, estimated from tagging data (1991-2007) (Table 8)

Proportions of legal size crab in crab length classes, estimated from trawl survey and observer data. (Table 9)

Analytic Approach

1. History of the modeling approach.

The Norton Sound red king crab stock IS assessed using a length-based synthesis model (Zheng et al. 1998).

Since adoption of the model a, the major challenge was the apparent conflict between the model and observed data, especially the model overestimating the abundance/proportion of large length classes, which resulted in overestimation of the projected biomass (Figure 12). This problem has been dealt with using the following approaches: (1) increase M of the last length class, (2) implement a dome-shaped catch selectivity for winter pot survey/catch), (3) reduce effective sample size of length composition data, and (4) increase M. Although all three approaches improve model fits and projections, none of those approaches are without major criticisms. Approaches (1) and (2) have unusual biological/fishery assumptions without supportive data. Approach (3) is biologically simpler and reasonable approach; however, it greatly increases the OFL and ABC, without any supportive evidence that the population can withstand a higher exploitation rate. Attempts to estimate M directly from the model itself failed, because of confounding effects between molting probability and natural mortality.

At the 2013-2014 crab modeling workshop, extensive examination of the model was conducted, including revision of historical survey abundance data, inclusion and exclusion of data (e.g., exclusion of summer pot survey data, inclusion/exclusion of winter pot survey CPUE), reduction of the number of parameters (e.g., molting probability, selectivity), and reevaluation of growth transition matrix.

Here is chronology of model modifications

2010

1) M =0.18,
2) include summer commercial discards mortality,
3) weight of fishing effort = 20,
4) the maximum effective sample size for commercial catch and winter surveys = 100,
5) M of the last length class = 0.288.

2012
1) M of the last length class = 0.648,
2) the maximum effective sample size for commercial catch and winter surveys = 50
3) weight of fishing effort = 50.

2013
1) replace likelihood of commercial catch effort to that of standardized commercial catch CPUE with weight = 1.0,
2) eliminate summer pot survey data from likelihood,
3) estimate survey selectivity of 1976-1991 NMFS survey with maximum of 1.0, and
4) reduce the maximum effective sample size for commercial catch and winter surveys = 20.

The model described here has been adjusted to accommodate 1) revised functional forms for selectivity and molting probability to improve parameter estimates, 2) inclusion of the winter pot survey CPUE, and 3) inclusion of the growth transition matrix estimated from tagging data.

2. Model Description

a. Description of overall modeling approach:

The model is a male-only size structured model that combines multiple sources of survey, catch, and mark-recovery data using a maximum likelihood approach to estimate abundance, recruitment, catchability of the commercial pot gear, commercial and survey selectivity, molting probability and growth. (See Appendix A for full model description). Model cycle is July 1st to June 30th of following year.

b-f. See Appendix A.

g. Critical assumptions of the model:

i. Male crab mature at 94mm CL.

The basis for this assumption have not been located. No formal study has been conducted to test this assumption.

ii. Instantaneous natural mortality *M* is 0.18 for all length classes, except for the last length group (> 123mm) where M =0.648 (0.18 × 3.6). M is constant over time.

This mortality is based on Bristol Bay red king crab, estimated with a maximum age 25 and the 1% rule (Zheng 2005), and was adopted for NSRKC by CPT. The assumption of the higher M for the last length group is based not on biological data, but rather a working hypothesis attempting to explain the lower than model predicted proportion of this group in summer commercial fisheries (Figures 10, 13).). It is possible, that the last length group moved into areas inaccessible to commercial fisheries (CPT review 2010). However, this does not explain the low proportion observed in the summer trawl survey, when all of the Norton Sound Area was surveyed. In addition, lowering the catch selectivity did not result in lower log likelihood than increasing the mortality (CPT 2010).

iii. Trawl survey selectivity is a logistic function with 0.999 for length classes 5-6. Selectivity is constant over time, separated between NMFS and ADFG survey.

This assumption was not based on biological/mechanistic data and reasoning, but rather an attempt to improve model fit.

iv. Winter pot survey selectivity is a dome shaped function: logistic function for length classes 1-4, 0.999 for length class 5, and model estimate for the last length group. Selectivity is constant over time.

This assumption is based on a belief (but no empirical data) that very large crab may be infrequently present in the nearshore area where the winter surveys occur.

v. Summer commercial fisheries selectivity is an asymptotic logistic function of 0.999 at the length class 5 and 6. It has two selectivity curves: (1) 1977-1992, and (2) 1993-present, reflecting changes in fishing vessel composition and pot configuration.

Since 2005 commercial buyers accept only legal crab of CW ≥ 5.0 inch and unknown numbers of legal crab with CW < 5.0 are discarded. Further, since 2008, commercial pots are required to install escapement rings for sublegal crabs. Hence one can argue that the catch selectivity changed in 2005. However, the model was not able to accurately estimate selectivity parameters for 2005-2013. Consequently, selectivity for both 1993-2004 and 2005-2013 were combined.

vi. Winter commercial and subsistence fishery selectivity and length-shell conditions are the same as those of the winter pot survey. All winter commercial and subsistence harvests occur after February 1st.

Winter commercial king crab pots can be any dimension (5AAC 34.925(d)). No data exists about length composition of crab harvested in commercial and subsistence fishery. However, because commercial fishers are also subsistence fishers, it is reasonable to assume that the commercial fishers used crab pots that they also used for subsistence harvest. Hence both fisheries have the same selectivity.

vii. Growth increments, which are estimated based on tag recovery data, are a function of length and are constant over time.

viii. Molting probability is an inverse logistic function of length for males.

ix. The summer directed fishing season is short.

x. Discard handling mortality in all fisheries is 20%.

No empirical estimate is available.

xi. Annual retained catches is measured without error.

xii. All legal size crabs (≥ 4-3/4 inch CW) are taken to the commercial dock.

Since 2005, buyers announced that only legal crab with ≥ 5 inch CW are acceptable for purchase. Since samples are taken at a commercial dock, it was anticipated that this change would lower the proportion of legal crab for length class 4. However, because inclusion of this factor did not change the results, this factor was not included in the assessment model.

xiii. All sublegal size crab or commercially unacceptable size crab (< 5 inch CW, since 2005) are discarded.

xiv. Length compositions have a multinomial error structure, and abundances have a log-normal error structure..

h. Changes of assumptions since last assessment:

None

i. Code validation. Model code was reviewed at the CPT modeling workshop in 2013 and 2014.2014. It is available from the authors.

Model Selection and Evaluation

a. Description of alternative model configurations.

Based on recommendations provided at the 2014 crab workshop, for this assessment the following alternative model configurations were examined:

0. Base Model at January 2014 crab workshop

1. NMFS and ADF&G trawl survey selectivity assumed identical

2. Growth transition matrix estimated within the assessment model
   - i. Molting probability estimated
   - io. Molting probability estimated (include Oldshell into likelihood)
   - ii. Molting probability fixed at1.0 for all length classes

3. Winter survey CPUE included, in addition to winter survey length composition data

4. All winter survey data (CPUE and length composition) excluded

Explanations:

The growth matrix and molting probability
The growth-transition matrix has been estimated inside and outside independently of the assessment model using tag-recovery data. However, because tag-recovery is confounded with catch selectivity it is preferable to estimate the matrix it within the assessment model. There is some question whether molting probability was simultaneously estimable. We examined both cases: model 2.i: estimate molting

probability using base model likelihood (newshell and oldshell combined), model 2.io: estimate molting probability revised likelihood (newshell and oldshell separate), and model 2.ii assume molting probability 1.0 for all length classes.

Winter survey data usage

In the base model only length composition data from the winter survey is used. At the January 2014 workshop, an omission of associated abundance information was noted as unconventional and it was recommended to either (1) include the pot survey CPUE data as an index of abundance or (2) remove all winter pot survey data from the model. For this assessment we have explored both of those options.

Trawl survey selectivity

At the September 2013 meeting, the CPT recommended separate NMFS and ADF&G trawl survey selectivity curves, which approach was implemented at the January 2014 workshop. Here we compare results of that approach with those of the other alternative models.

b. Evaluation of alternative model results

Log-likelihood

Scenario	Total	TBA	CCPUE	WCPUE	TLP	WLP	CLP	REC	OBS	TAG	B_{MSY}	MMB	OFL
0	61.5	7.0	-21.4		13.8	18.9	23.8	8.8	10.6		4.2	3.7	0.45
1	61.5	7.0	-21.4		13.8	18.9	23.8	8.8	10.6		4.2	3.7	0.46
2.i	141.9	6.9	-21.5		15.3	25.9	21.1	9.5	10.7	74.0	4.2	3.7	0.46
2.io	213.6	6.5	-22.3		16.4	50.6	53.4	11.9	23.0	74.0	4.2	3.7	0.46
2.ii	141.8	6.9	-21.5		15.4	25.9	21.1	9.4	10.7	73.9	4.2	3.7	0.46
3	115.7	10.6	-19.3	45.5	14.4	20.2	26.0	8.6	9.7		3.7	3.5	0.47
4	39.3	7.3	-22.8		13.5		23.3	8.1	9.8		4.3	3.6	0.41
2.i-3	196.0	10.3	-19.5	45.4	14.6	27.5	23.2	9.6	9.9	73.8	3.7	3.5	0.48
2.i-4	112.2	7.1	-23.2		16.1		21.3	7.9	9.7	73.2	4.4	3.7	0.44
2.ii-4	112.2	7.1	-23.2		16.1		21.3	7.9	9.7	73.2	4.4	3.7	0.44

TBA: Trawl survey abundance
CCPUE: Commercial catch CPUE
WCPUE: Winter survey CPUE
TLP: Trawl survey length composition
WLP: Winter pot survey length composition
CLP: Summer commercial catch length composition
REC: Recruitment deviation penalty
OBS: Summer commercial catch observer discard length composition
TAG: Tag recovery data composition

c. Search for balance:

Summary of results from fitting alternative models:

There was no change in log-likelihood between combining and separating NMFS and ADF&G trawl survey selectivity.

Including tag recovery data resulted in a an estimated molting probability of 0.999 when newshell and oldshell were combined in the likelihood. However, when oldshell and newshell were separated in the likelihood molting probability was estimable (Table 11).

Including tag recovery data resulted in a winter pot survey selectivity estimated at 0.999 for length classes 1 – 5, and low selectivity for size class 6 (Figure 5).
Including winter pot survey CPUE resulted in poorer model fits (higher log-likelihood for each component).
Removing the winter pot survey data did not lower the log-likelihood of each component and caused difficulty of meaningfully estimating winter pot survey selectivity.
Regardless of the differences in model configurations all alternative models resulted in similar estimates of Bmsy, MMB, and OFL values.

From the perspective of estimating all parameters within the assessment model, inclusion of tagging data (alternatives 2.i, 2.io, and 2.ii) is preferred. The difference between 2.i and 2.ii is whether molting probability is model estimated or assumed equal to 1.0. The assumption and model estimation of molting probability is 1.0 (model 2.i and 2.ii) implies that all crab are newshell, or absence of oldshell crabs. This, in reality, is not the case. Probable reason for this model estimate (2.i) is because proportion of newshell and oldshell crabs was combined for calculation of likelihood (Appendix A). On the other hand, when oldshell components are separated in the likelihood calculation (model 2.io), the model was able to estimate molting probability. Even so, in terms of overall model fit there was little difference among all the three models. A further result of the models 2.i, 2.io, and 2.ii was changing estimates of winter pot selectivity to 1.0 for all length classes, except for the last length class (Figures 5 a b). This seems unrealistic, and further investigation on this issue is warranted.

Inclusion of the winter pot survey CPUE (model 3) resulted in a poorer model fit (i.e., increased log-likelihood) to trawl survey abundance and commercial catch CPUE. This may indicate presence of internal conflicts between summer and winter abundance indices. The winter pot survey data may not reflect abundance and length composition of the population. The survey occurred on ice fields inshore of Nome where popular commercial and subsistence fishery occurred. The above reasons may favor removal of the winter survey data from the assessment model (model 4). However, removal of the winter survey data also resulted in a loss of the model's ability to estimate winter pot survey selectivity, leading to convergence failure. In the assessment model, winter pot selectivity is used as a proxy for a selectivity of winter commercial and subsistence harvests. Unrealistic selectivity may result in unrealistic estimates of the length composition of discards and catch and the overall winter harvest.

One option to counter this problem is to include an assumed winter pot selectivity, such as assuming 1.0 for all length classes or use the selectivity of the base model. However, because winter harvest is small, uncertainties of selectivity is unlikely to impact overall model fit and projections. Monitoring of the length composition of the winter commercial and subsistence fisheries is a priority objective due to recent increases in the magnitude of the winter harvest (Table 2).

Considering the above, we recommend the use of model 2.io for the assessment. The model uses all available data and has makes fewer assumptions. While our results suggest that some model simplification might be appropriate, (e.g., combining trawl NMFS and ADFG survey selectivity, winter pot selectivity = 1.0 for length classes 1-5), our preference is to not to simplify the model. It is our experience that re-evaluation of the reasons for model simplification are often requested each time composition of CPT membership changes.

Results

1. List of effective sample sizes and weighting factors (Figures 4a,b)

Estimated implied effective sample sizes were calculated as

$$n = \sum_l \hat{P}_{t,l}(1-\hat{P}_{t,l}) \Big/ \sum_l (P_{t,l} - \hat{P}_{t,l})^2$$

where $P_{t,l}$ and $\hat{P}_{t,l}$ are observed and estimated length compositions in year *t* and length group *l*, respectively. Estimated effective sample sizes vary greatly by year through the time series (Figures 4a,b,c).

Input effective sample sizes for length proportion data:

Survey data	Sample size
Summer commercial, winter pot, and summer observer	minimum of 0.1× actual sample size or 10
Summer trawl and pot survey	minimum of 0.5× actual sample size or 20

Weighting factor:

Recruitment SD: $SDR = 0.5$

Winter pot survey CPUE SD: $SDR_w = 0.3$

2. Tables of estimates.

a. Model Parameter estimates (Tables 10, 11, 12, 13).

b. Abundance and biomass time series (Table 14)

c. Recruitment time series (Table 14).

d. Time series of catch and biomass (Table 15)

3. Graphs of estimates.

a. Molting probability and trawl and pot survey selectivity (Figure 5)

b. Trawl survey abundance and model abundance (Figure 6)

c. Estimated male abundances (recruit, legal, and total) (Figure 7)

d. Estimated mature male biomass (Figure 8)

e. Time series of catch standardized CPUE (Figure 9).

f. Time series of catch and estimated harvest rate (Figure 10).

4. Evaluation of the fit to the data

a. Fits to observed and model predicted catches.
Not applicable. Catch is assumed to be measured without error; however fits of cpue are available (Figure 9, 11)

b. Model fits to survey numbers (Figure 6, 11).

c. Model fits to catch and survey length-class proportions (Figure 12, 13, 14, 15, 16).

d. Marginal distribution for the fits to the composition data: (Figure 13).

e. Plots of input vs. implied effective sample size: frequency (Figure 4a), correlation (Figure 4b), and time series (Figure 4c).

f. Tables of RMSEs for the indices:

Indices	Model 0	Model 2.i	Model 2.io
Trawl survey	0.284	0.282	0.268
CPUE	0.493	0.497	0.500

5. QQ plots and histograms of residuals (Figure 11).

5. Retrospective analyses (Figure 17)

6. Uncertainty and sensitivity analyses.
None

E. Calculation of the OFL

1. Specification of the Tier level and stock status.

The Norton Sound red king crab stock is currently placed in Tier 4 (NPFMC 2007). It is not possible to estimate the spawner-recruit relationship, but some abundance and harvest estimates are available to build a computer simulation model that capture the essential population dynamics. Whereas tier 4 stocks are assumed to have reliable estimates of current survey biomass and instantaneous M, the estimates for the Norton Sound red king crab stock remain uncertain. Survey biomass is based on triennial trawl surveys with CVs ranging from 15-42% (Table 4).

The OFL is determined using the OFL control rule

$$F_{OFL} = \gamma M, \quad when\ B / B_{MSY^{prox}} > 1, \tag{1}$$

$$F_{OFL} = \gamma M\ (B / B_{MSY^{prox}} - 0.1) / 0.9, \quad when \quad 0.25 < B / B_{MSY^{prox}} \le 1, \tag{2}$$

$$F_{OFL} = bycatch\ mortality\ \&\ directed\ \ fishery\ F = 0, \quad when\ B / B_{MSY^{prox}} \le 0.25, \tag{3}$$

where B is mature male biomass (MMB), B_{MSY} proxy is average mature male biomass over a specified time period, $M = 0.18$ is instantaneous natural mortality, and $\gamma = 1$. For Norton Sound red king crab, MMB is defined as the biomass of male crab measuring at least 94mm CL. The default data used for the selection of the B_{MSY} proxy is the survey MMB. The only available survey MMB data for the Norton Sound red king crab stock are triennial trawl surveys. We used the *model estimated* MMB for calculation of B_{MSY} proxy from 1980 to present.

B_{MSY} proxy = average model estimated MMB from 1980-2014

OFL was calculated for retained catch and total model male catch. The retained catch OFL is based on legal crab biomass catchable to summer commercial pot fisheries (*Legal_B*) that was calculated as: Projected legal abundance (July 1st) × Commercial pot selectivity × Proportion of legal crab per length class × Average weight (lb) by length class.

$$Legal\_B = \sum_l (N_{s,l,} + O_{s,l,}) S_{s,l} L_l wm_l$$

$$OFL_r = (1 - \exp(-F_{OFL})) Legal\_B$$

$$OFL_{nr} = (1 - \exp(-F_{OFL})) \sum_l (N_{s,l,} + O_{s,l,}) S_{s,l} (1 - L_l) wm_l\ hm$$

where $N_{s,l}$ and $O_{s,l}$ are summer abundances of newshell and oldshell crabs in length class l in the terminal year, L_l is the proportion of legal males in length class l, $S_{s,l}$ is summer commercial catch selectivity, wm_l is average weight in length class l and hm is handling mortality rate.

The total model male OFL is

$$OFL_T = OFL_r + OFL_{nr}$$

Predicted legal male and mature male biomass in 2014 are:

Legal male biomass:

3.05 million lb with a standard deviation of 0.46 million lb. (model 0)
3.22 million lb with a standard deviation of 0.49 million lb. (model 2.i)
3.19 million lb with a standard deviation of 0.48 million lb. (model 2.io)

Mature male biomass:

3.66 million lb with a standard deviation of 0.66 million lb. (model 0)
3.72 million lb with a standard deviation of 0.64 million lb. (model 2.i)
3.71 million lb with a standard deviation of 0.64 million lb. (model 2.io)

B_{MSY} proxy was calculated as an average MMB during 1980-2014 periods.

4.18 million lb (model 0)
4.21 million lb (model 2.i)
4.19 million lb (model 2.io)

Since projected MMB for 2014was less than B_{MSY} proxy, F_{OFL} calculation was based on equation (2),

$$F_{OFL} = \gamma M \; (B / B_{MSY^{prox}} - 0.1) / 0.9, \quad when \quad 0.25 < B / B_{MSY^{prox}} \le 1,$$

$F_{OFL} = 0.156$ Model 0

$F_{OFL} = 0.157$ Model 2.i

$F_{OFL} = 0.157$ Model 2.io

Retained OFL for summer commercial fishery is

$OFL_r =$ 0.437 million lb. Model 0
$OFL_r =$ 0.464 million lb. Model 2.i
$OFL_r =$ 0.463 million lb. Model 2.io

Non retained OFL for summer commercial fishery is

$OFL_{nr} =$ 0.017 million lb. Model 0
$OFL_{nr} =$ 0.013 million lb. Model 2.i
$OFL_{nr} =$ 0.014 million lb. Model 2.io

Total OFL for summer commercial fishery is

OFL_T = 0.454 million lb. Model 0
OFL_T = 0.477 million lb. Model 2.i
OFL_T = 0.477 million lb. Model 2.io

F. Calculation of the ABC

1. Specification of the probability distribution of the OFL.

Probability distribution of the OFL was determined based on the CPT recommendation in January 2013 as follows:

Tier 4 crab stocks
Calculation of a distribution for the OFL for Tier 4 stocks involves repeating four steps (detailed below). The aim is to have the median of the distribution for the OFL equal the point estimate (so that P*=0.5 implies that the ABC equals to the point estimate of the OFL). The proposed steps are: (a) Sample current MMB from a normal distribution with mean given by the point estimate of current MMB and CV equal to the sampling CV. (b) The B_{MSY} proxy is the average MMB over a pre-specified set of years. Uncertainty in the B_{MSY} proxy only accounts for uncertainty in MMB for the years for which it is assumed the stock was "at B_{MSY}" and not uncertainty in the years concerned. For each of the years used when defining the B_{MSY} proxy, sample MMB from a distribution with mean given by its point estimate and CV equal to the sampling CV. The pseudo B_{MSY} proxy is then the average of the samples values. (c)Sample *M* from a normal distribution with mean equal to the assumed *M* and CV equal to an assumed CV (e.g. 0.2). (d) Compute the OFL. Form a cumulative distribution for the OFL from the sampled values. Find the median of this distribution. Using normal quantiles to rescale the distribution so that the median equals the OFL (similar to a bias-corrected bootstrap).

For the Norton Sound red king crab, calculation of the OFL is based on MMB and applied to summer commercial retained legal male biomass. For calculation of the ABC, default percentile is P* = 49; however, for the Norton Sound Stock the NPFMC adopted 10% buffer of OFL (i.e., ABC = 0.9×OFL) in 2012.. Based on the status change from 4a to 4b a larger buffer may be recommended.

Retained ABC for legal male crab is 90% of OFL

ABC = 0.9*OFL
ABC = 0.394 million lb. Model 0
ABC = 0.417 million lb. Model 2.i
ABC = 0.417 million lb. Model 2.io

This ABC is inclusive of both summer commercial and winter commercial/subsistence fishery.

G. Rebuilding Analyses

Not applicable

H. Data Gaps and Research Priorities

The major data gap that hinder this year's OFL/ABC calculation is uncertainties regarding biomass of Norton Sound red king crab. In addition, life-history of the Norton Sound red king crab stock is poorly understood. This includes size-at-maturity, natural mortality rate, timing and locations of reproduction, and location of females during summer.

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Aleutian Islands Golden King Crab – 2014 Tier 5 Assessment

2014 Crab SAFE Report Chapter (draft May 7, 2014)

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Executive Summary

1. **Stock:** Aleutian Islands golden king crab *Lithodes aequispinus*

2. **Catches:**

The fishery has been prosecuted as a directed fishery since the 1981/82 season and has been open every season since. Retained catch peaked during the 1985/86–1989/90 seasons (average annual retained catch = 11.876-million lb, 5.387 kt), but the retained catch dropped sharply from the 1989/90 to 1990/91 seasons and average annual retained catch for the period 1990/91–1995/96 was 6.931-million lb (3.144 kt). A guideline harvest level (GHL) was introduced into management for the first time in the 1996/97 season. A GHL of 5.900-million lb (2.676 kt) was established in the 1996/97 and subsequently reduced to 5.700-million lb (2.585 kt) beginning with the 1998/99 season. The GHL (or, since the 2005/06 season, the total allowable catch, or TAC) remained at 5.700-million lb (2.585 kt) through the 2007/08 season, but was increased to 5.985-million lb (2.715 kt) for 2008/09–2011/12 seasons and increased to 6.290-million lb (2.853 kt) for the 2012/13 and 2013/14 seasons. Average annual retained catch for the period 1996/97–2007/08 was 5.623-million lb (2.550 kt). Average annual retained catch in 2008/09–2012/13 was 5.959-million lb (2.703 kt). The TAC for the 2012/13 season was 6.290-million lb (2.853 kt) and the landed harvest was 6,268-million lb (2.843 kt). Catch per pot lift of retained legal males decreased from the 1980s into the mid-1990s, but increased steadily following the 1994/95 season and increased markedly at the initiation of the Crab Rationalization program in the 2005/06 season. Non-retained bycatch occurs mainly during the directed fishery. Although minor levels of bycatch can occur during other crab fisheries, there have been no such fisheries prosecuted since 2004/05, except as surveys for red king crab conducted by industry under a commissioner's permit. Bycatch also occurs during fixed-gear and trawl groundfish fisheries. Although bycatch during groundfish fisheries exceeded 0.100-million lb (45 t) for the first time during 2007/08 and 2008/09, that bycatch was less than 10% of the weight of bycatch during the directed fishery for those seasons. Annual estimated bycatch in groundfish fisheries during 2009/10–2012/13 was ≤ 0.066-million lb (30 t). Annual non-retained catch (i.e., discarded bycatch) of golden king crab during crab fisheries has decreased relative to the retained catch and in absolute numbers and weight since the 1990s. Annual estimated weight of discarded bycatch during crab fisheries decreased from 13.824-million lb (6.270 kt) in 1990/91 (equivalent to 199% of the retained catch during that season), to 9.100-million lb (4.128 kt) in 1996/97 (equivalent to 156% of the retained catch for that season), and to 4.321-million lb (1.960 kt) in the 2004/05 season (equivalent to 78% of the retained catch for that season). During the eight seasons (2005/06–2012/13) since fishery rationalization, estimated weight of discarded bycatch during crab fisheries has ranged from 2.524-million lb (1.145 kt) for the 2005/06 season (equivalent to 46% of the retained catch for that season) to 3.035-million lb (1.377 kt) for the

2007/08 season (representing 55% of the retained catch for that season); the estimate for 2012/13 was 2.900-million lb (1.315 kt), equivalent to 46% of the retained catch. Estimates of the annual weight of bycatch mortality have correspondingly decreased since 1996/97, both in absolute value and relative to the retained catch weight. Estimated total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) has ranged from 5.816-million lb (2.638 kt) to 9.375-million lb (4.252 kt) during 1995/96–2012/13; estimated total fishery mortality for 2012/13 was 6.868-million lb (3115 kt).

The 2013/14 season ends by regulation on 15 May 2014 and complete fishery data is not yet available. Nonetheless, preliminary fish ticket landing data from 2013/14 season show that the TAC 3.31-million lb (1.501 kt) established in regulation (**5 AAC 34.612**) for the fishery east of 174º W longitude was essentially attained in December 2013 with a CPUE of 34 retained crab per pot lift (M. Good, ADF&G, Dutch Harbor, personal communication, 14 April 2014). Retained crab CPUE for the fishery east of 174º W longitude during the previous rationalized fisheries (i.e., 2005/06 – 2012/13) has ranged from 25 to 37 (ADF&G 2014); a CPUE of 34 would be comparable to the 2012/13 CPUE (33) and the second highest since rationalization. From fish ticket data available through 14 April 2014, approximately 80% of the 2.98-million pound (1,352 t) TAC for the fishery west of 174º W longitude has been harvested with a CPUE of 17 retained crab per pot lift. Note that availability of fish ticket data lags behind dockside sampling and data from fishery observer reports show that over 90% of the TAC has been harvested as of this writing (M. Good, ADF&G, Dutch Harbor, personal communication, 8 and 14 April 2014). Retained crab CPUE for the fishery west of 174º W longitude during the previous rationalized fisheries has ranged from 19 to 24 (ADF&G 2014).

3. Stock biomass:

Estimates of stock biomass are not available for this Tier 5 assessment.

4. Recruitment:

Estimates of recruitment trends and current levels relative to virgin or historic levels are not available for this Tier 5 assessment.

5. Management performance:

Because estimates of the minimum stock size threshold (MSST) are not available for this Tier 5 stock an overfished determination cannot occur. Overfishing did not occur during 2012/13 because the estimated total catch did not exceed the overfishing limit (OFL) of 12.54-million lb (5.69 kt). The total catch did not exceed the ABC established for 2012/13 (11.28-million lb, or 5.12 kt) and the 2013/14 season remains open until 15 May 2014. The OFL and ABC values for 2014/15 in the table below are the recommended values. The 2014/15 TAC has not yet been established; the value given in the table is the default total allowable catch (TAC) according to current State of Alaska (SOA) regulations (5 AAC 34.612). The TAC for 2013/14 and 2014/15 in the table below does not include landings towards a cost-recovery fishing goal of $300,000 to cover costs of observer deployments in the fishery.

Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch[a]	Total Catch[a,b]	OFL[a]	ABC[a]
2010/11	N/A	N/A	5.99	5.97	6.56	11.06	N/A
2011/12	N/A	N/A	5.99	5.96	6.51	11.40	10.26
2012/13	N/A	N/A	6.29	6.27	6.87	12.54	11.28
2013/14	N/A	N/A	6.29			12.54	11.28
2014/15	N/A	N/A	6.29			12.53	9.40

a. Millions of lb.
b. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.

Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch[a]	Total Catch[a,b]	OFL[a]	ABC[a]
2010/11	N/A	N/A	2.72	2.71	2.98	5.02	N/A
2011/12	N/A	N/A	2.72	2.71	2.95	5.17	4.66
2012/13	N/A	N/A	2.85	2.84	3.12	5.69	5.12
2013/14	N/A	N/A	2.85			5.69	5.12
2014/15	N/A	N/A	2.85			5.69	4.26

a. kt.
b. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.

<u>Basis for the OFL and ABC</u>: See table below; 2014/15 values are the recommended values.

Year	Tier	Years to define Average catch (OFL)	Natural Mortality[a]	Buffer
2010/11	5	1985/86–1995/96[b]	0.18	N/A
2011/12	5	1985/86–1995/96[b]	0.18	10%
2012/13	5	1985/86–1995/96[b]	0.18	10%
2013/14	5	1985/86–1995/96[b]	0.18	10%
2014/15	5	1985/86–1995/96[b]	0.18	25%

a. Assumed value for FMP king crab in NPFMC (2007b); does not enter into OFL estimation for Tier 5 stock.
b. OFL was for retained catch only and was determined by the average of the retained catch for these years.

6. **<u>PDF of the OFL:</u>** Sampling distribution of the recommended (status quo) Tier 5 OFL was estimated by bootstrapping (see section G.1). The standard deviation of the estimated sampling distribution of the recommended OFL is 1.18-million lb (CV = 0.09). Note that generated sampling distribution and computed standard deviation are meaningful as measures in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Sections E.2 and E.4.f).

7. **<u>Basis for the ABC recommendation:</u>** A 25% buffer on the OFL; i.e., ABC = (1.0-0.25)·OFL.

8. **<u>A summary of the results of any rebuilding analyses</u>:** Not applicable; stock is not under a rebuilding plan.

A. Summary of Major Changes

1. **<u>Changes to the management of the fishery</u>:**
   - Cost-recovery fishing to pay for observer coverage and coordination costs was initiated in the 2013/14 season. The cost-recovery goal in 2013/14 was $300,000, which resulted in a retained catch of 0.106 million pounds in the 2013/14 season; cost-recovery fishing harvest is not included in (i.e., is in addition to) the harvest counted towards the TAC.
   - In March 2014 the BOF changed the 9-month season opening date from 15 August to 1 August; that change will become effective in the 2015/16 season.

2. **<u>Changes to the input data</u>:**
   - Fishery data has been updated with the data for 2012/13: retained catch for the directed fishery and bycatch estimates for the directed fishery, non-directed crab fisheries, and groundfish fisheries.

3. **<u>Changes to the assessment methodology</u>:** None: the computation of OFL in this assessment follows the methodology recommended by the CPT in May 2012 and the SSC in June 2012. Note: a minor error in the computation of the OFL that appeared in the 2012 and 2013 assessments is corrected for 2014 in this assessment (the value of 12.54 million lb, 5.69 kt, that appeared in the 2012 and 2013 assessments was incorrect; the correct value is 12.53 million lb, 5.69 kt).

4. **<u>Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL</u>:**
   - The OFL established for each of 2008/09 and 2009/10 was 9.18-million lb (4.16 kt) of retained catch and was estimated by the average annual retained catch (not including deadloss) for the period 1985/86–1995/96.
   - The OFL for 2010/11 was established as a total-catch OFL of 11.06-million lb (5.02 kt) and, following the recommendation of the SSC in June 2010, was computed as the average of the annual retained catch during 1985/86–1995/96 plus the average of the annual retained catch during 1985/86–1995/96 times the estimated average annual value of (bycatch mortality in crab fisheries)/(retained catch) during 1996/97–2008/09 plus the estimated average annual bycatch mortality in groundfish fisheries during 1996/97–2008/09.
   - The OFL for 2011/12 was established as a total-catch OFL of 11.40-million lb (5.17 kt), with the ABC set at the maximum (i.e., with a 10% buffer below the OFL) of 10.26 million lb (4.66 kt). Methods and results followed the June 2010 CPT, May 2011 CPT and June 2011 SSC recommendations by using 1985/86–1995/96 data for retained catch, incorporating as much data on bycatch as is available, and "freezing" the final year of bycatch data included in the assessment at 2008/09. The recommended total catch OFL was computed as the average of the annual retained catch during 1985/86–1995/96 plus the average of the annual retained catch during 1985/86–1995/96 times the estimated average annual value of (bycatch mortality in crab fisheries)/(retained catch) during 1990/91–2008/09 (excluding 1993/94–1994/95 due to lack of sufficient data) plus the estimated average annual bycatch mortality in groundfish fisheries during 1993/94–2008/09.
   - The OFL and ABC for 2012/13 and 2013/14 was a total-catch OFL of 12.54-million lb (5.69 kt), with the ABC set at the maximum (i.e., with a 10% buffer below the OFL) of 11.28 million lb (5.12 kt). The methods to compute the OFL were the same as for the 2011/12 OFL, except that a different time period was used to estimate the

average annual value of (bycatch mortality in crab fisheries)/(retained catch) in the directed fishery (1990/91–1995/96 as opposed to 1990/91–2008/09).

- The recommended OFL and ABC for 2014/15 are a total-catch OFL of 12.53-million lb (5.69 kt) and an ABC of 9.40-million lb (4.26 kt) that was set using a 25% buffer (i.e., set at 75% of the OFL). The recommended OFL is the status quo value from 2013/14 (within a correction for an inexplicable minor error in arithmetic or typing) and no alternative OFL is offered. The recommended ABC is a departure from the maximum-value ABC (i.e., set with a 10% buffer below the OFL) that was established for 2013/14.

B. Responses to SSC and CPT Comments

1. **<u>Responses to the most recent two sets of SSC and CPT comments on assessments in general (and relevant to this assessment)</u>:**
    - <u>CPT, May 2013</u>: *None*.
    - <u>SSC, June 2013</u>: *None*.
    - <u>CPT, September 2013</u> (via September 2013 SAFE Introduction chapter): Not applicable for Tier 5 assessment, except for,
        - *The team requests all authors to follow the Guidelines for SAFE preparation and to follow the Terms of Reference as listed therein as applicable by individual assessment for both content and diagnostics."*
        - <u>Response</u>: Guidelines for SAFE preparation as supplied in 8 August 2013 email from the CPT chair were consulted and followed.
    - <u>SSC, October 2013</u>: *None*.

2. **<u>Responses to the most recent two sets of SSC and CPT comments specific to the assessment</u>:**

- <u>CPT, May 2013 (May 2013 CPT minutes)</u>:
    - *"The assessment author recommended that the same approach be used to determine the OFL as in 2012."* [Sentences summarizing that approach...] *"The CPT endorsed the author's recommendation."*
        - <u>Response</u>: The author's recommended OFL for 2014/15 follow the CPT's recommendations for 2013/14.
    - *"The CPT recommended an ABC that is 90% of the OFL* [i.e., a 10% buffer on the OFL]*, as is standard for the Tier 5 crab stocks."*
        - <u>Response</u>: The 10% buffer on the OFL is the minimum permissible for setting the ABC of a Tier 5 stock – not standard for Tier 5 crab stocks; e.g., a 40% buffer was used for the 2013/14 Western Aleutian Islands ("Adak") red king crab ABC. The author is recommending use of a 25% buffer for determination of the 2014/15 ABC.
- <u>SSC, June 2013 (June 2013 SSC minutes)</u>:
    - *"The recommended OFL and ABC* [*sic;* the inclusion of "and ABC" here is an error in the minutes] *for 2013/14 is 5.69 kt."*
        - <u>Response</u>: The author's recommended OFL for 2014/15 follow the SSC's recommendations for 2013/14.
    - *"The CPT recommended and the SSC agreed that an ABC this is 90% of the OFL* [i.e., a 10% buffer on the OFL]*, as is standard for the Tier 5 crab stocks."*
        - <u>Response</u>: The 10% buffer on the OFL is the minimum permissible for setting the ABC of a Tier 5 stock – not standard for Tier 5 crab stocks;

e.g., a 40% buffer was used for the 2013/14 Western Aleutian Islands ("Adak") red king crab ABC. The author is recommending use of a 25% buffer for determination of the 2014/15 ABC.

- CPT, September 2013 (via Sept 2013 SAFE): *"The team concurred with the author's recommendation to set the ABC based on the maximum permissible from the ABC control rule which specifies an ABC based on a 10% buffer on the OFL."*
  - Response: The author recommends that the application of the maximum permissible ABC be re-evaluated for this Tier 5 stock and recommends use of a 25% buffer for determination of the 2014/15 ABC.
- SSC, October 2013: *None*.

C. Introduction

1. **Scientific name:** *Lithodes aequispinus* J. E. Benedict, 1895

2. **Description of general distribution:**

General distribution of golden king crab is summarized by NMFS (2004):

> Golden king crab, also called brown king crab, range from Japan to British Columbia. In the BSAI [Bering Sea and Aleutian Islands], golden king crab are found at depths from 200 m to 1,000 m, generally in high-relief habitat such as inter-island passes (Chapter 3, pages 34–35).
>
> Golden, or brown, king crab occur from the Japan Sea to the northern Bering Sea (ca. 61° N latitude), around the Aleutian Islands, on various sea mounts, and as far south as northern British Columbia (Alice Arm) (Jewett et al. 1985). They are typically found on the continental slope at depths of 300–1,000 m on extremely rough bottom. They are frequently found on coral bottom (Chapter 3, page 44).

The Aleutian Islands king crab stock boundary is defined by the boundaries of the Aleutian Islands king crab Registration Area O (Figure 1). Baechler (2012, page 7) define those boundaries:

> The Aleutian Islands king crab Registration Area O has as its eastern boundary the longitude of Scotch Cap Light (164° 44' W long.), its northern boundary a line from Cape Sarichef (54° 36' N latitude) to 171° W long., north to 55° 30' N lat., and as its western boundary the Maritime Boundary Agreement Line as that line is described in the text of and depicted in the annex to the Maritime Boundary Agreement between the United States and the Union of Soviet Socialist Republics signed in Washington, June 1, 1990. Area O encompasses both the waters of the Territorial Sea (0–3 nautical miles) and waters of the Exclusive Economic Zone (3–200 nautical miles).

During the 1984/85–1995/96 seasons, the Aleutian Islands king crab populations had been managed using the Adak and Dutch Harbor Registration Areas, which were divided at 171° W longitude (Figure 2), but from the 1996/97 season to present the fishery has been managed using a division at 174° W longitude (Figure 1; Baechler 2012). In March 1996 the Alaska Board of Fisheries (BOF) replaced the Adak and Dutch Harbor areas with the newly created Aleutian Islands Registration Area O and directed Alaska Department of Fish and Game (ADF&G) to manage the golden king crab fishery in the areas east and west of 174° W longitude as two distinct stocks. That re-designation of management areas was intended to more accurately reflect golden king crab stock distribution, coherent with the longitudinal pattern in fishery production prior to the 1996/97 season (Figure 3). The longitudinal pattern in fishery production since 1996/97is similar to that observed prior to the change in management (Figure 4). In this chapter, “Aleutian Islands Area” means the area described by the current definition of Aleutian Islands king crab Registration Area O.

Commercial fishing for golden king crab in the Aleutian Islands Area typically occurs at depths of 100–275 fathoms (183–503 m). During the 2011/12 season the pots sampled by at-sea observers were fished at an average depth of 189 fathoms (346 m; N=361) in the area east of 174° W longitude and 170 fathoms (311 m; N=837) for the area west of 174° W longitude (Gaeuman 2013).

3. **Evidence of stock structure:**

Given the expansiveness of the Aleutian Islands Area and the existence of deep (>1,000 m) canyons between some islands, at least some weak structuring of the stock within the area would be expected. Data for making inferences on stock structure of golden king crab within the Aleutian Islands is largely limited to the geographic distribution of commercial fishery catch and effort. Effort and catch data by statistical area are available since 1982 and locations of over 70,000 fished pots sampled by observers since the 1996/97 season indicate that habitat for legal-sized males may be continuous throughout the waters adjacent to the Aleutian Islands. However, regions of low fishery catch suggest that availability of suitable habitat, in which golden king crab are present at only low densities, may vary longitudinally. Catch has been low in the fishery in the area between 174° W longitude and 176° W longitude (the Adak Island area, Figures 3 and 4) in comparison to adjacent areas, a pattern that is consistent with low CPUE for golden king crab in between 174° W longitude and 176° W longitude (Figure 5) during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys (von Szalay et al. 2011). In addition to longitudinal variation in density, there is also a gap in fishery catch and effort between the Petrel Bank-Petrel Spur area and the Bowers Bank area; both of those areas, which are separated by Bowers Canyon, have reported effort and catch. Recoveries during commercial fisheries of golden king crab tagged during ADF&G surveys (Blau and Pengilly 1994; Blau et al. 1998; Watson and Gish 2002; Watson 2004, 2007) provided no evidence of substantial movements by crab in the size classes that were tagged (males and females ≥90-mm carapace length [CL]). Maximum straight-line distance between release and recovery location of 90 golden king crab released prior to the 1991/92 season and recovered through the 1992/93 season was 33.1 nm (61.2 km; Blau and Pengilly 1994). Of the 4,053 recoveries reported through 14 March 2008 for the golden king crab tagged and released between 170.5° W longitude and 171.5° W longitude during the 1997, 2000, 2003, and 2006 triennial ADF&G Aleutian Island golden king pot surveys, none were recovered west of 174° W longitude and only four were recovered west of 172° W longitude (V. Vanek, ADF&G, Kodiak, personnel communication).

4. **Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology):**

The following review of molt timing and reproductive cycle of golden king crab is adapted from Watson et al. (2002):

> Unlike red king crab, golden king crab may have an asynchronous molting cycle (McBride et al. 1982; Otto and Cummiskey 1985; Sloan 1985; Blau and Pengilly 1994). In a sample of male golden king crab 95–155-mm CL and female golden king crab 104–157-mm CL collected from Prince William

Sound and held in seawater tanks, Paul and Paul (2000) observed molting in every month of the year, although the highest frequency of molting occurred during May–October. Watson et al. (2002) estimated that only 50% of 139-mm CL male golden king crab in the eastern Aleutian Islands molt annually and that the intermolt period for males ≥150-mm CL averages >1 year.

Female lithodids molt before copulation and egg extrusion (Nyblade 1987). From their observations on embryo development in golden king crab, Otto and Cummiskey (1985) suggested that time between successive ovipositions was roughly twice that of embryo development and that spawning and molting of mature females occurs approximately every two years. Sloan (1985) also suggested a reproductive cycle >1 year with a protracted barren phase for female golden king crab. Data from tagging studies on female golden king crab in the Aleutian Islands are generally consistent with a molt period for mature females of 2 years or less and that females carry embryos for less than two years with a prolonged period in which they remain in barren condition (Watson et al 2002). From laboratory studies of golden king crab collected from Prince William Sound, Paul and Paul (2001) estimated a 20-month reproductive cycle with a 12-month clutch brooding period.

Numerous observations on clutch and embryo condition of mature female golden king crab captured during surveys have been consistent with asynchronous, aseasonal reproduction (Otto and Cummiskey 1985; Hiramoto 1985; Sloan 1985; Somerton and Otto 1986, Blau and Pengilly 1994, Blau et al. 1998, Watson et al. 2002). Based on data from Japan (Hiramoto and Sato 1970), McBride et al. (1982) suggested that spawning of golden king crab in the Bering Sea and Aleutian Islands occurs predominately during the summer and fall.

The success of asynchronous and aseasonal spawning of golden king crab may be facilitated by fully lecithotrophic larval development (i.e., the larvae can develop successfully to juvenile crab without eating; Shirley and Zhou 1997). Current knowledge of reproductive biology and maturity of male and female golden king crab is also reviewed by Webb (2014).

Note that asynchronous, aseasonal, molting and the prolonged intermolt period (>1 year) of mature female and the larger male golden king crab likely makes precise scoring of shell conditions very difficult. This pattern would obscure potential relationships between shell condition and time-elapsed since molting and pose problems for inclusion of shell condition data into assessment models.

5. <u>Brief summary of management history</u>:

A complete summary of the management history through the 2010/11 season is provided in Baechler (2012, pages 12–18). The first commercial landing of golden king crab in the Aleutian Islands was in 1975/76, but directed fishing did not occur until 1981/82. Peak harvest occurred during 1986/87 when 14.739-million lb (6.686 kt) were harvested. Between 1981/82 and 1995/96 the fishery was managed as two separate fisheries in two separate registration areas, the Adak and Dutch Harbor areas, with the two areas divided at 172° W longitude through 1983/84 and at 171° W longitude after 1983/84. Prior to the 1996/97 season no formal preseason harvest target or limit was established for the fishery and average annual retained catch during 1981/82 – 1995/96 was 8.456-million lb (3.836 kt).

The Aleutian Islands golden king crab fishery was restructured beginning with the 1996/97 season to replace the Adak and Dutch Harbor areas with the newly created Aleutian Islands Registration Area O and golden king crab in the areas east and west of 174° W longitude were managed separately as two stocks. The 1996/97–1997/98 seasons were managed under a 5.900-million lb (2.676 kt) guideline harvest level (GHL), with 3.200-million lb (1.452 kt) apportioned to the area east of 174° W longitude and 2.700-million lb (1.225 kt) apportioned to the area west of 174° W longitude. The 1998/99–2004/05 seasons were managed under a 5.700-million lb (2.585 kt) GHL, with 3.000-million lb (1.361 kt) apportioned to the area east of 174° W longitude and 2.700-million lb (1.225 kt) apportioned to the area west of 174° W longitude. The 2005/06–2007/08 seasons were managed under a 5.700-million lb (2.585 kt) total allowable catch (TAC), with 3.000-million lb (1.361 kt) apportioned to the area east of 174° W longitude and 2.700-million lb (1.225 kt) apportioned to the area west of 174° W longitude. By state regulation (5 AAC 34.612), the TAC for retained catch for the Aleutian Islands golden king crab fishery for each of the 2008/09–2011/12 seasons was 5.985-million lb (2.715 kt), apportioned as 3.150-million lb (1.429 kt) for the area east of 174° W longitude and 2.835-million lb (1.286 kt) for the area west of 174° W longitude. In March 2012 the BOF changed **5 AAC 34.612** so that the TAC beginning with the 2012/13 season would be 6.290-million lb (2.853 kt), apportioned as 3.310-million lb (1.501 kt) for the area east of 174° W longitude and 2.980-million lb (1.352 kt) for the area west of 174° W longitude. Additionally, the BOF added a provision to **5 AAC 34.612** that allows ADF&G to lower the TAC below the specified level if conservation concerns arise. Over the period 1996/97–2012/13 the total of the annual retained catch has averaged 2% below the total of the annual GHL/TACs. During 1996/97–2012/13 the retained catch has been as much as 13% below (the 1998/99 season) and as much as 6% above (the 2000/01 season) the GHL/TAC. The retained catch for the 2012/13 season was <1% below the 6.290-million lb (2.853 kt) TAC. The TAC for the ongoing 2013/14 season was established at 6.290-million lb (2.853 kt). However, in addition to the retained catch that will count towards the 2013/14 TAC, an additional 0.106-million lb (48 t) was harvested during the 2013/14 season in cost-recovery fishing to provide $300,000 in funding to ADF&G to pay for observers deployed on catcher-only vessels and ADF&G administrative costs of the state-funded observer program for the Aleutian Islands golden king crab fishery (H. Fitch, ADF&G, Dutch Harbor, personal communication).

A summary of other relevant SOA fishery regulations and management actions pertaining to the Aleutian Islands golden king crab fishery is provided below.

The 2005/06 season was the first Aleutian Islands golden king crab fishery prosecuted under the Crab Rationalization Program. Accompanying the implementation of the Crab Rationalization program was implementation of a community development quota (CDQ) fishery for golden king crab in the eastern Aleutians (i.e., east of 174° W longitude) and the Adak Community Allocation (ACA) fishery for golden king crab in the western Aleutians (i.e., west of 174° W longitude; Hartill 2012). The CDQ fishery in the eastern Aleutians is allocated 10% of the golden king crab TAC for the area east of 174° W longitude and the ACA fishery in the western Aleutians is allocated 10% of the golden king crab TAC for the area west of 174° W longitude. The CDQ fishery and the ACA fishery are prosecuted concurrently with the IFQ fishery and are managed by ADF&G.

Only males of a minimum size may be retained by the commercial golden king crab fishery in the Aleutian Islands Area. By SOA regulation (**5 AAC 34.620 (b)**), the minimum legal size limit is 6.0-inches (152 mm) carapace width (CW), including spines. A carapace length (CL) ≥136 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007b). Note that size limit for golden king crab has been 6-inches

(165 mm) CW for the entire Aleutian Islands Area only since the 1985/86 season. Prior to the 1985/86 season the legal size limit was 6.5-inches for at least one of the now-defunct Adak or Dutch Harbor Registration Areas.

Golden king crab may be commercially fished only with king crab pots (defined in **5 AAC 34.050**). Pots used to fish for golden king crab in the Aleutian Islands Area must be operated from a shellfish longline and, since 1996, must have at least four escape rings of five and one-half inches minimum inside diameter installed on the vertical plane or at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized golden king crab (**5 AAC 34.625 (b)**). Prior to the regulation requiring an escape mechanism on pots, some participants in the Aleutian Islands golden king crab fishery voluntarily sewed escape rings (typically 139-mm or 5.5 inches) into their gear or, more rarely, included panels with escape mesh (Beers 1992). With regard to the gear used by fishers since the establishment of **5 AAC 34.625 (b)** in 1996, Linda Kozak, a representative of the industry, reported in a 19 September 2008 email to the Crab Plan Team that, "… the golden king crab fleet has modified their gear to allow for small crab sorting," and provided a written statement from Lance Nylander, of Dungeness Gear Works in Seattle, who "believes he makes all the gear for the golden king crab harvesting fleet," saying that, "Since 1999, DGW has installed 9[-inch] escape web on the door of over 95% of Golden Crab pot orders we manufactured." A study to estimate the contact-selection curve for male golden king crab that was conducted aboard one vessel commercial fishing for golden king crab during the 2012/13 season showed that gear and fishing practices used by that vessel was highly effective in reducing bycatch of sublegal-sized males and females (Vanek et al. 2013). In March 2011 (effective for the 2011/12 season), the BOF amended **5 AAC 34.625 (b)** to relax the "biotwine" specification for pots used in the Aleutian Islands golden king crab fishery relative to the requirement in **5 AAC 39.145** (Escape Mechanism for Shellfish and Bottomfish Pots) that "(1) a sidewall ...of all shellfish and bottomfish pots must contain an opening equal to or exceeding 18 inches in length... The opening must be laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 30 thread." Regulation **5 AAC 34.625 (b)(1)** allows the opening described in **5 AAC 39.145 (1)** to be "laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 60 [rather than 30] thread."

Regulation **5 AAC 34.610 (b)** sets the commercial fishing season for golden king crab in the Aleutian Islands Area as 15 August through 15 May. The BOF in March 2014 voted to change regulation **5 AAC 34.610 (b)** to set the commercial fishing season for golden king crab in the Aleutian Islands Area as 1 August through 30 April; that change will not become effective until the 2015/16 season.

Current regulations stipulate that onboard observers are required during the harvest of 50% of the total golden king crab weight harvested by each catcher vessel and 100% of the fishing activity of each catcher-processor during each of the three trimesters as outlined in **5 AAC 39.645 (d)(4)(A)**.

6. <u>Brief description of the annual ADF&G harvest strategy</u>:

The annual TAC is set by state regulation, **5 AAC 34.612 (Harvest Levels for Golden King Crab in Registration Area O),** as approved by the BOF in March 2012:

(a) Until the Aleutian Islands golden king crab stock assessment model and a state regulatory harvest strategy are established, the harvest levels for the Registration Area O golden king crab fishery are as follows:

(1) east of 174° W long.: 3.31 million pounds; and
(2) west of 174° W long.: 2.98 million pounds;

(b) The department may reduce the harvest levels based on the best scientific information available and considering the reliability of estimates and performance measures, sources of uncertainty as necessary to avoid overfishing, and any other factors necessary to be consistent with sustained yield principles.

7. **Summary of the history of B_{MSY}:** Not applicable for this Tier 5 stock.

D. Data

1. **Summary of new information:**
   - Fishery data on retained catch and non-retained bycatch during 2012/13 crab fisheries have been added.
   - Data on bycatch during groundfish fisheries in reporting areas 541, 542, and 543 have been updated with data grouped by "fixed" (hook-and-line and pot) and "trawl" (non-pelagic trawl) for 2012/13 have been added.
   - Estimates of total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) during 2012/13 have been added.

2. **Data presented as time series:**

***a. Total catch** and b. **Information on bycatch and discards**:*

- Fish ticket data on retained catch numbers, retained catch weight, pot lifts, CPUE, and average weight of retained catch for the 1981/82–2012/13 seasons are presented (Table 1).
- Statistics from all available data on bycatch of Aleutian Islands golden king crab obtained from pot lifts sampled by at-sea observers during the directed and non-directed crab fisheries are presented for 1990/91–1992/93 and 1995/96–2012/13 (Table 2). Some observer data exists for the 1988/89–1989/90 seasons, but that data is not considered reliable. Although bycatch can occur in the red king crab, scarlet king crab, grooved Tanner crab, and triangle Tanner crab fisheries of the Aleutian Islands, such bycatch accounts for ≤2% of the estimated total weight in the crab fisheries annually when those fisheries are prosecuted. Only one vessel was observed during the directed fishery throughout the 1993/94 season and only two vessels were observed throughout the 1994/95 season (an additional catcher vessel carried an observer for one trip during the 1993/94 season and an additional three catcher vessels carried an observer for one trip during the 1994/95 season, but observed effort was small relative to the total season effort for those vessels and the author does not consider the data from those vessels reliable). Hence, data on bycatch during the 1993/94 and 1994/95 directed fishery seasons are confidential and not presented here. Observer data on size distributions and estimated catch numbers of non-retained catch were used to estimate the weight of non-retained catch of red king crab by applying a weight-at-length estimator (see below); data on the size distribution of non-retained legal males was not recorded prior to 1998/99 and weights of retained legal males are used to estimate the weights of non-retained legal males during those years. Data on bycatch of golden king crab obtained by at-sea observers during groundfish fisheries in reporting areas 541, 542, and 543 (Figure 6) for crab fishery years 1993/94–

2012/13 are presented (estimates for 1991/92–1992/93 are also presented, but they appear to be suspect; Table 3).

- Estimates of bycatch mortality during 1990/91–1992/93 and 1995/96–2012/13 directed and non-directed crab fisheries and 1993/94–2011/12 groundfish fisheries are presented in Table 4. Estimates of total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) during 1995/96–2012/13 are presented (Table 4). Following Siddeek et al. (2012), the bycatch mortality rate of king crab captured and discarded during Aleutian Islands king crab fisheries was assumed to be 0.2; that value was also applied as the bycatch mortality during other crab fisheries. Following Foy (2012a, 2012b), the bycatch mortality of king crab captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crab captured by trawls during groundfish fisheries was assumed to be 0.8.

c. ***Catch-at-length:*** Not used in a Tier 5 assessment; none are presented.

d. ***Survey biomass estimates:*** Not used in a Tier 5 assessment; none are presented.

e. ***Survey catch at length:*** Not used in a Tier 5 assessment; none are presented (see section D.4).

f. ***Other data time series:*** See section D.4 on other time-series data that are available, but not presented here.

3. Data which may be aggregated over time:

a. ***Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):***

Growth per molt and probability of molt estimates are not used in a Tier 5 assessment. However, growth per molt and probability of molt have been estimated for Aleutian Islands golden king crab by Watson et al. (2002) based on information received from recoveries during the 1997/98–2000/01 commercial fisheries in the area east of 174° W longitude of male and female golden king crab tagged and released during July–August 1997 in the area east of 174° W longitude (see Tables 24–28 *in* Pengilly 2009).

Watson et al. (2002) used logistic regression to estimate the probability as a function of carapace length (CL, mm) at release that a male tagged and released in new-shell condition would molt within 12–15 months after release:

$$P(\text{molt}) = \exp(17.930 - 0.129*CL)/[1 + \exp(17.930 - 0.129*CL)].$$

Based on the above logistic regression, Watson et al. (2002) estimated that the size at which 50% of new-shell males would be expected to molt within 12–15 months is 139-mm CL (S.E. = 0.81-mm CL).

Watson et al. (2002) used a logistic regression to estimate the probability as a function of carapace length (CL, mm) at release that a male tagged and released as a sublegal ≥ 90-mm CL in new-shell condition would molt to legal size within 12–15 months after release:

$$P(\text{molt to legal size}) = 1 - \exp(15.541 - 0.127*CL)/[1 + \exp(15.541 - 0.127*CL)].$$

Based on the above logistic regression, Watson et al. (2002) estimated that the size at which 50% of sublegal ≥90-mm CL, new-shell males would be expected to molt to legal size within 12–15 months is 123-mm CL (S.E. = 1.54-mm CL).

See section C.4 for discussion of evidence that mature female and the larger male golden king crab exhibit asynchronous, aseasonal molting and a prolonged intermolt period (>1 year).

b. Weight-at length or weight-at-age (by sex):
Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female golden king crab according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007b) are: A = 0.0002988 and B = 3.135 for males and A = 0.001424 and B = 2.781 for females. Although the parameters A and B were derived from ovigerous females, those parameters were used to estimate the weight of all females without regard to reproductive status. Estimated weights in grams were converted to lb by dividing by 453.6.

c. Natural mortality rate:
The default natural mortality rate assumed for king crab species by NPFMC (2007b) is M=0.18. However, that natural mortality assumption was not used in this Tier 5 stock assessment.

4. Information on any data sources that were available, but were excluded from the assessment:
Data from triennial ADF&G pot surveys for Aleutian Islands golden king crab in a limited area east of 174° W longitude (between 170° 21' and 171° 33' W longitude) that were performed during 1997 (Blau et al. 1998), 2000 (Watson and Gish 2002), 2003 (Watson 2004), and 2006 (Watson 2007) are available, but were not used in this Tier 5 assessment.

E. Analytic Approach

1. **History of modeling approaches for this stock:** This is a Tier 5 stock. There is an assessment model in development for this stock (Siddeek et al. 2012).

2. **Model Description:** *Subsections a–i are not applicable to a Tier 5 stock.*

It was recommended by NPFMC (2007b) that the Aleutian Islands golden king crab stock be managed as a Tier 5 stock until an assessment model is accepted for use in management. Such a model is in development (Siddeek et al. 2012), but has not been accepted. In 2012 the SSC recommended that this stock be managed under Tier 5 for 2012/13 (June 2012 SSC minutes).

For Tier 5 stocks only an OFL is estimated, because it is not possible to estimate MSST without an estimate of biomass, and "the OFL represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock" (NPFMC 2007b). Additionally, NPFMC (2007b) states that for estimating the OFL of Tier 5 stocks, "The time period selected for computing the average catch, hence the OFL, should be based on the best scientific information available and provide the required risk aversion for stock conservation and utilization goals." Although NPFMC (2007b) defined the OFL in terms of the retained catch, total-catch OFLs may be considered for Tier 5 stocks for which nontarget fishery removal data are available (Federal Register/Vol. 73, No. 116, 33926). The CPT (in May 2010) and the SSC (in June 2010) endorsed the use of a total-catch OFL to establish the 2010/11 and subsequent OFLs for this stock. This assessment recommends – and only considers – use of a total-catch Tier 5 OFL for 2013/14.

For estimating the OFL of Tier 5 stocks, NPFMC (2007b) states, "The time period selected for computing the average catch, hence the OFL, should be based on the best scientific information available and provide the required risk aversion for stock conservation and utilization goals." Prior to 2008, two time periods were considered for computing the average retained catch for Aleutian Islands golden king crab: 1985–2005 (NPFMC 2007a) and 1985–1999 (NPFMC 2007b). The average retained catch over the years 1985 to 1999 was recommended by NPFMC (2007b) for the estimated OFL for Aleutian Islands golden king crab. Years post-1984 were chosen based on an assumed 8-year lag between hatching during the 1976/77 "regime shift" and growth to legal size. With regard to excluding data from years after 1999, NPFMC (2007b) states, "Years from 2000 to 2005 were excluded for Aleutian Islands golden king crab when the TAC was set below the previous average catch." Note, however, that there was no TAC or GHL established for the entire Aleutian Islands Area prior to the 1996/97 season (see above) and the GHL for the Aleutian Islands Area was reduced from 5.900-million lb (2.676 kt) for the 1996/97 and 1997/98 seasons to 5.700-million lb (2.585 kt) for the 1998/1999 season; the GHL or TAC has remained at 5.700-million lb (2.585 kt) for all subsequent seasons until it was increased to 5.985-million lb (2.715 kt) for the 2008/09 season. Pengilly (2008) discussed nine periods, spanning as long as 26 seasons (1981/82–2006/07) to as short as six seasons (1990/91–1995/96), for computing average annual retained catch and estimating the OFL for the 2008/09 season. Only periods beginning no earlier than 1985/86 were recommended for consideration, however, due to the size limit change that occurred prior to the 1985/86 season (Table 1, footnotes d–f). The Crab Plan Team in May 2008 recommended using the period 1990/91–1995/96 for computing the 2008/09 OFL. The CPT recommended the period 1990/91–1995/96 due to concerns raised by a decline in retained catch and CPUE that occurred from 1985/86 into the mid-1990s, the seasons of unconstrained catch under the current size limit. The SSC recommended using the period 1985/86–1995/96 for computing the 2008/09 OFL, however, because the period 1985/86–1995/96 is the longest possible period of unconstrained catch under the current size limit ("Earlier years were not recommended for inclusion because of a difference in the size limit regulations prior to 1985/86." Minutes of the NPFMC SSC meeting, 2–4 June 2008). Pengilly (2009) discussed only three time periods to consider for setting the 2009/10 OFL: 1985/86–1995/96 (the period recommended by the SSC for the 2008/09 OFL); 1990/91–1995/96; (the period recommended by the CPT for the 2008/09 OFL); and 1987/88–1995/96. The period 1987/88–1995/96 was offered for consideration on the basis of having the longest period of unconstrained catch under the current size limit, while excluding the two seasons with the highest retained catch in the history of the fishery (the 1985/86–1986/87 seasons). Trends of declining catch, declining CPUE, and declining average weight of landed crab that occurred from 1985/86 into the mid-1990s could be interpreted as resulting from a fishery that relied increasingly on annual recruitment to legal size while harvesting a declining stock of legal-size males. Hence the catches during the full period of unconstrained catch under the current size limit, 1985/86–1995/96, could be viewed as unsustainable. Removal of the two highest-catch seasons, 1985/86–1986/87, at the beginning of that time period was offered as a compromise between the desire for the longest period possible for averaging catch and the desire for a period reflecting long-term production potential of the stock. Of those, the CPT at the May 2009 again recommended using the period 1990/91–1995/96 for computing the 2009/10 OFL, whereas the SSC again recommended 1985/86–1995/96, noting that "the management system was relatively constant from 1985 onward" and that a "longer time period likely provides a more robust estimate than a shorter time period." (Minutes of the NPFMC SSC meeting, 1–3 June 2009).

Three alternatives were considered for setting a total-catch OFL for 2010/11 (see the Executive Summary of the May Draft of the 2010 Crab SAFE), none of which could be chosen with consensus by the CPT in May 2010 and all of which were rejected by the SSC in June 2010. In June 2010 the SSC recommended an approach to computing a total-catch OFL for this stock for 2010/11 as follows (Minutes of the NPFMC SSC meeting, 7–9 June 2010):

$$OFL_{2010/11} = (1+R_{96/97\text{-}08/09})\bullet RET_{85/86\text{-}95/96} + BM_{GF,96/97\text{-}08/09} = 11.0 \text{ million lb.,}$$

where

- $R_{96/97\text{-}08/09}$ is the average of the estimated annual ratios of lb of bycatch mortality due to crab fisheries to lb of retained catch in the directed fishery during the period 1996/97-2008/09,
- $RET_{85/86\text{-}95/96}$ is the average annual retained catch in the directed crab fishery during the period 1985/86-1995/96, and
- $BM_{GF,\ 96/97\text{-}08/09}$ is the average of the annual estimates of bycatch mortality due to groundfish fisheries over the period 1996/97-2008/09.

Additionally, the SSC in June 2010 recommended that "...this time period be frozen to stabilize the control rule."

Data on bycatch during crab fisheries prior to 1996/97 were presented to the CPT in May 2011 and the CPT recommended the following OFL for the 2011/12 season, which was also recommended by the SSC in June 2011:

$$OFL_{2011/12} = (1+R_{90/91\text{-}08/09})\bullet RET_{85/86\text{-}95/96} + BM_{GF,93/94\text{-}08/09},$$

where,

- $R_{90/91\text{-}08/09}$ is the average of the estimated annual ratios of lb of bycatch mortality due to crab fisheries to lb of retained catch in the directed fishery during the period 1990/91-2008/09 (excluding 1993/94–1994/95, due to data confidentialities and insufficiencies)
- $RET_{85/86\text{-}95/96}$ is the same as defined for $OFL_{2010/11}$, above (i.e., the average annual retained catch in the directed crab fishery during the period 1985/86-1995/96), and
- $BM_{GF,93/94\text{-}08/09}$ is the same as defined for $OFL_{2010/11}$, above (i.e., the average of the annual estimates of bycatch mortality due to groundfish fisheries over the period 1993/94-2008/09).

Trends in the estimated annual ratios of lb of bycatch mortality due to crab fisheries to lb of retained catch in the directed fishery during the period 1990/91-2008/09 were presented to the CPT in May 2012 and SSC in June 2012. The SSC found that the estimated annual ratios of lb of bycatch mortality due to crab fisheries to lb of retained catch in the directed fishery prior to the 1996/97 season were a better reflection of bycatch mortality during the 1985/86–1995/96 seasons than the estimates from the 1996/97–2008/09 seasons. Accordingly, the SSC (June 2012 SSC minutes) recommended that the OFL for the 2012/13 season be computed as:

$$OFL_{2012/13} = (1+R_{90/91\text{-}95/96})\bullet RET_{85/86\text{-}95/96} + BM_{GF,93/94\text{-}08/09},$$

where,

- $R_{90/91\text{-}95/96}$ is the average of the estimated annual ratios of lb of bycatch mortality due to crab fisheries to lb of retained catch in the directed fishery during the period 1990/91–1995/96 (excluding 1993/94–1994/95, due to data confidentialities and insufficiencies),

- $RET_{85/86-95/96}$ is the same as defined for Alternative 1, above (i.e., the average annual retained catch in the directed crab fishery during the period 1985/86-1995/96), and
- $BM_{GF,93/94-08/09}$ is the same as defined for Alternative 1, above (i.e., the average of the annual estimates of bycatch mortality due to groundfish fisheries over the period 1993/94-2008/09).

The OFL for 2013/14 was determined following the same procedure as for 2012/13.

3. <u>Model Selection and Evaluation</u>:

a. ***<u>Description of alternative model configurations</u>***

During the 2008–2012 reviews of a Tier 5 OFL stock (see section 2, above), the SSC has recommended the "time period be frozen to stabilize the control rule" and that computation of the Tier 5 OFL should use: 1) the period 1985/86–1995/96 to compute the average retained catch (June 2008, and 2009 SSC minutes); 2) the "time period [to compute the Tier 5 OFL] be frozen to stabilize the control rule" at 1985/86–2008/09 (June 2010 SSC minutes); and 3) that bycatch data from crab fisheries from the period prior to 1996/97 be used to compute the Tier 5 OFL. Given those recommendations from the SSC and the lack of any additional fishery data from the period 1985/86–2008/09 that was not available and presented in 2012, only one alternative is presented, the author's recommended alternative, which is the status quo (i.e., the same as the Tier 5 OFL for 2012/13 and for 2013/14 that was established in 2012):

$$OFL_{2014/15} = (1+R_{90/91-95/96}) \cdot RET_{85/86-95/96} + BM_{GF,93/94-08/09},$$

where,

- $R_{90/91-95/96}$ is the average of the estimated annual ratios of lb of bycatch mortality due to crab fisheries to lb of retained catch in the directed fishery during the period 1990/91–1995/96 (excluding 1993/94–1994/95, due to data confidentialities and insufficiencies),
- $RET_{85/86-95/96}$ is the average annual retained catch in the directed crab fishery during the period 1985/86-1995/96, and
- $BM_{GF,93/94-08/09}$ is the average of the annual estimates of bycatch mortality due to groundfish fisheries over the period 1993/94-2008/09.

Statistics on the data and estimates used to calculate, $RET_{(85/86-95/96}$, $R_{90/91-95/96}$, and $BM_{GF,93/94-08/09}$ are provided in Table 5; the column averages in Table 5 are the calculated values of $RET_{(85/86-95/96}$, $R_{90/91-95/96}$, and $BM_{GF,93/94-08/09.}$ Using those calculated values of $RET_{(85/86-95/96}$, $R_{90/91-95/96}$, and $BM_{GF,93/94-08/09}$, $OFL_{2014/15}$ is computed as,

$$OFL_{2014/15} = (1+0.363) \cdot (9{,}178{,}438) + 23{,}359 = 12{,}533{,}570 \text{ lb (12.53-million lb; 5.69 kt).}$$

Note that although the OFL for 2014/15 is computed using the same procedure and values as were used to compute the OFL for 2012/13 and 2013/14, the resulting computed value expressed in lb for $OFL_{2014/15}$ (12,533,569 lb) is inexplicably different from the value reported for $OFL_{2012/13}$ and $OFL_{2013/14}$ (12,537,757 lb) in the 2012 and 2013 SAFEs.

b. ***<u>Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed</u>:*** See the section A.4.

c. ***Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models:*** See the section A.4.

d. ***Convergence status and convergence criteria for the base-case model (or proposed base-case model):*** Not applicable.

e. ***Table (or plot) of the sample sizes assumed for the compositional data:*** Not applicable.

f. ***Do parameter estimates for all models make sense, are they credible?:***
The 1985/86–2008/09 time period and the time periods for fishery mortality subcomponents within 1985/86–2008/09 used for determining the OFL were established by the SSC during 2008–2012. The values for retained catch and estimated bycatch mortality used in the OFL computation are in Table 5. Temporal trends during 1985/86–2012/13 in retained catch and in the available estimates of bycatch mortality due to crab fisheries and groundfish fisheries are shown in Figure 7. Trends in the ratio of the estimated bycatch mortality due to crab fisheries to the retained catch are shown in Figures 8 and 9 for the years that data and estimates are available during 1985/86–2012/13. Retained catch data come from fish tickets and annual retained catch is assumed to be known. Estimates of bycatch from crab fisheries data are generally considered credible (e.g., Byrne and Pengilly 1998; Gaeuman 2013). Estimates of bycatch mortality were derived as estimates of bycatch times an assumed bycatch mortality rate. The assumed bycatch mortality rates (i.e., 0.2 for crab fisheries, 0.5 for fixed-gear groundfish fisheries, and 0.8 for trawl groundfish fisheries) have not been estimated from data.

g. ***Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty:*** See section E.3.c, above.

h. ***Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach):*** Not applicable.

i. ***Evaluation of the model, if only one model is presented; or evaluation of alternative models and selection of final model, if more than one model is presented:*** The model for computing the single recommended OFL follows the SSC recommendations to freeze the time period to stabilize the control role by using only 1985/86–1995/96 to estimate the average annual retained catch component of the OFL (June 2008 and June 2009 SSC minutes), to not include bycatch data after 2008/09 (June 2010 SSC minutes), and to use only the bycatch mortality estimates from the crab fisheries that are available from 1990/91–1995/96 (June 2012 SSC minutes). The author and the SSC (June 2012 SSC minutes) agree that the bycatch data from crab fisheries during 1990/91–1995/96 are the most representative data available of the conditions that existed during 1985/86–1995/96: those years fall within the period 1985/86–1995/96; regulations stipulating escape mechanisms in pots became effective after 1995/96 (see section **C.5-Brief summary of management history**); and there is a clear decreasing trend in the estimated ratio of lb of bycatch mortality due to crab fisheries to lb of retained crab in the directed fishery since 1996/97 (Figures 8 and 9).

4. Results (best model(s)):

a. List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties: Not applicable.

b. ***Tables of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible; include estimates from previous SAFEs for retrospective comparisons):*** See Tables 5–6.

c. ***Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible):*** Information requested for this subsection is not applicable to a Tier 5 stock.

d. ***Evaluation of the fit to the data:*** Not applicable for Tier 5 stocks.

e. ***Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments):*** Not applicable for Tier 5 stocks.

f. ***Uncertainty and sensitivity analyses (this section should highlight unresolved problems and major uncertainties, along with any special issues that complicate scientific assessment, including questions about the best model, etc.):*** For a Tier 5 assessment, the major uncertainties are:

- Whether the chosen time period is "representative of the production potential of the stock" and if it serves to "provide the required risk aversion for stock conservation and utilization goals" or whether any such time period exists.
  - The Tier 5 OFL for this stock is highly sensitive to the choice of years used to compute the average annual catch. The table on page 19 of Pengilly (2008) addressed the justifications for alternative choices of time periods that could be used to compute the retained-catch portion of the OFL and interested readers are directed to that document. Briefly, the average retained-catch of the OFL for the nine alternative time periods presented ranged from 5.633 million lb (2.555 kt; for 1996/97–2006/07) to 9.178 million lb (4.163 kt; for 1985/86–1995/96, the time period selected and "frozen" by the SSC). The CPT in 2008 and 2009 recommended that the years 1990/91–1995/96 be used to compute the retained-catch OFL (resulting in a retained-catch OFL of 6.931-million lb; 3.144 kt). In both 2008 and 2009, the SSC overrode the CPT's recommendation and selected the years 1985/86–1995/96 to compute the retained-catch OFL at 9.178-million lb (4.163 kt). The SSC recommended that the time period for computing the retained-catch portion of the OFL "be frozen" at 1985/86–1995/96 "to stabilize the control rule."
  - The Tier 5 OFL is also sensitive to the choice of years used to estimate the average annual ratio of lb of bycatch mortality to lb of retained crab in the crab fisheries. The SSC recommended that the time period for computing the bycatch-mortality portion of the OFL be frozen to end at 2008/09. The estimates of annual bycatch biomass (not discounted for bycatch mortality) to retained catch are generally highest during 1990/91–1995/96 and show a decreasing trend during 1996/97–2008/09: that ratio during 1990/91–1995/96 ranges from 1.5:1 to 2.1:1, during 1996/97–2004/05 ranges from 0.8:1 to 1.7:1, and during 2005/06–2008/09 ranges from 0.5:1 to 0.6:1 (see Figures 8 and 9 for the trend in ratios after a default bycatch mortality rate is applied to the bycatch biomass estimates). Hence, including the later years to compute the average annual ratio decreases the OFL estimate, whereas restricting the period to 1990/91–1995/96 increases the OFL estimate.

  - The Tier 5 OFL has only a slight sensitivity to the choice of years used to compute the bycatch due to groundfish fisheries. This assessment only considers the period 1993/94–2008/09 for bycatch in the groundfish fisheries. Estimates of annual bycatch mortality due to groundfish fisheries during 1993/94–2008/09 range from <0.001-million lb (<1 t) to 0.130-million lb (59 t). Because the estimate of bycatch biomass due to groundfish fisheries is small relative to the biomass of retained catch (≥4.819-million lb [2.186 kt] annually during 1985/86–2010/11), the effect of choice of years here is negligibly small.
- The bycatch mortality rates used in estimation of total fishery mortality are assumed values. Bycatch mortality is unknown and no data that could be used to estimate the bycatch mortality of this stock is known to the author. After discussion on information presented on the apparent "hardiness" of golden king relative to red king crab at the May 2013 meeting, the CPT concluded that the handling mortality rate used in golden king crab assessments remain at the status quo, 0.2, until data for estimating handling mortality are presented (May 2013 CPT minutes). Hence only the values that are assumed for other BSAI king crab stock assessments are considered in this assessment. Due to the difference in scale between the estimated bycatch in crab fisheries and the groundfish fisheries (see bullet above), the estimated OFL is most sensitive to the assumed bycatch mortality in crab fisheries and less sensitive to the assumed bycatch in groundfish fisheries. Given a fixed period of years to compute the average of annual bycatch biomass estimates for the crab fisheries, the estimated OFL is increases with an increase in the bycatch mortality rate assumed for the crab fisheries and decreases with a decrease in the assumed value. For the current *status quo* time periods used to compute the OFL, doubling the assumed bycatch mortality rate from 0.2 to 0.4 increases the OFL by 27%, from 12.53-million lb to 15.87-million lb; if the assumed bycatch mortality rate is halved from 0.2 to 0.1, the OFL estimate decreases by 13% to 10.87-million lb.
- This stock has been placed into Tier 5 for assessment due to the lack of reliable estimates of biomass as needed to estimate the B_{MSY} or a proxy of B_{MSY}, the status of the stock relative to B_{MSY} or a proxy of B_{MSY}, or trends in stock biomass. There has been no program to survey this stock in its entirety and a program to survey a portion of this stock on a triennial basis ended after 2006 due to the costs of survey implementation. An ongoing attempt to develop a stock assessment model using fishery data has as yet to produce a model acceptable to the CPT and SSC for use in stock assessment, status determination, and establishment of the OFL. Technical issues with the stock assessment model remain and the ability to use the fishery-dependent data from this stock in stock assessment has itself been recently questioned by the CPT: *"The CPT then discussed that the CPUE is not a useful index of abundance for stock assessment, as the CPUE is hyperstable because the fishery has figured out how to maximize catch post-rationalization"* (September 2013 Crab Plan Team Report). The CPT in September 2013 strongly recommended that, *"A survey is needed to provide a better index of abundance and information on recruitment for stock assessment"* and encouraged ADF&G, NMFS, and industry to discuss how to make such a survey happen; such discussions occurred at meetings in January and March 2014 and ADF&G has met with industry outside of those meeting to develop plans for a pilot survey in the near future.

F. Calculation of the OFL

1. **Specification of the Tier level and stock status level for computing the OFL:**

- Recommended as Tier 5, total-catch OFL computed as the estimated average annual total catch over a specified period.
- Recommended time period for computing retained-catch portion of the OFL: 1985/86–1995/96.
- Recommended time period for computing bycatch mortality due to crab fisheries: 1990/91–1995/96.
- Recommended time period for computing bycatch due to groundfish fisheries: 1993/94–2008/09.
- Recommended bycatch mortality rates: 0.2 for crab fisheries; 0.5 for fixed-gear groundfish fisheries; 0.8 for trawl groundfish fisheries.

2. **List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan:** Not applicable for Tier 5 stocks.

3. **Specification of the OFL:**

a. Provide the equations (from Amendment 24) on which the OFL is to be based:

From **Federal Register** / Vol. 73, No. 116, page 33926, "For stocks in Tier 5, the overfishing level is specified in terms of an average catch value over an historical time period, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information." Additionally, "For stocks where nontarget fishery removal data are available, catch includes all fishery removals, including retained catch and discard losses. Discard losses will be determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the overfishing level is set for and compared to the retained catch" (FR/Vol. 73, No. 116, 33926). That compares with the specification of NPFMC (2007b) that the OFL "represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock."

b. Basis for projecting MMB to the time of mating: Not applicable for Tier 5 stocks.

Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring: See tables below. The OFL and ABC values for 2014/15 in the table below are the recommended values. The 2014/15 TAC has not yet been established; the value given in the table is the default total allowable catch (TAC) according to current State of Alaska (SOA) regulations (5 AAC 34.612). The TAC for 2013/14 and 2014/15 in the table below does not include landings towards a cost-recovery fishing goal of $300,000 to cover costs of observer deployments in the fishery.

Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch[a]	Total Catch[a,b]	OFL[a]	ABC[a]
2010/11	N/A	N/A	5.99	5.97	6.56	11.06	N/A
2011/12	N/A	N/A	5.99	5.96	6.51	11.40	10.26
2012/13	N/A	N/A	6.29	6.27	6.87	12.54	11.28
2013/14	N/A	N/A	6.29			12.54	11.28
2014/15	N/A	N/A	6.29			12.54	9.40

a. Millions of lb.

b. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.

Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch[a]	Total Catch[a,b]	OFL[a]	ABC[a]
2010/11	N/A	N/A	2.72	2.71	2.98	5.02	N/A
2011/12	N/A	N/A	2.72	2.71	2.95	5.17	4.66
2012/13	N/A	N/A	2.85	2.84	3.12	5.69	5.12
2013/14	N/A	N/A	2.85			5.69	5.12
2014/15	N/A	N/A	2.85			5.69	4.26

a. kt.

b. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.

4. **Specification of the retained-catch portion of the total-catch OFL:**
   a. Equation for recommended retained-portion of total-catch OFL:
   Retained-catch portion = average retained catch during 1985/86–1995/96
   = 9,178,438 lb (9.18-million lb; 4.163 kt).

5. **Recommended F_{OFL}, OFL total catch and the retained portion for the coming year:**
   See sections ***F.3*** and ***F.4***, above; no F_{OFL} is recommended for a Tier 5 stock.

G. Calculation of ABC

1. PDF of OFL. Bootstrap estimate of the sampling distribution (assuming no error in estimation of bycatch) of the recommended OFL is shown in Figure 10 (1,000 samples drawn with replacement independently from each of the three columns of values in Table 5 to calculate $R_{90/91\text{-}95/96}$, $RET_{85/86\text{-}95/96}$, $BM_{GF,93/94\text{-}08/09}$ and $OFL_{Alt\text{-}2,2010/11}$). Table 6 provides statistics on the generated distributions. Note that generated sampling distribution and computed standard deviation are meaningful as measures in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Sections E.2 and E.4.f).

2. List of variables related to scientific uncertainty.

- The time period to compute the average catch relative to an assumption that this represents "a time period determined to be representative of the production potential of the stock."
- Bycatch mortality rate in each fishery that bycatch occurs. Note that for Tier 5 stocks, an increase in an assumed bycatch rate will increase the total-catch OFL (and hence the ABC), but has no effect on the retained-catch portion of the OFL or the retained-catch portion of the ABC.
- Estimated bycatch and bycatch mortality for each fishery that bycatch occurred in during 1985/86–1995/96.
- See **E.4.*f*** for details.

3. List of additional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.

5. **Author recommended ABC.**

(1.0-0.25)·12,533,570 lb = 9,400,177 lb (9.40-million lb; 4.264 kt).

The recommended ABC for 2014/15 was computed using a buffer of 0.25, rather than a buffer of 0.1 as was used to compute the ABCs for 2011/12 – 2013/14. The author makes this recommendation for the following reasons:

- The 10% buffer is not the "standard" buffer for computing the ABC of Tier 5 stocks – the 10% buffer sets the limit for the maximum ABC for a Tier 5 stock (see: Introduction chapter of September 2013 BSAI Crab SAFE). The ABC of the Tier 5 Western Aleutian Islands ("Adak") red king crab stock, for example, is based on a 40% buffer. Although "The Scientific and Statistical Committee … must provide an explanation for setting the ABC less than the maximum ABC" (see: Introduction chapter of September 2013 BSAI Crab SAFE), the SSC regularly sets the ABC less than the maximum ABC; of the eight SSC-recommended 2013/14 ABCs listed in Table 2 of the October 2013 SSC minutes, all are less than the maximum ABC.
- The review of "uncertainty" under Section E.4.f reviews the disagreement between the CPT and SSC in 2008 and 2009 (and hence the uncertainty) on whether the choice of time period established by the SSC in 2008 and 2009 to compute the OFL years is "representative of the production potential of the stock" in the long-term or in any given year or provides the "required risk aversion for stock conservation and utilization goals."
- The CPT in September 2013 highlighted the need for fishery-independent survey data for assessment of this stock. Of the six FMP stocks that are annually surveyed by the NMFS EBS continental shelf bottom trawl survey, the ABCs for three were computed using a buffer >10% (EBS Tanner crab with a buffer of 30%, and Pribilof Islands red king crab and St. Matthew blue king crab with buffers of 20% each). It is difficult to argue that there is greater uncertainty for those 3 annually surveyed stocks on the status of the stock relative to B_{MSY}, on stock trends, or on the OFL. The recommended 25% buffer is at the midpoint between the 20% and 30% buffers applied to those three surveyed stocks.

H. Rebuilding Analyses

Not applicable; this stock has not been declared overfished.

I. Data Gaps and Research Priorities

Currently, there are no biomass estimates for this stock and no program for providing fishery-independent data on the stock. The CPT in September 2013 identified development of a survey to provide better data than fishery CPUE and other fishery-dependent data to index stock abundance and recruitment. To address that priority need, ADF&G, NMFS, and industry began discussions in January 2014 to develop such a survey and plans are currently in development between ADF&G and industry to perform a pilot survey.

Bycatch mortality rate in directed fishery is unknown.

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Figure 10: page 39. Bootstrapped estimates of the sampling distribution of the recommended 2013/2014 Tier 5 OFL (lb of total-catch) for the Aleutian Islands golden king crab stock; histograms in left column, quantile plots in right column.

Table 1. Harvest history for the Aleutian Islands golden king crab fishery (GHL/TAC, lb and number of retained crabs, pot lifts, fishery catch per unit effort, and average weight of landed crab) by fishery season from the 1981/82 season through the 2012/13 season, including the Community Development Quota (CDQ) and Adak Community Allocation (ACA) fisheries for the 2005/06–2012/13 seasons; from 2013 SAFE.

Season	GHL/TAC Millions of Lb	Harvest Lb[a]	Harvest Number[a]	Pot lifts	CPUE[b]	Average Weight[c]
1981/82	-	1,319,666	242,407	28,263	8.4	5.4[d]
1982/83	-	9,236,942	1,746,206	179,888	9.4	5.3[d]
1983/84	-	10,495,045	1,964,772	267,519	7.2	5.3[d]
1984/85	-	4,819,347	995,453	90,066	10.7	4.8[e]
1985/86	-	12,734,212	2,811,195	236,281	11.9	4.5[f]
1986/87	-	14,738,744	3,340,627	433,020	7.7	4.4[f]
1987/88	-	9,257,005	2,174,576	306,730	7.1	4.2[f]
1988/89	-	10,627,042	2,488,433	321,927	7.6	4.3[f]
1989/90	-	12,022,052	2,902,913	357,803	8.0	4.1[f]
1990/91	-	6,950,362	1,703,251	214,814	7.7	4.1[f]
1991/92	-	7,702,141	1,847,398	234,857	7.7	4.2[f]
1992/93	-	6,291,197	1,528,328	203,221	7.4	4.1[f]
1993/94	-	5,551,143	1,397,530	234,654	5.8	4.0[f]
1994/95	-	8,128,511	1,924,271	386,593	4.8	4.2[f]
1995/96	-	6,960,406	1,582,333	293,021	5.2	4.4[f]
1996/97	5.900	5,815,772	1,334,877	212,727	6.0	4.4[f]
1997/98	5.900	5,945,683	1,350,160	193,214	6.8	4.4[f]
1998/99	5.700	4,941,893	1,150,029	119,353	9.4	4.3[f]
1999/00	5.700	5,838,788	1,385,890	186,169	7.2	4.2[f]
2000/01	5.700	6,018,761	1,410,315	172,790	8.0	4.3[f]
2001/02	5.700	5,918,706	1,416,768	168,151	8.3	4.2[f]
2002/03	5.700	5,462,455	1,308,709	131,021	9.8	4.2[f]
2003/04	5.700	5,665,828	1,319,707	125,119	10.3	4.3[f]
2004/05	5.700	5,575,051	1,323,001	91,694	14.2	4.2[f]
2005/06	5.700	5,520,318	1,263,339	54,685	22.9	4.4[f]
2006/07	5.700	5,262,342	1,178,321	53,065	22.0	4.5[f]
2007/08	5.700	5,508,100	1,233,848	52,609	23.5	4.5[f]
2008/09	5.985	5,680,084	1,254,607	50,666	24.8	4.5[f]
2009/10	5.985	5,912,287	1,308,218	52,787	24.8	4.5[f]
2010/11	5.985	5,968,849	1,297,229	55,795	23.2	4.6[f]
2011/12	5.985	5,964,416	1,284,946	44,241	29.0	4.6[f]
2012/13	6.290	6,267,759	1,360,582	53,543	25.4	4.6[f]

a. Includes deadloss.
b. Catch (number of crab) per pot lift.
c. Average weight (lb) of landed crab, including deadloss.
d. Managed with 6.5" CW minimum size limit.
e. Managed with 6.5" CW minimum size limit west of 171° W longitude and 6.0" minimum size limit east of 171° W longitude.
f. Managed with 6.0" minimum size limit.

Table 2. Retained catch (thousands of lb) of Aleutian Islands golden king crab, with the estimated non-retained catch (thousands of lb; not discounted for an assumed bycatch mortality rate) and components of non-retained catch (non-retained legal males, non-retained sublegal males, non-retained females) during commercial crab fisheries by season, 1990/91–2012/13; from 2013 SAFE.

Season	Retained Catch	Non-retained Catch	Components of non-retained catch: Legal males	Sublegal males	Females
1990/91	6,950	13,824	12	6,407	7,405
1991/92	7,702	11,257	214	5,533	5,510
1992/93	6,291	13,082	62	5,875	7,145
1993/94	5,551	—	—	—	—
1994/95	8,129	—	—	—	—
1995/96	6,960	12,050	64	6,054	5,932
1996/97	5,816	9,100	25	4,222	4,854
1997/98	5,946	8,733	40	4,199	4,494
1998/99	4,942	7,388	41	4,303	3,044
1999/00	5,839	7,552	64	3,930	3,557
2000/01	6,019	8,902	35	4,782	4,084
2001/02	5,919	6,888	27	3,787	3,075
2002/03	5,462	5,671	42	3,113	2,516
2003/04	5,666	4,973	39	2,664	2,271
2004/05	5,575	4,321	76	2,512	1,733
2005/06	5,520	2,524	140	1,479	905
2006/07	5,262	2,573	120	1,263	1,190
2007/08	5,508	3,035	128	1,505	1,402
2008/09	5,680	2,764	175	1,365	1,223
2009/10	5,912	2,787	164	1,364	1,260
2010/11	5,969	2,726	223	1,249	1,255
2011/12	5,964	2,540	269	1,181	1,089
2012/13	6,268	2,900	342	1,235	1,323

Table 3. Estimated annual weight (lb) of discarded bycatch of golden king crab (all sizes, males and females) and bycatch mortality (lb) during federal groundfish fisheries by gear type (fixed or trawl) in reporting areas 541, 542, and 543 (Aleutian Islands west of 170° W longitude), 1991/92–2012/13 (assumes bycatch mortality rate of 0.5 for fixed-gear fisheries and 0.8 for trawl fisheries; from 2013 SAFE).

	Bycatch		Bycatch Mortality		
Year	Fixed Gear	Trawl Gear	Fixed Gear	Trawl Gear	Total
1991/92	0	0	0	0	0
1992/93	5	3	3	2	5
1993/94	3,960	8,164	1,980	6,531	8,511
1994/95	1,346	2,674	673	2,139	2,812
1995/96	367	5,165	184	4,132	4,316
1996/97	26	13,862	13	11,090	11,103
1997/98	539	1,071	270	857	1,126
1998/99	3,901	1,381	1,951	1,105	3,055
1999/00	10,572	1,422	5,286	1,138	6,424
2000/01	7,166	669	3,583	535	4,118
2001/02	1,387	417	694	334	1,027
2002/03	75,952	871	37,976	697	38,673
2003/04	86,186	1,498	43,093	1,198	44,291
2004/05	2,450	2,452	1,225	1,962	3,187
2005/06	1,246	4,151	623	3,321	3,944
2006/07	72,306	3,077	36,153	2,462	38,615
2007/08	254,225	3,641	127,113	2,913	130,025
2008/09	108,683	22,712	54,342	18,170	72,511
2009/10	44,226	18,061	22,113	14,449	36,562
2010/11	31,456	34,801	15,728	27,841	43,569
2011/12	36,236	20,038	18,118	16,030	34,148
2012/13	1,191	24,593	596	19,674	20,270

Table 4. Estimated annual weight (thousands of lb) of total fishery mortality to Aleutian Islands golden king crab, 1990/91–2012/13, partitioned by source of mortality: retained catch, bycatch mortality during crab fisheries, and bycatch mortality during groundfish fisheries; from 2013 SAFE.

		Bycatch Mortality by Fishery Type		Total
Season	Retained Catch	Crab	Groundfish	Fishery Mortality
1990/91	6,950	2,765	—	—
1991/92	7,702	2,251	—	—
1992/93	6,291	2,616	—	—
1993/94	5,551	—	9	—
1994/95	8,129	—	3	—
1995/96	6,960	2,410	4	9,375
1996/97	5,816	1,815	11	7,642
1997/98	5,946	1,739	1	7,685
1998/99	4,942	1,478	3	6,423
1999/00	5,839	1,510	6	7,356
2000/01	6,019	1,780	4	7,803
2001/02	5,919	1,378	1	7,297
2002/03	5,462	1,134	39	6,635
2003/04	5,666	995	44	6,705
2004/05	5,575	864	3	6,442
2005/06	5,520	505	4	6,029
2006/07	5,262	515	39	5,816
2007/08	5,508	607	130	6,245
2008/09	5,680	553	73	6,305
2009/10	5,912	557	37	6,506
2010/11	5,969	545	44	6,558
2011/12	5,964	508	34	6,506
2012/13	6,268	580	20	6,868

Table 5. Data for calculation of $RET_{85/86-95/96}$ and estimates used in calculation of $R_{90/91-95/96}$ and $BM_{GF,93/94-08/09}$ for calculation of the recommended (status quo) Aleutian Islands golden king crab Tier 5 2013/14 OFL (lb); values under $RET_{85/86-95/96}$ are from Table 1, values under $R_{90/91-95/96}$ were computed from the retained catch data and the crab bycatch mortality estimates in Table 4; values under $BM_{GF,93/94-08/09}$ are from Table 4.

Season	$RET_{85/86-95/96}$ [a]	$R_{90/91-95/96}$ [b]	$BM_{GF,93/94-08/09}$ [c]
1985/86	12,734,212		
1986/87	14,738,744		
1987/88	9,257,005		
1988/89	10,627,042		
1989/90	12,022,052		
1990/91	6,950,362	0.398	
1991/92	7,702,141	0.292	
1992/93	6,291,197	0.416	
1993/94	5,551,143	—	8,511
1994/95	8,128,511	—	2,812
1995/96	6,960,406	0.346	4,315
1996/97			11,102
1997/98			1,126
1998/99			3,055
1999/00			6,424
2000/01			4,119
2001/02			1,027
2002/03			38,673
2003/04			44,291
2004/05			3,187
2005/06			3,944
2006/07			38,614
2007/08			130,026
2008/09			72,511
N	11	4	16
Average	9,178,438	0.363	23,359
S.E.M.	896,511	0.028	8,827
CV	0.10	0.08	0.38

a. $RET_{85/86-95/96}$ is the average annual retained catch (lb) in the directed crab fishery during the period 1985/86–1995/96; data from Table 1.

b. $R_{90/91-95/96}$ is the average of the estimated annual ratios of lb of bycatch mortality due to crab fisheries to lb of retained catch in the directed fishery during the period 1990/91–1995/96 (excluding 1993/94–1994/95, due to data confidentialities and insufficiencies); data from Table 4.

c. $BM_{GF,93/94-08/09}$ is the average of the annual estimates of bycatch mortality (lb) due to groundfish fisheries over the period 1993/94–2008/09; data from Table 4.

Table 6. Statistics for 1,000 bootstrap OFLs (lb) calculated according to the author recommended (status quo) approach for 2013/14 OFL calculation, with the computed OFL for comparison.

	Recommend – status quo approach
Computed OFL (lb)	12,537,757
Mean of 1,000 bootstrapped OFLs (lb)	12,510,742
Std. dev. of 1,000 bootstrapped OFLs	1,184,511
CV = (std. dev.)/(Mean)	0.09

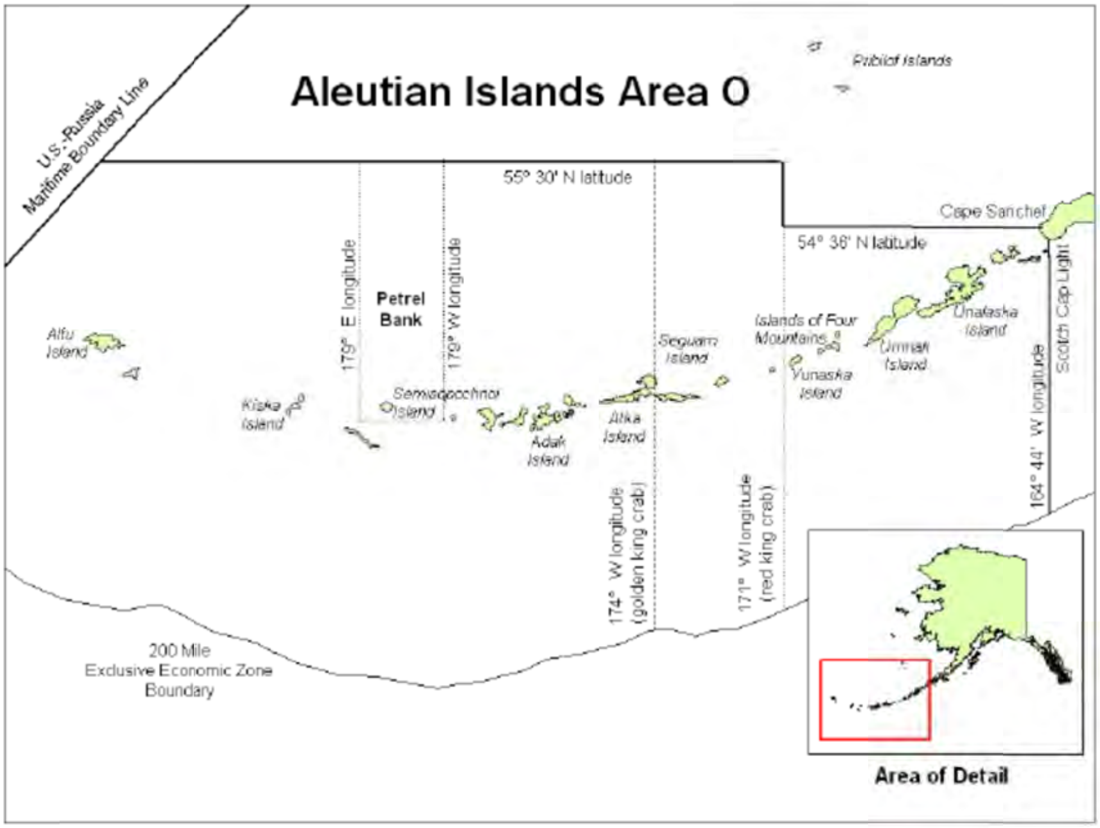

Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Baechler 2012).

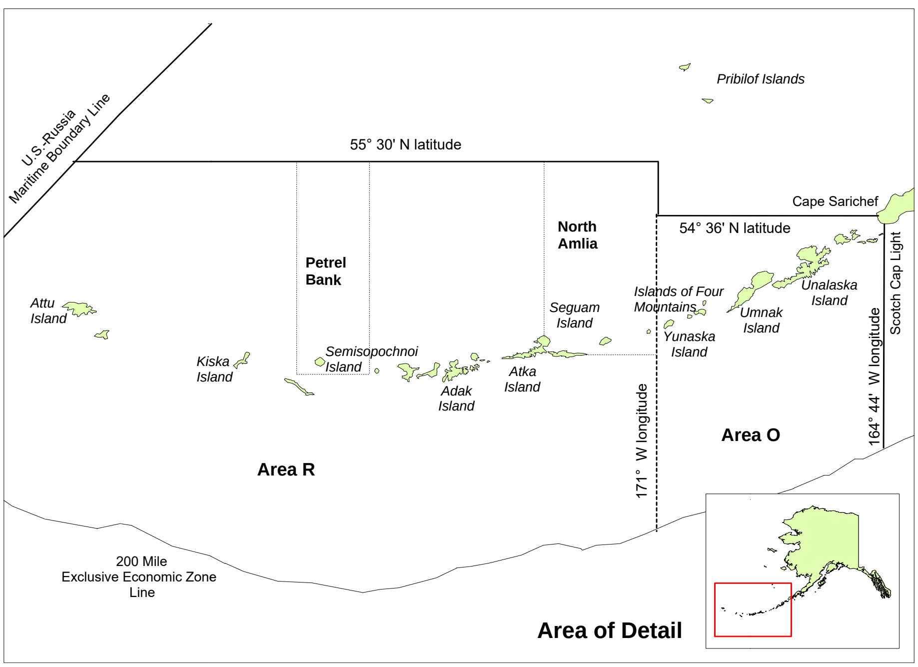

Figure 2. Adak (Area R) and Dutch Harbor (Area O) king crab Registration Areas and Districts, 1984/85–1995/96 seasons (from Baechler 2012).

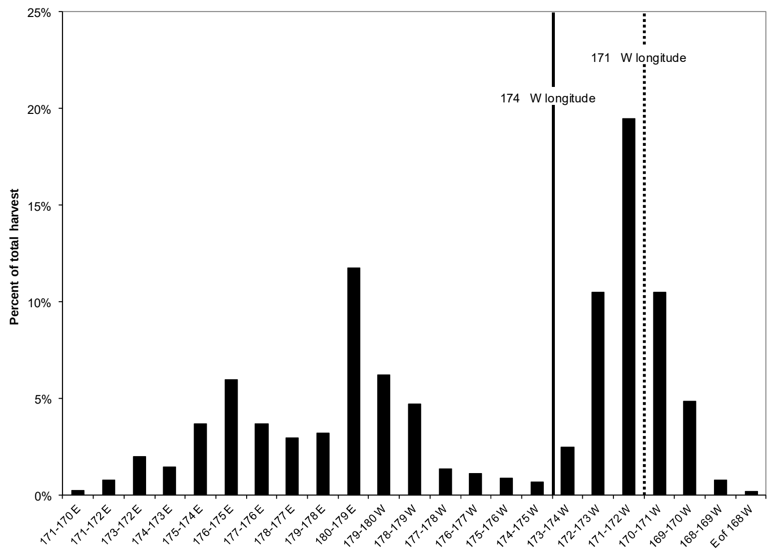

Figure 3. Percent of total 1981/82–1995/96 golden king crab harvest from one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude used during the 1984/85–1995/96 seasons to divide fishery management between the Dutch Harbor Area (east of 171° W longitude) and the Adak Area (west of 171° W longitude) and solid line denoting the border at 174° W longitude used since the 1996/97 season to manage crab east and west of 174° W longitude (adapted from Figure 4-2 *in* Morrison et al. 1998).

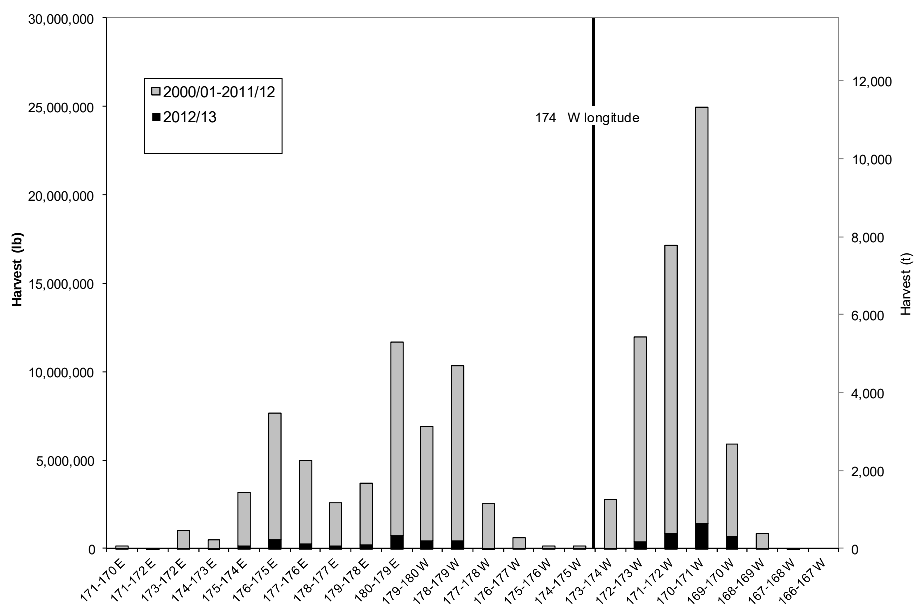

Figure 4. Harvest (lb on left axis and t on right axis) of golden king crab from one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2012/13 commercial fishery seasons; solid line denotes the border at 174° W longitude that has been used since the 1996/97 season to manage Aleutian Island golden king crab as separate stocks east and west of 174° W longitude (from 2013 SAFE).

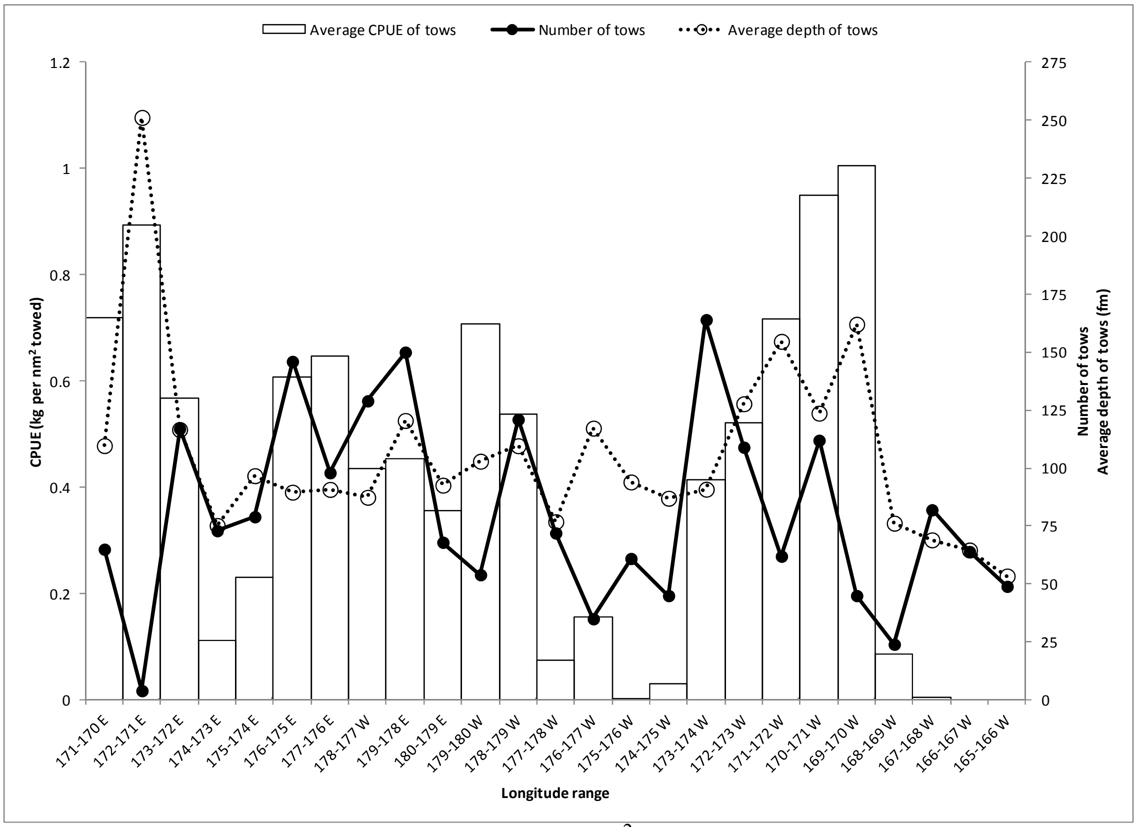

Figure 5. Average golden king crab CPUE (kg/nm^2) for tows, number of tows, and average depth of tows from one-degree longitude intervals during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys; preliminary summary of data obtained on 1 April 2013 from http://www.afsc.noaa.gov/RACE/groundfish/survey_data/default.htm.

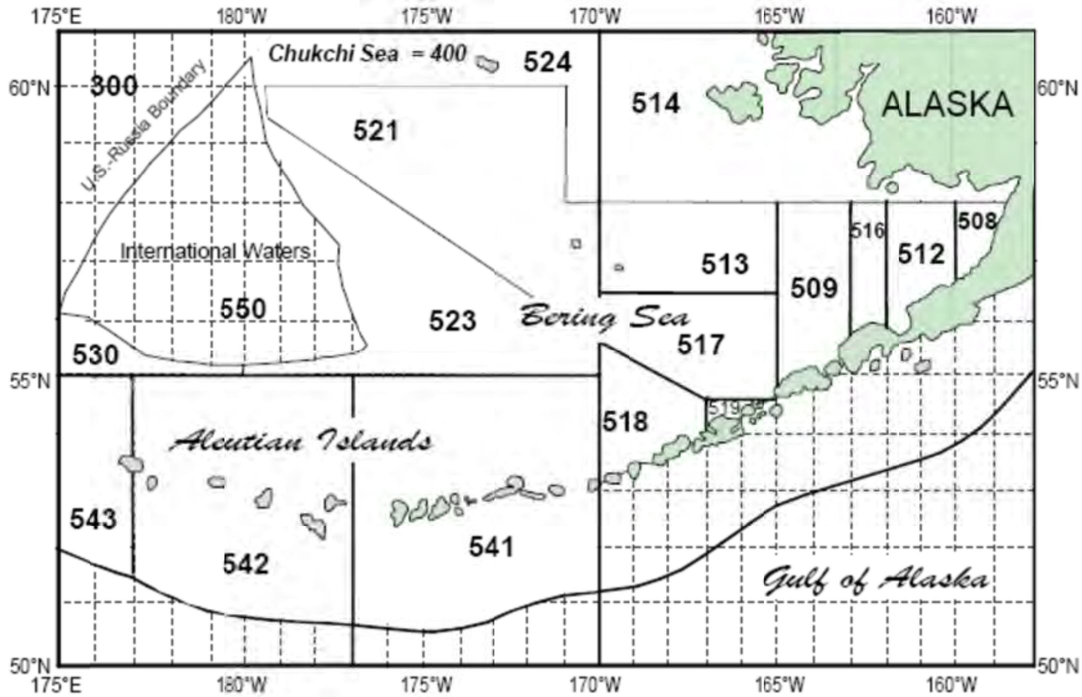

Figure 6. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands showing reporting areas 541, 542, and 543 that are used to summarize groundfish fisheries bycatch data for Aleutian Islands golden king crab (from http://www.alaskafisheries.noaa.gov/rr/figures/fig1.pdf).

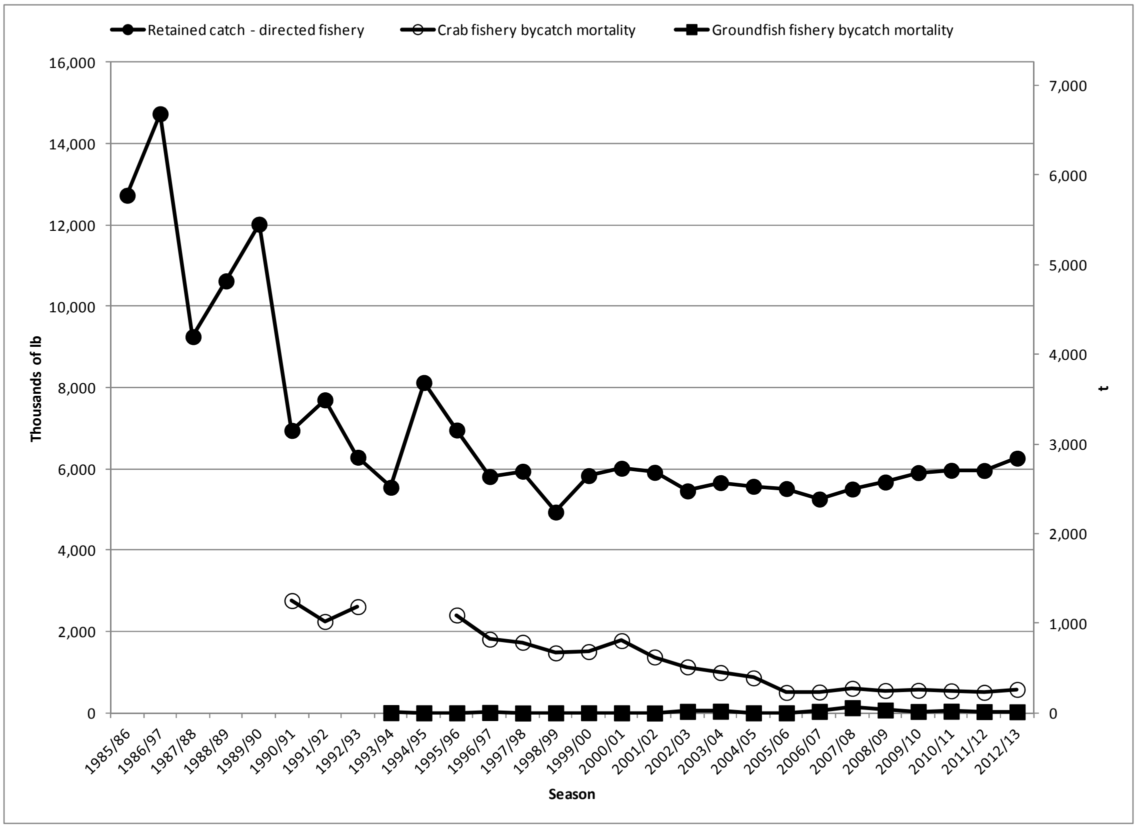

Figure 7. Retained catch during the Aleutian Islands golden king crab (AIGKC) fishery, estimated bycatch mortality of AIGKC (when available) during all crab fisheries, and estimated bycatch mortality of AIGKC (when available) for all groundfish fisheries, 1985/86–2012/13 (from Table 4; thousands of lb on left axis and t on right axis).

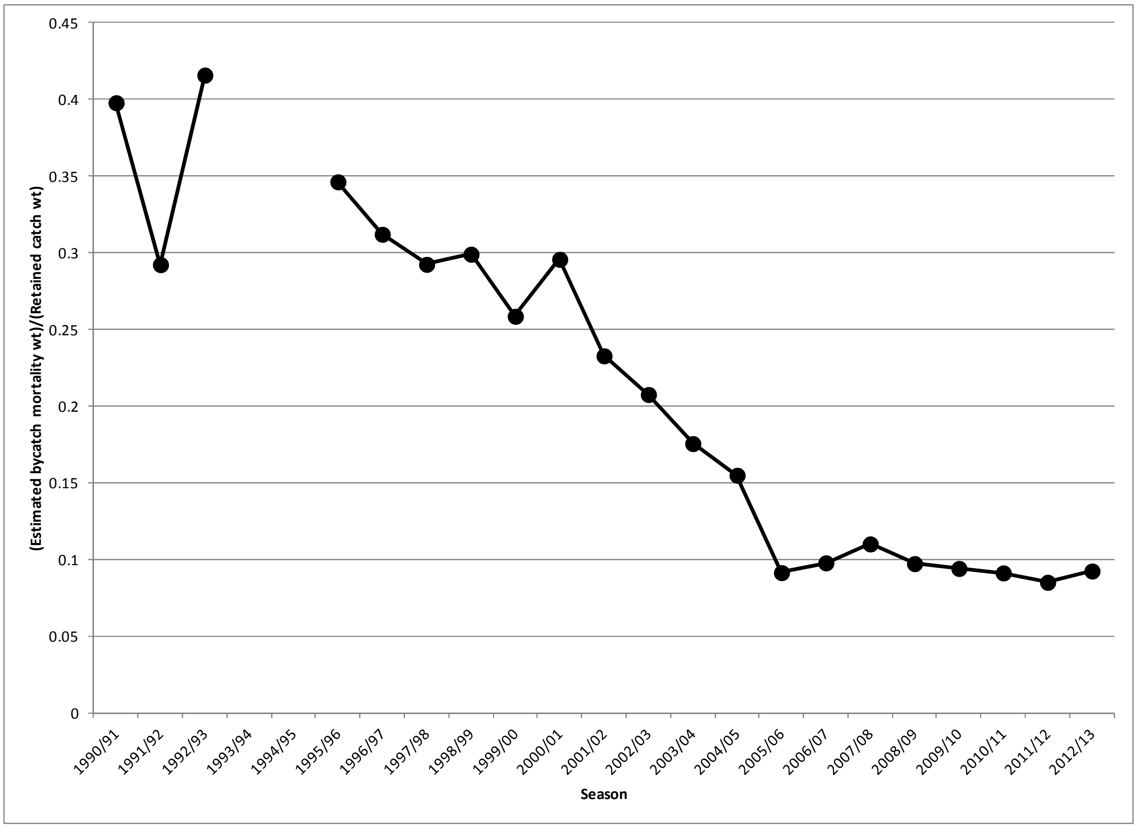

Figure 8. Ratio of estimated weight of bycatch mortality in directed and non-directed crab fisheries to weight of retained catch for Aleutian Islands golden king crab, 1990/91–2012/13 (ratios for 1993/94–1994/95 not available due to data confidentialities and insufficiencies).

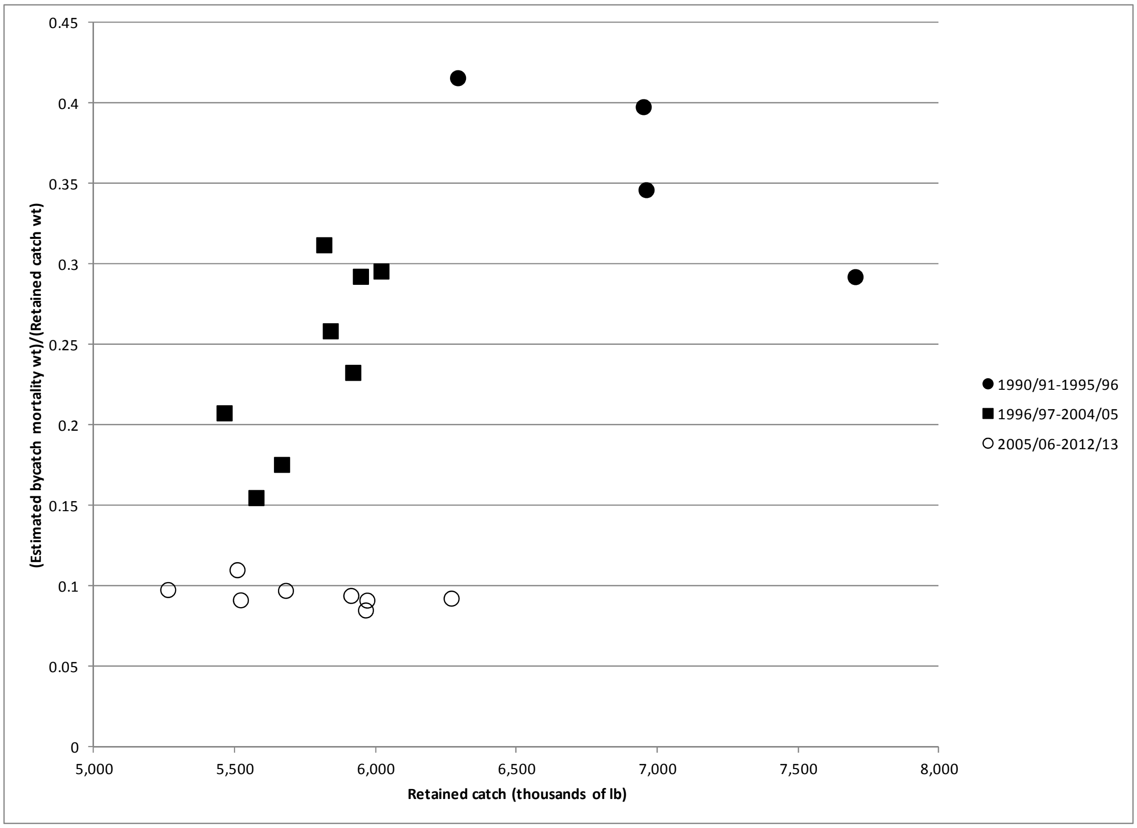

Figure 9. Ratio of estimated weight of bycatch mortality in directed and non-directed crab fisheries to weight of retained catch for Aleutian Islands golden king crab plotted against weight of retained catch, 1990/91–2012/13 (ratios for 1993/94–1994/95 not available due to data confidentialities and insufficiencies).

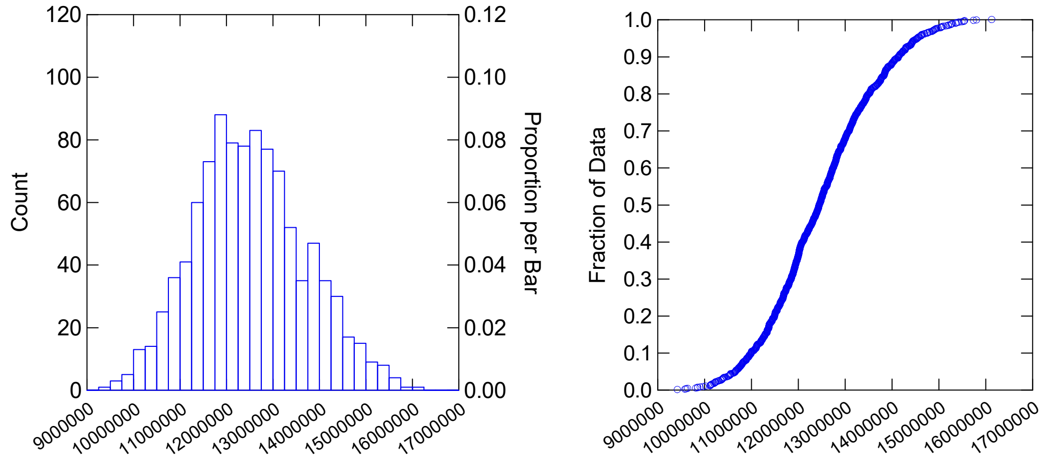

Figure 10. Bootstrapped estimates of the sampling distribution of the recommended 2013/2014 Tier 5 OFL (lb of total-catch) for the Aleutian Islands golden king crab stock; histograms in left column, cumulative distribution in right column.

Pribilof Islands Golden King Crab

– 2014 Tier 5 Assessment

2014 Crab SAFE Report Chapter (September 2014)

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Executive Summary

1. **Stock:** Pribilof Islands (Pribilof District) golden king crab *Lithodes aequispinus*

2. **Catches:**
Commercial fishing for golden king crab in the Pribilof District has been concentrated in the Pribilof Canyon. The domestic fishery developed in the 1982/83 season, although some limited fishing occurred at least as early as 1981/82. Peak harvest occurred in the 1983/84 season with a retained catch of 0.856-million lb (388 t) by 50 vessels. The fishing season for this stock has been defined as a calendar year (as opposed to 1-July-to-30-June "crab fishery year") following the close of the 1983/84 season and, since then, participation in the fishery has been sporadic and annually retained catch has been variable, from 0 lb in the nine years that no vessels participated (1984, 1986, 1990–1992, 2006–2009) up to a maximum of 0.342-million lb (155 t) in 1995, when seven vessels made landings. The fishery is not rationalized. There is no state harvest strategy in regulation. A guideline harvest level (GHL) was first established for the fishery in 1999 at 0.200-million lb (91 t) and has been managed with a GHL of 0.150-million lb (68 t) since 2000. No vessels participated in the directed fishery and no landings were made during 2006–2009. One vessel landed catch in 2010, two vessels landed catch in 2011, and one vessel landed catch in each of 2012 and 2013; catch and other fishery data from the directed fishery for those three years cannot be reported here under the confidentiality requirements of State of Alaska (SOA) statute Sec. 16.05.815. Non-retained bycatch occurs in the directed golden king crab fishery and can occur in the eastern Bering Sea snow crab fishery, the Bering Sea grooved Tanner crab fishery, and Bering Sea groundfish fisheries. Estimated annual weight of non-retained bycatch in directed and non-directed crab fisheries during calendar years 2001–2013 ranges from 0 lb to 0.049-million lb (22 t). Estimates of annual total fishery mortality during calendar years 2001–2013 due to crab fisheries range from 0 to 0.160-million lb (73 t), with an average of 0.072-million lb (33 t). Estimates of annually discarded bycatch during Bering Sea groundfish fisheries are reported for crab fishery years. Those estimates range from <0.001-million (<1 t) to 0.027-million lb (12 t) annually during the 1991/92–2012/13 crab fishery years. Estimates of annual fishery mortality during 1991/92–2012/13 due to groundfish fisheries range from <0.001-million lb (<1 t) to 0.019-million lb (9 t), with an average of 0.005-million lb (2 t).

3. **Stock biomass:**
Stock biomass (all sizes, both sexes) of golden king crab have been estimated for the Pribilof Canyon area using the area-swept technique applied to data obtained from the erstwhile biennial eastern Bering Sea upper continental slope trawl survey performed by NMFS-AFSC in 2002 (Hoff and Britt 2003), 2004 (Hoff and Britt 2005), 2008 (Hoff and Britt 2009), 2010

(Hoff and Britt 2011), and 2012 (Hoff 2013). Hoff (2013) estimated total stock biomass for the entire slope survey area in 2012 to be 4.475-million lb (2.030 t) and for the Pribilof Canyon area to be 1.716-million lb (778 t).

Complete data on size-sex composition of survey catch are available only from the 2008–2012 biennial surveys (C. Armistead, NMFS-AFSC, Kodiak). Biomass estimates by sex and size class from the 2008, 2010, and 2012 surveys were presented in a May 2013 (Gaeuman 2013b) report to the Crab Plan Team and biomass estimates of mature males from the 2008–2012 biennial surveys were presented in a September 2013 (Gaeuman 2013a) report to the Crab Plan Team. Using the size-sex composition data from the 2012 NMFS-AFSC eastern Bering Sea upper continental slope survey, Gaeuman (2013b) estimated total biomass for 2012 to be 4.244-million lb (1,925 t) for the entire survey area and 1.567-million lb (711 t) in the Pribilof Canyon area and Gaeuman (2013a) estimated mature male biomass for 2012 to be 1.790-million lb (812 t) for the entire survey area and 0.565-million lb (256 t) in the Pribilof Canyon area.

Sadly, the survey scheduled for 2014 was cancelled[1].

4. <u>Recruitment</u>:

Biomass of golden king crab (all sizes and both sexes) as estimated from data collected during the 2002–2012 biennial NMFS-AFSC eastern Bering Sea upper continental slope surveys increased in the entire slope survey area from 2.227-million lb (1,010 t) in 2002 (Hoff and Britt 2003) to 5.071-million lb (2,300 t) in 2010 (Hoff and Britt 2011); estimated biomass in the Pribilof Canyon area increased from 1.504-million lb (682 t) in 2002 to 3.560-million lb (1,615 t) in 2010. The estimate of total biomass for the entire survey area in 2012 is 88% of the 2010 estimate, however, and the estimate of total biomass for the Pribilof Canyon area in 2012 is 48% of the 2010 estimate (see **3. <u>Stock biomass</u>**, above).

Using the size-sex composition data from the surveys, Gaeuman (2013a) estimated mature male biomass in the entire survey area to have increased slightly from 1.692-million lb (767 t) in 2010 to 1.790-million lb (812 t) in 2012. However, estimated mature male biomass in the Pribilof canyon area was estimated to have decreased markedly from 0.970-million lb (440 t) in 2010 to 0.565-million lb (256 t) in 2012.

5. <u>Management performance</u>:

No overfished determination (i.e., MSST) has been made for this stock, although approaches to using data from the biennial NMFS-AFSC eastern Bering Sea upper continental slope surveys has been presented to and considered by the Crab Plan Team Gaeuman (2013a, 2013b). Overfishing did not occur during 2013; the estimated total catch did not exceed the OFL of 0.20-million lb (91 t). Total catch did not exceed the total-catch ABC of 0.18-million lb (82 t) that was established for the 2013 season. Retained catch and total-catch mortality in 2013 are confidential under the requirements of Sec. 16.05.815 (SOA statute). The 2014 season is currently ongoing. The 2015 OFL and ABC in the table below are the author's recommendations.

[1] https://www.fbo.gov/index?s=opportunity&mode=form&id=b3bb5ad289a0d04224c234acb57fe5aa&tab=core&_cview=1

Year[a]	MSST	Biomass (MMB)	GHL[b]	Retained Catch[c]	Total Catch[c,d]	OFL[c]	ABC[c]
2011	N/A	N/A	0.150	Conf.[e]	Conf.[e]	0.18	N/A
2012	N/A	N/A	0.150	Conf.[e]	Conf.[e]	0.20	0.18
2013	N/A	N/A	0.150	Conf.[e]	Conf.[e]	0.20	0.18
2014	N/A	N/A	0.150			0.20	0.18
2015	N/A	N/A				0.20	0.15

a. Season is based on a calendar year.
b. Guideline harvest level expressed in millions of lb.
c. Millions of lb.
d. Total retained catch plus estimated bycatch mortality during crab fisheries only. Bycatch mortality due to groundfish fisheries is not included here because available data are summarized by "crab fishery year" rather than calendar year; estimates of annual bycatch mortality during 1991/92–2012/13 groundfish fisheries are ≤0.019-million lb, with an average of 0.005-million lb.
e. Catch statistics are confidential under Sec. 16.05.815 (SOA statute): ≤2 vessels participated in each season.

Year[a]	MSST	Biomass (MMB)	GHL[b]	Retained Catch[c]	Total Catch[c,d]	OFL[c]	ABC[c]
2011	N/A	N/A	68	Conf. [e]	Conf. [e]	82	N/A
2012	N/A	N/A	68	Conf. [e]	Conf. [e]	91	82
2013	N/A	N/A	68	Conf. [e]	Conf. [e]	91	82
2014	N/A	N/A	68			91	82
2015	N/A	N/A				91	68

a. Season is based on a calendar year.
b. Guideline harvest level expressed in t.
c. Metric tons.
d. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries only. Bycatch mortality due to groundfish fisheries is not included here because available data are summarized by "crab fishery year" rather than calendar year; estimates of annual bycatch mortality during 1991/92–2012/13 groundfish fisheries are ≤9 t, with an average of 2 t.
e. Catch statistics are confidential under Sec. 16.05.815 (SOA statute): ≤2 vessels participated in each season.

6. **Basis for the OFL and ABC:** The values for 2015 are the author's recommendation.

Year[a]	Tier	Years to define Average catch (OFL)	Natural Mortality[d]	Buffer
2011	5	1993–1998[b]	0.18 yr^{-1}	N/A
2012	5	1993–1998[c]	0.18 yr^{-1}	10%
2013	5	1993–1998[c]	0.18 yr^{-1}	10%
2014	5	1993–1998[c]	0.18 yr^{-1}	10%
2015	5	1993–1998[c]	0.18 yr^{-1}	25%

a. Season is based on a calendar year.
b. OFL was for total catch and was determined by the average of the annual retained catch for these years times a factor of 1.05 to account for the estimated bycatch mortality occurring in the directed fishery plus an estimate of the average annual bycatch mortality due to non-directed crab fisheries and groundfish fisheries for the period.
c. OFL was for total catch and was determined by the average of the annual retained catch for these years times a factor of 1.052 to account for the estimated bycatch mortality occurring in the directed fishery plus an estimate of the average annual bycatch mortality due to non-directed crab fisheries and groundfish fisheries for the period.
d. Assumed value for FMP king crab in NPFMC (2007); does not enter into OFL estimation for Tier 5 stock.

7. **PDF of the OFL:** Sampling distribution of the recommended Tier 5 OFL was estimated by bootstrapping. The standard deviation of the estimated sampling distribution of the recommended OFL (Alternative 1) is 0.510-million lb (CV = 0.25). See section G.1.

8. **Basis for the ABC recommendation:** A 25% buffer on the OFL, the default; i.e., ABC = (1-0.25)·OFL. This is a data-poor stock.

9. **A summary of the results of any rebuilding analyses:** Not applicable; stock is not under a rebuilding plan.

A. Summary of Major Changes

1. **Changes to the management of the fishery:** None. Fishery continued into 2014 to be managed under authority of an ADF&G commissioner's permit and with a guideline harvest level (GHL) of 0.150-million lb (68 t). As of this writing, one vessel has fished in the 2014 season (J. Shaishnikoff, ADF&G, Dutch Harbor, 27 August 2014, *pers. comm*).

2. **Changes to the input data:**
   - Retained catch and bycatch data have been updated with the results for the 2013 directed fishery, during which only one vessel participated in the fishery, rendering the catch data confidential under the requirements of Sec. 16.05.815 (SOA statute).
   - Bycatch estimates from other non-directed crab fisheries have been updated with data from 2013.
   - Bycatch estimates from groundfish fisheries have been updated with estimates for 2012/13 and new estimates for 2009/10–2011/12.

3. **Changes to the assessment methodology:** None. This assessment follows the methodology recommended by the CPT since May 2012 and the SSC since June 2012.

4. **Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL:**
   - The OFLs for 2009 and 2010 were both established as retained-catch OFLs of 0.17-million lb. The 2009 OFL was estimated by the average annual retained catch for the period 1993–1999, whereas the 2010 OFL was estimated by the average annual retained catch for the period 1993–1998; in 2009 the CPT and SSC recommended removing 1999 from the period for computing retained catch because 1999 was the first year that a GHL was established for the fishery.
   - The OFL for 2011 was established as a total-catch OFL of 0.18-million lb and was estimated as the average retained catch (including deadloss) for the period 1993–1998 times 1.05 plus 0.006-million lb; i.e.,

$$OFL_{tot,2011} = 1.05 * OFL_{ret,1993\text{-}1998} + 0.006\text{-million lb.}$$

     $OFL_{ret,1993\text{-}1998}$ is the average annual retained catch in the directed fishery during 1993–1998. The factor of 1.05 was used to account for the crab bycatch mortality in the directed crab fishery and 0.006-million lb was used to account for the "background level" of bycatch mortality occurring in the groundfish and non-directed crab fisheries, estimated by the average annual bycatch mortality using data available; 2001–2005 for crab fisheries and 1991/92–2008/09 for groundfish fisheries.
   - The OFLs for 2012–2014 were each a total-catch OFL of 0.20-million lb and were estimated using 1993–1998 to compute average annual retained catch, an estimate of lb of bycatch mortality per pound of retained catch during the directed fishery, an estimate of the average annual bycatch mortality due to non-directed crab fisheries

during 1994–1998 and an estimate of average annual bycatch mortality due to groundfish fisheries during 1992/93–1998/99; i.e.,

$$OFL_{2012–2014} = (1+R_{2001–2010})*RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,1992/93–1998/99},$$

where,

- $R_{2001–2010}$ is the average of the estimated annual ratio of lb of bycatch mortality to lb of retained in the directed fishery during 2001–2010
- $RET_{1993\text{-}1998}$ is the average annual retained catch in the directed crab fishery during 1993–1998
- $BM_{NC,1994\text{-}1998}$ is the estimated average annual bycatch mortality in non-directed crab fisheries during 1994–1998
- $BM_{GF,1992/93–1998/99}$ is the estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99.

- The recommended Tier 5 OFL for 2015 is a total-catch OFL of 0.20-million lb, estimated by the calculations given for the 2012–2014 OFLs.

B. Responses to SSC and CPT Comments

- **Responses to the most recent two sets of SSC and CPT comments on assessments in general (and relevant to this assessment):**
  - CPT, May 2014: *None*.
  - SSC, June 2014: "*The SSC recommends conducting a workshop to address procedures for assigning buffers for data-poor stocks.*" … "*The outcome of such a workshop should clearly articulate the procedures and minimum requirements for establishing 10%, 20%,…, X% buffers such that they can be consistently applied across a range of species and different stocks*."
    - Response: The 25% buffer on the OFL that the author recommends using for setting the ABC is consistent with the buffer on OFL that the SSC recommended in June 2014 for the other unsurveyed golden king crab stock managed under the BSAI Crab FMP (i.e., Aleutian Islands golden king crab).
  - CPT, September 2013: *None*.
  - SSC, October 2013: *None*.
- **Responses to the most recent two sets of SSC and CPT comments specific to the assessment:**
  - CPT, May 2014: *None.*
  - SSC, June 2014: *None.*
  - CPT, September 2013: "*The CPT recommends that the author* (of an alternative Tier 5 approach for setting OFL*) include an update of this alternative approach in the spring 2014 assessment as an option to the average catch OFL procedure for consideration by the team prior to setting the 2014 OFL.* "
    - Response: Biennial EBS slope survey scheduled for 2014 was cancelled and the alternative approach anticipating the use of data from that survey was not updated.
  - SSC, October 2013: "*The OFL for 2014 was calculated as 90.7 t (0.20 million lb), and the ABC is based on a 10% buffer at 81.6 t (0.18 million lb). The SSC supports the CPT recommendation of a 10% buffer to set the ABC below the maximum permissible.*"

- Response: The author recommends the same Tier 5 OFL for 2015 as the SSC recommended for 2014, but departs from the SSC's recommendations for 2014 by recommending a 25% buffer to set the ABC in 2015.

C. Introduction

1. **Scientific name:** *Lithodes aequispinus* J. E. Benedict, 1895

2. **Description of general distribution:**

General distribution of golden king crab is summarized by NMFS (2004):

> Golden king crab, also called brown king crab, range from Japan to British Columbia. In the BSAI, golden king crab are found at depths from 200 m to 1,000 m, generally in high-relief habitat such as inter-island passes (pages 3–34).
>
> Golden, or brown, king crab occur from the Japan Sea to the northern Bering Sea (ca. 61° N latitude), around the Aleutian Islands, on various sea mounts, and as far south as northern British Columbia (Alice Arm) (Jewett et al. 1985). They are typically found on the continental slope at depths of 300–1,000 m on extremely rough bottom. They are frequently found on coral bottom (pages 3–43).

The Pribilof District is part of king crab Registration Area Q (Figure 1). Fitch et al. (2012, page 85) define those boundaries:

> The Bering Sea king crab Registration Area Q has as its southern boundary a line from 54° 36' N lat., 168° W long., to 54° 36' N lat., 171° W long., to 55° 30' N lat., 171° W. long., to 55° 30' N lat., 173° 30' E long., as its northern boundary the latitude of Point Hope (68° 21' N lat.), as its eastern boundary a line from 54° 36' N lat., 168° W long., to 58° 39' N lat., 168° W long., to Cape Newenham (58° 39' N lat.), and as its western boundary the United States-Russia Maritime Boundary Line of 1991. Area Q is divided into the Pribilof District, which includes waters south of Cape Newenham, and the Northern District, which incorporates all waters north of Cape Newenham.

Results of the 2002–2012 biennial NMFS-AFSC eastern Bering Sea continental slope trawl surveys show that the biomass, number, and density (in number per area and in weight per area) of golden king crab on the eastern Bering Sea continental slope are higher in the southern areas than in the northern areas (Gaeuman 2013a; Haaga et al. 2009; Hoff 2013; Hoff and Britt 2003, 2005, 2009, 2011). Of the six survey subareas (see Figure 1 in Hoff 2013), biomass and abundance of golden king crab were estimated through 2010 to be highest in the Pribilof Canyon area (survey subarea 2). Most of the commercial fishery catch for golden king crab is reported to occur in the Pribilof Canyon area (Fitch et al. 2012; Neufeld and Barnard 2003; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006). However, biomass was estimated to have decreased between 2010 and 2012 in the Pribilof Canyon area and to have increased between 2010 and 2012 in the survey subarea 1 (the southernmost of the survey subareas), so that biomass in 2012 was estimated to be highest in survey subarea 1.

Results of the 2002–2012 biennial NMFS-AFSC eastern Bering Sea continental slope trawl surveys showed that a majority of golden king crab on the eastern Bering Sea continental slope occurred in the 200–400 m and 400–600 m depth ranges (Haaga et al. 2009; Hoff 2013;

Hoff and Britt 2003, 2005, 2009, 2011). Commercial fishing for golden king crab in the Bering Sea typically occurs at depths of 100–300 fathoms (183–549 m; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006; Gaeuman 2011, 2013c; Neufeld and Barnard 2003); average depth of pots fished in the Pribilof District golden king crab fishery during the 2002 fishing season (the most recently prosecuted fishery for which fishery observer data are not confidential) was 214 fathoms (391 m).

3. **Evidence of stock structure:**

Although highest densities of golden king crab are found in the deep canyons of the eastern Bering Sea continental slope, golden king crab occur sporadically on the surveyed slope at locations between those canyons in the eastern Bering Sea (Hoff 2013; Hoff and Britt 2003, 2005, 2009, 2011; Gaeuman 2013b). Stock structure within the Pribilof District and the stock relationship of the golden king crab within the Pribilof District with the golden king crab outside of the Pribilof District have not been evaluated.

4. **Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology):**

The following review of molt timing and reproductive cycle of golden king crab is adapted from Watson et al. (2002):

> Unlike red king crab, golden king crab may have an asynchronous molting cycle (McBride et al. 1982, Otto and Cummiskey 1985, Sloan 1985, Blau and Pengilly 1994). In a sample of male golden king crab 95–155-mm CL and female golden king crab 104–157-mm CL collected from Prince William Sound and held in seawater tanks, Paul and Paul (2000) observed molting in every month of the year, although the highest frequency of molting occurred during May–October. Watson et al. (2002) estimated that only 50% of 139-mm CL male golden king crab in the eastern Aleutian Islands molt annually and that the intermolt period for males ≥150-mm CL averages >1 year.
>
> Female lithodids molt before copulation and egg extrusion (Nyblade 1987). From their observations on embryo development in golden king crab, Otto and Cummiskey's (1985) suggested that time between successive ovipositions was roughly twice that of embryo development and that spawning and molting of mature females occurs approximately every two years. Sloan (1985) also suggested a reproductive cycle >1 year with a protracted barren phase for female golden king crab. Data from tagging studies on female golden king crab in the Aleutian Islands are generally consistent with a molt period for mature females of 2 years or less and that females carry embryos for less than two years with a prolonged period in which they remain in barren condition (Watson et al 2002). From laboratory studies of golden king crab collected from Prince William Sound, Paul and Paul (2001b) estimated a 20-month reproductive cycle with a 12-month clutch brooding period.
>
> Numerous observations on clutch and embryo condition of mature female golden king crab captured during surveys have been consistent with asynchronous, aseasonal reproduction (Otto and Cummiskey 1985, Hiramoto 1985, Sloan 1985, Somerton and Otto 1986, Blau and Pengilly 1994, Blau et al. 1998, Watson et al. 2002). Based on data from Japan (Hiramoto and Sato 1970), McBride et al. (1982) suggested that spawning of golden king crab in

the Bering Sea and Aleutian Islands occurs predominately during the summer and fall.

The success of asynchronous and aseasonal spawning of golden king crab may be facilitated by fully lecithotrophic larval development (i.e., the larvae can develop successfully to juvenile crab without eating; Shirley and Zhou 1997).

Current knowledge of reproductive biology and maturity of male and female golden king crab is also reviewed by Webb (2014).

Note that asynchronous, aseasonal molting and the prolonged intermolt period (>1 year) of mature female and the larger male golden king crab likely makes scoring shell conditions very difficult and especially difficult to relate to "time post-molt," posing problems for inclusion of shell condition data into assessment models.

5. <u>Brief summary of management history</u>:

A complete summary of the management history through 2010 is provided in Fitch et al. (2012, pages 89–91).

The first domestic harvest of golden king crab in the Pribilof District was in 1982 when two vessels fished. Peak harvest and participation occurred in the 1983/84 season with a retained catch of 0.856-million lb landed by 50 vessels. Since 1984 the fishery has been managed with a calendar-year season under authority of a commissioner's permit and landings and participation has been low and sporadic. Retained catch during 1984–2009 has ranged from 0 lb to 0.342-million lb and the number of vessels participating annually has ranged from 0 to 8; no vessels registered for the fishery and there was no retained catch in 2006–2009. One vessel fished in the 2010 season and two vessels fished in the 2011 season; catch statistics for those two seasons are confidential under Sec. 16.05.815 of SOA statutes. The fishery is not rationalized and has been managed inseason to a guideline harvest level (GHL) since 1999. The GHL for 1999 was 0.200-million lb, whereas the GHL for 2000-2012 has been 0.150-million lb.

A summary of relevant fishery regulations and management actions pertaining to the Pribilof District golden king crab fishery is provided below.

Only males of a minimum legal size may be retained. By State of Alaska regulation (**5 AAC 34.920 (a)**), the minimum legal size limit for Pribilof District golden king crab is 5.5-inches (140 mm) carapace width (CW), including spines. A carapace length (CL) ≥124 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007). Golden king crab may be commercially fished only with king crab pots (as defined in 5 AAC 34.050). Pots used to fish for golden king crab in the Pribilof Islands must have at least four escape rings of no less than five and one-half inches inside diameter installed on the vertical plane or at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized golden king crab (5 AAC 34.925 (c)) and the sidewall "…must contain an opening equal to or exceeding 18 inches in length... The opening must be laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 30 thread." (5 AAC 39.145(1)). There is a pot limit of 40 pots for vessels ≤125-feet LOA and of 50 pots for vessels >125-feet LOA (5 AAC 34.925 (e)(1)(B)). Golden king crab can be harvested from 1 January through 31 December only under conditions of a permit issued by the commissioner of ADF&G (**5 AAC**

34.910 (b)(3)). Since 2001 those conditions have included the carrying of a fisheries observer.

D. Data

1. **Summary of new information**:
   1. Retained catch and estimated bycatch during the 2013 directed fishery (both of which are confidential), estimated bycatch in non-directed crab fisheries during 2013, and new estimates of bycatch in groundfish fisheries during the 2009/10–2012/13 crab fishery years have been added.

2. **Data presented as time series**:

a. Total catch and b. Information on bycatch and discards:

- The 1981/82–1983/84, 1984–2013 time series of retained catch (number and lb of crab harvested, including deadloss), effort (vessels, landings, and pot lifts), average weight of landed crab, average carapace length of landed crab, and CPUE (number of landed crab captured per pot lift) are presented in Table 1.
- The 1993–2013 time series of weight of retained catch, estimated bycatch and estimated weight of fishery mortality of Pribilof golden king crab during commercial crab fisheries are given in Table 2. Bycatch of Pribilof golden king crab occurs mainly in the directed golden king crab fishery, when prosecuted, and to a lesser extent in the Bering Sea snow crab fishery and the Bering Sea grooved Tanner crab fishery. Because the Bering Sea snow crab fishery is prosecuted mainly or entirely between January and May and the Bering Sea grooved Tanner crab fishery is prosecuted with a calendaryear season, bycatch for the crab fisheries can be estimated on a calendaryear basis to align with the season for Pribilof District golden king crab. Observer data on size distributions and estimated catch numbers of non-retained catch were used to estimate the weight of non-retained catch of golden king crab by applying a weight-at-length estimator (see below). Observers were first deployed to collect bycatch data during the Pribilof District golden king crab fishery in 2001 and during the Bering Sea grooved Tanner crab fishery in 1994. Retained catch or observer data are confidential for at least one of the crab fisheries in 1999–2001, 2003–2005, and 2010−2013. Following Siddeek et al. (2011), the bycatch mortality rate of golden king crab captured and discarded during Aleutian Islands golden king crab fishery was assumed to be 0.2. Following Foy (2013), bycatch mortality rate of king crab during the snow crab fishery was assumed to be 0.5. The bycatch mortality rate during the grooved Tanner crab fishery was also assumed to be 0.5.
- The groundfish fishery bycatch data were grouped into crab fishery years, rather than into calendar years. The 1991/92–2012/13 time series of estimated annual weight of bycatch and total fishery mortality of golden king crab during federal groundfish fisheries by gear type (combining pot and hook-and-line gear as a single “fixed gear” category and combining non-pelagic and pelagic trawl gear as a single “trawl” category) is provided in Table 3. Following Foy (2013), the bycatch mortality of king crab captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crab captured by trawls during groundfish fisheries was assumed to be 0.8. Data from 1991/92–2008/09 are from federal reporting areas 513, 517, and 521, whereas the data from 2009/10–2012/13 (received 30 July 2014) are from the State statistical areas falling within the Pribilof district (see various attachments to 30 July 2014 email from R. Foy, NMFS-AFSC-Kodiak).

c. ***Catch-at-length:*** Not used in a Tier 5 assessment; none are presented.

d. ***Survey biomass estimates:*** Survey biomass estimates are not used in a Tier 5 assessment. However, see Gaeuman (2013a) for biomass estimates of mature male golden king crab using data from NMFS-AFSC eastern Bering Sea upper continental slope trawl survey.

e. ***Survey catch at length:*** Survey catch at length data are not used in a Tier 5 assessment. However, see Gaeuman (2013b) and Hoff (2013) for size data composition by sex of golden king crab during Bering Sea upper continental slope trawl surveys.

f. ***Other data time series:*** None.

3. Data which may be aggregated over time:

a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):

The author is not aware of data on growth per molt collected from golden king crab in the Pribilof District. Growth per molt of juvenile golden king crab, 2–35 mm CL, collected from Prince William Sound have been observed in a laboratory setting and equations describing the increase in CL and intermolt period were estimated from those observations (Paul and Paul 2001a); those results are not provided here. Growth per molt has also been estimated from golden king crab with CL ≥90 mm that were tagged in the Aleutian Islands and recovered during subsequent commercial fisheries (Watson et al. 2002); those results are not presented here because growth-per-molt information does not enter into a Tier 5 assessment.

See section **C.4** for discussion of evidence that mature female and the larger male golden king crab exhibit asynchronous, aseasonal molting and a prolonged intermolt period (>1 year).

b. Weight-at length or weight-at-age (by sex):

Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female golden king crab according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007) are: A = 0.0002988 and B = 3.135 for males and A = 0.001424 and B = 2.781 for females; note that although the estimated parameters, A and B, are those estimated for ovigerous females, those parameters were used to estimate the weight of all females without regard to reproductive status. Estimated weights in grams were converted to lb by dividing by 453.6.

c. Natural mortality rate:

The default natural mortality rate assumed for king crab species by NPFMC (2007) is M=0.18. Note, however, natural mortality was not used for OFL estimation because this stock belongs to Tier 5.

4. Information on any data sources that were available, but were excluded from the assessment:

- Standardized bottom trawl surveys to assess the groundfish and invertebrate resources of the eastern Bering Sea (EBS) upper continental slope were performed in 2002, 2004, 2008, 2010, and 2012 (Hoff and Britt 2003, 2005, 2009, 2011; Haaga et al. 2009, Gaeuman 2013a, b). Data and analysed results from the 2008–2012 EBS upper continental slope surveys were presented in Gaeuman (2013a, b), but are not presented in this Tier 5 assessment.
- Data on the size and sex composition of retained catch and bycatch of Pribilof District golden king crab during the directed fishery and other crab fisheries are available but are not presented in this Tier 5 assessment.

E. Analytic Approach

1. History of modeling approaches for this stock:

Although Gaeuman (2013a, b) presented assessment-modelling approaches for this stock to the Crab Plan Team using data from the biennial NMFS EBS continental slope survey, this stock continues to be managed as a Tier 5 stock as recommended by NPFMC (2007) and by the CPT and SSC in 2008−2013.

2. Model Description: *Subsections a–i are not applicable to a Tier 5 sock.*

Only an OFL and ABC is estimated For Tier 5 stocks, where "the OFL represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock" (NPFMC 2007). Although NPFMC (2007) defined the OFL in terms of the retained catch, total-catch OFLs may be considered for Tier 5 stocks for which non-target fishery removal data are available (Federal Register/Vol. 73, No. 116, 33926). The CPT (in May 2010) and the SSC (in June 2010) endorsed the use of a total-catch OFL to establish the OFL for this stock. This assessment recommends – and only considers – use of a total-catch OFL for 2015.

Additionally, NPFMC (2007) states that for estimating the OFL of Tier 5 stocks, "The time period selected for computing the average catch, hence the OFL, should be based on the best scientific information available and provide the required risk aversion for stock conservation and utilization goals." Given that a total-catch OFL is to be used, alternative configurations for the Tier 5 model are limited to: 1) alternative time periods for computing the average total-catch mortality; and 2) alternative approaches for estimating the non-retained component of the total catch mortality during that period.

With regard to choosing from alternative time periods for computing average annual catch to compute the OFL, NPFMC (2007) suggested using the average retained catch over the years 1993 to 1999 as the estimated OFL for Pribilof Islands golden king crab. Years post-1984 were chosen based on an assumed 8-year lag between hatching and growth to legal size after the 1976/77 "regime shift". With regard to excluding data from years 1985 to 1992 and years after 1999, NPFMC (2007) states, "The excluded years are from 1985 to 1992 and from 2000 to 2005 for Pribilof Islands golden king crab when the fishing effort was less than 10% of the average or the GHL was set below the previous average catch." In 2008 the CPT and SSC endorsed the approach of estimating OFL as the average retained catch during 1993–1999 for setting a retained-catch OFL for 2009. However, in May 2009 the CPT setting a retained-catch OFL for 2010, but using the average retained catch during 1993–1998; 1999 was excluded because it was the first year that a preseason GHL was established for the fishery. In May 2010, the CPT established a total-catch OFL computed as a function of the average retained catch during 1993–1998, a ratio-based estimate of the bycatch mortality during the directed fishery of that period, and an estimate of the "background" bycatch mortality due to other fisheries. Other time periods, extending into years post-1999, had been considered for computing the average retained catch in the establishment of the 2009, 2010, 2011 OFLs, but those time periods were rejected by the CPT and the SSC. Hence the period for calculating the retained-catch portion of the Tier 5 total-catch OFL for this stock has been firmly established by the CPT and SSC at 1993–1998 (the CPT said "this freezes the time frame..."). For the 2012 and the 2013 OFLs, the CPT and SSC recommended the period 2001–2010 for calculating the ratio-based estimate of the bycatch mortality during the 1993–1998 directed fishery, the period 1994–1998 for calculating the estimated bycatch mortality due to non-directed crab fisheries during 1993–1998, and the period 1992/93–1998/99 for calculating the estimated bycatch mortality due to groundfish fisheries during 1993–1998.

Two alternative approaches for determination of the 2013 OFL were presented to the CPT and SSC in May–June 2013. Alternative 1 was the status quo approach (i.e., the approach used to establish the 2012 total-catch OFL). Alternative 2 was the same as Alternative 1 except that it used updated bycatch data from crab fisheries in 2011. Alternative 2 was presented specifically to allow the CPT and the SSC to clarify whether the 2013 and subsequent OFLs should be computed using data collected after 2010, or if the time periods for data used to calculate the 2013 and subsequent OFLs should be "frozen" at the years used to calculate the 2012 OFL. The CPT and the SSC both recommended Alternative 1, clarifying that Tier 5 OFLs for future years should be computed using only data collected through 2010. Following that recommendation from CPT and the SSC, only one alternative for computing the 2014 Tier 5 OFL was presented (i.e., the Alternative 1 that was presented in 2013). The 2015 Tier 5 OFL recommended here is the same as for the 2014 Tier 5 OFL.

3. Model Selection and Evaluation:

a. *Description of alternative model configurations*

Alternative 1 (status quo and author's recommendation). The recommended OFL is set as a total-catch OFL using 1993–1998 to compute average annual retained catch, an estimate of lb of bycatch mortality per pound of retained catch during the directed fishery, an estimate of the average annual bycatch mortality due to the non-directed crab fisheries during 1994–1998 and an estimate of average annual bycatch mortality due to the groundfish fisheries during 1992/93–1998/99; i.e.,

$$OFL_{1,\,2015} = (1+R_{2001\text{–}2010})*RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,92/93\text{–}98/99},$$

where,

- $R_{2001\text{–}2010}$ is the average of the estimated annual ratio of lb of bycatch mortality to lb of retained catch in the directed fishery during 2001–2010
- $RET_{1993\text{-}1998}$ is the average annual retained catch in the directed crab fishery during 1993–1998
- $BM_{NC,1994\text{-}1998}$ is the estimated average annual bycatch mortality in non-directed crab fisheries during 1994–1998
- $BM_{GF,92/93\text{–}98/99}$ is the estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99.

The average of the estimated annual ratio of lb of bycatch mortality to lb of retained in the directed fishery during 2001–2010 is used as a factor to estimate bycatch mortality in the directed fishery during 1993–1998 because, whereas there are no data on bycatch for the directed fishery during 1993–1998, there are such data from the directed fishery during 2001–2010 (excluding 2006–2009, when there was no fishery effort).

The estimated average annual bycatch mortality in non-directed fisheries during 1994–1998 is used to estimate the average annual bycatch mortality in non-directed fisheries during 1993–1998 because there are no bycatch data available for the non-directed fisheries during 1993.

The estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99 is used to estimate the average annual bycatch mortality in groundfish fisheries during 1993–1998 because 1992/93–1998/99 is the shortest time period of crab fishery years that encompasses calendar years 1993–1998.

Statistics on the data and estimates used to calculate $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$ are provided in Table 4; the column means in Table 4 are the calculated values of $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$. Using the calculated values of $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$, $OFL_{1,\,2015}$ is,

$$OFL_{1,2015} = (1+0.052)*173{,}722 + 13{,}418 + 8{,}353 = 204{,}611 \text{ lbs (0.20-million lbs).}$$

b. ***Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed:*** See the table, below.

Model	Retained-vs. Total-catch	Time Period	Resulting OFL (millions of lb)
Alt. 1 – recommended/status quo	Total-catch	1993–1998	0.20

Alternative 1 is recommended and is the status quo; it is recommended as being the best approach with the limited data available and follows the advice of the CPT and SSC to "freeze" the period for calculation of the OFL at the time period that was established for the 2012 OFL.

c. ***Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models:*** See Section E, above.

d. ***Convergence status and convergence criteria for the base-case model (or proposed base-case model):*** Not applicable.

e. ***Table (or plot) of the sample sizes assumed for the compositional data:*** Not applicable.

f. ***Do parameter estimates for all models make sense, are they credible?:***
The time period used for determining the OFL was established by the SSC in June 2012. Estimates of total retained catch (lb) during a season are from fish tickets landings and are assumed here to be correct. Estimates of bycatch from crab fisheries data are generally considered credible (e.g., Byrne and Pengilly 1998, Gaeuman 2011, 2013c), but may have greater uncertainty in a small, low effort fishery such as the Pribilof golden king crab fishery. Estimates of bycatch mortality are estimates of bycatch times an assumed bycatch mortality rate. Bycatch mortality rates have not been estimated from data.

g. ***Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty:*** See section E.3.c, above.

h. ***Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach):*** Not applicable.

i. ***Evaluation of the model, if only one model is presented; or evaluation of alternative models and selection of final model, if more than one model is presented:*** See section E.3.c, above.

4. Results (best model(s)):

a. List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties: Not applicable.

b. Tables of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible; include estimates from previous SAFEs for retrospective comparisons): See Tables 2–5.

c. Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible): Information requested for this subsection is not applicable to a Tier 5 stock.

d. Evaluation of the fit to the data: Not applicable for Tier 5 stock.

e. Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments): Not applicable for Tier 5 stock.

f. Uncertainty and sensitivity analyses (this section should highlight unresolved problems and major uncertainties, along with any special issues that complicate scientific assessment, including questions about the best model, etc.): For this assessment, the major uncertainties are:

- Whether the time period is "representative of the production potential of the stock" and if it serves to "provide the required risk aversion for stock conservation and utilization goals." Or whether any such time period exists.
    - Only a period of 6 years is used to compute the OFL, 1993–1998. The SSC has noted its uneasiness with that situation ("6 years of data are very few years upon which to base these catch specifications." June 2011 SSC minutes).
- No data on bycatch due to the directed fishery are available from the period used to compute the OFL. Estimation of the OFL rests on the assumption that data on the ratio of bycatch to retained catch during the post-2000 seasons can be used to accurately estimate that ratio for the 1993–1998 seasons.
- The bycatch mortality rates used in estimation of total catch. Bycatch mortality is unknown and no data that could be used to estimate the bycatch mortality of this stock are known to the author. Hence, only the values that are assumed for other BSAI king crab stock assessments are considered in this assessment. The estimated OFL increases (or decreases) relative to the bycatch mortality rates assumed: doubling the assumed bycatch mortality rates increases the OFL estimate by a factor of 1.15; halving the assumed bycatch mortality rates decreases the OFL estimate by a factor of 0.92.

F. Calculation of the OFL

1. **Specification of the Tier level and stock status level for computing the OFL:**
   - Recommended as Tier 5, total-catch OFL estimated by estimated average total catch over a specified period.
   - Recommended time period for computing retained-catch OFL: 1993–1998.
     - This is the same time period that was used to establish OFL for the 2010–2014 seasons. The time period 1993–1998 provides the longest continuous time period through 2014 during which vessels participated in the fishery, retained-catch data can be retrieved that are not confidential, and the retained catch was not constrained by a GHL. Data on bycatch mortality contemporaneous with 1993-1998 to the extent possible are used to calculate the total-catch OFL in the recommended Alternative 1.

2. **List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan:** Not applicable for Tier 5 stock.

3. **Specification of the total-catch OFL:**

a. Provide the equations (from Amendment 24) on which the OFL is to be based:
From **Federal Register** / Vol. 73, No. 116, page 33926, "For stocks in Tier 5, the overfishing level is specified in terms of an average catch value over an historical time period, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information." Additionally, "For stocks where nontarget fishery removal data are available, catch includes all fishery removals, including retained catch and discard losses. Discard losses will be determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the overfishing level is set for and compared to the retained catch" (FR/Vol. 73, No. 116, 33926). That compares with the specification of NPFMC (2007) that the OFL "represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock."

b. Basis for projecting MMB to the time of mating: Not applicable for Tier 5 stock.

c. ***Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring:*** See table below. Although the retained and total catch for 2013 cannot be presented here due to the confidentiality of data, the author can report that total catch in 2013 did not exceed the 2013 OFL. Values for the 2015 OFL and ABC are the author's recommendations.

Year[a]	MSST	Biomass (MMB)	GHL[b]	Retained Catch[c]	Total Catch[c,d]	OFL[c]	ABC[c]
2011	N/A	N/A	0.150	Conf.[e]	Conf.[e]	0.18	N/A
2012	N/A	N/A	0.150	Conf.[e]	Conf.[e]	0.20	0.18
2013	N/A	N/A	0.150	Conf.[e]	Conf.[e]	0.20	0.18
2014	N/A	N/A	0.150			0.20	0.18
2015	N/A	N/A				0.20	0.15

a. Season is based on a calendar year.
b. Guideline harvest level expressed in millions of lb.
c. Millions of lb.
d. Total retained catch plus estimated bycatch mortality during crab fisheries only. Bycatch mortality due to groundfish fisheries is not included here because available data are summarized by "crab fishery year" rather than calendar year; estimates of annual bycatch mortality during 1991/92–2010/11 groundfish fisheries are ≤0.019-million lb, with an average of 0.006-million lb.
e. Catch statistics are confidential under Sec. 16.05.815 (SOA statute): ≤2 vessels participated in each season.

Year[a]	MSST	Biomass (MMB)	GHL[b]	Retained Catch[c]	Total Catch[c,d]	OFL[c]	ABC[c]
2011	N/A	N/A	68	Conf.[e]	Conf.[e]	82	N/A
2012	N/A	N/A	68	Conf.[e]	Conf.[e]	91	82
2013	N/A	N/A	68	Conf.[e]	Conf.[e]	91	82
2014	N/A	N/A	68			91	82
2015	N/A	N/A				91	68

a. Season is based on a calendar year.
b. Guideline harvest level expressed in t.
c. Metric tons.
d. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries only. Bycatch mortality due to groundfish fisheries is not included here because available data are summarized by "crab fishery year" rather than calendar year; estimates of annual bycatch mortality during 1991/92–2010/11 groundfish fisheries are ≤9 t, with an average of 3 t.
e. Catch statistics are confidential under Sec. 16.05.815 (SOA statute): ≤2 vessels participated in each season.

4. **Specification of the retained-catch portion of the total-catch OFL:**
   a. **Equation for recommended retained-portion of total-catch OFL.**
   Retained-catch portion = average retained catch during 1993–1998
   = 173,722 lb (0.17-million lb; 79 t).

5. **Recommended F_{OFL}, OFL total catch and the retained portion for the coming year:** See sections ***F.3*** and ***F.4***, above; no F_{OFL} is recommended for a Tier 5 stock.

G. Calculation of ABC

1. PDF of OFL. A bootstrap estimates of the sampling distribution (assuming no error in estimation of bycatch) of the status quo Alternative 1 OFL is shown in Figure 2 (1,000 samples drawn with replacement independently from each of the four columns of values in Table 4 to calculate $R_{2001\text{-}2010}$, $RET_{1993\text{-}1998}$, $BM_{NC,1994\text{-}1998}$, $BM_{GF,92/93\text{-}98/99}$ and $OFL_{1,2014}$). Table 5 provides statistics on the generated distributions.

2. List of variables related to scientific uncertainty.

- Bycatch mortality rate in each fishery that bycatch occurs. Note that for Tier 5 stocks, an increase in an assumed bycatch rate will increase the OFL (and hence the ABC), but has no effect on the retained-catch portion of the OFL or the retained-catch portion of the ABC.
- Estimated bycatch and bycatch mortality for each fishery that bycatch occurred in during 1993–1998.
- The time period to compute the average catch under the assumption of representing "a time period determined to be representative of the production potential of the stock."
- Stock size in 2015 is unknown.

3. List of addititional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.

4. Author recommended ABC. 25% buffer on OFL; i.e., ABC = (1-0.25)·(204,612 lb) = 0.15-million lb (68 t).

H. Rebuilding Analyses

Not applicable; this stock has not been declared overfished.

I. Data Gaps and Research Priorities

Data from the 2008–2012 biennial NMFS-AFSC eastern Bering Sea upper continental shelf trawl surveys have been examined for their utility in determining overfishing levels and stock status by Gaeuman (2103a, b). Cancellation of the survey that was scheduled for 2014 raises uncertainties on the prospects for obtaining fishery-independent survey data on this stock in the future.

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Table 1. Harvest history for the Pribilof District golden king crab fishery from the 1981/82 season through 2013 (from 2013 SAFE, updated with 2013 data provided by J. Shaisnikoff, ADF&G, Kodiak via 27 September 2014 email).

	Number of						Average			
Season	Vessels	Landings	Crabs[a]	Pots lifted	GHL[b]	Harvest[a,c]	Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1981/82	2	CF	CF	CF	-	CF	CF	CF	CF	CF
1982/83	10	19	15,330	5,252	-	69,970	4.6	3	151	570
1983/84	50	115	253,162	26,035	-	856,475	3.4	10	127	20,041
1984	0	0	0	0	-	0	0	0	0	0
1985	1	CF	CF	CF	-	CF	CF	CF	CF	CF
1986	0	0	0	0	-	0	0	0	0	0
1987	1	CF	CF	CF	-	CF	CF	CF	CF	CF
1988	2	CF	CF	CF	-	CF	CF	CF	CF	CF
1989	2	CF	CF	CF	-	CF	CF	CF	CF	CF
1990	0	0	0	0	-	0	0	0	0	0
1991	0	0	0	0	-	0	0	0	0	0
1992	0	0	0	0	-	0	0	0	0	0
1993	5	15	17,643	15,395	-	67,458	3.8	1	NA	0
1994	3	5	21,477	1,845	-	88,985	4.1	12	NA	730
1995	7	22	82,489	9,551	-	341,908	4.1	9	NA	716
1996	6	32	91,947	9,952	-	329,009	3.6	9	NA	3,570
1997	7	23	43,305	4,673	-	179,249	4.1	9	NA	5,554
1998	3	9	9,205	1,530	-	35,722	3.9	6	NA	474
1999	3	9	44,098	2,995	200,000	177,108	4.0	15	NA	319
2000	7	19	29,145	5,450	150,000	127,217	4.4	5	NA	4,599
2001	6	14	33,723	4,262	150,000	145,876	4.3	8	143	8,227
2002	8	20	34,860	5,279	150,000	150,434	4.3	6	144	8,984
2003	3	CF	CF	CF	150,000	CF	CF	CF	CF	CF
2004	5	CF	CF	CF	150,000	CF	CF	CF	CF	CF
2005	4	CF	CF	CF	150,000	CF	CF	CF	CF	CF
2006-2009	0	0	0	0	150,000	0	0	0	0	0
2010	1	CF	CF	CF	150,000	CF	CF	CF	CF	CF
2011	2	CF	CF	CF	150,000	CF	CF	CF	CF	CF
2012	1	CF	CF	CF	150,000	CF	CF	CF	CF	CF
2013	1	CF	CF	CF	150,000	CF	CF	CF	CF	CF

Note: CF = confidential, less than three vessels or processors participated in fishery

[a] Deadloss included.

[b] Guideline harvest level (lb).

[c] lb.

[d] Number of legal crab per pot lift.

[e] Carapace length in millimeters.

Table 2. Weight (in lb) of retained catch and estimated non-retained bycatch of Pribilof golden king crab during crab fisheries, 1993–2013, with total fishery mortality estimated by assuming a bycatch mortality rate of 0.2 for the directed fishery and a bycatch mortality rate of 0.5 for non-directed fisheries (from 2013 Crab SAFE, with update for 2013 catch and bycatch data).

		Bycatch in crab fisheries (lb; no mortality rate applied)			
Year	Retained Catch (lb)	Pribilof Islands golden king crab	Bering Sea snow crab	Bering Sea grooved Tanner crab	Total Mortality (lb)
1993	67,458	no data	0	no data	—
1994	88,985	no data	8,387	2,531	—
1995	341,908	no data	1,391	34,492	—
1996	329,009	no data	526	5,151	—
1997	179,249	no data	8,937	no fishing	—
1998	35,722	no data	72,760	no fishing	—
1999	177,108	no data	0	confidential	—
2000	127,217	no data	0	confidential	—
2001	145,876	39,278	0	confidential	confidential
2002	150,434	41,894	2,335	no fishing	159,980
2003	confidential	confidential	329	confidential	159,184
2004	confidential	confidential	0	confidential	147,552
2005	confidential	confidential	0	confidential	65,817
2006	no fishing	no fishing	0	0	0
2007	no fishing	no fishing	0	0	0
2008	no fishing	no fishing	0	no fishing	0
2009	no fishing	no fishing	2,122[a]	no fishing	1,061[a]
2010	confidential	confidential	0	no fishing	confidential
2011	confidential	confidential	591[b]	no fishing	confidential
2012	confidential	confidential	598[c]	no fishing	confidential
2013	confidential	confidential	1,284[d]	no fishing	confidential

a. Only 5 golden king crab (1 sublegal male and 4 legal males) were counted in 1,657 pot lifts sampled out of the 163,536 pot lifts performed during the 2008/09 Bering Sea snow crab fishery (including waters north of the Pribilof District; Gaeuman 2010), but none of those were measured to provide an estimate of weight. Bycatch weight was estimated by (4.3)x(5)x(163,536)/(1,657); the assumed average weight per crab (4.3 lb) is the average weight of landed golden king crab during the 2002 Pribilof District golden king crab fishery.

b. Only 2 golden king crab (1 sublegal male and 1 legal male) were counted in 2,142 pot lifts sampled out of the 147,244 pot lifts performed during the 2010/11 Bering Sea snow crab fishery (including waters north of the Pribilof District; Gaeuman 2011), but none of those were measured to provide an estimate of weight. Bycatch weight was estimated by 4.3x(2x147,244)/2,142; the assumed average weight per crab (4.3 lb) is the average weight of landed golden king crab during the 2002 Pribilof District golden king crab fishery.

c. A single 156 mm CL legal male golden king crab occurred in the 2,235 pot lifts sampled out of the 270,602 pot lifts performed during the 2011/12 Bering Sea snow crab fishery (including waters north of the Pribilof District; Gaeuman 2013c). Total bycatch weight was estimated by (4.9)x(270,602)/(2,235), where 4.9 is the average weight (lb) of a 156 mm CL male golden king crab estimated by the weight-at-length estimator (Section D.3.b).

d. Only 2 sublegal and 1 legal male golden king crab of unknown sizes were counted in the 2,348 pot lifts sampled within the Pribilof District and within calendar year 2013 during the 2012/13 Bering Sea snow crab fishery; no golden king crab occurred in pot lifts sampled during the 2013/14 snow crab season prior to 1 Jan 2014. During the 2012/13 snow crab season, 216,580 pot lifts were recorded within the Pribilof District. The author assumed a very generous average weight of 4.64 lb for the 3 captured golden king crab males. You do the math.

Table 3. Estimated annual weight (lb) of discarded bycatch of Pribilof golden king crab (all sizes, males and females) during federal groundfish fisheries by gear type (fixed or trawl), 1991/92–2012/13, with total bycatch mortality (lb) estimated by assuming bycatch mortality rate = 0.5 for fixed-gear fisheries and bycatch mortality rate = 0.8 for trawl fisheries (updated from 2013 SAFE with 2009/10–2012/13 data provided by R. Foy AFSC, Kodiak Laboratory via 30 July 2014 email).

	Bycatch in groundfish fisheries (lb; no mortality rate applied)			Total
Season	Fixed	Trawl	Total	Mortality (lb)
1991/92	110	13,464	13,574	10,826
1992/93	7,690	19,544	27,234	19,480
1993/94	1,116	21,248	22,364	17,556
1994/95	558	7,103	7,661	5,962
1995/96	895	4,187	5,082	3,797
1996/97	53	1,918	1,971	1,561
1997/98	2,952	1,074	4,026	2,335
1998/99	14,930	395	15,324	7,781
1999/00	10,556	1,426	11,982	6,419
2000/01	3,589	4,134	7,723	5,101
2001/02	3,300	783	4,083	2,276
2002/03	1,219	472	1,691	987
2003/04	503	401	904	572
2004/05	342	860	1,202	859
2005/06	198	126	324	200
2006/07	2,915	254	3,168	1,660
2007/08	18,678	351	19,028	9,619
2008/09	8,799	3,433	12,231	7,145
2009/10	5,299	2,573	7,873	4,708
2010/11	1,431	2,070	3,501	2,372
2011/12	1,614	2,502	4,117	2,809
2012/13	1,549	1,929	3,478	2,318
Average	3,690	4,425	8,116	5,385

Table 4. Data for calculation of $RET_{1993\text{-}1998}$ and estimates used in calculation of $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,92/93\text{-}98/99}$ for calculation of the Alternative 1 Pribilof Islands golden king crab Tier 5 2015 total-catch OFL; values under $RET_{1993\text{-}1998}$ are from Table 1, values under $R_{2001\text{-}2010}$ were computed from the retained catch data and the directed fishery bycatch estimates in Table 2 (assumed bycatch mortality rate = 0.2), values under $BM_{NC,1994\text{-}1998}$ were computed from the non-directed crab fishery bycatch estimates in Table 2 (assumed bycatch mortality rate = 0.5) and values under $BM_{GF,92/93\text{-}98/99}$ are from Table 3; from 2012 SAFE.

Season[a]	Season[b]	$RET_{1993\text{-}1998}$	$R_{2001\text{-}2010}$	$BM_{NC,1994\text{-}1998}$	$BM_{GF,92/93\text{-}98/99}$
1993	1992/93	67,458			19,480
1994	1993/94	88,985		5,459	17,556
1995	1994/95	341,908		17,941	5,962
1996	1995/96	329,009		2,839	3,797
1997	1996/97	179,249		4,469	1,561
1998	1997/98	35,722		36,380	2,335
1999	1998/99				7,781
2000	1999/00				
2001	2000/01		0.054		
2002	2001/02		0.056		
2003	2002/03		conf.		
2004	2003/04		conf.		
2005	2004/05		conf.		
2006	2005/06				
2007	2006/07				
2008	2007/08				
2009	2008/09				
2010	2009/10		conf.		
	N	6	6	5	7
	Mean	173,722	0.052	13,418	8,353
	S.E.M	54,756	0.004	6,337	2,750
	CV	0.32	0.07	0.47	0.33

a. Season convention corresponding with values under $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, and $BM_{NC,1994\text{-}1998}$.
b. Season convention corresponding with values under $BM_{GF,92/93\text{-}98/99}$.

Table 5. Statistics for 1,000 bootstrap 2015 OFL for Pribilof Islands golden king crab stock calculated according to Alternatives 1 with the computed OFL for comparison.

	Alternative 1 OFL
Computed OFL	204,611
Mean of 1,000 bootstrapped OFLs	203,870
Std. dev. of 1,000 bootstrapped OFLs	51,030
CV = (std. dev.)/(Mean)	0.25

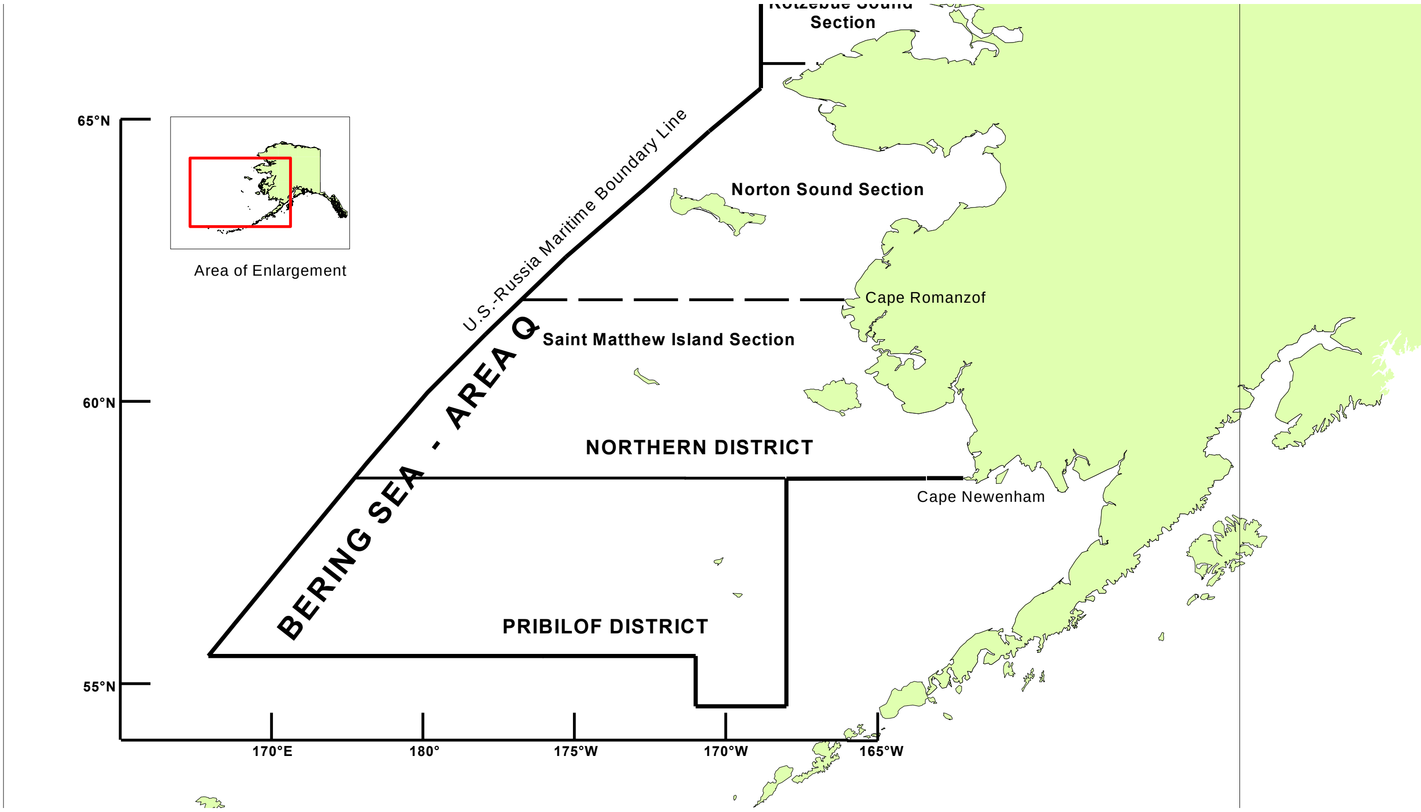

Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District (from Figure 2-4 *in* Fitch et al. 2012).

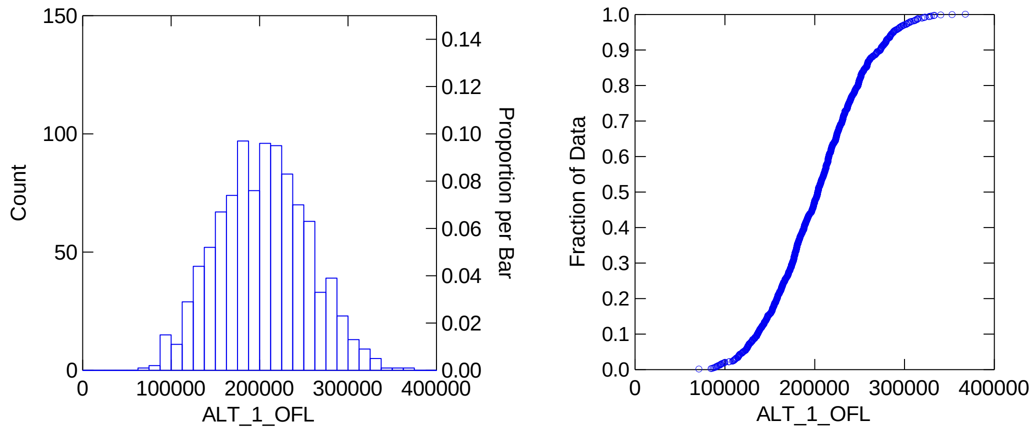

Figure 2. Bootstrapped estimates of the sampling distribution of the Alternative 1 2015 Tier 5 OFLs (lb of total catch) for the Pribilof Islands golden king crab stock; histograms in left column, quantile plots in right column.

Western Aleutian Islands (“Adak”) Red King Crab

– 2014 Tier 5 Assessment

2014 Crab SAFE Report Chapter (May 2014)

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Executive Summary

1. **Stock:**

Western Aleutian Islands (“Adak”; the Aleutian Islands, west of 171° W longitude) red king crab, *Paralithodes camtschaticus*

The Alaska Board of Fisheries in March 2014 established two districts for red king crab in the waters of the Aleutian Islands west of 171º (the Adak District for the waters 171º to 179º W longitude and the Petrel Bank District for the waters west of 179º W longitude). Although this stock has been referred to colloquially as the “Adak” stock, to avoid confusion with the Adak District, this report will refer to the stock as the “Western Aleutian Islands (WAI) red king crab” stock.

2. **Catches:**

The domestic fishery has been prosecuted since 1960/61 and was opened every season through the 1995/96 season. Peak harvest occurred during the 1964/65 season with a retained catch of 21.193-million lb (9,613 t). During the early years of the fishery through the late 1970s, most or all of the retained catch was harvested in the area between 172° W longitude and 179°15' W longitude. As the annual retained catch decreased into the mid-1970s and the early-1980s, the area west of 179°15' W longitude began to account for a larger portion of the retained catch. Retained catch during the 10-year period 1985/86–1994/95 averaged 0.943-million lb (428 t), but the retained catch during the 1995/96 season was only 0.039-million lb (18 t). During the 1995/96 through 2011/12 seasons, the fishery was opened only occasionally. There was an exploratory fishery with a low guideline harvest level (GHL) in 1998/99, three commissioner’s permit fisheries in limited areas during 2000/01–2002/03 to allow for ADF&G-Industry surveys, and two commercial fisheries with a GHL of 0.500-million lb (227 t) during the 2002/03 and 2003/04 seasons. Most of the catch since the 1990/91 season was harvested in the Petrel Bank area (between 179° W longitude and 179° E longitude) and the last two commercial seasons (the 2002/03 and 2003/04 seasons) were opened only in the Petrel Bank area. Retained catch in the last two commercial fishery seasons was 0.506-million lb (230 t) in 2002/03 and 0.479-million lb (217 t) in 2003/04. The fishery has been closed every season since the end of the 2003/04 season through the 2013/14 season. Non-retained catch of red king crab occurs in the directed red king crab fishery (when prosecuted), in the Aleutian Islands golden king crab fishery, and in groundfish fisheries. Estimated annual weight of bycatch mortality during the 1995/96–2012/13 seasons averaged

0.002-million lb (1 t) in crab fisheries and 0.019-million lb (9 t) in groundfish fisheries. Estimated weight of annual total fishery mortality during 1995/96–2012/13 averaged 0.091-million lb (41 t); the average annual retained catch during that period was 0.070-million lb (32 t). Estimated total fishery mortality for 2012/13 was <0.001-million lb (<1 t). Data for estimating total fishery mortality for the 2013/14 season are not yet available.

3. Stock biomass:

Estimates of past or present stock biomass are not available. There is no assessment model developed for this stock and standardized stock surveys have been too limited in geographic scope and too infrequent to provide a reliable index of abundance for the entire red king crab population in the Aleutian Islands west of 171° W longitude.

4. Recruitment:

Estimates of recruitment trends and current levels relative to virgin or historic levels are not available. The fishery has been closed since the end of the 2003/04 season due to apparent poor recruitment. A pot survey conducted by ADF&G in the Petrel Bank area (roughly, 179° W longitude to 179° E longitude) in November 2006 provided no evidence of strong recruitment (Gish 2007). The overall survey CPUEs (catch per pot lift) of red king crab in the standard, systematic survey (170 stations with 4 pots per station resulting in 680 pot lifts) of the Petrel Bank area were 1.2 legal males, 0.2 sublegal males, and 0.2 females; 98% of all red king crab were captured at 30 stations within an area of approximately 185 nmi^2 (633 km^2). Additionally, concurrent with the November 2006 ADF&G survey, 165 pots were fished in "string" arrays, similar to the setting of pots during commercial fishing, between standard survey stations in areas with highest CPUE during the standard survey and at locations where strings were fished during the November 2001 ADF&G-Industry survey (see Bowers et al. 2002). The CPUEs of red king crab in those "niche fishing" pots in 2006 were 15.6 legal males, 4.1 sublegal males, and 3.1 females. Ninety-two pots fished in four strings during the November 2006 ADF&G survey at the locations where four strings were fished during the November 2001 ADF&G-Industry yielded CPUEs of 9.8 legal males, 2.5 sublegal males, and 2.1 females; during the November 2001 ADF&G-Industry survey the CPUEs for the 121 pots fished at those locations were 85.5 legal males, 5.5 sublegal males, and 9.7 females. Red king crab captured during the November 2009 pot survey conducted by ADF&G were predominately larger, mature-sized crab, but the size distribution of captured males provided no expectations for near-term recruitment of legal males (Gish 2010). Only 117 4-pot stations (468 pot lifts) were fished in the November 2009 ADF&G survey. The overall CPUEs of red king crab during the November 2009 ADF&G survey was 1.5 legal males, <0.1 sublegal males, and 0.1 females. Limited (18 pot lifts) exploratory catch-and-release fishing for red king crab was also conducted by a commercial fishing vessel during mid-October to mid-December 2009 under provisions of a commissioner's permit at depths ≤ 100 fathoms (183 m) using red king crab pot gear (i.e., fished as single-pots, not long-lined) with escape webbing closed to help retain sublegal and female crab in four areas west of Petrel Bank between 178°00' E longitude and 175°30' E longitude; that limited effort yielded a catch of one legal-sized male red king crab (J. Alas, ADF&G, 7 May 2010 ADF&G Memorandum).

Another ADF&G-Industry survey was conducted as a commissioner's permit fishery in the Adak-Atka-Amlia Islands area in November 2002 (Granath 2003). Although the survey design called for a possible 2,900 pot lifts to be performed, survey participants only completed 1,085 pot lifts before withdrawing from participation. Four legal male red king crabs were captured: three legal males and one sublegal male red king crab were captured around Adak Island; no red king crabs were captured in areas on the north side of Atka

Island, but an estimated 520 sublegal males and females were captured in one pot on the north side of Atka Island; one legal male and no sublegal or female red king crabs were captured on the north side of Amlia Island; and no red king crabs were captured on the south side of Atka and Amlia Islands. By comparison, ADF&G conducted a pot survey in the Atka-Amlia Islands area in 1977 and captured 4,035 male and 1,088 female red king crabs in 360 pot lifts (ADF&G 1978), although from those results it was reported at that time that "King crab stocks at Adak still seem to be depressed" (ADF&G 1978, page 167).

5. Management performance:

No overfished determination (i.e., MSST) is possible for this stock given the lack of biomass information. Overfishing did not occur during 2012/13; the estimated total catch did not exceed the OFL of 0.12-million lb (56 t). The total catch did not exceed the ABC established for 2012/13 (0.07-million lb, or 34 t). Data for computing total catch relative to the 2013/14 OFL and ABC are not yet available. The OFL and ABC values for 2014/15 in the tables below are the author's recommended values. No determination has yet been made for a fishery opening or harvest level, if opened, for the 2014/15 season.

Year	MSST	Biomass (MMB)	TAC	Retained Catch[a]	Total Catch[a,b]	OFL[a]	ABC[a]
2010/11	N/A	N/A	Closed	0	0.004	0.12	N/A
2011/12	N/A	N/A	Closed	0	0.002	0.12	0.03
2012/13	N/A	N/A	Closed	0	<0.001	0.12	0.07
2013/14	N/A	N/A	Closed	0		0.12	0.07
2014/15	N/A	N/A				0.12	0.07

a. Millions of lb.
b. Includes bycatch mortality of discarded bycatch.

Year	MSST	Biomass (MMB)	TAC	Retained Catch[a]	Total Catch[a,b]	OFL[a]	ABC[a]
2010/11	N/A	N/A	Closed	0	2	56[c]	N/A
2011/12	N/A	N/A	Closed	0	1	56[c]	12
2012/13	N/A	N/A	Closed	0	<1	56[c]	34
2013/14	N/A	N/A	Closed	0		56[c]	34
2014/15	N/A	N/A				56	34

a. t.
b. Includes bycatch mortality of discarded bycatch.
c. The text in the June 2013 Draft SSC Report gives that value as "54 t" rather than "56 t"; the author guesses that the difference is due to the SSC making their lb-to-t conversion on the rounded value of the OFL, 0.12-million lb, rather than on the computed value of the OFL, 123,867 lb.

6. Basis for the OFL and ABC: See table, below; values for 2014/15 are the author's recommended values.

Year	Tier	Years to define Average catch (OFL)	Natural Mortality	Buffer
2010/11	5	1995/96-2007/08[a]	0.18[b]	N/A
2011/12	5	1995/96-2007/08[a]	0.18[b]	75%
2012/13	5	1995/96-2007/08[a]	0.18[b]	40%
2013/14	5	1995/96-2007/08[a]	0.18[b]	40%
2014/15	5	1995/96-2007/08[a]	0.18[b]	40%

a. OFL is for total catch and was determined by the average of the total catch for these years.

b. Assumed value for FMP king crab in NPFMC (2007); does not enter into OFL estimation for Tier 5 stock.

7. **<u>PDF of the OFL:</u>** Sampling distribution of the recommended Tier 5 OFL was estimated by bootstrapping; see section G.1. Estimated CV (sample standard error of mean divided by sample mean) of the annual total catch estimates for 1995/96–2007/08 is 0.43. Note that generated sampling distribution and computed standard deviation are meaningful as measures in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Section E.4.f).

8. **<u>Basis for the ABC recommendation:</u>** The recommended ABC is the status quo; i.e., the ABC as was recommended by the CPT and SSC for 2012/13 and 2013/14. The ABC established for 2012/13 and 2013/14 was an increase from the ABC established for 2011/12 (0.027 million lb, 12 t), which the 2011/12 ABC was based on the mean bycatch in non-directed crab fisheries and groundfish fisheries during the period 1995/96–2007/08 (June 2011 SSC minutes, page 4). The increase in the ABC for 2012/13 and maintenance of the ABC at the same level for 2013/14 was made to accommodate an Industry request for a small test fishery during 2012/13 or in the future to obtain additional data on the stock (CPT minutes for May 2013 meeting and SSC minutes for June 2013 meeting). As it turns out, Industry chose not to conduct a test fishery in 2012/13 and no such test fishery has been scheduled to date for 2013/14.

9. **<u>A summary of the results of any rebuilding analyses</u>:** Not applicable; stock is not under a rebuilding plan.

A. Summary of Major Changes

1. **<u>Changes to the management of the fishery</u>:**
   - The following notable changes to State of Alaska regulations pertaining to management of the fishery were approved by the BOF during their March 2014 meeting and which will become effective in the 2014/15 season:
     - Two districts for red king crab in the waters of the Aleutian Islands west of 171º W longitude were established: 1) the Adak District, 171º to 179º W longitude; and the Petrel Bank District, west of 179º W longitude.
     - Daily fishing periods (pots operated only from 8:00 AM to 5:59 PM), logbook, and daily reporting requirements were established for the newly-established Adak (red king crab) District.
     - Close federal waters in the newly-established Adak (red king crab) District when the red king crab GHL for the district is less than 250,000 lb (113 t), and establish pot limits of 10 pots per vessel in state waters and 15 pots per vessel in federal waters when the season is opened.

- o Changed the season opening date in regulation for the newly-established Adak (red king crab) District from October 15 to August 1; the season closing date in regulation remains unchanged at February 15.
- o For the newly-established Adak (red king crab) District, decreased the time that fishery participants are prohibited from operating longline, trawl, and pot gear for commercial, subsistence, personal use, or sport fisheries prior to the scheduled opening of the fishery from 30 days to 7 days.

- The Council has received a request to consider removing the red king crab occupying the Aleutian Islands between 171º and 179º W longitude from the BSAI crab FMP (CPT May 2013 and September 2013 meeting minutes).

2. <u>Changes to the input data</u>:

- Data on non-retained bycatch and estimates of bycatch mortality in crab and groundfish fisheries during 2012/13 have been added, but are not included in the calculation of the recommended 2014/15 total-catch OFL. Data on bycatch mortality from 2013/14 are not presently available.

3. <u>Changes to the assessment methodology</u>: None.

4. <u>Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL</u>: None.

B. Responses to SSC and CPT Comments

1. <u>Responses to the most recent two sets of SSC and CPT comments on assessments in general</u>:

- <u>CPT, May 2013</u>: *None*.
- <u>SSC, June 2013</u>: *None*.
- <u>CPT, September 2013</u> (via September 2013 SAFE Introduction chapter): Not applicable for Tier 5 assessment, except for, *"The team requests all authors to follow the Guidelines for SAFE preparation and to follow the Terms of Reference as listed therein as applicable by individual assessment for both content and diagnostics."*
    - <u>Response</u>: Guidelines for SAFE preparation as supplied in 8 August 2013 email from the CPT chair were consulted and followed.
- <u>SSC, October 2013</u>: *None*.

2. <u>Responses to the most recent two sets of SSC and CPT comments specific to the assessment</u>:

- <u>CPT, May 2013</u>: Recommended that the OFL and ABC for 2013/14 be the status quo OFL and ABC that were established for 2012/13.
    - <u>Response</u>: The author's recommended OFL and ABC for 2014/15 is the same as those established for 2012/13.
- <u>SSC, June 2013</u>: Established the OFL and ABC for 2013/14 to be the status quo OFL and ABC that were established for 2012/13.
    - <u>Response</u>: The author's recommended OFL and ABC for 2014/15 is the same as those established for 2012/13.
- <u>CPT, September 2013 (via Sept 2013 SAFE)</u>: *None.*

- SSC, October 2013: *None*.

C. Introduction

1. **Scientific name:** *Paralithodes camtschaticus*, Tilesius, 1815

2. Description of general distribution:

The general distribution of red king crab is summarized by NMFS (2004):

> "Red king crab are widely distributed throughout the BSAI, GOA, Sea of Okhotsk, and along the Kamchatka shelf up to depths of 250 m. Red king crab are found from eastern Korea around the Pacific rim to northern British Columbia and as far north as Point Barrow (page 3-27).
>
> Most red and blue king crab fisheries occur at depths from 50-200 m, but red king crab fisheries in the Aleutian Islands sometimes extend to 300 m (page 3-41).
>
> Red king crab is native to waters of 300 m or less extending from eastern Korea, the northern coast of the Japan Sea, Hokkaido, the Sea of Okhotsk, through the eastern Kamchatkan Peninsula, the Aleutian Islands, the Bering Sea, the GOA, and the Pacific Coast of North America as far south as Alice Arm in British Columbia. They are not found north of the Kamchatkan Peninsula on the Asian Pacific Coast. In North America red king crab range includes commercial fisheries in Norton Sound and sparse populations extending through the Bering Straits as far east as Barrow on the northern coast of Alaska. Red king crab have been acclimated to Atlantic Ocean waters in Russia and northern Norway. In the Bering Sea, red king crab are found near the Pribilof Islands and east through Bristol Bay; but north of Bristol Bay (58 degrees 39 minutes) they are associated with the mainland of Alaska and do not extend to offshore islands such as St. Matthew or St. Laurence Islands (pages 3-41–42)."

Commercial fishing for WAI red king crab during the last two prosecuted seasons (2002/03 and 2003/04) was opened only in the Petrel Bank area (i.e., between 179° W longitude and 179° E longitude; Baechler 2012) and effort during those two seasons typically occurred at depths of 60–90 fathoms (110–165 m); average depth of pots fished in the Aleutian Islands area during the 2002/03 season was 68 fathoms (124 m; Barnard and Burt 2004) and during the 2003/04 season was 82 fathoms (151 m; Burt and Barnard 2005). In the 580 pot lifts sampled by observers during the 1996/97–2006/07 Aleutian Islands golden king crab fishery that contained one or more red king crab, depth was recorded for 578 pots (ADF&G observer database, Dutch Harbor, April 2008). Of those, the deepest recorded depth was 266 fathoms (486 m) and 90% of pot lifts had recorded depths of 100–200 fathoms (183–366 m); no red king crab were present in any of the 6,465 pot lifts sampled during the 1996/97–2006/07 Aleutian Islands golden king crab fishery with depths >266 fathoms (486 m).

Although the Adak Registration Area is no longer defined in State regulation, in this chapter we will refer to the area west of 171° W longitude within the Aleutian Islands king crab Registration Area O as the "Western Aleutian Islands" (WAI). The Aleutian Islands king crab Registration Area O is described by Baechler (2012, page 7) as follows (see also Figure 1):

> "The Aleutian Islands king crab Registration Area O has as its eastern boundary the longitude of Scotch Cap Light (164° 44' W longitude), its northern boundary a line from Cape Sarichef (54° 36' N latitude) to 171° W longitude, north to 55° 30' N latitude, and as its western boundary the Maritime Boundary Agreement Line as that line is described in the text of and depicted in the annex to the Maritime Boundary Agreement between the United States and the Union of Soviet Socialist Republics signed in Washington, June 1, 1990 [Figure 1]. Area O encompasses both the waters of the Territorial Sea (0-3 nautical miles) and waters of the Exclusive Economic Zone (3-200 nautical miles)."

From the 1984/85 season until the March 1996 Alaska Board of Fisheries meeting, the Aleutian Islands king crab Registration Area O as currently defined had been subdivided at 171° W longitude into the historic Adak Registration Area R and the Dutch Harbor Registration Area O. The geographic boundaries of the WAI red king crab stock are defined here by the boundaries of the historic Adak Registration Area R; i.e., the current Aleutian Islands king crab Registration Area O, west of 171° W longitude.

3. <u>Evidence of stock structure</u>:

Seeb and Smith (2005) analyzed microsatellite DNA variability in nearly 1,800 individual red king crab originating from the Sea of Okhotsk to Southeast Alaska, including a sample 75 specimens collected during 2002 from the vicinity of Adak Island in the Aleutian Islands (51° 51' N latitude, 176° 39' W longitude), to evaluate the degree to which the established geographic boundaries between stocks in the BSAI reflect genetic stock divisions. Seeb and Smith (2005) concluded that, "There is significant divergence of the Aleutian Islands population (Adak sample) and the Norton Sound population from the southeastern Bering Sea population (Bristol Bay, Port Moller, and Pribilof Islands samples)." Recent analysis of patterns of genetic diversity among red king crab stocks in the western north Pacific (Asia), eastern North Pacific, and Bering Sea by multiple techniques (SNPs, allozymes, and mtDNA) also showed that red king crab sampled near Adak Island had a greater genetic relationship to stocks in Asia rather than other stocks in Alaskan waters including Bristol Bay and the Gulf of Alaska (Grant et al. 2014).

We know of no analyses of genetic relationships among red king crab from different locations within the WAI. However, given the expansiveness of the WAI and the canyons between some islands that are deep (>1,000 m) relative to the depth zone restrictions of red king crab (see above), at least some weak structuring within the WAI red king crab stock would be expected. A summary of total retained catch by 1-degree longitude groupings during 1985/86–1995/96 (seasons for which state statistical area definitions allow for grouping by 1-degree longitude and for which catch distribution was not affected by area closures and openings; see Section C.5) shows that catch and, presumably, distribution of legal-sized male red king crab is not evenly distributed across the Aleutian Islands, with most catch during that period having come from Petrel Bank, followed by the vicinity of Adak, Atka, and Amlia Islands (Figure 2). Note that the 1-degree longitude grouping of catch does not portray the spatial gaps in catch that are apparent in a closer inspection of the 1985/86–1995/96 catch data by state statistical areas. For example, no catch was reported during 1985/86–1995/96 from the two statistical areas (795102 and 795132) that include Amchitka Pass (Amchitka Pass lies between Petrel Bank and the Delarof Is; see Figure 2).

McMullen and Yoshihara (1971) reported the following on male red king crab that were tagged in February 1970 on the Bering Sea and Pacific Ocean sides of Atka Island and recovered in the subsequent fishery season:

> "Fishermen landing tagged crabs were questioned carefully concerning the location of recapture. In no instance did crabs migrate through ocean passes between the Pacific Ocean and Bering Sea."

4. <u>Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology)</u>:

Red king crab eggs are fertilized externally and the clutch of fertilized eggs (embryos) are carried under the female's abdominal flap until hatching. Male king crab fertilize eggs by passing spermatophores from the fifth periopods to the gonopores and coxae of the female's third periopods; the eggs are fertilized during ovulation and attach to the female's pleopodal setae (Nyblade 1987; McMullen 1967). Females are generally mated within hours after molting (Powell and Nickerson 1965), but may mate up to 13 days after molting (McMullen 1969). Males must wait at least 10 days after completing a molt before mating (Powell et al. 1973), but, unlike females, do not need to molt prior to mating (Powell and Nickerson 1965).

Wallace et al. (1949, page 23) described the "egg laying frequency" of red king crab:

> "Egg laying normally takes place once a year and only rarely are mature females found to have missed an egg laying cycle. The eggs are laid in the spring immediately following shedding [i.e., molting] and mating and are incubated for a period of nearly a year. Hatching of the eggs does not occur until the following spring just prior to moulting [i.e., molting] season."

McMullen and Yoshihara (1971) reported that from 804 female red king crab (79–109-mm CL) collected during the 1969/70 commercial fishery in the western Aleutians, "Female king crab in the western Aleutians appeared to begin mating at 83 millimeters carapace length and virtually all females appeared to be mature at 102 millimeters length." Blau (1990) estimated size at maturity for WAI red king crab females as the estimated CL at which 50% of females are mature (SM50; as evidenced by presence of clutches of eggs or empty) according to a logistic regression: 89-mm CL (SD = 2.6 mm). Size at maturity has not been estimated for WAI male red king crab. However, because the estimated SM50 for WAI red king crab females is the same as that estimated for Bristol Bay red king crab females (Otto et al. 1990), the estimated maturity schedule used for Bristol Bay red king crab males (see SAFE chapter on Bristol Bay red king crab) could be applied to males in the WAI stock as a proxy.

Few data are available on the molting and mating period for red king crab specifically in the WAI. Among the red king crab captured by ADF&G staff for tagging on the south side of Amlia Island (173° W longitude to 174° W longitude) in the first half of April 1971, males and females were molting, females were hatching embryos, and mating was occurring (McMullen and Yoshihara 1971). The spring mating period for red king crab is known to last for several months, however. For example, although mating activity in the Kodiak area apparently peaks in April, mating pairs in the Kodiak area have been documented from January through May (Powell et al. 2002). Due to the season timing for the commercial fishery, little data on reproductive condition of WAI red king crab females have been collected by at-sea fishery observers that can be used for evaluating the mating period. For example, of the 3,211 mature females that were examined during the 2002/03 and 2003/04 red king crab seasons in the Petrel Bank area, both of which seasons were restricted to late October, only 10 females were scored as “hatching” (ADF&G observer database, Dutch Harbor, April 2008).

Data on mating pairs of red king crab collected from the Kodiak area during March–May of 1968 and 1969 showed that size of the females in the pairs increased from March to May, indicating that females tend to release their larvae and mate later in the mating season with increasing age (Powell et al. 2002). Size of the males in those mating pairs did not increase with later sampling periods, but did show a decreasing trend in estimated time since last molt. In all the data on mating pairs collected from the Kodiak area during 1960–1984, the proportion of males that were estimated to have not recently molted prior to mating decreased monthly over the mating period (Powell et al. 2002). Those data suggest that males not molting early in the mating period have a mating advantage at that time when smaller, younger mature females and primiparous females tend to ovulate, whereas males that molt early in the mating period participate later in the mating period when the larger, older females tend to be mated.

Current knowledge of red king crab reproductive biology, including male and female maturation, migration, mating dynamics, and potential effects of exploitation on reproductive potential, is summarized by Webb (2014).

5. <u>Brief summary of management history</u>:

A complete summary of the management history through 2010/11 is provided in Baechler (2012, pages 7–12). The domestic fishery for red king crab in the WAI began with the 1960/61 season. Retained catch of red king crab in the Aleutians west of 172º W longitude averaged 11.595-million lb (5,259 t) during the 1960/61–1975/76 seasons, with a peak harvest of 21.193-million lb (9,613 t) in the 1964/65 season (Table 1, Figure 3). Guideline harvest levels (GHL; sometimes expressed as ranges, with an upper and lower GHL) for the fishery have been established for most seasons since the 1970s. The fishery was closed for the 1976/77 season in the area west of 172º W longitude, but reopened for the 1977/78–1995/96 seasons. Average retained catch during the 1977/78–1995/96 seasons (for the area west of 172º W longitude prior to the 1984/85 season and for the area west of 171º W longitude since the 1984/85 season) was 1.044-million lb (474 t); the peak harvest during that period was 1.982-million lb (899 t) for the 1983/84 season. During the mid-to-late 1980s, significant portions of the catch during the WAI red king crab fishery occurred west of 179º E longitude or east of 179º W longitude, whereas most of the retained catch was harvested from the Petrel Bank area (179° W longitude to 179° W longitude) during the 1990/91–1994/95 seasons (Figure 4). The WAI red king crab fishery was closed for the 1996/97 season following the diminishing harvests of the preceding two seasons that did not reach the lower GHL. Due to concerns about low stock levels and poor recruitment, the fishery has been opened only intermittently since 1996/97. The fishery was closed for the 1996/97–1997/98 seasons, closed in the Petrel Bank area for the 1998/99 season, closed for the 1999/2000 season, restricted to the Petrel Bank area for the 2000/01–2003/04 seasons (except for an ADF&G-Industry survey in the Adak, Atka, and Amlia Islands area conducted as a commissioner’s permit fishery), and closed for the 2004/05–2012/13 seasons. Management history since the 1996/97 closure is summarized in the table below. The peak harvest since the 1996/97 season was 0.506-million lb (229 t), which occurred in the 2002/03 season. A summary of relevant fishery regulations and management actions pertaining to the WAI red king crab fishery since the 1996/97 season is provided in Table 2.

Only males of a minimum legal size may be retained by the commercial red king crab fishery in the WAI. By State of Alaska regulation (**5 AAC 34.620 (a)**), the minimum legal size limit is 6.5-inches (165 mm) carapace width (CW), including spines. A carapace length (CL) ≥138 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007). Except for the years 1968–1970, the minimum size has been 6.5-inches CW since 1950; in 1968 there was a "first-season" minimum size of 6.5-inches CW and a "second-season" minimum size of 7.0-inches and in 1969–1970 the minimum size was 7.0-inches CW (Donaldson and Donaldson 1992).

Red king crab may be commercially fished only with king crab pots (as defined in 5 AAC 34.050). Pots used to fish for red king crab in the WAI must, since 1996, have at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized red king crab and may not be longlined (5 AAC 34.625 (e)). The sidewall of the pot "…must contain an opening equal to or exceeding 18 inches in length... The opening must be laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 30 thread." (5 AAC 39.145(1)).

By State of Alaska regulation (**5 AAC 34.610 (a)**), the WAI red king crab commercial fishing season is from October 15 to February 15, unless closed by emergency order.

The WAI red king crab fishery west of 179° W longitude has been managed since the 2005/06 season under the Crab Rationalization program (50 CFR Parts 679 and 6805). The WAI red king crab fishery in the area east of 179° W longitude was not included in the Crab Rationalization program (Baechler 2012). In March 2013, the Alaska Board of Fisheries reduced the vessel size limit in state waters from 171° W longitude to 179° W longitude from a maximum of 90 feet to no more than 60 feet in overall length and established a 10 pot limit for vessels fishing red king crab in state waters from 171° W longitude to 179° W longitude; there are no vessel size limits or pot limits in the federal waters from 171° W longitude to 179° W longitude. There is a pot limit of 250 pots per vessel for vessels fishing for red king crab in the Petrel Bank area (**5 AAC 34.625 (d)**).

The WAI red king crab fishery was closed for the 1996/97–1997/98 seasons. The following area closures and harvest restrictions have been applied to the red king crab fishery, when opened, in the WAI since the 1998/99 season:

- The 1998/99 season for red king crab in the WAI was open east of 179° W longitude with a guideline harvest level (GHL) of 0.005-million lb (2 t) and west of 179° E longitude with a GHL of 0.010-million lb (5 t), but was closed between 179° W longitude and 179° E longitude.
- ADF&G-Industry pot surveys for red king crab were conducted in January—February 2001 (the 2000/01 season) and November 2001 (the 2001/02 season) under the restrictions of a commissioner's permit fishery in the Petrel Bank area (north of 51° 45' N latitude and between 179° W longitude and 179° E longitude; Bowers et al. 2002, Baechler 2012). The WAI was closed to commercial red king crab fishing outside of the designated survey area.
- The 2002/03 season opened in those waters of king crab Registration Area O between 179° W longitude and 179° E longitude and north of 51° 45' N latitude (the Petrel Bank area; Baechler 2012) with a GHL of 0.500-million lb (227 t). Additionally, an ADF&G-Industry pot survey for red king crab was conducted in November 2002 under the restrictions of a commissioner's permit fishery in the vicinity of Adak, Atka, and Amlia Islands to assess the

WAI red king crab stock in the area between 172° W longitude and 179° W longitude (Granath 2003). The remaining area outside of the Petrel Bank area and the designated survey area in the WAI was closed to commercial red king crab fishing during the 2002/03 season.

- The 2003/04 season opened in those waters of king crab Registration Area O between 179° W longitude and 179° E longitude and north of 51° 45' N latitude (the so-called "Petrel Bank area"; Baechler 2012). The remaining area in the WAI was closed to commercial red king crab fishing during the 2003/04 season.

6. **Brief description of the annual ADF&G harvest strategy:**

There is no harvest strategy in state regulation for WAI red king crab. Following results of the January/February and November 2001 ADF&G-Industry pot surveys for red king crab in the Petrel Bank area, which showed healthy levels of legal males (CPUE = 28 crab per pot lift), but low catches of females and sublegal males, ADF&G opened the 2002/03 and 2003/04 seasons with a GHL of 0.500-million lb (227 t); that GHL was established as the minimum GHL that could be managed inseason, given expected participation and effort (Baechler 2012). The fishery was closed for the 2004/05 season due to continued uncertainty on the status of pre-recruit legal males, a reduction in legal male CPUE between the 2002/03 and 2003/04 seasons (18 legal crab per pot in 2002/03 and 10 legal crab per pot in 2003/04), and a strategy adopted by ADF&G to close the fishery before the CPUE of legal crab dropped below 10 per pot. The CPT and the SSC have highlighted the need for survey data on this stock, most recently by the SSC in June 2013 (SSC June 2013 meeting minutes).

7. **Summary of the history of B_{MSY}:** Not applicable for this Tier 5 stock.

D. Data

1. **Summary of new information:**
   - Retained catch data from the closed 2012/13 directed fishery season has been added; the retained catch was 0 lb.
   - Data on non-retained bycatch in crab and groundfish fisheries has been updated with data from the 2012/13 Aleutian Islands golden king crab fishery and the 2012/13 groundfish fisheries in reporting areas 541, 542, and 543 (Figure 5).

2. **Data presented as time series:**

a. Total catch** and b. **Information on bycatch and discards:

- The 1960/61–2013/14 time series of retained catch (number and lb of crab harvested, including deadloss), effort (vessels, landings, and pot lifts), average weight of landed crab, average carapace length of landed crab, and CPUE (number of landed crab captured per pot lift) is presented in Table 1.
- The 1960/61–2013/14 time series of retained catch (lb of landed crab) is presented graphically in Figure 3.
- The 1995/96–2012/13 times series of weight of retained legal males and estimated weight of non-retained legal male, non-retained sublegal male, and non-retained female red king crab in the WAI during commercial crab fisheries is given in Table 3. Observer data on size distributions and estimated catch numbers of non-retained catch were used to estimate the weight of non-retained catch of red king crab by applying a weight-at-length estimator (see below). Estimates of bycatch prior to the 1995/96 season are not given due to non-existence of data or to limitations on bycatch sampling during the crab fisheries. Prior to 1988/89 there was no fishery observer

program for Aleutian Islands crab fisheries and during the 1988/89–1994/95 seasons observers were required only on vessels processing king crab at sea, including catcher-processor vessels. Observer data from the Aleutian Islands prior to 1990/91 is considered unreliable and the observer data from the directed WAI red king crab fishery in the 1990/91 and 1992/93–1994/95 seasons and golden king crab fishery in the 1993/94 and 1994/95 seasons are confidential due to the limited number of observed vessels. During the 1995/96–2004/05 seasons, observers were required on all vessels fishing for king crab in the Aleutian Islands area at all times that a vessel was fishing. With the advent of the Crab Rationalization program in the 2005/06 season, all vessels fishing for golden king crab in the Aleutian Islands area are now required to carry an observer for a period during which 50% of the vessel's harvest was obtained during each trimester of the fishery; observers continue to be required at all times a vessel is fishing in the red king crab fishery west of 179° W longitude. All king crab that were captured as bycatch during the Aleutian Islands golden king crab fishery west of 174° W longitude by a vessel while an observer was on board during the 2001/02–2002/03 and 2004/05–2012/13 seasons were counted and recorded for capture location and biological data.

- The 1993/94–2012/13 time series of estimated weight of bycatch and estimated bycatch mortality of red king crab in the WAI (reporting areas 541, 542, and 543; i.e., Aleutian Islands west of 170° W longitude; Figure 5) during federal groundfish fisheries by gear type (fixed or trawl) is provided in Table 4. Following Foy (2012a, 2012b), the bycatch mortality rate of king crab captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crab captured by trawls during groundfish fisheries was assumed to be 0.8. Estimated weight of bycatch (not discounted by an assumed mortality rate) during the 1993/94–2012/13 groundfish fisheries by reporting area (541, 542, or 543) is provided in Table 5. Bycatch estimates for 1992/93 are available, but appear to be suspect because they are extremely low.
- The 1995/96–2012/13 time series of estimated weight of total fishery mortality of red king crab in the WAI, partitioned into retained catch, bycatch mortality during crab fisheries, and bycatch mortality during federal groundfish fisheries, is provided in Table 6. Following Siddeek et al. (2011), the bycatch mortality rate of king crab captured and discarded during Aleutian Islands king crab fisheries was assumed to be 0.2; bycatch mortality in crab fisheries was estimated for Table 6 by applying that assumed bycatch mortality rate to the estimates of non-retained catch given in Table 3. The estimates of bycatch mortality in groundfish fisheries given in Table 6 are from Table 4.

c. ***Catch-at-length:*** Not used in a Tier 5 assessment; none are presented here.

d. Survey biomass estimates: Not available; there is no program for regular performance of standardized surveys sampling from the entirety of the stock range.

e. Survey catch at length: Not used in a Tier 5 assessment; none are presented here.

f. Other data time series:

Data on CPUE (number of retained crab per pot lift) during the red king crab in the WAI are available for the 1972/73–2013/14 seasons (see Table 1).

3. Data which may be aggregated over time:

a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):

Growth per molt was estimated for WAI male red king crab by Vining et al. (2002) based on information received from recoveries during commercial fisheries of tagged red king crab released in the Adak Island to Amlia Island area during the 1970s (see Table 5 in Pengilly 2009). Vining et al. (2002) used a logit estimator to estimate the probability as a function of carapace length (CL, mm) at release that a male WAI red king tagged and released in new-shell condition would molt within 8–14 months after release (see Tables 6 and 7 in Pengilly 2009).

b. Weight-at length or weight-at-age (by sex):

Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female red king crab according to the equation, Weight = $A*CL^{B}$ (from Table 3-5, NPFMC 2007) are: A = 0.000361 and B = 3.16 for males and A = 0.022863 and B = 2.23382 for females; note that although the estimated parameters, A and B, are those estimated for ovigerous females, those parameters were used to estimate the weight of all females without regard to reproductive status. Estimated weights in grams were converted to lb by dividing by 453.6.

c. ***Natural mortality rate:*** Natural mortality rate has not been estimated specifically for red king crab in the WAI. A natural mortality rate of M =0.18 for king crab species was assumed by NPFMC (2007).

4. Information on any data sources that were available, but were excluded from the assessment:

- Distribution of effort and catch during the 2006 ADF&G Petrel Bank red king crab pot survey (Gish 2007) and the 2009 ADF&G Petrel Bank red king crab pot survey (Gish 2010).
- Sex-size distribution of catch and distribution of effort and catch during the January/February 2001 and November 2001 ADF&G-Industry red king crab survey of the Petrel Bank area (Bowers et al. 2002) and ADF&G-Industry red king crab pot survey conducted as a commissioner's permit fishery in November 2002 in the Adak Island and Atka-Amlia Islands areas (Granath 2003).
- Observer data on size distribution and geographic distribution of bycatch of red king crab in the WAI red king crab fishery and the Aleutian Islands golden king crab fishery, 1988/89–2012/13 (ADF&G observer database).
- Summary of data collected by ADF&G WAI red king crab fishery observers or surveys during 1969–1987 (Blau 1993).
- Retained catch-at-length data for the red king crab fishery in the WAI for the 1984/85–1995/96, 1999/00, 2000/01–2001/02, and 2002/03–2003/04 seasons (data from the 1999/2000 season and the 2000/01–2001/02 seasons collected made during either restricted exploratory fishing or during ADF&G-Industry surveys).

E. Analytic Approach

1. **History of modeling approaches for this stock:** This is a Tier 5 stock; there is no assessment model and no history of assessment modelling approaches for this stock.

2. **Model Description:** There is no regular survey of this stock. No assessment model for the WAI red king crab stock exists and none is in development. The SSC in June 2010 recommended that: the WAI red king crab stock be managed as a Tier 5 stock; the OFL be specified as a total-catch OFL; the total-catch OFL be established as the estimated average annual weight of the retained catch and bycatch mortality in crab and groundfish fisheries over the period 1995/96–2007/08; and the period used for computing the Tier 5 total-catch OFL be fixed at 1995/96–2007/08.

   Given the strong recommendations from the SSC in June 2010, the Tier 5 total-catch OFL would change only if retained catch data and bycatch estimates for the period 1995/96–2007/08 or assumed values of bycatch mortality rates used in the 2010 SAFE were revised. Given that no need has been shown to revise either retained catch data and bycatch estimates for the period 1995/96–2007/08 or assumed values of bycatch mortality rates used in the 2010 SAFE, the recommended approach for establishing the 2014/15 OFL is the approach identified by the SSC in June 2010 and no alternative approaches are suggested by the author. Hence the recommended total-catch OFL for 2014/15 is

$$OFL_{2014/15} = RET_{95/96\text{-}07/08} + BM_{CF,\ 95/96\text{-}07/08} + BM_{GF,\ 95/96\text{-}07/08},$$

   where,

   - $RET_{95/96\text{-}07/08}$ is the average annual retained catch in the directed crab fishery during 1995/96–2007/08
   - $BM_{CF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the directed and non-directed crab fisheries during 1995/96–2007/08, and
   - $BM_{GF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the groundfish fisheries during 1995/96–2007/08.

   Given the June 2010 SSC recommendations, items ***E.2 a–i*** are not applicable.

3. **Model Selection and Evaluation:** Not applicable; see section ***E.2***.

4. **Results (best model(s)):**

a. ***List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties:*** Not applicable.

b. ***Tables of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible; include estimates from previous SAFEs for retrospective comparisons):*** See Table 6.

c. ***Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible):*** Information requested for this subsection is not applicable to a Tier 5 stock.

d. ***Evaluation of the fit to the data:*** Not applicable for Tier 5 stock.

e. ***Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments):*** Not applicable for Tier 5 stock.

f. ***Uncertainty and sensitivity analyses (this section should highlight unresolved problems and major uncertainties, along with any special issues that complicate scientific assessment, including questions about the best model, etc.):*** For a Tier 5 assessment, the major uncertainties are:

- Whether the time period is "representative of the production potential of the stock" and if it serves to "provide the required risk aversion for stock conservation and utilization goals." Or whether any such time period exists.
    - In this regard, the CPT (May 2011 minutes) noted that the OFL (0.12 million lb; 56 t) that was established for this stock by the SSC in June 2010 "could be considered biased high because of years of high exploitation" and questioned "whether the time frame used to compute the OFL is meaningful as an estimate of the productivity potential of this stock." Additionally, the CPT registered its concern with a fishery mortality equivalent to 90% of that OFL: "Discussion further noted to what extent removing 110,000 lbs in perpetuity is reasonable rate of sustainable catch for this stock given its current size."
- The bycatch mortality rates used in estimation of total catch. Because most (78%) of the estimated total mortality during 1995/96–2007/08 is due to the retained catch component, the total catch estimate is not severely sensitive to assumed bycatch mortality rates. Doubling the assumed bycatch mortality during crab fisheries from 0.2 to 0.4 would increase the OFL by a factor of 1.02; halving that assumed rate from 0.2 to 0.1 would decrease the OFL by a factor of 0.99. Increasing the assumed bycatch mortality rate for all groundfish fisheries (regardless of gear type) to 1.0 would increase the OFL by a factor of 1.07.

F. Calculation of the OFL

1. **Specification of the Tier level and stock status level for computing the OFL:**

- Recommended as Tier 5: total-catch OFL specified as the estimated average annual total-catch during the period 1995/96–2007/08; i.e.,

$$OFL_{2014/15} = RET_{95/96\text{-}07/08} + BM_{CF,\ 95/96\text{-}07/08} + BM_{GF,\ 95/96\text{-}07/08},$$

where,

- $RET_{95/96\text{-}07/08}$ is the average annual retained catch in the directed crab fishery during 1995/96–2007/08
- $BM_{CF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the directed and non-directed crab fisheries during 1995/96–2007/08, and
- $BM_{GF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the groundfish fisheries during 1995/96–2007/08.

Statistics on the data and estimates used to calculate $RET_{95/96\text{-}07/08}$, $BM_{CF,\ 95/96\text{-}07/08}$, and $BM_{GF,95/96\text{-}07/08}$ are provided in the "Mean, 1995/96–2007/08" row of Table 6. Using the calculated values of $RET_{95/96\text{-}07/08}$, $BM_{CF,\ 95/96\text{-}07/08}$, and $BM_{GF,95/96\text{-}07/08}$, $OFL_{2014/15}$ is,

$$OFL_{2014/15} = 96{,}932 + 3{,}000 + 23{,}935 = 123{,}867 \text{ lb (0.12-million lb; 56 t).}$$

[Note: The text in the June 2013 Draft SSC Report gives that value as "54 t" rather than "56 t"; the author guesses that the difference is due to the SSC making their lb-to-t conversion on the rounded value of the OFL rather than on 123,867 lb.]

2. **<u>List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan</u>:** Not applicable for Tier 5 stock.

3. **<u>Specification of the OFL</u>:**

a. ***<u>Provide the equations (from Amendment 24) on which the OFL is to be based</u>:***

From **Federal Register** / Vol. 73, No. 116, page 33926, "For stocks in Tier 5, the overfishing level is specified in terms of an average catch value over an historical time period, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information." Additionally, "For stocks where nontarget fishery removal data are available, catch includes all fishery removals, including retained catch and discard losses. Discard losses will be determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the overfishing level is set for and compared to the retained catch" (FR/Vol. 73, No. 116, 33926). That compares with the specification of NPFMC (2007) that the OFL "represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock."

b. ***<u>Basis for projecting MMB to the time of mating</u>:*** Not applicable for Tier 5 stock.

c. ***<u>Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring</u>:***

See table, below. The OFL and ABC values for 2014/15 are those recommended by the author.

Year	MSST	Biomass (MMB)	TAC	Retained Catch[a]	Total Catch[a,b]	OFL[a]	ABC[a]
2010/11	N/A	N/A	Closed	0	0.004	0.12	N/A
2011/12	N/A	N/A	Closed	0	0.002	0.12	0.03
2012/13	N/A	N/A	Closed	0	<0.001	0.12	0.07
2013/14	N/A	N/A	Closed	0		0.12	0.07
2014/15	N/A	N/A				0.12	0.07

a. Millions of lb.

b. Includes bycatch mortality of discarded bycatch.

Year	MSST	Biomass (MMB)	TAC	Retained Catch[a]	Total Catch[a,b]	OFL[a]	ABC[a]
2010/11	N/A	N/A	Closed	0	2	56[c]	N/A
2011/12	N/A	N/A	Closed	0	1	56[c]	12
2012/13	N/A	N/A	Closed	0	<1	56[c]	34
2013/14	N/A	N/A	Closed	0		56[c]	34
2014/15	N/A	N/A				56	34

a. t.

b. Includes bycatch mortality of discarded bycatch.

c. The text in the June 2013 Draft SSC Report gives that value as "54 t" rather than "56 t"; the author guesses that the difference is due to the SSC making their lb-to-t conversion on the rounded value of the OFL, 0.12-million lb, rather than on the computed value of the OFL, 123,867 lb.

4. **Specification of the recommended retained-catch portion of the total-catch OFL:**

   a. Equation for recommended retained portion of the total-catch OFL,
   Retained-catch portion = average retained catch during 1995/96–2007/08
   = 96,932 lb (0.10-million lb; 44 t).

5. **Recommended F_{OFL}, OFL total catch and the retained portion for the coming year:** See sections ***F.3*** and ***F.4***, above; no F_{OFL} is recommended for a Tier 5 stock.

G. Calculation of ABC

1. PDF of OFL. A bootstrap estimate (1,000 samples drawn with replacement from the 1995/96–2007/08 estimates of total fishery mortality in Table 6) of the sampling distribution (assuming no error in estimation of bycatch) of the OFL is shown in Figure 6. The mean and CV computed from the 1,000 replicates are essentially the same as fthe mean and CV of the 1995/96–2007/08 total catch estimates given in Table 6. Note that the generated sampling distribution is meaningful as a measure of OFL uncertainty only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Section E.4.f).

2. List of variables related to scientific uncertainty.

- Bycatch mortality rate in each fishery that bycatch occurs. Note that for Tier 5 stocks, an increase in an assumed bycatch rate will increase the OFL (and hence the ABC), but has no effect on the retained-catch portion of the OFL or the retained-catch portion of the ABC.
- Estimated bycatch mortality during each fishery that bycatch occurred in during 1995/96–2007/08.
- The time period to compute the average catch relative to assumption that it represents "a time period determined to be representative of the production potential of the stock."

3. List of addititional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.

4. Author recommended ABC. 74,000 lb (0.07-million lb, 34 t). This is the status quo based on the ABC for 2013/14 that was recommended by the SSC in June 2013 as a value that would "be sufficient to cover bycatch and the proposed test fishery catch" (June 2013 SSC meeting minutes, page 10). Note that the lower ABC recommended for 2011/12 by the SSC in June 2011 was based on the estimated average bycatch mortality due to groundfish and the non-directed crab fisheries during 1995/96–2007/08, 26,935 lb (0.03-million lb; 12 t).

H. Rebuilding Analyses

Entire section is not applicable; this stock has not been declared overfished.

I. Data Gaps and Research Priorities

This fishery has a long history, with the domestic fishery dating back to 1960/61. However, much of the data on this stock prior to the early-mid 1980s is difficult to retrieve for analysis. Fishery data summarized to the level of statistical area are presently not available prior to 1980/81. Changes in definitions of fishery statistical areas between 1984/85 and 1985/86 also make it difficult to assess geographic trends in effort and catch over much of the fishery's history. An effort to compile all fishery data and other written documentation on the stock and fishery and to enter all existing fishery, observer, survey, and tagging data into a database that allows for analysis of all data from the stock through the history of the fishery would be very valuable.

The SSC in October 2008, June 2011, and June 2013 noted the need for systematic surveys to obtain the data to estimate the biomass of this stock. Surveys on this stock have, however, been few and the geographic scope of the surveyed area is limited. Aside from the pot surveys performed in the Adak-Atka area during the mid-1970s (ADF&G 1978, Blau 1993), the only standardized surveys for red king crab performed by ADF&G were performed in November 2006 and November 2009 and those were limited to the Petrel Bank area (Gish 2007, 2010). The ADF&G-Industry surveys, conducted as limited fisheries that allowed retention of captured legal males under provisions of a commissioner's permit, have been performed in limited areas of the WAI: during January–February 2001 and November 2001 in the Petrel Bank area (Bowers et al. 2002) and during November 2002 in the Adak-Atka-Amlia area (Granath 2003). A very limited (18 pot lifts) Industry exploratory survey without any retention of crab performed during mid-October to mid-December 2009 between 178°00' E longitude and 175°30' E longitude produced a catch of one red king crab, a legal-sized male (Baechler 2012). Based on requests from Industry in 2012, ADF&G designed a state-waters red king crab pot survey for the Adak Island group. Twenty-five stations were designated with 20 pot lifts in each station. To defray cost of the survey, participants would be allowed to sell up to 31,417 lb (14 t) of red king crab. In addition, bycatch mortality during the proposed survey was assumed not to exceed 20,000 lb (9 t) based on assumed maximum bycatch and an assumed bycatch mortality rate of 0.2. In 2012, the CPT and SSC recommended an ABC of 0.074-million lb (34 t) for 2012/13 to accommodate the proposed red king crab survey. In late summer 2012, industry advocates decided to forgo the fall 2012 survey.

Trawl surveys are preferable to pot surveys for providing density estimates, but crab pots may be the only practical gear for sampling king crab in the Aleutians. Standardized pot surveys are a prohibitively expensive approach to surveying the entire WAI. Surveys or exploratory fishing performed by Industry in cooperation with ADF&G, with or without allowing retention of captured legal males, reduce the costs to agencies. Agency-Industry cooperation can provide a means to obtain some information on distribution and density during periods of fishery closures. However, there can be difficulties in assuring standardization of procedures during ADF&G-Industry surveys (Bowers et al. 2002). Moreover, costs of performing a survey have resulted in incompletion of ADF&G-Industry surveys (Granath 2003). Hence, surveys performed by Industry in cooperation with ADF&G cannot be expected to provide sampling over the entire WAI during periods of limited stock distribution and overall low density, as apparently currently exists.

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Table 1. Aleutian Islands, Area O, red king crab commercial fishery data, 1960/61–2013/14, partitioned into the Adak Area (west of 172º W longitude prior to 1984/85 and west of 171º W longitude since 1984/85) and the Dutch Harbor Area (from 2013 Crab SAFE, updated for the 2013/14 season).

		Number of							Average		
Season	Location	Vessels	Landings	Crab[a]	Pots lifted	GHL/TAC[b]	Harvest[a,c]	Deadloss[c]	Weight[c]	CPUE[d]	Length[e]
1960/61	East of 172° W	NA	NA	NA	NA		NA	NA	NA	NA	NA
	West of 172° W	4	41	NA	NA		2,074,000	NA	NA	NA	NA
	TOTAL										
1961/62	East of 172° W	4	69	NA	NA		533,000	NA	NA	NA	NA
	West of 172° W	8	218	NA	NA		6,114,000	NA	NA	NA	NA
	TOTAL		**287**				**6,647,000**				
1962/63	East of 172° W	6	102	NA	NA		1,536,000	NA	NA	NA	NA
	West of 172° W	9	248	NA	NA		8,006,000	NA	NA	NA	NA
	TOTAL		**350**				**9,542,000**				
1963/64	East of 172° W	4	242	NA	NA		3,893,000	NA	NA	NA	NA
	West of 172° W	11	527	NA	NA		17,904,000	NA	NA	NA	NA
	TOTAL		**769**				**21,797,000**				
1964/65	East of 172° W	12	336	NA	NA		13,761,000	NA	NA	NA	NA
	West of 172° W	18	442	NA	NA		21,193,000	NA	NA	NA	NA
	TOTAL		**778**				**34,954,000**				
1965/66	East of 172° W	21	555	NA	NA		19,196,000	NA	NA	NA	NA
	West of 172° W	10	431	NA	NA		12,915,000	NA	NA	NA	NA
	TOTAL		**986**				**32,111,000**				
1966/67	East of 172° W	27	893	NA	NA		32,852,000	NA	NA	NA	NA
	West of 172° W	10	90	NA	NA		5,883,000	NA	NA	NA	NA
	TOTAL		**983**				**38,735,000**				
1967/68	East of 172° W	34	747	NA	NA		22,709,000	NA	NA	NA	NA
	West of 172° W	22	505	NA	NA		14,131,000	NA	NA	NA	NA
	TOTAL		**1,252**				**36,840,000**				
1968/69	East of 172° W	NA	NA	NA	NA		11,300,000	NA	NA	NA	NA
	West of 172° W	30	NA	NA	NA		16,100,000	NA	NA	NA	NA
	TOTAL						**27,400,000**				
1969/70	East of 172° W	41	375	NA	72,683		8,950,000	NA	NA	NA	NA
	West of 172° W	33	435	NA	115,929		18,016,000	NA	6.5	NA	NA
	TOTAL		**810**		**188,612**		**26,966,000**				
1970/71	East of 172° W	32	268	NA	56,198		9,652,000	NA	NA	NA	NA
	West of 172° W	35	378	NA	124,235		16,057,000	NA	NA	NA	NA
	TOTAL		**646**		**180,433**		**25,709,000**				
1971/72	East of 172° W	32	210	1,447,692	31,531		9,391,615	NA	7	46	NA
	West of 172° W	40	166	NA	46,011		15,475,940	NA	NA	NA	NA
	TOTAL		**376**		**77,542**		**24,867,555**				
1972/73	East of 172° W	51	291	1,500,904	34,037		10,450,380		7	44	
	West of 172° W	43	313	3,461,025	81,133		18,724,140	NA	5.4	43	NA
	TOTAL		**604**	**4,961,929**	**115,170**		**29,174,520**		**5.9**	**43**	
1973/74	East of 172° W	56	290	1,780,673	41,840	10.0[f]	12,722,660	NA	7.1	43	NA
	West of 172° W	41	239	1,844,974	70,059	20.0[f]	9,741,464	NA	5.3	26	148.6
	TOTAL		**529**	**3,625,647**	**111,899**		**22,464,124**		**6.2**	**32**	

-continued-

Table 1. page 2 of 3.

Season	Locale	Number of Vessels[a]	Landings	Crabs[b]	Pots Lifted	Harvest[b,c]	Average Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1974/75	East of 172° W	87	372	1,812,647	71,821	13,991,190	7.7	25		
	West of 172° W	36	97	532,298	32,620	2,774,963	5.2	16	148.6	NA
	TOTAL		**469**	**2,344,945**	**104,441**	**16,766,153**	**7.1**	**22**		
1975/76	East of 172° W	79	369	2,147,350	86,874	15,906,660	7.4	25		
	West of 172° W	20	25	79,977	8,331	411,583	5.2	10	147.2	NA
	TOTAL		**394**	**2,227,327**	**95,205**	**16,318,243**	**7.3**	**23**		
1976/77	East of 172° W	72	226	1,273,298	65,796	9,367,965 [f]	7.4	19		
	East of 172° W	38	61	86,619	17,298	830,458 [g]	9.6	5	NA	NA
	West of 172° W	F I S H E R Y C L O S E D								
	TOTAL		**287**	**1,359,917**	**83,094**	**10,198,423**	**7.5**	**16**		
1977/78	East of 172° W	33	227	539,656	46,617	3,658,860 [f]	6.8	12		
	East of 172° W	6	7	3,096	812	25,557 [h]	8.3	4	NA	NA
	West of 172° W	12	18	160,343	7,269	905,527	5.7	22	152.2	NA
	TOTAL		**252**	**703,095**	**54,698**	**4,589,944**	**6.5**	**13**		
1978/79	East of 172° W	60	300	1,233,758	51,783	6,824,793	5.5	24	NA	NA
	West of 172° W	13	27	149,491	13,948	807,195	5.4	11	NA	1,170
	TOTAL		**327**	**1,383,249**	**65,731**	**7,631,988**	**5.5**	**21**		
1979/80	East of 172° W	104	542	2,551,116	120,554	15,010,840	5.9	21	NA	NA
	West of 172° W	18	23	82,250	9,757	467,229	5.7	8	152	24,850
	TOTAL		**565**	**2,633,366**	**130,311**	**15,478,069**	**5.9**	**20**		

Season	Location	Number of Vessels	Landings	Crab[a]	Pots lifted	GHL/TAC[b]	Harvest[a,c]	Deadloss[c]	Average Weight[c]	CPUE[d]	Length[e]
1980/81	East of 172° W[g]	114	830	2,772,287	231,607	7.0 - 17.0[f]	17,660,620	NA	6.4	12	NA
	East of 172° W[i]	54	120	182,349	30,000		1,392,923		7.6	6	
	West of 172° W	17	52	254,390	20,914	0.5 - 3.0	1,419,513	54,360	5.6	12	149
	TOTAL		**1,002**	**3,209,026**	**282,521**		**20,473,056**		**6.4**	**11**	
1981/82	East of 172° W	92	683	741,966	220,087	7.0 - 17.0[f]	5,155,345	NA	6.9	3	NA
	West of 172° W	46	106	291,311	40,697	0.5 - 3.0	1,648,926	8,759	5.7	7	148.3
	TOTAL		**789**	**1,033,277**	**260,784**		**6,804,271**		**6.6**	**4**	
1982/83	East of 172° W	81	278	64,380	72,924	2.0 - 3.0[j]	431,179		6.7	1	
	West of 172° W	72	191	284,787	66,893	0.5 - 3.0	1,701,818	7,855	6.0	4	150.8
	TOTAL		**469**	**349,167**	**139,817**		**2,132,997**		**6.1**	**3**	
1983/84	East of 172° W	FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
	West of 172° W	106	248	298,958	60,840	0.5 - 3.0	1,981,579	3,833	6.6	5	157.3
1984/85	East of 171° W	FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
	West of 171° W	64	106	196,276	48,642	1.5 - 3.0	1,296,385	0	6.6	4	155.1
1985/86	East of 171° W	FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
	West of 171° W	35	82	156,097	29,095	0.5 - 2.0	868,828	0	5.6	5	152.2
1986/87	East of 171° W	FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
	West of 171° W	33	69	126,204	29,189	0.5 - 1.5	712,543	800	5.7	4	NA
1987/88	East of 171° W	FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
	West of 171° W	71	103	211,692	43,433	0.5 - 1.5	1,213,892	6,900	5.7	5	148.5

-continued-

Table 1. page 3 of 3.

Season	Locale	Number of Vessels[a]	Landings	Crabs[b]	Pots Lifted	Harvest[b,c]	Average Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1988/89	East of 171° W	FISHERY CLOSED								
	West of 171° W	73	156	266,053	64,334	1,567,314	5.9	4	153.1	557
1989/90	East of 171° W	FISHERY CLOSED								
	West of 171° W	56	123	193,177	54,213	1,105,971	5.7	4	151.5	759
1990/91	East of 171° W	FISHERY CLOSED								
	West of 171° W	7	34	146,903	10,674	828,105	5.6	14	148.1	0
1991/92	East of 171° W	FISHERY CLOSED								
	West of 171° W	10	35	165,356	16,636	951,278	5.8	10	149.8	0
1992/93	East of 171° W	FISHERY CLOSED								
	West of 171° W	12	30	218,049	16,129	1,286,424	6.0	14	151.5	5,000
1993/94	East of 171° W	FISHERY CLOSED								
	West of 171° W	12	21	119,330	13,575	698,077	5.9	9	154.6	7,402
1994/95	East of 171° W	FISHERY CLOSED								
	West of 171° W	20	31	30,337	18,146	196,967	6.5	2	157.5	1,430
1995/96	East of 171° W	FISHERY CLOSED								
	West of 171° W	4	12	6,880	1,986	38,941	5.7	3	153.6	235
1996/97		FISHERY CLOSED								
1997/98		FISHERY CLOSED								

Season	Location	Number of Vessels	Landings	Crab[a]	Pots lifted	GHL/TAC[b]	Harvest[a,c]	Deadloss[c]	Average Weight[c]	CPUE[d]	Length[e]
1998/99	West of 174° W	1	CF	CF	CF	0.015	CF	CF	CF	CF	CF
1999/00		FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
2000/01[k]	Petrel Bank[l]	1	3	11,299	496	FC	76,562	0	6.8	23	161.0
2001/02[m]	Petrel Bank[l]	4	5	22,080	564	FC	153,961	82	7.0	39	159.5
2002/03	Petrel Bank[l]	33	35	68,300	3,786	0.5	505,642	1,311	7.4	18	162.4
2003/04	Petrel Bank[l]	30	31	59,828	5,774	0.5	479,113	2,617	8.0	10	167.9
2004/05 - 2010/11		FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
2011/12–2013/14		FC	FC	FC	FC	FC	FC	FC	FC	FC	FC

Note: NA = Not available.

[a] Many vessels fished both east and west of 171° W long., thus total number of vessels reflects registrations for entire Aleutian Islands.

[b] Deadloss included.

[c] In lb.

[d] Number of legal crab per pot lift.

[e] Carapace length in millimeters.

[f] Split season based on 6.5 inch minimum legal size.

[g] Split season based on 8 inch minimum legal size.

[h] Split season based on 7.5 inch minimum legal size.

[i] January/February 2001 Petrel Bank survey (fish ticket harvest code 15, exploratory shellfish harvest).

[j] Those waters of king crab Registration Area O between 179° E long., 179° W long., and north of 51° 45' N lat.

[k] November 2001 Petrel Bank survey (fish ticket harvest code 15, exploratory shellfish harvest).

[m] November Petrel Bank survey (fish ticket harvest code 15, exploratory shellfish harvest).

Table 2. Summary of relevant fishery regulations and management actions pertaining to the Western Aleutian Islands red king crab fishery, 1996/97 to present.

Season	Change in management measure
1998/99	• GHL of 15,000 lb (7 t) for exploratory fishing with fishery closed in the Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) o 1 vessel
1999/00	• Fishery closed

2000/01	• Fishery closed
	• Catch retained during ADF&G-Industry survey of Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) conducted as commissioner's permit fishery, Jan–Feb 2001
	  o 1 vessel
	  o 76,562 lb
	  o CPUE = 23 legals/pot lift

2001/02	• Fishery closed
	• Catch retained ADF&G-Industry survey of Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) conducted as commissioner's permit fishery, November 2001
	  o 4 vessels
	  o 153,961 lb
	  o CPUE = 39 legals/pot lift

2002/03	• Fishery opened with GHL of 500,000 lb (227 t) restricted to Petrel Bank area (i.e., between 179° W longitude and 179° E longitude)
	  o 33 vessels
	  o 505,642 lb
	  o CPUE = 18 legals/pot lift
	• ADF&G-Industry survey of the Adak, Atka, and Amlia Islands area conducted as a commissioner's permit fishery
	  o 4 legal males captured in 1,085 pot lifts

2003/04	• Fishery opened with GHL of 500,000 lb (227 t) restricted to Petrel Bank area (i.e., between 179° W longitude and 179° E longitude)
	  o 30 vessels
	  o 479,113 lb
	  o 10 legals/pot lift

2004/05–2013/14	• Fishery closed o 2006 and 2009 ADF&G pot surveys on Petrel Bank

Table 3. Retained catch (lb) of Western Aleutian Islands red king crab, with the estimated non-retained catch (thousands of lb; not discounted for an assumed bycatch mortality rate) and components of non-retained catch (legal males, non-retained sublegal males, and females during commercial crab fisheries by season, 1995/96–2012/13; from 2013 SAFE).

	WAI red king crab fishery				AI golden king crab fishery			
	Retained	Non-retained						Total
Season	legal male	Legal male	Sublegal male	Female	Legal male	Sublegal male	Female	non-retained
1995/96	38,941	0	20,669	27,624	0	2,047	314	50,654
1996/97	0	0	0	0	3,292	2,024	666	5,982
1997/98	0	0	0	0	178	579	179	936
1998/99[a]	5,900	-	-	-	747	138	186	-
1999/00	0	0	0	0	161	756	93	1,010
2000/01	76,562	0	771	374	365	274	35	1,819
2001/02	153,961	174	6,574	8,369	19,995	0	364	35,476
2002/03	505,642	1,658	6,027	17,432	21,738	355	512	47,722
2003/04	479,113	631	6,597	7,962	9,425	6,352	6,686	37,653
2004/05	0	0	0	0	2,143	210	0	2,353
2005/06	0	0	0	0	189	0	49	239
2006/07	0	0	0	0	323	117	50	491
2007/08	0	0	0	0	615	1,819	561	2,995
2008/09	0	0	0	0	220	20	97	337
2009/10	0	0	0	0	574	249	43	866
2010/11	0	0	0	0	4,312	167	82	4,561
2011/12	0	0	0	0	958	29	92	1,079
2012/13	0	0	0	0	871	75	35	980
Average	70,007	145	2,390	3,633	3,673	845	558	11,480

[a.] Data on non-retained bycatch of red king crab during the red king crab fishery not available (Moore et al. 2000).

Table 4. Estimated annual weight (lb) of discarded bycatch of red king crab (all sizes, males and females) and bycatch mortality (lb) during federal groundfish fisheries by gear type (fixed or trawl) in reporting areas 541, 542, and 543 (Aleutian Islands west of 170° W longitude), 1993/94–2012/13 (assumes bycatch mortality rate of 0.5 for fixed-gear fisheries and 0.8 for trawl fisheries; from 2013 SAFE).

	Bycatch		Bycatch Mortality		
Season	Fixed Gear	Trawl Gear	Fixed Gear	Trawl Gear	Total
1993/94	1,312	88,384	656	70,707	71,363
1994/95	2,993	22,792	1,497	18,234	19,730
1995/96	5,804	15,289	2,902	12,231	15,133
1996/97	2,874	44,662	1,437	35,730	37,167
1997/98	3,819	11,717	1,910	9,374	11,283
1998/99	10,143	45,532	5,072	36,426	41,497
1999/00	37,765	27,973	18,883	22,378	41,261
2000/01	2,697	13,879	1,349	11,103	12,452
2001/02	5,340	59,552	2,670	47,642	50,312
2002/03	11,295	73,027	5,648	58,422	64,069
2003/04	3,577	9,151	1,789	7,321	9,109
2004/05	791	12,930	396	10,344	10,740
2005/06	3,546	2,359	1,773	1,887	3,660
2006/07	6,781	617	3,391	494	3,884
2007/08	16,971	2,630	8,486	2,104	10,590
2008/09	10,778	10,290	5,389	8,232	13,621
2009/10	315	14,104	158	11,283	11,441
2010/11	92	4,381	46	3,504	3,551
2011/12	2,632	1,801	1,316	901	2,216
2012/13	20	523	10	418	428
Average	6,477	23,080	3,239	18,437	21,675

Table 5. Estimated lb of bycatch (not discounted by an assumed bycatch mortality) of red king crab during federal groundfish fisheries (all gear types combined) by NMFS Reporting Area, 1993/94–2011/12; from 2013 SAFE.

	Reporting Area			
Season	541	542	543	Total
1993/94	83,752	5,862	82	89,696
1994/95	23,637	1,922	226	25,785
1995/96	13,122	4,056	3,916	21,094
1996/97	4,294	6,810	36,433	47,537
1997/98	2,218	8,739	4,579	15,536
1998/99	14,892	15,798	24,986	55,676
1999/00	36,027	17,755	11,955	65,738
2000/01	3,899	8,056	4,621	16,577
2001/02	7,661	52,986	4,244	64,891
2002/03	24,250	46,980	13,092	84,323
2003/04	4,915	7,778	36	12,728
2004/05	1,164	12,523	34	13,721
2005/06	3,540	87	2,278	5,905
2006/07	6,545	853	0	7,398
2007/08	11,295	6,708	1,598	19,601
2008/09	2,522	16,635	1,911	21,068
2009/10	3,686	8,278	2,455	14,419
2010/11	468	4,004	1	4,473
2011/12	1,933	2,499	0	4,433
2012/13	344	199	0	543
Average	12,508	11,426	5,622	29,557

Table 6. Estimated annual weight (thousands of lb) of total fishery mortality to Western Aleutian Islands red king crab, 1995/96–2012/13, partitioned by source of mortality: retained catch, bycatch mortality during crab fisheries, and bycatch mortality during groundfish fisheries; from 2013 SAFE.

		Bycatch Mortality by Fishery Type		
Season	Retained Catch	Crab	Groundfish	Total Estimated Fishery mortality
1995/96	38,941	10,131	15,133	64,205
1996/97	0	1,196	37,167	38,363
1997/98	0	187	11,283	11,470
1998/99[a]	5,900	1,535	41,497	48,931
1999/00	0	202	41,261	41,463
2000/01	76,562	364	12,452	89,378
2001/02	153,961	7,095	50,312	211,368
2002/03	505,642	9,544	64,069	579,256
2003/04	479,113	7,531	9,109	495,753
2004/05	0	471	10,740	11,210
2005/06	0	48	3,660	3,708
2006/07	0	98	3,884	3,982
2007/08	0	599	10,590	11,189
2008/09	0	67	13,621	13,688
2009/10	0	173	11,441	11,614
2010/11	0	912	3,551	4,463
2011/12	0	216	2,216	2,432
2012/13	0	196	428	624
Mean, 1995/96–2007/08	96,932	3,000	23,935	123,867
CV of mean	52%	37%	23%	43%
Mean, 1995/96–2012/13	70,007	2,254	19,023	91,283
CV of mean	53%	37%	23%	44%

a. No bycatch data was available from the 1998/99 directed fishery for red king crab (see Table 2); bycatch mortality due to the 1998/99 crab fisheries was estimated by multiplying the retained catch for the 1998/99 directed red king crab fishery by the ratio of the 1995/96 bycatch mortality in crab fisheries to the 1995/96 retained catch.

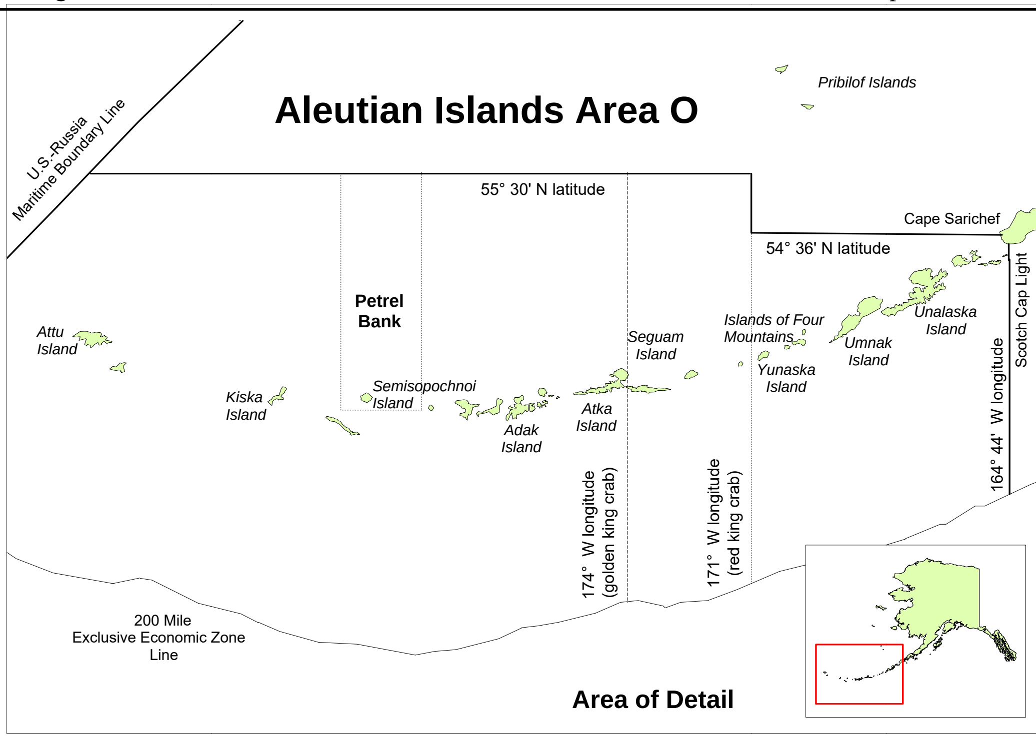

Figure 1. Aleutian Islands, Area O, red and golden king crab management area (Baechler 2012).

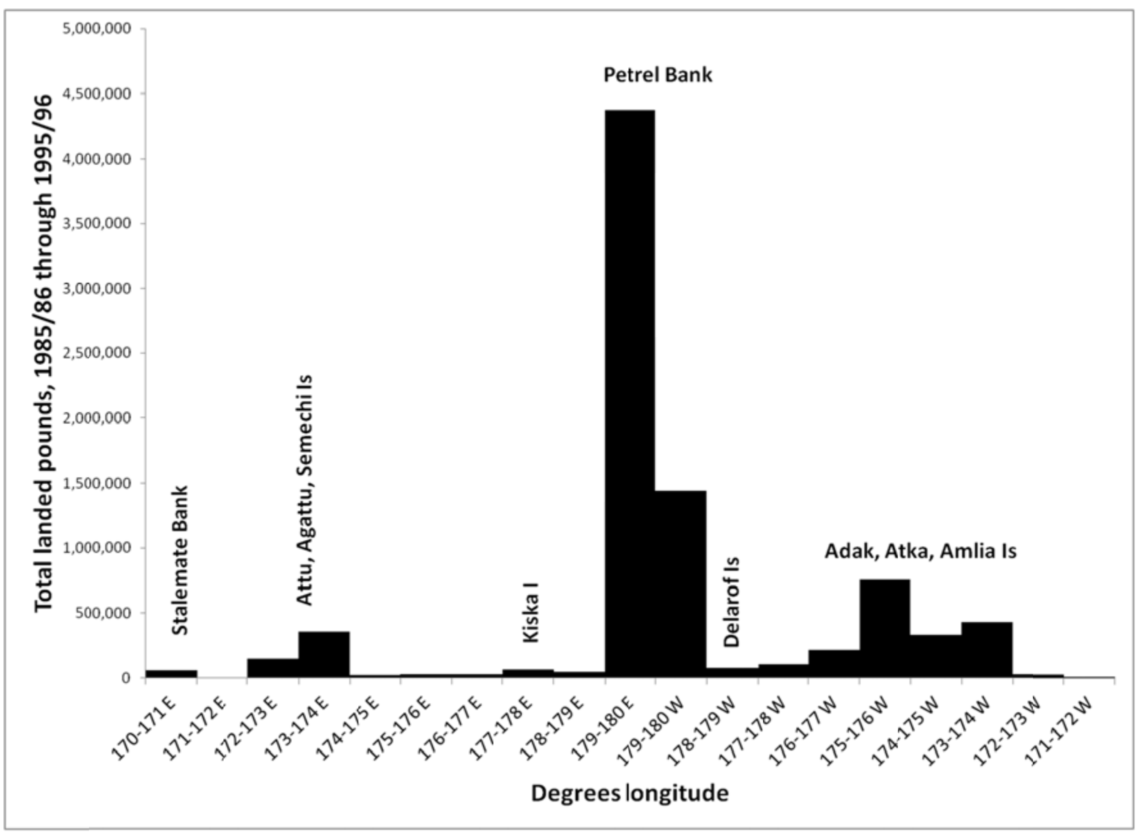

Figure 2. Retained catch (lb) in the Western Aleutian Islands red king crab fishery, 1985/86–1995/96 by 1-degree longitude grouping, summarized from fish ticket catch by state statistical area landing data.

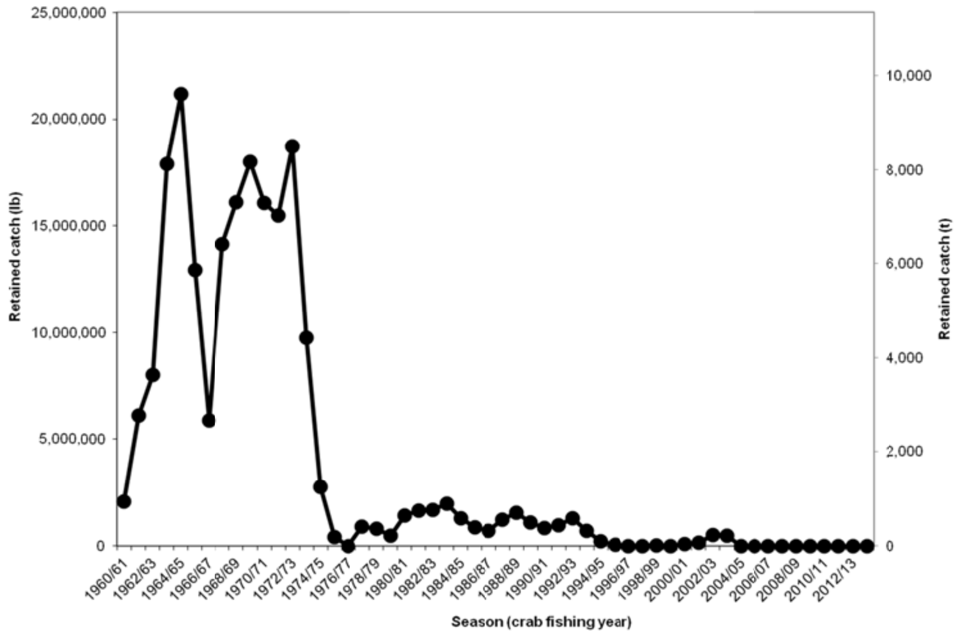

Figure 3. Retained catch (lb on left axis, t on right axis) in the Western Aleutian Islands red king crab fishery, 1960/61–2012/12 (catch is for the area west of 172º W longitude during 1960/61–1983/84 and for the area west of 171º W longitude during 1984/85–2012/13; Table 1).

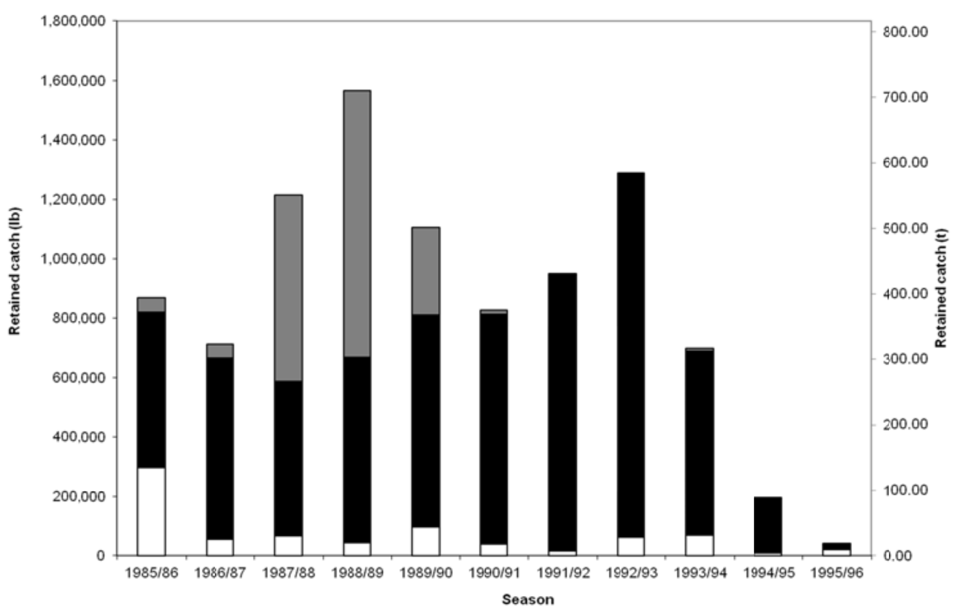

Figure 4. Retained catch (lb on left axis, t on right axis) in the Western Aleutian Islands red king crab fishery for the 1985/86–1995/96 seasons, partitioned into three longitudinal zones: 171º W longitude to 179º W longitude (white bars); 179º W longitude to 179º E longitude (black bars); and 179º E longitude to 171º E longitude (gray bars; data from ADF&G fish ticket summary provided by F. Bowers, ADF&G, March 2008).

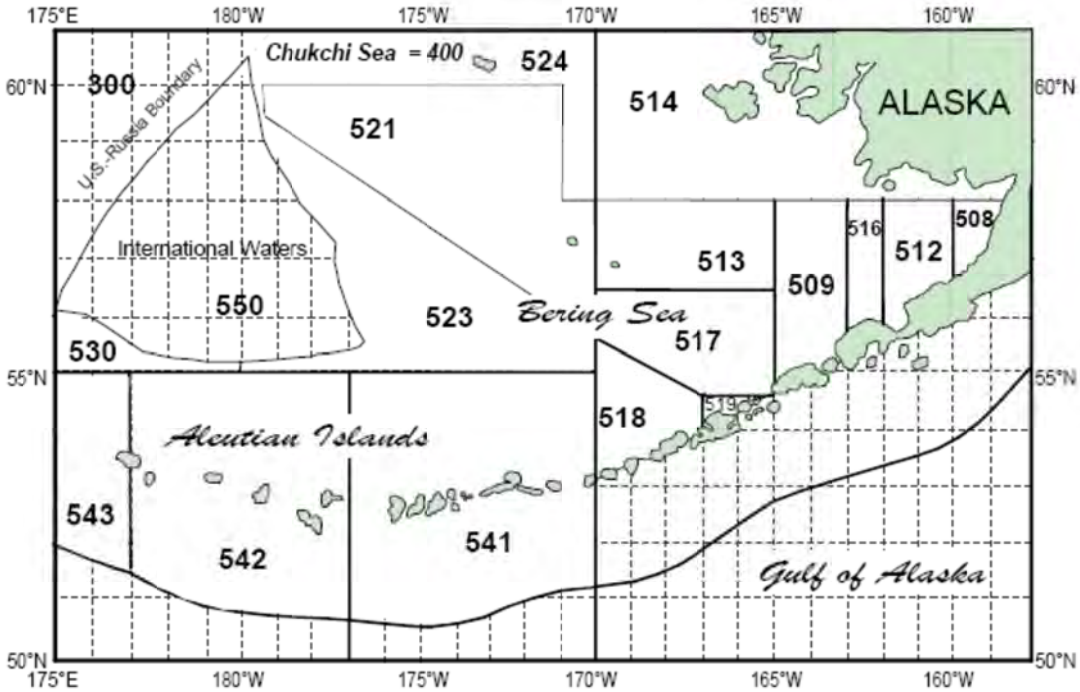

Figure 5. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands showing reporting areas 541, 542, and 543 that are used to obtain data on bycatch of Western Aleutian Islands red king crab during groundfish fisheries (from http://www.alaskafisheries.noaa.gov/rr/figures/fig1.pdf).

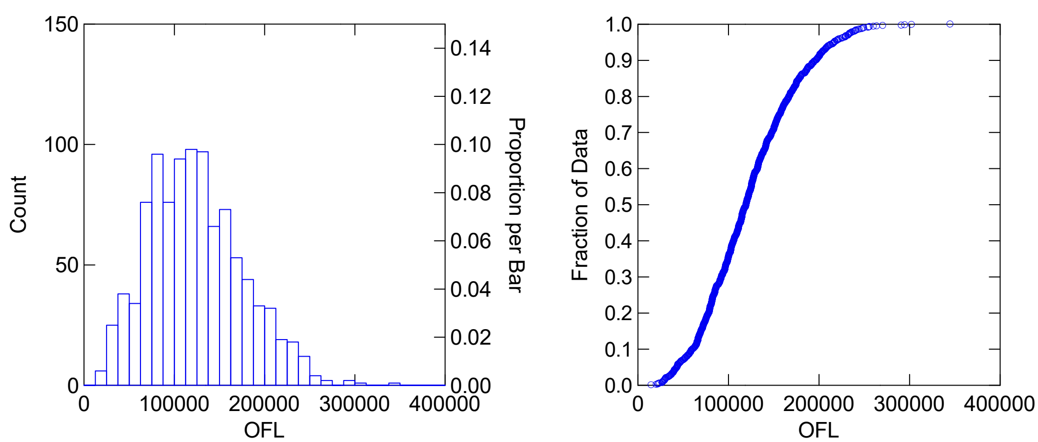

Figure 6. Bootstrapped estimate of the sampling distribution of the recommended 2014/2015 Tier 5 OFL (total catch, lb) for the Western Aleutian Islands red king crab stock; histogram in left column, cumulative distribution in right column (2013 SAFE).