2016 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
6 September 2016

THIS INFORMATION IS DISTRIBUTED SOLELY FOR THE PURPOSE OF PREDISSEMINATION PEER REVIEW UNDER APPLICABLE INFORMATION QUALITY GUIDELINES. IT HAS NOT BEEN FORMALLY DISSEMINATED BY NOAA FISHERIES/ALASKA FISHERIES SCIENCE CENTER AND SHOULD NOT BE CONSTRUED TO REPRESENT ANY AGENCY DETERMINATION OR POLICY

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 not overfished in 2012/13 (Stockhausen et al., 2013) 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 t) for the area west of 166º W and at 1,463,000 lbs (664 t) for the area east of 166º W in the SOA's Eastern Subdistrict of the Bering Sea District Tanner crab Registration Area J. The fisheries opened on October 15 and closed on March 31. On closing, 79.6% (594 t) of the TAC was taken in the western area while 98.6% (654 t) was taken in the eastern area. Prior to the closures, the retained catch averaged 770 t per year between 2005/06-2009/10.

Following the 2014 assessment (Stockhausen, 2014), TAC was set at 6,625,000 lbs (2,329 t) for the area west of 166º W and at 8,480,000 lbs (3,829 t) for the area east of 166º W. On closing, 77.5% (2,329 t) of the TAC was taken in the western area while 99.6% (3,829 t) were taken in the eastern area.

Following last year's assessment (Stockhausen, 2015), TAC was set at 11,272,000 lbs (5,113 t) for the eastern area and 8,396,000 lbs (3808 t) for the western area. On closing, essentially 100% of the TAC was taken in both areas (11,268,885 lbs [5,111 t] in the eastern area, 8,373,493 lbs [3,798 t] in the western area based on the 5/20/2016 in-season catch report).

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 3,104 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 1,414 t for the 5-year period 2011/12-2015/16. Bycatch in the snow crab fishery in 2015/16 was 3,536 t. The groundfish fisheries have been the next major source of Tanner crab bycatch over the same five year time period, averaging 296 t. Bycatch in the groundfish fisheries in 2015/16 was 352 t. The Bristol Bay red king crab fishery has typically been the smallest source of Tanner crab bycatch among these fisheries, averaging 61 t over the 5-year time period, although 297 t caught and discarded in 2014/15. In 2015/16, this fishery accounted for 180 t of Tanner crab bycatch.

This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Marine Fisheries Service and should not be construed to represent any agency determination or policy.

In order to account for mortality of discarded crab, handling mortality rates are assumed to be 32.1% 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.

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 (Model C), estimated MMB for 2015/16 was 73.9 thousand t (Table 30, Fig. 48). This was slightly smaller than that for 2014/15 (75.4 thousand t), but larger than that for 2013/14 (61.2 thousand t). MMB has generally been rising since 2011/12. It remains above the very low levels seen in the mid-1990s to early 2000s (1990 to 2005 average: 29 thousand t) and the 2014/15 estimate is the largest since 1978/79. However, it is considerably below model-estimated historic levels in the early 1970s when MMB peaked at ~241 thousand t (1971).

4. Recruitment: trends and current levels relative to virgin or historic levels.

From the author's preferred model (Model C), the estimated total recruitment in 2016/17 (number of crab entering the population on July 1) is 120 million crab (Table 33, Fig. 45). Recruitment recently peaked in 2013 at 124 million crab, then declined in 2014 and 2015 below 100 million.

5. Management performance

Historical status and catch specifications for eastern Bering Sea Tanner crab.

(a) in 1000's t.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2012/13	16.77	59.35^{A}	0.00	0.00	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	13.40	71.57^{A}	6.85	6.16	9.16	31.48	25.18
2015/16	12.82^{C}	73.93^{A}	8.92	8.91	11.38	27.19	21.75
2016/17		45.34^{B}				25.61^{C}	20.49^{C}

(b) in millions lbs.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2012/13	36.97	130.84^{A}	0.00	0.00	1.57	41.93	18.01
2013/14	37.43	160.28^{A}	3.11	2.78	6.14	55.89	39.29
2014/15	29.53	157.78^{A}	15.10	13.58	20.19	69.40	55.51
2015/16	28.27^{C}	162.99^{A}	19.67	19.64	25.09	59.94	47.95
2016/17		99.95^{B}				56.46^{C}	45.17^{C}

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 (Model C).

6. Basis for the OFL

a) in 1000’s t.

Year	Tier[A]	B_{MSY}[A]	Current MMB[A]	B/B_{MSY}[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	29.82	63.80	2.14	0.61 yr-1	1982-2014	0.23 yr-1
2015/16	3a	26.79	53.70	2.00	0.58 yr-1	1982-2015	0.23 yr-1
2016/17	3a	25.65	45.34	1.77	0.79 yr^{-1}	1982-2016	0.23 yr^{-1}

b) in millions lbs.

Year	Tier[A]	B_{MSY}[A]	Current MMB[A]	B/B_{MSY}[A]	F_{OFL}[A]	Years to define B_{MSY}[A]	Natural Mortality[A]
2012/13	3a	73.74	129.17	1.75	0.61 yr^{-1}	1982-2012	0.23 yr^{-1}
2013/14	3a	73.94	130.84	1.77	0.73 yr^{-1}	1982-2013	0.23 yr^{-1}
2014/15	3a	65.74	140.66	2.14	0.61 yr-1	1982-2014	0.23 yr-1
2015/16	3a	59.06	118.38	2.00	0.58 yr-1	1982-2015	0.23 yr-1
2016/17	3a	56.54	99.95	1.77	0.58 yr^{-1}	1982-2016	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 2016/17.

B—Nominal rate of natural mortality. Actual rates used in the assessment are estimated and may be different.

Current male spawning stock biomass (MMB), as projected for 2016/17, is estimated at 45.34 thousand t. B_{MSY} for this stock is calculated to be 25.65 thousand t, so MSST is 12.82 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 0.321 for pot gear and 0.8 for trawl gear) in 2015/16 was 11.38 thousand t, which was less than the OFL for 2015/16 (27.19 thousand t); consequently **overfishing did not occur**. The OFL for 2016/17 based on the author’s preferred model (Model C) is 25.61 thousand t. The ABC_{max} for 2016/17, based on the p^* ABC, is 25.57 thousand t. In 2014, the SSC adopted a 20% buffer to calculate ABC for Tanner crab to incorporate concerns regarding model uncertainty for this stock. Based on this buffer, the ABC would be 20.49 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.
At the March, 2015 SOA Board of Fish meeting, the Board adopted a revised harvest strategy for Tanner crab in the Bering Sea District[1], wherein the TAC for the area east of 166° W longitude would be based on a minimum preferred harvest size of 127 mm CW (5.0 inches), including the lateral spines. Formerly, this calculation was based on a minimum preferred size of 140 mm CW (5.5 inches). The TAC in the area west of 166° W longitude continues to be based on a minimum preferred harvest size of 127 mm CW (including lateral spines).

Based on the 2015 assessment (Stockhausen, 2015) and the new harvest strategy, TAC was set at 11,272,000 lbs (5,113 t) for the eastern area and 8,396,000 lbs (3,808 t) for the western area. On closing, essentially 100% of the TAC was taken in both areas (11,268,885 lbs [5,111 t] in the eastern area, 8,373,493 lbs [3,798 t] in the western area based on the 5/20/2016 in-season catch report).

2. Changes to the input data
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, biomass, size compositions	2016	new	NMFS
NMFS EBS Bottom Trawl Survey	biomass cv's	1975-2015	new calculation	NMFS
Directed fishery	retained catch (numbers, biomass)	2015/16	new	ADFG
	retained catch size compositions	2015/16	new	ADFG
	effort	2015/16	new	ADFG
	total catch, discards (biomass)	2015/16	new	ADFG
	total catch, discards size compositions	2015/16	new	ADFG
Snow Crab Fishery	effort	2015/16	new	ADFG
	total catch, discards (biomass)	2015/16	new	ADFG
	size compositions	2015/16	new	ADFG
Bristol Bay Red King Crab Fishery	effort	2015/16	new	ADFG
	total catch, discards (biomass)	2015/16	new	ADFG
	size compositions	2015/16	new	ADFG
Groundfish Fisheries	total catch, discards (biomass)	2015/16	new	NMFS/AKFIN
	size compositions	2015/16	new	NMFS/AKFIN

3. Changes to the assessment methodology.
A number of potential changes to the model were reviewed by the CPT at its May 2016 meeting. The author's preferred model (Model C) embodies a number of the changes endorsed by the CPT, including: 1) using the Gmacs fishing mortality model; 2) estimating ln-scale female offsets to male fishing mortality in all fisheries; 3) estimating annual F-devs for 1992-present for bycatch in the BBRKC fishery; 4) eliminating constraints on minimum F's for bycatch in the BBRKC fishery; 5) requiring logistic selectivity curves to reach 1 in the largest model size bin; 5) using a logit scale, rather than a log scale, to estimate size-specific probabilities of terminal molt-to-maturity, 6) weighting sex-specific size composition by observed, rather than input, sample sizes when combining size compositions for bycatch in the groundfish fisheries, and 7) starting "current" recruitment estimates in 1975 (coincident with the NMFS EBS bottom trawl survey data), rather than in 1974. Model scenarios were also evaluated using 200 model runs using jittered initial parameter values to better achieve model convergence to the global minimum value for the model objective function. Additionally, CV's for estimates of mature survey biomass were recalculated using an approach that calculated CPUE across size classes at the haul level, then scaled to the regional (EBS) level using a standard approach for a stratified sampling design, as

---

[1] https://aws.state.ak.us/OnlinePublicNotices/Notices/Attachment.aspx?id=100244

opposed to the approach used last year which calculated CPUE in 1-mm CW size bins, scaled to the EBS, and then aggregated across size bins assuming independence of "errors" across size bins.

4. Changes to the assessment results

Results from the author's preferred model this year (Model C) are reasonably similar to those from the previous assessment, considering the large number of changes in the model. Average recruitment (1982-present) was estimated at 179 million in last year's model, whereas it was estimated at 182 million in the author's preferred model this year. B_{MSY} was estimated at 26.79 thousand t last year and 25.65 thousand t this year. The largest difference was in F_{MSY}, which last year was estimated at 0.58 yr^{-1} and 0.79 yr^{-1} this year. This is partly due to the change this year to the Gmacs fishing mortality model which, although it assumes that fishery *capture* rates have a logistic size structure, imposes a somewhat different size-specific *mortality* pattern for males in the directed fishery vis-à-vis the old model (which assumes fishing *mortality* has a logistic size dependence).

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 unaddressed comments prior to the most recent two sets of comments.]

June 2016 SSC Meeting

No general comments.

May2016 Crab Plan Team Meeting

No general comments.

October 2015 SSC Meeting

No general comments.

September 2015 Crab Plan Team 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.]

June 2016 SSC Meeting

The SSC endorsed the CPT suggestions from its May meeting.

May2016 Crab Plan Team Meeting

The CPT outlined the base model to be used for this assessment, based on results presented by the author for a suite of models.
Response: The base model recommended by the CPT is the base model used here (Model B).

The CPT outlined a number of alternative models built on its recommended base model to be evaluated.
Response: These models were evaluated for the assessment.

October 2015 SSC Meeting

Comment: "The SSC endorses all of the CPT recommendations with respect to the poor fits to some of the retained catch time series, poor fits to the size composition data for retained catch and survey data, and issues with the total directed fishery selectivity curve for males (in particular the 1996 'outlier')."
Response: See responses to CPT comments below.

Comment: “The SSC was unable to fully compare models, as the summary tables in the assessment did not include the number of model parameters for evaluating differences in likelihoods.”
Response: A good point, and an oversight on my part. The number of model parameters will be included in at least one summary table.

Comment: “The SSC would have liked to have seen residual diagnostic plots for models assuming a log-normal likelihood (B and D) to assess more fully the rationale for not further considering these models.”
Response: Residual diagnostic output (z-scores) have been added to model output, and z-score plots are now included in the standard plots produced following a converged model run.

Comment: “There are continuing concerns about the most appropriate weights to use for different data components (CVs, effective N, etc.), and the SSC looks forward to recommendations from the data-weighting workshop.”
Response: The CPT endorsed using an iterative approach to weighting composition data (the “Francis method”), but it has not yet been implemented for this model.

Comment: “Strong residual patterns in numbers at size remain a concern and suggest model mis-specification with respect to growth.”
Response: Growth increment data for Tanner crab in the Bering Sea was collected in 2015 for sub-adults and April-June, 2016 for smaller crab. This data was made available to the author this summer, but time did not permit substantive results to include in this assessment. The data appears to be very consistent with previous growth data collected near Kodiak Island, and is plotted against mean growth as estimated in last year’s assessment in Fig. 2.

Comment: “The period with elevated M differs between male (1981-1985) and female crab (1980-84).”
Response: This was a mistake (now corrected) in the code that produced the plot. The periods are the same (1980).

Comment: “The model overestimates female bycatch mortality in the snow crab fishery.”
Response: One factor responsible for this observation was that the estimated male fishing mortality rate in each fishery was equally applied to females, with only changes in selectivity available to better fit female bycatch. The option to estimate female-specific offsets to (log-scale mean) male fishing mortality rates has been added to the model and reduces this problem. Fits were also improved using a lognormal likelihood (with assumed cv’s), rather than the standard normal likelihood.

September 2015 CPT Meeting

Comment: “The model fits total catch well, but does a poorer job in fitting retained catch, catch of females, and catch in the bycatch fisheries.”
Response: There appears to be a conflict in the model between fitting total (male) catch and retained catch in the directed fishery. Fitting discard catch rather than total catch improves the fit to retained catch. This may be an issue related to treating retained and total catch with equal uncertainty in the standard model likelihood. Fits to female bycatch are improved when estimating a female-specific offset to (log-scale male) mean fishing mortality. Fits to bycatch improved, in general, using a lognormal likelihood assumption for fishery catch data, but it is unclear whether the cv’s assumed are reasonable.

Comment: “Strong residual patterns exist in fits of male survey and retained-catch size composition…”
Response: See response to SSC comment regarding collection of growth increment data.

Comment: “It was not clear why the model estimates full selection [for males in the directed fishery] in 1996 at roughly 100 cm…”
Response: This occurs due to a combination of two factors: 1) the sample size for male size comps from the directed fishery in 1996 is quite small, meaning that a poor fit to this size frequency has little effect on

the overall likelihood, and 2) the size-at-50% selected in the directed fishery prior to 1992 is based on the mean size-at-50% selected in the directed fishery after 1991 (size-at-50% selected in the directed fishery is allowed to vary annually after 1991). Although it has cascading effects through many likelihood components because of its influence on underling population structure, the size-at-50% selected in the directed fishery prior to 1992 most directly influences (I think) fits to retained catch size compositions prior to 1992. If the fit to the pre-1992 retained catch size compositions can be improved by changing the size-at-50% selected in the pre-1992 directed fishery, there is little “cost” to doing so even by making the size-50%-selected in 1996 any value whatsoever.

Comment: “The poor fit of the models with lognormal fishery catch likelihoods (Models B and D [in the 2015 assessment] … was surprising to some CPT members.”
Response: These models exhibited questionable convergence in the 2015 assessment. From results obtained in May using similar models, it is clear those models had not converged and the results were spurious (as was suggested by the author at the time). For this assessment, I ran each model scenario 200 times with randomly-selected (jittered) initial parameter values to improve confidence in obtaining a “converged” model result. The models with lognormal fishery likelihoods (models including changes L0 and L1 in the report) now fit the data well—perhaps too well, in some cases.

Comment: “The author should consider fitting retained catch exactly.”
Response: Time did not allow exploring this possibility.

June 2015 SSC Meeting
No specific comments.

3. Older comments that were addressed this year or remain to be addressed:
Comment: “Future exploration…should consider the impact of handling mortality on the estimate of natural mortality and how the model behaves if Q for the most recent years is assumed known rather than being estimated.”
Response: Not yet addressed.

Comment: “The CPT reiterates its suggestions from the September 2014 meeting, in particular that the sensitivity of the results to the prior on Q should be explored.”
Response: Not yet addressed.

Comment: “The SSC encourages authors to explore alternative models such as time-varying growth to help address retrospective bias and patterns in other residuals.”
Response: This can be addressed in the future with the new model code (currently being tested), but not with the current model.

Comment: “The SSC also encourages authors to explore model alternatives without time-varying selectivity for the groundfish fishery.”
Response: Not yet addressed.

Comment: “Examine issues related to misfits of the size composition residuals for retained males and total males in the directed fishery. Consider exploring alternative growth components, specification of sample sizes, or a combination of fishing selectivity and handling mortality is causing mis-fits.”
Response: Not yet addressed.

Comment: “Examine retrospective patterns of models being brought forward.”
Response: Retrospective patterns for the author’s preferred model are examined here for the first time. Patterns for rejected models were similar (but are not presented here).

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: 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.

Comment: "Plot the input effective sample sizes for the compositional data versus the effective sample sizes inferred by the fit of the model…"
Response: Done.

Comment: "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: "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: "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.

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."
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 (Fig. 1). *C. bairdi* is common in the southern half of Bristol Bay, around the Pribilof Islands, and along the shelf break, although males less than the industry-preferred size (>125 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^{o}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

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.

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). Relationships between pre-molt and post-molt size specific to Tanner crab in the EBS have not been evaluated, although data on individual molt increments from 125 crab collected in the EBS in 2015 and 2016 (Fig. 2).

Rugolo and Turnock (2012a) derived growth relationships for male and female Tanner crab used as priors for estimated growth parameters in this (and previous) assessments 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, unpublished.; Donaldson et al. 1981; Fig. 2).

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.

c. Weight at Size

Weight-at-size relationships used in this assessment were revised in 2014 based on a comprehensive re-evaluation of data from the NMFS EBS Bottom Trawl Survey (Daly et al., 2014). Weight-at-size is described by a power-law model of the form $w = a \cdot z^b$, where w is weight in kg and z is size in mm CW (Daly et al., 2016; table below). Parameter values are presented in the following table:

sex	maturity	a	b
males		0.000270	3.022134
females	immature (non-ovigerous)	0.000562	2.816928
	mature (ovigerous)	0.000441	2.898686

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 166ºW, 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 166ºW), 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 2011). 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 2011).

The Bering Sea District of Tanner crab Registration Area J (Fig. 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 this report, I use the terms “east region” and “west region” as shorthand to refer to the regions demarcated by 166ºW.

In March 2011, the Alaska Board of Fisheries BOF) approved a new minimum size limit harvest 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 166º W. The minimum size limit for the fishery to the east of 166ºW is now 4.8” (122 mm CW) and that to the west is 4.4” (112 mm CW), where the size measurement includes the lateral spines. For economic reasons, fishers may adopt larger minimum sizes for retention of crab in both areas, and the SOA’s harvest strategy and total allowable catch (TAC) calculations are based on assumed minimum preferred sizes that are larger than the legal minimums. In 2011, these minimum preferred sizes were set at 5.5” (140 mm CW) in the east and 5” (127 mm CW) in the west, including the lateral spines. In 2015, following a petition by the crab industry, the BOF revised the minimum preferred size for TAC calculations in the area east of 166º W longitude to 5” (127 mm CW), the same as that in the western area. These new “preferred” sizes were used to set the TAC for the 2015/16 fishery season.

In previous assessments, the term “legal males” was used to refer to male crab ≥ 138 mm CW (not including the lateral spines), although this was not strictly correct as it referred to the industry’s “preferred” crab size in the east region, as well as to the minimum size in the east used in the SOA’s harvest strategy for TAC setting. In this assessment, I use the term “legal males” to refer to crab 125 mm CW, the minimum “preferred” size used in both eastern and western areas the SOA’s harvest strategy, and larger.

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; Fig. 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; Fig.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. 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. 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 t) for the area west of 166º W and at 1,463,000 lbs (664 t) for the area east of 166º 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, 79.6% (594 t) of the TAC had been taken in the western area while 98.6% (654 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. In 2014, TAC was set at 6,625,000 lbs (3,005 t) for the area west of 166º W and at 8,480,000 lbs (3,846 t) for the area east of 166º W. On closing, 77.5% (2,329 t) of the TAC was taken in the western area while 99.6% (3,829 t) were taken in the eastern area. In 2015, TAC was set at 8,396,000 lbs (3,808 t) in the western area and 11,272,000 lbs (5,113 t) in the eastern area. On closing, essentially 100% of the TAC was taken in each area (3,798 t in the west, 5,111 t in the east). The total retained catch in 2015/16 (8,910 t) was the largest taken in the fishery since 1992/93 (Tables 1, 2; Fig. 3).

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 (Tables 4 and 5, Fig.s 5-7). Bycatch estimates are converted to discard mortality using assumed handling mortality rates of 32.1% for bycatch in the crab fisheries and 80% for bycatch in the groundfish fisheries. 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 (although bycatch in the crab fisheries was undocumented at the time). From 1992/93 (when reliable crab fishery bycatch estimates are first available) to 2004/05, the groundfish fisheries accounted for the largest proportion of discard mortality. Since 2005/06, however, the crab fisheries have accounted for the largest proportion.

D. Data

1. Summary of new information

Survey biomass and size composition data from the 2016 NMFS EBS Bottom Trawl Survey were added to the assessment dataset. Last year, coefficients of variation for annual mature male and female survey biomass were calculated based on survey biomass information (estimates and cv's) provided at 1mm CW size bins for the EBS region by the NMFS Kodiak Lab (R. Foy, NMFS, pers. comm.). In this assessment, the cv's for mature survey biomass for the EBS were calculated by aggregating over sizes at the haul level, then scaling up to the EBS. Model runs with cv's calculated using both approaches were made to discern the impact of the change. This change is discussed in more detail in the section on survey biomass estimates below (Section D.2.d).

Estimates of total retained biomass and abundance, as well as retained size frequencies by shell condition, in the 2015/16 directed fishery were provided by ADFG (J. Webb, ADFG, pers. comm.) based on fish ticket data and dockside observer sampling. ADFG also provided estimates of Tanner crab bycatch (sex-specific numbers, biomass and size compositions) in the 2015/16 directed Tanner crab, snow crab, and Bristol Bay red king crab fisheries.

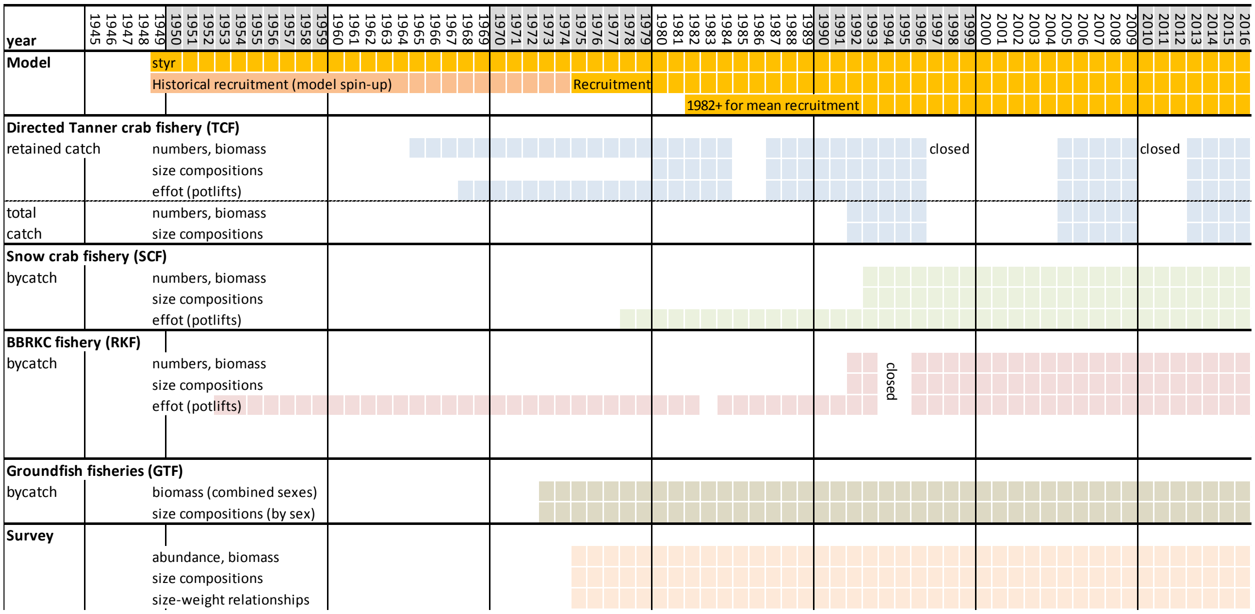
Tanner crab bycatch data in the groundfish fisheries (biomass, size compositions) were extracted for 2015/16 from the groundfish observer and AKFIN databases.

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, biomass, size compositions	2016	new	NMFS
NMFS EBS Bottom Trawl Survey	biomass cv's	1975-2015	new calculation	NMFS
Directed fishery	retained catch (numbers, biomass)	2015/16	new	ADFG
	retained catch size compositions	2015/16	new	ADFG
	effort	2015/16	new	ADFG
	total catch, discards (biomass)	2015/16	new	ADFG
	total catch, discards size compositions	2015/16	new	ADFG
Snow Crab Fishery	effort	2015/16	new	ADFG
	total catch, discards (biomass)	2015/16	new	ADFG
	size compositions	2015/16	new	ADFG
Bristol Bay Red King Crab Fishery	effort	2015/16	new	ADFG
	total catch, discards (biomass)	2015/16	new	ADFG
	size compositions	2015/16	new	ADFG
Groundfish Fisheries	total catch, discards (biomass)	2015/16	new	NMFS/AKFIN
	size compositions	2015/16	new	NMFS/AKFIN

The following table summarizes the data coverage in the assessment model:



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., 2015/16 indicates the 2015 bottom trawl survey and the winter 2015/16 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. 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.

Directed fisheries for Tanner crab in the EBS began in 1965. Retained catch has followed a "boom-and-bust" cycle over the years, with the fishery experiencing periods of rapidly increasing catches followed by rapidly declining ones, after which it is closed for a time during which the stock partially recovers. Retained catch increased rapidly from 1965 to 1975, reaching ~ 25,000 t in 1970. It declined to ~13,000 t in 1973/74 coinciding with the termination of Russian fishing and the beginning of the domestic pot fishery. It increased again, this time to its highest level, in 1977/78 (~35,000 t) as the domestic fishery developed rapidly, but it subsequently declined again and the fishery was closed in 1985/86 and 1986/87. In the late 1980s and early 1990s, the fishery experienced another, somewhat smaller, "boom" followed by a "bust" and closure of the fishery from 1997/98 to 2004/05. From 2005/06 to 2009/10, the fishery experienced its smallest boom-and-bust cycle, peaking at only ~1,000 t retained catch, and was closed again from 2010/11 to 2012/13. The fishery was re-opened in 2013/14, and retained catch has increased each of the last three years as TACs have increased (Fig.s 3, 6). The retained catch for 2015/16 (8,910 t) was the largest since 1992/1993 (15,920 t; Table 1).

b. Information on bycatch and discards

Annual bycatch (discards) of Tanner crab are provided by sex in Tables 3 and 4 (and Fig.s 4-6) from ADFG 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, based on NMFS groundfish observer programs, are also provided starting in 1973/74, but sex is undifferentiated. A value of 0.321 is used for "handling mortality" in the crab fisheries to convert observed bycatch to (unobserved) mortality (Stockhausen, 2014). For the groundfish fisheries, a value of 0.8 for handling mortality is used to reflect differences in gear and on-deck operations with those of the crab fleets.

Estimated bycatch mortality in the groundfish fisheries was highest (~15,000 t) in the early 1970s, but was substantially reduced by1977 to ~2,000 t with the curtailment of foreign fishing fleets. It declined further in the 1980s (to ~500 t) but increased somewhat in the late 1980s to a peak of ~2,000 t before undergoing a slow but rather steady decline to the present (282 t in 2015/16). Since reliable at-sea ADFG crab observer data has been available (1992), the snow crab fishery has consistently accounted for the fraction of bycatch mortality among the crab fisheries, followed by the directed fishery and the BBRKC fishery (Table 4, Fig. 5). Estimated bycatch mortality was highest for all crab fisheries in the early 1990s (~12,000 t total) but subsequently declined as (presumably) the stock declined and the directed fishery was curtailed. Since the directed fishery re-opened in 2013/14, bycatch mortality has averaged 325 t in the directed fishery, 579 t in the snow crab fishery, 32 t in the BBRKC fishery, and 300 t in the groundfish fisheries.

In the crab fisheries, the largest component of bycatch occurs on males. In the early 1990s, female bycatch ranged between 6 and 40% of the bycatch in the directed and snow crab fisheries. Since the directed fishery re-opened in 2014/14, the fraction of bycatch that is female has ranged between 2% and 6% in the directed fishery, between 0.3 and 3% in the BBRKC fishery, and has been below 1% in the snow crab fishery. Estimates of total groundfish bycatch are not currently available by sex.

c. Catch-at-size for fisheries, bycatch, and discards

Retained (male) catch-at-size in the directed Tanner crab fishery from ADFG crab observer sampling is presented in Fig. 7 by fishery region (and total) for the two most recent periods the fishery was open (spanning 2005/06-2015/16). These appear to indicate a shift to retaining somewhat smaller minimum sizes since 2013/14, compared with 2005/06-2009/10.

Size compositions of estimated total catch (retained + discards) from at-sea crab fishery observer sampling in the directed fishery are presented by shell condition and fishery region in Fig. 8 for male crab and in Fig. 9 for female crab. The male size compositions suggest that about half the males caught in the directed fishery in 2015/16 were less than the minimum "preferred" size of 125 mm CW. If old shell males really are males at least one year past their terminal molt (as assumed in the assessment model), the size compositions for these crab suggest that 30-50% of these crab (which will not grow) are less than the preferred size.

Size compositions for Tanner crab bycatch by sex in the snow crab fishery from at-sea crab fishery observer sampling are presented by shell condition in Fig. 10. Fig. 11 presents similar information for the BBRKC fishery. Fig. 12 presents relative catch size composition information from groundfish observer sampling in the groundfish fisheries for males and females, respectively, from 1973/74 to the present. The male bycatch size compositions in the snow crab fishery clearly reflect some sort of "dome-shaped" selectivity pattern (as assumed in the assessment model), with selectivity small for small and large males and highest for intermediate-sized males. In contrast, the BBRKC fishery appears to catch mostly larger Tanner crab males, while the groundfish fisheries take a wide range of sizes as bycatch.

Raw and input sample sizes (number of individuals measured) for the various fisheries are presented in Tables 5-9.

d. Survey biomass estimates

Time series trends from the NMFS EBS bottom trawl survey suggest the Tanner crab stock in the EBS has undergone decadal-scale fluctuations (Table 10, Fig. 13). Estimated biomass of mature crab in the survey time series started at its maximum (281,000 t) in 1975, decreased rapidly to a low (14,000 t) in 1986, and rebounded quickly to a smaller peak (134,000 t) in 1991. After 1991, mature survey biomass decreased again, reaching a minimum of 10,500 t in 1998. Recovery following this decline was slow and mature survey biomass did not peak again until 2008 (67,000 t), after which it has fluctuated more rapidly—immediately decreasing the following year by almost 50% and reaching a minimum in 2012 (36,000 t), followed by an increase of almost 50% in 2013 and reaching a peak in 2014 (82,000 t). The most recent trend (2014-2016) has been a declining one (Fig. 14). Trends in the male and female components of mature survey biomass, as well as legal male abundance, have primarily been in synchrony with one another (Fig. 13), as have changes in the eastern and western fishery regions (east and west of 166°W longitude; Fig.s 15, 16), although the magnitudes differ.

Survey biomass estimates are not direct inputs to the stock assessment model. Instead, survey size compositions and standardized sex-specific weight-at-size regressions from Daly et al. (2014) are used to calculate the corresponding sex-specific mature survey biomass on an annual basis. This approach has been used since the 2012 assessment (Rugolo and Turnock, 2012a), although the weight-at-size regressions were changed in 2015 to agree with the standardized versions used by the NMFS EBS Bottom Trawl Survey (Daly et al., 2014). These biomass estimates, while similar in scale, do not correspond exactly to corresponding time series published in recent survey technical memoranda. First, the minimum size of crab included in the assessment model is 25 mm CW, while the "tech memo" time series includes crab of all sizes. Second, maturity state for males in the assessment has been based on a maturity ogive developed by Rugolo and Turnock (2010), while size cut-points are used to classify male maturity for the tech memos.

Last year, coefficients of variation for annual mature male and female survey biomass were calculated based on survey biomass information (estimates and cv's) provided at 1mm CW size bins for the EBS region by the NMFS Kodiak Lab (R. Foy, NMFS, pers. comm.). For this data, haul-level estimates of CPUE at 1-mm CW size bin widths were expanded to regional (east/west of 166°W longitude, entire EBS) scales using standard formulae. In order to obtain estimates of mature (or any other combination of sizes) survey biomass across the EBS for each sex , it was simply necessary to sum across sizes—which was the rationale for providing the data in this format. In order to obtain the associated cv's with the summed data, however, it was necessary to assume observation "errors" were uncorrelated between size bins. However, this approach tends to underestimate the "true" cv's one obtains by aggregating first across sizes at the haul level, then scaling up to the EBS (as opposed to aggregating to the EBS level for 1mm CW size bins, then aggregating across size bins; Fig. 17). In this assessment, the cv's for mature survey biomass for the EBS were calculated by aggregating over sizes at the haul level, then scaling up to the EBS. Model runs with cv's calculated using both approaches were made to discern the impact of the change (discussed below).

e. Survey catch-at-length

Plots of survey size compositions for male crab, expanded to total abundance by shell condition and fishery region, in Fig.s 18 and 19. The absence of small (new shell) crab in the eastern region since 2009 is notable, as is the progression of a possible cohort (with two size modes) through the new shell size classes in both regions starting in 2009 that starts to show up, but much reduced in amplitude, in the old shell crab size comps in 2014. Plots of survey size compositions for female crab, expanded to total abundance by maturity status (based on morphometric characteristics) and fishery region, are shown in Fig.s 20 and 21. Similar to males, a cohort progression of immature females starting in 2009 is evident in both regions, although it is much clearer in the eastern region. It can also be tracked into the old shell size size comps starting in 2013.

Observed sample sizes for the size compositions, aggregated to the EBS regional level used in the assessment, are presented in Table 11.

f. Other time series data.

Spatial patterns of abundance in the 2013-2016 NMFS bottom trawl surveys are mapped in Fig.s 22-26 for immature males, mature males, legal males, immature females, and mature females, respectively. A decline in the abundance of immature crab over time in the middle shelf of the EBS and around the Pribilof Islands is evident in Fig. 22. A similar decline is apparent for mature and legal-sized males crab in the middle shelf (Fig.s 23 and 24), but it does not occur in the Pribilofs. Immature females (Fig. 25) do not extend as far into the middle shelf as males (compare distributions for 2013), and the distribution appears to recede from the middle shelf to the shelf edge over 2013-2016. A similar phenomenon occurs for mature females (Fig. 26), although these extended further into the middle shelf region than immature females in 2013 (more like mature males).

The decline in abundance of Tanner crab from the middle shelf region over the last four years has occurred as bottom temperatures in the EBS have risen since 2012 from the second-lowest value during the 1975-2015 annual NMFS EBS summer trawl surveys to the second-highest in 2016 (Fig. 27). Associated with these increased mean temperatures is a withdrawal of an extensive cold pool in summer 2012 to the northwest in subsequent years and a concomitant warming of the middle and inner shelf areas (Fig. 28). It is unknown, however, whether or not the increasingly-warm middle shelf in the summer is responsible for the increased absence of Tanner crab from the middle shelf during the survey and, if it is, whether this constitutes a survey-specific phenomenon (i.e., changes in catchability or availability without actual changes in population abundance) or a factor driving a true decline in the Tanner crab stock.

While of interest, it should be noted that these spatial patterns of survey abundance and bottom temperature, as well as the time series of average bottom temperature during the survey, do not play a role in the assessment model.

Annual effort in the snow crab and BBRKC fisheries is used in the model to “project” bycatch fishing mortality rates backward in time from the period when data on bycatch in these fisheries exists (1992-present). A table of annual effort (number of potlifts) is provided for the snow crab and BBRKC fisheries (Table 12).

3. Data which may be aggregated over time:

a. Growth-per-molt

Sex-specific growth curves derived by Rugolo and Turnock (2010) were shown in Fig. 2. These curves provide the basis for priors on sex-specific growth estimated within the assessment model.

b. Weight-at size

Weight-at-size relationships used in the assessment model for males, immature females, and mature females is depicted in Fig. 29.

c. Size distribution at recruitment

The assumed size distribution for recruits to the population in the assessment model is presented in Fig. 30.

4. Information on any data sources that were available, but were excluded from the assessment.

The 1974 NMFS trawl survey was dropped entirely from the standardized survey dataset in 2015 due to inconsistencies in spatial coverage with the standardized dataset.

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 detailed description of the 2013 model (TCSAM2013) is presented in Appendix 3 of the 2014 SAFE chapter (Stockhausen, 2014). Following the 2014 assessment, the model code was put under version control using "git" software and is publicly available for download from the GitHub website[2].

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 of the 2014 assessment (Stockhausen, 2014).

In brief, crab enter the modeled population as recruits following the size distribution in Fig. 30. 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-

---

[2] https://github.com/wStockhausen/wtsTCSAM2013.git

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 mature survey biomass, survey size compositions, retained catch, retained catch size compositions, bycatch mortality in the bycatch fisheries, and bycatch size compositions in the bycatch fisheries (Stockhausen, 2014).

b. Changes since the previous assessment.

Model code is available on github (https://github.com/wStockhausen/wtsTCSAM2013; the current branch is '2016AssessmentModel'). A substantial amount of work has been done since Sept. 2015 to implement alternative approaches to model parameterization, data-fitting, and model output formats in the code. In addition, all model options can now be specified in a "control file", as can parameter estimation phases and initial parameter values, and are no longer "hard-wired" in the model code. The changes made up to May 2016 are summarized in the following table:

Category	Description
recruitment	The beginning of the "historic" and "current" recruitment periods now inputs. Initial parameter values and estimation phase set now inputs.
natural mortality	Iinitial parameter values and estimation phase now inputs. Time period for high natural mortality now an input.
fishing mortality	Phase to estimate fishing mortality in BBRKC fishery now an input. Lognormal likelihoods implemented for fishery catch data (assumed cv's are inputs). Option to fit male discard (rather than total mortality) in directed fishery implemented. Ln-scale offsets to mean fishing mortality/capture for female crab added as parameters. Parameters added to estimate scalars to extrapolate fishing mortality using effort. Methods to estrapolate fishing mortality using effort are set in control file. Implemented alternative methods to normalize size comps from the groundfish fisheries. Normalization method for size comps from the groundfish fisheries set in control file.
molt to maturity	Implemented parameter estimation on logit scale.
control file	Added nominal legal size as input. Was hard-wired to 138 mm CW. Survey Q: means, std devs now set in control file.
other	Model start year now an input. Revised code to vectorize many calculations. Added z-scores from likelihood calculations to output. Added ability to jitter initial parameter values R package revised to run multiple models, jittered parameter runs

Models implementing many of these changes were reviewed by the CPT at its May 2016 meeting; the most substantial option not reviewed was the addition of using parameters to estimate the values used to extrapolate effort to fishing mortality in the snow crab and BBRKC bycatch fisheries. This option is addressed in models considered for this assessment.

Model changes made subsequent to May 2016 are summarized here:

Category	Description
fishing mortality	implemented phased reduction of penalties on F-devs as option
	implemented option to remove penalties on F-devs in final estimation phase
	implemented option to remove minimum F's for BBRKC bycatch fishery
control file	All parameter phases now inputs (no longer hardwired)
	All initial parameter values now inputs (if not jittering)
	legal/preferred size now an input (no longer hardwired)
other	Model output completely revised to facilitate model comparisons
	R package revised to facilitate model comparisons

The model changes above associated with fishing mortality were implemented to address CPT requests for alternative models to be considered for this assessment.

i. Methods used to validate the code used to implement the model

The model code has been previously reviewed by members of the CPT and the assessment author.

3. Model Selection and Evaluation

a. Description of alternative model configurations

Based on analyses presented to the CPT at its May 2016 meeting, it was concluded that the 2015 assessment model ("2015AMO", with "O" for "original") had not converged to its *global* minimum objective function value; instead, it had converged to a *local* minimum. The model was re-evaluated using the 2015 data to determine its global minimum by making 200 runs with randomly-selected ("jittered") initial values. The run ("2015AMR", with "R" for "re-run") with the smallest objective function and smallest maximum gradient was selected as the run most likely to have arrived at the global minimum. The 2015AMR achieved a slightly lower objective function value (2048.68) than the 2015AMO assessment model (2049.07), conclusively indicating that the 2015AMO had not converged to the global minimum.

Two data configurations were considered in this assessment; the two configurations differed in how input cv's for regional (EBS) mature survey biomass estimates were calculated. In the "old" method, cv's were calculated assuming independence of errors across 1-mm CW size bins:

$$cv_{mat} = \frac{\sqrt{\sum_z (cv_z \cdot b_z)^2}}{\sum_z \ b_z}$$

where cv_{mat} is the cv associated with the estimate of mature biomass (=$\sum_z \ b_z$) and cv_z is the cv associated with b_z, the survey estimate of mature biomass for size bin z. In the "new" method, estimates of survey biomass at the individual haul level (i.e., summed across size bins for each individual haul) were expanded to the regional (EBS) level using the survey's stratified sampling design, with the regional level cv calculated based on this stratification. The impact of this change on the assessment was quantified using the new cv's for mature survey biomass, but without otherwise updating the 2015 datafiles to 2016, and evaluating the 2015 assessment model using the parameter jittering approach with 200 jittered runs. The resulting "best" model run is referred to here as 2015AMN ("N" for "new").

At the May CPT meeting, models with the following incremental changes to the 2015 assessment model were evaluated:

Change	Description
0	2015 assessment model
A	start "current" recruitment estimation in 1975, instead of 1974
B	normalize groundfish fishery size comps using original sample sizes, not input sample sizes
C	estimate log-scale fishing mortality/capture rate offsets for female crab
D	fit to male discard mortality in directed fishery
E	turn on fishing mortality/capture rate estimation for BBRKC
F	set initial estimate for historic log-scale recruitment (= 11.4)
G	estimate probability of molt-to-maturity using logit-scale parameterization
H	change model start year to 1930, keep start year for "historic" recruitment deviations = 1949
I	enforce logistic selectivity = 1 in largest size bin
J	use GMACS fishing mortality model
L0	use lognormal NLL's with moderate cv's for fits to fishery catch data
L1	use lognormal NLL's with small cv's for fits to fishery catch data

Based on these the review of these models, the CPT requested the following configuration, referred to here as Model B ("B" for "base"), be used as the "base" model for evaluating additional alternative model configurations:

Change	Description
A	start "current" recruitment estimation in 1975, instead of 1974
B	normalize groundfish fishery size comps using original sample sizes, not input sample sizes
C	estimate log-scale fishing mortality/capture rate offsets for female crab
E	turn on fishing mortality/capture rate estimation for BBRKC
G	estimate probability of molt-to-maturity using logit-scale parameterization
I	enforce logistic selectivity = 1 in largest size bin
J	use GMACS fishing mortality model

Based on requested alternatives proposed by the CPT in May, the following alternative models were evaluated for this assessment:

Scenario	Description
2015AMO	2015 assessment model and data
2015AMR	2015AMO re-evaluated using parameter jittering
2015AMN	2015AMO + new approach to calculate CVs for mature survey biomass
2015AM	2015AMN + 2016 data (using new approach to calculate CVs for mature survey biomass)
Model A	Model B, but using old fishing mortality model
Model B	Model selected by CPT in May as "base" model for 2016 assessment
Model C	Model B + no minimum F's imposed on BBRKC fishery bycatch
Model D	Model C + effort extrapolation parameters estimated
Model E	Model D + penalty on F-devs reduced to 0 in final estimation phase
Model F	Model D + lognormal likelihoods assumed for fishery catch data (change L0 from May)
Model G	Model E + lognormal likelihoods assumed for fishery catch data (change L0 from May)

In implementing the lognormal fishery catch likelihoods (Models F and G), it was necessary to specify relative error sizes for each data source. The same set of values were used for both models, as documented in the following table:

Fishery	Data Source	Likelihood Component	Assumed CV
Directed fishery	fish tickets	retained catch	5%
	at-sea observers	total catch/discards	20%
snow crab	at-sea observers	total catch/discards	20%
BBRKC	at-sea observers	total catch/discards	20%
groundfish	at-sea observers	total catch/discards	20%

The values chosen were subjective, based on the author's experience with such data. It seems likely the chosen values can be refined in future work.

b. Progression of results from the previous assessment to the preferred base model

The following table summarizes basic model results for the 11 model/data combinations considered here:

Model Scenario	Final Year	Data	# params	# of jitter runs	Objective Function		invertible hessian?	Mean Recruitment		MMB (1000's t)		
					value	max gradient		1982+	2000+	1982+	last 3 years	final year
2015AMO	2015	old cv's	307	--	2049.07	0.0000875	yes	179.4	164.9	36.5	59.6	71.6
2015AMR	2015	old cv's	307	200	2048.68	0.0002388	yes	176.8	163.9	35.8	57.7	69.3
2015AMN	2015	new cv's	307	200	1838.14	0.0003343	yes	193.4	188.1	42.7	68.7	83.3
2015AM	2016	new cv's	312	200	1952.73	0.0002182	yes	183.5	174.1	41.8	71.3	74.3
Model A	2016	new cv's	341	200	2338.77	1.5256000	yes	--	--	--	--	--
Model B	2016	new cv's	341	200	2406.67	0.0002237	yes	182.2	171.4	39.7	70.2	73.9
Model C	2016	new cv's	341	200	2406.75	0.0004336	yes	182.3	171.5	40.7	70.2	73.9
Model D	2016	new cv's	343	200	2391.11	0.0004838	yes	168.8	165.2	37.9	63.7	67.2
Model E	2016	new cv's	343	200	2286.11	0.0000145	yes	174.2	176.0	40.1	68.3	72.4
Model F	2016	new cv's	343	200	2997.88	0.0003812	yes	163.6	160.8	37.6	61.8	63.3
Model G	2016	new cv's	343	200	2672.99	0.0000301	yes	172.7	175.6	40.5	68.8	70.9

The first three models illustrate progress from the 2015 assessment model (2015AMO) to a converged version based on the same data but evaluated using 200 jittered parameter runs (2015AMR), and finally to a converged version using cv's for the NMFS trawl survey mature biomass time series based on the "new" cv calculation (2015AMN). The next three (2015AM, Model A, Model B) illustrate the progression from the 2015 assessment model configuration with 2016 data to the CPT's requested base model for this assessment (Model B). Models C through G illustrate incremental changes to Model B requested by the CPT in May.

All new model scenarios were evaluated using 200 runs with jittered initial parameter values to select the run with the smallest objective function value and smallest maximum gradient. For each model, the selected run was re-run to invert the hessian and obtain standard deviations for parameter estimates. While all models resulted in hessians that were invertible and provided uncertainty estimates associated with the parameter estimates, the "best" run for Model A had clearly not yet converged to a minimum because the maximum gradient value was far too large (1.5256). It is surprising that the hessian was invertible for this model, but the result is clearly not valid and Model A is dropped from further consideration (note: it was not a model requested by the CPT).

Results of the progression from the 2015 assessment model with 2015, model scenario 2015AMO, to the same model configuration but with 2016 data (including the "new" survey biomass cv's), model scenario 2015AM, are provided in Appendix A.

Results of the change from the 2015AM model scenario to the base model requested by the CPT for the 2016 assessment, Model B, are summarized in Appendix B.

Results of the change from Model B to Model C, relevant to model selection, are summarized in Appendix C.

Results of the progression from Model C: Model D: Model E: Model F: Model G, relevant to model selection, are summarized in Appendix D.

More complete comparisons are provided in the accompanying on-line material at the Council website.

c. Evidence of search for balance between realistic (but possibly overparameterized) and simpler (but not realistic) models.

All models considered were parameterized in substantially similar fashion, so no simpler or more realistic models were considered.

d. Convergence status and convergence criteria

Convergence in all models was assessed by running each model 200 times with randomly-selected (“jittered”) initial parameter values for each run. The run with the smallest objective function value and smallest maximum gradient was selected as the “converged” model, if it was also possible to invert the associated hessian and obtain standard deviation estimates for parameter values. Theoretically, all gradients at a minimum of the objective function would be zero. However, because numerical methods have finite precision, the numerical search for the minimum is terminated after achieving a minimum threshold for the max gradient or exceeding the maximum number of iterations.

e. Sample sizes assumed for the compositional data

Input sample sizes used for compositional data are listed in Tables 5-9 for fishery-related size compositions. Input 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 as described in Stockhausen (2014, 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.

f. Parameter sensibility

As noted in Appendix D, estimates for the ln-scale effort extrapolation (fishery q) parameters estimated for the snow crab and BBRKC fisheries in Models D, E, F and G are unreasonably small (on the order of -19) and consequently result in associated bycatch fishing mortality rates before 1992 in these fisheries that are essentially zero. Uncertainty estimates associated with these parameters were also very large (std. dev. = ~800). Consequently, these models were no longer considered as viable candidates for preferred model.

Most parameter estimates obtained for Model C appear to be reasonable, or at least consistent with the 2015 assessment (Tables 20-28). An exception was the estimated 1996 ln-scale deviation to 50%-selected for total-catch of males in the directed fishery, which hit its lower bound in Model C. Other parameters that were limited by the bounds placed on them in Model C were also limited un the 2015 assessment, and those that did so hit their upper bounds. These included the female growth parameter “a” (Table 20), the offset from 50-to-95% selected for female selectivity in surveys 1982-present (Table 20), and the sizes at 50%-selected for male bycatch in the BBRKC fishery before 1997 and after 2004 (Table 25). Another parameter in Model C that had a questionable value was the ln-scale female offset to the fully-selected male fishery capture rate in the BBRKC fishery, which had a value of 2.44 (Table 24)—implying female Tanner crab experienced 10 times the capture rate in the BBRKC fishery that males did. However, a similar value (2.44) was estimated in Model B.

g. Criteria used to evaluate the model or to choose among alternative models

Criteria used to evaluate the alternative models were based primarily on: 1) goodness of fit and likelihood criteria, 2) parameter sensibility, and 3) biological realism.

h. Residual analysis

Residuals for the author's preferred model, Model C, are discussed below under the Results section.

i. Evaluation of the model(s)

Of the models evaluated with data for 2016, Models 2015AM and Model A were run to illustrate the progression of models (and data) from the 2015 assessment to the CPT's base model for this assessment (Model B), and thus were not considered as suitable for selection. Of the remaining models, Models B and C yielded almost identical results, so Model C was preferred relative to Model B because it removed a constraint on bycatch F rates in the BBRKC fishery that fixed minimum F's. Model D was eliminated from consideration because the estimated parameters converting effort to bycatch fishing mortality rates (i.e., fishery q's) in the snow crab and BBRKC fisheries were unreasonably small—resulting in predicted bycatches of almost 0 prior to the period when observations of bycatch were available (early 1990s). Models E, F, and G were also eliminated from further consideration for this reason, because each was "built" on Model D as a base model. It will be worthwhile, in future work, to reconsider the incremental changes embodied in Models E, F and G using Model C as a base rather than model D (i.e., eliminate estimating fishery q's as model parameters).

4. Results (best model(s))

Model C was selected as the author's preferred model for the 2016 assessment.

a. List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties.

Input and effective sample sizes for size composition data fit in the model are listed in Tables 13-18 fro the 2015 assessment model and Model C. Weighting factors applied to the various components included in the overall model objective function, including likelihoods, penalties and priors, are listed in Table 19.

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 Tables 21-28.

ii. Abundance and biomass time series, including spawning biomass and MMB.

Estimates for mature survey biomass, by sex, are listed in Table 29 and for mature biomass at mating, by sex, in Table 30. Numbers at size for males and females are given by year in 5 mm CW size bins in Tables 31 and 32, respectively.

iii. Recruitment time series

The estimated recruitment time series from the 2015 assessment and Model C are listed in Table 33.

iv. Time series of catch divided by biomass.

A comparison of catch divided by biomass (i.e., exploitation rate) from the 2015 assessment and Model C is listed in Table 34.

c. Graphs of estimates

i. Fishery and survey selectivities, molting probabilities, and other schedules depending on parameter estimates.

Estimates of natural mortality by sex and maturity state are shown in Fig. 31. 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 following table summarizes the estimated rates by stock component:

Stock component	Normal period		High Mortality	
	2015 assessment	Model C	2015 Assessment	Model C
immature crab	0.24	0.24	0.24	0.24
mature females	0.35	0.33	0.37	0.44
mature males	0.26	0.27	0.92	0.76

While the rates are almost identical in the “normal” period, Model C’s estimates for mature males and females are substantially smaller than those from the 2015 assessment. This is the reverse of what occurred moving from the 2014 assessment to the 2015 assessment with the adoption of the “standardized” trawl survey dataset that included the “old” mature survey biomass cv’s. When these were replaced by the new cv’s, the natural mortality rates decreased.

Estimated sex- and size-specific probabilities of the terminal molt-to-maturity are quite similar for the 2015 assessment model and Model C, despite different parameterizations used in the two models (Fig. 32). Estimated sex-specific mean post-molt size, as a function of pre-molt size, is also quite similar for the two models (Fig. 33).

For both sexes, survey selectivity curves (Fig. 34) estimated by the 2015 assessment model and Model C are almost identical for the first survey time period (pre-1982) for both sexes, but have slightly larger slopes and reach higher asymptotes in the 2015 assessment model for the second and third time periods (1982-present). This is a result of Model C estimating a smaller survey q for females and a larger estimated size at 95%-selected for males.

Retention curves in the directed fishery estimated by the 2015 assessment model and Model C are almost identical (Fig. 35). The estimated selectivity curve for males in the directed fishery prior to 1991 (Fig. 36) for Model C is slightly left-shifted to smaller sizes relative to that from the 2015 assessment; this is probably a result of the different fishing mortality models used (the 2015 assessment used the “standard” Tanner crab model used in prior assessments, while Model C uses the Gmacs model; see Stockhausen, 2015). Conversely, the estimated selectivity curve for female bycatch in the directed fishery (Fig. 36) for Model C is substantially left-shifted to smaller sizes relative to that from the 2015 assessment model. This is not a result of the two different fishing mortality models; rather, it is a result of estimating a female-specific offset to the male capture rate in the directed fishery in Model C (none was estimated in the 2015 assessment).

Estimated selectivity curves in the period 1991-present from Model C are generally left-shifted to smaller sizes compared to those from the 2015 assessment model (Fig. 37). In part, this reflects the difference in fishing mortality models: the selectivity functions in Model C reflect annual size-dependence in fishery *capture* rates in the directed fishery while those in the 2015 assessment model reflect the size dependence of fishery (retained + discard) mortality rates.

Separate curves are estimated for 3 different time periods for each bycatch 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. Estimated male selectivity curves in the bycatch fisheries (Fig.s 38-40) from the two models are similar for each time period, whereas the female selectivity curves tend to be left-shifted to smaller sizes in Model A relative to the 2015 assessment model (Fig.s 38-40). Again, this latter phenomenon is due to estimating female-specific offsets to male capture rates in Model A.

iii. Estimated full selection F over time

Estimated time series of fully-selected F on males in the directed fishery and as bycatch in the snow crab, BBRKC and groundfish fisheries are compared in Fig.s 41-44 between Model C and the 2015 assessment. It should be noted that fully-selected “capture rates” are estimated directly in Model C while mortality rates are derived after applying assumed handling mortality rates, whereas the 2015 assessment model estimates the mortality rates directly (and does not estimate capture rates at all). For males in the directed fishery (Fig. 41), rates in Model C are slightly higher early in the model period (pre-2000), but rates in both models are similar more recently (post 2000). Because these are “fully-selected” rates, there is no difference between capture rate, total mortality rate, and retained mortality rate as long as retention is 100% for large crab (as is the case for both models). In contrast, capture and (bycatch) mortality rates for females in the directed fishery in Model C are generally lower than for the 2015 assessment model because the same mortality rates are applied to males and females in the 2015 assessment model while a female-specific ln-scale offset to the male rate is estimated in Model C. Similar observations hold for comparisons of the results for the snow crab fishery (Fig. 42) and the groundfish fisheries (Fig. 44). Results for the BBRKC fishery show more contrast between the two models (Fig. 43), but this is partly because the F’s were fixed (not estimated) in the 2015 assessment whereas they are estimated for 1992-present in Model C. As noted previously, the estimated female-specific offset for this fishery in Model C is greater than 1.

ii. Estimated male, female, mature male, total and effective mature biomass time series

The time series of recruitment estimated in the 2015 assessment and by Model C are remarkably similar (Table 33, Fig. 45). Both indicate a peak in recruitment in 1964 (probably a model artifact reflecting the start of retained catch data in 1965) followed by a steady decline into the mid-1970s, another peak in1976 followed again by declining recruitment. This decline bottoms out in 1980-1982, recruitment increases to a 4-year plateau in the mid-1980s, declines to low values in the early-to-mid 1990s, then undergoes a period of oscillations with increasing amplitude through 2005 followed by a 4-year low to 2008. After 2008, both models estimate increased recruitment in 2009-2011, followed by a return to lower levels in 2012-present. In general, recruitment is estimated to be much lower since 1990 than prior to 1990.

Estimates of population abundance in the 2015 assessment and from Model C exhibit similar patterns of variability, although the magnitudes differ in some cases (Fig.s 46, 47). Abundance in both models builds to a maximum in 1965-66, although the 2015 assessment estimates a somewhat larger maximum than does Model C. Abundance then follows a declining trend, with superimposed fluctuations, to 1982-83, rebuilds to a much smaller peak in 1987, and declines into a broad “valley” extending from 1993 to 2001 or so. Since 2000, population abundance has exhibited (in both models) fairly large fluctuations, possibly superimposed on a (very) gradual upward trend. Model C estimates slightly higher abundance than the 2015 assessment, although the pattern of variability is the same.

Estimates of mature biomass from the 2015 assessment and Model C also (not surprisingly) exhibit similar patterns of variability (Fig. 48), being basically smoothed versions of the population abundance trajectories.

iv. Estimated fishing mortality versus estimated spawning stock biomass

See Section F (Calculation of the OFL; Fig. 94).

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

Model fit to retained catch is shown Fig. 49. The fits are generally quite good in both the 2015 assessment and for Model C, except for the terminal model year, where both models underpredict actual retained catch. Similarly, fits to male total (retained+discard) mortality, based on at-sea observer data, are generally quite good for both models, although (in contrast to retained catch) both models overpredict total mortality in the terminal model year (Fig. 50). Similar observations hold for predictions of male discard mortality in the directed fishery (Fig. 51), although these data are not directly fit in the model. These opposing terminal year misfits may indicate a recently-introduced (post-2009) bias between the at-sea observer data and the dockside observer data which the models can’t resolve. Recent changes in retention practices not reflected in the models may also be a source of this tension.

Fits to bycatch data are also generally good for males in both the 2015 assessment and for Model C for the snow crab fishery (Fig. 52). Fits to males look poorer in both models in the BBRKC fishery (Fig. 53), although Model C captures the mean level slightly better than does the 2015 assessment. One reason for the “poor” fits to the BBRKC fishery bycatch is that the bycatch levels (< 100 t) are smaller than the assumed uncertainty (~500 t) in the likelihood, so the models think the fits are adequate. Improving the fits would require assuming smaller levels of uncertainty, but this may not be worthwhile in terms of overall model performance.

Fits to female bycatch data in all the crab fisheries (Fig. 51-53) are not really very good for either the 2015 assessment model or Model C, even though Model C includes female-specific offsets to male fishing mortality. The problem with both models is twofold: first) predicted female bycatch is constrained to follow a temporal pattern similar to that for males, but observed mortality des not; and second) female bycatch levels in all the crab fisheries are much smaller than the assumed uncertainty levels and consequently fitting female bycatch levels more closely has little leverage in minimizing the overall model objective functions.

Bycatch in the groundfish fisheries is not sex-specific. Fits to total bycatch mortality in the groundfish fisheries are very good both for Model C and in the 2015 assessment. Both models nicely capture the peak at the beginning of the time series, followed by the rapid decline and subsequent fluctuations. Since 2008/09, total bycatch mortality has been less than 500 t and both models have over-predicted it (although the predictions are essentially identical).

The “goodness of fit”s to the fishery catch data, as they influence the likelihoods in the 2015 assessment model and Model C, is also evident of plots of z-scores for the fishery catch data (Fig.s 55 and 56, males only). That almost all the z-scores are < 1 indicates that probably little improvement to the current fits in terms of absolute (rather than relative) error will occur without changing the assumed uncertainty levels for the fishery data.

ii. Graphs of model fits to survey numbers

Time series of observed biomass of mature crab in the NMFS bottom trawl surveys are compared by sex with model-predicted values for Model C and the 2015 assessment in Fig. 57. The difference in cv's for the observed data appears to have little direct impact on the trajectories of the model-predicted time series. Both the model and the assessment under-predict mature female survey biomass in the early 1980s and again in the early 1990s. They also under-predict mature male survey biomass in the early 1990s as well as in the mid-2000s. The scale of the standardized log-scale residuals (Fig. 58) indicates mediocre fits for (the standard deviation of the residuals is ~2, whereas ~1 would indicate a good fit). In almost all cases, though, Model C exhibits slightly smaller relative errors in comparison with the 2015 assessment results.

Model predictions for total survey numbers of preferred males (≥ 125 mm CW) are compared with observations from the survey in Fig. 59. These data are not fit in the models, and so provide a somewhat independent test of model fitting. Prior to 2000, both models tended to underpredict observed survey abundance when it was high, but overpredict it when it was low. In recent years, both models rather substantially over-predict numbers of large crab in the survey.

iii. Graphs of model fits to catch proportions by length

Model-predicted proportions at size from the 2015 assessment and Model A for retained males in the directed Tanner crab fishery are presented in Fig. 60. A plot of the Pearson's residuals for the fits is presented in Fig. 61. Both models appear to fit the observed proportions quite similarly, although Model C fits slightly better in 1991-1996 and 2005-2008 (the fishery was closed 1997-2004) because, although its shapes are similar to those from the 2015 assessment, they are slightly right-shifted to larger sizes (as the data tends to be). For 2014 (2014/15), both models predict more retained crab at larger sizes than is seen in the data. This pattern extends to 2015 (2015/16) for Model C. This is consistent with a recent shift in industry retention to smaller sizes not yet reflected in the models.

Model-predicted patterns from the 2015 assessment and Model C for the proportions caught-at-size in the directed fishery are shown in Fig. 62 for males, Fig. 63 for females, and as Pearson's residuals for both sexes in Fig. 64. General residual patterns indicate that the fishery catches a larger proportion of small male crab than predicted by the models (except in 1996), and catches fewer large male crab than predicted by the models. This is particularly true in 2009 (2009/10), when the area west of 166^{o}W longitude was closed to directed fishing. Conceivably, among other potential explanations, this pattern may indicate that an asymptotic selectivity curve is inappropriate for the male selection process or that the model overestimates growth into the largest size classes for males. 1996 is the exception to this, and exhibits extremely poor (though different) absolute fits to the data for the two models (Fig. 62), although the relative fits are good (as evidenced by the small values for the Pearson's residuals for males in 1996; Fig. 64). As previously noted, however, the relative weight (input sample size) put on fitting this data in the likelihood is quite small. It is notable that the fit to the 1996 bycatch size composition for females is much better, but in general the residuals for females are much smaller. This is somewhat surprising given that a single selectivity pattern is estimated for females while the male selectivity pattern (the 50%-selected parameter of the logistic function) is allowed to vary from year-to-year after 1991.

Model-predicted patterns from the 2015 assessment and Model C for the proportions caught-at-size as bycatch in the snow crab fishery are shown in Fig. 65 for males, Fig. 66 for females, and as Pearson's residuals for both sexes in Fig. 67. Estimates from both models for males are almost identical. Estimates for females are quite similar, although some differences between the models can be seen at small sizes for 1992-1996.

Model-predicted patterns from the 2015 assessment and Model C for the proportions caught-at-size as bycatch in the BBRKC fishery are shown in Fig. 68 for males, Fig. 69 for females, and as Pearson's residuals for both sexes in Fig. 70. As with snow crab, estimates from both models for males are almost identical. Estimates for females are also almost identical.

Model-predicted patterns from the 2015 assessment and Model C for the proportions caught-at-size as bycatch in the groundfish fisheries are shown in Fig. 71 for males, Fig. 72 for females, and as Pearson's residuals for both sexes in Fig. 73. These proportions-at-size are fit as *extended* size compositions, where the annual proportions sum to 1 over both sexes, in contrast to the proportions in the crab fisheries where the proportions sum to 1 over each sex individually. Extended size compositions are fit for the groundfish fisheries because the associated observed bycatch mortality is not sex-specific and the extended compositions allow the models to extract information on the relative abundance of males vs. females in these fisheries. The model-predicted size compositions in the groundfish fisheries are relatively similar for males, differing mainly in magnitude. For females, the patterns for 1973-1996 are similar and differ, like males, somewhat in overall magnitude rather than in shape. However, during the period 1997-present the magnitudes are substantially different (unfortunately, the model-predicted size compositions from the 2015 assessment blend into the data bars)—with the 2015 assessment size compositions of much smaller magnitude (and much worse fit) than those from Model C. The poor behavior of the 2015 assessment model was traced earlier this year to how the sex-specific size compositions were combined to form the extended composition. Previous to this year, the size compositions were combined using the input sample sizes to weight the size compositions. However, this approach did not always preserve the relative abundance scales inherent in the observed sample sizes. In Model C, the extended size compositions are created using the observed male and female sample sizes to weight the sex-specific size compositions, then fit using the input effective sample sizes. The new approach vastly improved the overall fits for the female size compositions (Fig. 73), as well as slightly improving the fits to the male size compositions.

iv. Graphs of model fits to survey proportions by length

Model fits from the 2015 assessment and Model C to observed proportions-at-size in the annual NMFS trawl survey are shown for males in Fig. 74. The similarity in results between the two models is fairly remarkable. As with the 2015 assessment model, Model C 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. 75. The model tends to over-predict proportions-at-size in the 65-85 mm CW range. The patterns of residuals for males and females evident in the bubble plots for Model A are almost identical to those obtained from the 2015 assessment (Fig. 76).

v. Marginal distributions for the fits to the compositional data.

Marginal fits for the Model C-predicted proportion of crab by size in the directed fishery catch are similar to those for the 2015 assessment model: the models somewhat over-predict proportions for retained males at sizes smaller than the peak and under-predict proportions at sizes larger than the peak (Fig. 77). Model C does a slightly poorer job in this respect than the 2015 assessment model. In contrast, the model under-predicts proportions near the peak and somewhat smaller for all males caught (retained and discarded) in the directed fishery, but over-estimates the proportions for crab larger than the peak (Fig. 78, lower plot). This may indicate an unresolved tension between the retained size comps and the total-catch size comps. Model C appears to reflect observed marginal female bycatch size composition pattern quite well, while the 2015 assessment model under-predicts proportions of crab just smaller than the peak and over-predicts proportions just larger (Fig. 78, upper plot).

The observed and predicted (Model A) marginal proportions for males taken as bycatch in the snow crab fishery are in good agreement at all sizes for both models (Fig. 79, lower plot), while both models tend 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. 79, upper plot). The opposite pattern is true for both models regarding 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. 80). The patterns of model-predicted marginal proportions-at-size for males taken as bycatch in the BBRKC fishery are similar to that found for the snow crab fishery, but shifted to larger sizes by ~20 mm CW. Unfortunately, these result in poorer fits to the observations, overestimating proportions at larger sizes and underestimating them at smaller sizes, than those for the snow crab fishery. The patterns of marginal predicted proportions at size for males and females taken in the groundfish fishery (Fig. 81) obtained using Model C are much closer to the data than those obtained in the 2015 assessment. The improvement occurs Model C uses an improved approach to combining the male and female size compositions prior to fitting them (documented at the May 2016 CPT meeting).

Marginal fits of Model A-predicted proportion-at-sizes in the survey are presented in Fig. 82. The model's marginal survey proportions fit the data quite well, and in quite similar fashion to the 2014 assessment.

vi. Plots of implied versus input effective sample sizes and time-series of implied effective sample sizes.

Time series of implied effective sample sizes, using the McAllister-Ianelli method, are shown in Fig.s 83-85 for retained catch and total catch size compositions in the directed fishery (Fig. 83), bycatch size compositions in the snow crab, BBRKC and groundfish fisheries (Fig. 84), and the NMFS EBS bottom trawl survey (Fig. 85). For the most part, the implied effective sample sizes tend to be substantially larger than the input values.

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).

Results from a 10-year retrospective analysis for Model C, the author's preferred model, are shown in Fig.s 86-89 for mature biomass-at-mating, recruitment, mature survey biomass and retained catch biomass. The plots for mature biomass-at-mating and recruitment (Fig.s 86, 87) display strong retrospective patterns, such that models that are terminated earlier are biased high relative to models that are terminated later. The plot for mature survey biomass indicates the model is almost always biased high in the terminal year of the model run, particularly when the end-year observations are smaller than the previous year (Fig. 88). However, there does not seem to be a similar pattern for fitting retained catch biomass (Fig. 89).

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 2015 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).

g. Uncertainty and sensitivity analyses
Not available.

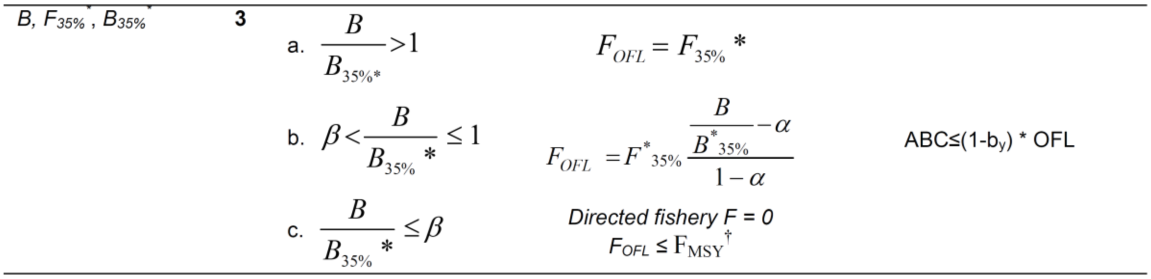
F. Calculation of the OFL and ABC

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 2015/16 was 27.19 thousand t while the total catch mortality for 2014/15 was 11.38 thousand t, based on applying discard mortality rates of 1.000 for retained catch, 0.321 to bycatch in the crab fisheries, and 0.800 to bycatch in the groundfish fisheries to the reported catch by fleet for 2015/16 (Tables 1 and 4). 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. 90):



$B, F_{35\%}^{*}, B_{35\%}^{*}$	**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* $F_{OFL} \le F_{MSY}{}^{\dagger}$	

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, $\bar{R}$, then $B_{35\%} = 0.35 \cdot \bar{R} \cdot \phi(0)$.

Thus Tier 3 status determination and OFL setting for 2015/16 require estimates of B = $MMB_{2016/17}$ (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. 90). 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.

In 2015, the SOA's Board of Fish, under petition from the commercial Tanner crab fishing industry, changed the minimum preferred size for crab in the area east of 166^{o}W longitude in calculations used for setting TACs from 138 mm CW (not including lateral spines) to 125 mm CW. The minimum preferred size in the area west of 166^{o}W remained the same (125 mm CW). In previous assessments, an attempt was made to account for retention of slightly (10 mm CW) smaller crab in the directed fishery in the western area. Because the preferred size is now the same in both areas, the OFL is calculated assuming both selectivity (as previously) and retention (new) curves are the same in both areas. Selectivity curves in the bycatch fisheries were set using the average curves over the last 5 years for each fishery, the same approach as in previous assessments (Rugolo and Turnock, 2012b; Stockhausen 2015). The selectivity and retention curves used to calculate the OFL are shown in Fig.s 91-92.

To calculate the F_{OFL}, the fishery capture rate for males in the directed fishery is adjusted until the longterm (equilibrium) MMB-at-mating is 35% of its unfished value. However, this calculation also depends on the assumed bycatch F's on Tanner crab in the snow crab, BBRKC and groundfish fisheries. For the latter two fisheries, the average F over the last 5 years is used in the calculations. Because the snow crab fishery typically accounts for the largest bycatch mortality in the bycatch fisheries, and because the FOFL for snow crab is frequently a good predictor of the actual F in the upcoming year, a different approach is used to determine the snow crab fishery F for Tanner crab bycatch. For the snow crab fishery, the ratio of the F_{OFL} from the snow crab assessment author's preferred model to the average F over the last 5 years is used to scale the 5-year average bycatch F on Tanner crab. For this assessment, the snow crab FOFL is 1.24 yr^{-1} (Szuwalski, 2016), the 5-year average F is 0.979 yr^{-1}, the resulting ratio is 1.266, and the fully-selected Tanner crab bycatch capture rate used in the projection model was 0.092 yr^{-1}.

OFL results from the projection model using the same approach for each of the "converged" models considered in this assessment (consequently values for Model A are missing) are listed for illustrative purposes only in Table 35. The change from the "old" (2015AMR) to the "new" (2015AMN) survey biomass cv's resulted in higher values for average recruitment (176.78 vs. 193.44 million crab), projected MMB-at-mating (*B*) for 2015/16 (51.41 vs. 63.85 thousand t), B_{MSY} (25.68 vs. 29.42 thousand t), and OFL for 2015/16 (25.68 vs. 30.96 thousand t), although F_{MSY} was similar (0.58 vs. 0.56). Adding the 2015/16 fishery data and 2016 survey data (2015AM) reduced estimates of average recruitment (183.46 million crab), projected MMB-at-mating for 2016/17 (48.07 thousand t), and B_{MSY} (26.68 thousand t), while F_{MSY} was similar (0.59). The OFL for 2016/17 using the 2015 assessment model configuration would be substantially smaller (23.79 thousand t) than that for 2015/16 from the converged model (2015AMR). Moving to the base 2016 model (Model B) involved a host of changes to the model configuration reviewed during the May 2016 CPT meeting. Compared with the 2015 model configuration run with the 2016 data (2015AM), the results from Models B and C (the author's preferred model) are really fairly similar except that F_{MSY} is 0.79 for the latter models and 0.59 for 2015AM. The value of F_{MSY} from Model D (0.09) does not appear to be valid, and calls into question results from the succeeding models (E through G) which build on it, although they seem more plausible. Model D, as discussed previously, was the first model to estimate the conversion from effort to fishery capture rates in the absence of bycatch data as parameters for the snow crab and BBRKC fisheries—resulting in anomalously small conversion factors.

The estimate of *B* from Model C, the author's preferred model, is 45.34 thousand t (Table 35). Male spawning biomass per recruit in an unfished stock was calculated using the TCSAM population dynamics equations (Stockhausen, 2014) with total recruitment set to 1 and fishing mortality from all sources (directed fishery and all bycatch fisheries) set to 0, resulting in $\phi(0)$ = 0.402 kg/recruit. $F_{35\%}$ was calculated for this model as 0.79 yr^{-1}, which is quite a bit larger than that calculated last year (0.58 yr^{-1}) but this is primarily an effect of the change to the Gmacs fishing mortality model. For the 2015 assessment, the size dependence of fishing mortality rates on males in the directed fishery followed a logistic curve. For the Gmacs fishing mortality model, the size dependence of the fishery capture rates follows a logistic curve, but the resulting size dependence for fishing mortality is no longer a logistic shape.

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 182.27 million. The estimates of average recruitment are reasonably similar between the 2015 assessment model and the author's preferred model (Table 33, Fig. 45). The value of B_{MSY}=$B_{35\%}$ for $\bar{R}$ is 25.65 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. 90), 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, 2016 as estimated by the assessment model.

Assessment uncertainty was included in the calculation of OFL using the same approach as that used for previous assessments (Stockhausen, 2014, 2015). Basically, initial numbers at size on July 1, 2016 were randomized based on an assumed lognormal assessment error distribution and the cv of estimated MMB for 2015/16 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. **The value of OFL for 2016/17 from the author's preferred model (Model C) is 25.61 thousand t** (Table 35, Fig. 93)**.**

Model C is the author's preferred model for calculating the B_{MSY} proxy as $B_{35\%}$, so MSST = 0.5 B_{MSY} = 12.82 thousand t. Because current B = 45.34 thousand t > MSST, **the stock is not overfished**. The population state (directed F vs. MMB) is plotted for each year from 1965-2014 in Fig. 94 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%. In 2014, however, the SSC adopted a buffer of 20% on OFL for the Tanner crab stock for calculating ABC. 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 35). ABCs were also calculated using the SSC's 20% OFL buffer (Table 35).

For the author's preferred model, Model C, the P* ABC (ABC_{max}) is 25.57 thousand t while the 20% Buffer ABC is 20.49 thousand t. The author remains concerned that the projection model, based on $F_{35\%}$ as a proxy for F_{MSY}, is 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. 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 currently assumed for this stock. Given this uncertainty concerning the stock, **the author recommends using the 20% buffer adopted by the SSC last yearfor this stock to calculate ABC. Consequently, the author's recommended ABC is 20.49 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 has finally been collected in the EBS on Tanner crab (molt increments observed on 100+ individuals collected in 2015 and 2016; R. Foy, AFSC, pers. comm.). More data regarding temperature-dependent effects on molting frequency would be helpful to assess potential impacts of the EBS cold pool on the stock. Information on temperature-dependent changes in crab movement and survey catchability would also e of value. In addition, it would be extremely worthwhile to develop a "better" index of reproductive potential than MMB that can be calculated in the assessment model and to revisit the issue of MSY proxies for this stock.

The characterization of fisheries in the assessment model needs to be carefully reconsidered. How, and whether or not, the East 166°W and West 166°W directed fisheries should be explicitly represented in the assessment model should be addressed. In addition, how, and whether or not, bycatch in the groundfish fisheries should be split into pot- and trawl-related components should be addressed.

Transition to the new model code (TCSAM2015) will occur this fall in preparation for the Modeling Workshop. Substantial progress was made this summer to allow detailed comparison of model results from the current model code (TCSAM2013) and the new code (TCSAM2015). With the implementation of TCSAM2015, several research avenues can be explored: 1) time-varying growth; 2) fitting molt increment data directly in the model, 3) alternative time periods for defining retention/selectivity functions, and 4) decomposing the currently "lumped" directed fishery into its eastern and western components. Development of a fully Gmacs version of the Tanner crab model will also begin.

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. Thus, use of MMB to reflect Tanner crab reproductive potential may be misleading as to stock health. 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 (Rugolo and Turnock, 2012), suggesting a potential climatic driver.

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 (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	possible concern

		fishery	
Fishery effects on age-at-maturity and fecundity	none	unknown	possible concern

J. Literature Cited

Adams, A. E. and A. J. Paul. 1983. Male parent size, sperm storage and egg production in the Crab *Chionoecetes bairdi* (DECAPODA, MAJIDAE). International Journal of Invertebrate Reproduction. 6:181-187.

Aydin, K., S. Gaichas, I. Ortiz, D. Kinzey, and N. Friday. 2007. A comparison of the Bering Sea, Gulf of Alaska, and Aleutian Islands large marine ecosystems through food web modeling. NOAA Tech. Memo. NMFS-AFSC-178. 298 p.

Brown, R. B. and G. C. Powell. 1972. Size at maturity in the male Alaskan Tanner crab, *Chionoecetes bairdi*, as determined by chela allometry, reproductive tract weights, and size of precopulatory males. Journal of the Fisheries Research Board of Canada. 29:423-427.

Bowers, F.R., M. Schwenzfeier, S. Coleman, B. Failor-Rounds, K. Milani, K. Herring, M. Salmon and M. Albert. 2008. Annual Management Report for the Commercial and Subsistence Shellfish Fisheries of the Aleutian Islands, Bering Sea and the Westward Regionss Shellfish Observer Program, 2006/07. Fishery Management Report No. 08-02. 242 p.

Daly, B., C. Armistead and R. Foy. 2014. The 2014 Eastern Bering Sea Continental Shelf Bottom Trawl Survey: Results for Commercial Crab Species. NOAA Technical Memorandum NMFS-AFSC-282 172 p.

Daly, B., C. Armistead and R. Foy. in prep. The 2015 Eastern Bering Sea Continental Shelf Bottom Trawl Survey: Results for Commercial Crab Species. NOAA Technical Memorandum NMFS-AFSC-XX 172 p.

Donaldson, W .E. and D. M. Hicks. 1977. Technical report to industry on the Kodiak crab population surveys. Results, life history, information, and history of the fishery for Tanner crab. Alaska Dept. Fish and Game, Kodiak Tanner crab research. 46 p.

Donaldson, W. E., and A. A. Adams. 1989. Ethogram of behavior with emphasis on mating for the Tanner crab *Chionoecetes bairdi* Rathbun. Journal of Crustacean Biology. 9:37-53.

Donaldson, W. E., R. T. Cooney, and J. R. Hilsinger. 1981. Growth, age, and size at maturity of Tanner crab *Chionoecetes bairdi* M. J. Rathbun, in the northern Gulf of Alaska. Crustaceana. 40:286-302.

Haynes, E., J. F. Karinen, J. Watson, and D. J. Hopson. 1976. Relation of number of eggs and egg length to carapace width in the brachyuran crabs *Chionoecetes baridi* and *C. opilio* from the southeastern Bering Sea and *C. opilio* from the Gulf of St. Lawrence. J. Fish. Res. Board Can. 33:2592-2595.

Hilsinger, J. R. 1976. Aspects of the reproductive biology of female snow crabs, *Chionoecetes bairdi*, from Prince William Sound and the adjacent Gulf of Alaska. Marine Science Communications. 2:201-225.

Hoenig, J. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82: 898-903.

Hosie, M. J. and T. F. Gaumer. 1974. Southern range extension of the Baird crab *(Chionoecetes bairdi* Rathbun). Calif. Fish and Game. 60:44-47.

Karinen, J. F. and D. T. Hoopes. 1971. Occurrence of Tanner crabs (*Chionoecetes* sp.) in the eastern Bering Sea with characteristics intermediate between *C. bairdi* and *C. opilio*. Proc. Natl. Shellfish Assoc. 61:8-9.

Kon, T. 1996. Overview of Tanner crab fisheries around the Japanese Archipelago, p. 13-24. *In* High Latitude Crabs: Biology, Management and Economics. Alaska Sea Grant Report, AK-SG-96-02, Universityof Alaska Fairbanks.

Martel, S and D. Stram. 2011. Report on the North Pacific Fishery Management Council's Crab Modeling Workshop, 16-18 February 2011, Alaska Fisheries Science Center, Seattle WA.

McLaughlin, P. A. and 39 coauthors. 2005. Common and scientific names of aquatic invertebrates from the United States and Canada: crustaceans. American Fisheries Society Special Publication 31. 545 p.

Munk, J. E., S. A. Payne, and B. G. Stevens. 1996. Timing and duration of the mating and molting season for shallow water Tanner crab (*Chionoecetes bairdi*), p. 341 (abstract only). *In* High Latitude Crabs: Biology, Management and Economics. Alaska Sea Grant Report, AK-SG-96-02, University of Alaska Fairbanks.

Nevisi, A., J. M. Orensanz, A. J. Paul, and D. A. Armstrong. 1996. Radiometric estimation of shell age in *Chionoecetes* spp. from the eastern Bering Sea, and its use to interpret shell condition indices: preliminary results, p. 389-396. *In* High Latitude Crabs: Biology, Management and Economics. Alaska Sea Grant Report, AK-SG-96-02, University of Alaska Fairbanks.

NMFS. 2004. Final Environmental Impact Statement for Bering Sea and Aleutian Islands Crab Fisheries. National Marine Fisheries Service, P.O. Box 21668, Juneau, AK 99802-1668.

NPFMC. 2011. Fishery Management Plan for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands. North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite, 306, Anchorage, AK 99501.

NPFMC. 2007. Initial Review Draft Environmental Assessment, Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner crabs to Revise Overfishing Definitions. North Pacific Fishery Management Council, 605 W. 4th Avenue, 306, Anchorage, AK 99501.

Otto, R. S. 1998. Assessment of the eastern Bering Sea snow crab, *Chionoecetes opilio,* stock under the terminal molting hypothesis, p. 109-124. *In* G. S. Jamieson and A. Campbell, (editors), Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Canadian Special Publication of Fisheries and Aquatic Sciences.

Paul, A. J. 1982. Mating frequency and sperm storage as factors affecting egg production in multiparous *Chionoecetes bairdi,* p. 273-281. *In* B. Melteff (editor), Proceedings of the International Symposium on the Genus *Chionoecetes:* Lowell Wakefield Symposium Series, Alaska Sea Grant Report, 82-10. University of Alaska Fairbanks.

Paul, A. J. 1984. Mating frequency and viability of stored sperm in the Tanner crab *Chionoecetes bairdi* (DECAPODA, MAJIDAE). Journal of Crustacean Biology. 4:375-381.

Paul, A. J. and J. M. Paul. 1992. Second clutch viability of *Chionoecetes bairdi* Rathbun (DECAPODA: MAJIDAE) inseminated only at the maturity molt. Journal of Crustacean Biology. 12:438-441.

Paul, A. J. and J. M. Paul. 1996. Observations on mating of multiparous *Chionoecetes bairdi* Rathbun (DECAPODA: MAJIDAE) held with different sizes of males and one-clawed males. Journal of Crustacean Biology. 16:295-299.

Rathbun, M. J. 1924. New species and subspecies of spider crabs. Proceedings of U.S. Nat. Museum. 64:1-5.

Rodionov, S., and J. E. Overland. 2005. Application of a sequential regime shift detection method to the Bering Sea ecosystem. ICES Journal of Marine Science, 62: 328-332.

Rugolo L,J. and B.J. Turnock. 2010. 2010 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. Draft Report to the North Pacific Fishery Management Council, Crab Plan Team. 61 p.

Rugolo, L.J. and B.J. Turnock. 2011a. Length-Based Stock Assessment Model of eastern Bering Sea Tanner Crab. Report to Subgroup of NPFMC Crab Plan Team. 61p.

Rugolo L,J. and B.J. Turnock. 2011b. 2011 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. Draft Report to the North Pacific Fishery Management Council, Crab Plan Team. 70 p.

Rugolo, L.J. and B.J. Turnock. 2012a. Length-Based Stock Assessment Model of eastern Bering Sea Tanner Crab. Report to Subgroup of NPFMC Crab Plan Team. 69p.

Rugolo L,J. and B.J. Turnock. 2012b. 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.

Slizkin, A. G. 1990. Tanner crabs *(Chionoecetes opilio, C. bairdi*) of the northwest Pacific: distribution, biological peculiarities, and population structure, p. 27-33. *In* Proceedings of the International Symposium on King and Tanner Crabs. Lowell Wakefield Fisheries Symposium Series, Alaska Sea Grant College Program Report 90-04. University of Alaska Fairbanks.

Somerton, D. A. 1980. A computer technique for estimating the size of sexual maturity in crabs. Can. J. Fish. Aquat. Sci. 37:1488-1494.

Somerton, D. A. 1981a. Life history and population dynamics of two species of Tanner crab, *Chionoecetes bairdi* and *C. opilio*, in the eastern Bering Sea with implications for the management of the commercial harvest, PhD Thesis, University of Washington, 220 p.

Somerton, D. A. 1981b. Regional variation in the size at maturity of two species of Tanner Crab (*Chionoecetes bairdi* and *C. opilio*) in the eastern Bering Sea, and its use in defining management subareas. Canadian Journal of Fisheries and Aquatic Science. 38:163-174.

Somerton, D. A. and W. S. Meyers. 1983. Fecundity differences between primiparous and multiparous female Alaskan Tanner crab (*Chionoecetes bairdi*). Journal of Crustacean Biology. 3:183-186.

Somerton, D. A. and R. S. Otto. 1999. Net efficiency of a survey trawl for snow crab, *Chionoecetes opilio*, and Tanner crab, *C. bairdi*. Fish. Bull. 97:617-625.

Stevens, B. G. 2000. Moonlight madness and larval launch pads: tidal synchronization of Mound Formation and hatching by Tanner crab, *Chionoecetes bairdi*. Journal of Shellfish Research. 19:640-641.

Stockhausen, W., L. Rugolo and B. Turnock. 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 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 342-478.

Stockhausen, W. 2014. 2014 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: 2014 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 324-545.

Stockhausen, W. 2015. 2015 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: 2015 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK.

Stone, R.P., M.M. Masuda and J.Clark. 2003. Growth of male Tanner crabs, *Chionoecetes bairdi*, in a Southeast Alaska Estuary. Draft document to Alaska Department of Fish and Game Headquarters. 36p.

Tamone, S. L., S. J. Taggart, A. G. Andrews, J. Mondragon, and J. K. Nielsen. 2007. The relationship between circulating ecdysteroids and chela allometry in male Tanner crabs: Evidence for a terminal molt in the genus *Chionoecetes*. J. Crust. Biol. 27:635-642.

Thompson, G. and R Lauth. 2012. Chapter 2: Assessment of the Pacific cod stock in the eastern Bering Sea and Aleutian Islands Area. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, North Pacific Fishery Management Council, Anchorage, 245-544 p.

Turnock, B. and L. Rugolo. 2011. Stock assessment of eastern Bering Sea snow crab (*Chionoecetes opilio*). Report to the North Pacific Fishery Management Council, Crab Plan Team. 146 p.

Williams, A. B., L. G. Abele, D. L. Felder, H. H. Hobbs, Jr., R. B. Manning, P. A. McLaughlin, and I. Perez Farfante. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. American Fisheries Society Special Publication 17. 77 p.

Zheng, J. and G.H. Kruse, 1999. Evaluation of harvest strategies for Tanner crab stocks that exhibit periodic recruitment. J. Shellfish Res., 18(2):667-679.

Zheng, J. and M.S.M. Siddeek. 2012. Bristol Bay Red King Crab Stock Assessment In Fall 2012. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2012 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 161-266.

Tables

Table 1. Retained catch (males) in directed Tanner crab fisheries.

Eastern Bering Sea *Chionoecetes bairdi* Retained Catch (1,000's t)				
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	1.25			1.25
2014/15	6.16			6.16
2015/16	8.91			8.91

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
2015/16	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	1,426,670	2,751,124	3.108	32	10/15-03/31
2014/15	7,442,931	13,576,105	15.105	100	10/15-03/31
2015/16	10,856,418	19,642,462	19.668	112	10/15-03/31

Table 3. Total bycatch (discards, 1000’s t) of Tanner crab in various fisheries.

Discards (1,000's t) of Tanner Crab by Fishery								Total
	Tanner Crab		Snow Crab		Red King Crab		Groundfish	Discards
Year	Male	Female	Male	Female	Male	Female	All	(1,000's t)
1973/74							17.735	17.735
1974/75							24.449	24.449
1975/76							9.408	9.408
1976/77							4.699	4.699
1977/78							2.776	2.776
1978/79							1.869	1.869
1979/80							3.397	3.397
1980/81							2.114	2.114
1981/82							1.474	1.474
1982/83							0.449	0.449
1983/84							0.671	0.671
1984/85							0.644	0.644
1985/86							0.399	0.399
1986/87							0.649	0.649
1987/88							0.640	0.640
1988/89							0.463	0.463
1989/90							0.671	0.671
1990/91							0.943	0.943
1991/92							2.545	2.545
1992/93	6.175	1.005	25.759	1.787	1.188	0.029	2.758	38.700
1993/94	3.870	1.028	14.530	1.814	2.967	0.198	1.760	26.167
1994/95	3.130	1.270	7.124	1.271	0.000	0.000	2.096	14.891
1995/96	2.762	1.760	4.797	1.759	0.000	0.000	1.524	12.603
1996/97	0.116	0.045	0.833	0.229	0.027	0.004	1.597	2.851
1997/98	0.000	0.000	1.750	0.226	0.165	0.003	1.179	3.323
1998/99	0.000	0.000	1.989	0.175	0.119	0.003	0.934	3.220
1999/00	0.000	0.000	0.695	0.145	0.076	0.004	0.630	1.551
2000/01	0.000	0.000	0.146	0.022	0.067	0.002	0.739	0.976
2001/02	0.000	0.000	0.323	0.011	0.043	0.002	1.184	1.563
2002/03	0.000	0.000	0.557	0.037	0.062	0.003	0.721	1.379
2003/04	0.000	0.000	0.193	0.026	0.056	0.003	0.422	0.700
2004/05	0.000	0.000	0.078	0.014	0.048	0.003	0.676	0.819
2005/06	0.462	0.044	0.968	0.043	0.042	0.002	0.621	2.182
2006/07	1.370	0.355	1.462	0.169	0.026	0.003	0.717	4.102
2007/08	2.041	0.097	1.872	0.102	0.056	0.009	0.694	4.871
2008/09	0.431	0.014	1.119	0.050	0.269	0.004	0.531	2.417
2009/10	0.071	0.002	1.324	0.014	0.150	0.001	0.374	1.937
2010/11	0.000	0.000	1.344	0.016	0.033	0.001	0.231	1.625
2011/12	0.000	0.000	2.119	0.014	0.017	0.000	0.203	2.352
2012/13	0.000	0.000	1.187	0.009	0.042	0.001	0.153	1.392
2013/14	0.387	0.023	1.832	0.015	0.113	0.001	0.348	2.720
2014/15	2.515	0.039	5.383	0.050	0.296	0.001	0.423	8.706
2015/16	3.045	0.059	3.519	0.017	0.174	0.006	0.352	7.172

Table 4. Bycatch (discard) mortality (1000's t) of Tanner crab in various fisheries. Discard mortality was calculated assuming mortality rates of 0.321 in the crab fisheries and 0.80 in the groundfish fisheries.

Discard Mortality (1,000's t) of Tanner Crab by Fishery								Total Discard
	Tanner Crab		Snow Crab		Red King Crab		Groundfish	Mortality
Year	Male	Female	Male	Female	Male	Female	All	(1,000's t)
1973/74							14.188	14.188
1974/75							19.559	19.559
1975/76							7.526	7.526
1976/77							3.759	3.759
1977/78							2.221	2.221
1978/79							1.495	1.495
1979/80							2.718	2.718
1980/81							1.691	1.691
1981/82							1.179	1.179
1982/83							0.359	0.359
1983/84							0.537	0.537
1984/85							0.515	0.515
1985/86							0.319	0.319
1986/87							0.519	0.519
1987/88							0.512	0.512
1988/89							0.370	0.370
1989/90							0.537	0.537
1990/91							0.755	0.755
1991/92							2.036	2.036
1992/93	1.982	0.322	8.269	0.574	0.381	0.009	2.206	13.744
1993/94	1.242	0.330	4.664	0.582	0.952	0.063	1.408	9.243
1994/95	1.005	0.408	2.287	0.408	0.000	0.000	1.676	5.784
1995/96	0.887	0.565	1.540	0.565	0.000	0.000	1.219	4.776
1996/97	0.037	0.014	0.267	0.074	0.009	0.001	1.277	1.680
1997/98	0.000	0.000	0.562	0.073	0.053	0.001	0.943	1.632
1998/99	0.000	0.000	0.638	0.056	0.038	0.001	0.748	1.481
1999/00	0.000	0.000	0.223	0.047	0.025	0.001	0.504	0.800
2000/01	0.000	0.000	0.047	0.007	0.021	0.001	0.591	0.667
2001/02	0.000	0.000	0.104	0.004	0.014	0.001	0.947	1.069
2002/03	0.000	0.000	0.179	0.012	0.020	0.001	0.577	0.788
2003/04	0.000	0.000	0.062	0.008	0.018	0.001	0.337	0.427
2004/05	0.000	0.000	0.025	0.004	0.015	0.001	0.541	0.587
2005/06	0.148	0.014	0.311	0.014	0.014	0.001	0.497	0.998
2006/07	0.440	0.114	0.469	0.054	0.008	0.001	0.573	1.660
2007/08	0.655	0.031	0.601	0.033	0.018	0.003	0.555	1.896
2008/09	0.138	0.004	0.359	0.016	0.086	0.001	0.425	1.030
2009/10	0.023	0.001	0.425	0.005	0.048	0.000	0.299	0.801
2010/11	0.000	0.000	0.431	0.005	0.011	0.000	0.185	0.632
2011/12	0.000	0.000	0.680	0.004	0.006	0.000	0.162	0.852
2012/13	0.000	0.000	0.381	0.003	0.013	0.000	0.123	0.520
2013/14	0.124	0.007	0.588	0.005	0.036	0.000	0.278	1.040
2014/15	0.807	0.012	1.728	0.016	0.095	0.000	0.339	2.998
2015/16	0.977	0.019	1.130	0.005	0.056	0.002	0.282	2.471

Table 5. Sample sizes 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	97.8
1981/82	11,311	83.1
1982/83	13,519	99.3
1983/84	1,675	12.3
1984/85	2,542	18.7
1988/89	12,380	91.0
1989/90	4,123	30.3
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	200.0
1995/96	1,525	11.2
1996/97	4,430	32.6
2005/06	705	5.2
2006/07	2,940	21.6
2007/08	6,935	51.0
2008/09	3,490	25.6
2009/10	2,417	17.8
2013/14	4,760	35.0
2014/15	14,055	103.3
2015/16	24,420	200.0

Table 6. Sample sizes 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	42.6	15.3
1995/96	5,589	3,119	41.1	22.4
1996/97	352	168	2.6	1.2
2005/06	19,715	1,107	144.9	7.9
2006/07	24,226	4,432	178.0	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	127.0	1.1
2013/14	17,287	710	127.0	5.2
2014/15	85,114	1,191	200.0	8.8
2015/16	119,846	1,622	200.0	11.9

Table 7. Sample sizes 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	46.1	6.3
1993/94	6,969	1,542	51.2	11.3
1994/95	2,982	1,523	21.9	11.2
1995/96	1,898	428	13.9	3.1
1996/97	3,265	662	24.0	4.9
1997/98	3,970	657	29.2	4.8
1998/99	1,911	324	14.0	2.4
1999/00	976	82	7.2	0.6
2000/01	1,237	74	9.1	0.5
2001/02	3,113	160	22.9	1.2
2002/03	982	118	7.2	0.9
2003/04	688	152	5.1	1.1
2004/05	848	707	6.2	5.2
2005/06	9,792	368	72.0	2.7
2006/07	10,391	1,256	76.4	9.2
2007/08	13,797	728	101.4	5.3
2008/09	8,455	722	62.1	5.3
2009/10	11,057	474	81.2	3.5
2010/11	12,073	250	88.7	1.8
2011/12	9,453	189	69.5	1.4
2012/13	7,336	190	53.9	1.4
2013/14	12,932	356	95.0	2.6
2014/15	24,877	804	182.8	5.9
2015/16	19,838	230	145.8	1.7

Table 8. Sample sizes 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	15.1	0.8
1993/94	7,359	1,196	54.1	8.8
1996/97	114	5	0.8	0.0
1997/98	1,030	41	7.6	0.3
1998/99	457	20	3.4	0.1
1999/00	207	14	1.5	0.1
2000/01	845	44	6.2	0.3
2001/02	456	39	3.4	0.3
2002/03	750	50	5.5	0.4
2003/04	555	46	4.1	0.3
2004/05	487	44	3.6	0.3
2005/06	983	70	7.2	0.5
2006/07	798	76	5.9	0.6
2007/08	1,399	91	10.3	0.7
2008/09	3,797	121	27.9	0.9
2009/10	3,395	72	24.9	0.5
2010/11	595	30	4.4	0.2
2011/12	344	4	2.5	0.0
2012/13	618	48	4.5	0.4
2013/14	2,110	60	15.5	0.4
2014/15	3,110	32	22.9	0.2
2015/16	2,176	182	22.9	0.2

Table 9. Sample sizes 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	23.2	16.7
1974/75	2,492	1,600	18.3	11.8
1975/76	1,251	839	9.2	6.2
1976/77	6,950	6,683	51.1	49.1
1977/78	10,685	8,386	78.5	61.6
1978/79	18,596	13,665	136.6	100.4
1979/80	19,060	11,349	140.1	83.4
1980/81	12,806	5,917	94.1	43.5
1981/82	6,098	4,065	44.8	29.9
1982/83	13,439	8,006	98.8	58.8
1983/84	18,363	8,305	134.9	61.0
1984/85	27,403	13,771	200.0	101.2
1985/86	23,128	12,728	170.0	93.5
1986/87	14,860	7,626	109.2	56.0
1987/88	23,508	15,857	172.7	116.5
1988/89	10,586	7,126	77.8	52.4
1989/90	59,943	41,234	200.0	200.0
1990/91	23,545	11,212	173.0	82.4
1991/92	6,817	3,479	50.1	25.6
1992/93	3,128	1,175	23.0	8.6
1993/94	1,217	358	8.9	2.6
1994/95	3,628	1,820	26.7	13.4
1995/96	3,904	2,669	28.7	19.6
1996/97	8,306	3,400	61.0	25.0
1997/98	9,949	3,900	73.1	28.7
1998/99	12,105	4,440	89.0	32.6
1999/00	11,053	4,522	81.2	33.2
2000/01	12,895	3,087	94.8	22.7
2001/02	15,788	3,083	116.0	22.7
2002/03	15,401	3,249	113.2	23.9
2003/04	9,572	2,733	70.3	20.1
2004/05	13,844	4,460	101.7	32.8
2005/06	17,785	3,709	130.7	27.3
2006/07	15,903	3,047	116.9	22.4
2007/08	16,031	3,788	117.8	27.8
2008/09	25,976	4,164	190.9	30.6
2009/10	18,852	2,650	138.5	19.5
2010/11	15,044	2,247	110.5	16.5
2011/12	16,115	4,237	118.4	31.1
2012/13	12,983	3,080	95.4	22.6
2013/14	28,781	6,064	200.0	44.6
2014/15	39,119	4,212	200.0	31.0
2015/16	26,656	5,705	195.9	41.9

Table 10. Trends in mature and total Tanner crab biomass (1000’s t) in the NMFS summer bottom trawl survey.

	Mature Biomass (1000 t)			Legal males (10^6 crab)
Year	Male	Female	Total	
1974	--	--	--	--
1975	252.38	28.28	280.66	278.67
1976	127.66	27.02	154.67	144.48
1977	110.46	31.51	141.97	119.76
1978	75.30	20.43	95.73	83.39
1979	31.30	11.93	43.22	38.51
1980	79.58	33.79	113.37	92.05
1981	45.50	21.74	67.24	53.33
1982	45.60	29.82	75.42	58.70
1983	26.99	13.25	40.24	36.15
1984	22.12	11.10	33.23	29.07
1985	10.64	4.40	15.04	13.07
1986	10.80	3.36	14.16	11.53
1987	19.69	7.87	27.56	24.65
1988	53.48	22.89	76.37	58.41
1989	89.26	15.96	105.22	104.71
1990	92.45	28.18	120.63	110.05
1991	101.95	31.74	133.70	125.66
1992	100.79	19.22	120.01	123.66
1993	57.99	8.21	66.20	72.61
1994	40.05	7.09	47.13	49.92
1995	29.44	8.71	38.16	39.23
1996	24.41	6.76	31.17	31.43
1997	9.36	2.38	11.74	11.55
1998	8.79	1.68	10.47	10.45
1999	8.68	2.81	11.49	9.30
2000	13.92	3.14	17.05	15.85
2001	15.37	3.29	18.66	18.53
2002	14.36	2.63	16.99	16.45
2003	19.02	4.18	23.19	22.84
2004	22.42	2.86	25.27	28.63
2005	39.47	7.21	46.67	52.70
2006	52.55	10.22	62.77	69.40
2007	56.34	9.47	65.81	71.33
2008	58.78	7.91	66.69	74.83
2009	33.92	5.64	39.55	45.56
2010	37.05	4.02	41.07	49.39
2011	37.65	4.37	42.02	47.16
2012	29.51	6.75	36.26	34.34
2013	59.58	10.93	70.51	63.99
2014	73.33	9.04	82.37	85.74
2015	58.36	6.13	64.49	76.70
2016	53.64	4.24	57.88	71.58

Table 11. Sample sizes for NMFS survey size composition data. In the assessment model, an effective sample size of 200 is used for all survey-related compositional data.

		females						males					
		immature		mature				immature		mature			
		new shell		new shell		old shell		new shell		new shell		old shell	
year	number of hauls	number of nonzero hauls	number of crab	number of nonzero hauls	number of crab	number of nonzero hauls	number of crab	number of nonzero hauls	number of crab	number of nonzero hauls	number of crab	number of nonzero hauls	number of crab
1975	136	73	1,040	91	1,861	39	706	127	2,895	127	3,993	80	399
1976	214	87	1,095	91	1,304	39	311	130	2,023	130	2,469	47	242
1977	155	66	765	76	1,183	60	738	114	1,778	114	1,971	79	485
1978	230	87	1,932	82	638	65	1,307	147	2,957	147	1,570	104	700
1979	307	71	725	62	735	42	341	138	1,805	138	808	68	306
1980	320	101	1,476	95	1,471	49	570	164	4,602	164	2,359	71	569
1981	305	71	579	79	1,319	94	1,206	158	3,809	158	2,293	116	886
1982	342	85	814	72	457	103	2,384	181	1,751	181	1,371	147	2,082
1983	353	102	2,108	56	201	102	2,154	166	2,484	166	983	132	1,181
1984	355	135	1,867	53	284	94	1,531	171	1,965	171	490	126	1,399
1985	353	140	846	52	228	65	601	179	1,060	179	381	86	459
1986	353	162	1,581	64	191	68	331	213	2,141	213	528	115	468
1987	355	189	4,230	105	445	73	392	226	4,659	226	1,306	103	498
1988	370	206	3,733	149	1,753	100	530	252	5,627	252	2,210	101	475
1989	373	204	3,264	144	1,241	108	882	237	4,977	237	3,201	135	1,067
1990	370	197	3,105	155	1,502	126	1,511	247	5,107	247	3,149	151	1,342
1991	371	159	2,227	138	1,283	141	2,568	227	4,361	227	2,692	181	2,893
1992	355	107	1,494	119	820	123	2,205	215	2,958	215	2,047	177	1,924
1993	374	99	865	96	545	122	1,337	207	2,051	207	1,677	180	1,865
1994	374	97	909	52	148	104	1,293	175	1,281	175	724	174	1,827
1995	375	113	830	35	140	107	1,057	153	958	153	220	137	1,611
1996	374	114	869	57	109	98	963	148	1,069	148	222	134	1,414
1997	375	116	1,325	62	168	83	504	161	1,336	161	289	125	582
1998	374	146	1,704	53	160	73	344	176	2,032	176	396	128	624
1999	372	137	2,608	52	255	85	510	170	2,816	170	550	124	567
2000	371	142	2,249	61	242	55	345	188	2,836	188	628	133	653
2001	374	164	3,675	83	364	72	644	211	4,036	211	629	145	817
2002	374	154	3,583	81	350	70	500	186	3,912	186	458	154	1,089
2003	375	153	2,830	111	923	83	752	203	4,754	203	900	153	1,349
2004	374	173	3,563	90	427	80	656	236	4,568	236	1,027	179	1,873
2005	372	201	3,349	103	634	74	928	254	4,496	254	1,280	185	1,753
2006	375	210	4,355	143	1,332	125	1,327	254	6,224	254	1,757	211	4,054
2007	375	185	2,420	138	1,311	136	1,396	261	4,697	261	1,982	201	2,907
2008	374	153	1,747	104	580	120	1,783	240	3,127	240	2,116	196	2,146
2009	375	171	2,408	75	363	115	1,317	216	2,879	216	1,144	187	1,954
2010	375	186	3,171	67	245	104	941	223	3,654	223	1,268	166	1,702
2011	375	193	5,044	90	471	102	705	210	6,095	210	1,115	167	1,941
2012	375	195	3,577	100	942	97	720	215	5,526	215	1,564	139	1,296
2013	375	163	2,900	116	1,417	101	1,002	207	5,592	207	2,675	137	1,344
2014	375	165	2,207	98	482	121	1,584	222	4,746	222	3,286	167	2,829
2015	375	118	1,455	60	445	94	1,363	225	2,737	225	1,859	200	2,817
2016	375	110	1,372	56	370	82	1,248	222	2,235	222	1,170	218	3,668

Table 12. Effort data (1000’s potlifts) in the snow crab and BBRKC fisheries.

	Effort (1000's Potlifts)	
Year	BBRKC Fishery	Snow Crab Fishery
1951/52		
1952/53		
1953/54	30.083	--
1954/55	17.122	--
1955/56	28.045	--
1956/57	41.629	--
1957/58	23.659	--
1958/59	27.932	--
1959/60	22.187	--
1960/61	26.347	--
1961/62	72.646	--
1962/63	123.643	--
1963/64	181.799	--
1964/65	180.809	--
1965/66	127.973	--
1966/67	129.306	--
1967/68	135.283	--
1968/69	184.666	--
1969/70	175.374	--
1970/71	168.059	--
1971/72	126.305	--
1972/73	208.469	--
1973/74	194.095	--
1974/75	212.915	--
1975/76	205.096	--
1976/77	321.01	--
1977/78	451.273	--
1978/79	406.165	190.746
1979/80	315.226	255.102
1980/81	567.292	435.742
1981/82	536.646	469.091
1982/83	140.492	287.127
1983/84	0	173.591
1984/85	107.406	370.082
1985/86	84.443	542.346
1986/87	175.753	616.113
1987/88	220.971	747.395
1988/89	146.179	665.242
1989/90	205.528	912.718
1990/91	262.761	1382.908
1991/92	227.555	1278.502
1992/93	206.815	969.209
1993/94	254.389	716.524
1994/95	0.697	507.603
1995/96	0.547	520.685
1996/97	77.081	754.14
1997/98	91.085	930.794
1998/99	145.689	945.533
1999/00	151.212	182.634
2000/01	104.056	191.2
2001/02	66.947	326.977
2002/03	72.514	153.862
2003/04	134.515	123.709
2004/05	97.621	75.095
2005/06	116.32	117.375
2006/07	72.404	86.288
2007/08	113.948	140.857
2008/09	139.937	163.537
2009/10	118.521	136.477
2010/11	131.627	147.244
2011/12	45.166	270.602
2012/13	38.159	225.489
2013/14	45.927	225.245
2014/15	57.725	279.183
2015/16	48.665	201.65

Table 13. Effective sample sizes used for NMFS EBS trawl survey size composition data for the 2015 assessment model (2015AMO) and the author’s preferred model (Model C). Effective sample sizes were estimated using the McAllister-Ianelli approach.

year	2015AMO		Model C	
	input	effective	input	effective
1975	200	104	200	106
1976	200	167	200	175
1977	200	138	200	149
1978	200	175	200	167
1979	200	244	200	236
1980	200	132	200	142
1981	200	102	200	101
1982	200	30	200	26
1983	200	266	200	231
1984	200	134	200	162
1985	200	46	200	90
1986	200	106	200	175
1987	200	84	200	89
1988	200	214	200	220
1989	200	234	200	279
1990	200	518	200	548
1991	200	422	200	437
1992	200	491	200	629
1993	200	187	200	252
1994	200	161	200	208
1995	200	554	200	404
1996	200	521	200	448
1997	200	184	200	217
1998	200	212	200	251
1999	200	149	200	156
2000	200	247	200	251
2001	200	305	200	283
2002	200	179	200	169
2003	200	421	200	403
2004	200	269	200	304
2005	200	377	200	411
2006	200	278	200	300
2007	200	222	200	245
2008	200	346	200	406
2009	200	171	200	149
2010	200	279	200	224
2011	200	345	200	330
2012	200	279	200	280
2013	200	484	200	529
2014	200	296	200	300
2015	200	440	200	543
2016			200	268

Table 14. Effective sample sizes used for retained catch size composition data from the directed fishery for the 2015 assessment model (2015AMO) and the author's preferred model (Model C). Effective sample sizes were estimated using the McAllister-Ianelli approach.

year	2015AMO		Model C	
	input	effective	input	effective
1980	97.8	22.8	97.8	20.2
1981	83.1	548.4	83.1	805.1
1982	99.3	1143.2	99.3	1622.3
1983	12.3	43.4	12.3	50.3
1984	18.7	560.6	18.7	342.1
1988	91.0	111.7	91.0	141.1
1989	30.3	1078.7	30.3	1042.2
1990	200.0	415.6	200.0	263.6
1991	200.0	47.1	200.0	20.7
1992	200.0	37.8	200.0	17.8
1993	200.0	48.2	200.0	23.2
1994	200.0	82.9	200.0	47.8
1995	11.2	32.4	11.2	15.5
1996	32.6	16.1	32.6	12.6
2005	5.2	7.3	5.2	6.6
2006	21.6	18.6	21.6	15.0
2007	51.0	21.5	51.0	17.0
2008	25.6	38.8	25.6	19.3
2009	17.8	158.4	17.8	70.6
2013	35.0	50.7	35.0	141.1
2014	103.3	19.5	103.3	34.5
2015			200.0	39.3

Table 15. Effective sample sizes used for total catch size composition data from the directed fishery for the 2015 assessment model (2015AMO) and the author's preferred model (Model C). Effective sample sizes were estimated using the McAllister-Ianelli approach.

year	2015AMO				Model C			
	female		male		female		male	
	input	effective	input	effective	input	effective	input	effective
1991	41.2	218.3	200.0	11.4	41.2	322.9	200.0	12.0
1992	64.3	264.9	200.0	11.2	64.3	940.8	200.0	13.3
1993	76.9	904.9	200.0	12.3	76.9	296.2	200.0	12.9
1994	15.7	73.3	42.6	12.1	15.7	78.7	42.6	10.9
1995	22.9	71.5	41.1	60.8	22.9	152.1	41.1	80.8
1996	2.5	111.7	5.0	29.4	2.5	149.0	5.0	37.2
2005	8.1	18.6	144.9	8.0	8.1	34.3	144.9	7.8
2006	32.6	101.0	178.0	92.9	32.6	279.0	178.0	65.0
2007	24.4	61.2	200.0	13.2	24.4	310.7	200.0	10.2
2008	4.7	19.9	200.0	13.4	4.7	41.7	200.0	13.8
2009	1.1	51.7	127.0	11.0	1.1	28.2	127.0	10.9
2013	5.2	94.8	127.0	16.8	5.2	82.1	127.0	15.7
2014	8.8	121.1	200.0	8.8	8.8	208.1	200.0	7.6
2015					11.9	69.6	200.0	6.1

Table 16. Effective sample sizes used for bycatch size composition data from the snow crab fishery for the 2015 assessment model (2015AMO) and the author’s preferred model (Model C). Effective sample sizes were estimated using the McAllister-Ianelli approach.

	2015AMO				**Model C**			
year	**female**		**male**		**female**		**male**	
	input	**effective**	**input**	**effective**	**input**	**effective**	**input**	**effective**
1992	6.3	25.7	46.1	229.2	6.3	16.5	46.1	185.3
1993	11.3	32.5	51.2	168.9	11.3	27.4	51.2	170.8
1994	11.2	26.4	21.9	49.6	11.2	49.6	21.9	42.6
1995	3.1	29.9	13.9	128.7	3.1	38.1	13.9	122.2
1996	4.9	54.7	24.0	236.8	4.9	36.2	24.0	290.7
1997	4.8	178.6	29.2	347.3	4.8	134.6	29.2	345.9
1998	2.4	21.9	14.0	475.7	2.4	19.5	14.0	617.1
1999	0.6	30.2	7.2	118.9	0.6	27.6	7.2	134.1
2000	0.5	31.7	9.1	205.0	0.5	29.9	9.1	224.8
2001	1.2	147.4	22.9	1089.6	1.2	139.0	22.9	1123.1
2002	0.9	51.3	7.2	66.0	0.9	45.2	7.2	61.9
2003	1.1	47.6	5.1	112.1	1.1	43.8	5.1	102.8
2004	5.2	34.0	6.2	25.9	5.2	30.1	6.2	24.5
2005	2.7	167.9	72.0	145.8	2.7	95.1	72.0	127.4
2006	9.2	57.9	76.4	94.4	9.2	33.6	76.4	86.8
2007	5.3	49.7	101.4	645.0	5.3	28.8	101.4	455.6
2008	5.3	13.7	62.1	99.6	5.3	18.4	62.1	92.9
2009	3.5	19.4	81.2	404.4	3.5	31.0	81.2	430.0
2010	1.8	72.9	88.7	260.6	1.8	87.0	88.7	339.6
2011	1.4	58.2	69.5	156.6	1.4	53.7	69.5	186.9
2012	1.4	45.3	53.9	120.5	1.4	49.1	53.9	139.7
2013	2.6	274.0	95.0	192.8	2.6	128.8	95.0	222.5
2014	5.9	52.3	182.8	477.6	5.9	118.9	182.8	525.0
2015					1.7	61.8	145.8	475.2

Table 17. Effective sample sizes used for bycatch size composition data from the BBRKC fishery for the 2015 assessment model (2015AMO) and the author's preferred model (Model C). Effective sample sizes were estimated using the McAllister-Ianelli approach.

year	2015AMO				Model C			
	female		male		female		male	
	input	effective	input	effective	input	effective	input	effective
1992	0.8	37.7	15.1	181.6	0.8	47.2	15.1	154.7
1993	8.8	123.4	54.1	405.8	8.8	326.2	54.1	432.7
1996	0.0	4.0	0.8	66.0	0.0	3.8	0.8	60.8
1997	0.3	16.3	7.6	26.5	0.3	17.3	7.6	24.7
1998	0.1	18.4	3.4	70.2	0.1	19.3	3.4	67.2
1999	0.1	16.1	1.5	64.1	0.1	16.6	1.5	63.0
2000	0.3	38.9	6.2	212.0	0.3	37.0	6.2	190.0
2001	0.3	53.2	3.4	139.3	0.3	46.9	3.4	131.0
2002	0.4	36.0	5.5	130.5	0.4	45.9	5.5	110.4
2003	0.3	53.1	4.1	88.2	0.3	49.0	4.1	76.5
2004	0.3	20.1	3.6	49.9	0.3	22.2	3.6	41.5
2005	0.5	7.3	7.2	36.9	0.5	8.2	7.2	38.4
2006	0.6	17.7	5.9	19.3	0.6	19.7	5.9	20.1
2007	0.7	53.7	10.3	68.7	0.7	64.9	10.3	79.0
2008	0.9	48.7	27.9	100.2	0.9	55.9	27.9	79.8
2009	0.5	110.7	24.9	23.7	0.5	119.6	24.9	21.6
2010	0.2	28.9	4.4	48.9	0.2	29.0	4.4	49.8
2011	0.0	6.7	2.5	62.2	0.0	6.4	2.5	63.8
2012	0.4	9.9	4.5	61.4	0.4	9.3	4.5	65.1
2013	0.4	16.0	15.5	84.2	0.4	14.3	15.5	83.7
2014	0.2	22.1	22.9	126.3	0.2	23.2	22.9	139.6
2015					0.2	66.4	22.9	163.2

Table 18. Effective sample sizes used for bycatch size composition data from the groundfish fisheries for the 2015 assessment model (2015AMO) and the author's preferred model (Model C). Effective sample sizes were estimated using the McAllister-Ianelli approach.

	2015AMO		Model C	
year	input	effective	input	effective
1973	39.9	95.5	39.9	284.9
1974	30.1	172.4	30.1	396.0
1975	15.4	119.2	15.4	250.0
1976	100.2	63.9	100.2	133.6
1977	140.1	96.6	140.1	229.7
1978	237.1	100.5	237.1	208.7
1979	223.5	143.2	223.5	567.2
1980	137.6	249.3	137.6	621.7
1981	74.7	112.1	74.7	135.8
1982	157.6	102.0	157.6	128.5
1983	196.0	199.3	196.0	219.3
1984	301.2	202.2	301.2	311.2
1985	263.5	117.1	263.5	224.6
1986	165.2	105.1	165.2	224.0
1987	289.3	158.0	289.3	437.4
1988	130.2	171.4	130.2	295.9
1989	400.0	272.5	400.0	910.5
1990	255.4	413.1	255.4	625.1
1991	75.7	364.3	75.7	629.3
1992	31.6	148.3	31.6	113.2
1993	11.6	75.4	11.6	54.7
1994	40.0	82.0	40.0	69.9
1995	48.3	51.8	48.3	60.4
1996	86.0	399.0	86.0	288.0
1997	101.8	44.8	101.8	74.1
1998	121.6	95.5	121.6	246.1
1999	114.4	115.0	114.4	599.4
2000	117.4	179.0	117.4	392.0
2001	138.7	174.8	138.7	230.4
2002	137.0	88.0	137.0	122.2
2003	90.4	155.0	90.4	505.7
2004	134.5	140.6	134.5	369.3
2005	157.9	395.8	157.9	1101.6
2006	139.2	172.7	139.2	212.4
2007	145.6	223.1	145.6	596.1
2008	221.5	350.2	221.5	437.0
2009	156.9	143.0	158.0	400.9
2010	127.5	230.0	127.1	965.0
2011	150.1	79.2	149.6	60.9
2012	118.6	75.4	118.0	192.3
2013	244.7	101.0	244.6	373.6
2014	230.1	151.2	231.0	2083.9
2015			237.8	291.7

Table 19. Objective function components and associated applied weighting factors for the 2015 assessment model and the author's preferred model (Model C). TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: BBRKC fishery; GTF: groundfish fisheries.

category	description	weight	2015AMO	Model C
likelihood: catch biomass	fishery: GTF total catch biomass	10.0	2.52	2.43
likelihood: catch biomass	fishery: RKF total catch biomass	10.0	9.59	12.81
likelihood: catch biomass	fishery: SCF total catch biomass	10.0	10.52	6.21
likelihood: catch biomass	fishery: TCF female catch biomass	10.0	6.64	5.11
likelihood: catch biomass	fishery: TCF male total catch biomass	10.0	18.21	11.54
likelihood: catch biomass	fishery: TCF retained males	10.0	31.87	18.47
likelihood: catch biomass	survey: mature crab	1.0	311.35	199.10
likelihood: size comps	fishery: GTF males+females	1.0	135.17	463.33
likelihood: size comps	fishery: RKC females	1.0	2.68	2.25
likelihood: size comps	fishery: RKC males	1.0	24.21	26.69
likelihood: size comps	fishery: SCF females	1.0	13.95	12.49
likelihood: size comps	fishery: SCF males	1.0	49.26	52.63
likelihood: size comps	fishery: TCF discarded females	1.0	14.32	9.70
likelihood: size comps	fishery: TCF retained males	1.0	194.52	308.98
likelihood: size comps	fishery: TCF total males	1.0	115.60	184.30
likelihood: size comps	survey: immature females	1.0	307.31	281.23
likelihood: size comps	survey: immature males	1.0	280.47	269.49
likelihood: size comps	survey: mature females	1.0	99.13	128.52
likelihood: size comps	survey: mature males	1.0	272.48	250.07
penalty	maturity curve smoothness (females)	1.0	1.41	2.33
penalty	maturity curve smoothness (males)	0.5	0.16	0.79
penalty	natural mortality penalty (immature females)	1.0	51.27	36.42
penalty	natural mortality penalty (immatures)	1.0	0.64	0.59
penalty	natural mortality penalty (mature males)	1.0	4.21	5.62
penalty	penalty on F-devs in BBRKC fishery	3.0	0.00	0.13
penalty	penalty on F-devs in directed fishery	1.0	49.39	56.77
penalty	penalty on F-devs in groundfish fishery	0.5	11.69	12.98
penalty	penalty on F-devs in snow crab fishery	0.5	7.70	7.47
penalty	recruitment penalty	1.0	2.30	2.44
penalty	sex ratio penalty	0.0	0.00	0.00
penalty	z50 devs for male selectivity in TCF (AR1)	0.0	0.00	0.00
penalty	z50 devs for male selectivity in TCF (norm2)	0.0	0.00	0.00
priors	female growth parameter a	1.0	0.90	0.90
priors	female growth parameter b	1.0	0.68	0.64
priors	female survey q penalty	1.0	16.35	29.11
priors	male growth parameter a	1.0	0.57	0.23
priors	male growth parameter b	1.0	0.04	0.03
priors	survey q penalty	1.0	1.97	4.97

Table 20. Comparison of parameter estimates from the 2015 assessment model and the author's preferred model (Model C).

process	description	param	index	2015AMO	Model C	
				estimate	estimate	std. dev.
growth	female mean growth a parameter	pGrAF1		0.7	0.7	6.98E-05
	female mean growth b parameter	pGrBF1		0.884217	0.885004	0.0011352
	male mean growth a parameter	pGrAM1		0.411176	0.420826	0.021848
	male mean growth b parameter	pGrBM1		0.976754	0.972702	0.0051716
	size transition beta parameter	pGrBeta_x	female	0.750005	0.750005	0
	size transition beta parameter	pGrBeta_x	male	0.750005	0.750005	0
natural mortality multipliers	multiplier for 1980-1984	pMfac_Big	female	1.4936	1.32933	0.10943
	multiplier for 1980-1984	pMfac_Big	male	3.50292	2.82341	0.33557
	multiplier for immature crab	pMfac_Imm		1.05671	1.05437	0.049567
	multiplier for mature female crab	pMfac_MatF		1.50633	1.4267	0.036859
	multiplier for mature male crab	pMfac_MatM		1.14505	1.1676	0.041043
recruitment	initial log-scale mean	pMnLnRecInit		5.58529	5.52749	0.49162
	log-scale mean	pMnLnRec		4.92158	5.00006	0.066058
	size distribution alpha parameter	pRecAlpha		11.5	11.5	0
	size distribution beta parameter	pRecBeta		4	4	0
survey selectivity	male offset to 95%-selected [-1981]	pSrv1M_dz5095		21.5698	22.1348	3.2621
	male offset to 95%-selected [1982+]	pSrv2M_dz5095		55.6208	62.917	8.2923
	male size at 50%-selected [-1981]	pSrv1M_z50		49.0101	50.2176	1.9188
	male size at 50%-selected [1982+]	pSrv2M_z50		32.4911	32.0113	3.2009
	female offset to 95%-selected [-1981]	pSrv1F_dz5095		40.8236	38.3361	6.1379
	female offset to 95%-selected [1982+]	pSrv2F_dz5095		100	100	0.0011952
	female size at 50%-selected [-1981]	pSrv1F_z50		53.6264	54.1952	2.7904
	female size at 50%-selected [1982+]	pSrv2F_z50		7.10091	-9.24299	15.073
survey Q	females [-1981]	pSrv1_QF		0.5	0.5	4.94E-05
	females [1982+]	pSrv2_QF		0.594041	0.498521	0.032247
	males [-1981]	pSrv1_QM		0.5	0.5	1.95E-05
	males [1982+]	pSrv2_QM		0.780778	0.722284	0.036416

Table 21. Comparison of molt-to-maturity parameter estimates from the 2015 assessment model (ln-scale) and the author's preferred model (Model C; logit-scale).

process	sex	index	2015AMO	Model C	
			estimate	estimate	std. dev.
molt-to-maturity	female	1	-15	-15	0.001669
		2	-13.7474	-13.7599	0.78396
		3	-12.4437	-12.4653	1.1857
		4	-11.0381	-11.0616	1.288
		5	-9.47992	-9.49471	1.1517
		6	-7.72241	-7.71458	0.86232
		7	-5.74099	-5.69543	0.52458
		8	-3.60849	-3.5189	0.24124
		9	-1.84318	-1.68486	0.11369
		10	-0.816855	-0.323703	0.092391
		11	-0.49044	0.351804	0.097912
		12	-0.364766	0.624612	0.11199
		13	-0.116204	1.56765	0.20163
		14	-1.62E-09	3.35975	0.43493
		15	-0.004397	5.29665	0.91207
		16	-7.31E-09	7.25082	1.6735
molt-to-maturity	male	1	-12.5966	-12.574	7.6581
		2	-11.3868	-11.3492	5.804
		3	-10.1769	-10.1244	4.1786
		4	-8.96725	-8.89994	2.8214
		5	-7.76337	-7.68183	1.7702
		6	-6.58653	-6.49274	1.0552
		7	-5.50199	-5.41539	0.65571
		8	-4.75364	-4.73182	0.42447
		9	-4.28405	-4.29816	0.32128
		10	-3.73777	-3.66934	0.24836
		11	-3.22015	-3.07813	0.18999
		12	-2.72516	-2.61618	0.15466
		13	-2.21933	-2.15688	0.13134
		14	-1.69388	-1.57984	0.11092
		15	-1.34277	-1.04442	0.10084
		16	-1.15377	-0.682264	0.095451
		17	-1.03171	-0.491641	0.091504
		18	-0.744137	-0.0111597	0.10251
		19	-0.457181	0.614424	0.12613
		20	-0.197996	1.46862	0.18207
		21	-0.057145	2.80554	0.32536
		22	-3.53E-09	4.83562	0.58774
		23	-1.20E-09	6.83313	1.0416
		24	-5.72E-10	8.57423	1.6365
		25	-8.69E-10	10.0308	2.258
		26	-1.11E-09	11.2281	2.7858
		27	-1.69E-09	12.201	3.1259
		28	-2.68E-09	12.9862	3.2073
		29	-6.06E-09	13.6211	2.9765
		30	-2.54E-08	14.1434	2.3927
		31	-0.02458	14.5905	1.425
		32	-0.046673	15	0.004866

Table 22. Comparison of recruitment dev parameter estimates from the 2015 assessment model and the author's preferred model (Model C).

process	description	index	2015AMO	Model C	
			estimate	estimate	std. dev.
recruitment devs	ln-scale deviations	1974	0.781402	--	--
		1975	1.00935	1.40735	0.19124
		1976	2.09407	1.99712	0.12382
		1977	1.7989	1.76148	0.13002
		1978	1.02156	1.09033	0.18136
		1979	-0.084761	0.165901	0.28812
		1980	-0.863678	-0.465899	0.37249
		1981	-0.583826	-0.0998744	0.21578
		1982	-1.25	-0.492159	0.257
		1983	0.697598	0.844003	0.10129
		1984	0.664298	0.773732	0.12865
		1985	1.59035	1.22589	0.10923
		1986	1.32829	1.14466	0.11947
		1987	1.26382	1.11144	0.12015
		1988	1.17427	1.08617	0.10976
		1989	0.206281	0.251569	0.15225
		1990	-0.659541	-0.700321	0.24908
		1991	-1.21385	-1.24123	0.28364
		1992	-1.49599	-1.51533	0.26874
		1993	-1.59883	-1.58988	0.24782
		1994	-1.4773	-1.36351	0.20511
		1995	-1.19304	-1.07756	0.17332
		1996	-1.08994	-1.0552	0.18889
		1997	-0.187066	-0.150971	0.10073
		1998	-1.09187	-1.04219	0.18016
		1999	0.0239972	0.0283579	0.10104
		2000	-0.479089	-0.491797	0.1734
		2001	0.71017	0.622348	0.091225
		2002	-0.232096	-0.34659	0.19167
		2003	0.298983	0.343703	0.12506
		2004	0.803452	0.774672	0.088924
		2005	-0.452713	-0.457059	0.19478
		2006	-0.660771	-0.716854	0.21518
		2007	-0.952789	-1.11789	0.27647
		2008	-0.81074	-0.897263	0.25379
		2009	0.949498	0.979229	0.099073
		2010	1.12564	1.19858	0.093302
		2011	0.604113	0.658634	0.12958
		2012	-0.966442	-1.09582	0.38298
		2013	-0.169695	-0.178842	0.17489
		2014	-0.101268	-0.400162	0.19932
		2015	-0.530748	-0.756357	0.26304
		2016	--	-0.212413	0.24664

Table 23. Comparison of initial recruitment dev parameter estimates from the 2015 assessment model and the author's preferred model (Model C).

process	description	index	2015AMO	Model C	
			estimate	estimate	std. dev.
initial recruitment devs	ln-scale deviations	1949	-1.49633	-1.51108	1.6339
		1950	-1.49394	-1.50848	1.4913
		1951	-1.48822	-1.50227	1.3541
		1952	-1.47783	-1.49106	1.224
		1953	-1.46091	-1.47287	1.1033
		1954	-1.43472	-1.44486	0.99453
		1955	-1.39531	-1.4029	0.9007
		1956	-1.33677	-1.34086	0.82451
		1957	-1.24998	-1.24927	0.76768
		1958	-1.12031	-1.1129	0.73004
		1959	-0.922636	-0.905456	0.70936
		1960	-0.609611	-0.576943	0.7035
		1961	-0.089749	-0.0349116	0.71159
		1962	0.696762	0.760147	0.71249
		1963	1.54121	1.54366	0.69657
		1964	1.98044	1.85947	0.66979
		1965	1.9796	1.7515	0.66744
		1966	1.75795	1.49285	0.67554
		1967	1.51683	1.29124	0.67351
		1968	1.3381	1.23276	0.6577
		1969	1.24572	1.32514	0.6379
		1970	1.19425	1.424	0.61001
		1971	1.01783	1.26129	0.56459
		1972	0.76483	0.955299	0.54235
		1973	0.542804	0.470023	0.5477
		1974	--	0.186495	0.57714

Table 24. Comparison of fishery mortality/capture rate parameter estimates from the 2015 assessment model and the author's preferred model (Model C). GTF: groundfish fisheries; RKF: BBRKC fishery; SCF: snow crab fishery; TCF: directed Tanner crab fishery.

process	description	param	2015AMO	Model C	
			estimate	estimate	std. dev.
fishery mortality/capture rates	GTF effort extrapolation	pLnEffXtr_GTF	1	1	0
	GTF ln-scale female offset	pAvgLnF_GTFF	0	-1.02364	0.066812
	GTF ln-scale mean [1973+]	pAvgLnF_GTF	-4.16128	-4.11576	0.072179
	RKF effort extrapolation	pLnEffXtr_RKF	1	1	0
	RKF ln-scale female offset	pAvgLnF_RKFF	0	2.43851	1.3139
	RKF ln-scale mean [1992+]	pAvgLnF_RKF	-5.25	-4.29718	0.92
	SCF effort extrapolation	pLnEffXtr_SCF	1	1	0
	SCF ln-scale female offset	pAvgLnF_SCFF	0	-1.48444	0.21286
	SCF ln-scale mean [1992+]	pAvgLnF_SCF	-3.71005	-2.55969	0.12387
	TCF effort extrapolation	pLnEffXtr_TCF	1	1	0
	TCF ln-scale female offset	pAvgLnF_TCFF	0	-1.6111	0.34153
	TCF ln-scale mean [1965+]	pAvgLnF_TCF	-1.49637	-1.32647	0.08658

Table 25. Comparison of fishery retention and selectivity curve parameter estimates from the 2015 assessment model and the author's preferred model (Model C). GTF: groundfish fisheries; RKF: BBRKC fishery; SCF: snow crab fishery; TCF: directed Tanner crab fishery.

type	description	param	index	2015AMO	Model C	
				estimate	estimate	std. dev.
TCF retention	size at 50%-selected [-1990]	pRetTCFM_z50A1		137.669	138.347	0.46329
	size at 50%-selected [1991+]	pRetTCFM_z50A2		133.078	133.013	0.5927
	slope [-1990]	pRetTCFM_slpA1		0.790725	0.68447	0.12092
	slope [1991+]	pRetTCFM_slpA2		0.366973	0.254571	0.018647
TCF selectivity	female size at 50%-selected [all years]	pSelTCFF_z50		117.466	94.5043	2.1571
	female slope [all years]	pSelTCFF_slp		0.140497	0.196036	0.020346
	male ln-scale devs in size at 50%-selected [1991+]	pSelTCFM_devsZ50	1991	0.0832307	0.160928	0.030713
	male ln-scale devs in size at 50%-selected [1991+]	pSelTCFM_devsZ50	1992	0.130107	0.167735	0.022307
	male ln-scale devs in size at 50%-selected [1991+]	pSelTCFM_devsZ50	1993	0.100172	0.152329	0.026045
	male ln-scale devs in size at 50%-selected [1991+]	pSelTCFM_devsZ50	1994	0.136988	0.245468	0.028421
	male ln-scale devs in size at 50%-selected [1991+]	pSelTCFM_devsZ50	1995	-0.00932885	-0.116733	0.091221
	male ln-scale devs in size at 50%-selected [1991+]	pSelTCFM_devsZ50	1996	-0.431057	-0.500471	0.013172
	male ln-scale devs in size at 50%-selected [1991+]	pSelTCFM_devsZ50	2005	-0.0562356	-0.0691252	0.024499
	male ln-scale devs in size at 50%-selected [1991+]	pSelTCFM_devsZ50	2006	-0.0640353	-0.0855568	0.023566
	male ln-scale devs in size at 50%-selected [1991+]	pSelTCFM_devsZ50	2007	-0.0943149	-0.0977496	0.02153
	male ln-scale devs in size at 50%-selected [1991+]	pSelTCFM_devsZ50	2008	0.0460822	0.0331269	0.02221
	male ln-scale devs in size at 50%-selected [1991+]	pSelTCFM_devsZ50	2009	0.219118	0.264636	0.020202
	male ln-scale devs in size at 50%-selected [1991+]	pSelTCFM_devsZ50	2013	-0.0185012	-0.0165809	0.021704
	male ln-scale devs in size at 50%-selected [1991+]	pSelTCFM_devsZ50	2014	-0.0422246	-0.047993	0.019172
	male ln-scale devs in size at 50%-selected [1991+]	pSelTCFM_devsZ50	2015	--	-0.090013	0.021611
	male ln-scale mean size at 50%-selected	pSelTCFM_mnLnZ50A2		4.83157	4.75673	0.011685
	male slope [-1996]	pSelTCFM_slpA1		0.114058	0.0898399	0.006701
	male slope [1997+]	pSelTCFM_slpA2		0.144611	0.179297	0.014102
GTF selectivity	female size at 50%-selected [-1987]	pSelGTFF_z50A1		125.01	40.0799	1.4501
	female size at 50%-selected [1988-1996]	pSelGTFF_z50A2		159.214	40	0.000155
	female size at 50%-selected [1997+]	pSelGTFF_z50A3		143.991	79.148	2.4561
	female slope [-1987]	pSelGTFF_slpA1		0.0286752	0.152178	0.02319
	female slope [1988-1996]	pSelGTFF_slpA2		0.0158887	0.183165	0.037518
	female slope [1997+]	pSelGTFF_slpA3		0.052039	0.0768591	0.005855
	male size at 50%-selected [-1987]	pSelGTFM_z50A1		57.0742	54.7273	1.8329
	male size at 50%-selected [1988-1996]	pSelGTFM_z50A2		72.6065	66.3956	4.993
	male size at 50%-selected [1997+]	pSelGTFM_z50A3		83.1856	84.6716	2.0078
	male slope [-1987]	pSelGTFM_slpA1		0.10874	0.103462	0.009792
	male slope [1988-1996]	pSelGTFM_slpA2		0.0427268	0.0483958	0.007576
	male slope [1997+]	pSelGTFM_slpA3		0.0777645	0.075398	0.003877
RKF selectivity	female size at 50%-selected [-1996]	pSelRKFF_z50A1		98.3537	97.2472	11.723
	female size at 50%-selected [1997-2004]	pSelRKFF_z50A2		103.261	97.0295	10.201
	female size at 50%-selected [2005+]	pSelRKFF_z50A3		157.074	114.727	17.968
	female slope [-1996]	pSelRKFF_slpA1		0.238438	0.210067	0.11678
	female slope [1997-2004]	pSelRKFF_slpA2		0.179464	0.203964	0.13997
	female slope [2005+]	pSelRKFF_slpA3		0.183223	0.164415	0.060323
	male size at 50%-selected [-1996]	pSelRKFM_z50A1		150	150	0.000611
	male size at 50%-selected [1997-2004]	pSelRKFM_z50A2		133.217	138.978	14.126
	male size at 50%-selected [2005+]	pSelRKFM_z50A3		150	150	0.001334
	male slope [-1996]	pSelRKFM_slpA1		0.101212	0.113097	0.011114
	male slope [1997-2004]	pSelRKFM_slpA2		0.0915078	0.0863304	0.022917
	male slope [2005+]	pSelRKFM_slpA3		0.082357	0.0851915	0.006282
SCF selectivity	female size at 50%-selected [-1996]	pSelSCFF_z50A1		110.423	67.4884	7.1383
	female size at 50%-selected [1997-2004]	pSelSCFF_z50A2		76.1912	75.3363	4.7225
	female size at 50%-selected [2005+]	pSelSCFF_z50A3		88.6981	78.9834	3.9168
	female slope [-1996]	pSelSCFF_slpA1		0.05	0.206465	0.17212
	female slope [1997-2004]	pSelSCFF_slpA2		0.254036	0.271067	0.14346
	female slope [2005+]	pSelSCFF_slpA3		0.134828	0.206033	0.068651
	male ascending size at 50%-selected [-1996]	pSelSCFM_z50A1		86.8038	87.6083	1.4676
	male ascending size at 50%-selected [1997-2004]	pSelSCFM_z50A2		93.9094	94.1945	3.3921
	male ascending size at 50%-selected [2005+]	pSelSCFM_z50A3		103.632	104.944	1.6099
	male ascending slope [-1996]	pSelSCFM_slpA1		0.404304	0.401603	0.13411
	male ascending slope [1997-2004]	pSelSCFM_slpA2		0.231803	0.226234	0.07431
	male ascending slope [2005+]	pSelSCFM_slpA3		0.178644	0.171992	0.01611
	male descending ln-scale offset to size at 50%-selected [-1996]	pSelSCFM_lnZ50D1		3.97235	3.95657	0.036866
	male descending ln-scale offset to size at 50%-selected [1997-2004]	pSelSCFM_lnZ50D2		3.80135	3.79291	0.16484
	male descending ln-scale offset to size at 50%-selected [2005+]	pSelSCFM_lnZ50D3		3.53118	3.48534	0.091741
	male descending slope [-1996]	pSelSCFM_slpD1		0.499994	0.499999	0.000334
	male descending slope [1997-2004]	pSelSCFM_slpD2		0.17705	0.154555	0.090084
	male descending slope [2005+]	pSelSCFM_slpD3		0.183485	0.176146	0.027094

Table 26. Comparison of fishery mortality/capture rate dev parameter estimates from the 2015 assessment model and the author's preferred model (Model C). TCF: directed Tanner crab fishery.

type	description	index	2015AMO	Model C	
			estimate	estimate	std. dev.
TCF mortality/capture rate devs	ln-scale devs [1965+]	1965	-0.518187	-0.512072	0.49992
		1966	-0.773462	-0.753569	0.38716
		1967	0.359217	0.431136	0.34912
		1968	0.121306	0.253429	0.32494
		1969	0.220923	0.433976	0.31293
		1970	0.0220202	0.314614	0.31273
		1971	-0.200343	0.144671	0.30767
		1972	-0.365518	-0.0134198	0.27973
		1973	-0.570184	-0.273418	0.21589
		1974	-0.323904	-0.126451	0.14351
		1975	-0.040857	0.0557562	0.10496
		1976	0.761268	0.81054	0.095966
		1977	1.49067	1.60134	0.10925
		1978	1.688	1.98097	0.15051
		1979	2.38683	2.80725	0.1968
		1980	2.44285	2.34269	0.27763
		1981	0.596186	0.304394	0.14568
		1982	-0.350215	-0.709751	0.12706
		1983	-1.2767	-1.69005	0.24792
		1984	0.0970324	-0.611706	0.182
		1987	-0.866666	-1.30304	0.21134
		1988	-0.113462	-0.47743	0.10694
		1989	0.879841	0.73493	0.083425
		1990	1.37173	1.45872	0.09428
		1991	1.28887	1.41528	0.15539
		1992	1.66753	1.63773	0.14433
		1993	0.961286	0.995718	0.13994
		1994	0.761891	0.982647	0.19767
		1995	-0.070297	-0.168372	0.13396
		1996	-1.2281	-0.959074	0.17763
		2005	-2.14795	-2.12915	0.20981
		2006	-1.65181	-1.64818	0.143
		2007	-1.68988	-1.64767	0.13607
		2008	-1.75263	-1.96315	0.15983
		2009	-1.04851	-1.32018	0.25734
		2013	-1.68639	-1.70897	0.13862
		2014	-0.442409	-0.491133	0.092358
		2015	--	-0.199011	0.09397

Table 27. Comparison of fishery mortality/capture rate dev parameter estimates from the 2015 assessment model and the author's preferred model (Model C). RKF: BBRKC fishery; SCF: snow crab fishery.

type	description	index	2015AMO	Model C	
			estimate	estimate	std. dev.
RKF mortality/capture rate devs	ln-scale devs [1992+]	1992	0	-0.141197	0.35612
		1993	0	-0.0285905	0.37414
		1994	0	-0.0710423	0.36889
		1995	0	0.0118673	0.38532
		1996	0	0.080407	0.40387
		1997	0	0.0817798	0.40921
		1998	0	0.0129244	0.39762
		1999	0	-0.00110857	0.39589
		2000	0	0.0012108	0.39612
		2001	0	-0.00950446	0.3933
		2002	0	-0.0200168	0.39105
		2003	0	-0.00521674	0.39159
		2004	0	-0.0290172	0.38766
		2005	0	0.00917559	0.39966
		2006	0	0.00985092	0.39917
		2007	0	0.0119242	0.39923
		2008	0	0.0267412	0.40101
		2009	0	0.0171997	0.39891
		2010	0	0.00829416	0.3981
		2011	0	0.00289747	0.39786
		2012	0	0.0030385	0.39824
		2013	0	0.0101265	0.39829
		2014	0	0.0251161	0.39837
		2015	--	-0.00686042	0.39308
SCF mortality/capture rate devs	ln-scale devs [1992+]	1992	1.84979	1.82084	0.11859
		1993	1.62748	1.57903	0.12573
		1994	1.2734	1.21802	0.14901
		1995	1.27571	1.20648	0.17512
		1996	0.19664	0.14783	0.45612
		1997	0.733603	0.750337	0.38909
		1998	0.494163	0.672925	0.43946
		1999	-0.381905	-0.326133	0.6841
		2000	-0.621997	-0.654371	0.66115
		2001	-0.580084	-0.618835	0.62982
		2002	-0.568142	-0.547399	0.59508
		2003	-0.811723	-0.853073	0.58876
		2004	-1.14597	-1.08342	0.5689
		2005	-0.649415	-0.609679	0.50401
		2006	-0.339788	-0.33246	0.41964
		2007	-0.20635	-0.224263	0.34989
		2008	-0.609894	-0.662066	0.42994
		2009	-0.486074	-0.521409	0.42481
		2010	-0.419701	-0.379555	0.43452
		2011	0.0130669	0.0832503	0.35008
		2012	-0.577714	-0.525958	0.46695
		2013	-0.479325	-0.494068	0.3501
		2014	0.414236	0.353441	0.17733
		2015	--	0.000536055	0.23227

Table 28. Comparison of fishery mortality/capture rate dev parameter estimates from the 2015 assessment model and the author's preferred model (Model C). GTF: groundfish fisheries.

type	description	index	2015AMO	Model C	
			estimate	estimate	std. dev.
GTF mortality/capture rate devs	ln-scale devs [1973+]	1973	0.84482	1.10031	0.10447
		1974	1.27268	1.46916	0.081611
		1975	0.460622	0.609631	0.078217
		1976	-0.028137	0.0774622	0.090286
		1977	-0.248686	-0.209844	0.11808
		1978	-0.419782	-0.440285	0.15604
		1979	0.218235	0.233132	0.11269
		1980	0.0456019	-0.0216788	0.15222
		1981	-0.07109	-0.206465	0.19247
		1982	-0.726093	-0.916129	0.39423
		1983	-0.150186	-0.413008	0.35909
		1984	0.251739	-0.20437	0.39205
		1985	-0.285296	-0.629289	0.47766
		1986	-0.367893	-0.548176	0.38022
		1987	-0.649807	-0.719865	0.37764
		1988	-1.11646	-1.10449	0.40795
		1989	-1.03265	-0.951716	0.34438
		1990	-0.716481	-0.605589	0.27986
		1991	0.392271	0.49366	0.12766
		1992	0.686347	0.783903	0.11916
		1993	0.555778	0.635226	0.16501
		1994	1.06755	1.12753	0.1428
		1995	1.11494	1.15185	0.18109
		1996	1.47253	1.48679	0.17172
		1997	1.37406	1.44223	0.23212
		1998	1.06557	1.11859	0.33244
		1999	0.531428	0.573452	0.50148
		2000	0.657746	0.648246	0.4107
		2001	1.00301	1.01488	0.25273
		2002	0.366648	0.396099	0.37669
		2003	-0.216728	-0.151861	0.48062
		2004	-0.125303	-0.00093073	0.36869
		2005	-0.353084	-0.222611	0.37665
		2006	-0.289489	-0.174462	0.33252
		2007	-0.367112	-0.280821	0.33126
		2008	-0.583965	-0.517741	0.3744
		2009	-0.769095	-0.672724	0.4316
		2010	-0.880976	-0.74587	0.48448
		2011	-0.879599	-0.7536	0.50303
		2012	-1.05669	-0.946181	0.50307
		2013	-1.01702	-0.932219	0.42678
		2014	-1.02995	-0.963513	0.3941
		2015	--	-1.02871	0.42894

Table 29. Comparison of fits to mature survey biomass by sex (in 1000's t) from the 2015 assessment model and the author's preferred model (Model C).

year	mature female biomass (Kt)			mature male biomass (Kt)		
	observed	2015AMO	Model C	observed	2015AMO	Model C
1975	31.7	46.4	47.8	246.0	155.1	148.1
1976	31.4	40.4	42.0	126.2	133.7	133.6
1977	38.8	34.5	35.8	110.6	102.2	105.5
1978	26.2	30.9	32.7	77.6	68.3	75.1
1979	19.7	32.2	34.7	32.2	59.0	67.0
1980	64.2	34.2	36.5	86.2	61.5	63.0
1981	43.1	28.2	31.5	49.4	46.4	53.8
1982	64.4	25.2	25.7	49.0	58.9	68.1
1983	20.6	17.2	19.2	28.5	37.3	49.1
1984	15.0	11.6	14.5	24.2	21.5	32.6
1985	5.6	8.5	11.7	11.4	13.0	23.0
1986	3.5	9.3	12.3	12.8	18.3	28.8
1987	5.2	12.3	14.3	24.1	31.6	40.7
1988	25.5	17.2	17.0	60.4	51.1	55.2
1989	19.5	22.2	19.8	91.9	77.0	70.2
1990	37.8	24.8	21.4	96.3	85.7	74.4
1991	45.0	24.6	21.2	109.7	74.5	64.8
1992	26.5	21.8	19.1	103.2	68.4	60.1
1993	11.7	16.9	15.3	60.1	50.4	45.1
1994	10.0	12.6	11.6	42.1	36.0	32.9
1995	12.7	9.2	8.6	31.1	25.9	23.9
1996	9.8	6.9	6.5	26.3	18.6	17.3
1997	3.5	5.3	5.1	10.7	14.6	13.9
1998	2.3	4.3	4.3	10.3	12.9	12.5
1999	3.9	3.9	4.0	12.5	12.6	12.4
2000	4.2	4.2	4.3	16.1	14.3	14.1
2001	4.6	4.5	4.7	17.9	17.6	17.4
2002	4.5	5.1	5.2	17.8	20.2	20.0
2003	8.4	6.0	6.0	23.3	24.4	23.7
2004	4.9	7.5	7.2	26.3	30.6	29.0
2005	11.6	8.8	8.3	43.1	39.6	36.3
2006	15.0	9.7	9.3	64.2	44.9	41.0
2007	13.5	10.8	10.6	66.4	49.3	45.4
2008	11.7	11.0	10.8	62.7	55.3	51.3
2009	8.6	9.6	9.6	36.3	53.9	50.7
2010	5.5	8.1	8.1	37.6	47.2	44.3
2011	5.5	7.8	7.7	41.5	41.9	38.8
2012	12.5	9.8	9.8	41.2	42.9	39.4
2013	18.0	13.2	13.5	65.7	57.4	53.4
2014	14.9	15.0	15.6	79.5	73.8	71.1
2015	11.3	13.8	14.6	60.2	72.6	72.2
2016	7.6	--	12.4	57.6	--	59.1

Table 30. Comparison of estimates of mature biomass-at-mating by sex (in 1000's t) from the 2015 assessment model and the author's preferred model (Model C).

year	MMB (1000's t)		MFB (1000's t)	
	2015AMO	Model C	2015AMO	Model C
1949	0.0	0.0	0.0	0.0
1950	0.0	0.0	0.0	0.0
1951	0.2	0.1	0.3	0.3
1952	1.4	1.2	1.1	1.1
1953	4.8	4.1	2.3	2.2
1954	8.7	7.8	3.3	3.2
1955	11.6	10.6	4.1	4.0
1956	13.8	12.7	4.6	4.5
1957	15.5	14.4	5.0	5.0
1958	16.9	15.8	5.4	5.3
1959	18.2	17.0	5.7	5.7
1960	19.4	18.2	6.2	6.2
1961	21.0	19.7	6.7	6.7
1962	23.1	21.8	7.7	7.7
1963	26.8	25.4	9.5	9.5
1964	34.2	32.5	13.9	13.9
1965	49.9	47.5	24.3	24.3
1966	90.2	84.2	45.3	43.7
1967	150.6	136.5	74.9	68.6
1968	233.5	200.1	103.0	89.0
1969	291.4	235.6	118.9	98.4
1970	317.0	244.9	121.9	98.9
1971	317.5	240.8	117.2	96.4
1972	305.4	236.2	109.7	93.9
1973	287.6	235.9	101.5	92.7
1974	257.2	229.8	92.2	89.4
1975	226.4	219.6	82.3	83.0
1976	171.8	179.3	71.1	71.8
1977	106.2	119.0	60.0	60.0
1978	70.3	81.1	53.8	55.3
1979	48.2	54.7	55.1	57.4
1980	31.2	44.9	52.1	56.0
1981	40.7	56.6	44.4	49.7
1982	37.9	54.9	33.3	40.5
1983	25.3	41.0	22.8	30.8
1984	12.8	25.7	15.2	23.1
1985	13.6	26.2	12.5	20.0
1986	19.1	32.6	13.7	20.6
1987	31.2	44.4	18.0	23.8
1988	48.3	58.5	25.3	28.5
1989	60.3	63.3	32.2	32.6
1990	55.1	54.3	35.1	34.3
1991	55.1	52.5	34.7	34.0
1992	48.2	45.2	30.2	30.6
1993	40.8	39.5	24.0	25.0
1994	31.5	31.4	18.0	19.0
1995	22.8	23.1	13.3	14.2
1996	17.7	18.1	10.0	10.8
1997	14.7	15.2	7.6	8.5
1998	13.2	13.9	6.3	7.3
1999	13.4	14.3	5.8	6.9
2000	15.2	16.3	6.2	7.3
2001	18.4	19.8	6.7	7.9
2002	21.5	23.1	7.5	8.8
2003	26.2	27.7	8.9	10.2
2004	32.9	33.8	11.2	12.4
2005	41.9	41.6	13.1	14.4
2006	46.8	46.3	14.4	16.0
2007	51.3	51.3	16.1	18.2
2008	58.4	58.9	16.3	18.5
2009	57.4	58.5	14.3	16.4
2010	51.0	51.7	12.1	13.9
2011	45.1	45.2	11.5	13.3
2012	46.5	46.2	14.6	17.0
2013	60.6	61.2	19.7	23.4
2014	71.6	75.4	22.0	26.7
2015	--	73.9	--	24.9

Table 31. Estimated population size (thousands) for females on July 1 of year. from the author's preferred model, Model C.

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	4.26E+00	1.01E+01	9.88E+00	9.34E+00	6.98E+00	4.37E+00	2.41E+00	1.22E+00	5.73E-01	2.56E-01	1.09E-01	4.50E-02	1.80E-02	7.00E-03	2.66E-03	9.89E-04	3.60E-04	1.28E-04	4.46E-05	1.53E-05	5.20E-06	1.75E-06	5.84E-07	1.93E-07	6.33E-08	2.06E-08	6.61E-09	2.11E-09	6.66E-10	2.09E-10	6.67E-11	2.61E-11
1951	4.29E+00	1.01E+01	9.95E+00	9.69E+00	8.35E+00	7.16E+00	5.93E+00	4.44E+00	3.01E+00	1.86E+00	1.03E+00	5.07E-01	2.15E-01	8.05E-02	2.89E-02	9.91E-03	2.78E-03	6.10E-04	1.24E-04	3.02E-05	8.97E-06	2.92E-06	9.69E-07	3.20E-07	1.05E-07	3.41E-08	1.10E-08	3.50E-09	1.11E-09	3.47E-10	1.11E-10	4.34E-11
1952	4.34E+00	1.03E+01	1.01E+01	9.77E+00	8.42E+00	7.33E+00	6.47E+00	5.72E+00	5.23E+00	4.66E+00	3.56E+00	2.29E+00	1.24E+00	5.71E-01	2.46E-01	9.45E-02	2.67E-02	5.07E-03	6.96E-04	8.79E-05	1.50E-05	3.90E-06	1.24E-06	4.06E-07	1.33E-07	4.32E-08	1.39E-08	4.43E-09	1.40E-09	4.40E-10	1.40E-10	5.50E-11
1953	4.42E+00	1.04E+01	1.02E+01	9.91E+00	8.53E+00	7.40E+00	6.54E+00	5.87E+00	5.83E+00	6.11E+00	5.48E+00	4.18E+00	2.82E+00	1.65E+00	8.98E-01	4.16E-01	1.34E-01	2.79E-02	3.96E-03	4.33E-04	4.45E-05	6.17E-06	1.49E-06	4.67E-07	1.52E-07	4.95E-08	1.59E-08	5.07E-09	1.60E-09	5.04E-10	1.61E-10	6.29E-11
1954	4.54E+00	1.07E+01	1.05E+01	1.01E+01	8.69E+00	7.53E+00	6.64E+00	6.00E+00	6.22E+00	7.03E+00	6.70E+00	5.38E+00	3.98E+00	2.61E+00	1.59E+00	8.24E-01	2.95E-01	6.79E-02	1.07E-02	1.28E-03	1.28E-04	1.25E-05	1.98E-06	5.49E-07	1.76E-07	5.72E-08	1.84E-08	5.87E-09	1.86E-09	5.83E-10	1.86E-10	7.28E-11
1955	4.74E+00	1.12E+01	1.09E+01	1.05E+01	8.95E+00	7.72E+00	6.79E+00	6.16E+00	6.54E+00	7.73E+00	7.60E+00	6.25E+00	4.82E+00	3.31E+00	2.11E+00	1.14E+00	4.22E-01	1.01E-01	1.66E-02	2.11E-03	2.17E-04	1.96E-05	2.49E-06	6.21E-07	1.97E-07	6.37E-08	2.05E-08	6.54E-09	2.07E-09	6.49E-10	2.07E-10	8.11E-11
1956	5.04E+00	1.19E+01	1.15E+01	1.10E+01	9.36E+00	8.03E+00	7.03E+00	6.37E+00	6.86E+00	8.31E+00	8.31E+00	6.91E+00	5.45E+00	3.82E+00	2.49E+00	1.36E+00	5.13E-01	1.24E-01	2.09E-02	2.71E-03	2.82E-04	2.48E-05	2.88E-06	6.78E-07	2.13E-07	6.89E-08	2.22E-08	7.07E-09	2.24E-09	7.02E-10	2.24E-10	8.77E-11
1957	5.53E+00	1.30E+01	1.25E+01	1.18E+01	9.99E+00	8.50E+00	7.39E+00	6.67E+00	7.21E+00	8.85E+00	8.91E+00	7.46E+00	5.95E+00	4.21E+00	2.76E+00	1.52E+00	5.78E-01	1.41E-01	2.39E-02	3.13E-03	3.28E-04	2.85E-05	3.18E-06	7.28E-07	2.28E-07	7.36E-08	2.37E-08	7.55E-09	2.39E-09	7.50E-10	2.39E-10	9.37E-11
1958	6.33E+00	1.49E+01	1.42E+01	1.32E+01	1.10E+01	9.26E+00	7.96E+00	7.13E+00	7.67E+00	9.42E+00	9.51E+00	7.98E+00	6.39E+00	4.55E+00	3.00E+00	1.66E+00	6.33E-01	1.55E-01	2.64E-02	3.47E-03	3.66E-04	3.18E-05	3.49E-06	7.93E-07	2.48E-07	8.01E-08	2.58E-08	8.22E-09	2.60E-09	8.16E-10	2.60E-10	1.02E-10
1959	7.79E+00	1.83E+01	1.72E+01	1.56E+01	1.28E+01	1.05E+01	8.90E+00	7.85E+00	8.32E+00	1.01E+01	1.02E+01	8.53E+00	6.83E+00	4.87E+00	3.21E+00	1.78E+00	6.79E-01	1.67E-01	2.85E-02	3.75E-03	3.96E-04	3.46E-05	3.84E-06	8.76E-07	2.74E-07	8.86E-08	2.85E-08	9.09E-09	2.87E-09	9.03E-10	2.88E-10	1.13E-10
1960	1.08E+01	2.52E+01	2.32E+01	2.03E+01	1.61E+01	1.28E+01	1.06E+01	9.08E+00	9.36E+00	1.11E+01	1.11E+01	9.22E+00	7.35E+00	5.22E+00	3.44E+00	1.90E+00	7.27E-01	1.79E-01	3.05E-02	4.03E-03	4.27E-04	3.78E-05	4.33E-06	1.01E-06	3.16E-07	1.02E-07	3.29E-08	1.05E-08	3.32E-09	1.04E-09	3.33E-10	1.30E-10
1961	1.86E+01	4.31E+01	3.82E+01	3.14E+01	2.35E+01	1.77E+01	1.39E+01	1.14E+01	1.12E+01	1.28E+01	1.24E+01	1.02E+01	8.06E+00	5.68E+00	3.72E+00	2.05E+00	7.82E-01	1.92E-01	3.27E-02	4.33E-03	4.61E-04	4.19E-05	5.14E-06	1.25E-06	3.94E-07	1.28E-07	4.10E-08	1.31E-08	4.13E-09	1.30E-09	4.14E-10	1.62E-10
1962	4.12E+01	9.48E+01	8.11E+01	6.21E+01	4.34E+01	3.03E+01	2.20E+01	1.68E+01	1.51E+01	1.59E+01	1.49E+01	1.19E+01	9.18E+00	6.36E+00	4.10E+00	2.24E+00	8.46E-01	2.07E-01	3.51E-02	4.64E-03	5.01E-04	4.83E-05	6.75E-06	1.76E-06	5.59E-07	1.81E-07	5.83E-08	1.86E-08	5.87E-09	1.85E-09	5.88E-10	2.30E-10
1963	9.02E+01	2.08E+02	1.78E+02	1.36E+02	9.39E+01	6.33E+01	4.34E+01	3.08E+01	2.47E+01	2.31E+01	2.01E+01	1.54E+01	1.13E+01	7.57E+00	4.75E+00	2.54E+00	9.46E-01	2.29E-01	3.87E-02	5.13E-03	5.71E-04	6.27E-05	1.09E-05	3.10E-06	9.97E-07	3.23E-07	1.04E-07	3.31E-08	1.05E-08	3.29E-09	1.05E-09	4.10E-10
1964	1.24E+02	2.89E+02	2.66E+02	2.31E+02	1.75E+02	1.26E+02	8.98E+01	6.40E+01	4.88E+01	4.12E+01	3.29E+01	2.36E+01	1.62E+01	1.02E+01	6.11E+00	3.15E+00	1.15E+00	2.73E-01	4.57E-02	6.07E-03	7.13E-04	9.35E-05	2.00E-05	6.04E-06	1.96E-06	6.36E-07	2.05E-07	6.52E-08	2.06E-08	6.48E-09	2.07E-09	8.08E-10
1965	1.11E+02	2.64E+02	2.66E+02	2.67E+02	2.26E+02	1.85E+02	1.49E+02	1.17E+02	9.42E+01	8.00E+01	6.26E+01	4.35E+01	2.82E+01	1.67E+01	9.48E+00	4.70E+00	1.66E+00	3.84E-01	6.26E-02	8.15E-03	9.65E-04	1.35E-04	3.07E-05	9.44E-06	3.07E-06	9.96E-07	3.20E-07	1.02E-07	3.23E-08	1.01E-08	3.23E-09	1.27E-09
1966	8.58E+01	2.06E+02	2.16E+02	2.30E+02	2.11E+02	1.93E+02	1.75E+02	1.53E+02	1.41E+02	1.34E+02	1.12E+02	8.07E+01	5.29E+01	3.11E+01	1.74E+01	8.48E+00	2.93E+00	6.63E-01	1.05E-01	1.30E-02	1.44E-03	1.80E-04	3.76E-05	1.13E-05	3.68E-06	1.19E-06	3.84E-07	1.22E-07	3.87E-08	1.22E-08	3.87E-09	1.52E-09
1967	7.01E+01	1.68E+02	1.73E+02	1.82E+02	1.70E+02	1.62E+02	1.55E+02	1.48E+02	1.57E+02	1.72E+02	1.59E+02	1.23E+02	8.66E+01	5.38E+01	3.14E+01	1.56E+01	5.47E+00	1.24E+00	1.95E-01	2.36E-02	2.41E-03	2.46E-04	4.10E-05	1.15E-05	3.71E-06	1.20E-06	3.87E-07	1.24E-07	3.90E-08	1.23E-08	3.91E-09	1.53E-09
1968	6.61E+01	1.57E+02	1.56E+02	1.57E+02	1.41E+02	1.31E+02	1.24E+02	1.23E+02	1.44E+02	1.80E+02	1.80E+02	1.49E+02	1.13E+02	7.55E+01	4.65E+01	2.42E+01	8.74E+00	2.03E+00	3.26E-01	4.01E-02	4.00E-03	3.52E-04	4.39E-05	1.09E-05	3.44E-06	1.11E-06	3.58E-07	1.14E-07	3.61E-08	1.13E-08	3.61E-09	1.42E-09
1969	7.25E+01	1.71E+02	1.64E+02	1.56E+02	1.34E+02	1.17E+02	1.07E+02	1.04E+02	1.26E+02	1.70E+02	1.79E+02	1.54E+02	1.24E+02	8.68E+01	5.57E+01	2.99E+01	1.11E+01	2.67E+00	4.41E-01	5.58E-02	5.63E-03	4.65E-04	4.71E-05	1.01E-05	3.14E-06	1.01E-06	3.26E-07	1.04E-07	3.29E-08	1.03E-08	3.29E-09	1.29E-09
1970	8.01E+01	1.88E+02	1.81E+02	1.71E+02	1.43E+02	1.21E+02	1.05E+02	9.80E+01	1.17E+02	1.60E+02	1.71E+02	1.48E+02	1.22E+02	8.80E+01	5.75E+01	3.14E+01	1.19E+01	2.91E+00	4.92E-01	6.39E-02	6.57E-03	5.37E-04	5.00E-05	9.95E-06	3.04E-06	9.81E-07	3.15E-07	1.01E-07	3.18E-08	9.99E-09	3.18E-09	1.25E-09
1971	6.80E+01	1.62E+02	1.66E+02	1.70E+02	1.50E+02	1.30E+02	1.13E+02	1.03E+02	1.18E+02	1.56E+02	1.65E+02	1.42E+02	1.18E+02	8.49E+01	5.56E+01	3.04E+01	1.16E+01	2.85E+00	4.88E-01	6.44E-02	6.72E-03	5.54E-04	5.14E-05	1.02E-05	3.10E-06	1.00E-06	3.22E-07	1.03E-07	3.24E-08	1.02E-08	3.25E-09	1.27E-09
1972	5.01E+01	1.21E+02	1.28E+02	1.39E+02	1.30E+02	1.21E+02	1.13E+02	1.07E+02	1.22E+02	1.59E+02	1.66E+02	1.41E+02	1.15E+02	8.25E+01	5.37E+01	2.93E+01	1.11E+01	2.74E+00	4.70E-01	6.23E-02	6.53E-03	5.41E-04	5.03E-05	9.97E-06	3.04E-06	9.81E-07	3.15E-07	1.01E-07	3.18E-08	9.99E-09	3.18E-09	1.25E-09
1973	3.08E+01	7.52E+01	8.42E+01	9.75E+01	9.60E+01	9.51E+01	9.37E+01	9.48E+01	1.17E+02	1.58E+02	1.67E+02	1.43E+02	1.16E+02	8.18E+01	5.25E+01	2.82E+01	1.06E+01	2.59E+00	4.42E-01	5.82E-02	6.06E-03	4.97E-04	4.49E-05	8.67E-06	2.63E-06	8.48E-07	2.73E-07	8.70E-08	2.75E-08	8.64E-09	2.76E-09	1.08E-09
1974	2.32E+01	5.58E+01	5.90E+01	6.44E+01	6.34E+01	6.50E+01	6.70E+01	7.22E+01	9.81E+01	1.44E+02	1.57E+02	1.37E+02	1.13E+02	8.09E+01	5.20E+01	2.79E+01	1.05E+01	2.55E+00	4.33E-01	5.66E-02	5.84E-03	4.68E-04	3.94E-05	7.06E-06	2.11E-06	6.79E-07	2.19E-07	6.97E-08	2.20E-08	6.92E-09	2.21E-09	8.65E-10
1975	4.65E+01	1.07E+02	9.30E+01	7.41E+01	5.75E+01	4.93E+01	4.65E+01	5.04E+01	7.52E+01	1.20E+02	1.37E+02	1.23E+02	1.04E+02	7.56E+01	4.91E+01	2.65E+01	1.00E+01	2.45E+00	4.18E-01	5.48E-02	5.64E-03	4.43E-04	3.46E-05	5.63E-06	1.64E-06	5.29E-07	1.70E-07	5.42E-08	1.71E-08	5.39E-09	1.72E-09	6.73E-10
1976	8.38E+01	1.94E+02	1.70E+02	1.37E+02	9.91E+01	7.02E+01	5.22E+01	4.57E+01	6.16E+01	9.94E+01	1.15E+02	1.04E+02	9.06E+01	6.70E+01	4.40E+01	2.40E+01	9.12E+00	2.25E+00	3.88E-01	5.15E-02	5.35E-03	4.26E-04	3.42E-05	5.78E-06	1.70E-06	5.48E-07	1.76E-07	5.62E-08	1.78E-08	5.58E-09	1.78E-09	6.96E-10
1977	6.62E+01	1.59E+02	1.65E+02	1.71E+02	1.45E+02	1.14E+02	8.80E+01	6.97E+01	7.15E+01	9.47E+01	1.02E+02	8.96E+01	7.66E+01	5.60E+01	3.62E+01	1.94E+01	7.36E+00	1.82E+00	3.17E-01	4.25E-02	4.49E-03	3.73E-04	3.48E-05	6.87E-06	2.09E-06	6.75E-07	2.17E-07	6.92E-08	2.19E-08	6.87E-09	2.19E-09	8.58E-10
1978	3.38E+01	8.38E+01	9.97E+01	1.22E+02	1.22E+02	1.19E+02	1.11E+02	9.90E+01	9.91E+01	1.14E+02	1.11E+02	9.03E+01	7.10E+01	4.83E+01	2.91E+01	1.49E+01	5.45E+00	1.33E+00	2.29E-01	3.06E-02	3.25E-03	2.78E-04	2.83E-05	6.05E-06	1.87E-06	6.03E-07	1.94E-07	6.18E-08	1.95E-08	6.14E-09	1.96E-09	7.67E-10
1979	1.34E+01	3.41E+01	4.46E+01	6.07E+01	6.84E+01	7.72E+01	8.33E+01	8.80E+01	1.05E+02	1.31E+02	1.30E+02	1.05E+02	7.84E+01	5.00E+01	2.85E+01	1.38E+01	4.84E+00	1.13E+00	1.88E-01	2.41E-02	2.48E-03	2.07E-04	2.07E-05	4.37E-06	1.34E-06	4.34E-07	1.40E-07	4.45E-08	1.41E-08	4.42E-09	1.41E-09	5.53E-10
1980	7.14E+00	1.76E+01	2.08E+01	2.63E+01	3.04E+01	3.69E+01	4.38E+01	5.36E+01	7.95E+01	1.18E+02	1.28E+02	1.09E+02	8.45E+01	5.44E+01	3.12E+01	1.52E+01	5.28E+00	1.21E+00	1.92E-01	2.33E-02	2.25E-03	1.73E-04	1.42E-05	2.53E-06	7.53E-07	2.43E-07	7.81E-08	2.49E-08	7.87E-09	2.47E-09	7.88E-10	3.09E-10
1981	1.03E+01	2.40E+01	2.19E+01	1.95E+01	1.74E+01	1.78E+01	2.00E+01	2.65E+01	4.80E+01	8.40E+01	9.83E+01	8.83E+01	7.23E+01	4.88E+01	2.92E+01	1.49E+01	5.39E+00	1.27E+00	2.06E-01	2.52E-02	2.41E-03	1.75E-04	1.13E-05	1.39E-06	3.76E-07	1.20E-07	3.86E-08	1.23E-08	3.89E-09	1.22E-09	3.89E-10	1.52E-10
1982	6.95E+00	1.68E+01	1.83E+01	2.01E+01	1.78E+01	1.51E+01	1.35E+01	1.55E+01	2.93E+01	5.62E+01	6.88E+01	6.37E+01	5.49E+01	3.89E+01	2.44E+01	1.29E+01	4.87E+00	1.20E+00	2.03E-01	2.62E-02	2.63E-03	1.94E-04	1.18E-05	1.21E-06	3.03E-07	9.60E-08	3.08E-08	9.83E-09	3.11E-09	9.76E-10	3.11E-10	1.22E-10
1983	2.65E+01	6.03E+01	4.89E+01	3.36E+01	2.28E+01	1.75E+01	1.49E+01	1.47E+01	2.26E+01	4.04E+01	4.87E+01	4.50E+01	3.97E+01	2.91E+01	1.90E+01	1.05E+01	4.07E+00	1.03E+00	1.82E-01	2.46E-02	2.57E-03	1.95E-04	1.18E-05	1.17E-06	2.87E-07	9.09E-08	2.92E-08	9.30E-09	2.94E-09	9.23E-10	2.94E-10	1.15E-10
1984	2.47E+01	5.85E+01	5.83E+01	5.69E+01	4.49E+01	3.18E+01	2.21E+01	1.74E+01	2.11E+01	3.28E+01	3.76E+01	3.39E+01	2.95E+01	2.17E+01	1.44E+01	8.05E+00	3.18E+00	8.18E-01	1.47E-01	2.04E-02	2.19E-03	1.76E-04	1.35E-05	2.10E-06	6.06E-07	1.95E-07	6.27E-08	2.00E-08	6.32E-09	1.98E-09	6.33E-10	2.48E-10
1985	3.88E+01	9.00E+01	8.10E+01	6.88E+01	5.47E+01	4.53E+01	3.78E+01	3.08E+01	2.86E+01	3.29E+01	3.32E+01	2.83E+01	2.36E+01	1.71E+01	1.13E+01	6.28E+00	2.47E+00	6.30E-01	1.13E-01	1.56E-02	1.70E-03	1.43E-04	1.32E-05	2.55E-06	7.75E-07	2.50E-07	8.04E-08	2.56E-08	8.10E-09	2.55E-09	8.11E-10	3.18E-10
1986	3.57E+01	8.48E+01	8.49E+01	8.41E+01	7.03E+01	5.63E+01	4.56E+01	3.86E+01	3.84E+01	4.30E+01	4.09E+01	3.26E+01	2.49E+01	1.70E+01	1.08E+01	5.89E+00	2.28E+00	5.74E-01	1.01E-01	1.39E-02	1.53E-03	1.38E-04	1.59E-05	3.71E-06	1.16E-06	3.77E-07	1.21E-07	3.86E-08	1.22E-08	3.84E-09	1.22E-09	4.79E-10
1987	3.46E+01	8.19E+01	8.11E+01	8.02E+01	7.06E+01	6.27E+01	5.55E+01	4.84E+01	4.72E+01	5.16E+01	4.89E+01	3.93E+01	2.97E+01	1.98E+01	1.22E+01	6.39E+00	2.36E+00	5.71E-01	9.69E-02	1.28E-02	1.37E-03	1.27E-04	1.62E-05	4.01E-06	1.27E-06	4.11E-07	1.32E-07	4.22E-08	1.33E-08	4.19E-09	1.34E-09	5.23E-10
1988	3.37E+01	7.98E+01	7.89E+01	7.77E+01	6.79E+01	6.00E+01	5.41E+01	5.01E+01	5.34E+01	6.16E+01	5.91E+01	4.74E+01	3.55E+01	2.35E+01	1.44E+01	7.55E+00	2.77E+00	6.63E-01	1.10E-01	1.42E-02	1.48E-03	1.34E-04	1.66E-05	4.06E-06	1.28E-06	4.15E-07	1.34E-07	4.26E-08	1.35E-08	4.23E-09	1.35E-09	5.28E-10
1989	1.46E+01	3.68E+01	4.63E+01	5.93E+01	5.85E+01	5.51E+01	5.11E+01	4.82E+01	5.34E+01	6.53E+01	6.53E+01	5.41E+01	4.18E+01	2.83E+01	1.76E+01	9.24E+00	3.39E+00	8.09E-01	1.34E-01	1.72E-02	1.77E-03	1.55E-04	1.79E-05	4.21E-06	1.32E-06	4.28E-07	1.38E-07	4.39E-08	1.39E-08	4.36E-09	1.39E-09	5.45E-10
1990	5.65E+00	1.44E+01	1.91E+01	2.65E+01	3.11E+01	3.67E+01	4.01E+01	4.21E+01	5.08E+01	6.59E+01	6.76E+01	5.68E+01	4.49E+01	3.10E+01	1.96E+01	1.04E+01	3.86E+00	9.26E-01	1.54E-01	1.97E-02	2.00E-03	1.64E-04	1.59E-05	3.28E-06	1.01E-06	3.26E-07	1.05E-07	3.35E-08	1.06E-08	3.32E-09	1.06E-09	4.15E-10
1991	3.29E+00	8.05E+00	9.22E+00	1.13E+01	1.31E+01	1.61E+01	1.96E+01	2.51E+01	3.88E+01	5.89E+01	6.43E+01	5.57E+01	4.50E+01	3.13E+01	1.97E+01	1.05E+01	3.88E+00	9.35E-01	1.56E-01	2.01E-02	2.03E-03	1.59E-04	1.28E-05	2.18E-06	6.44E-07	2.07E-07	6.67E-08	2.13E-08	6.72E-09	2.11E-09	6.73E-10	2.64E-10
1992	2.50E+00	6.00E+00	6.33E+00	6.92E+00	6.91E+00	7.41E+00	8.54E+00	1.19E+01	2.36E+01	4.34E+01	5.16E+01	4.73E+01	4.05E+01	2.92E+01	1.88E+01	1.01E+01	3.77E+00	9.15E-01	1.54E-01	1.99E-02	2.01E-03	1.53E-04	1.07E-05	1.48E-06	4.15E-07	1.33E-07	4.28E-08	1.36E-08	4.31E-09	1.35E-09	4.32E-10	1.69E-10
1993	2.32E+00	5.51E+00	5.51E+00	5.56E+00	5.09E+00	4.88E+00	5.02E+00	6.76E+00	1.50E+01	3.05E+01	3.77E+01	3.53E+01	3.15E+01	2.37E+01	1.57E+01	8.68E+00	3.33E+00	8.29E-01	1.43E-01	1.89E-02	1.94E-03	1.47E-04	9.44E-06	1.09E-06	2.87E-07	9.13E-08	2.94E-08	9.36E-09	2.96E-09	9.30E-10	2.96E-10	1.16E-10
1994	2.91E+00	6.81E+00	6.38E+00	5.81E+00	4.85E+00	4.23E+00	3.98E+00	4.96E+00	1.09E+01	2.23E+01	2.77E+01	2.59E+01	2.35E+01	1.79E+01	1.20E+01	6.70E+00	2.61E+00	6.61E-01	1.17E-01	1.59E-02	1.67E-03	1.27E-04	7.97E-06	8.47E-07	2.15E-07	6.84E-08	2.20E-08	7.01E-09	2.22E-09	6.96E-10	2.22E-10	8.70E-11
1995	3.87E+00	9.04E+00	8.37E+00	7.42E+00	5.91E+00	4.74E+00	4.04E+00	4.39E+00	8.55E+00	1.69E+01	2.07E+01	1.92E+01	1.74E+01	1.32E+01	8.79E+00	4.87E+00	1.90E+00	4.83E-01	8.60E-02	1.18E-02	1.26E-03	9.72E-05	6.22E-06	6.91E-07	1.79E-07	5.69E-08	1.83E-08	5.83E-09	1.84E-09	5.79E-10	1.85E-10	7.24E-11
1996	3.96E+00	9.35E+00	9.14E+00	8.78E+00	7.31E+00	5.95E+00	4.95E+00	4.76E+00	7.52E+00	1.35E+01	1.60E+01	1.47E+01	1.31E+01	9.86E+00	6.51E+00	3.58E+00	1.39E+00	3.52E-01	6.28E-02	8.65E-03	9.26E-04	7.26E-05	4.96E-06	6.36E-07	1.74E-07	5.55E-08	1.78E-08	5.69E-09	1.80E-09	5.65E-10	1.80E-10	7.06E-11
1997	9.78E+00	2.24E+01	1.90E+01	1.42E+01	1.01E+01	7.66E+00	6.20E+00	5.62E+00	7.43E+00	1.17E+01	1.33E+01	1.19E+01	1.03E+01	7.64E+00	4.98E+00	2.71E+00	1.04E+00	2.63E-01	4.67E-02	6.41E-03	6.87E-04	5.48E-05	4.08E-06	6.09E-07	1.74E-07	5.58E-08	1.79E-08	5.72E-09	1.81E-09	5.68E-10	1.81E-10	7.09E-11
1998	4.01E+00	1.02E+01	1.30E+01	1.65E+01	1.49E+01	1.18E+01	8.96E+00	7.30E+00	8.14E+00	1.13E+01	1.21E+01	1.05E+01	8.80E+00	6.34E+00	4.05E+00	2.17E+00	8.26E-01	2.06E-01	3.63E-02	4.95E-03	5.34E-04	4.51E-05	4.26E-06	8.49E-07	2.59E-07	8.36E-08	2.69E-08	8.57E-09	2.71E-09	8.51E-10	2.71E-10	1.06E-10
1999	1.17E+01	2.68E+01	2.23E+01	1.65E+01	1.29E+01	1.20E+01	1.15E+01	1.04E+01	1.07E+01	1.25E+01	1.24E+01	1.02E+01	8.22E+00	5.76E+00	3.63E+00	1.93E+00	7.23E-01	1.78E-01	3.09E-02	4.15E-03	4.43E-04	3.75E-05	3.68E-06	7.62E-07	2.34E-07	7.55E-08	2.43E-08	7.74E-09	2.45E-09	7.69E-10	2.45E-10	9.59E-11
2000	6.96E+00	1.70E+01	1.92E+01	2.17E+01	1.86E+01	1.41E+01	1.09E+01	9.62E+00	1.11E+01	1.42E+01	1.42E+01	1.16E+01	8.91E+00	6.00E+00	3.70E+00	1.93E+00	7.15E-01	1.74E-01	2.96E-02	3.93E-03	4.19E-04	3.77E-05	4.48E-06	1.06E-06	3.35E-07	1.08E-07	3.49E-08	1.11E-08	3.51E-09	1.10E-09	3.52E-10	1.38E-10
2001	2.12E+01	4.84E+01	4.01E+01	2.90E+01	2.11E+01	1.74E+01	1.52E+01	1.30E+01	1.27E+01	1.47E+01	1.46E+01	1.22E+01	9.71E+00	6.72E+00	4.22E+00	2.22E+00	8.16E-01	1.95E-01	3.26E-02	4.21E-03	4.39E-04	3.88E-05	4.52E-06	1.06E-06	3.34E-07	1.08E-07	3.48E-08	1.11E-08	3.50E-09	1.10E-09	3.51E-10	1.37E-10
2002	8.04E+00	2.06E+01	2.71E+01	3.51E+01	3.16E+01	2.44E+01	1.84E+01	1.50E+01	1.52E+01	1.77E+01	1.71E+01	1.38E+01	1.06E+01	7.20E+00	4.55E+00	2.43E+00	9.12E-01	2.22E-01	3.76E-02	4.92E-03	5.24E-04	4.94E-05	6.68E-06	1.71E-06	5.44E-07	1.76E-07	5.67E-08	1.81E-08	5.71E-09	1.79E-09	5.72E-10	2.24E-10
2003	1.60E+01	3.70E+01	3.22E+01	2.64E+01	2.33E+01	2.38E+01	2.36E+01	2.14E+01	2.03E+01	2.14E+01	1.99E+01	1.60E+01	1.23E+01	8.38E+00	5.27E+00	2.79E+00	1.03E+00	2.48E-01	4.16E-02	5.40E-03	5.70E-04	5.16E-05	6.39E-06	1.56E-06	4.93E-07	1.60E-07	5.13E-08	1.64E-08	5.17E-09	1.62E-09	5.18E-10	2.03E-10
2004	2.47E+01	5.73E+01	5.17E+01	4.36E+01	3.26E+01	2.39E+01	1.90E+01	1.79E+01	2.10E+01	2.60E+01	2.54E+01	2.03E+01	1.51E+01	1.00E+01	6.21E+00	3.29E+00	1.22E+00	2.94E-01	4.92E-02	6.38E-03	6.68E-04	6.04E-05	7.51E-06	1.84E-06	5.81E-07	1.88E-07	6.05E-08	1.93E-08	6.10E-09	1.92E-09	6.11E-10	2.39E-10
2005	7.20E+00	1.91E+01	2.80E+01	3.96E+01	3.84E+01	3.31E+01	2.73E+01	2.22E+01	2.16E+01	2.55E+01	2.58E+01	2.20E+01	1.76E+01	1.22E+01	7.78E+00	4.14E+00	1.52E+00	3.63E-01	6.01E-02	7.70E-03	8.05E-04	7.41E-05	9.65E-06	2.43E-06	7.70E-07	2.50E-07	8.03E-08	2.56E-08	8.09E-09	2.54E-09	8.11E-10	3.18E-10
2006	5.55E+00	1.33E+01	1.41E+01	1.61E+01	1.90E+01	2.38E+01	2.65E+01	2.64E+01	2.79E+01	3.15E+01	3.00E+01	2.41E+01	1.88E+01	1.32E+01	8.59E+00	4.73E+00	1.80E+00	4.38E-01	7.38E-02	9.56E-03	9.91E-04	8.47E-05	9.12E-06	2.04E-06	6.34E-07	2.05E-07	6.59E-08	2.10E-08	6.64E-09	2.09E-09	6.65E-10	2.61E-10
2007	3.72E+00	9.01E+00	9.84E+00	1.11E+01	1.07E+01	1.09E+01	1.21E+01	1.54E+01	2.29E+01	3.26E+01	3.41E+01	2.85E+01	2.22E+01	1.53E+01	9.76E+00	5.27E+00	1.97E+00	4.76E-01	7.97E-02	1.03E-02	1.07E-03	8.87E-05	8.40E-06	1.69E-06	5.16E-07	1.66E-07	5.34E-08	1.70E-08	5.38E-09	1.69E-09	5.39E-10	2.11E-10
2008	4.64E+00	1.09E+01	1.02E+01	9.41E+00	8.28E+00	7.87E+00	7.83E+00	8.79E+00	1.42E+01	2.44E+01	2.88E+01	2.65E+01	2.27E+01	1.68E+01	1.12E+01	6.15E+00	2.32E+00	5.57E-01	9.25E-02	1.18E-02	1.20E-03	9.46E-05	7.82E-06	1.37E-06	4.07E-07	1.31E-07	4.21E-08	1.34E-08	4.24E-09	1.33E-09	4.24E-10	1.66E-10
2009	3.03E+01	6.86E+01	5.38E+01	3.36E+01	1.95E+01	1.18E+01	8.26E+00	7.48E+00	1.13E+01	1.95E+01	2.30E+01	2.13E+01	1.92E+01	1.50E+01	1.05E+01	6.06E+00	2.37E+00	5.87E-01	1.00E-01	1.31E-02	1.35E-03	1.06E-04	7.96E-06	1.23E-06	3.53E-07	1.13E-07	3.63E-08	1.15E-08	3.65E-09	1.15E-09	3.65E-10	1.43E-10
2010	3.77E+01	8.83E+01	8.27E+01	7.35E+01	5.43E+01	3.56E+01	2.21E+01	1.44E+01	1.32E+01	1.78E+01	1.97E+01	1.78E+01	1.59E+01	1.25E+01	8.85E+00	5.14E+00	2.03E+00	5.09E-01	8.86E-02	1.20E-02	1.28E-03	1.10E-04	1.10E-05	2.30E-06	7.04E-07	2.27E-07	7.27E-08	2.31E-08	7.31E-09	2.30E-09	7.32E-10	2.86E-10
2011	2.20E+01	5.38E+01	6.12E+01	7.08E+01	6.51E+01	5.61E+01	4.62E+01	3.56E+01	2.85E+01	2.63E+01	2.31E+01	1.81E+01	1.46E+01	1.09E+01	7.51E+00	4.32E+00	1.69E+00	4.23E-01	7.36E-02	1.00E-02	1.10E-03	1.04E-04	1.36E-05	3.36E-06	1.06E-06	3.41E-07	1.09E-07	3.48E-08	1.10E-08	3.45E-09	1.10E-09	4.31E-10
2012	3.80E+00	1.11E+01	2.07E+01	3.46E+01	4.06E+01	4.52E+01	4.64E+01	4.43E+01	4.36E+01	4.40E+01	3.80E+01	2.80E+01	1.95E+01	1.26E+01	7.80E+00	4.19E+00	1.57E+00	3.80E-01	6.43E-02	8.55E-03	9.36E-04	9.16E-05	1.29E-05	3.33E-06	1.05E-06	3.40E-07	1.09E-07	3.47E-08	1.10E-08	3.44E-09	1.10E-09	4.30E-10
2013	9.51E+00	2.18E+01	1.85E+01	1.51E+01	1.57E+01	2.05E+01	2.56E+01	3.05E+01	3.94E+01	4.98E+01	4.91E+01	3.97E+01	2.91E+01	1.88E+01	1.14E+01	5.87E+00	2.10E+00	4.83E-01	7.69E-02	9.53E-03	9.68E-04	8.56E-05	1.03E-05	2.49E-06	7.78E-07	2.51E-07	8.04E-08	2.56E-08	8.09E-09	2.54E-09	8.10E-10	3.17E-10
2014	7.62E+00	1.82E+01	1.89E+01	1.95E+01	1.61E+01	1.27E+01	1.13E+01	1.39E+01	2.41E+01	4.00E+01	4.56E+01	4.08E+01	3.35E+01	2.38E+01	1.54E+01	8.29E+00	3.05E+00	7.17E-01	1.16E-01	1.43E-02	1.41E-03	1.14E-04	1.08E-05	2.22E-06	6.76E-07	2.17E-07	6.97E-08	2.22E-08	7.01E-09	2.20E-09	7.02E-10	2.75E-10
2015	5.34E+00	1.29E+01	1.39E+01	1.54E+01	1.46E+01	1.38E+01	1.27E+01	1.22E+01	1.73E+01	2.96E+01	3.53E+01	3.31E+01	2.97E+01	2.29E+01	1.59E+01	9.03E+00	3.48E+00	8.49E-01	1.43E-01	1.84E-02	1.86E-03	1.46E-04	1.16E-05	1.95E-06	5.71E-07	1.83E-07	5.87E-08	1.87E-08	5.90E-09	1.85E-09	5.91E-10	2.32E-10
2016	9.20E+00	2.13E+01	1.89E+01	1.58E+01	1.28E+01	1.15E+01	1.09E+01	1.15E+01	1.66E+01	2.65E+01	3.03E+01	2.73E+01	2.43E+01	1.90E+01	1.35E+01	7.87E+00	3.11E+00	7.79E-01	1.35E-01	1.81E-02	1.89E-03	1.49E-04	1.10E-05	1.65E-06	4.67E-07	1.49E-07	4.78E-08	1.52E-08	4.81E-09	1.51E-09	4.81E-10	1.89E-10

Table 32. Estimated population size (thousands) for males on July 1 of year. from the author's preferred mode, Model C.

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	4.26E+00	9.97E+00	9.56E+00	8.60E+00	6.54E+00	4.53E+00	2.79E+00	1.58E+00	8.52E-01	4.43E-01	2.22E-01	1.09E-01	5.20E-02	2.45E-02	1.13E-02	5.19E-03	2.34E-03	1.05E-03	4.65E-04	2.04E-04	8.92E-05	3.87E-05	1.67E-05	7.13E-06	3.03E-06	1.28E-06	5.32E-07	2.18E-07	8.81E-08	3.49E-08	1.41E-08	7.04E-09
1951	4.29E+00	1.00E+01	9.62E+00	8.80E+00	7.31E+00	6.15E+00	5.34E+00	4.35E+00	3.38E+00	2.52E+00	1.77E+00	1.19E+00	7.65E-01	4.81E-01	2.95E-01	1.76E-01	1.03E-01	5.90E-02	3.31E-02	1.81E-02	9.66E-03	5.03E-03	2.59E-03	1.32E-03	6.61E-04	3.12E-04	1.36E-04	5.24E-05	1.70E-05	4.22E-06	6.70E-07	6.60E-08
1952	4.34E+00	1.01E+01	9.71E+00	8.88E+00	7.37E+00	6.21E+00	5.49E+00	4.73E+00	4.08E+00	3.59E+00	3.21E+00	2.78E+00	2.34E+00	1.93E+00	1.54E+00	1.18E+00	8.75E-01	6.32E-01	4.43E-01	3.00E-01	1.96E-01	1.24E-01	7.78E-02	4.82E-02	2.88E-02	1.61E-02	8.22E-03	3.70E-03	1.39E-03	3.97E-04	7.21E-05	7.26E-06
1953	4.42E+00	1.03E+01	9.87E+00	9.01E+00	7.46E+00	6.29E+00	5.55E+00	4.79E+00	4.14E+00	3.70E+00	3.38E+00	3.07E+00	2.79E+00	2.57E+00	2.38E+00	2.16E+00	1.90E+00	1.66E+00	1.42E+00	1.17E+00	9.18E-01	6.94E-01	5.15E-01	3.76E-01	2.62E-01	1.70E-01	9.96E-02	5.12E-02	2.19E-02	7.15E-03	1.52E-03	1.87E-04
1954	4.54E+00	1.06E+01	1.01E+01	9.21E+00	7.61E+00	6.40E+00	5.65E+00	4.87E+00	4.21E+00	3.77E+00	3.48E+00	3.20E+00	2.96E+00	2.82E+00	2.73E+00	2.59E+00	2.36E+00	2.24E+00	2.10E+00	1.91E+00	1.65E+00	1.36E+00	1.11E+00	8.84E-01	6.81E-01	4.88E-01	3.16E-01	1.80E-01	8.49E-02	3.07E-02	7.40E-03	1.09E-03
1955	4.74E+00	1.11E+01	1.05E+01	9.53E+00	7.85E+00	6.58E+00	5.79E+00	4.99E+00	4.31E+00	3.87E+00	3.59E+00	3.32E+00	3.10E+00	3.01E+00	2.99E+00	2.90E+00	2.70E+00	2.64E+00	2.57E+00	2.44E+00	2.20E+00	1.87E+00	1.56E+00	1.27E+00	1.01E+00	7.45E-01	4.99E-01	2.93E-01	1.43E-01	5.38E-02	1.36E-02	2.19E-03
1956	5.04E+00	1.18E+01	1.11E+01	1.00E+01	8.22E+00	6.85E+00	6.01E+00	5.16E+00	4.45E+00	4.00E+00	3.71E+00	3.45E+00	3.24E+00	3.19E+00	3.22E+00	3.16E+00	2.96E+00	2.95E+00	2.94E+00	2.85E+00	2.62E+00	2.26E+00	1.90E+00	1.56E+00	1.25E+00	9.33E-01	6.32E-01	3.75E-01	1.85E-01	7.07E-02	1.82E-02	3.01E-03
1957	5.53E+00	1.29E+01	1.21E+01	1.08E+01	8.79E+00	7.28E+00	6.34E+00	5.42E+00	4.66E+00	4.17E+00	3.87E+00	3.60E+00	3.39E+00	3.36E+00	3.42E+00	3.39E+00	3.19E+00	3.21E+00	3.24E+00	3.17E+00	2.95E+00	2.56E+00	2.16E+00	1.78E+00	1.43E+00	1.07E+00	7.31E-01	4.36E-01	2.17E-01	8.30E-02	2.15E-02	3.60E-03
1958	6.33E+00	1.47E+01	1.38E+01	1.21E+01	9.72E+00	7.97E+00	6.87E+00	5.83E+00	4.98E+00	4.44E+00	4.10E+00	3.81E+00	3.58E+00	3.56E+00	3.64E+00	3.61E+00	3.41E+00	3.45E+00	3.50E+00	3.45E+00	3.22E+00	2.81E+00	2.37E+00	1.95E+00	1.57E+00	1.18E+00	8.08E-01	4.83E-01	2.41E-01	9.25E-02	2.41E-02	4.05E-03
1959	7.79E+00	1.81E+01	1.67E+01	1.43E+01	1.13E+01	9.13E+00	7.75E+00	6.50E+00	5.50E+00	4.85E+00	4.45E+00	4.10E+00	3.85E+00	3.81E+00	3.89E+00	3.86E+00	3.64E+00	3.69E+00	3.75E+00	3.71E+00	3.47E+00	3.03E+00	2.56E+00	2.10E+00	1.70E+00	1.28E+00	8.72E-01	5.22E-01	2.60E-01	1.00E-01	2.62E-02	4.41E-03
1960	1.08E+01	2.50E+01	2.26E+01	1.87E+01	1.44E+01	1.13E+01	9.31E+00	7.65E+00	6.37E+00	5.54E+00	5.02E+00	4.57E+00	4.25E+00	4.17E+00	4.23E+00	4.18E+00	3.93E+00	3.98E+00	4.03E+00	3.99E+00	3.73E+00	3.25E+00	2.74E+00	2.25E+00	1.81E+00	1.36E+00	9.33E-01	5.59E-01	2.79E-01	1.07E-01	2.80E-02	4.74E-03
1961	1.86E+01	4.28E+01	3.74E+01	2.92E+01	2.12E+01	1.59E+01	1.25E+01	9.92E+00	8.03E+00	6.81E+00	6.02E+00	5.39E+00	4.92E+00	4.76E+00	4.76E+00	4.65E+00	4.34E+00	4.36E+00	4.40E+00	4.33E+00	4.04E+00	3.52E+00	2.96E+00	2.42E+00	1.95E+00	1.46E+00	1.00E+00	5.99E-01	2.98E-01	1.15E-01	3.00E-02	5.06E-03
1962	4.12E+01	9.43E+01	7.97E+01	5.84E+01	3.99E+01	2.79E+01	2.05E+01	1.53E+01	1.18E+01	9.54E+00	8.09E+00	6.99E+00	6.19E+00	5.81E+00	5.67E+00	5.44E+00	5.01E+00	4.96E+00	4.94E+00	4.82E+00	4.46E+00	3.87E+00	3.24E+00	2.64E+00	2.12E+00	1.59E+00	1.08E+00	6.48E-01	3.23E-01	1.24E-01	3.23E-02	5.44E-03
1963	9.02E+01	2.07E+02	1.75E+02	1.28E+02	8.70E+01	5.95E+01	4.18E+01	2.97E+01	2.17E+01	1.66E+01	1.32E+01	1.08E+01	9.11E+00	8.12E+00	7.56E+00	7.00E+00	6.29E+00	6.06E+00	5.90E+00	5.65E+00	5.16E+00	4.44E+00	3.69E+00	2.99E+00	2.39E+00	1.78E+00	1.21E+00	7.21E-01	3.58E-01	1.37E-01	3.56E-02	5.97E-03
1964	1.24E+02	2.86E+02	2.59E+02	2.14E+02	1.60E+02	1.18E+02	8.67E+01	6.29E+01	4.61E+01	3.47E+01	2.68E+01	2.10E+01	1.68E+01	1.41E+01	1.23E+01	1.08E+01	9.28E+00	8.52E+00	7.95E+00	7.35E+00	6.55E+00	5.53E+00	4.54E+00	3.64E+00	2.88E+00	2.13E+00	1.43E+00	8.47E-01	4.18E-01	1.59E-01	4.11E-02	6.83E-03
1965	1.11E+02	2.61E+02	2.56E+02	2.42E+02	2.01E+02	1.64E+02	1.35E+02	1.08E+02	8.52E+01	6.78E+01	5.43E+01	4.33E+01	3.48E+01	2.87E+01	2.42E+01	2.04E+01	1.70E+01	1.48E+01	1.31E+01	1.15E+01	9.84E+00	8.06E+00	6.47E+00	5.10E+00	3.96E+00	2.88E+00	1.91E+00	1.11E+00	5.42E-01	2.04E-01	5.20E-02	8.50E-03
1966	8.58E+01	2.03E+02	2.07E+02	2.06E+02	1.82E+02	1.61E+02	1.48E+02	1.29E+02	1.11E+02	9.56E+01	8.33E+01	7.16E+01	6.11E+01	5.28E+01	4.60E+01	3.96E+01	3.32E+01	2.87E+01	2.49E+01	2.13E+01	1.77E+01	1.41E+01	1.10E+01	8.43E+00	6.37E+00	4.53E+00	2.94E+00	1.68E+00	8.02E-01	2.96E-01	7.37E-02	1.16E-02
1967	7.01E+01	1.65E+02	1.66E+02	1.63E+02	1.45E+02	1.32E+02	1.26E+02	1.15E+02	1.04E+02	9.65E+01	9.10E+01	8.42E+01	7.72E+01	7.17E+01	6.70E+01	6.11E+01	5.39E+01	4.89E+01	4.40E+01	3.86E+01	3.26E+01	2.64E+01	2.08E+01	1.60E+01	1.21E+01	8.58E+00	5.55E+00	3.15E+00	1.50E+00	5.47E-01	1.35E-01	2.08E-02
1968	6.61E+01	1.55E+02	1.51E+02	1.41E+02	1.21E+02	1.07E+02	1.01E+02	9.24E+01	8.47E+01	8.07E+01	7.91E+01	7.66E+01	7.39E+01	7.33E+01	7.35E+01	7.13E+01	6.61E+01	6.34E+01	6.01E+01	5.53E+01	4.84E+01	4.01E+01	3.17E+01	2.40E+01	1.84E+01	1.33E+01	8.71E+00	5.01E+00	2.40E+00	8.87E-01	2.19E-01	3.37E-02
1969	7.25E+01	1.69E+02	1.59E+02	1.42E+02	1.17E+02	9.88E+01	8.90E+01	7.91E+01	7.10E+01	6.69E+01	6.57E+01	6.43E+01	6.35E+01	6.57E+01	6.91E+01	6.98E+01	6.66E+01	6.71E+01	6.68E+01	6.42E+01	5.84E+01	4.98E+01	4.00E+01	3.02E+01	2.38E+01	1.75E+01	1.18E+01	6.92E+00	3.38E+00	1.27E+00	3.23E-01	5.12E-02
1970	8.01E+01	1.87E+02	1.75E+02	1.56E+02	1.26E+02	1.04E+02	9.05E+01	7.77E+01	6.74E+01	6.17E+01	5.92E+01	5.71E+01	5.62E+01	5.88E+01	6.30E+01	6.46E+01	6.22E+01	6.41E+01	6.56E+01	6.47E+01	6.01E+01	5.20E+01	4.14E+01	3.03E+01	2.40E+01	1.79E+01	1.22E+01	7.28E+00	3.61E+00	1.38E+00	3.58E-01	5.84E-02
1971	6.80E+01	1.60E+02	1.59E+02	1.54E+02	1.31E+02	1.11E+02	9.78E+01	8.38E+01	7.19E+01	6.44E+01	6.02E+01	5.68E+01	5.48E+01	5.65E+01	6.01E+01	6.13E+01	5.88E+01	6.08E+01	6.26E+01	6.23E+01	5.82E+01	5.05E+01	3.97E+01	2.82E+01	2.23E+01	1.68E+01	1.15E+01	6.91E+00	3.45E+00	1.33E+00	3.49E-01	5.80E-02
1972	5.01E+01	1.19E+02	1.23E+02	1.24E+02	1.11E+02	1.00E+02	9.42E+01	8.46E+01	7.48E+01	6.83E+01	6.43E+01	6.04E+01	5.77E+01	5.85E+01	6.12E+01	6.16E+01	5.84E+01	5.98E+01	6.12E+01	6.06E+01	5.64E+01	4.88E+01	3.80E+01	2.65E+01	2.10E+01	1.57E+01	1.08E+01	6.46E+00	3.23E+00	1.25E+00	3.28E-01	5.49E-02
1973	3.08E+01	7.39E+01	8.02E+01	8.65E+01	8.11E+01	7.65E+01	7.54E+01	7.07E+01	6.53E+01	6.25E+01	6.16E+01	6.00E+01	5.86E+01	6.02E+01	6.32E+01	6.36E+01	6.02E+01	6.13E+01	6.21E+01	6.10E+01	5.65E+01	4.87E+01	3.77E+01	2.64E+01	2.07E+01	1.55E+01	1.05E+01	6.29E+00	3.13E+00	1.21E+00	3.16E-01	5.28E-02
1974	2.32E+01	5.50E+01	5.65E+01	5.74E+01	5.31E+01	5.10E+01	5.23E+01	5.09E+01	4.87E+01	4.84E+01	4.97E+01	5.02E+01	5.09E+01	5.43E+01	5.89E+01	6.07E+01	5.85E+01	6.03E+01	6.18E+01	6.10E+01	5.66E+01	4.89E+01	3.83E+01	2.73E+01	2.15E+01	1.60E+01	1.09E+01	6.48E+00	3.22E+00	1.24E+00	3.22E-01	5.36E-02
1975	4.65E+01	1.07E+02	9.11E+01	6.91E+01	5.07E+01	4.08E+01	3.72E+01	3.46E+01	3.29E+01	3.34E+01	3.55E+01	3.72E+01	3.92E+01	4.37E+01	4.92E+01	5.21E+01	5.11E+01	5.40E+01	5.64E+01	5.67E+01	5.32E+01	4.63E+01	3.65E+01	2.62E+01	2.08E+01	1.56E+01	1.06E+01	6.35E+00	3.16E+00	1.22E+00	3.17E-01	5.29E-02
1976	8.38E+01	1.93E+02	1.67E+02	1.28E+02	9.10E+01	6.51E+01	4.84E+01	3.71E+01	3.02E+01	2.73E+01	2.73E+01	2.80E+01	2.97E+01	3.41E+01	3.98E+01	4.32E+01	4.30E+01	4.65E+01	4.97E+01	5.07E+01	4.82E+01	4.23E+01	3.32E+01	2.35E+01	1.87E+01	1.41E+01	9.66E+00	5.82E+00	2.91E+00	1.13E+00	2.96E-01	4.98E-02
1977	6.62E+01	1.56E+02	1.58E+02	1.55E+02	1.30E+02	1.04E+02	8.28E+01	6.41E+01	4.96E+01	4.02E+01	3.43E+01	3.05E+01	2.89E+01	3.06E+01	3.42E+01	3.63E+01	3.55E+01	3.83E+01	4.09E+01	4.17E+01	3.96E+01	3.45E+01	2.58E+01	1.64E+01	1.29E+01	9.69E+00	6.66E+00	4.02E+00	2.02E+00	7.84E-01	2.07E-01	3.48E-02
1978	3.38E+01	8.21E+01	9.43E+01	1.08E+02	1.03E+02	9.71E+01	9.33E+01	8.34E+01	7.18E+01	6.20E+01	5.41E+01	4.71E+01	4.18E+01	3.96E+01	3.92E+01	3.78E+01	3.45E+01	3.43E+01	3.41E+01	3.28E+01	2.96E+01	2.47E+01	1.61E+01	8.22E+00	6.17E+00	4.55E+00	3.08E+00	1.83E+00	9.12E-01	3.52E-01	9.20E-02	1.50E-02
1979	1.34E+01	3.32E+01	4.18E+01	5.26E+01	5.54E+01	5.83E+01	6.35E+01	6.34E+01	6.10E+01	5.97E+01	5.90E+01	5.67E+01	5.35E+01	5.18E+01	5.04E+01	4.72E+01	4.16E+01	3.85E+01	3.51E+01	3.08E+01	2.57E+01	2.01E+01	1.20E+01	6.41E+00	4.63E+00	3.21E+00	2.04E+00	1.14E+00	5.38E-01	1.96E-01	4.79E-02	6.99E-03
1980	7.14E+00	1.73E+01	1.96E+01	2.28E+01	2.41E+01	2.67E+01	3.12E+01	3.37E+01	3.51E+01	3.78E+01	4.13E+01	4.32E+01	4.43E+01	4.62E+01	4.78E+01	4.66E+01	4.21E+01	3.87E+01	3.42E+01	2.87E+01	2.28E+01	1.72E+01	1.09E+01	7.40E+00	5.36E+00	3.58E+00	2.15E+00	1.13E+00	4.92E-01	1.64E-01	3.55E-02	4.11E-03
1981	1.03E+01	2.38E+01	2.13E+01	1.78E+01	1.47E+01	1.36E+01	1.43E+01	1.50E+01	1.59E+01	1.79E+01	2.06E+01	2.27E+01	2.45E+01	2.69E+01	2.93E+01	3.00E+01	2.85E+01	2.75E+01	2.55E+01	2.26E+01	1.92E+01	1.57E+01	1.16E+01	8.78E+00	6.86E+00	4.93E+00	3.19E+00	1.79E+00	8.30E-01	2.94E-01	6.83E-02	8.78E-03
1982	6.95E+00	1.66E+01	1.75E+01	1.81E+01	1.57E+01	1.32E+01	1.14E+01	9.92E+00	9.05E+00	9.13E+00	9.92E+00	1.08E+01	1.19E+01	1.36E+01	1.56E+01	1.69E+01	1.69E+01	1.76E+01	1.78E+01	1.73E+01	1.61E+01	1.42E+01	1.17E+01	9.59E+00	7.95E+00	6.09E+00	4.20E+00	2.52E+00	1.25E+00	4.80E-01	1.24E-01	1.98E-02
1983	2.65E+01	6.01E+01	4.83E+01	3.21E+01	2.06E+01	1.48E+01	1.24E+01	1.06E+01	9.18E+00	8.26E+00	7.74E+00	7.39E+00	7.30E+00	7.80E+00	8.71E+00	9.35E+00	9.41E+00	1.01E+01	1.08E+01	1.11E+01	1.09E+01	1.00E+01	8.71E+00	7.42E+00	6.34E+00	5.00E+00	3.55E+00	2.20E+00	1.13E+00	4.46E-01	1.20E-01	2.09E-02
1984	2.47E+01	5.78E+01	5.63E+01	5.21E+01	4.12E+01	3.06E+01	2.18E+01	1.53E+01	1.13E+01	9.07E+00	8.01E+00	7.33E+00	6.86E+00	6.74E+00	6.86E+00	6.86E+00	6.55E+00	6.75E+00	7.02E+00	7.18E+00	7.03E+00	6.49E+00	5.71E+00	4.94E+00	4.25E+00	3.38E+00	2.43E+00	1.52E+00	7.92E-01	3.18E-01	8.75E-02	1.59E-02
1985	3.88E+01	8.93E+01	7.90E+01	6.36E+01	4.84E+01	3.87E+01	3.32E+01	2.74E+01	2.20E+01	1.75E+01	1.38E+01	1.09E+01	8.73E+00	7.46E+00	6.79E+00	6.33E+00	5.83E+00	5.70E+00	5.62E+00	5.48E+00	5.15E+00	4.61E+00	3.95E+00	3.31E+00	2.78E+00	2.16E+00	1.53E+00	9.45E-01	4.87E-01	1.94E-01	5.30E-02	9.56E-03
1986	3.57E+01	8.38E+01	8.19E+01	7.65E+01	6.27E+01	5.03E+01	4.08E+01	3.28E+01	2.69E+01	2.31E+01	2.05E+01	1.81E+01	1.58E+01	1.39E+01	1.23E+01	1.08E+01	9.20E+00	8.24E+00	7.54E+00	6.93E+00	6.24E+00	5.40E+00	4.59E+00	3.91E+00	3.25E+00	2.50E+00	1.74E+00	1.07E+00	5.42E-01	2.14E-01	5.75E-02	1.02E-02
1987	3.46E+01	8.09E+01	7.83E+01	7.27E+01	6.13E+01	5.27E+01	4.74E+01	4.09E+01	3.46E+01	2.96E+01	2.58E+01	2.24E+01	1.96E+01	1.78E+01	1.67E+01	1.55E+01	1.39E+01	1.29E+01	1.19E+01	1.08E+01	9.38E+00	7.85E+00	6.50E+00	5.42E+00	4.35E+00	3.22E+00	2.17E+00	1.29E+00	6.36E-01	2.44E-01	6.39E-02	1.10E-02
1988	3.37E+01	7.89E+01	7.61E+01	7.05E+01	5.91E+01	5.05E+01	4.54E+01	3.98E+01	3.50E+01	3.18E+01	2.97E+01	2.74E+01	2.49E+01	2.31E+01	2.18E+01	2.02E+01	1.80E+01	1.68E+01	1.56E+01	1.43E+01	1.26E+01	1.06E+01	8.88E+00	7.47E+00	6.02E+00	4.45E+00	2.99E+00	1.75E+00	8.59E-01	3.25E-01	8.33E-02	1.38E-02
1989	1.46E+01	3.59E+01	4.36E+01	5.22E+01	5.01E+01	4.60E+01	4.29E+01	3.81E+01	3.37E+01	3.08E+01	2.90E+01	2.72E+01	2.56E+01	2.48E+01	2.45E+01	2.37E+01	2.20E+01	2.12E+01	2.01E+01	1.86E+01	1.65E+01	1.39E+01	1.15E+01	9.46E+00	7.55E+00	5.55E+00	3.70E+00	2.16E+00	1.05E+00	3.98E-01	1.02E-01	1.68E-02
1990	5.65E+00	1.40E+01	1.78E+01	2.28E+01	2.48E+01	2.71E+01	3.05E+01	3.07E+01	2.94E+01	2.83E+01	2.76E+01	2.64E+01	2.51E+01	2.47E+01	2.48E+01	2.44E+01	2.28E+01	2.23E+01	2.15E+01	2.02E+01	1.80E+01	1.53E+01	1.23E+01	9.45E+00	7.49E+00	5.51E+00	3.67E+00	2.14E+00	1.04E+00	3.92E-01	9.95E-02	1.60E-02
1991	3.29E+00	7.90E+00	8.73E+00	9.87E+00	1.03E+01	1.15E+01	1.36E+01	1.50E+01	1.62E+01	1.79E+01	2.00E+01	2.12E+01	2.16E+01	2.22E+01	2.31E+01	2.31E+01	2.18E+01	2.13E+01	2.03E+01	1.88E+01	1.65E+01	1.38E+01	1.04E+01	7.10E+00	5.52E+00	4.03E+00	2.67E+00	1.55E+00	7.50E-01	2.81E-01	7.09E-02	1.11E-02
1992	2.50E+00	5.91E+00	6.06E+00	6.15E+00	5.76E+00	5.70E+00	6.23E+00	6.72E+00	7.27E+00	8.47E+00	1.02E+01	1.18E+01	1.30E+01	1.47E+01	1.69E+01	1.83E+01	1.82E+01	1.88E+01	1.88E+01	1.78E+01	1.56E+01	1.25E+01	9.33E+00	6.93E+00	5.33E+00	3.83E+00	2.51E+00	1.44E+00	6.92E-01	2.55E-01	6.25E-02	9.29E-03
1993	2.32E+00	5.44E+00	5.31E+00	5.01E+00	4.37E+00	3.99E+00	4.03E+00	4.05E+00	4.11E+00	4.66E+00	5.64E+00	6.59E+00	7.31E+00	8.49E+00	1.03E+01	1.16E+01	1.19E+01	1.30E+01	1.36E+01	1.33E+01	1.18E+01	9.11E+00	6.63E+00	5.12E+00	3.96E+00	2.88E+00	1.91E+00	1.12E+00	5.42E-01	2.02E-01	4.97E-02	7.29E-03
1994	2.91E+00	6.75E+00	6.19E+00	5.32E+00	4.27E+00	3.60E+00	3.37E+00	3.20E+00	3.08E+00	3.36E+00	3.98E+00	4.57E+00	4.91E+00	5.58E+00	6.81E+00	7.74E+00	7.92E+00	8.84E+00	9.51E+00	9.51E+00	8.48E+00	6.46E+00	4.67E+00	3.71E+00	2.91E+00	2.13E+00	1.44E+00	8.59E-01	4.27E-01	1.63E-01	4.21E-02	6.72E-03
1995	3.87E+00	8.97E+00	8.14E+00	6.82E+00	5.28E+00	4.20E+00	3.59E+00	3.14E+00	2.83E+00	2.89E+00	3.25E+00	3.61E+00	3.75E+00	4.14E+00	4.98E+00	5.62E+00	5.72E+00	6.40E+00	6.93E+00	6.99E+00	6.26E+00	4.75E+00	3.41E+00	2.70E+00	2.06E+00	1.45E+00	9.50E-01	5.52E-01	2.71E-01	1.03E-01	2.70E-02	4.52E-03
1996	3.96E+00	9.25E+00	8.83E+00	7.99E+00	6.49E+00	5.27E+00	4.46E+00	3.76E+00	3.22E+00	3.03E+00	3.13E+00	3.24E+00	3.19E+00	3.33E+00	3.84E+00	4.22E+00	4.21E+00	4.63E+00	4.96E+00	4.97E+00	4.41E+00	3.31E+00	2.39E+00	1.95E+00	1.52E+00	1.10E+00	7.28E-01	4.28E-01	2.12E-01	8.15E-02	2.14E-02	3.64E-03
1997	9.78E+00	2.23E+01	1.86E+01	1.34E+01	9.14E+00	6.68E+00	5.43E+00	4.52E+00	3.83E+00	3.49E+00	3.39E+00	3.30E+00	3.12E+00	3.10E+00	3.38E+00	3.57E+00	3.48E+00	3.74E+00	3.95E+00	3.92E+00	3.48E+00	2.64E+00	1.94E+00	1.60E+00	1.26E+00	9.17E-01	6.12E-01	3.62E-01	1.79E-01	6.91E-02	1.82E-02	3.09E-03
1998	4.01E+00	9.90E+00	1.23E+01	1.47E+01	1.34E+01	1.10E+01	8.58E+00	6.55E+00	5.10E+00	4.30E+00	3.94E+00	3.69E+00	3.41E+00	3.31E+00	3.42E+00	3.46E+00	3.28E+00	3.40E+00	3.49E+00	3.41E+00	3.03E+00	2.36E+00	1.79E+00	1.49E+00	1.18E+00	8.68E-01	5.82E-01	3.44E-01	1.71E-01	6.57E-02	1.72E-02	2.93E-03
1999	1.17E+01	2.67E+01	2.19E+01	1.54E+01	1.11E+01	9.36E+00	9.21E+00	8.56E+00	7.56E+00	6.61E+00	5.79E+00	5.02E+00	4.35E+00	3.95E+00	3.83E+00	3.69E+00	3.41E+00	3.43E+00	3.44E+00	3.32E+00	2.95E+00	2.36E+00	1.85E+00	1.54E+00	1.23E+00	9.05E-01	6.08E-01	3.59E-01	1.77E-01	6.79E-02	1.77E-02	2.98E-03
2000	6.96E+00	1.67E+01	1.83E+01	1.95E+01	1.68E+01	1.33E+01	1.01E+01	7.83E+00	6.48E+00	6.00E+00	6.00E+00	5.90E+00	5.62E+00	5.38E+00	5.21E+00	4.89E+00	4.38E+00	4.19E+00	4.02E+00	3.76E+00	3.31E+00	2.68E+00	2.14E+00	1.77E+00	1.41E+00	1.04E+00	6.98E-01	4.12E-01	2.03E-01	7.74E-02	2.00E-02	3.34E-03
2001	2.12E+01	4.83E+01	3.95E+01	2.74E+01	1.87E+01	1.44E+01	1.28E+01	1.11E+01	9.40E+00	7.97E+00	6.83E+00	5.91E+00	5.28E+00	5.08E+00	5.17E+00	5.17E+00	4.93E+00	4.96E+00	4.91E+00	4.68E+00	4.18E+00	3.46E+00	2.80E+00	2.31E+00	1.82E+00	1.33E+00	8.87E-01	5.19E-01	2.53E-01	9.56E-02	2.44E-02	4.02E-03
2002	8.04E+00	2.00E+01	2.55E+01	3.12E+01	2.84E+01	2.30E+01	1.76E+01	1.32E+01	1.04E+01	8.91E+00	8.24E+00	7.67E+00	7.08E+00	6.70E+00	6.44E+00	6.04E+00	5.44E+00	5.28E+00	5.19E+00	5.01E+00	4.57E+00	3.88E+00	3.25E+00	2.74E+00	2.21E+00	1.66E+00	1.13E+00	6.69E-01	3.31E-01	1.26E-01	3.25E-02	5.36E-03
2003	1.60E+01	3.68E+01	3.15E+01	2.43E+01	1.94E+01	1.81E+01	1.88E+01	1.78E+01	1.57E+01	1.35E+01	1.15E+01	9.65E+00	8.31E+00	7.64E+00	7.39E+00	7.11E+00	6.60E+00	6.51E+00	6.40E+00	6.12E+00	5.54E+00	4.69E+00	3.89E+00	3.24E+00	2.59E+00	1.92E+00	1.30E+00	7.68E-01	3.79E-01	1.45E-01	3.75E-02	6.30E-03
2004	2.47E+01	5.69E+01	5.05E+01	4.05E+01	2.97E+01	2.18E+01	1.67E+01	1.34E+01	1.18E+01	1.15E+01	1.18E+01	1.17E+01	1.13E+01	1.08E+01	1.04E+01	9.63E+00	8.57E+00	8.10E+00	7.75E+00	7.32E+00	6.61E+00	5.62E+00	4.71E+00	3.95E+00	3.18E+00	2.38E+00	1.61E+00	9.59E-01	4.74E-01	1.81E-01	4.67E-02	7.76E-03
2005	7.20E+00	1.84E+01	2.61E+01	3.47E+01	3.36E+01	2.95E+01	2.50E+01	2.02E+01	1.61E+01	1.32E+01	1.13E+01	9.96E+00	9.29E+00	9.42E+00	9.94E+00	1.02E+01	9.83E+00	9.95E+00	9.92E+00	9.53E+00	8.65E+00	7.36E+00	6.13E+00	5.08E+00	4.03E+00	2.98E+00	2.00E+00	1.18E+00	5.78E-01	2.20E-01	5.64E-02	9.38E-03
2006	5.55E+00	1.31E+01	1.34E+01	1.41E+01	1.48E+01	1.69E+01	2.00E+01	2.04E+01	1.91E+01	1.76E+01	1.60E+01	1.42E+01	1.27E+01	1.18E+01	1.14E+01	1.08E+01	9.91E+00	9.88E+00	1.00E+01	9.91E+00	9.28E+00	8.11E+00	6.93E+00	5.90E+00	4.80E+00	3.62E+00	2.48E+00	1.48E+00	7.34E-01	2.81E-01	7.24E-02	1.20E-02
2007	3.72E+00	8.86E+00	9.39E+00	9.86E+00	9.09E+00	8.56E+00	8.73E+00	9.11E+00	9.81E+00	1.11E+01	1.27E+01	1.35E+01	1.37E+01	1.40E+01	1.42E+01	1.38E+01	1.27E+01	1.23E+01	1.20E+01	1.15E+01	1.05E+01	8.95E+00	7.49E+00	6.26E+00	5.04E+00	3.78E+00	2.57E+00	1.54E+00	7.67E-01	2.95E-01	7.71E-02	1.31E-02
2008	4.64E+00	1.08E+01	9.89E+00	8.57E+00	7.11E+00	6.34E+00	6.23E+00	5.99E+00	5.75E+00	5.91E+00	6.45E+00	7.10E+00	7.97E+00	9.46E+00	1.11E+01	1.22E+01	1.22E+01	1.29E+01	1.33E+01	1.32E+01	1.22E+01	1.05E+01	8.85E+00	7.40E+00	5.93E+00	4.42E+00	2.99E+00	1.78E+00	8.77E-01	3.34E-01	8.62E-02	1.43E-02
2009	3.03E+01	6.85E+01	5.34E+01	3.27E+01	1.84E+01	1.09E+01	7.34E+00	5.58E+00	4.71E+00	4.56E+00	4.84E+00	5.19E+00	5.68E+00	6.75E+00	8.09E+00	8.95E+00	9.05E+00	1.01E+01	1.12E+01	1.18E+01	1.15E+01	1.03E+01	8.92E+00	7.69E+00	6.34E+00	4.85E+00	3.35E+00	2.03E+00	1.01E+00	3.92E-01	1.02E-01	1.71E-02
2010	3.77E+01	8.75E+01	8.04E+01	6.81E+01	5.05E+01	3.54E+01	2.34E+01	1.51E+01	9.90E+00	7.07E+00	5.70E+00	5.09E+00	5.03E+00	5.70E+00	6.74E+00	7.41E+00	7.46E+00	8.36E+00	9.34E+00	1.00E+01	9.91E+00	8.96E+00	7.84E+00	6.79E+00	5.61E+00	4.28E+00	2.96E+00	1.80E+00	9.10E-01	3.57E-01	9.50E-02	1.65E-02
2011	2.20E+01	5.28E+01	5.82E+01	6.32E+01	5.69E+01	4.90E+01	4.21E+01	3.41E+01	2.66E+01	2.05E+01	1.56E+01	1.19E+01	9.39E+00	8.19E+00	7.85E+00	7.59E+00	7.07E+00	7.50E+00	8.13E+00	8.59E+00	8.48E+00	7.67E+00	6.73E+00	5.86E+00	4.86E+00	3.73E+00	2.59E+00	1.57E+00	7.99E-01	3.14E-01	8.39E-02	1.47E-02
2012	3.80E+00	1.05E+01	1.89E+01	2.95E+01	3.30E+01	3.48E+01	3.69E+01	3.52E+01	3.20E+01	2.90E+01	2.62E+01	2.30E+01	2.00E+01	1.76E+01	1.56E+01	1.36E+01	1.15E+01	1.04E+01	9.81E+00	9.30E+00	8.53E+00	7.39E+00	6.29E+00	5.36E+00	4.38E+00	3.32E+00	2.29E+00	1.38E+00	6.98E-01	2.73E-01	7.28E-02	1.27E-02
2013	9.51E+00	2.17E+01	1.82E+01	1.37E+01	1.22E+01	1.37E+01	1.74E+01	1.95E+01	2.06E+01	2.18E+01	2.29E+01	2.30E+01	2.24E+01	2.21E+01	2.16E+01	2.04E+01	1.84E+01	1.71E+01	1.59E+01	1.45E+01	1.26E+01	1.05E+01	8.57E+00	6.98E+00	5.46E+00	3.98E+00	2.64E+00	1.54E+00	7.54E-01	2.86E-01	7.37E-02	1.24E-02
2014	7.62E+00	1.80E+01	1.82E+01	1.77E+01	1.46E+01	1.15E+01	9.30E+00	8.31E+00	8.42E+00	9.75E+00	1.18E+01	1.36E+01	1.51E+01	1.71E+01	1.90E+01	1.99E+01	1.94E+01	1.97E+01	1.96E+01	1.89E+01	1.71E+01	1.46E+01	1.21E+01	1.00E+01	7.93E+00	5.82E+00	3.88E+00	2.26E+00	1.10E+00	4.12E-01	1.04E-01	1.67E-02
2015	5.34E+00	1.27E+01	1.33E+01	1.37E+01	1.25E+01	1.14E+01	1.09E+01	9.79E+00	8.49E+00	7.67E+00	7.42E+00	7.58E+00	8.35E+00	1.02E+01	1.26E+01	1.43E+01	1.46E+01	1.60E+01	1.73E+01	1.77E+01	1.69E+01	1.48E+01	1.26E+01	1.07E+01	8.66E+00	6.53E+00	4.46E+00	2.66E+00	1.32E+00	5.02E-01	1.29E-01	2.11E-02
2016	9.20E+00	2.12E+01	1.85E+01	1.46E+01	1.12E+01	9.38E+00	8.83E+00	8.25E+00	7.73E+00	7.65E+00	7.90E+00	8.05E+00	8.31E+00	9.29E+00	1.06E+01	1.13E+01	1.10E+01	1.19E+01	1.31E+01	1.38E+01	1.35E+01	1.18E+01	9.95E+00	8.52E+00	7.06E+00	5.45E+00	3.80E+00	2.32E+00	1.17E+00	4.58E-01	1.21E-01	2.04E-02

Table 33. Comparison of estimates of recruitment (in millions) from the 2015 assessment model and the author's preferred model (Model C).

year	2015AMO	Model C	year	2015AMO	Model C
1949	59.6776	55.50094	1981	76.5356	134.3166
1950	59.8205	55.64543	1982	39.3139	90.73108
1951	60.1639	55.99151	1983	275.663	345.1917
1952	60.7919	56.62214	1984	266.635	321.7581
1953	61.8298	57.66209	1985	673.123	505.7285
1954	63.4703	59.29945	1986	517.949	466.2398
1955	66.0213	61.84307	1987	485.609	451.0147
1956	70.0018	65.79869	1988	444.015	439.7472
1957	76.3484	72.11052	1989	168.656	190.8714
1958	86.9194	82.64877	1990	70.9547	73.67769
1959	105.917	101.6972	1991	40.7613	42.89692
1960	144.847	141.2456	1992	30.7408	32.61264
1961	243.604	242.8879	1993	27.7367	30.2713
1962	534.886	537.8609	1994	31.3207	37.95875
1963	1244.52	1177.443	1995	41.6183	50.5266
1964	1930.88	1614.854	1996	46.1383	51.67117
1965	1929.26	1449.538	1997	113.808	127.6255
1966	1545.71	1119.122	1998	46.0495	52.34728
1967	1214.54	914.795	1999	140.552	152.6885
1968	1015.76	862.8147	2000	84.9866	90.76738
1969	926.124	946.3382	2001	279.151	276.5523
1970	879.663	1044.716	2002	108.797	104.9517
1971	737.391	887.8475	2003	185.039	209.3066
1972	572.562	653.799	2004	306.444	322.0478
1973	458.562	402.4215	2005	87.258	93.97229
1974	299.761	303.081	2006	70.8674	72.47198
1975	376.505	606.3152	2007	52.9206	48.53087
1976	1113.94	1093.567	2008	60.9981	60.50948
1977	829.217	863.9371	2009	354.632	395.1637
1978	381.131	441.598	2010	422.936	492.0597
1979	126.068	175.2126	2011	251.061	286.7756
1980	57.8529	93.14897	2012	52.203	49.61038
			2013	115.803	124.1139
			2014	124.004	99.47437
			2015	80.7077	69.66514
			2016	--	120.013

Table 34. Comparison of exploitation rates (i.e., catch divided by biomass) from the 2015 assessment model and the author’s preferred model (Model C).

year	2015AMO	Model C
1949	0.002	0.003
1950	0.005	0.005
1951	0.009	0.009
1952	0.015	0.013
1953	0.023	0.016
1954	0.027	0.020
1955	0.029	0.022
1956	0.030	0.023
1957	0.031	0.023
1958	0.031	0.023
1959	0.031	0.023
1960	0.030	0.022
1961	0.029	0.022
1962	0.026	0.021
1963	0.021	0.018
1964	0.018	0.016
1965	0.027	0.024
1966	0.027	0.024
1967	0.064	0.059
1968	0.066	0.064
1969	0.082	0.082
1970	0.076	0.077
1971	0.067	0.066
1972	0.061	0.060
1973	0.063	0.065
1974	0.086	0.084
1975	0.082	0.074
1976	0.135	0.118
1977	0.196	0.172
1978	0.163	0.159
1979	0.210	0.227
1980	0.180	0.160
1981	0.075	0.070
1982	0.041	0.035
1983	0.023	0.017
1984	0.050	0.033
1985	0.018	0.019
1986	0.022	0.027
1987	0.040	0.042
1988	0.058	0.052
1989	0.134	0.117
1990	0.211	0.197
1991	0.175	0.171
1992	0.208	0.208
1993	0.155	0.153
1994	0.121	0.118
1995	0.114	0.110
1996	0.077	0.073
1997	0.052	0.047
1998	0.039	0.037
1999	0.020	0.019
2000	0.020	0.018
2001	0.026	0.023
2002	0.017	0.016
2003	0.011	0.011
2004	0.011	0.011
2005	0.019	0.018
2006	0.027	0.025
2007	0.030	0.027
2008	0.022	0.020
2009	0.018	0.017
2010	0.009	0.009
2011	0.010	0.010
2012	0.007	0.006
2013	0.020	0.018
2014	0.069	0.060
2015	--	0.081772

Table 35. OFL and ABC values for the models considered here. These values are presented only to illustrate the effect of incremental changes in the data used for the assessment on the OFL and ABC. The models highlighted in blue are based on data through 2014/15 (including the 2015 NMFS EBS trawl survey), while the others are based on data through 2015/16 (including the 2016 survey). Results from the author's preferred model (Model C) are highlighted in yellow.

Model	Snow Crab Fofl	Efffective Snow Crab F	Average Recruitment	B	Fmsy	Bmsy	B/Bmsy	OFL	ABC P-star	ABC (20% buffer)
2015 Model	1.32	0.049	179.37	53.70	0.58	26.79	2.00	27.19	27.15	21.75
2015AMR	1.32	0.051	176.78	51.41	0.64	25.68	2.00	27.27	27.23	21.82
2015AMN	1.32	0.044	193.44	63.85	0.56	29.42	2.17	30.96	30.91	24.77
2015AM	1.24	0.030	183.46	48.07	0.59	26.68	1.80	23.79	23.75	19.03
Model A	--	--	--	--	--	--	--	--	--	--
Model B	1.24	0.092	182.17	45.32	0.79	25.64	1.77	25.60	25.56	20.48
Model C	1.24	0.092	182.27	45.34	0.79	25.65	1.77	25.61	25.57	20.49
Model D	1.24	0.111	168.84	39.06	0.09	22.85	1.71	25.79	25.75	20.63
Model E	1.24	0.097	174.24	42.19	0.44	23.06	1.83	27.36	27.31	21.89
Model F	1.24	0.070	163.57	39.52	0.96	22.41	1.76	21.83	21.79	17.46
Model G	1.24	0.061	171.74	43.26	1.02	23.70	1.83	24.55	24.51	19.64

Figures

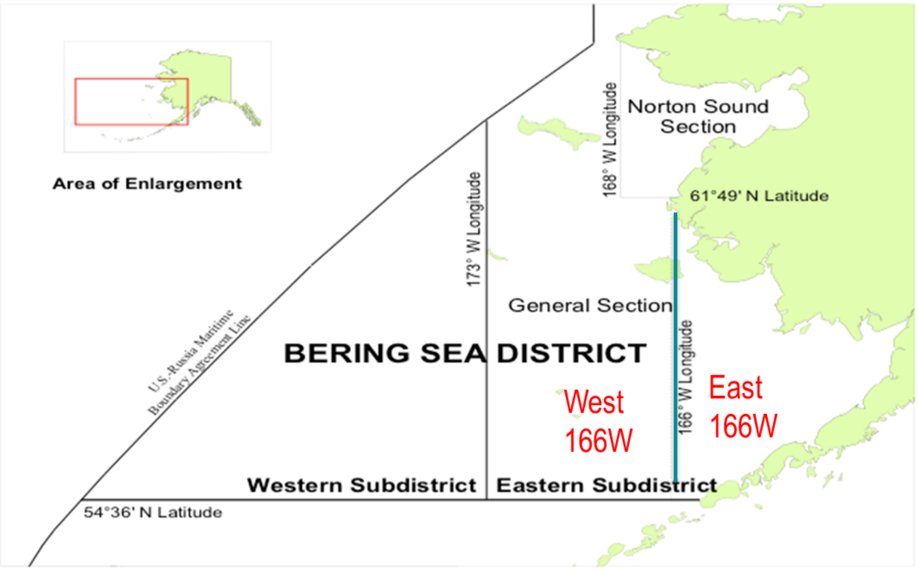


Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008).

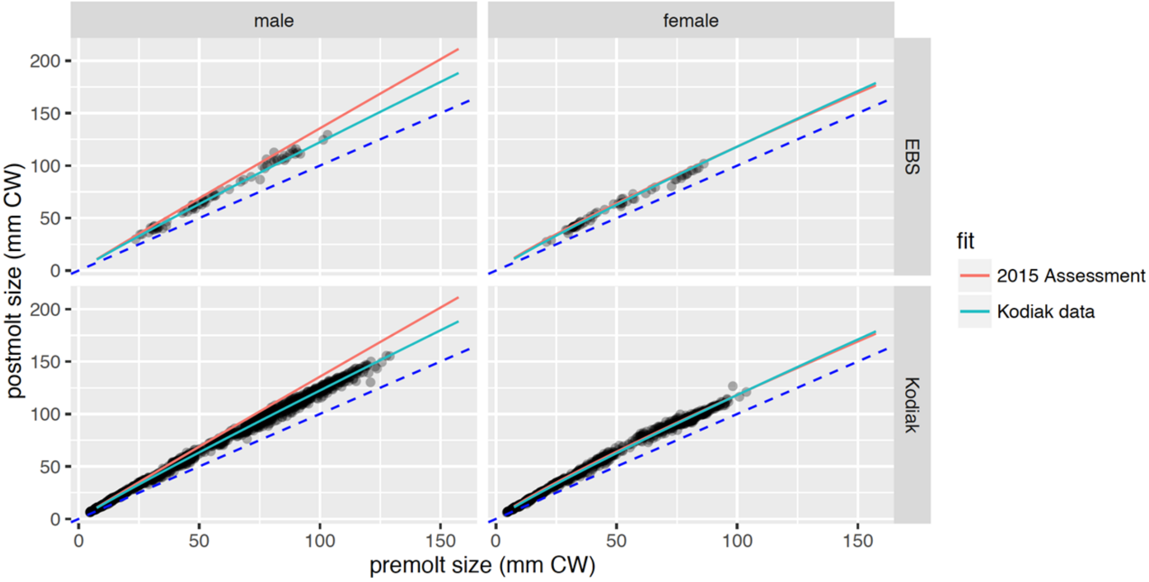


Figure 2. Growth of male (a) and female (b) Tanner crab as a function of premolt size. Grey circles: observations; red lines: post-molt size estimated in the 2015 assessment; green line: post-molt regression based on Kodiak data; dotted blue line: no-growth line.

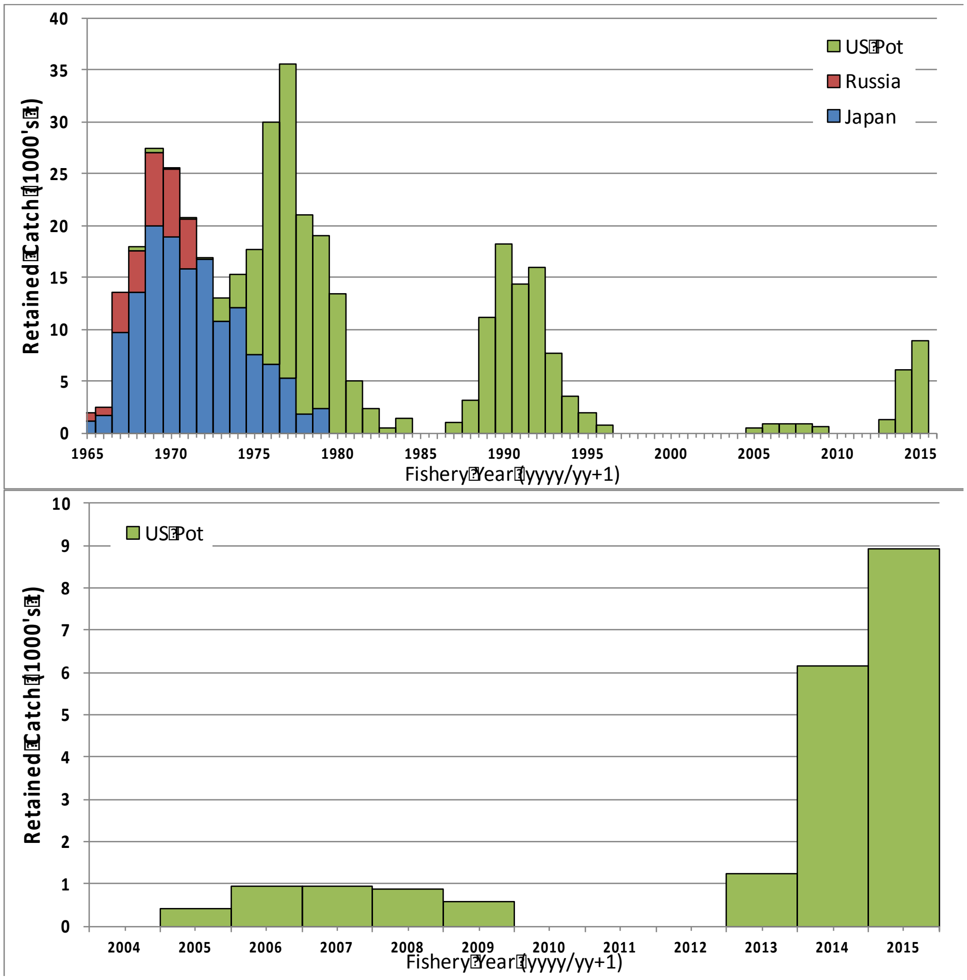


Figure 3. Upper: retained catch (males, 1000's t) in the directed fisheries (US pot fishery [green bars], Russian tangle net fishery [red bars], and Japanese tangle net fisheries [blue bars]) for Tanner crab since 1965/66. Lower: Retained catch (males, 1000's t) in directed fishery since 2001/02. The directed fishery was closed from 1996/97 to 2004/05 and from 2010/11 to 2012/13.

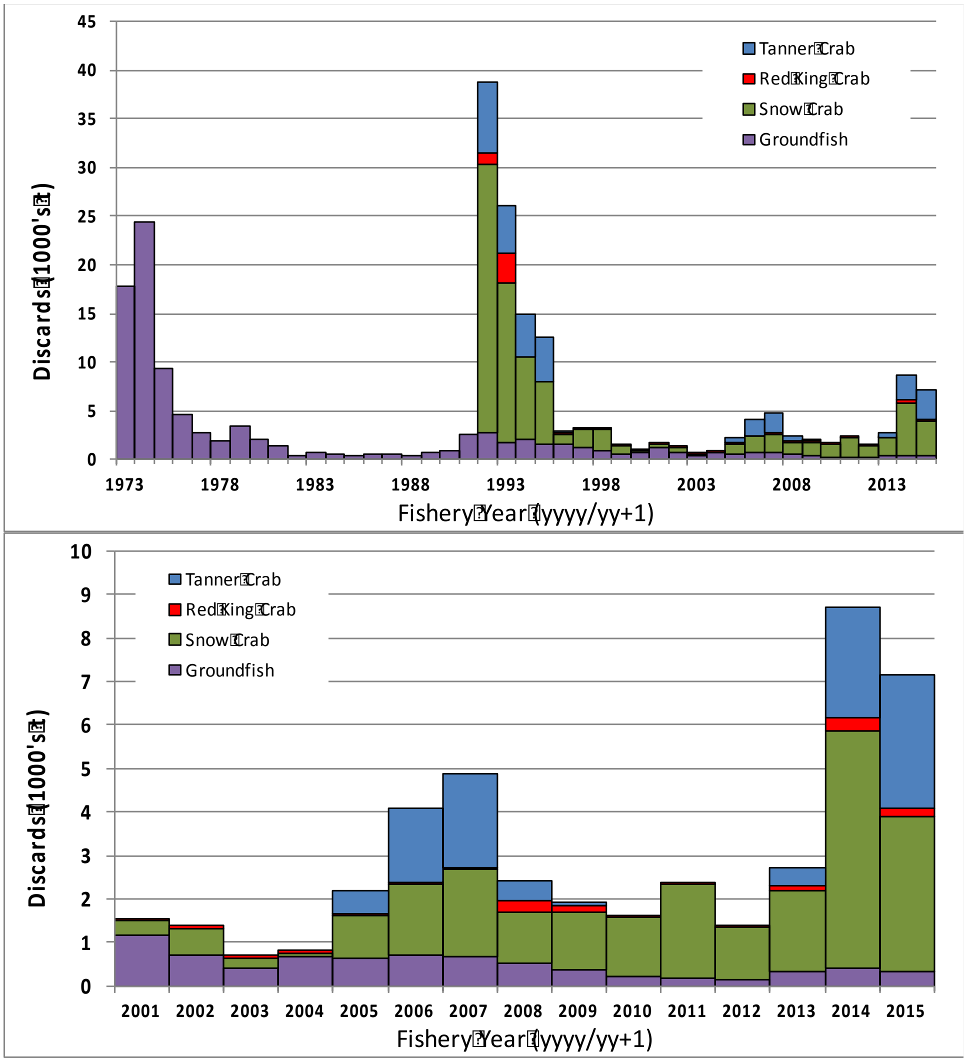


Figure 4. Upper: Tanner crab discards (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Discard reporting began in 1973 for the groundfish fisheries and in 1992 for the crab fisheries. Lower: detail since 2001.

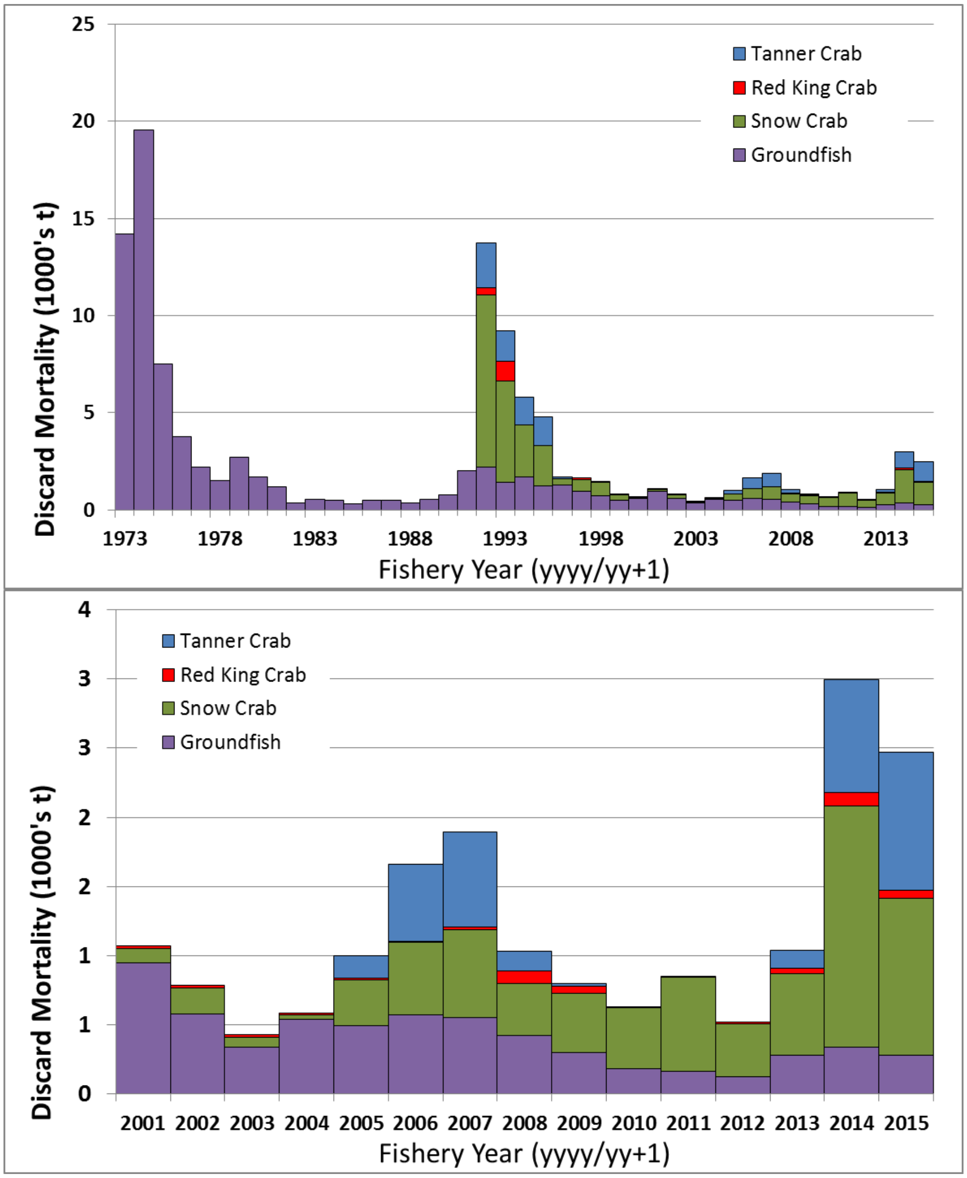


Figure 5. Upper: Tanner crab discard mortality (males and females, 1000’s t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Assumed handling mortality rates of 0.321 for the crab fisheries and 0.80 for the groundfish fisheries were applied to discard biomass to obtain discard mortality. Lower: detail since 2001.

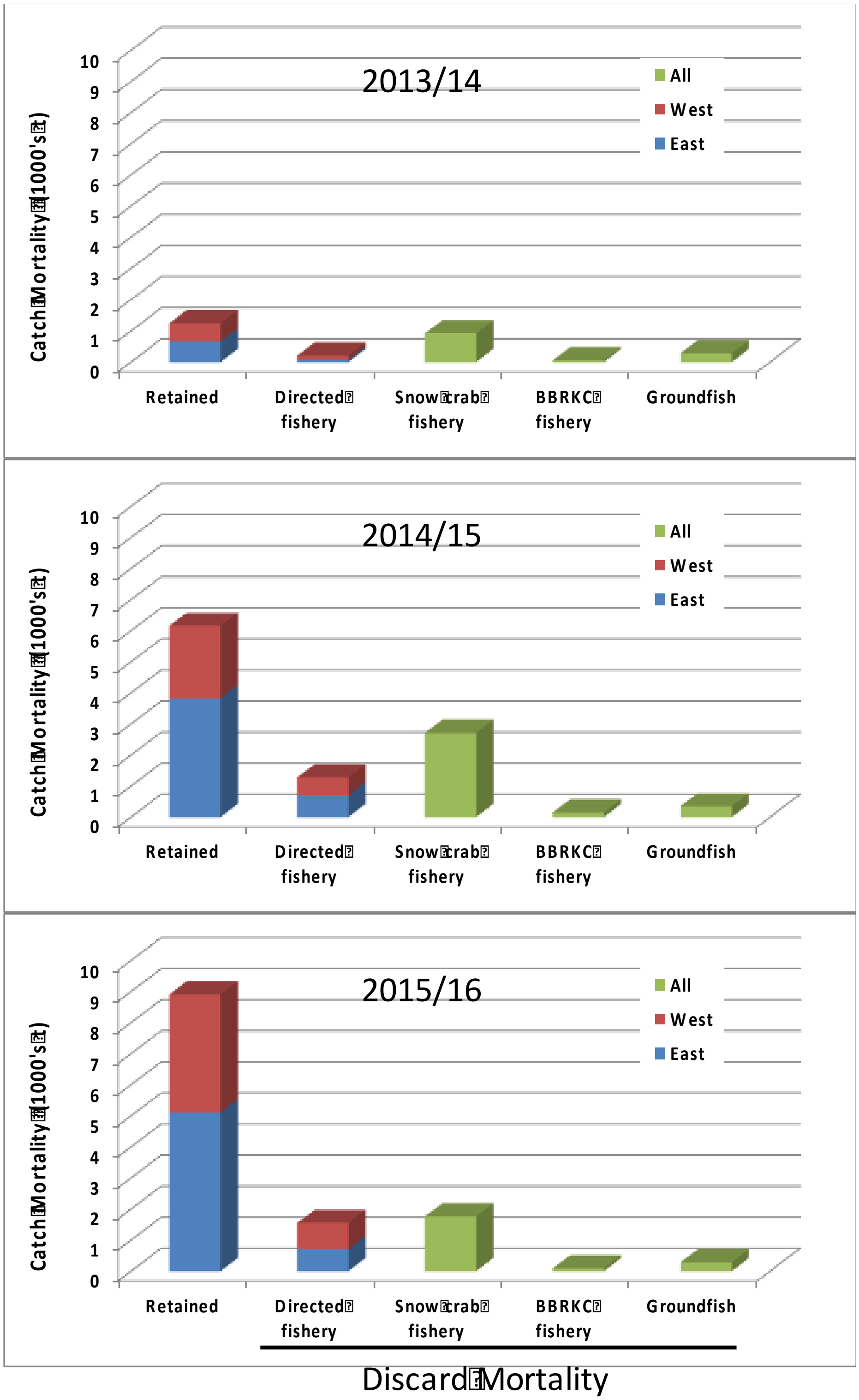


Figure 6. Retained and discard catch mortality (1000’s t) in the directed, snow crab, BBRKC and groundfish fisheries. Handling mortality rates of 0.321 for the crab fisheries and 0.8 for the groundfish fisheries were applied to estimated discards.

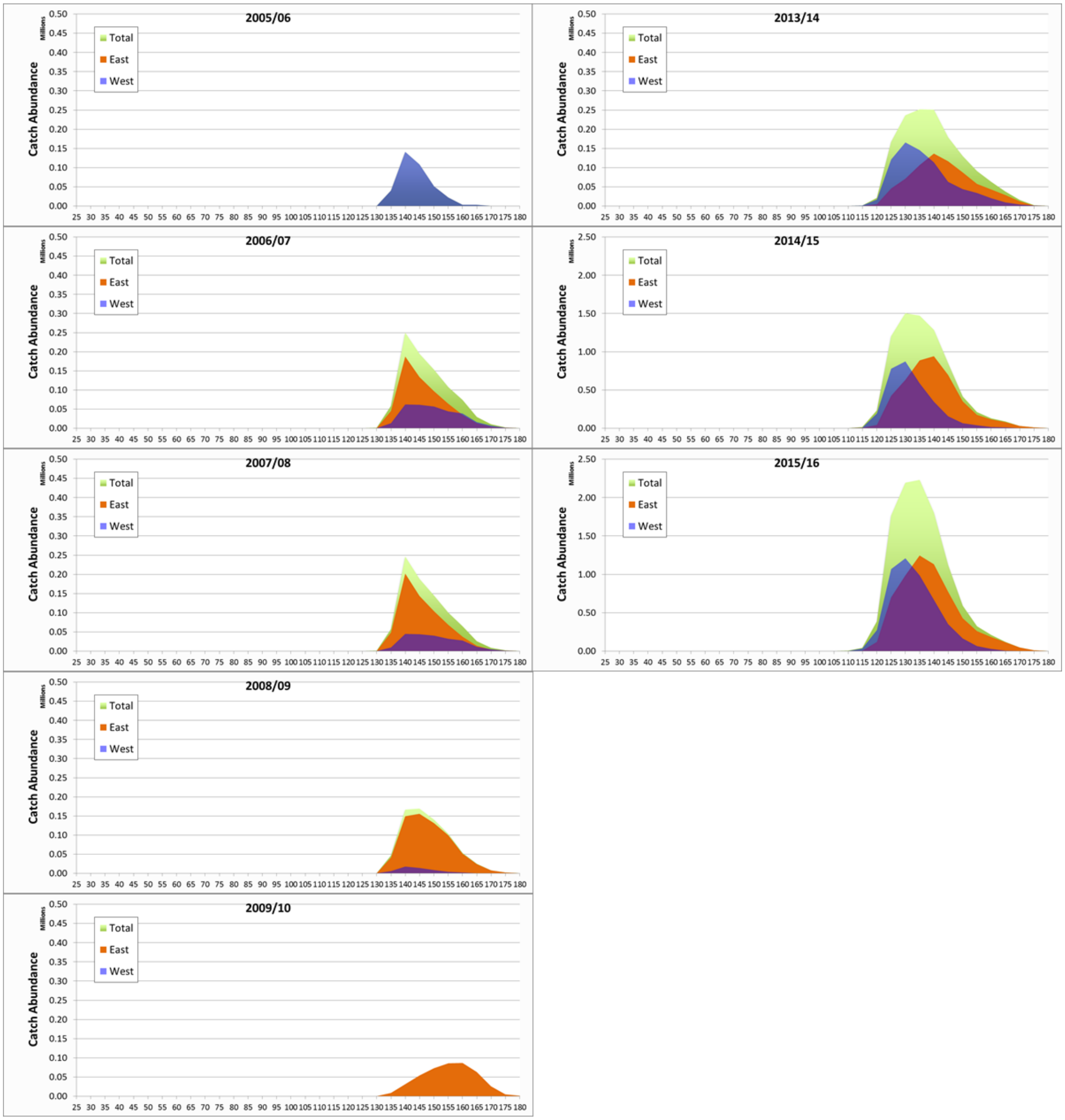


Figure 7. Size compositions, by 5 mm CW bins and expanded to total retained catch, for retained (male) crab in the directed Tanner crab pot fisheries since 2006/07, from dockside crab fishery observer sampling. Fishing occurred only east of 166ºW in 2009/10. The entire fishery was closed in 2010/11-2012/13. Note scale change in 2014/15.

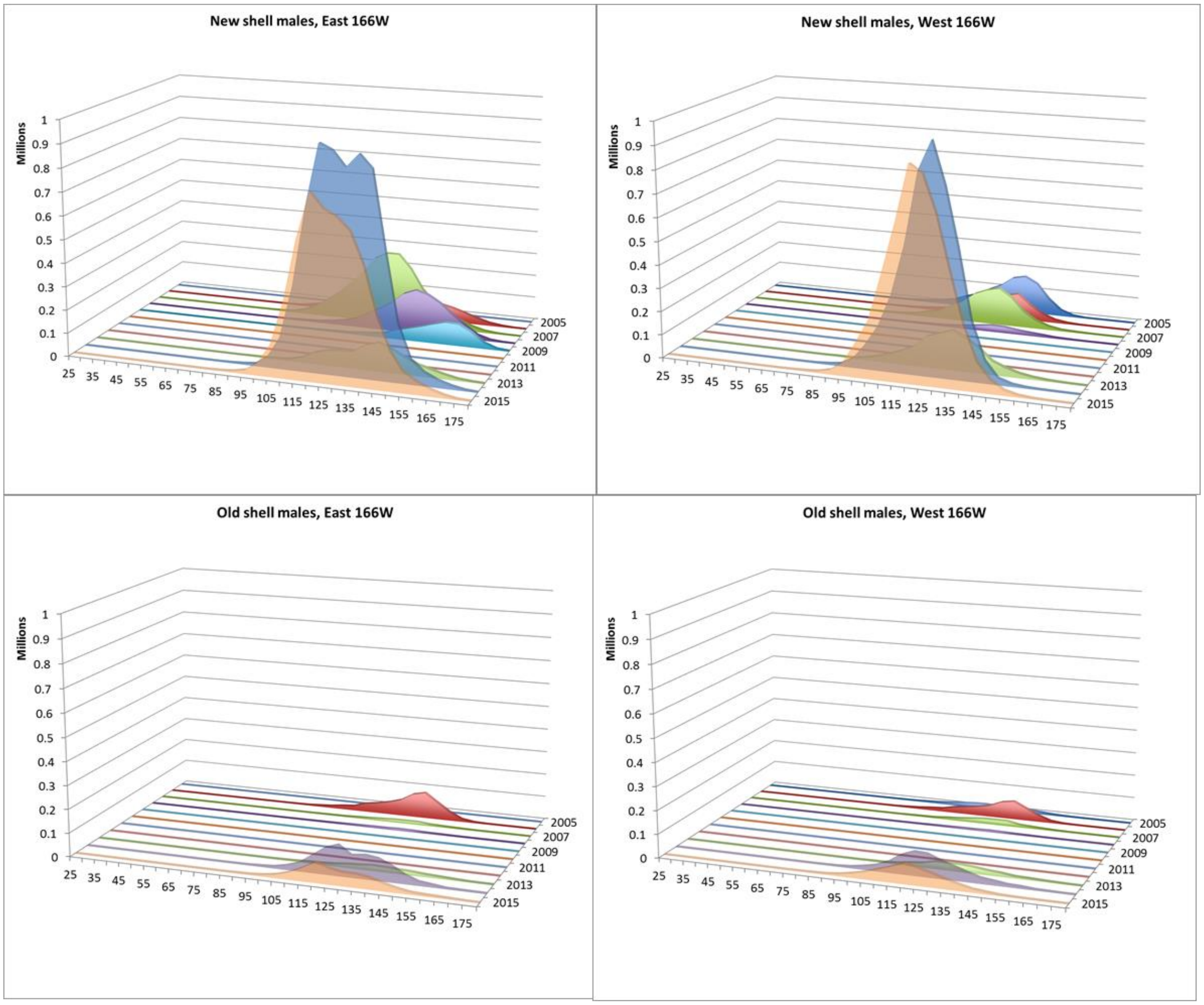


Figure 8. Male Tanner crab catch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling.

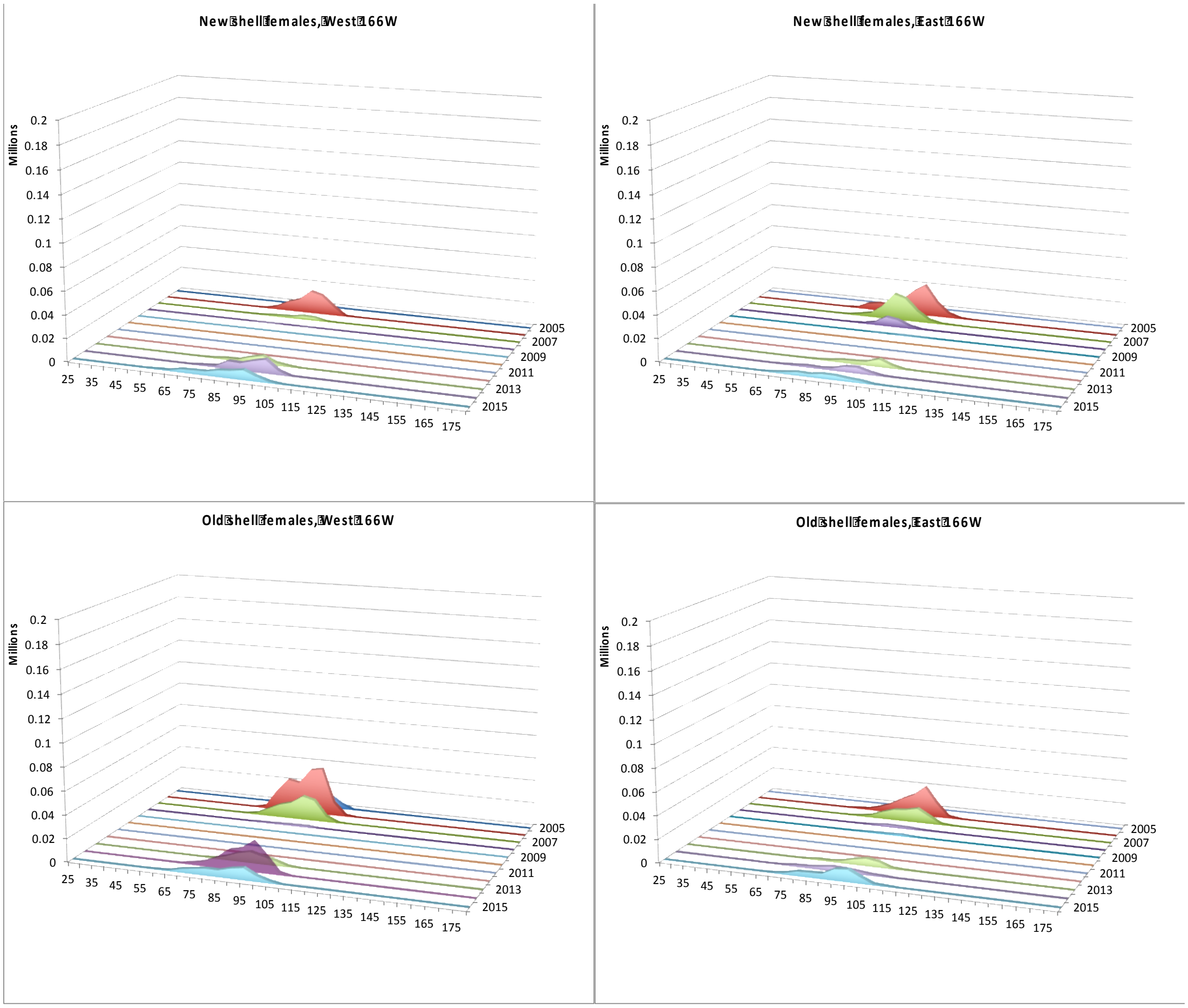


Figure 9. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling.

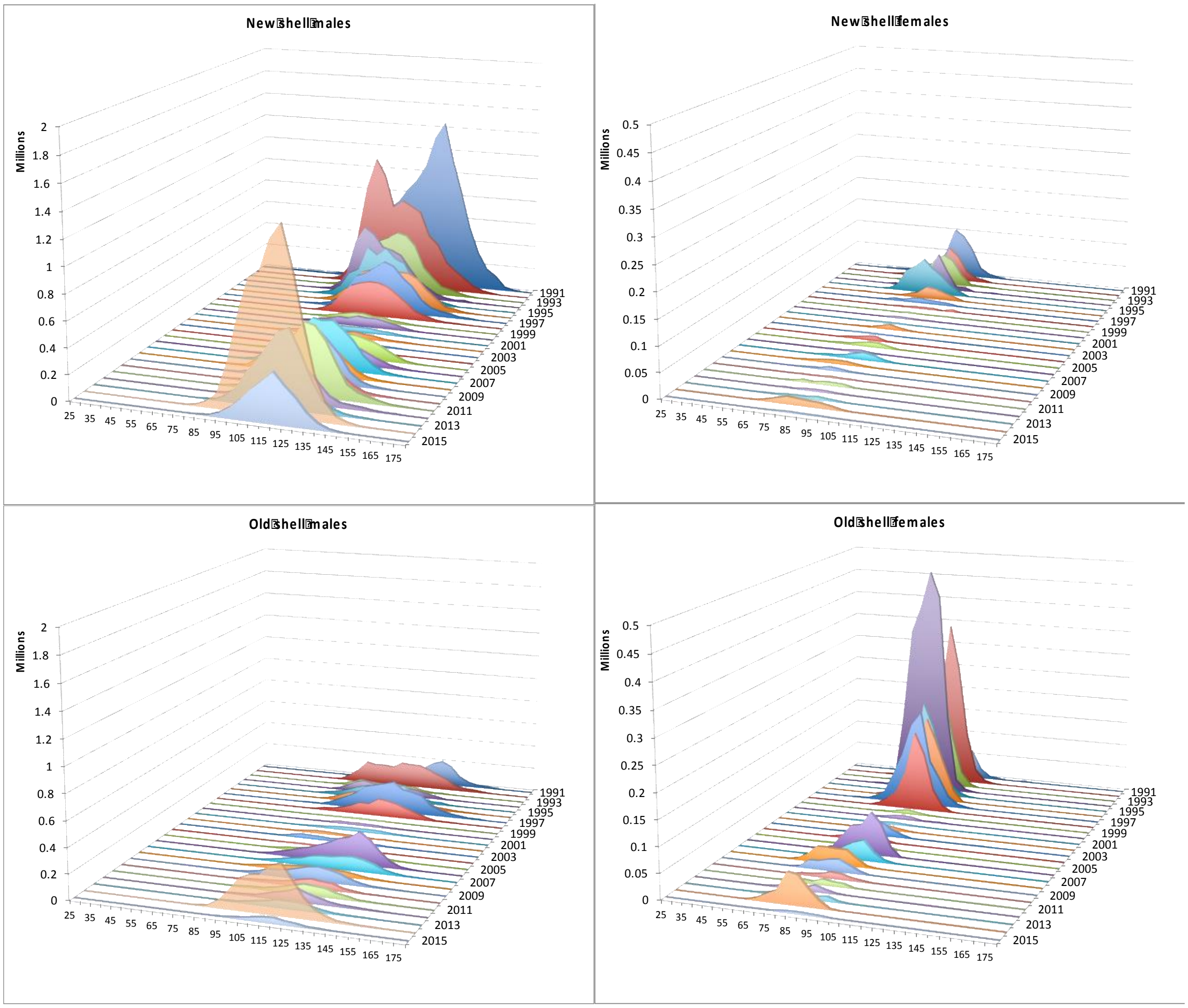


Figure 10. Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the snow crab pot fishery, from at-sea crab fishery observer sampling.

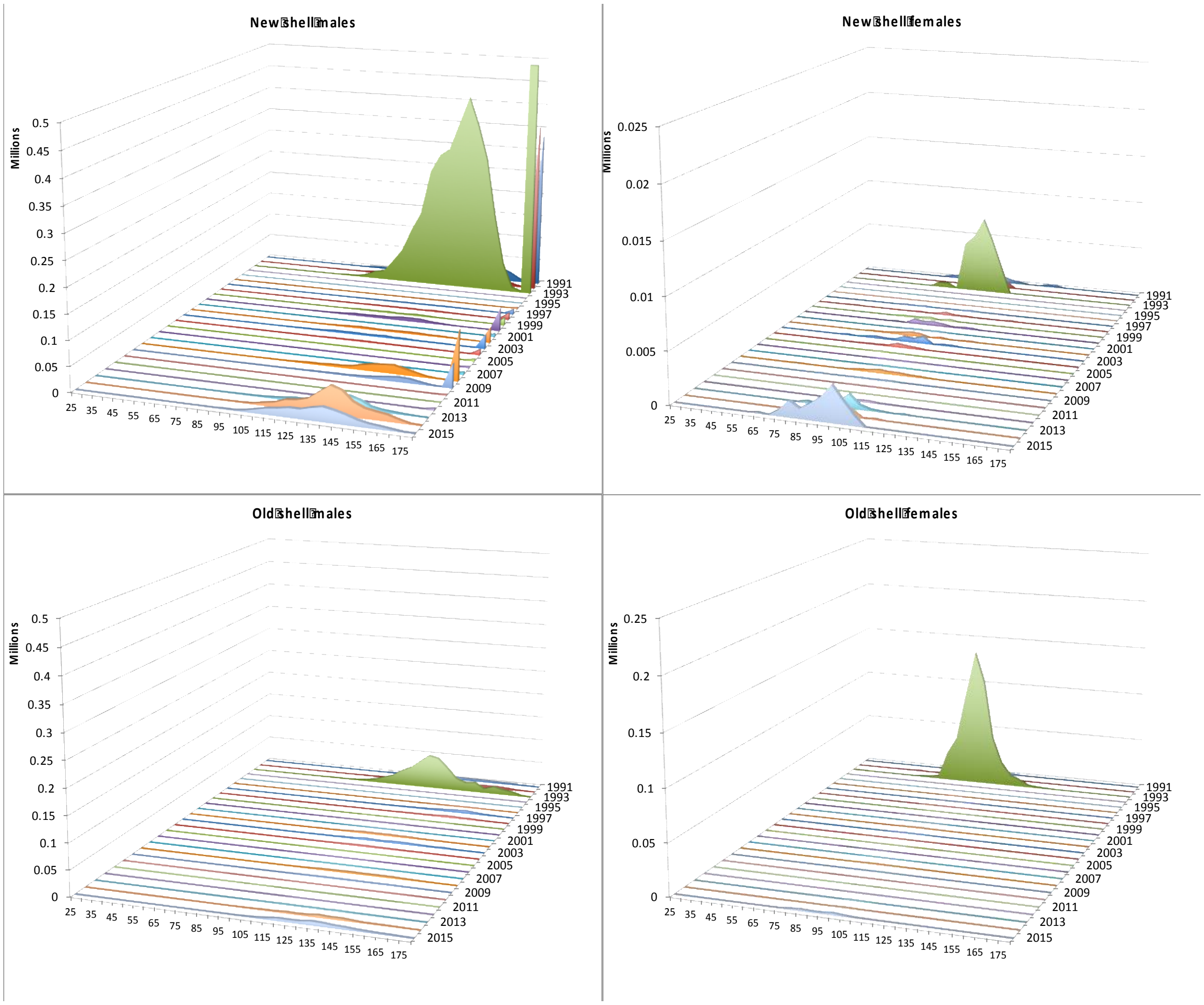


Figure 11. Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the BBRKC pot fishery, from at-sea crab fishery observer sampling.

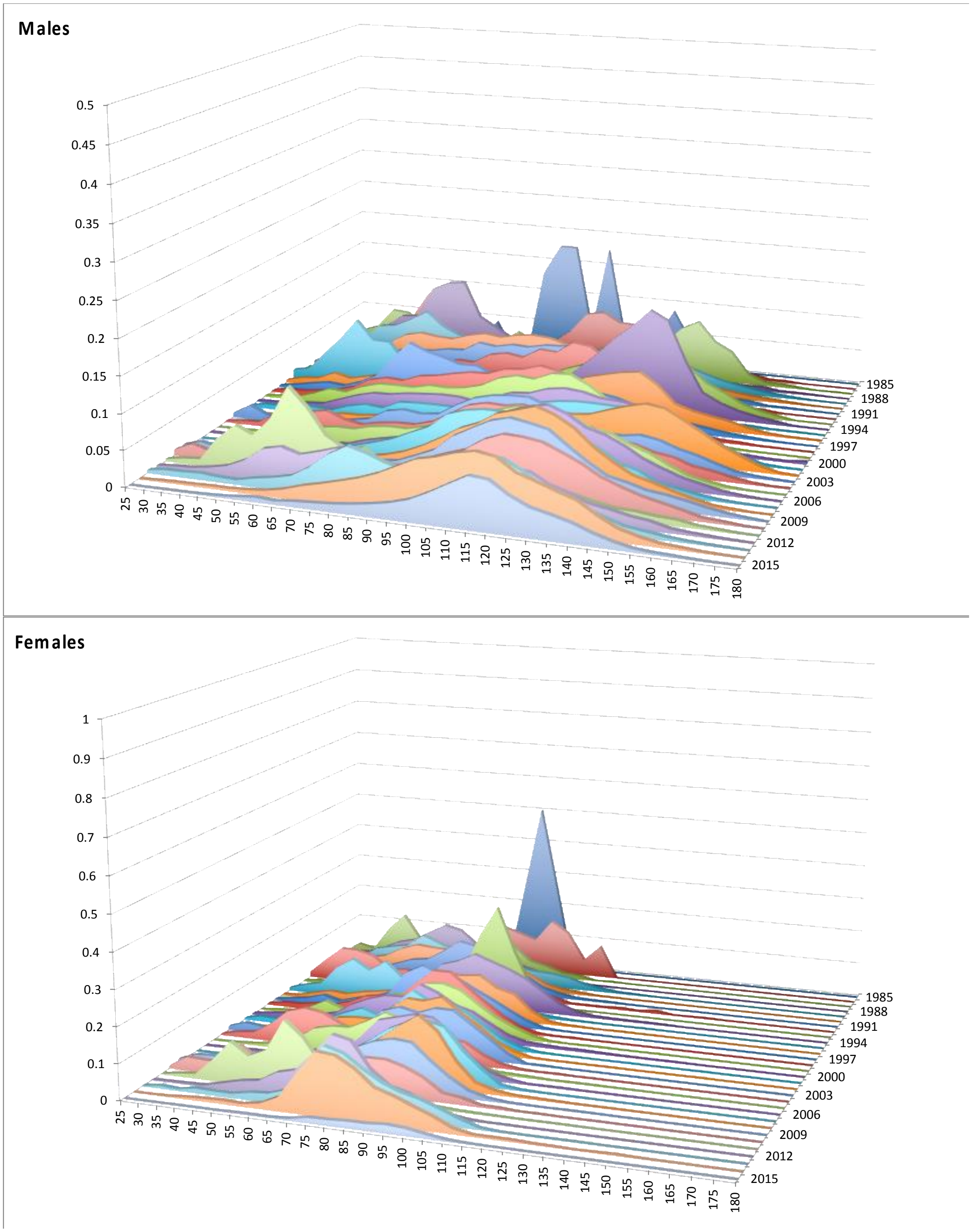


Figure 12. Normalized Tanner crab bycatch size compositions in the groundfish fisheries, from groundfish observer sampling. Size compositions have been normalized to sum to 1 for each year.

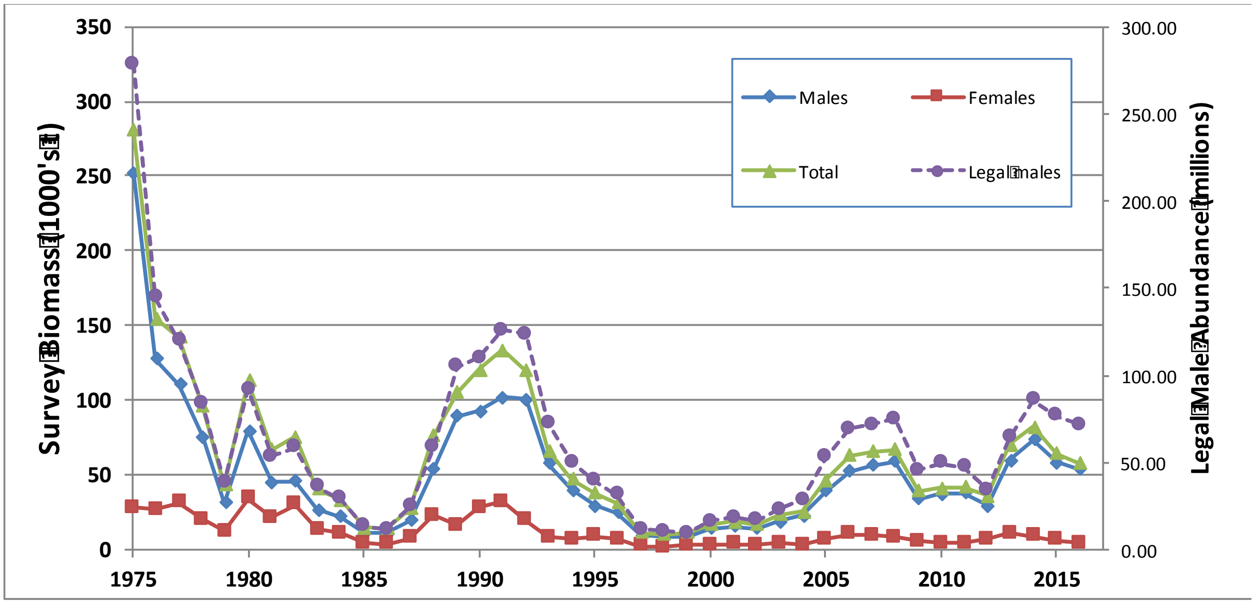


Figure 13. Trends in survey biomass for mature male and female Tanner crab, and in abundance for legal males, based on the NMFS EBS bottom trawl survey.

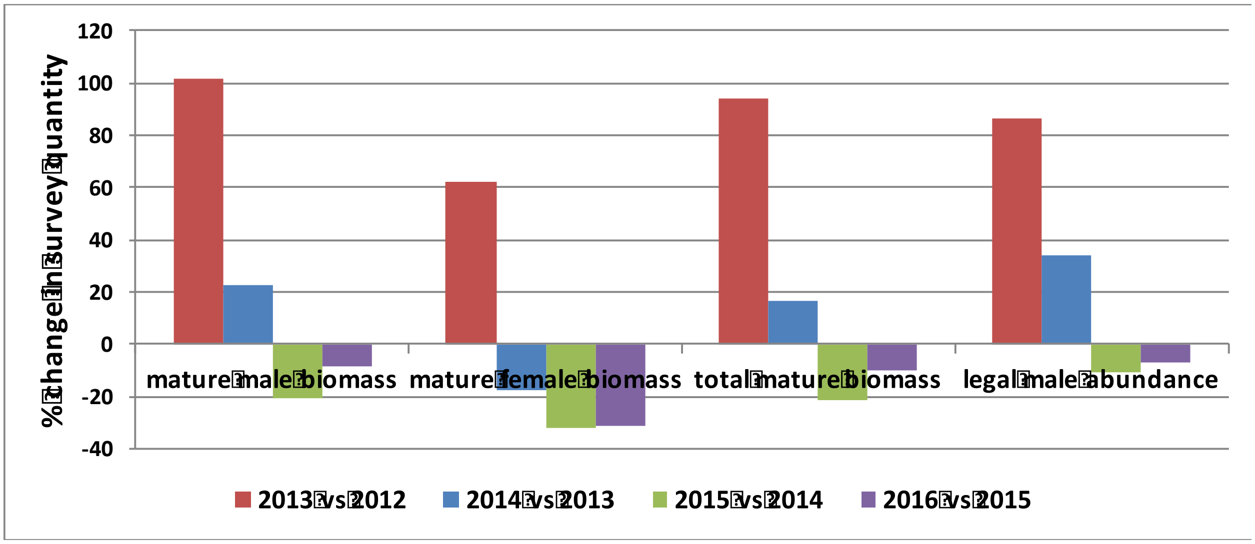


Figure 14. Percent change in mature male biomass, mature female biomass, total mature biomass and abundance of legal crab observed in the NMFS bottom trawl survey during the past 4 surveys.

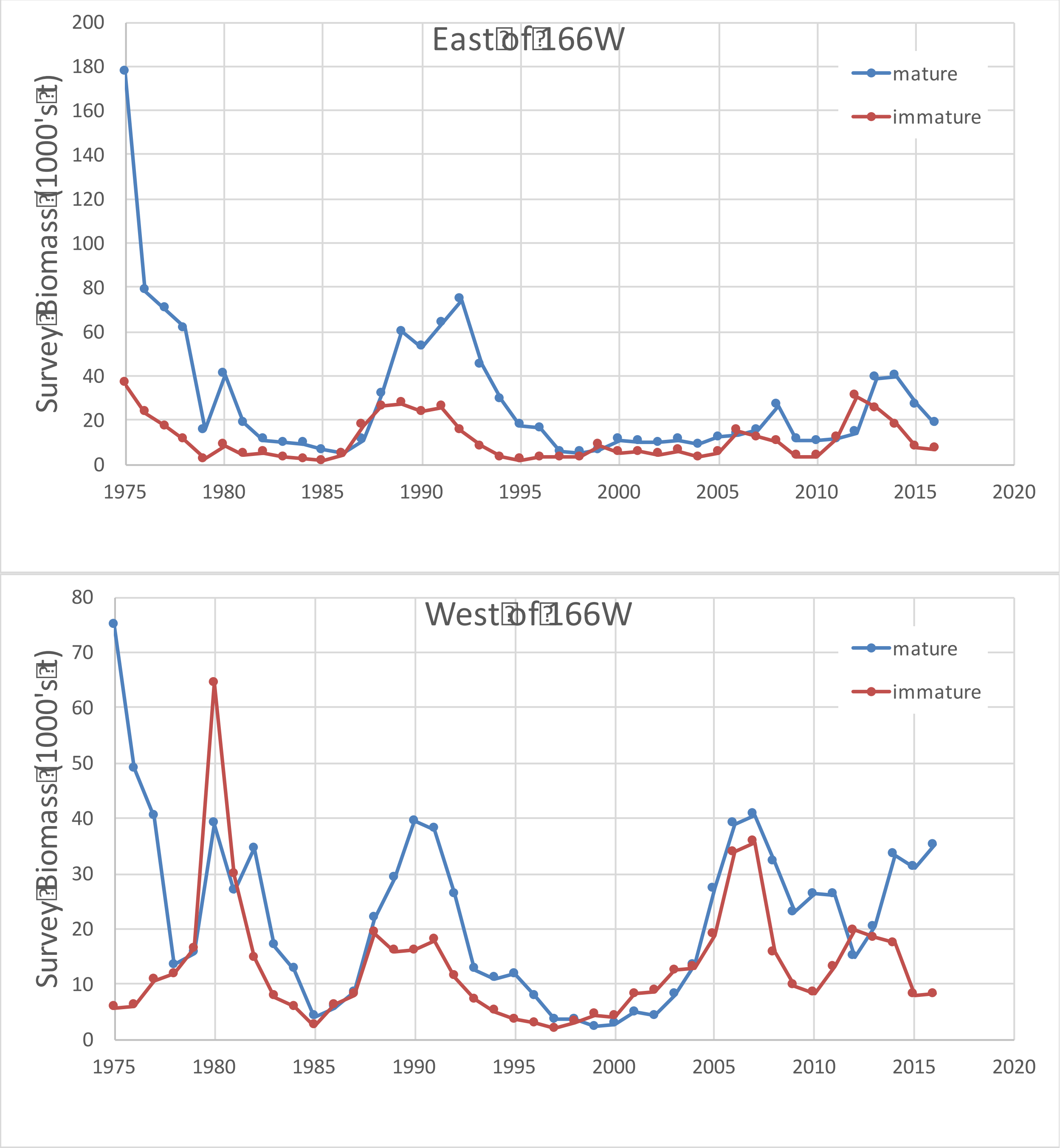


Figure 15. Trends in survey biomass for male Tanner crab in areas east and west of 166^{o}W longitude, based on the NMFS EBS bottom trawl survey.

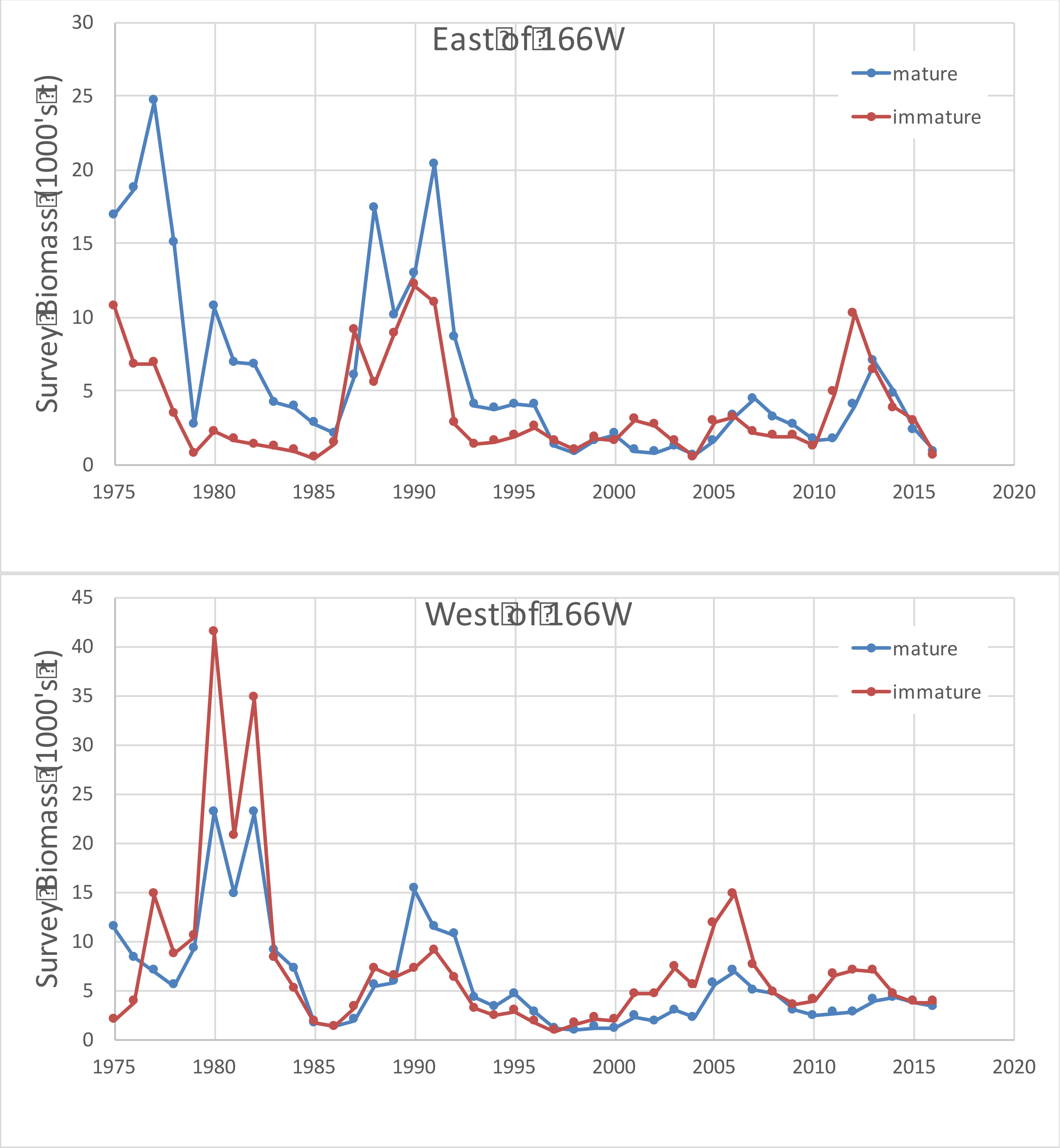


Figure 16. Trends in survey biomass for female Tanner crab in areas east and west of 166ºW longitude, based on the NMFS EBS bottom trawl survey.

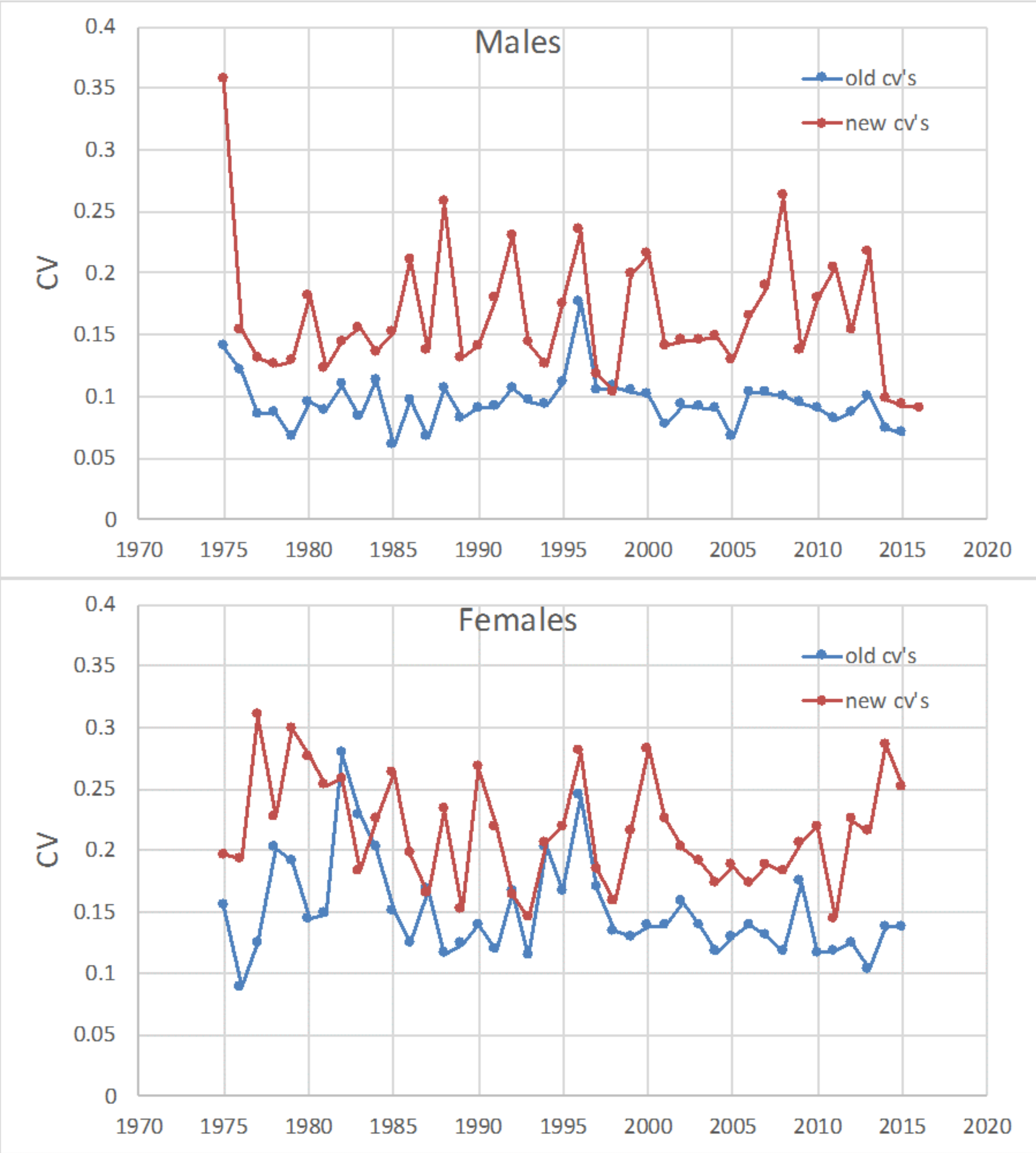


Figure 17. Comparison of cv’s for mature survey biomass using the “new” and “old” approaches.

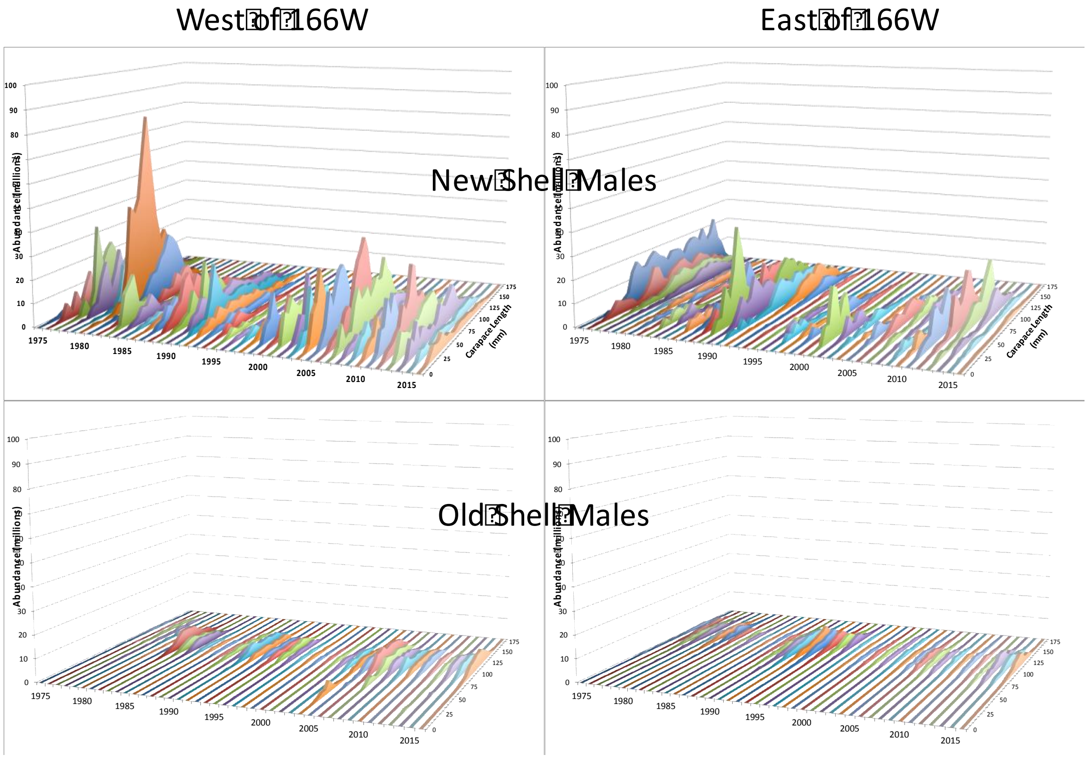


Figure 18. Numbers at size (millions) by area and shell condition for male Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW.

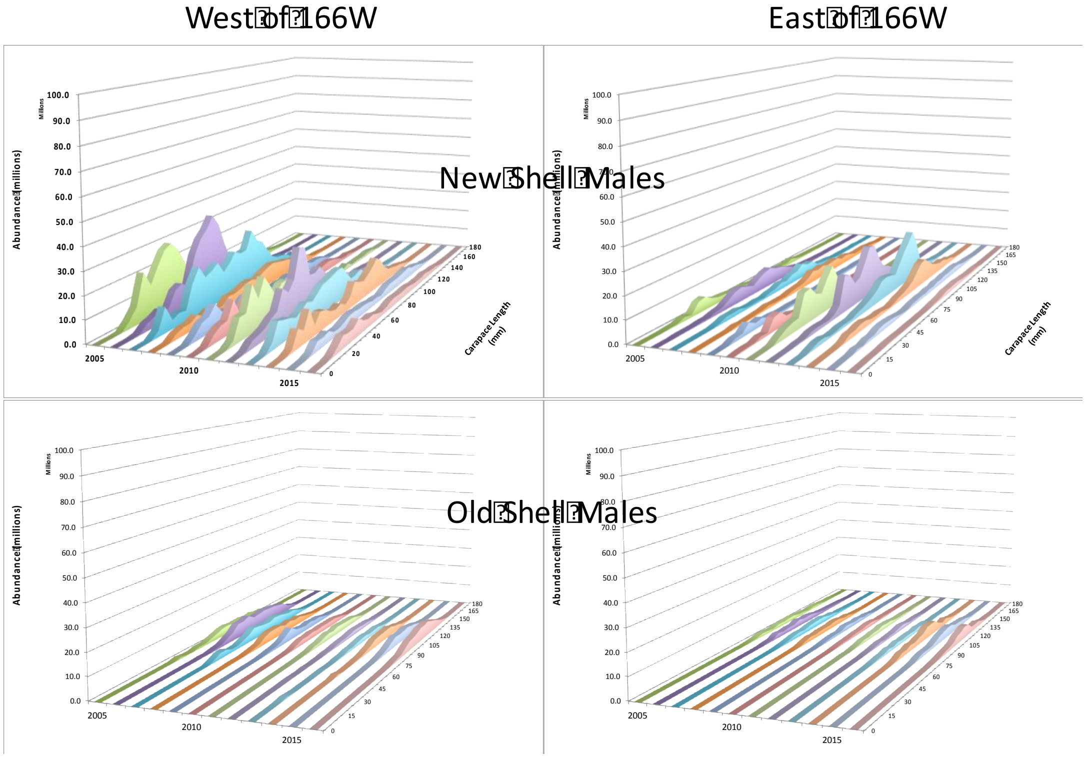


Figure 19. Numbers at size (millions) by area and shell condition for male Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW, since 2005.

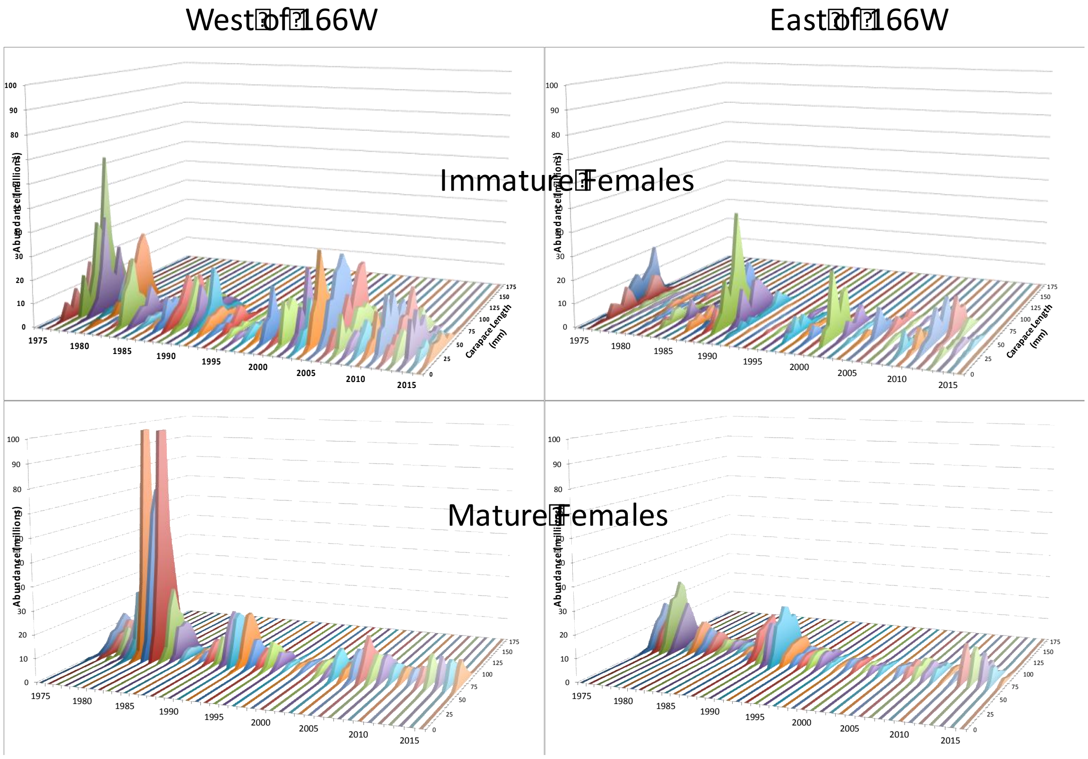


Figure 20. Numbers at size (millions) by area and shell condition for female Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW.

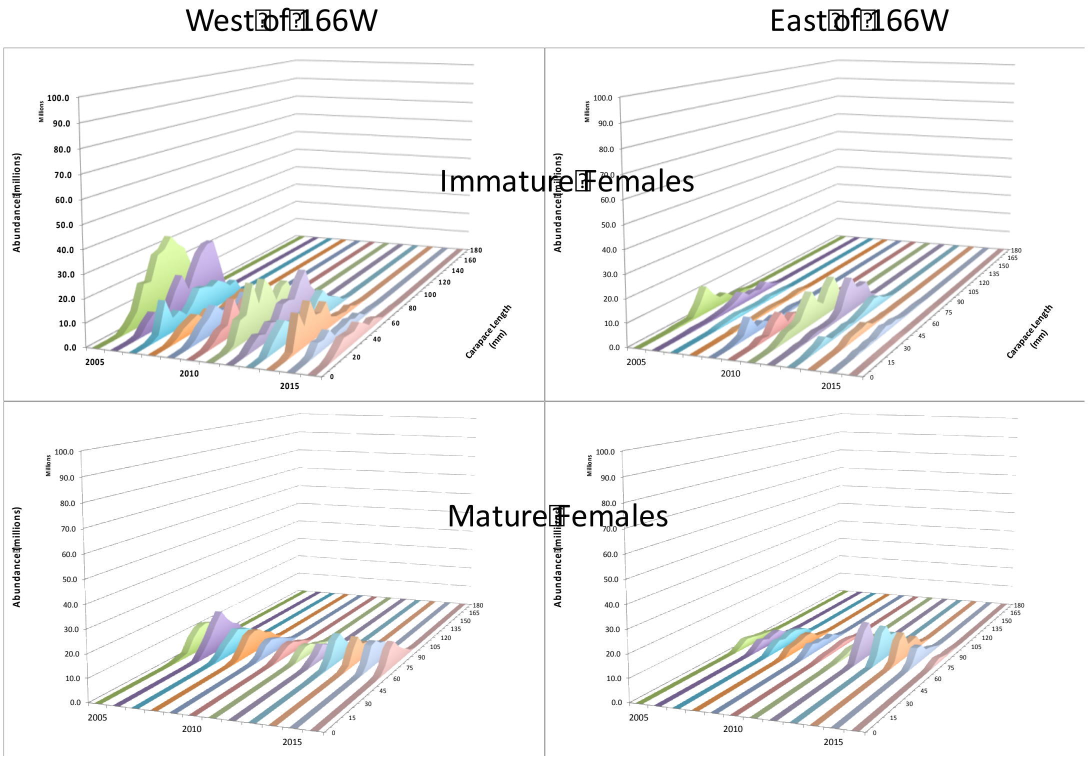


Figure 21. Numbers at size (millions) by area and shell condition for female Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW, since 2005.

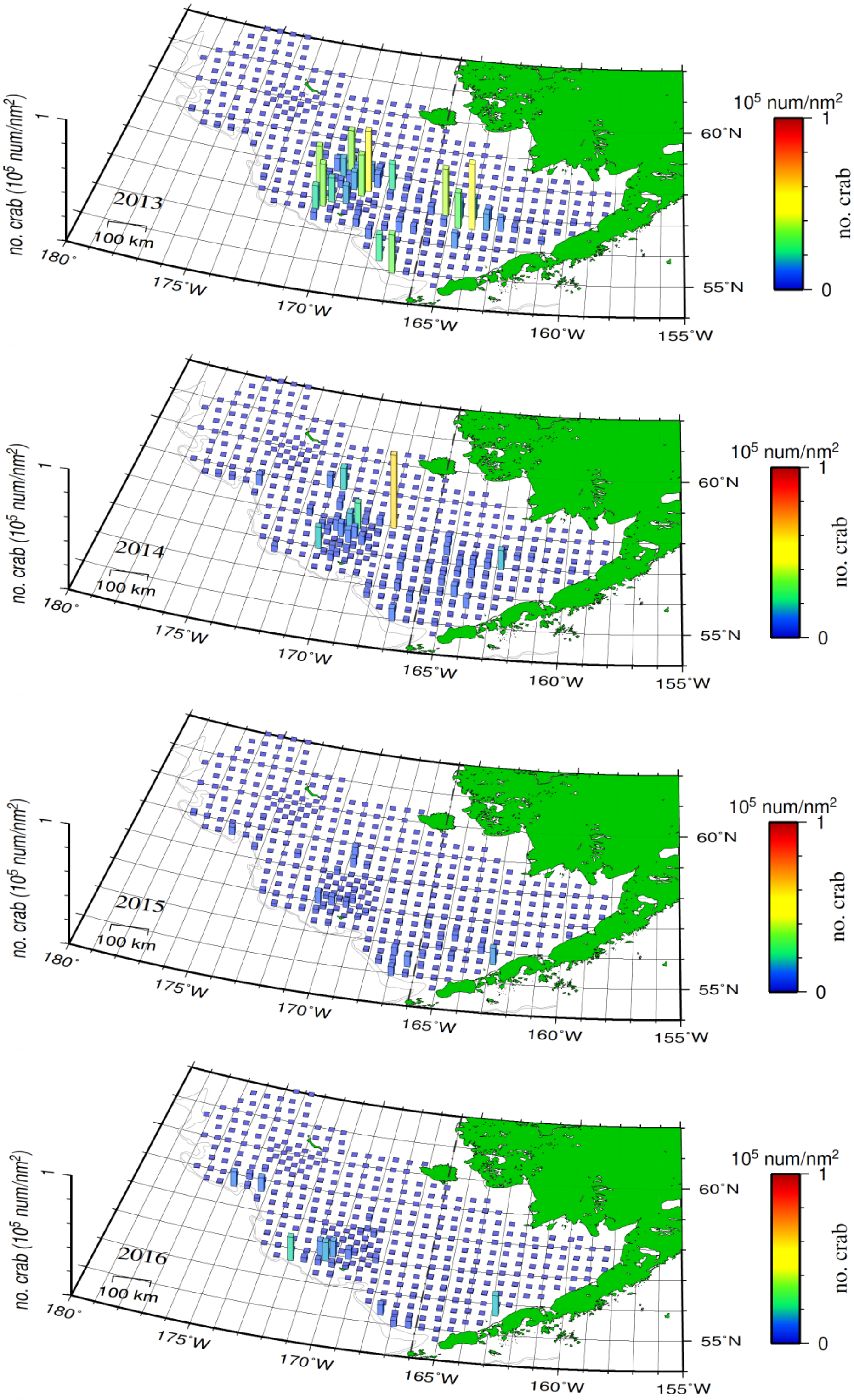


Figure 22. Distribution of immature males (number/ sq. nm) in the summer trawl survey for 2013-16.

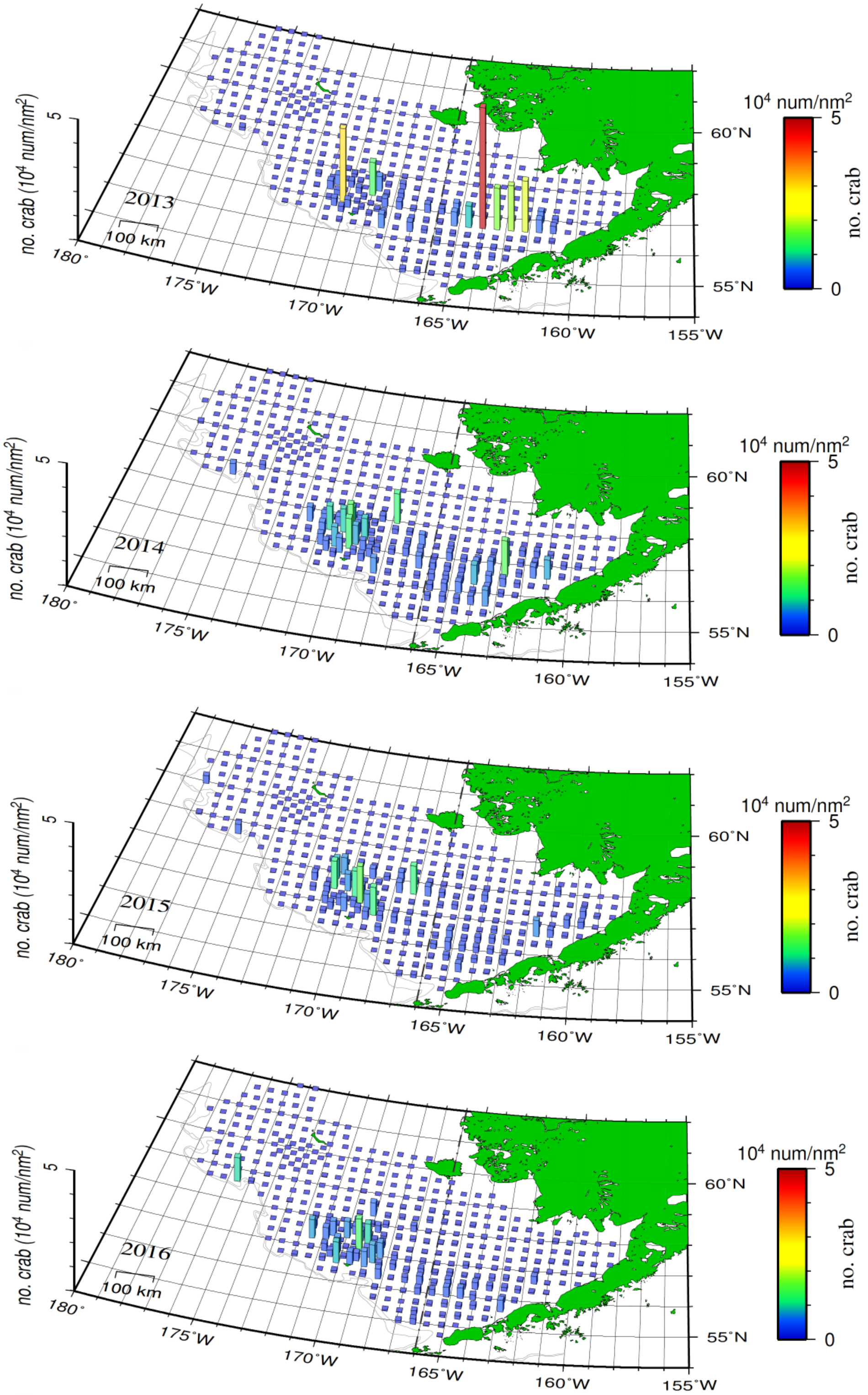


Figure 23. Distribution of mature males (number/ sq. nm) in the summer trawl survey for 2013-16.

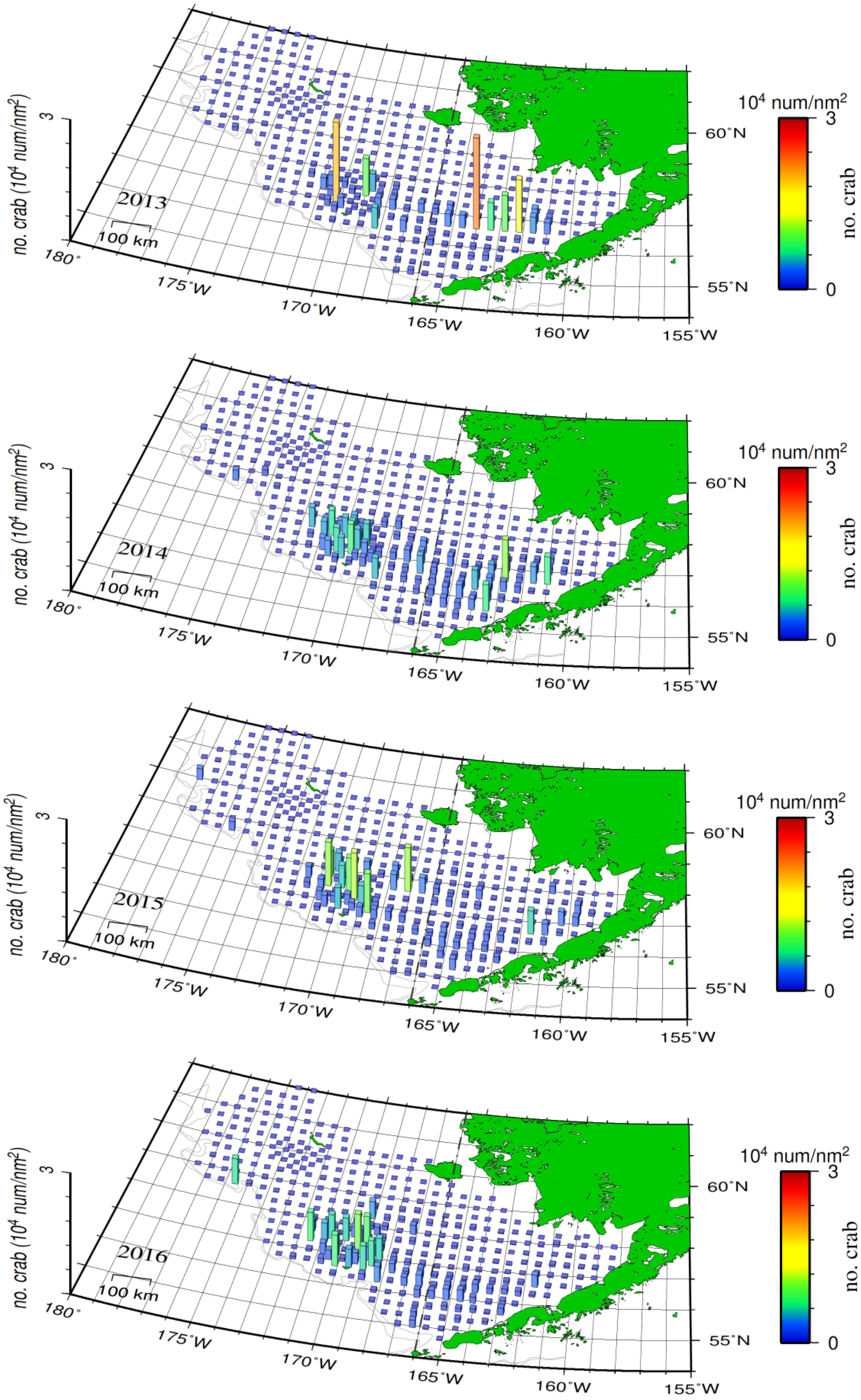


Figure 24. Distribution of legal males (≥ 110 mm CW west of 166ºW, ≥ 120 mm CW east of 166ºW; number/ sq. nm) in the summer trawl survey for 2013-16.

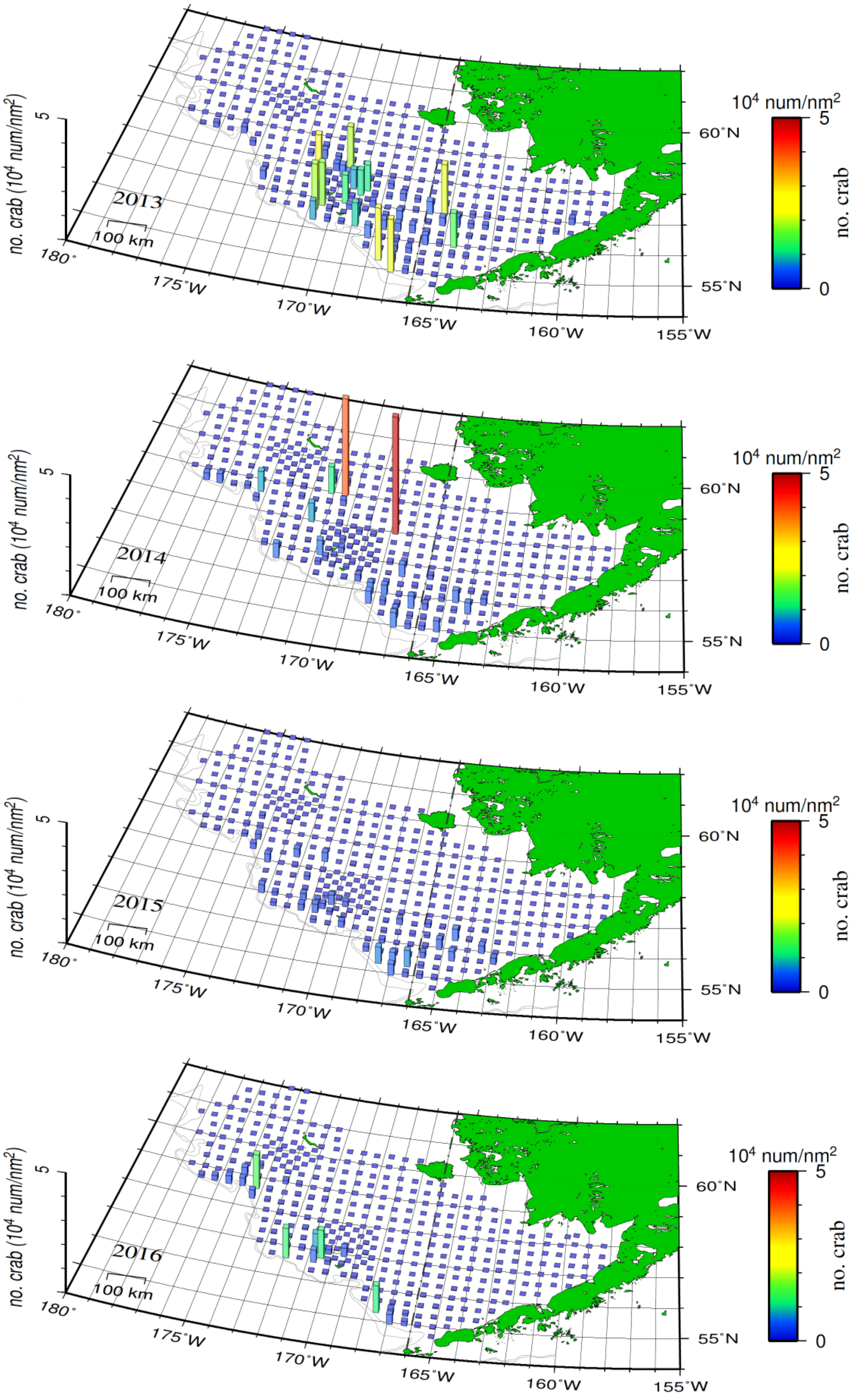


Figure 25. Distribution of immature females (number/ sq. nm) in the summer trawl survey for 2013-16.

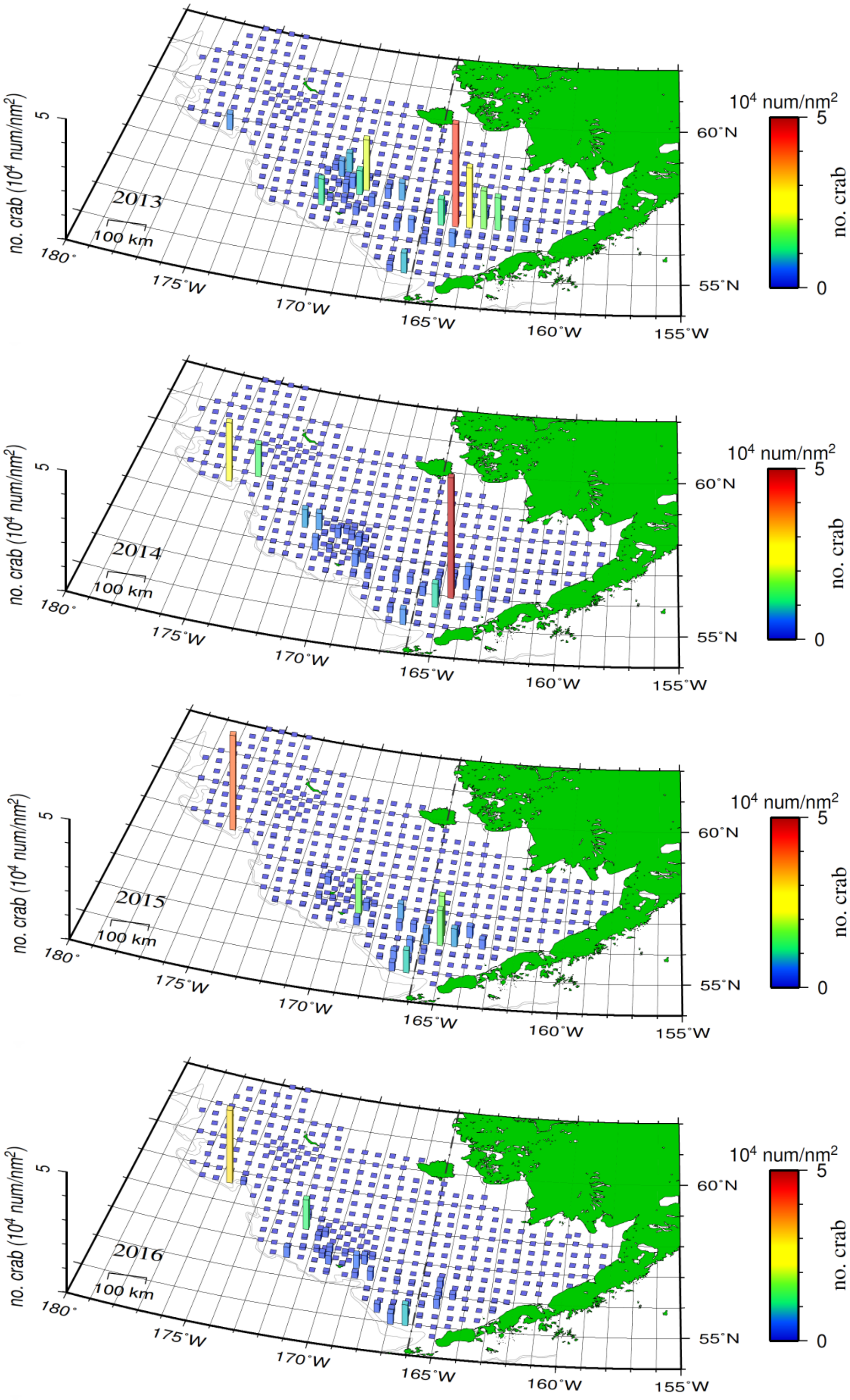


Figure 26. Distribution of mature females (number/ sq. nm) in the summer trawl survey for 2013-16.

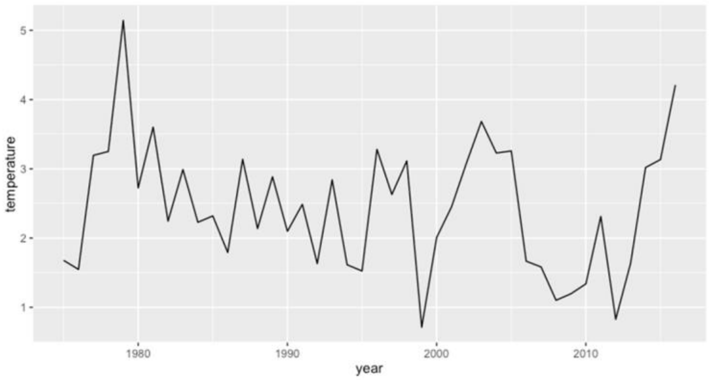


Figure 27. Average bottom temperatures (°C) in the NMFS EBS summer trawl survey for 1975-2016.

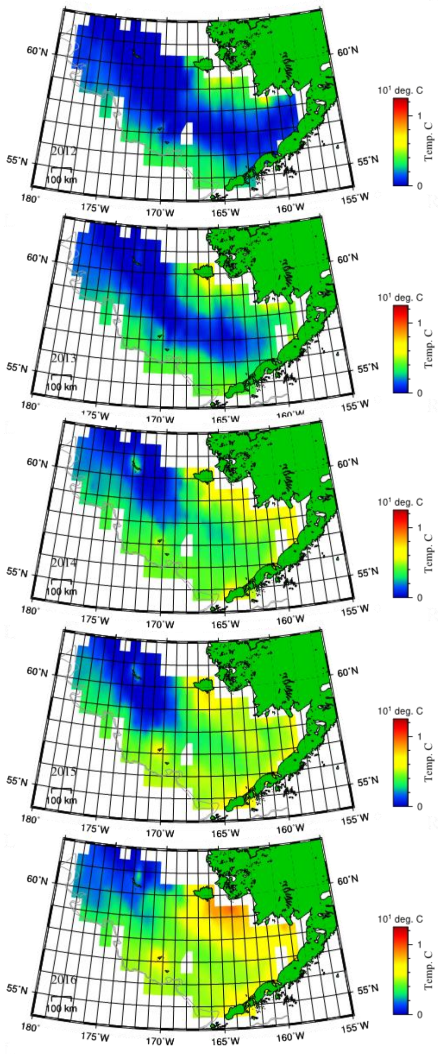


Figure 28. Distribution of bottom temperatures (°C) in the NMFS EBS summer trawl survey for 2012-16.

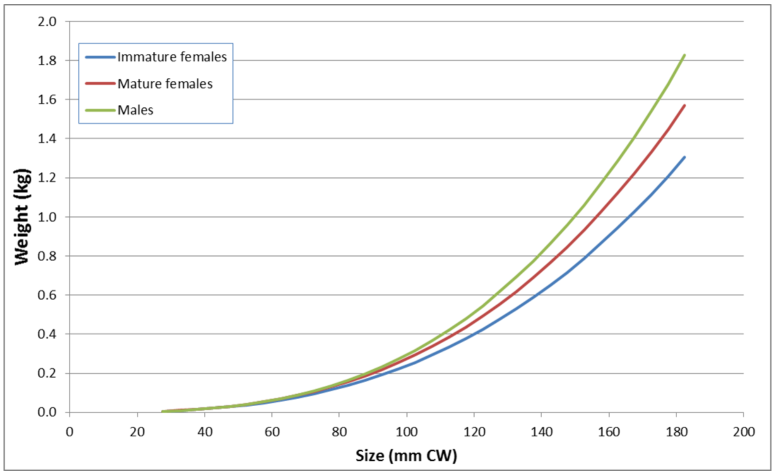


Figure 29. Size-weight relationships developed from NMFS EBS summer trawl survey data.

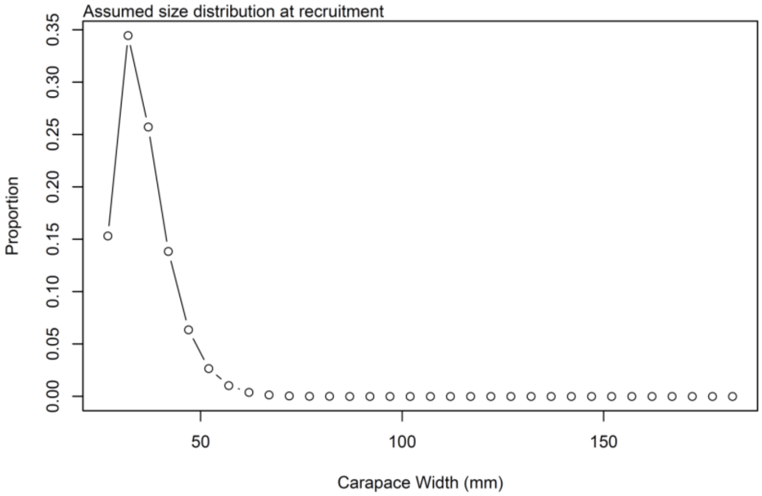


Figure 30. Assumed size distribution for recruits entering the population.

Figure 31. Estimated natural mortality rates from the 2015 assessment (2015AMO) and the author's preferred model (Model C).

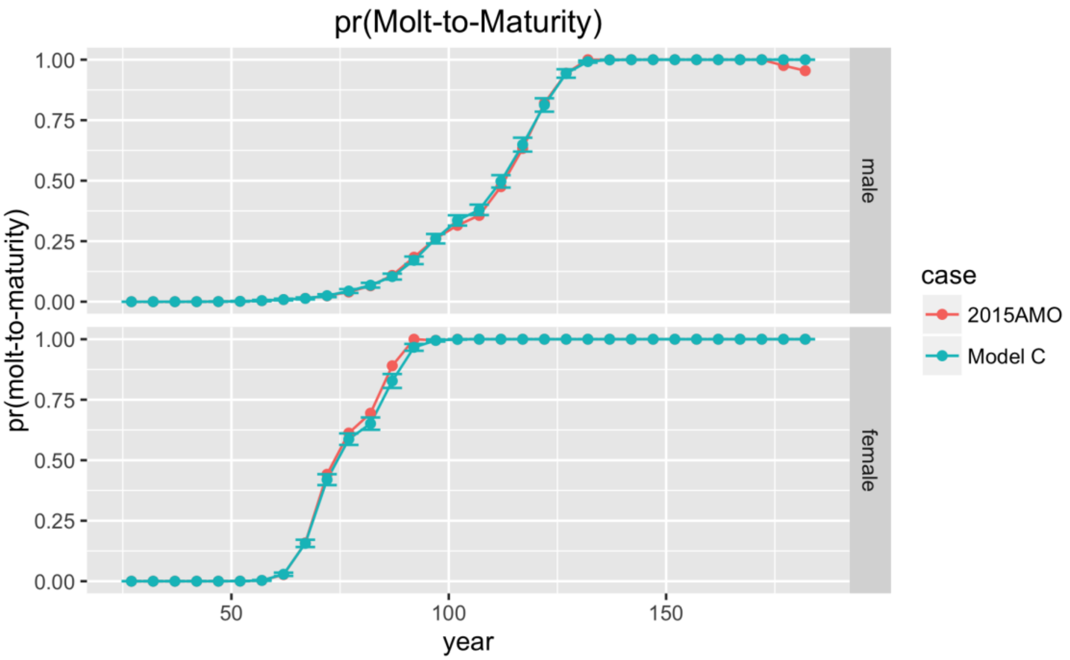


Figure 32. Estimated sex and size-specific probabilities of terminal molt-to-maturity from the 2015 assessment (2015AMO) and the author's preferred model (Model C).

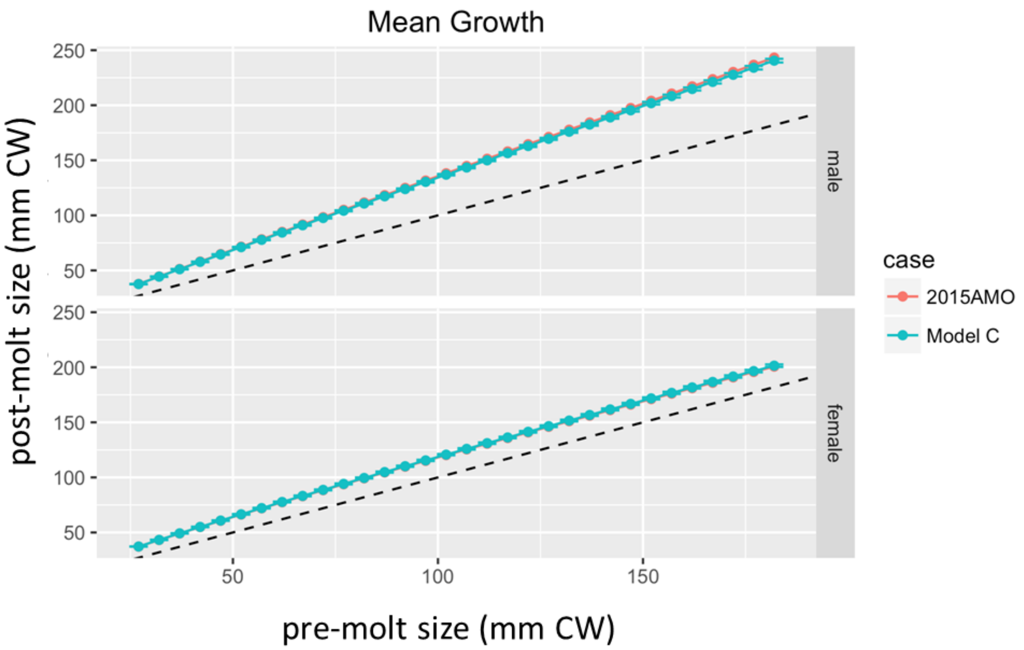


Figure 33. Estimated mean post-molt size, as a function of pre-molt size, from the 2015 assessment (2015AMO) and the author's preferred model (Model C).

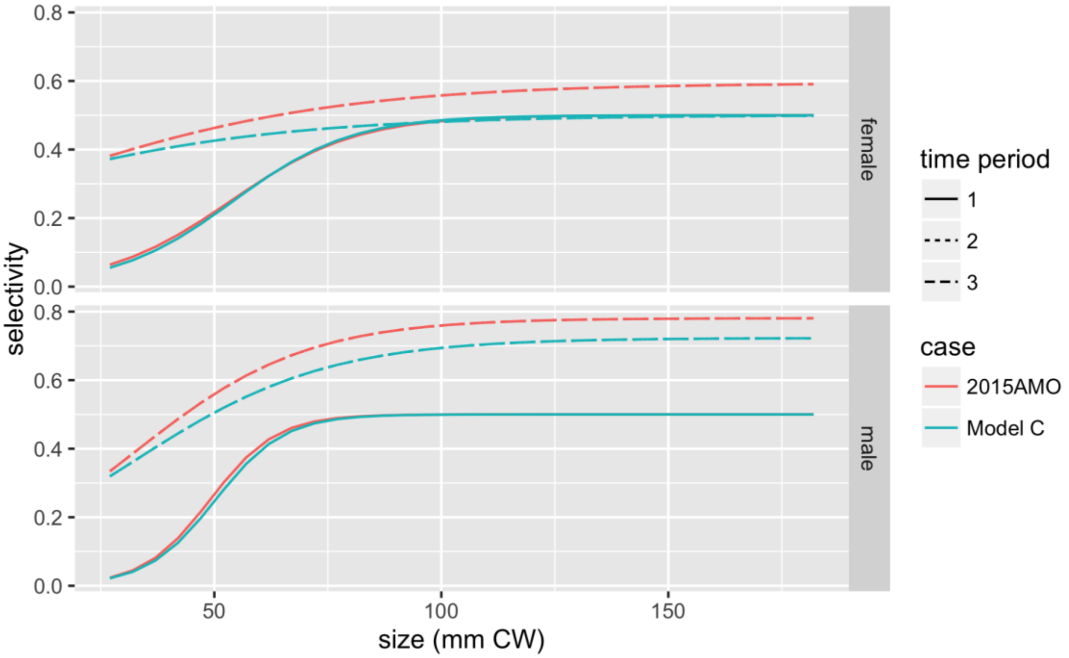


Figure 34. Estimated survey selectivity functions from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Time periods: 1) pre-1982, 2) 1982-1986, 3) 1987-present.

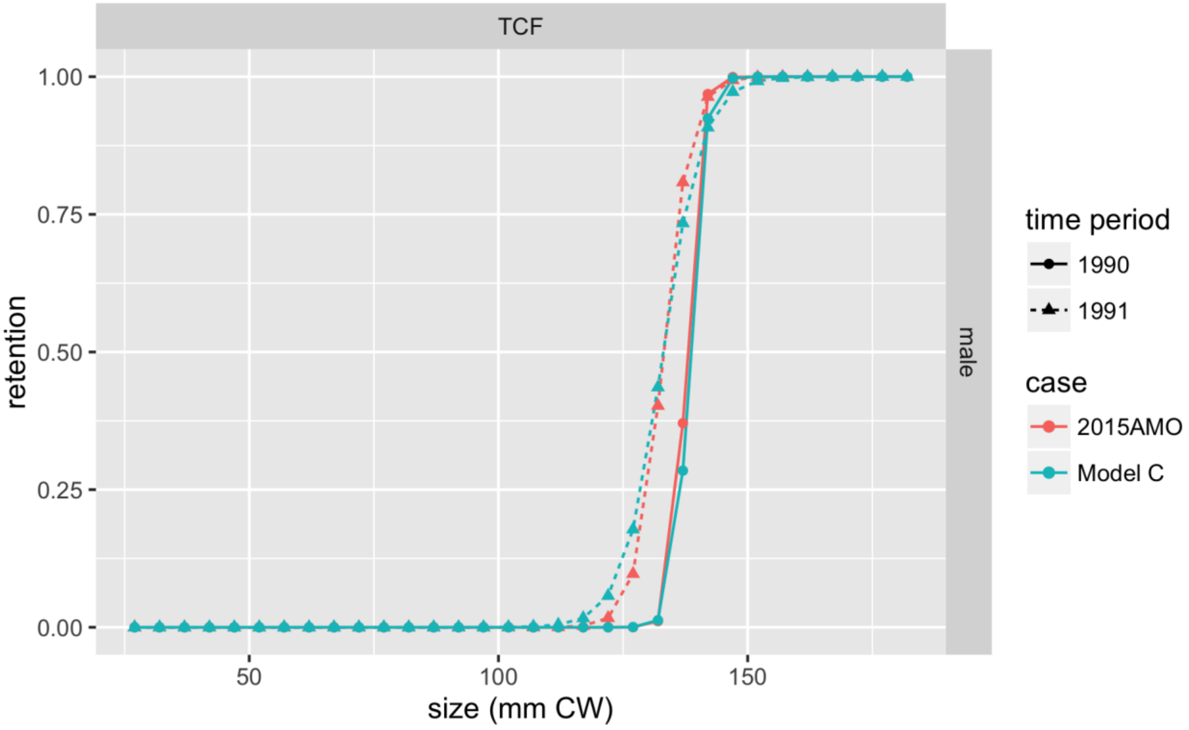


Figure 35. Estimated retention functions from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Time periods: 1) 1974-1981, 2) 1982-1986, 3) 1987-present.

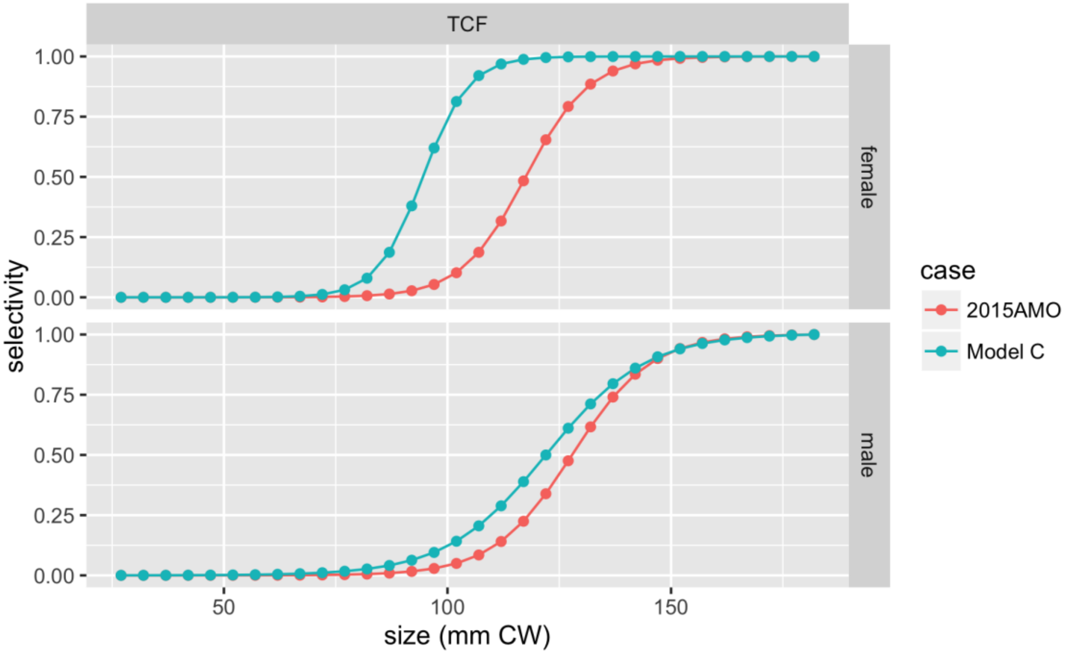


Figure 36. Estimated selectivity functions in the directed fishery from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Time periods: females-entire model period, males-pre-1991.

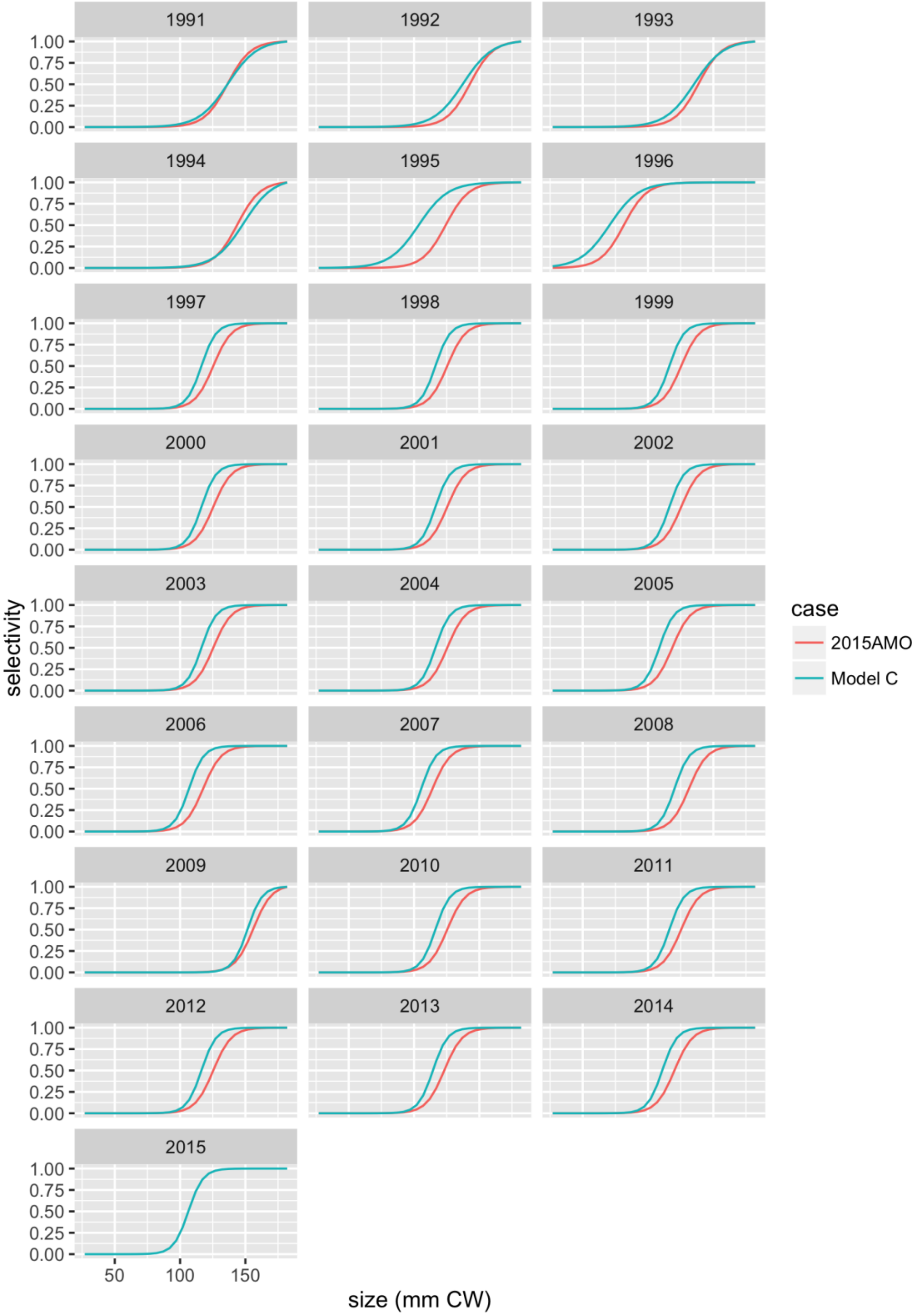


Figure 37. Estimated male selectivity functions in the directed fishery from the 2015 assessment (2015AMO) and the author's preferred model (Model C) during 1991-present.

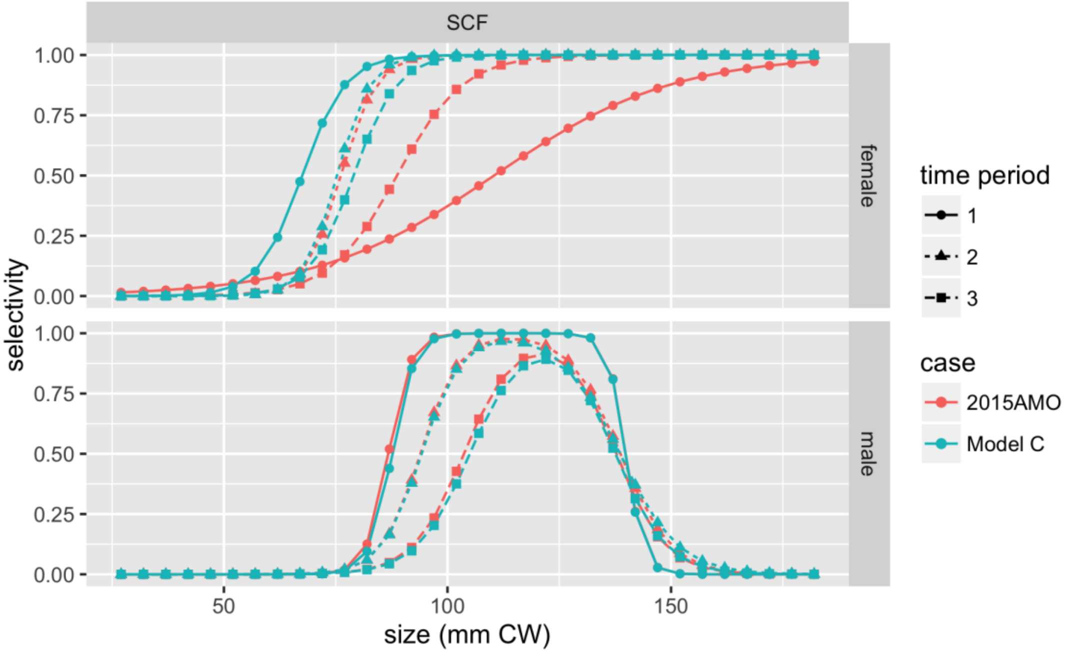


Figure 38. Estimated bycatch selectivity functions in the snow crab fishery (SCF) from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Time periods: 1) pre-1997, 2) 1997-2004, 3) 2005-present.

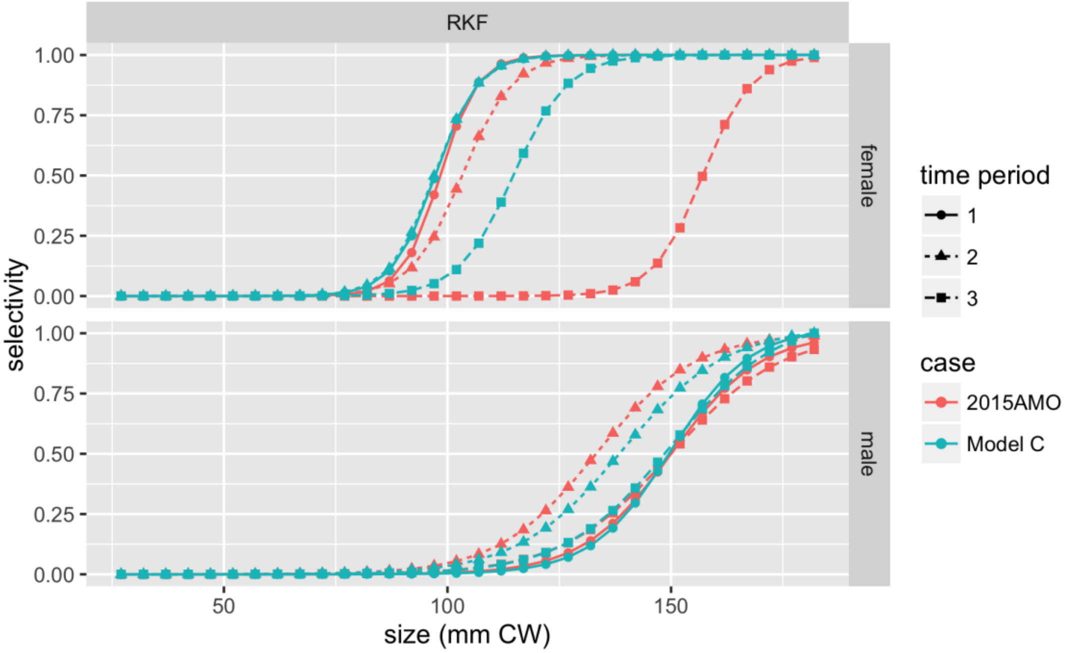


Figure 39. Estimated bycatch selectivity functions in the BBRKC fishery (RKC) from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Time periods: 1) pre-1997, 2) 1997-2004, 3) 2005-present.

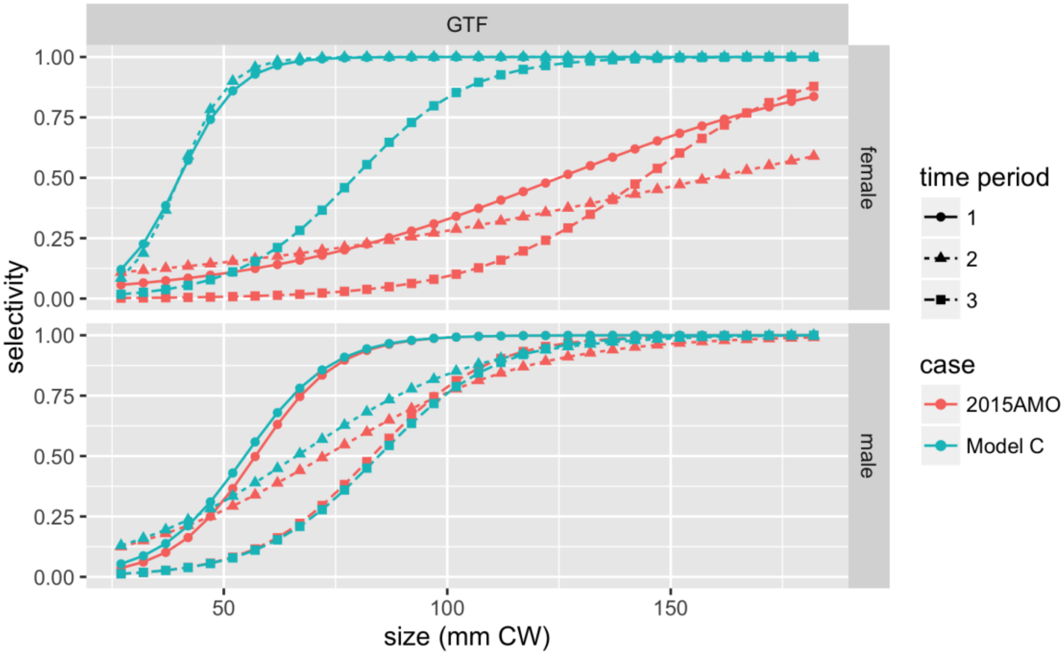


Figure 40. Estimated bycatch selectivity functions in the groundfish fisheries (GTF) from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Time periods: 1) pre-1988, 2) 1988-1996, 3) 1997-present.

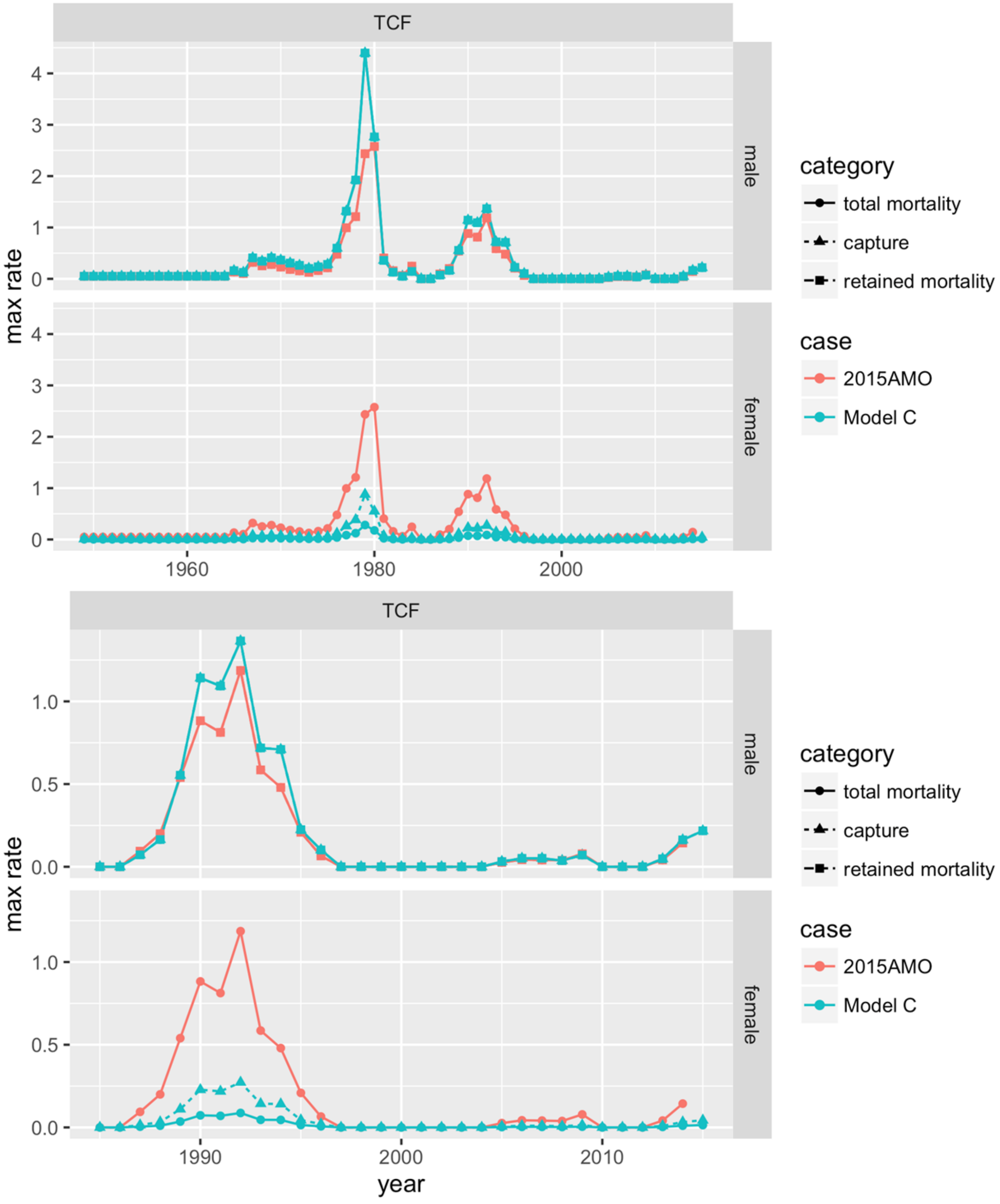


Figure 41. Estimated full selection fishing mortality from the 2015 assessment (2015AMO) and fishery capture rate from the author's preferred model (Model C) for the directed Tanner crab fishery (TCF). Lower plot is zoomed to 1985-2015. For males, fully-selected capture, retained and total mortality rates will generally be identical. There is no retained mortality for females.

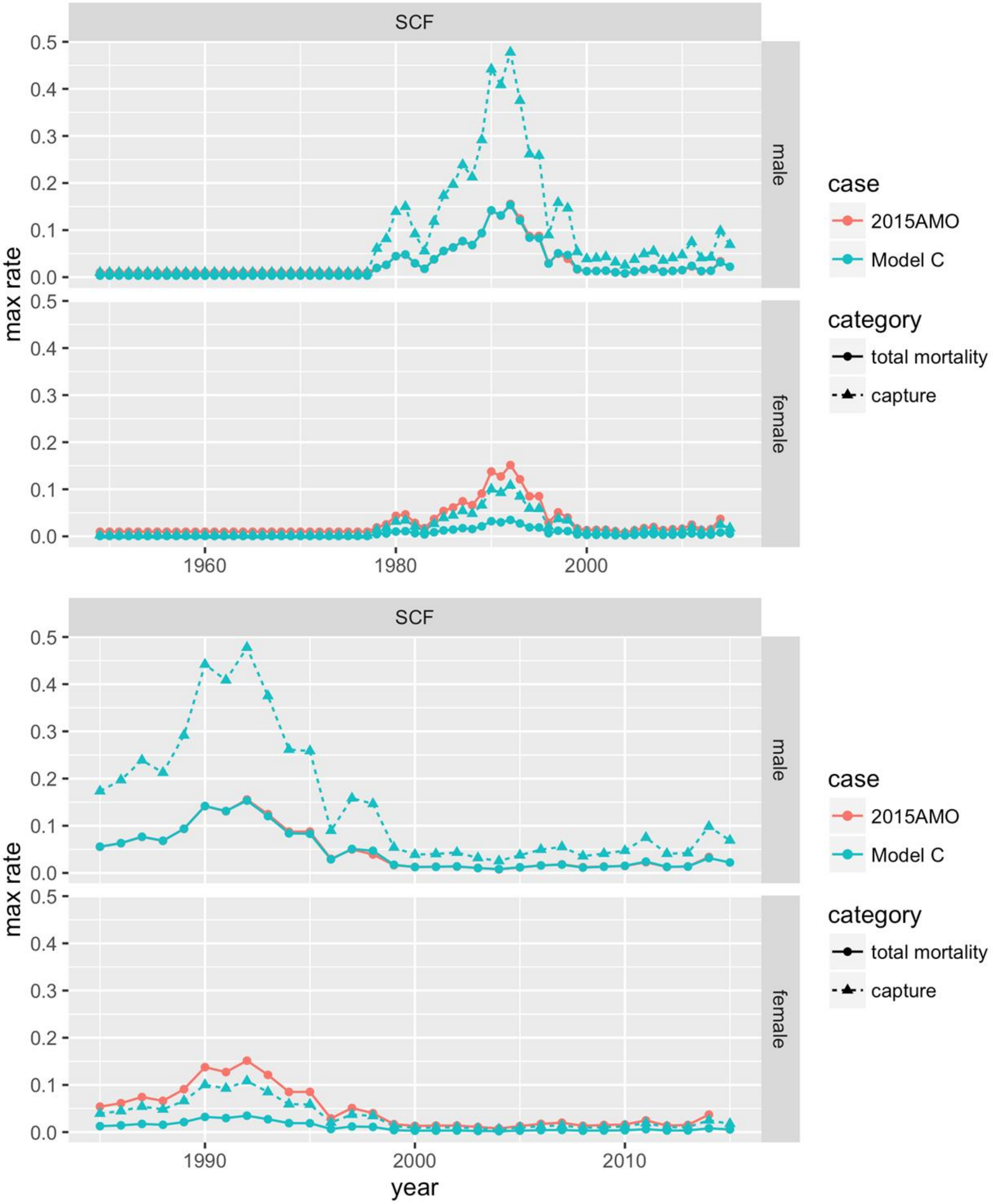


Figure 42. Estimated full selection fishing mortality from the 2015 assessment (2015AMO) and fishery capture rate from the author's preferred model (Model C) for the snow crab fishery (SCF). Lower plot is zoomed to 1985-2015.

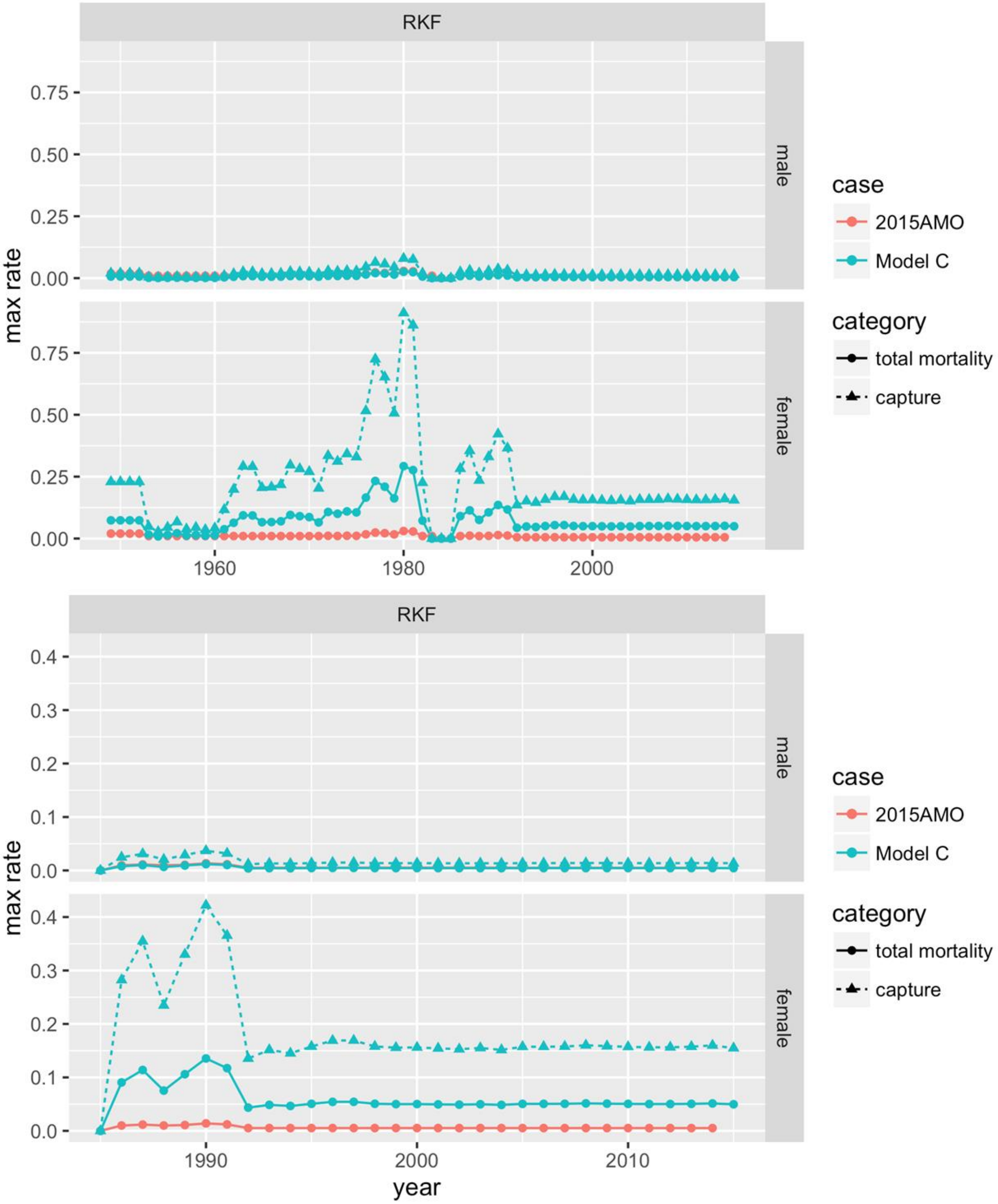


Figure 43. Estimated full selection fishing mortality from the 2015 assessment (2015AMO) and fishery capture rate from the author’s preferred model (Model C) for the BBRKC fishery (RKF). Lower plot is zoomed to 1985-2015.

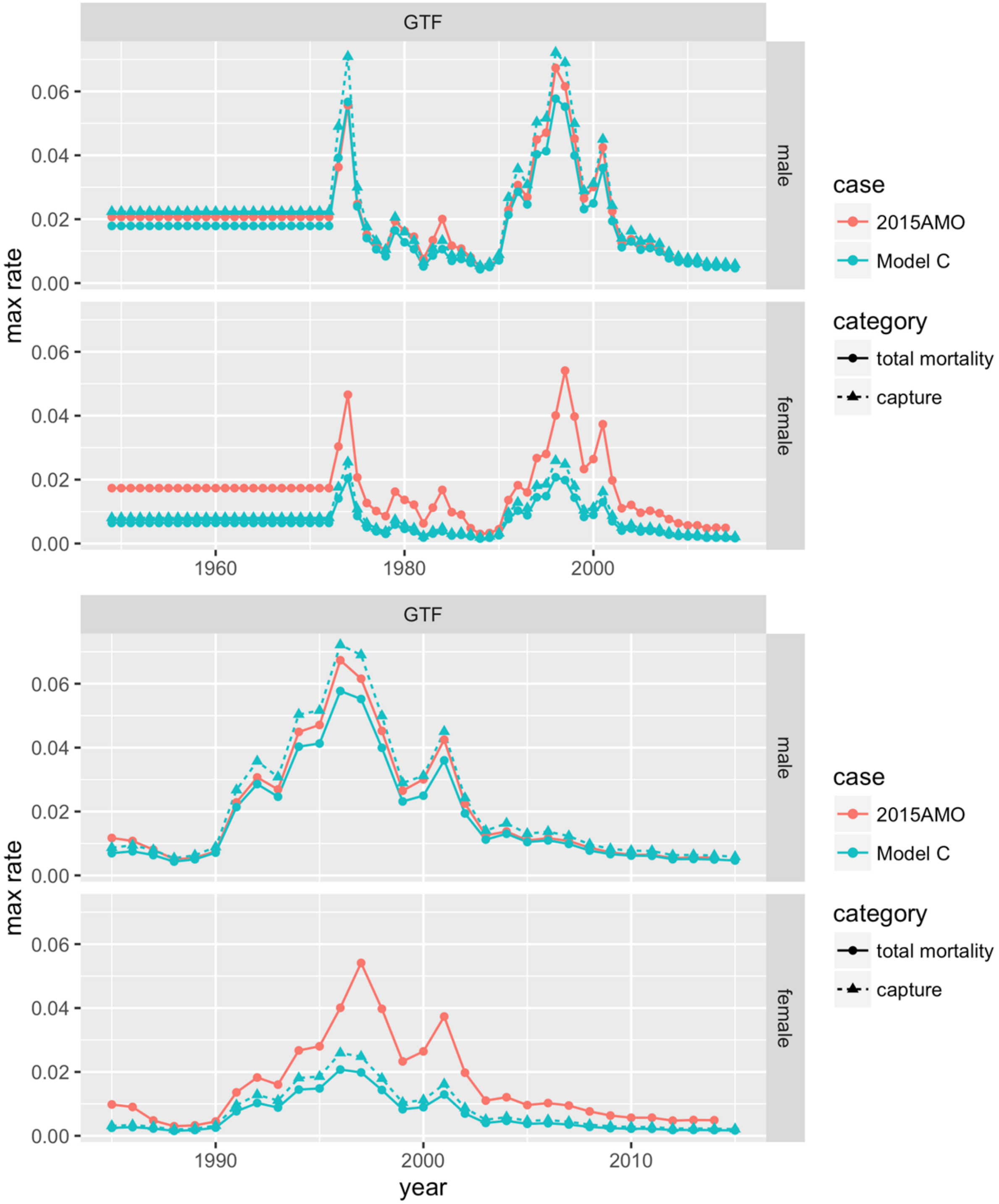


Figure 44. Estimated full selection fishing mortality from the 2015 assessment (2015AMO) and fishery capture rate from the author’s preferred model (Model C) for the groundfish fisheries (GTF). Lower plot is zoomed to 1985-2015.

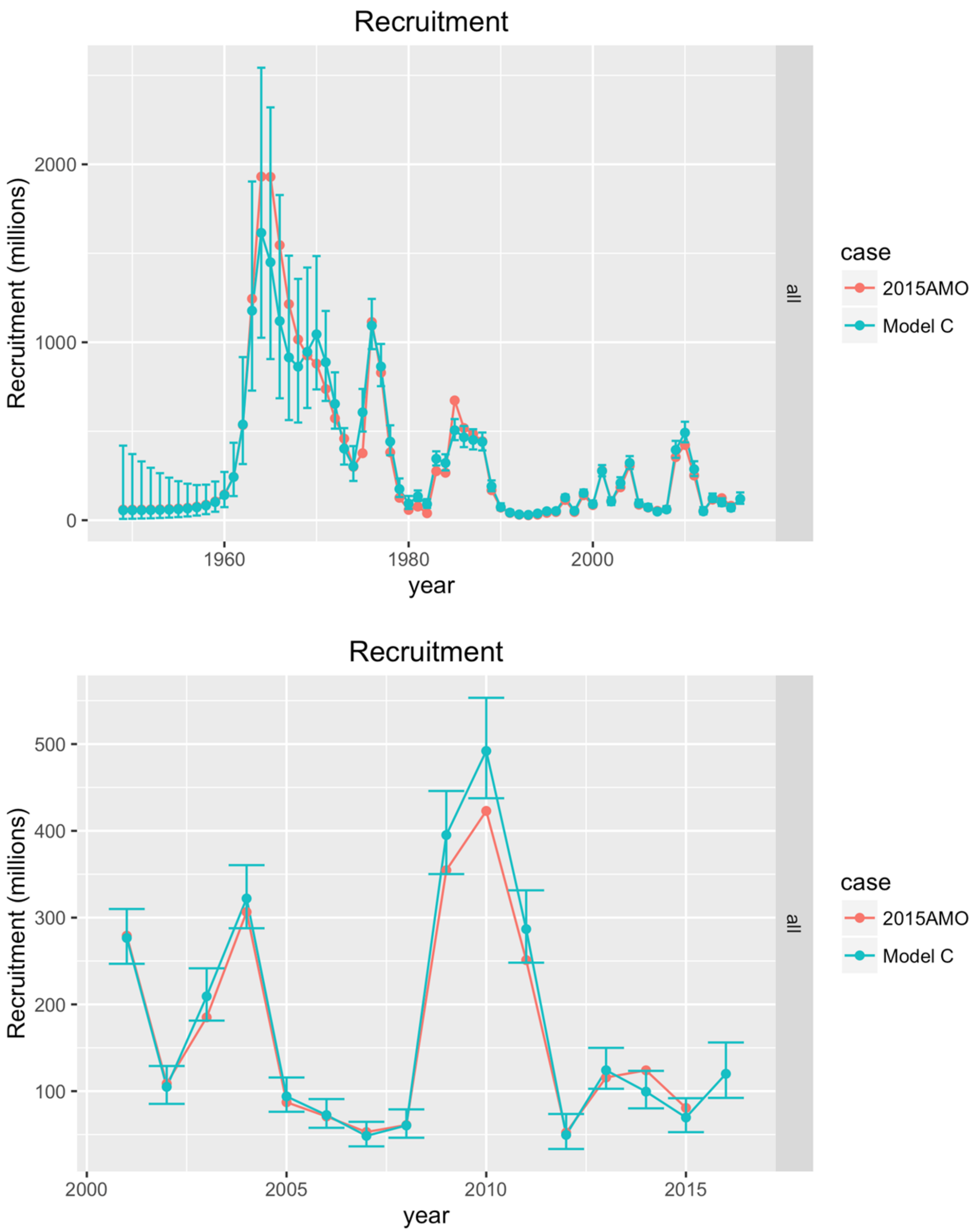


Figure 45. Estimated recruitment from the 2015 assessment (2015AMO) and the author’s preferred model (Model C) during 1991-present. Lower plot is zoomed to 2000-present.

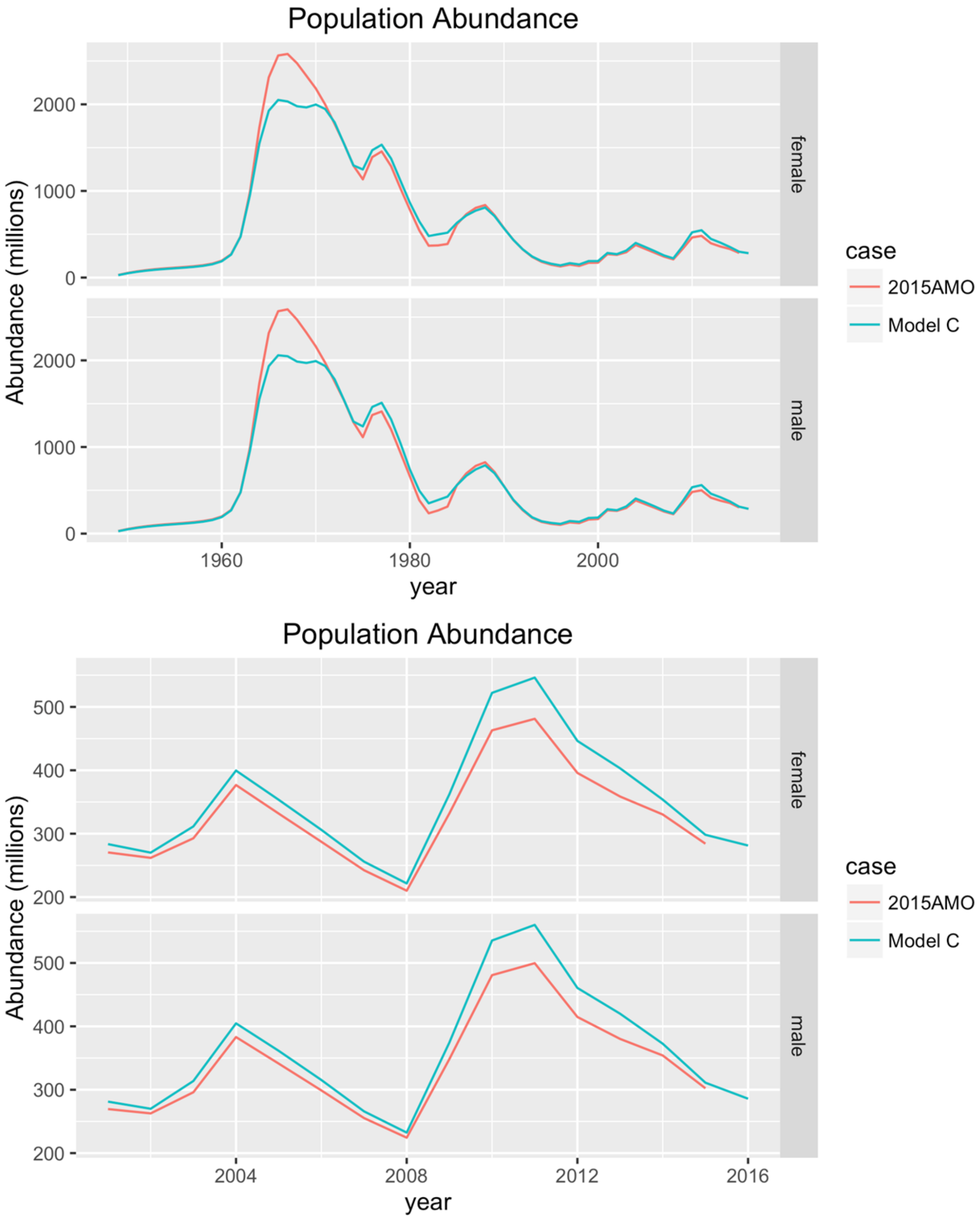


Figure 46. Estimated population abundance by sex from the 2015 assessment (2015AMO) and the author’s preferred model (Model C). Lower plot is zoomed to 2000-present.

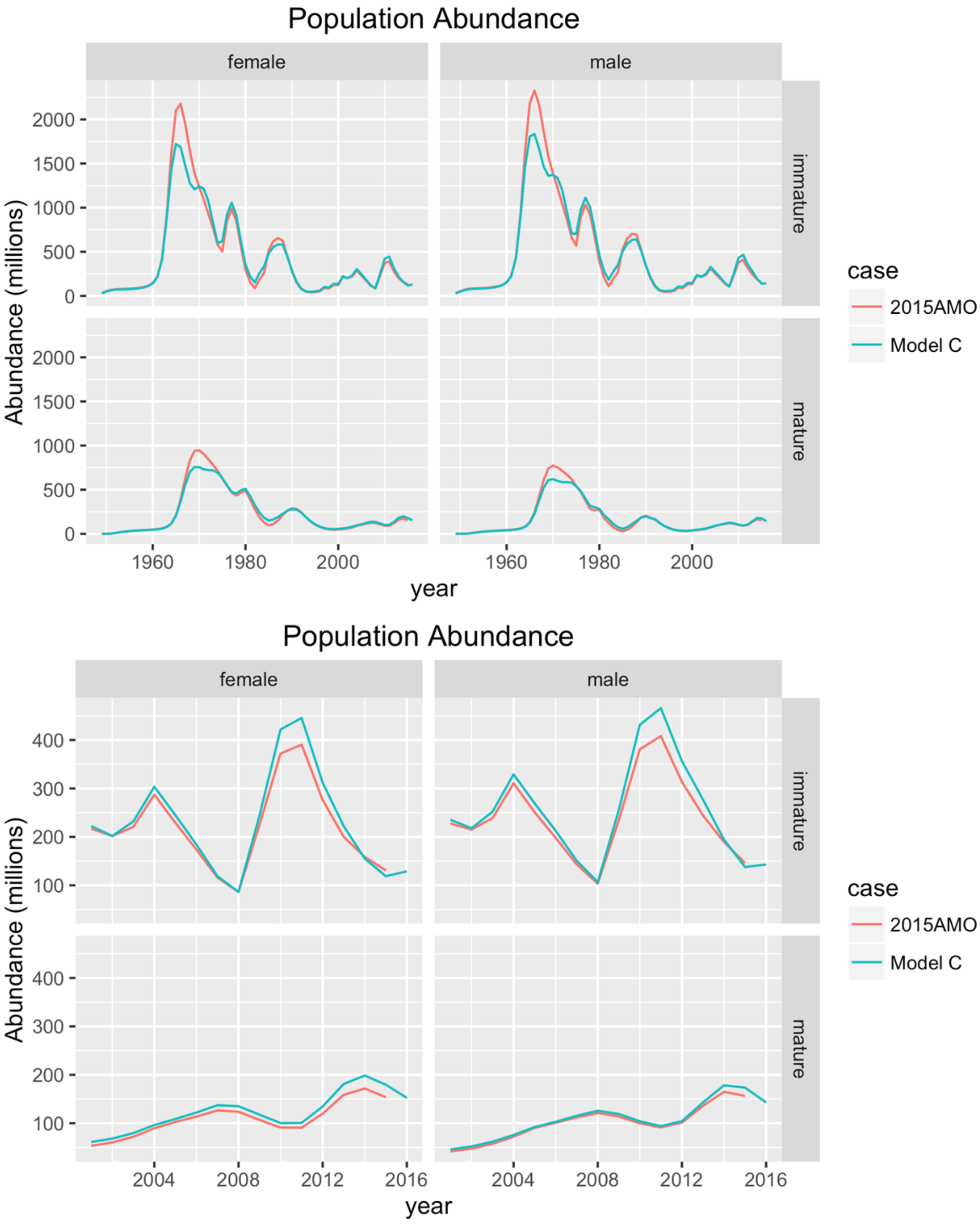


Figure 47. Estimated population abundance by sex and maturity state from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Lower plot is zoomed to 2000-present.

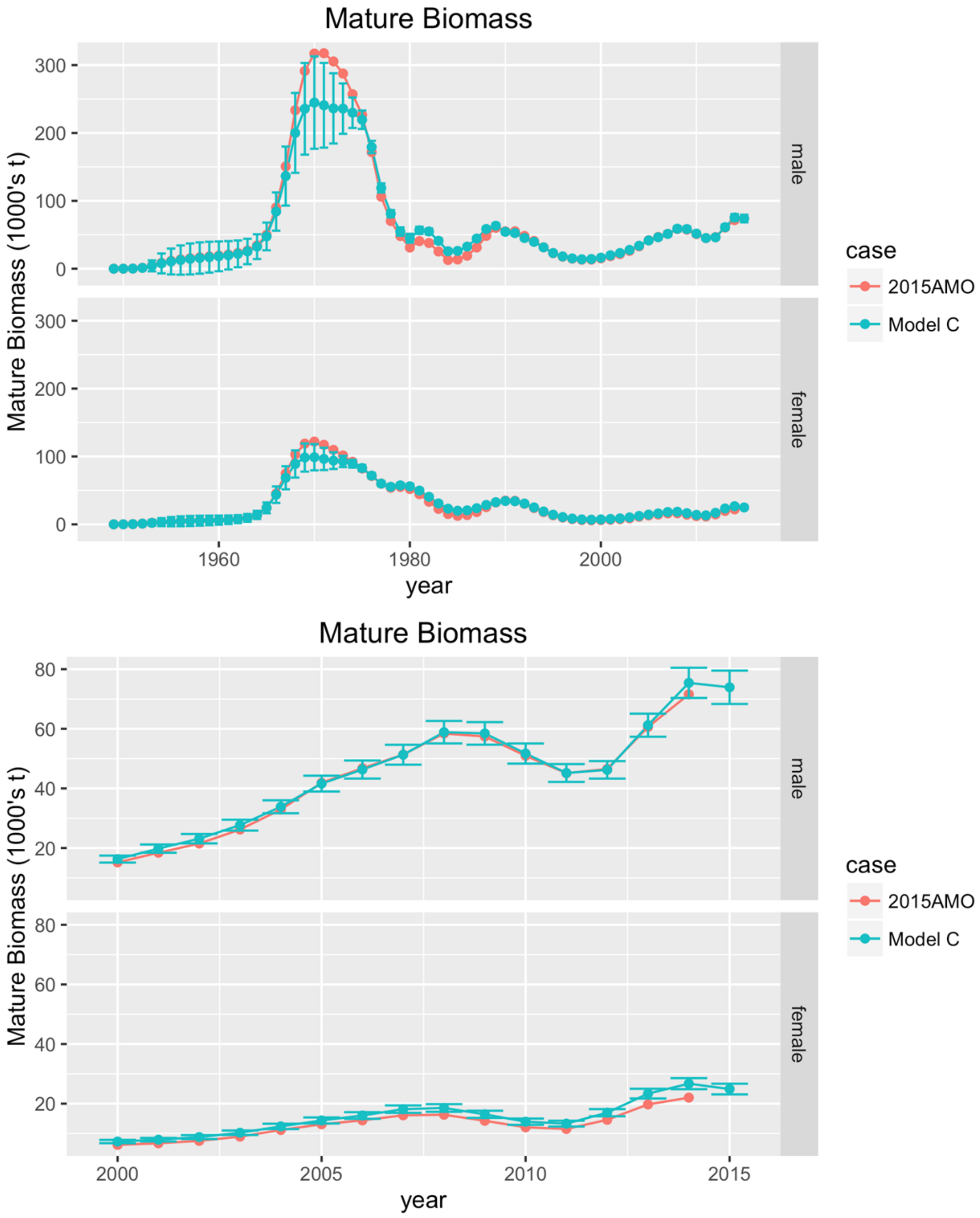


Figure 48. Estimated mature biomass-at-mating from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Lower plot is zoomed to 2000-present.

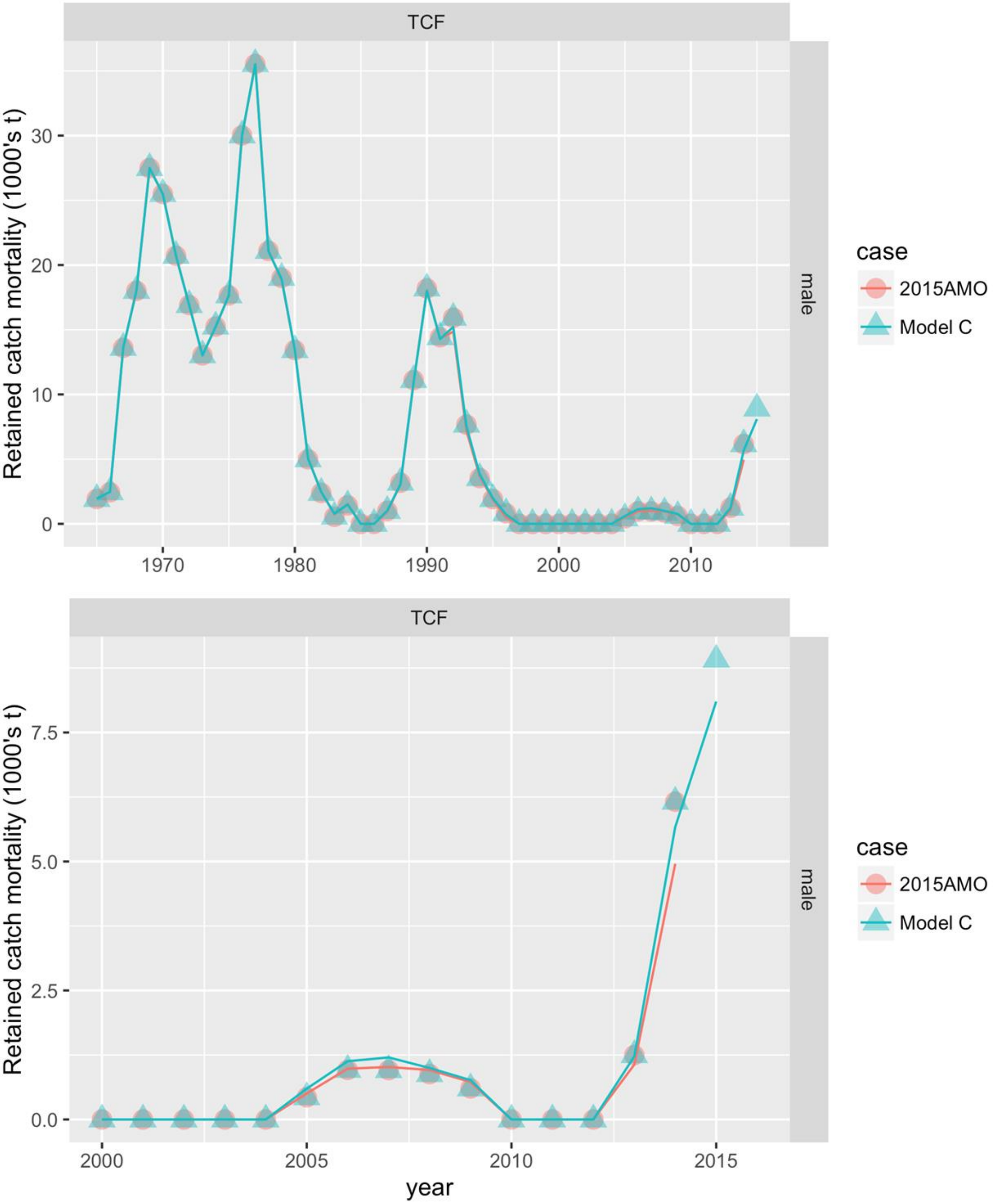


Figure 49. Fits to retained catch biomass from the 2015 assessment (2015AMO) and the author's preferred model (Model C) for the directed Tanner crab fishery (TCF). Lower plot is zoomed to 2000-2015. Predicted: lines. Observed: symbols.

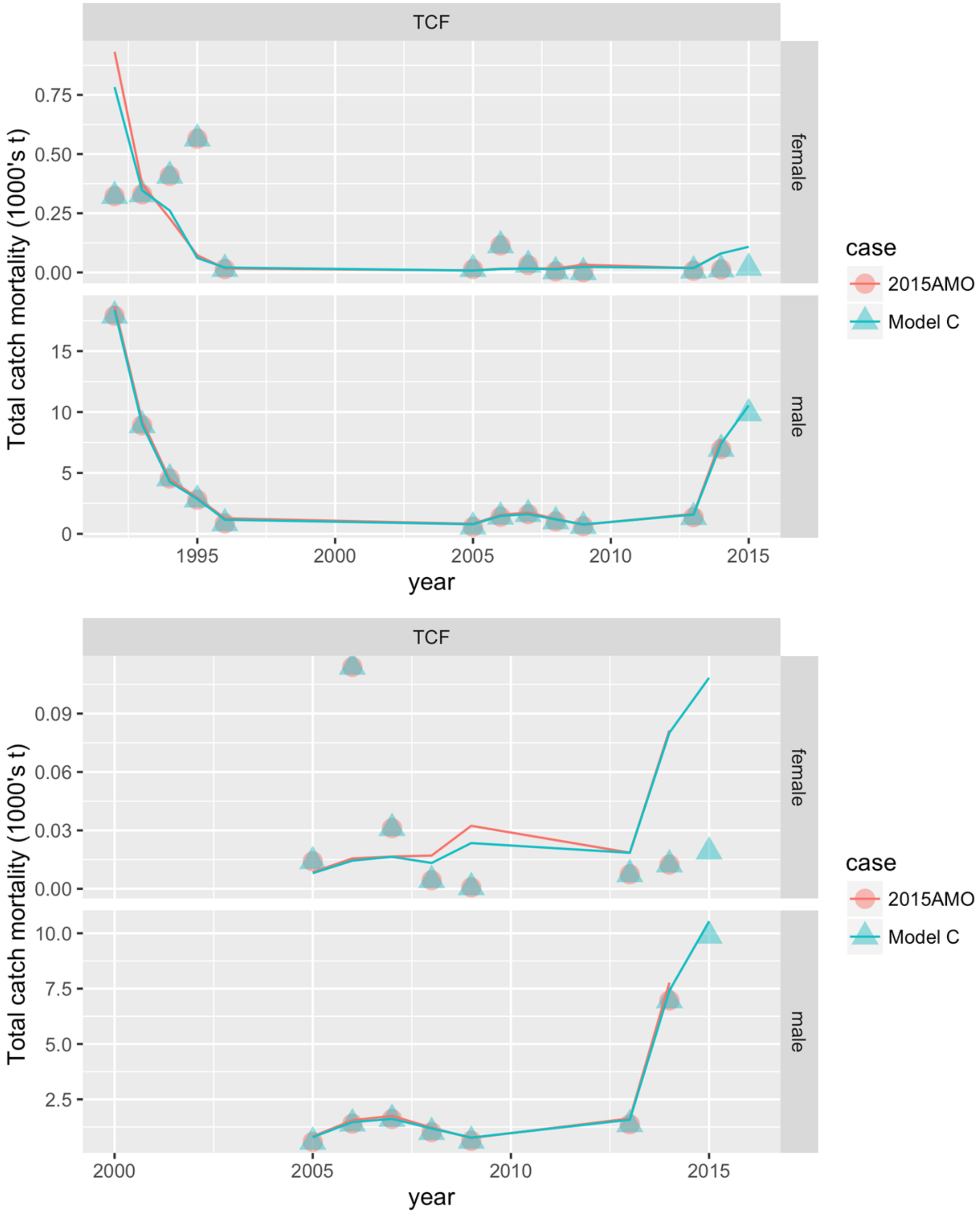


Figure 50. Fits to total catch biomass from the 2015 assessment (2015AMO) and the author's preferred model (Model C) for males in the directed Tanner crab fishery (TCF). Lower plot is zoomed to 2000-2015. Observed: symbols.

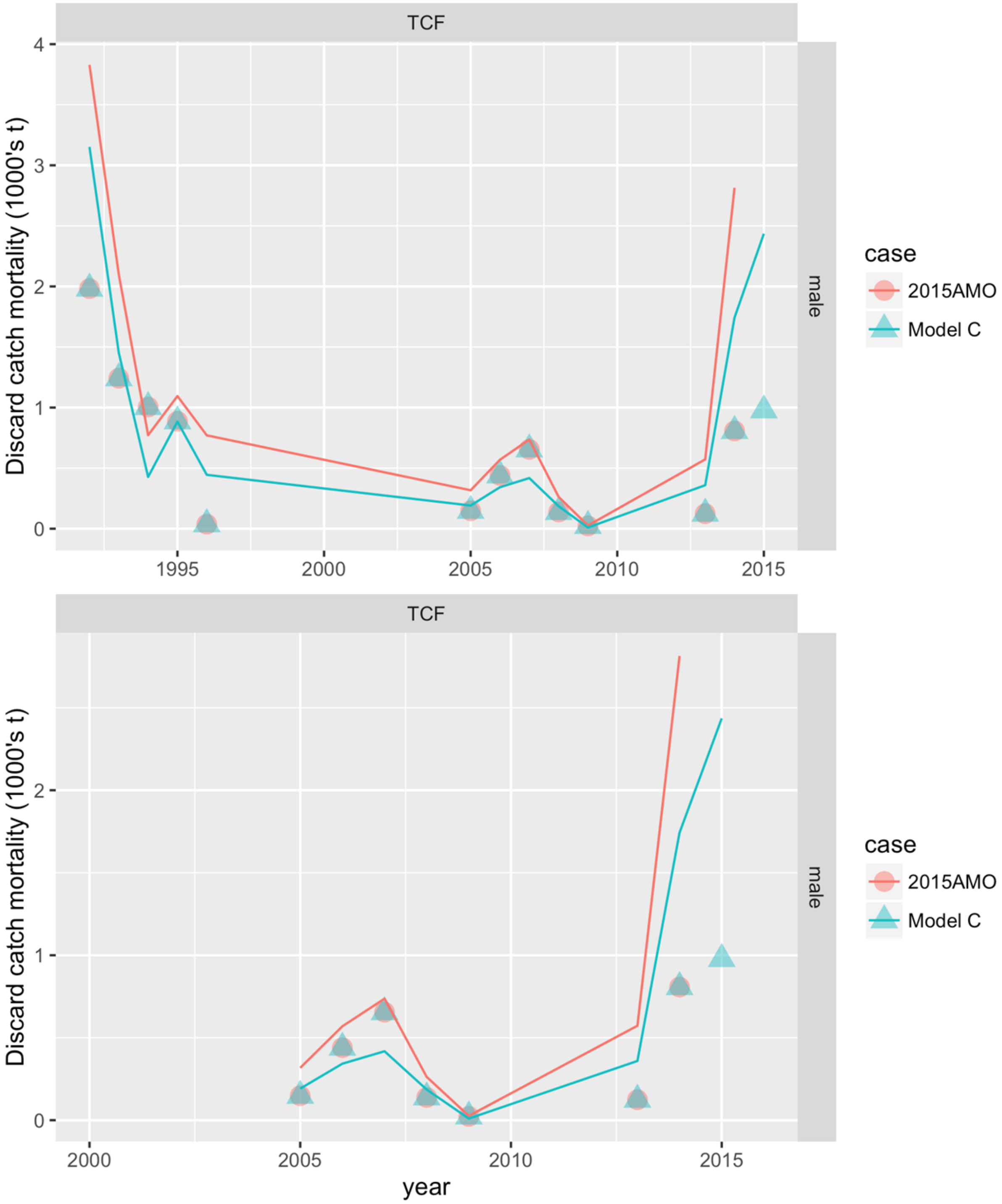


Figure 51. Fits to total catch biomass from the 2015 assessment (2015AMO) and the author's preferred model (Model C) for males in the directed Tanner crab fishery (TCF). Lower plot is zoomed to 2000-2015. Observed: symbols.

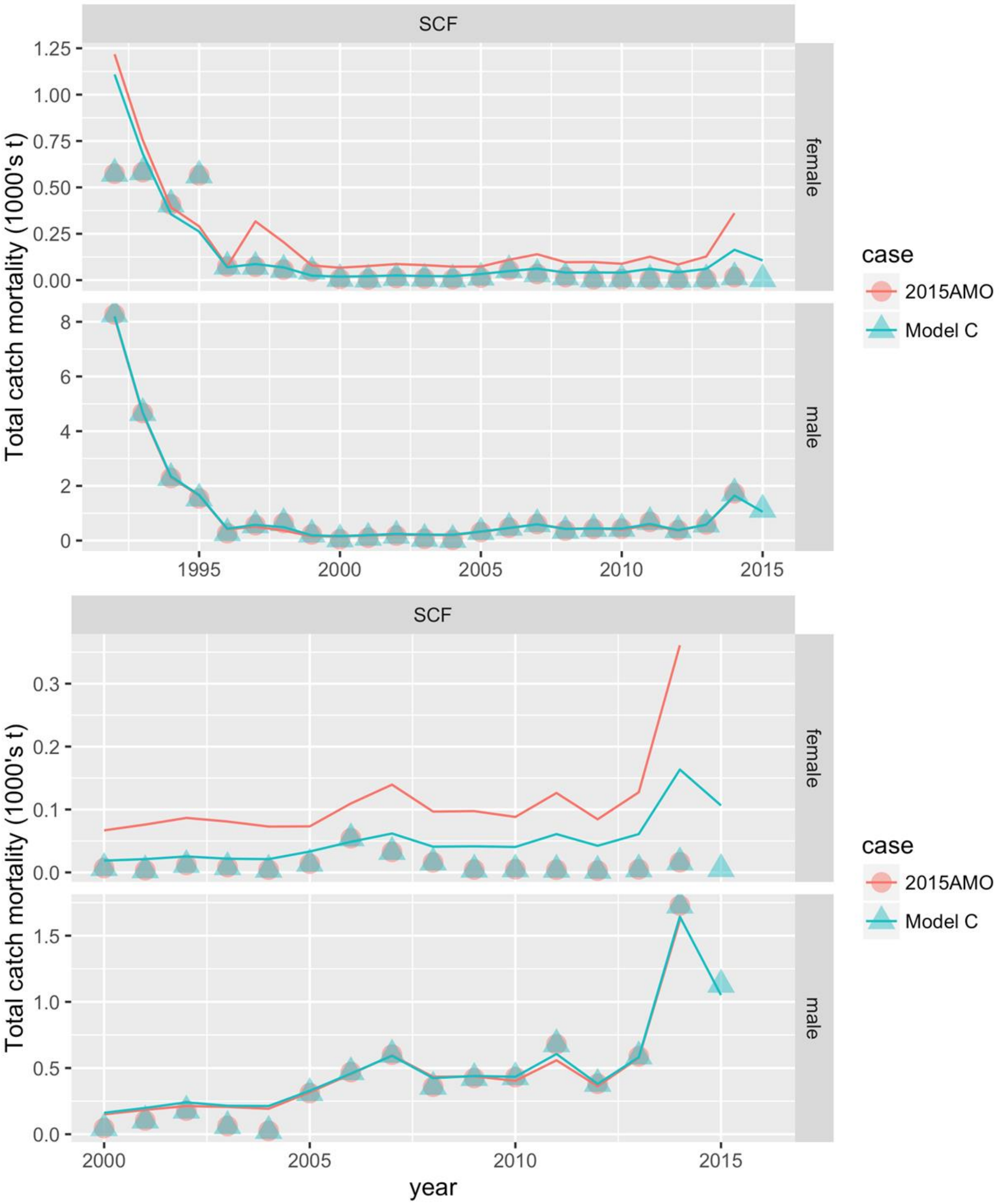


Figure 52. Fits to total catch biomass from the 2015 assessment (2015AMO) and the author's preferred model (Model C) for males in the snow crab bycatch fishery (SCF). Lower plot is zoomed to 2000-2015. Observed: symbols.

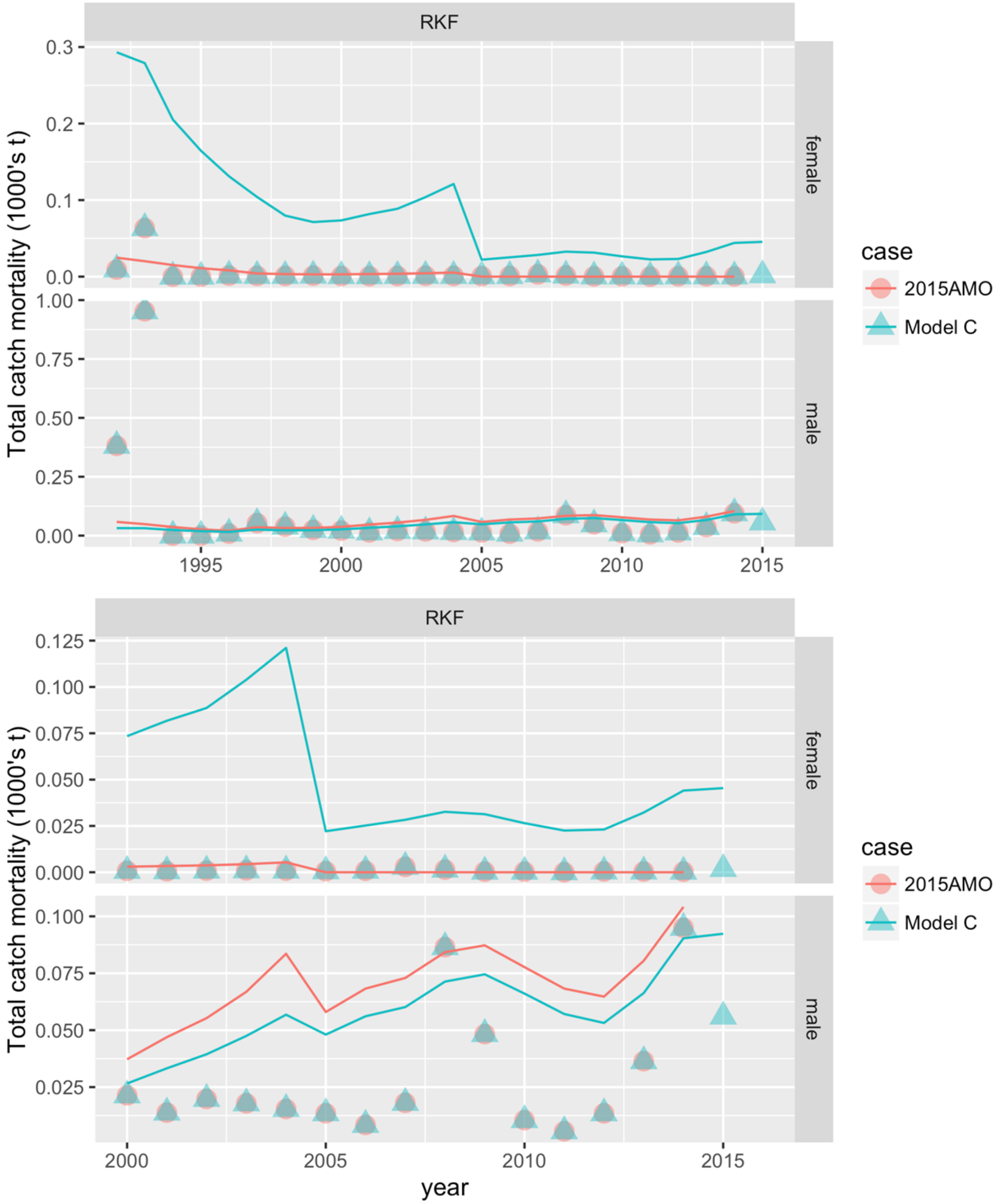


Figure 53. Fits to total catch biomass from the 2015 assessment (2015AMO) and the author's preferred model (Model C) for males in the BBRKC bycatch fishery (RKF). Lower plot is zoomed to 2000-2015. Observed: symbols.

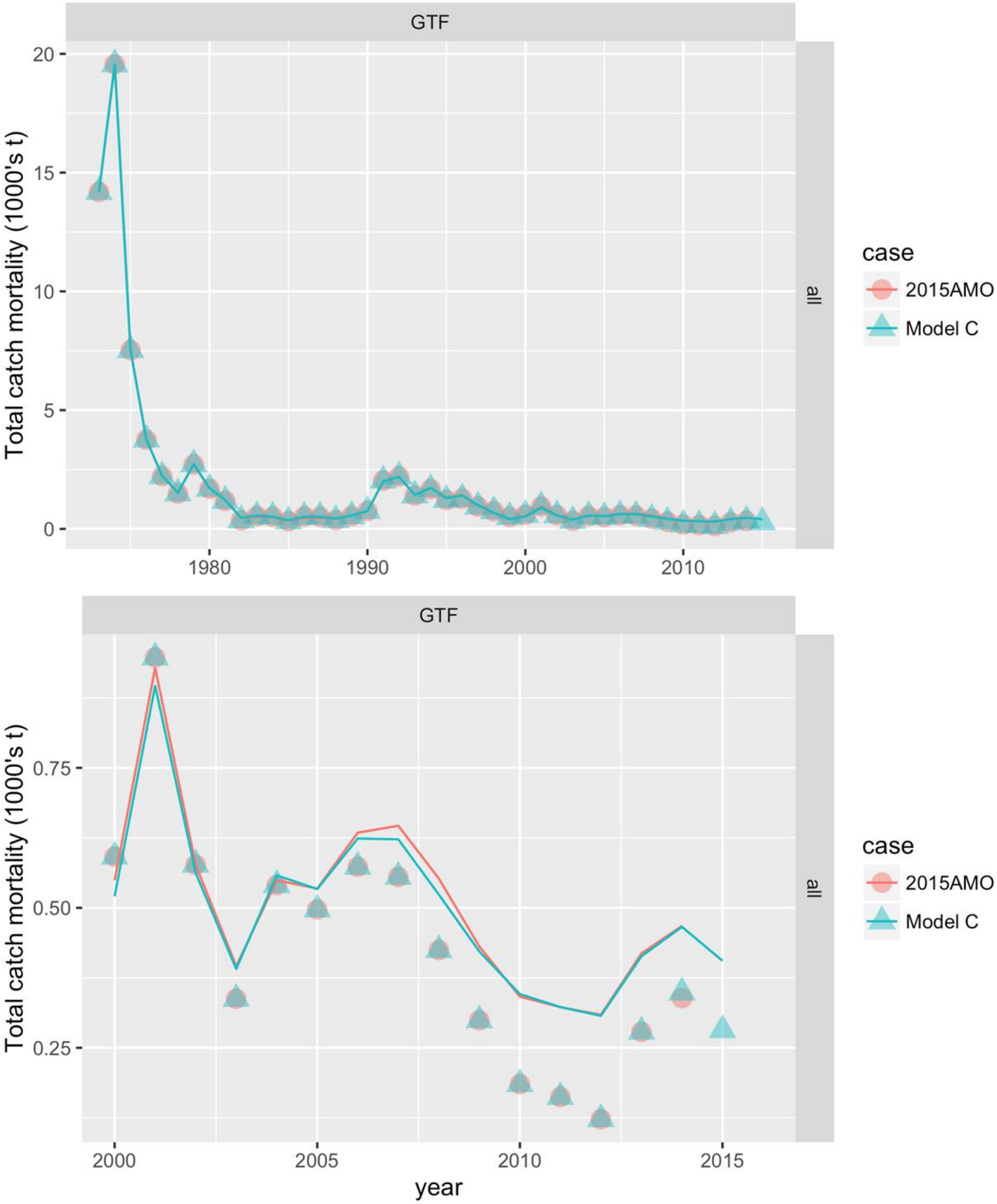


Figure 54. Fits to total catch biomass from the 2015 assessment (2015AMO) and the author’s preferred model (Model C) for males in the groundfish fisheries (GTF). Lower plot is zoomed to 2000-2015. Observed: symbols.

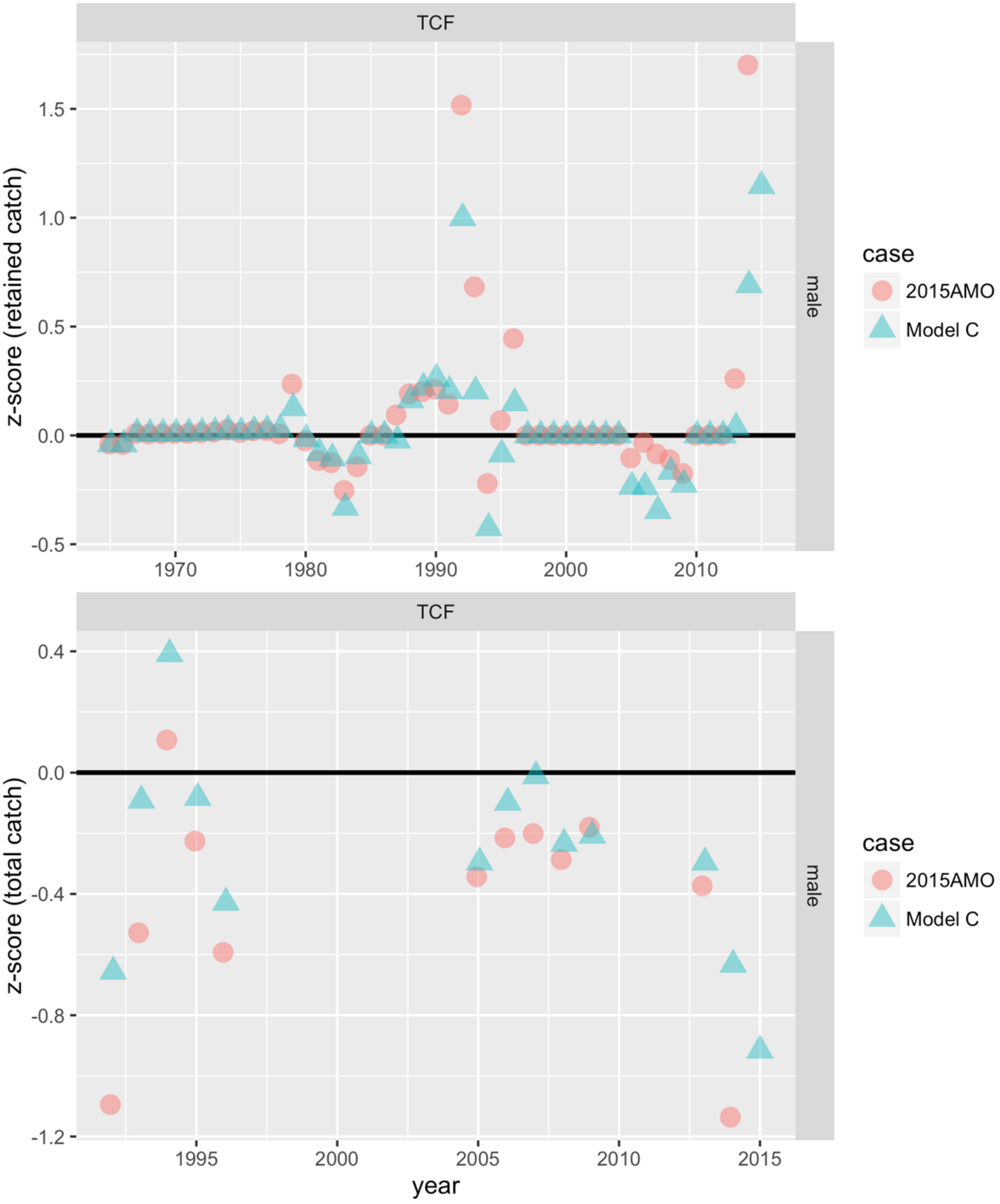


Figure 55. Z-scores for fits to retained and male total catch biomass from the 2015 assessment (2015AMO) and the author's preferred model (Model C) for males in the directed Tanner crab (TCF) fisheries.

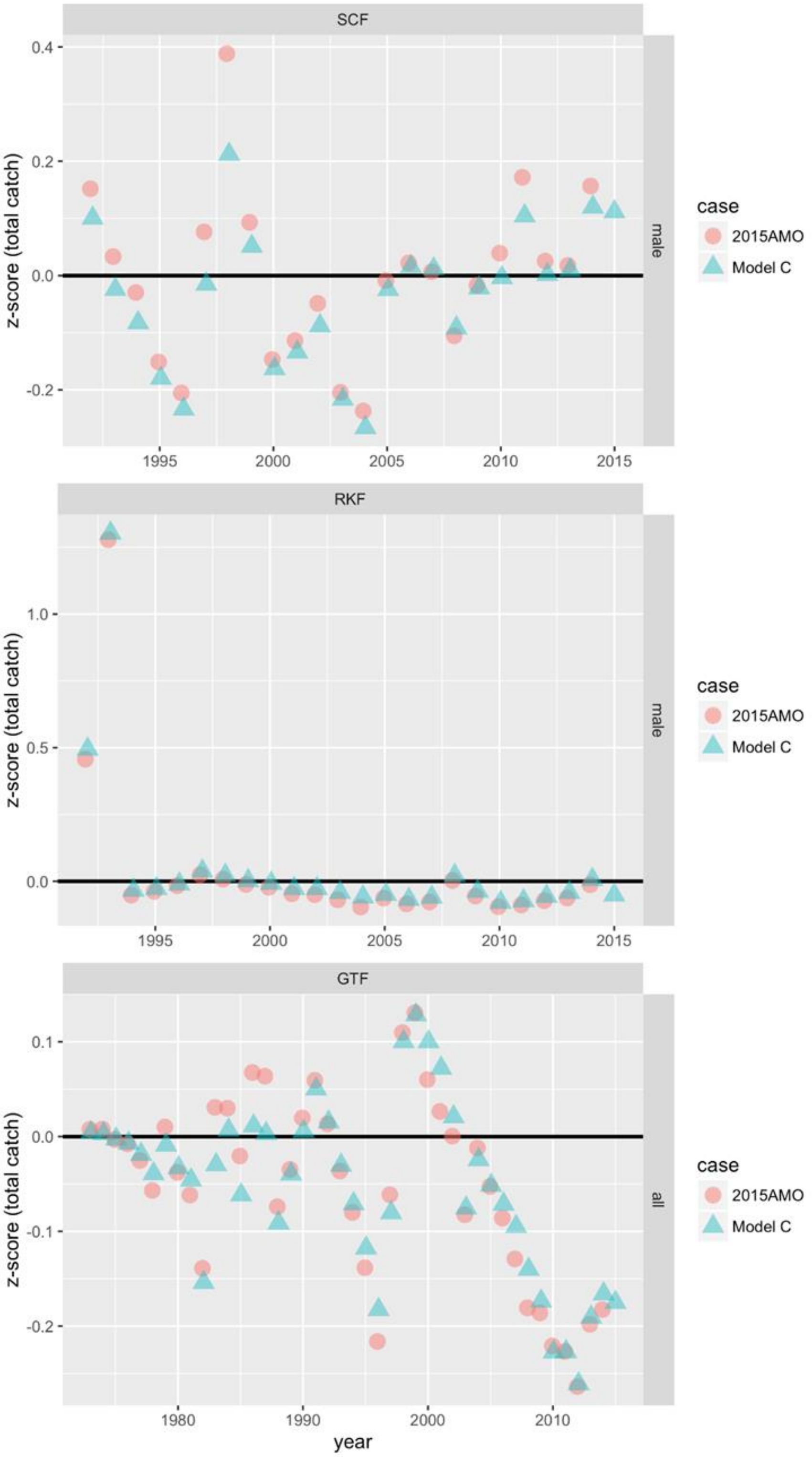


Figure 56. Z-scores for fits to total catch biomass from the 2015 assessment (2015AMO) and the author's preferred model (Model C) for males in the snow crab (SCF) , BBRKC (RKF), and groundfish (GTF) fisheries.

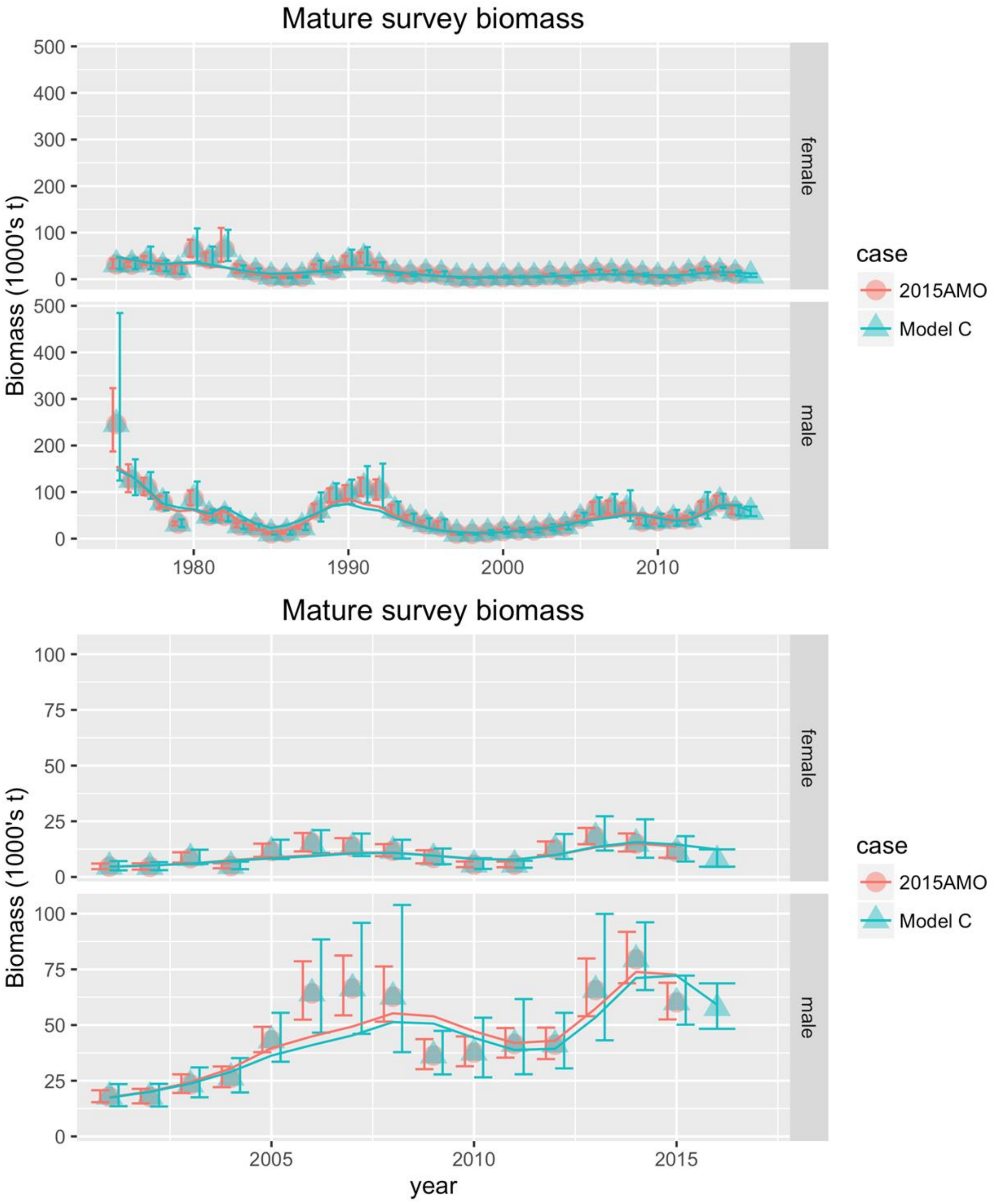


Figure 57. Estimated survey biomass (lines) from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Observed survey biomass (symbols) and associated confidence intervals based on cv's (error bars) are also shown.

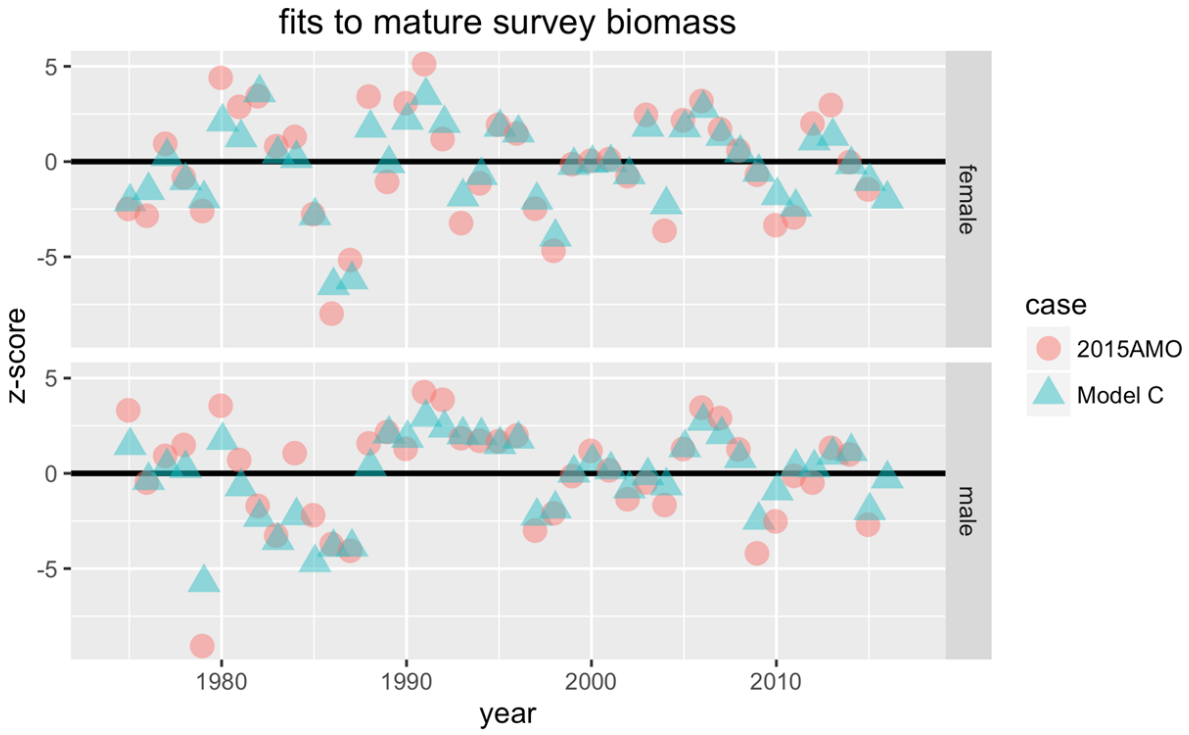


Figure 58. Z-scores for fits to mature survey biomass (lines) from the 2015 assessment (2015AMO) and the author’s preferred model (Model C).

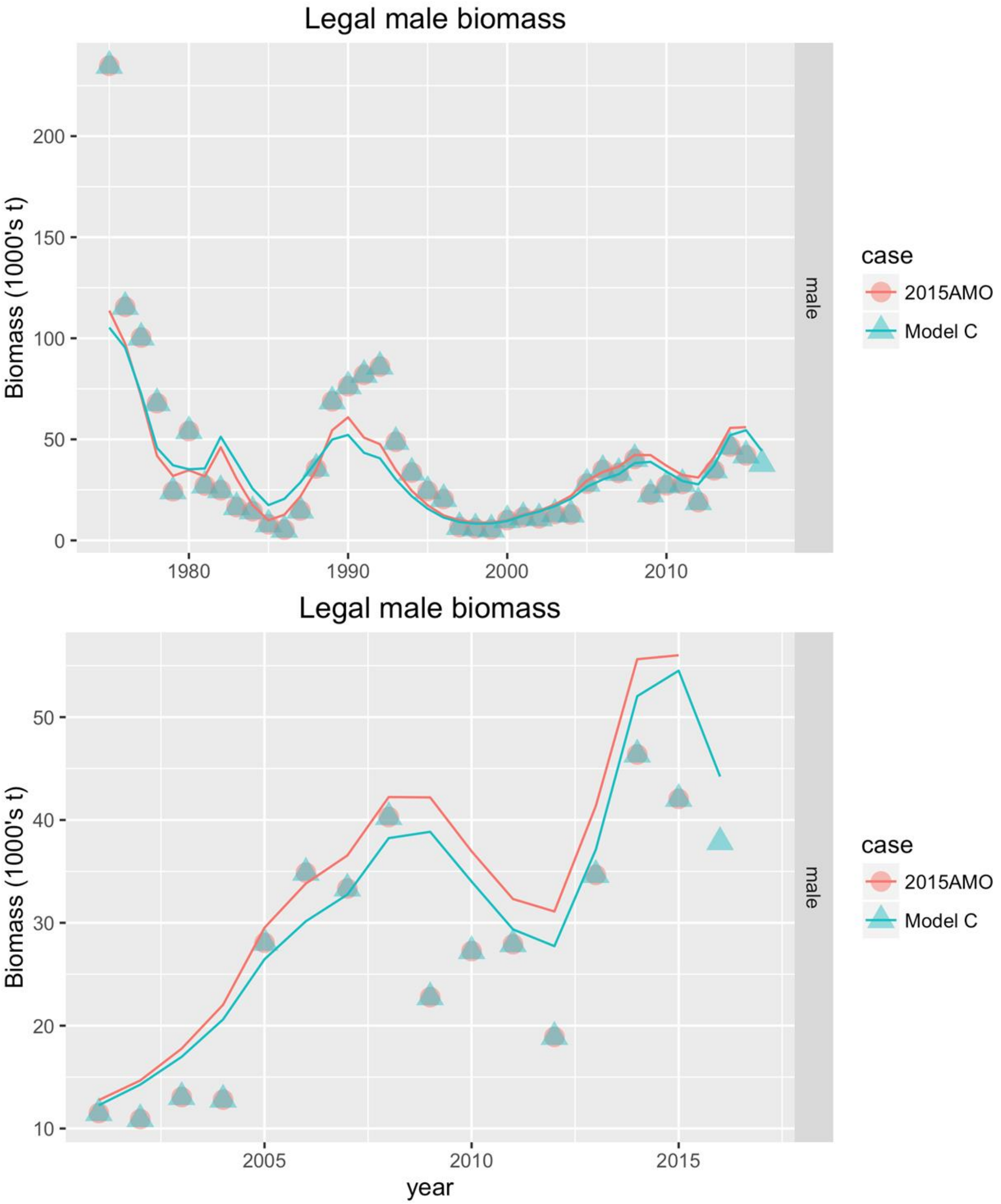


Figure 59. Estimated preferred (≥ 125 mm CW) male biomass in the NMFS trawl survey (lines) from the 2015 assessment (2015AMO) and the author’s preferred model (Model C). Observed biomass of legal males in the survey is plotted as symbols.

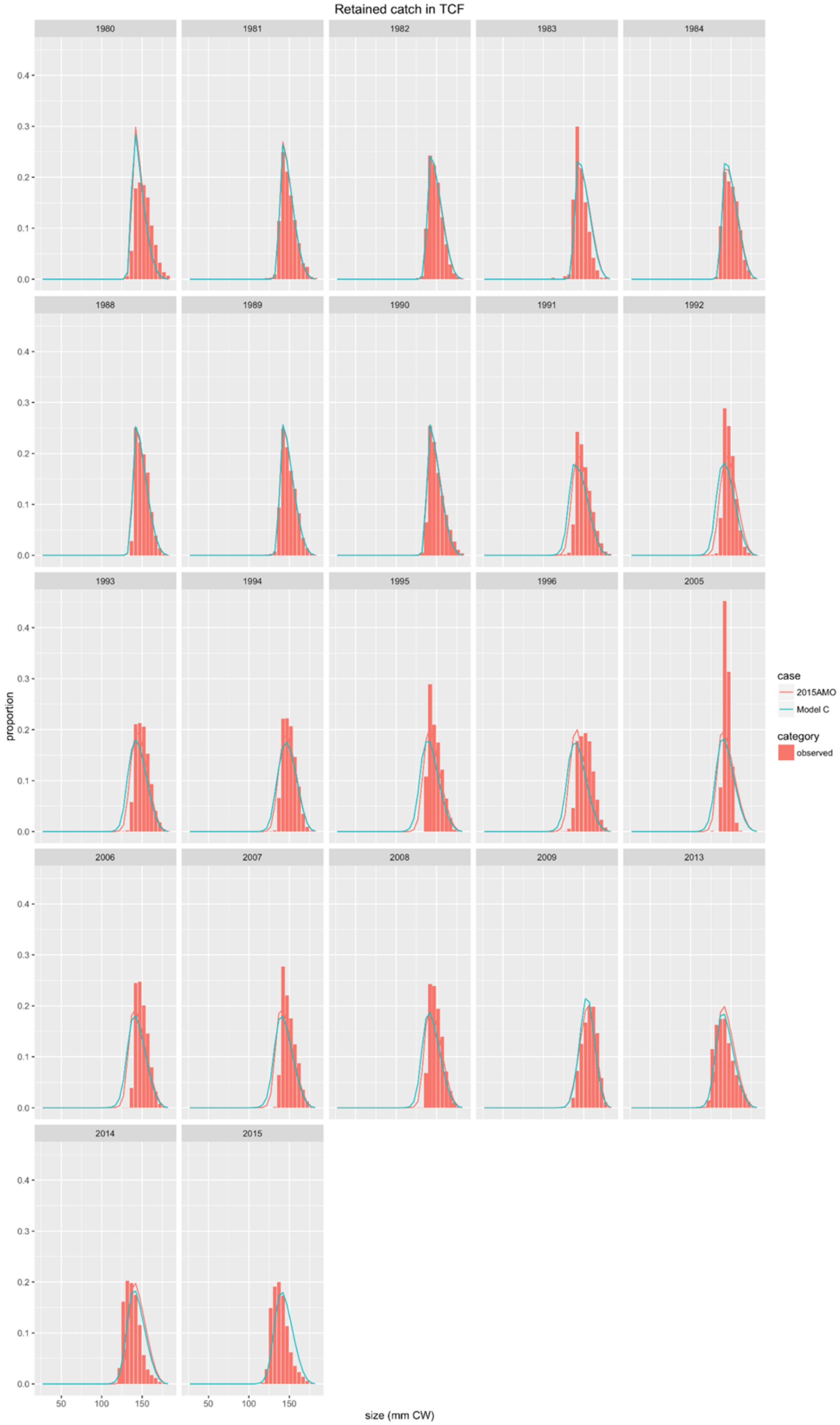


Figure 60. Fits to retained catch (dockside) size compositions from the directed Tanner crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

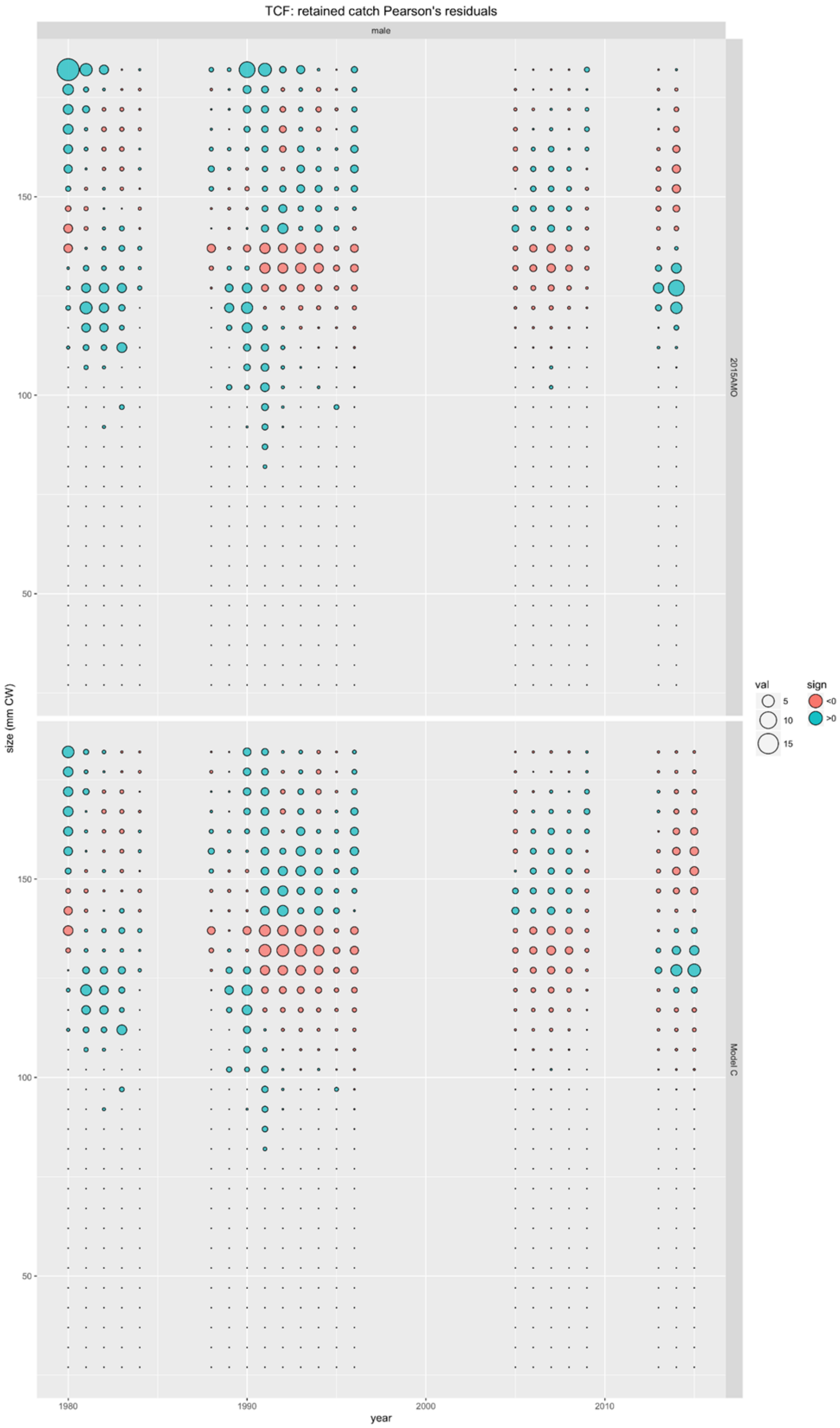


Figure 61. Pearson’s residuals for fits to retained catch (dockside) size compositions from the directed Tanner crab fishery for the 2015 assessment (2015AMO) and the author’s preferred model (Model C).

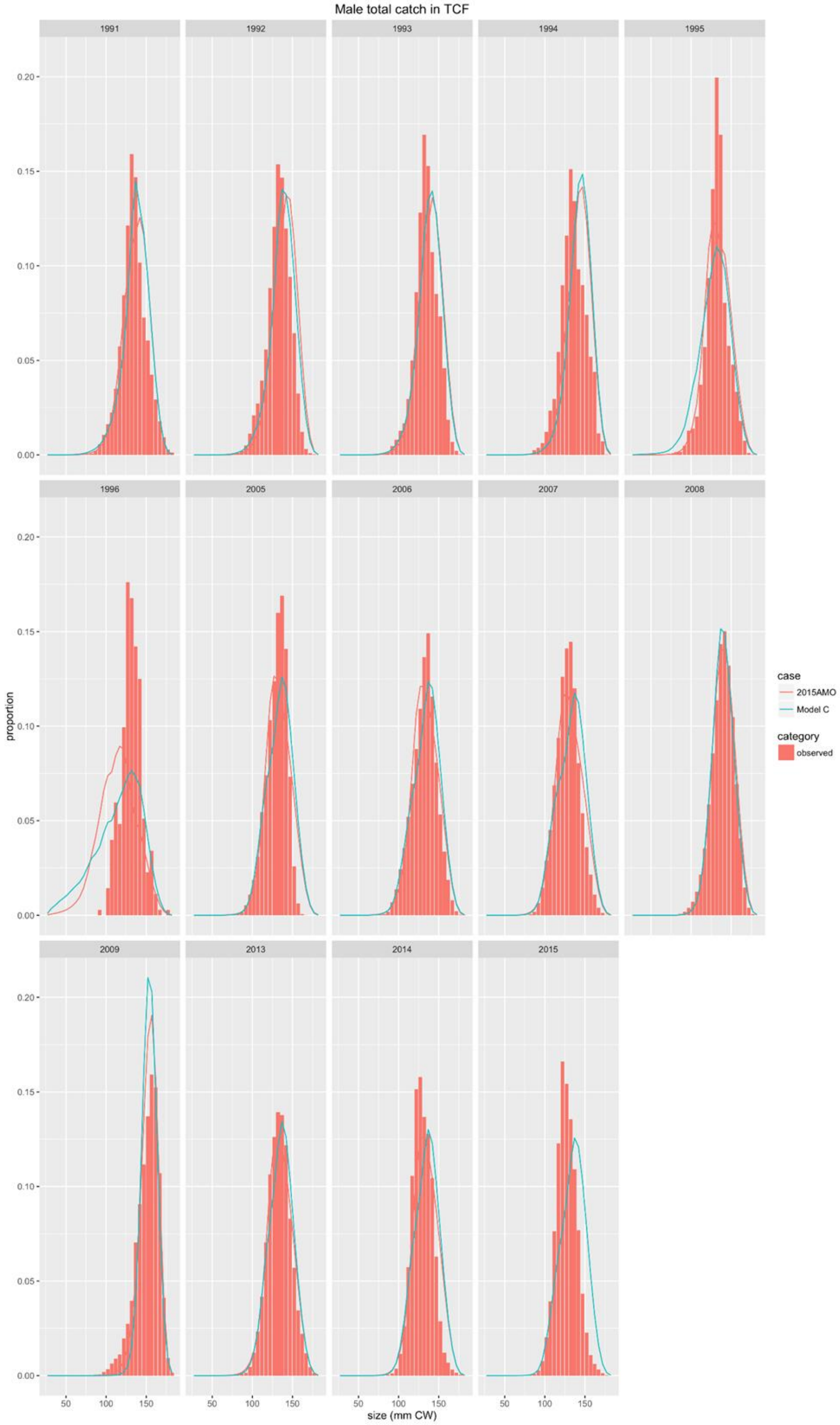


Figure 62. Fits to total catch (at-sea) male size compositions from the directed Tanner crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

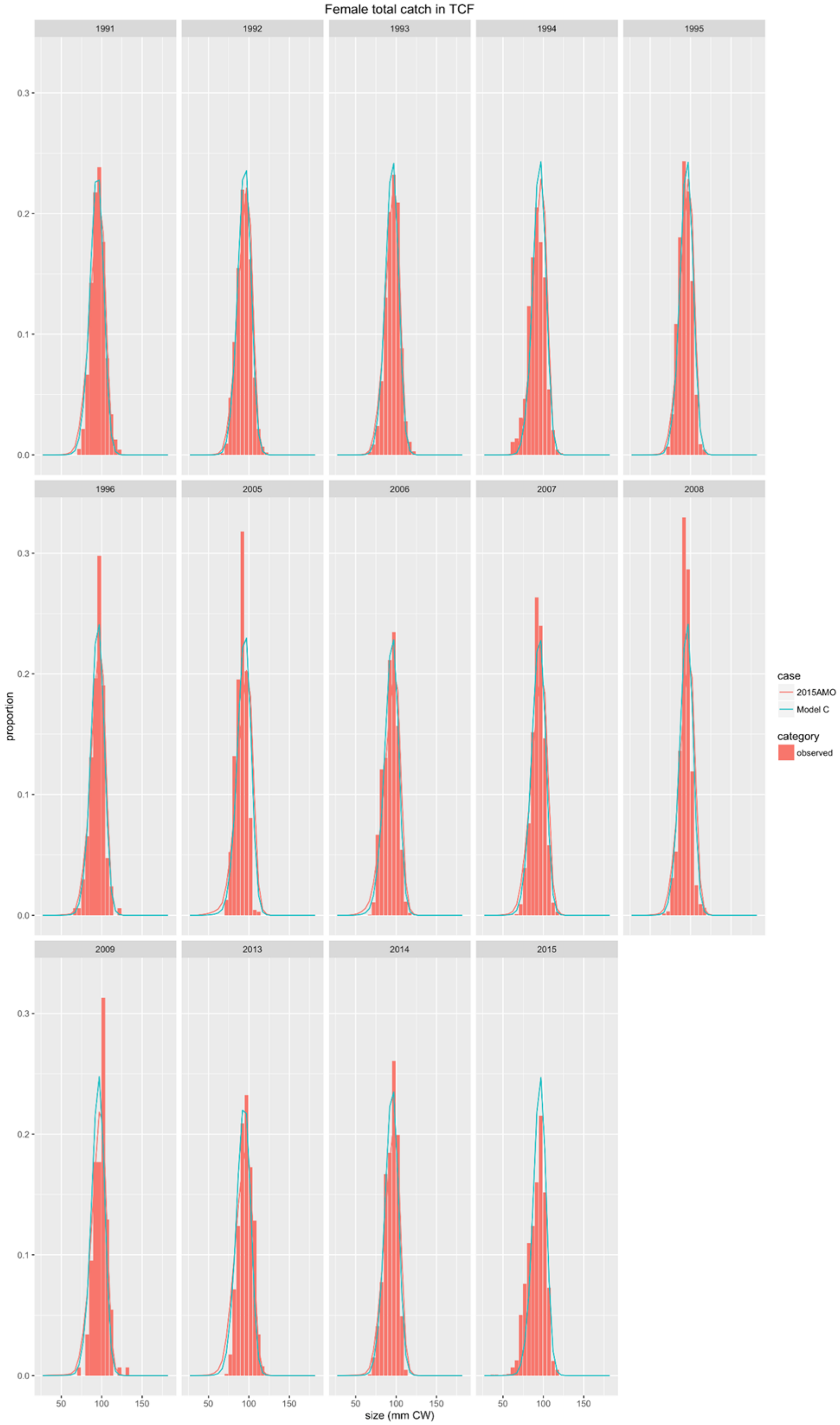


Figure 63. Fits to total catch (at-sea) female size compositions from the directed Tanner crab fishery for the 2015 assessment (2015AMO) and the author’s preferred model (Model C). Bars: observed; lines: predicted.

Figure 64. Pearson’s residuals for fits to total catch (at-sea) size compositions from the directed fishery for the 2015 assessment (2015AMO) and the author’s preferred model (Model C).

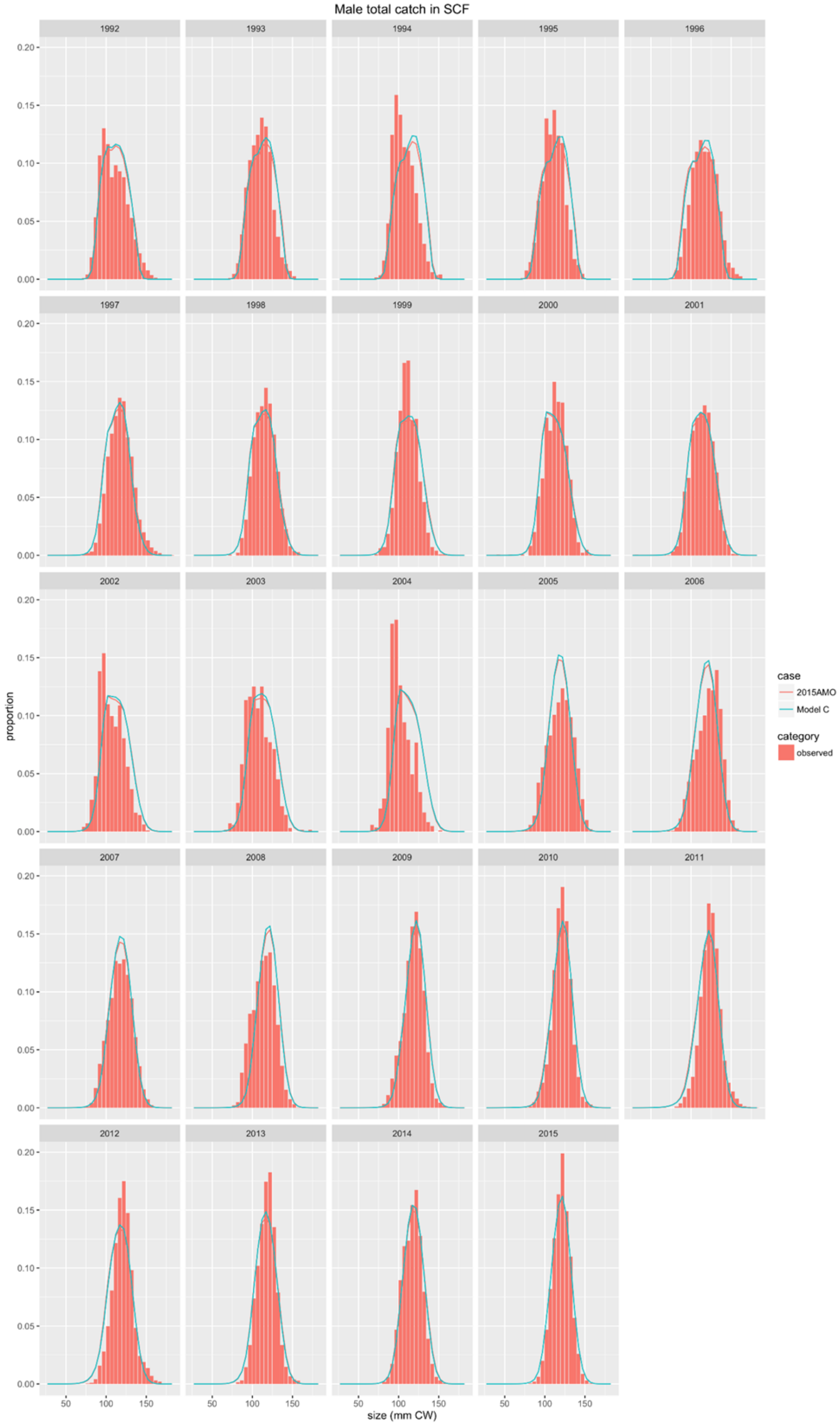


Figure 65. Fits to bycatch male size compositions from the snow crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

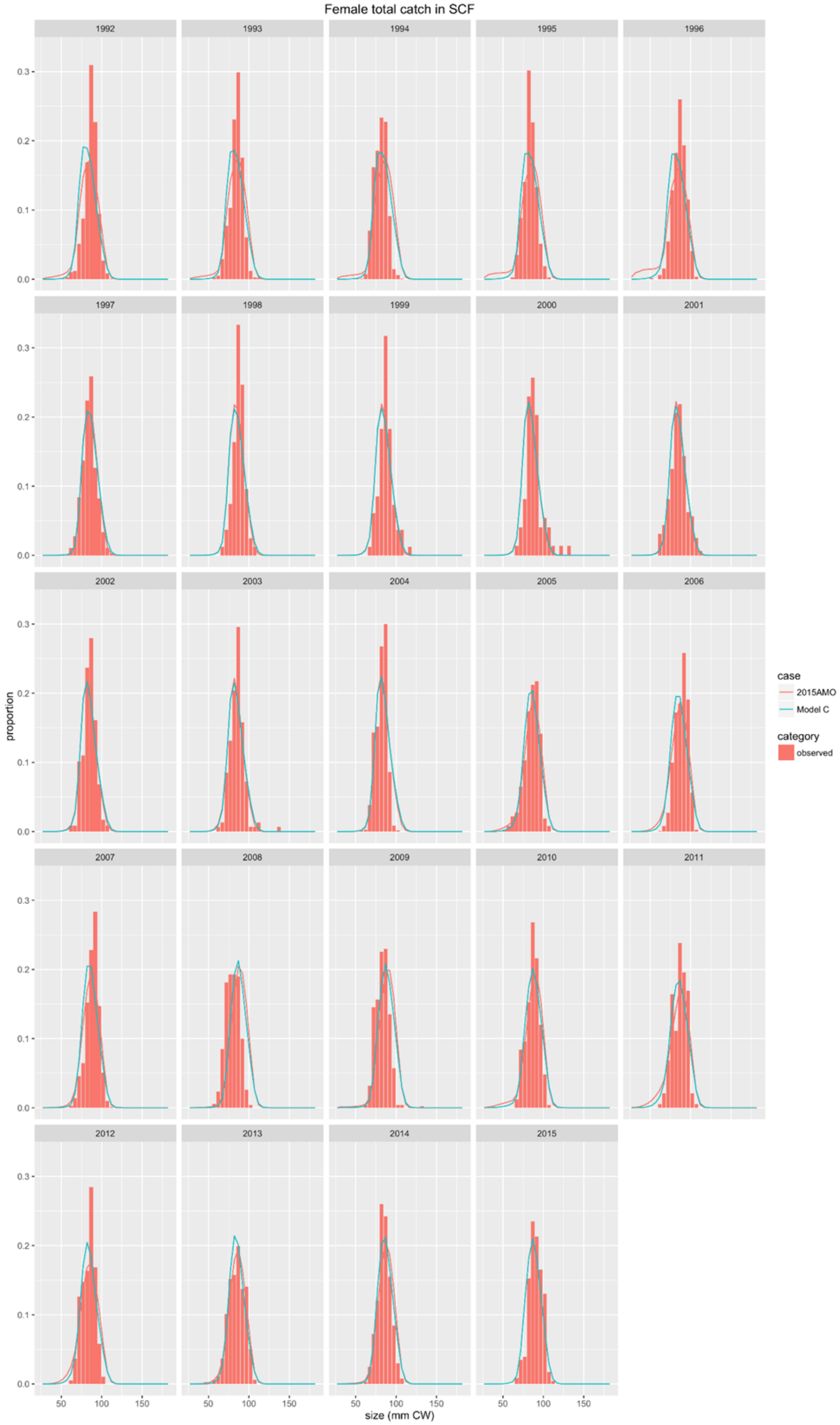


Figure 66. Fits to bycatch female size compositions from the snow crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

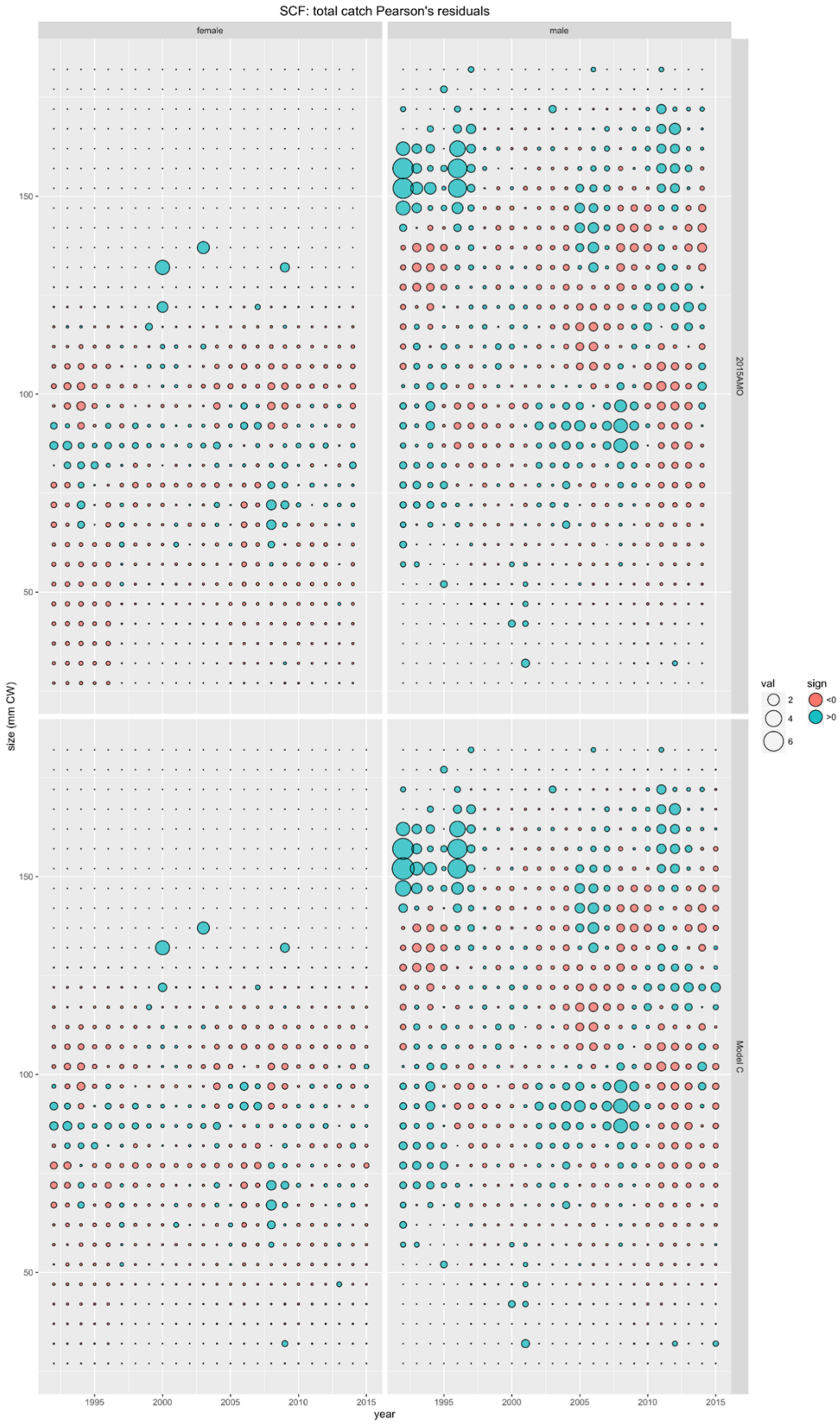


Figure 67. Pearson’s residuals for fits to bycatch size compositions from the snow crab fishery for the 2015 assessment (2015AMO) and the author’s preferred model (Model C).

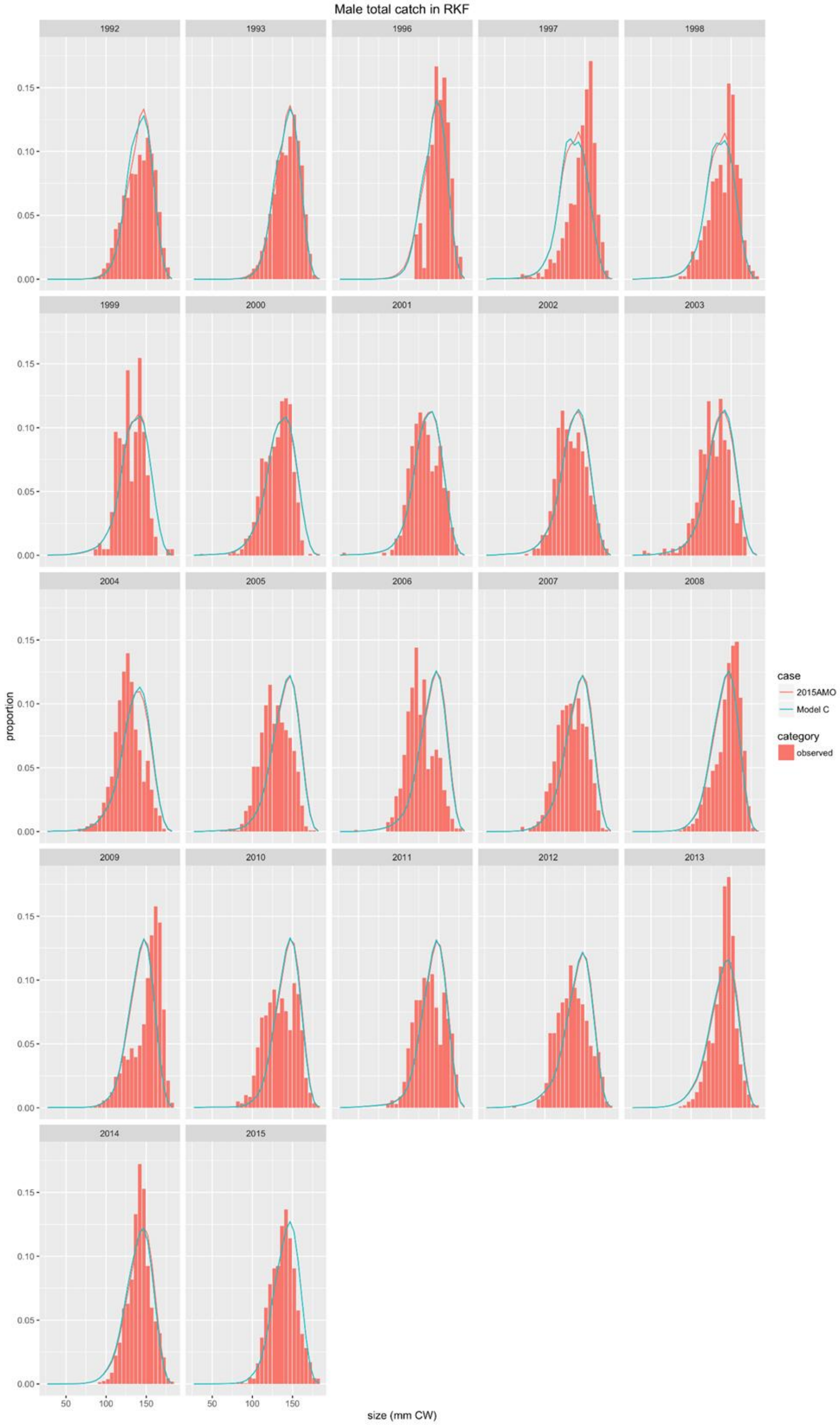


Figure 68. Fits to bycatch male size compositions from the BBRKC fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

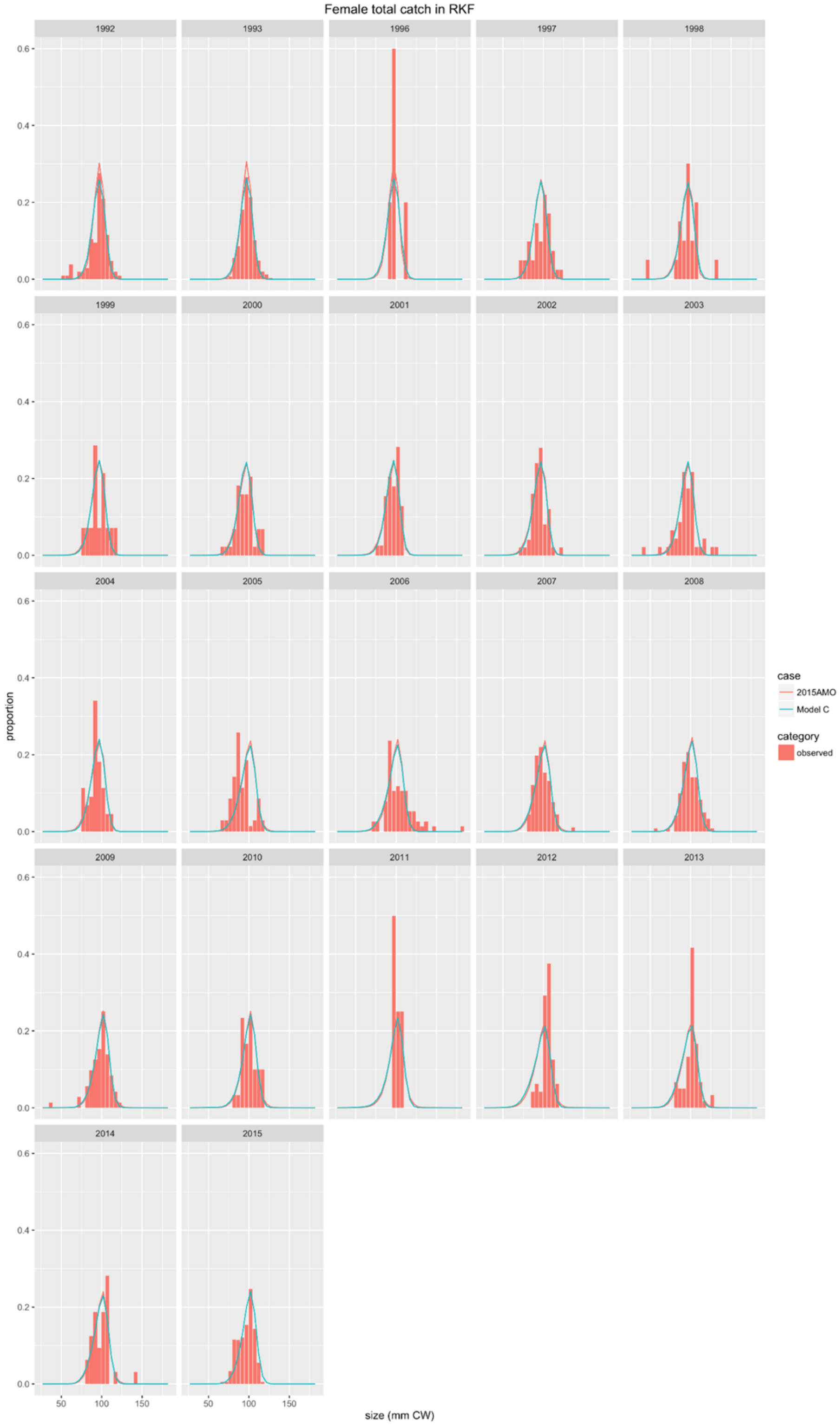


Figure 69. Fits to bycatch female size compositions from the BBRKC fishery for the 2015 assessment (2015AMO) and the author’s preferred model (Model C). Bars: observed; lines: predicted.

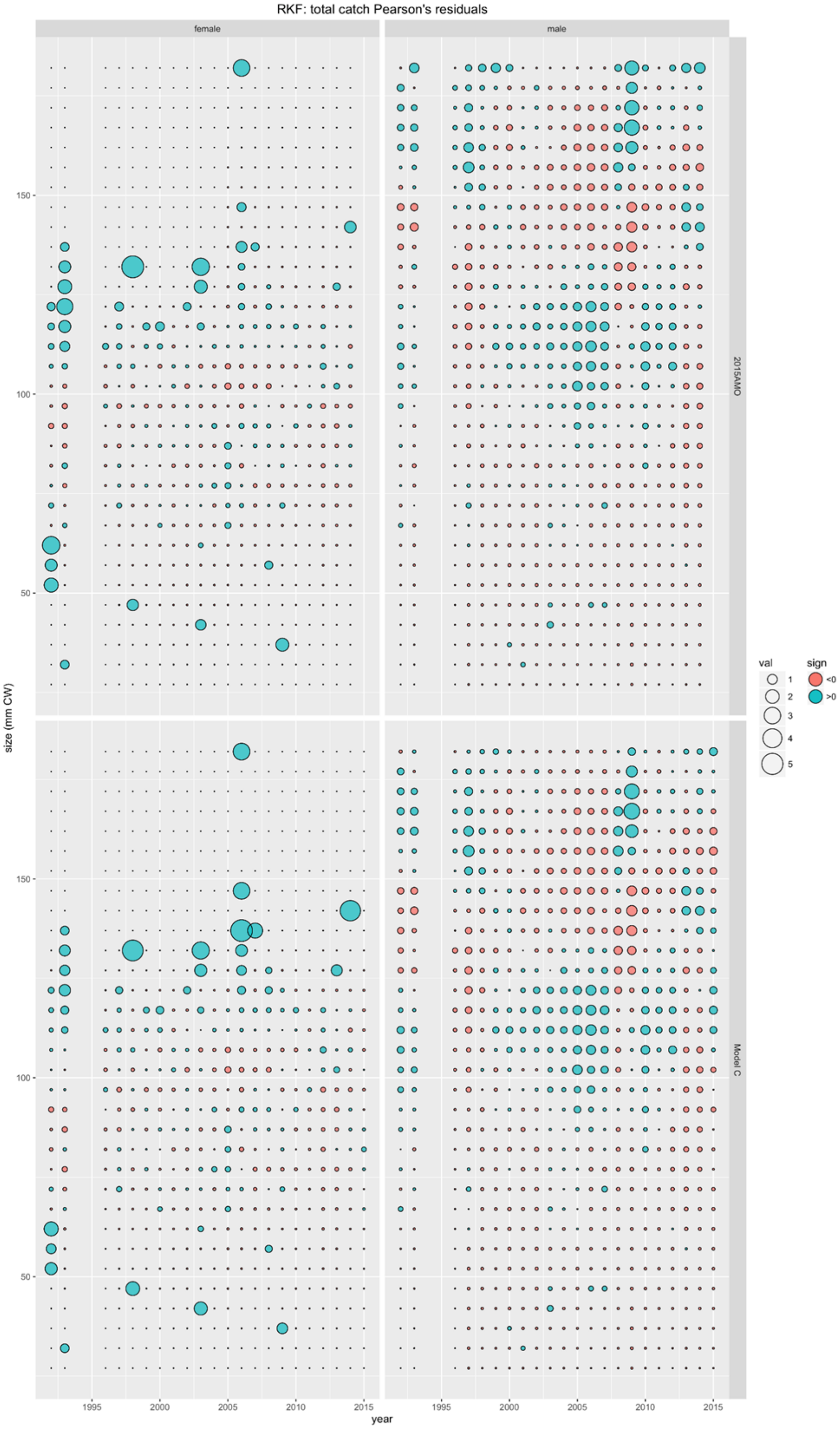


Figure 70. Pearson's residuals for fits to bycatch size compositions from the BBRKC fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C).

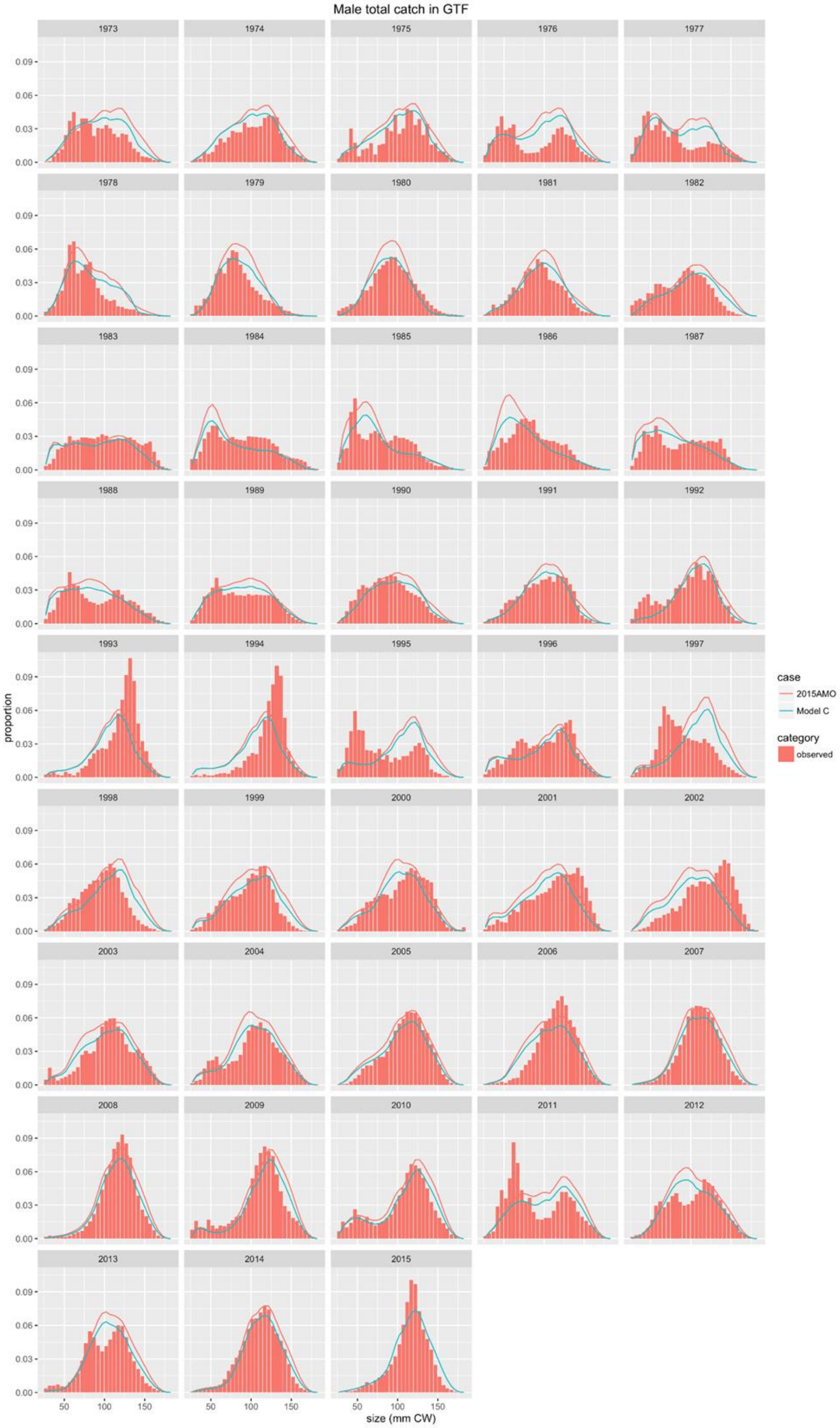


Figure 71. Fits to bycatch male size compositions from the groundfish fisheries for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

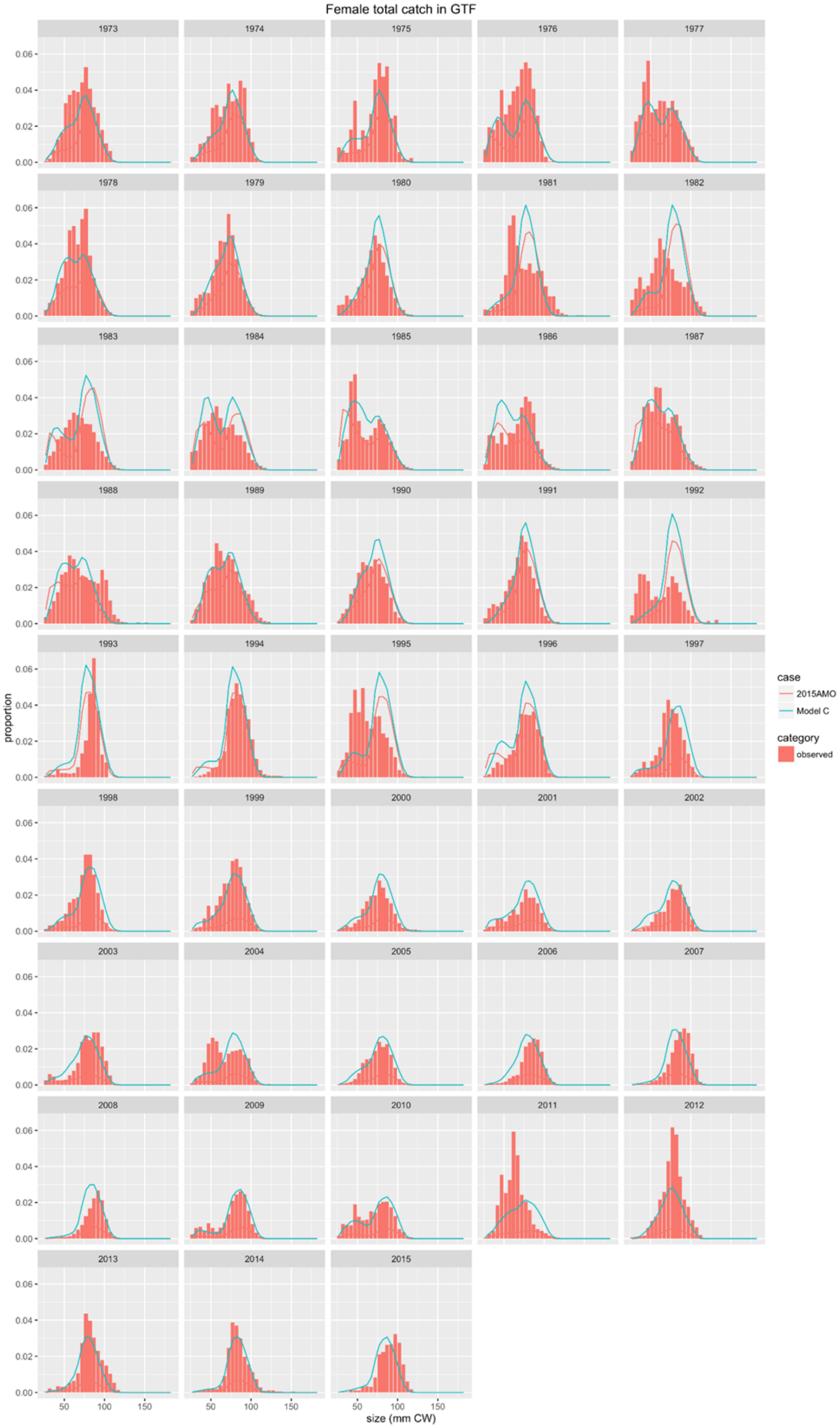


Figure 72. Fits to bycatch female size compositions from the groundfish fisheries for the 2015 assessment (2015AMO) and the author’s preferred model (Model C). Bars: observed; lines: predicted.

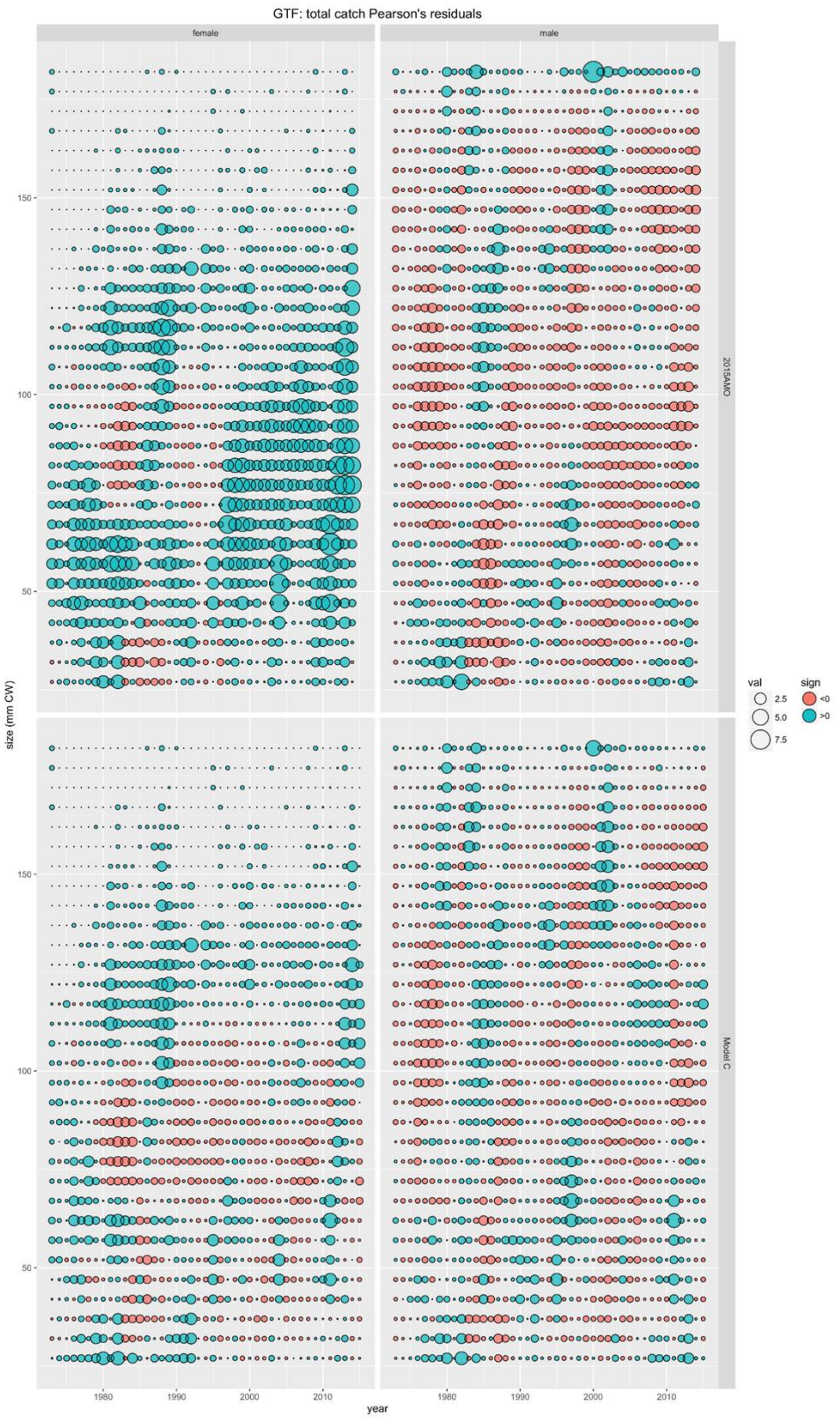


Figure 73. Pearson’s residuals for fits to bycatch size compositions from the groundfish fisheries for the 2015 assessment (2015AMO) and the author’s preferred model (Model C).

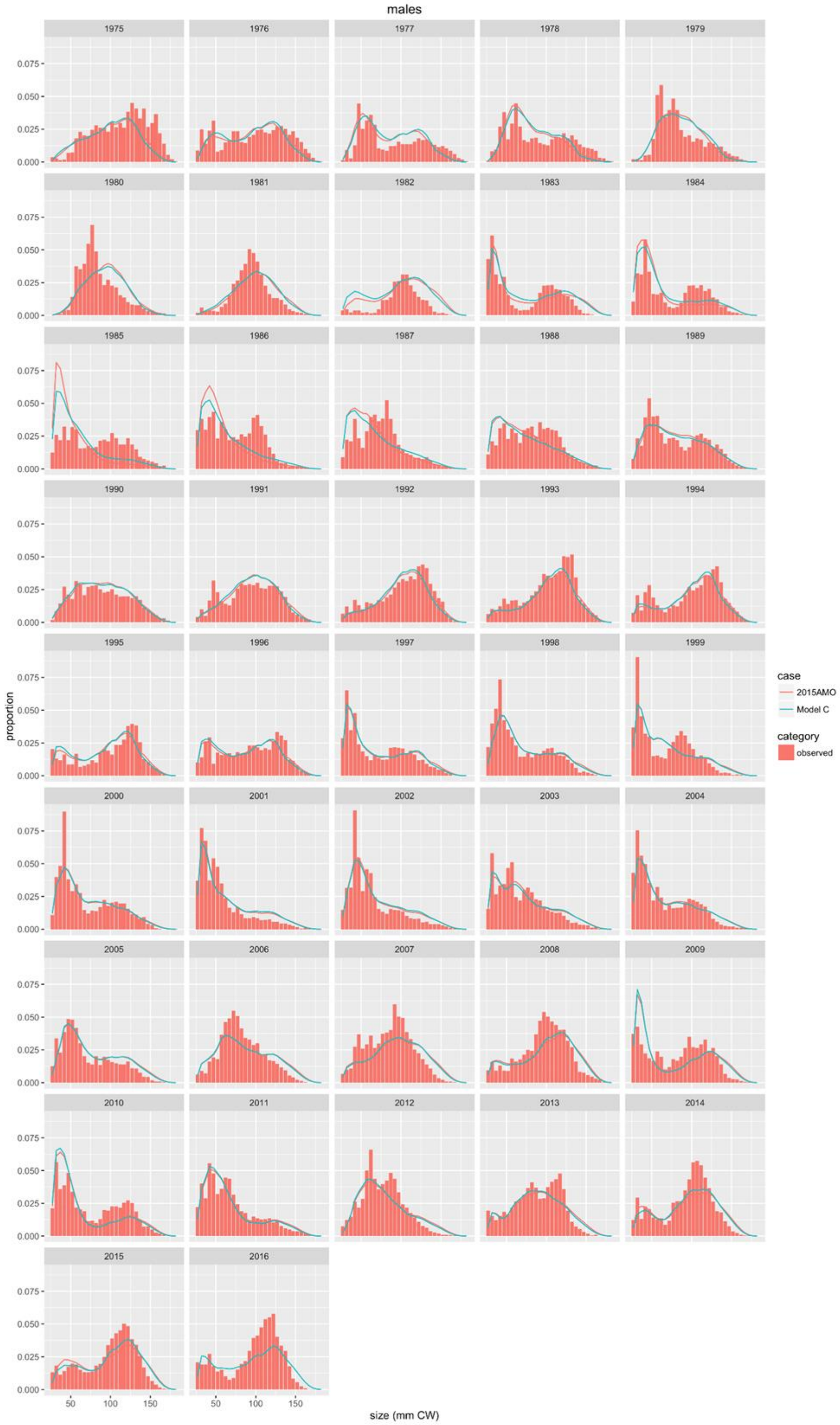


Figure 74. Fits to bycatch male size compositions from the NFS EBS bottom trawl survey for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

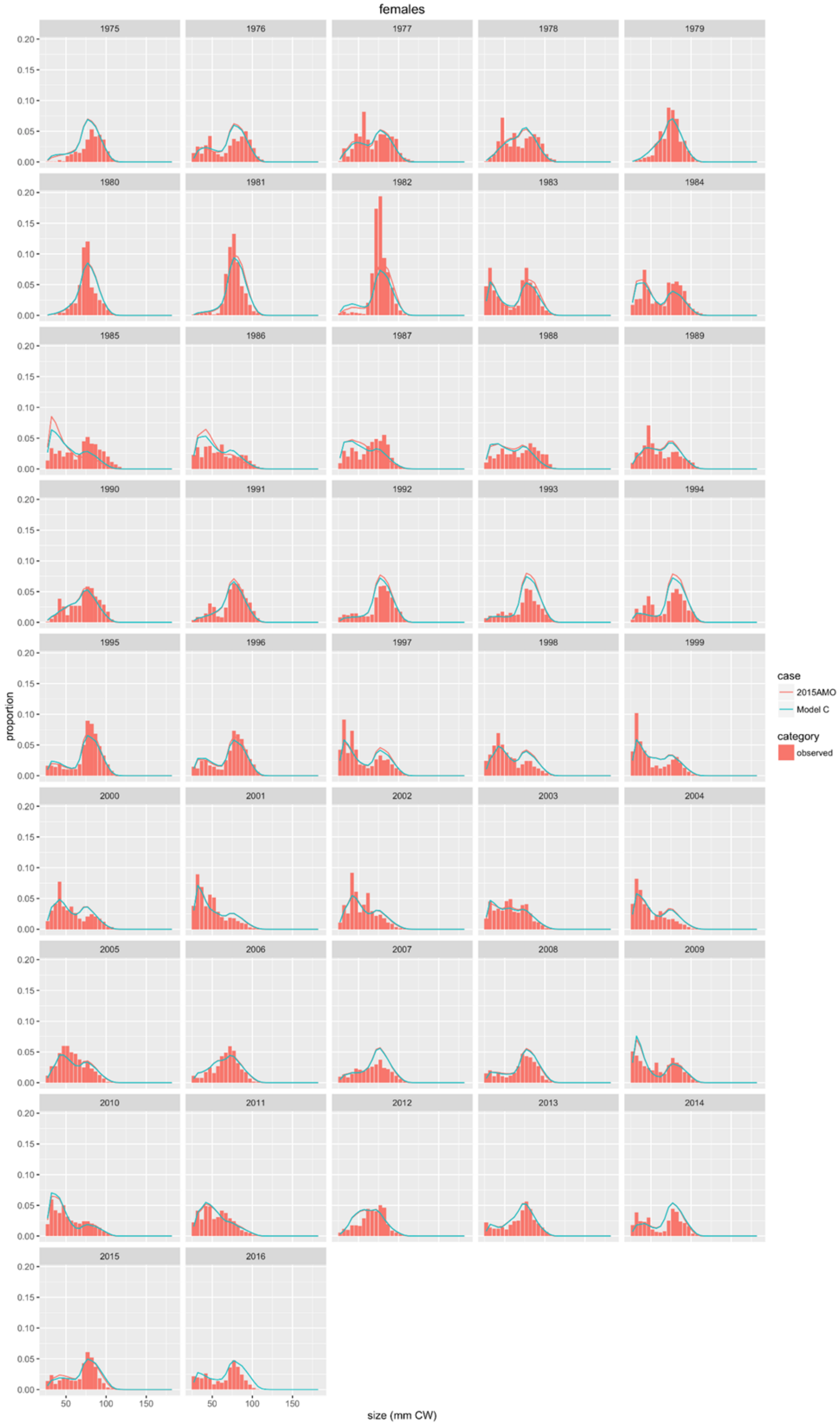


Figure 75. Fits to bycatch female size compositions from the NFS EBS bottom trawl survey for the 2015 assessment (2015AMO) and the author’s preferred model (Model C). Bars: observed; lines: predicted.

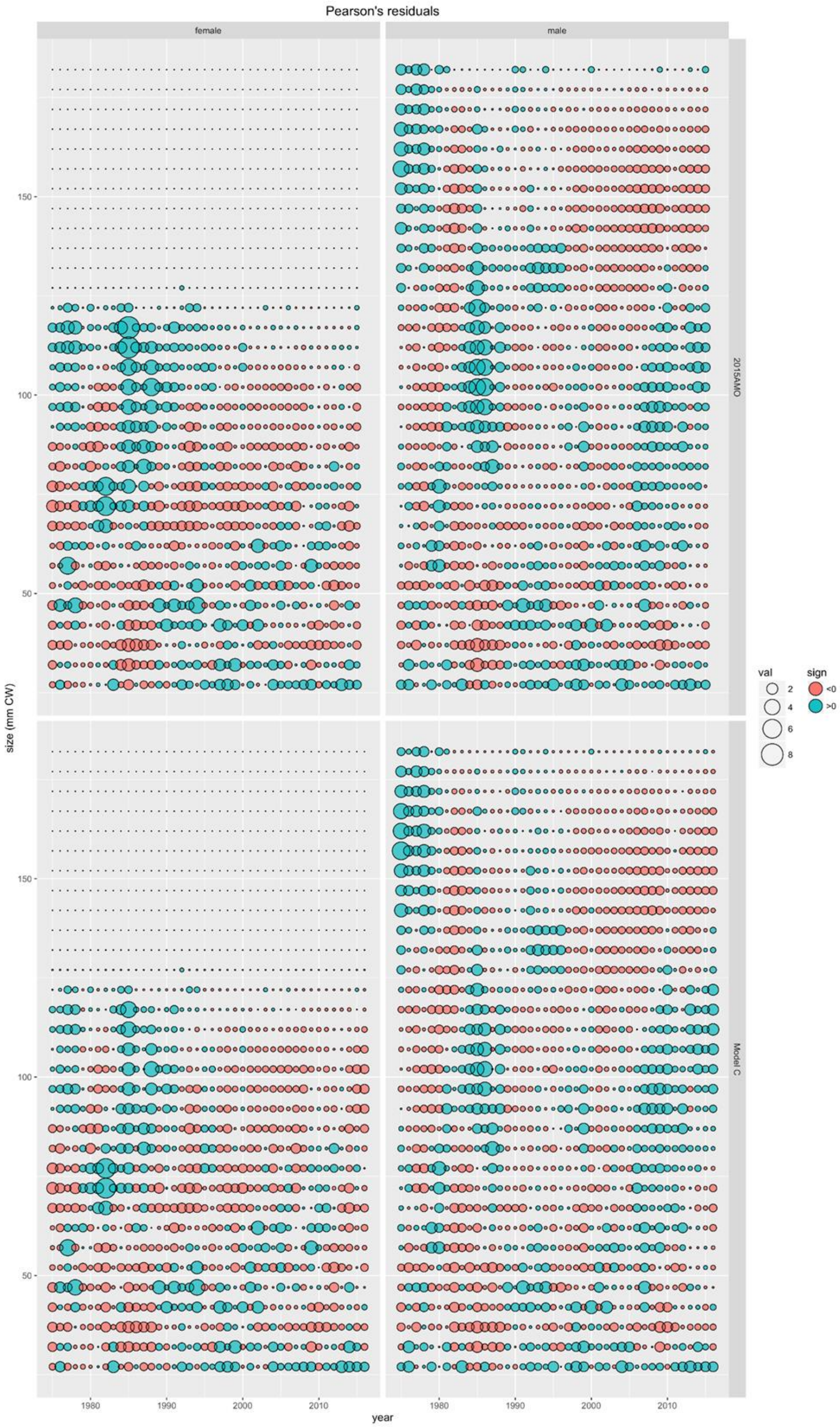


Figure 76. Pearson's residuals for fits to size compositions from the NFS EBS bottom trawl survey for the 2015 assessment (2015AMO) and the author's preferred model (Model C).

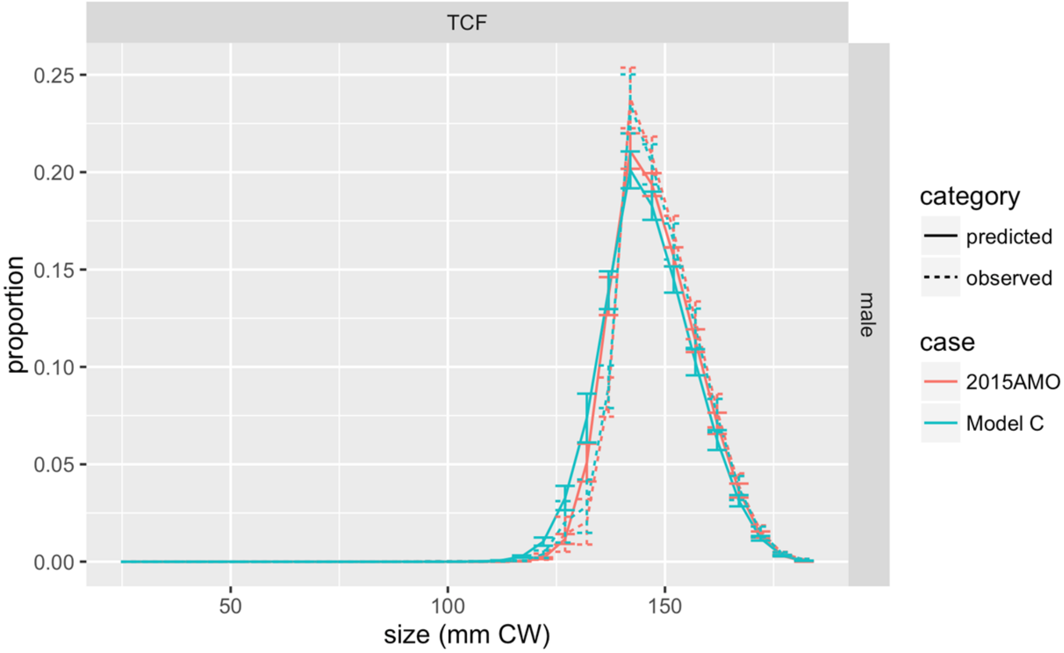


Figure 77. Marginal distributions for retained catch (dockside) size compositions from the directed Tanner crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Dotted lines: observed; solid lines: predicted.

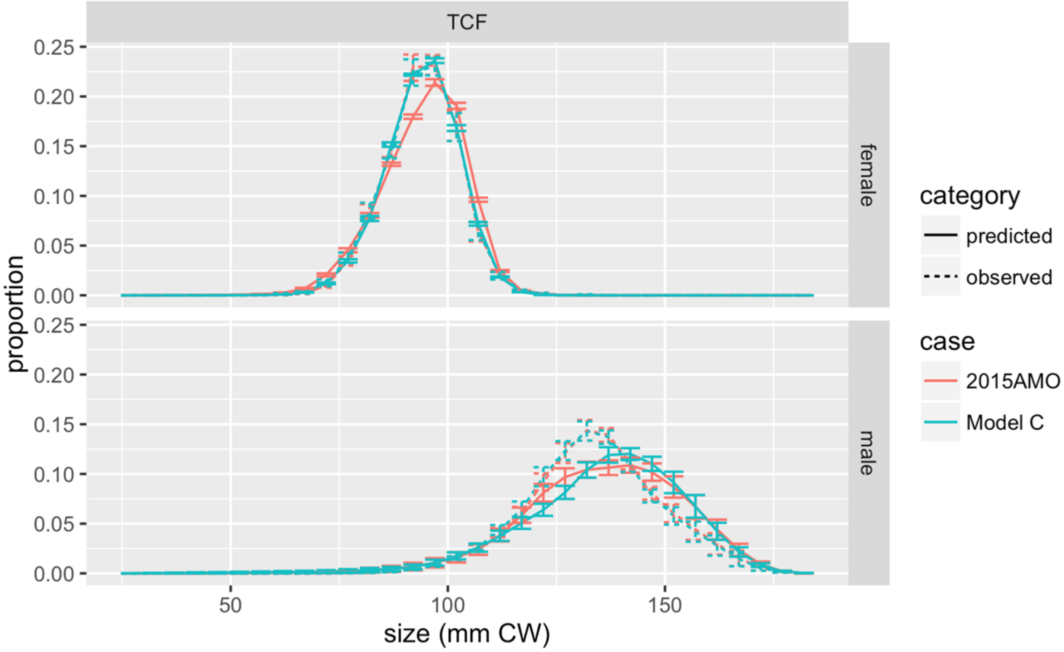


Figure 78. Marginal distributions for total catch (at-sea) size compositions from the directed Tanner crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Dotted lines: observed; solid lines: predicted.

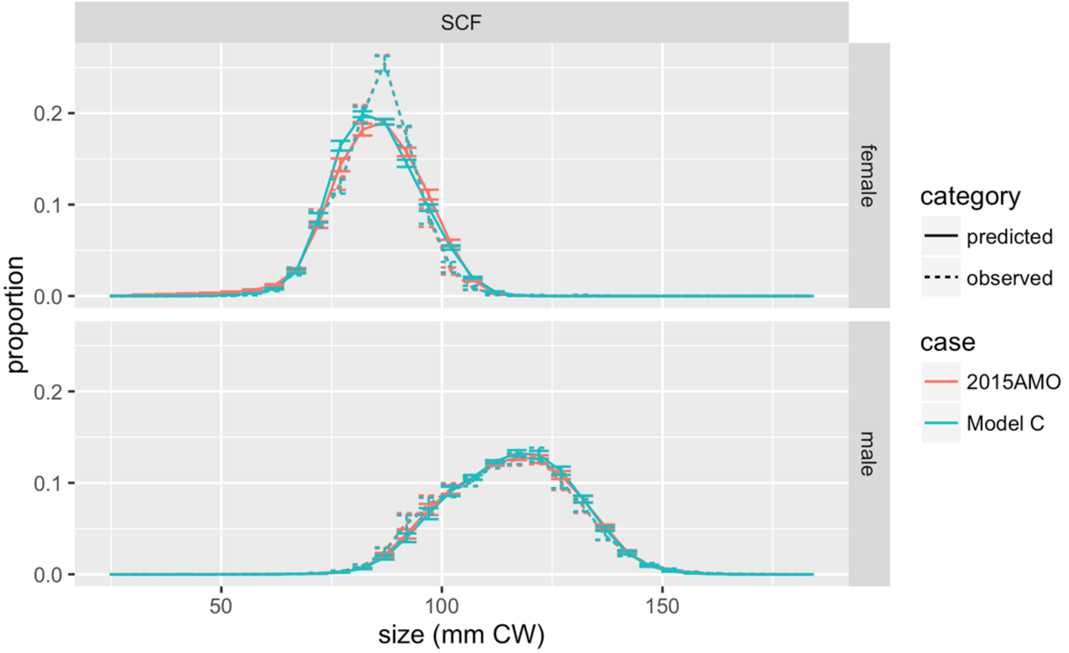


Figure 79. Marginal distributions for bycatch (at-sea) size compositions from the snow crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Dotted lines: observed; solid lines: predicted.

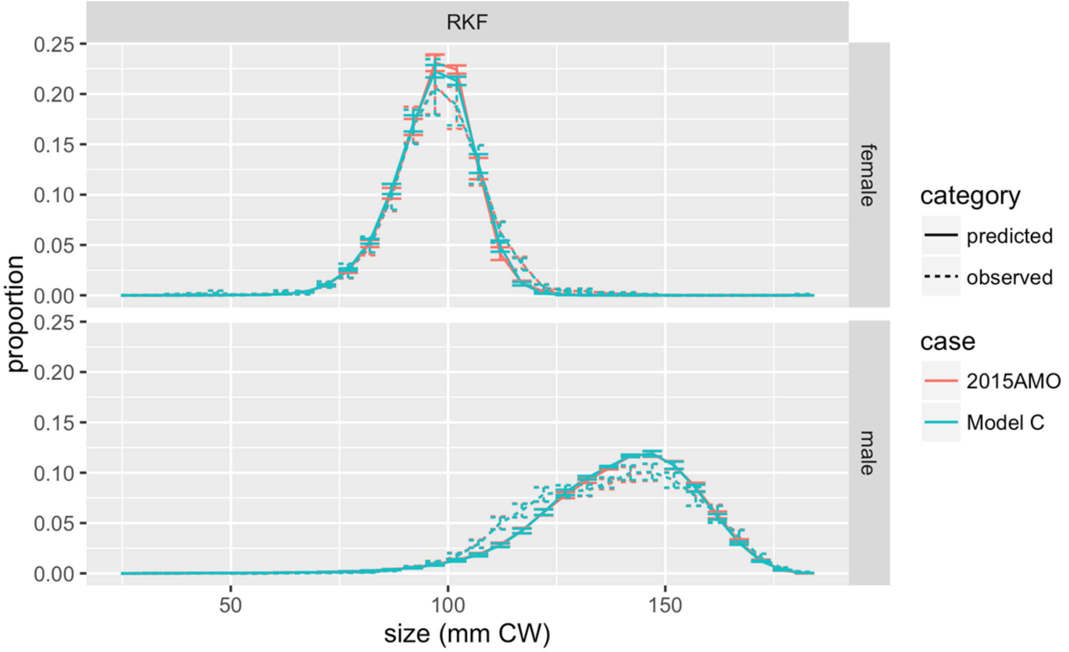


Figure 80. Marginal distributions for bycatch (at-sea) size compositions from the BBRKC fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Dotted lines: observed; solid lines: predicted.

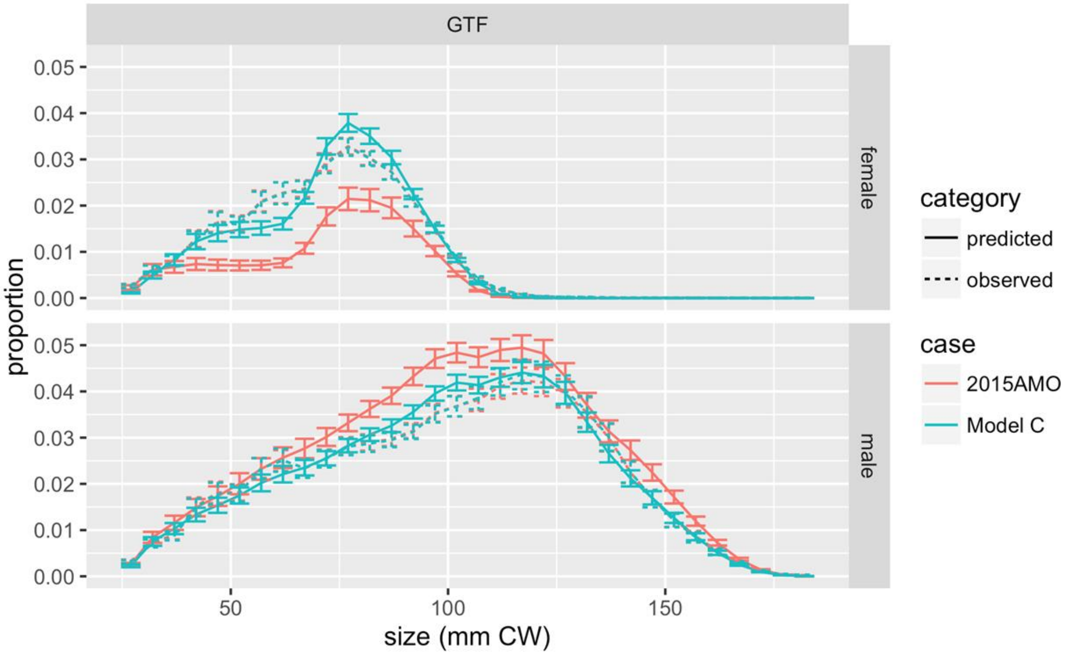


Figure 81. Marginal distributions for bycatch (at-sea) size compositions from the groundfish fisheries for the 2015 assessment (2015AMO) and the author’s preferred model (Model C). Dotted lines: observed; solid lines: predicted.

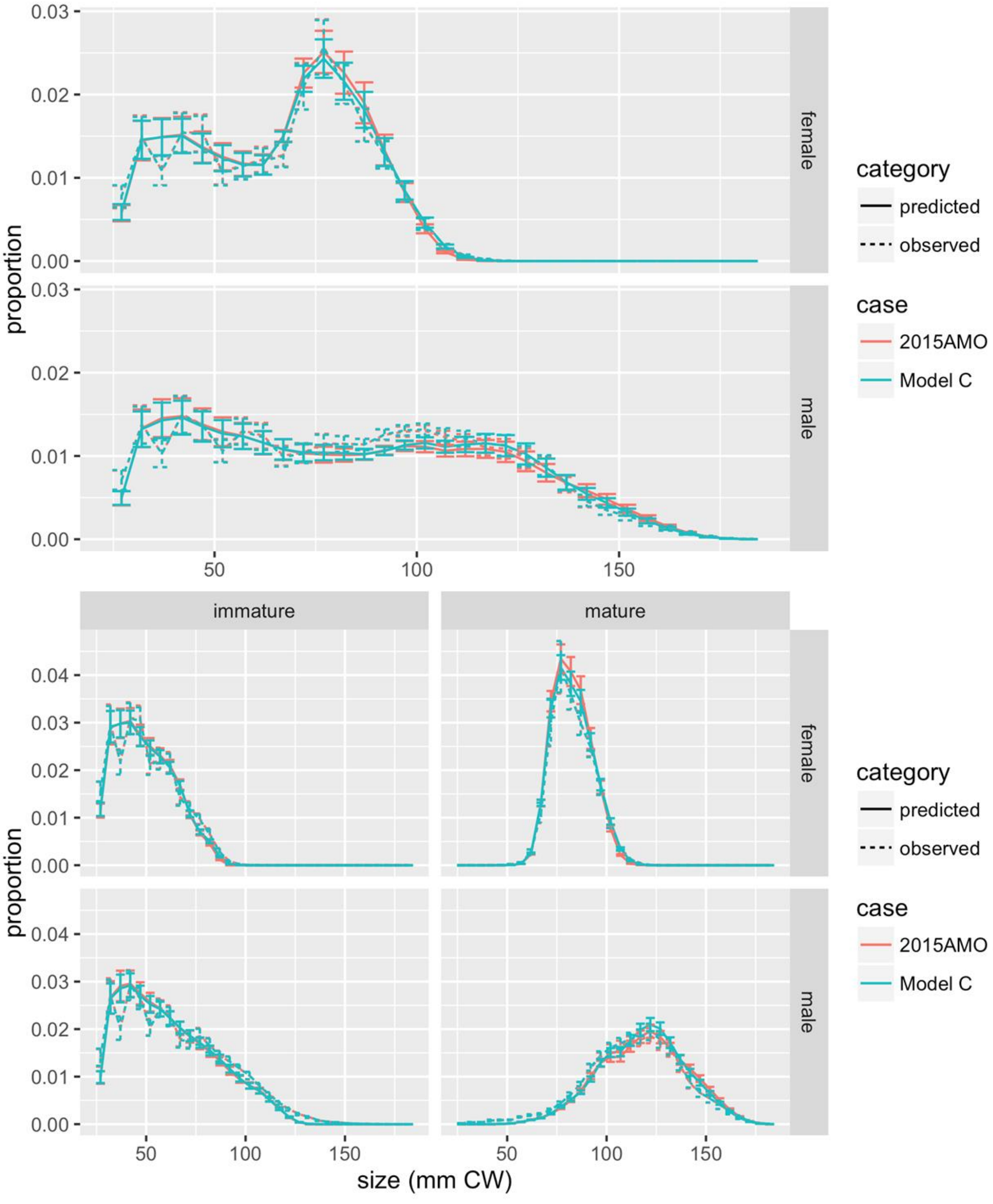


Figure 82. Marginal distributions for size compositions from the NMFS EBS trawl survey for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Dotted lines: observed; solid lines: predicted. Distributions are shown: top) by sex; bottom) by sex and maturity state.

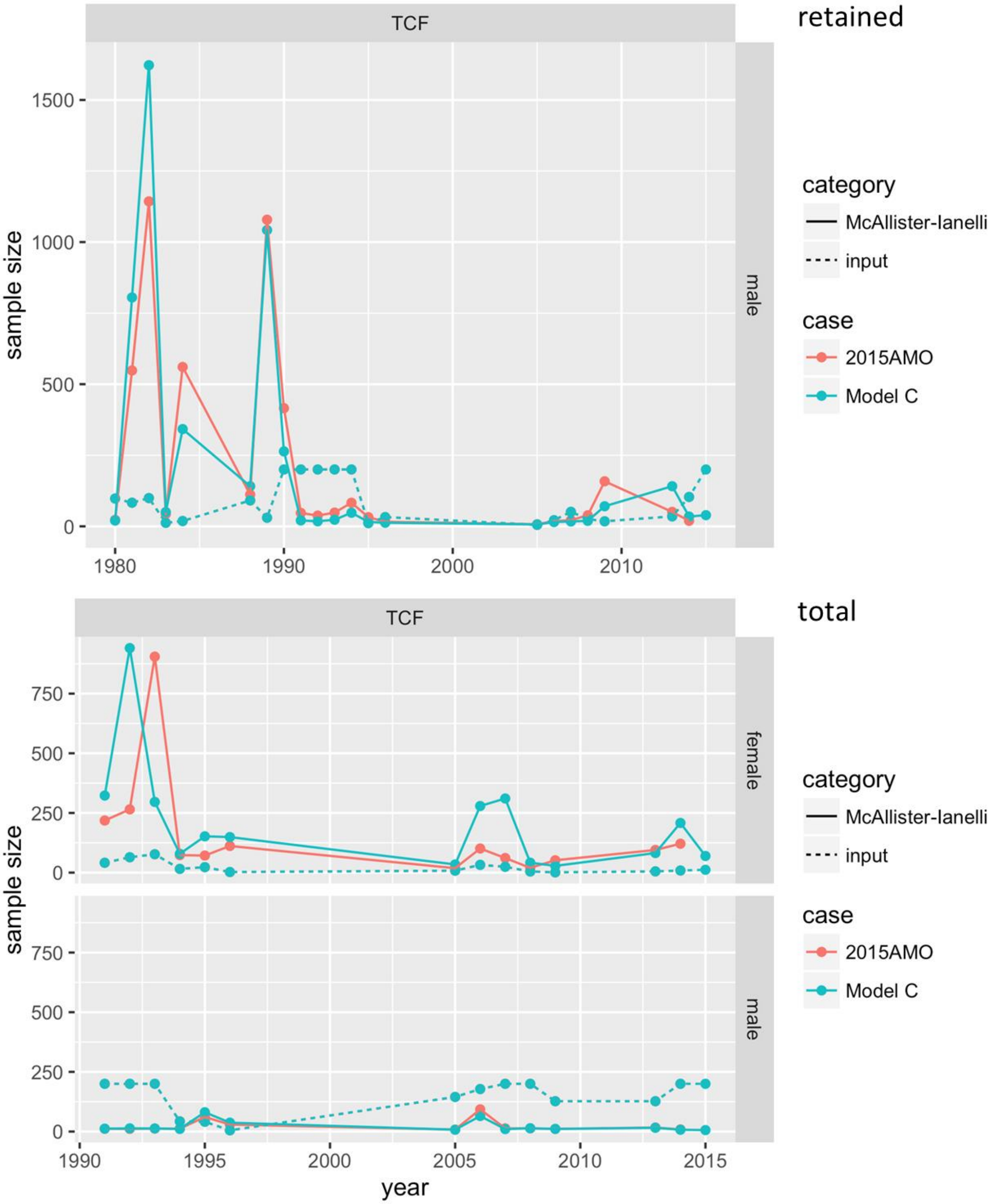


Figure 83. Input and effective (McAllister-Ianelli) sample sizes for retained (upper) and total catch (lower) size compositions from the directed Tanner crab fishery for the 2015 assessment (2015AMO) and the author’s preferred model (Model C). dotted lines: input; solid lines: effective.

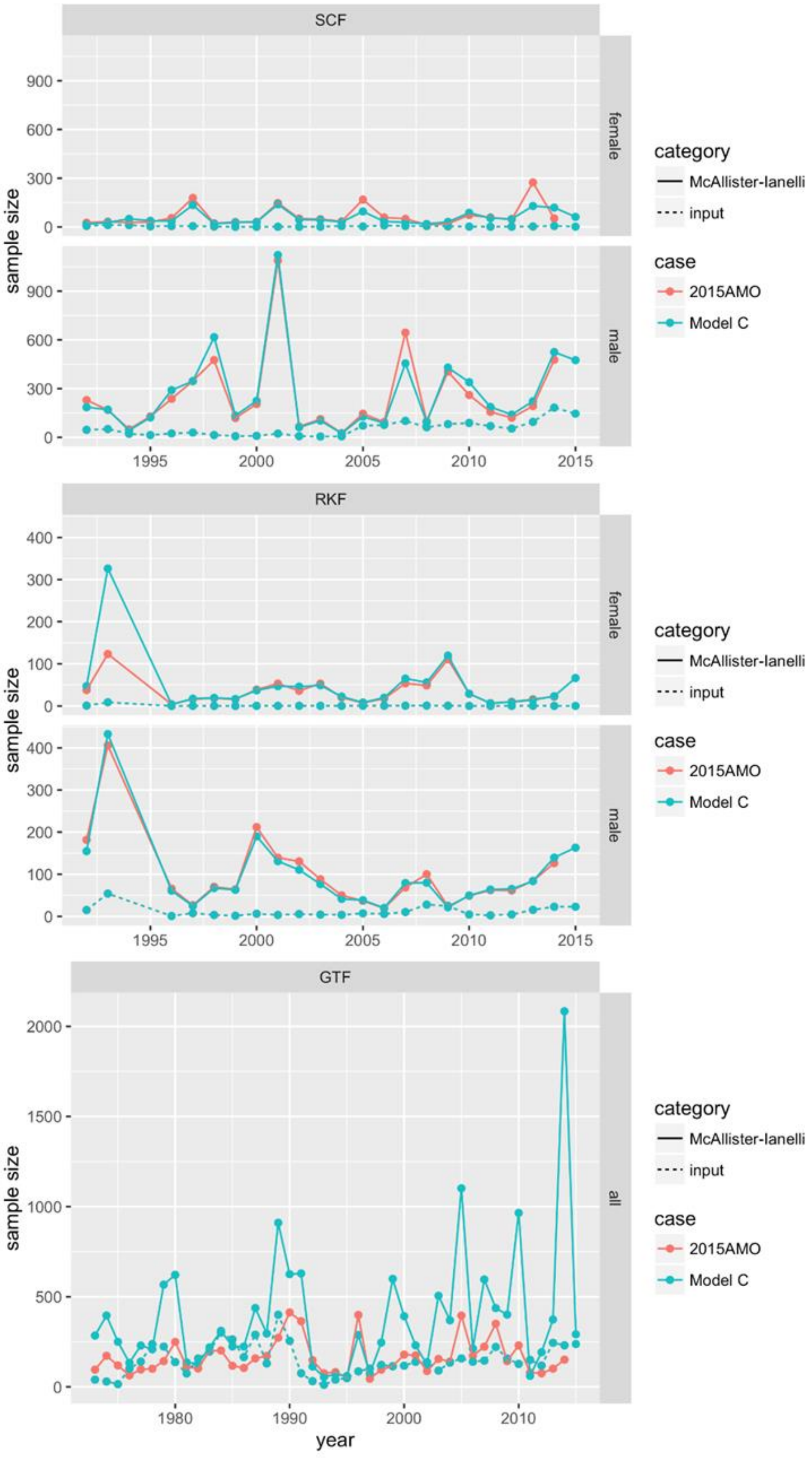


Figure 84. Input and effective (McAllister-Ianelli) sample sizes for bycatch size compositions from the snow crab fishery (upper), BBRKC (middle), and groundfish fisheries (lower) for the 2015 assessment (2015AMO) and the author’s preferred model (Model C). dotted lines: input; solid lines: effective.

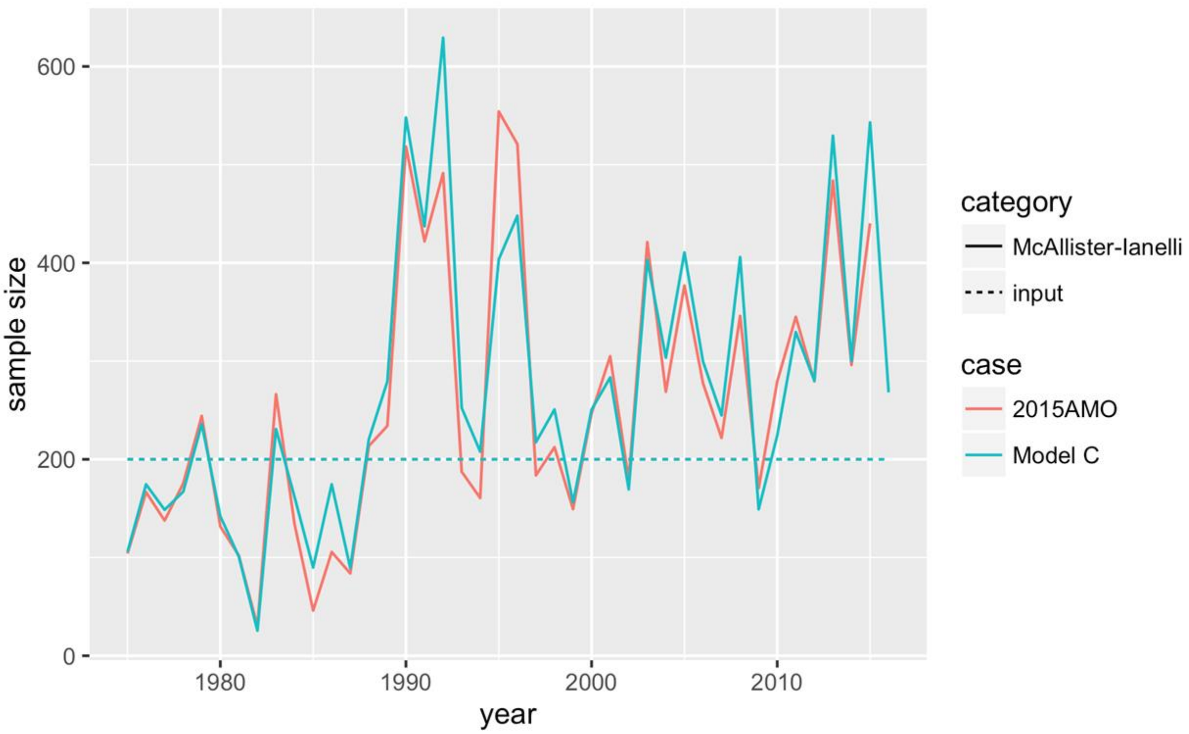


Figure 85. Input and effective (McAllister-Ianelli) sample sizes for size compositions from the NMFS EBS trawl survey for the 2015 assessment (2015AMO) and the author's preferred model (Model C). dotted lines: input; solid lines: effective.

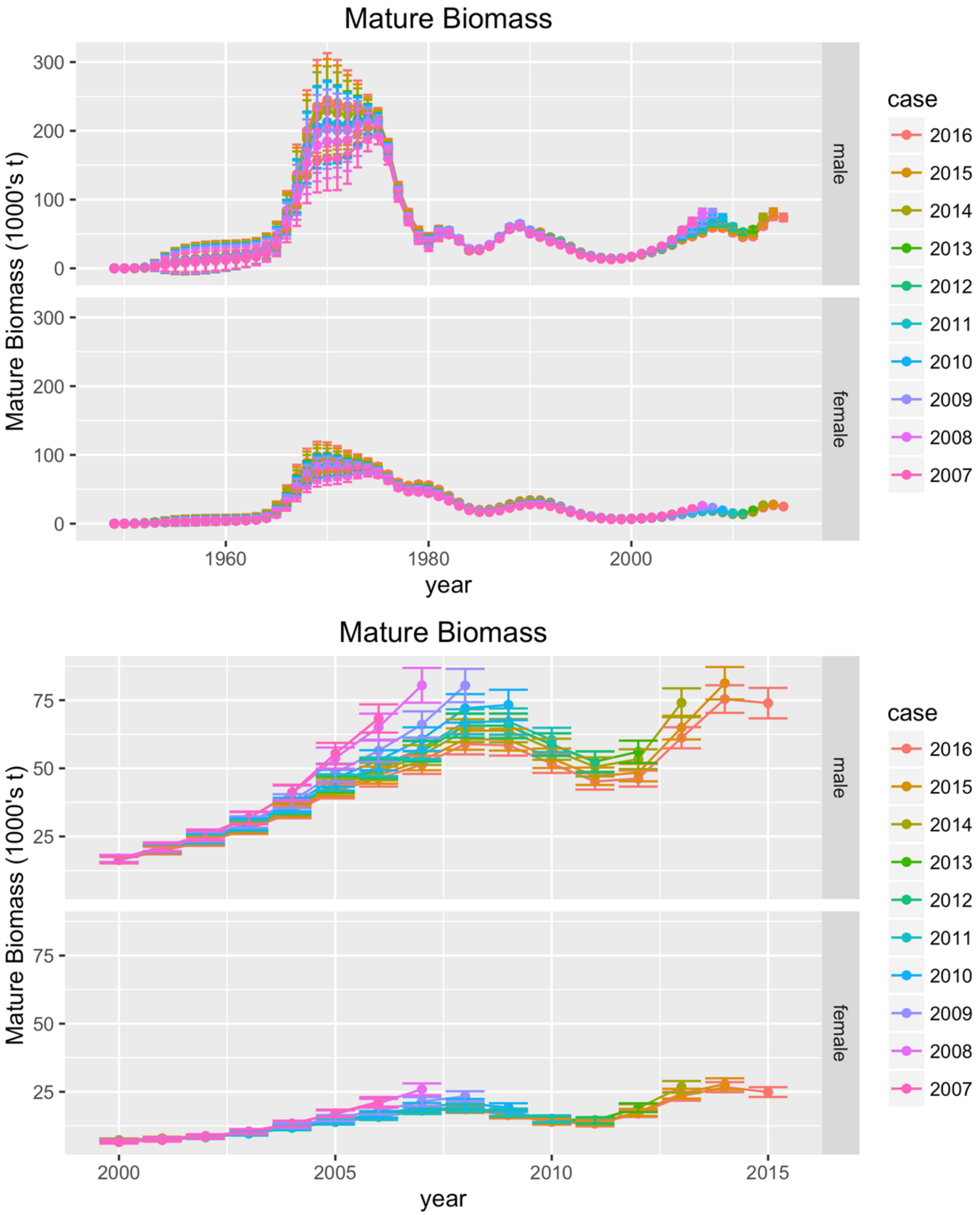


Figure 86. Retrospective analysis for estimated mature biomass-at-mating from the author's preferred model (Model C). Model C was run for each case as though the assessment were conducted in the year indicated by the case name. Upper plot: full model time series; lower plot: recent time period.

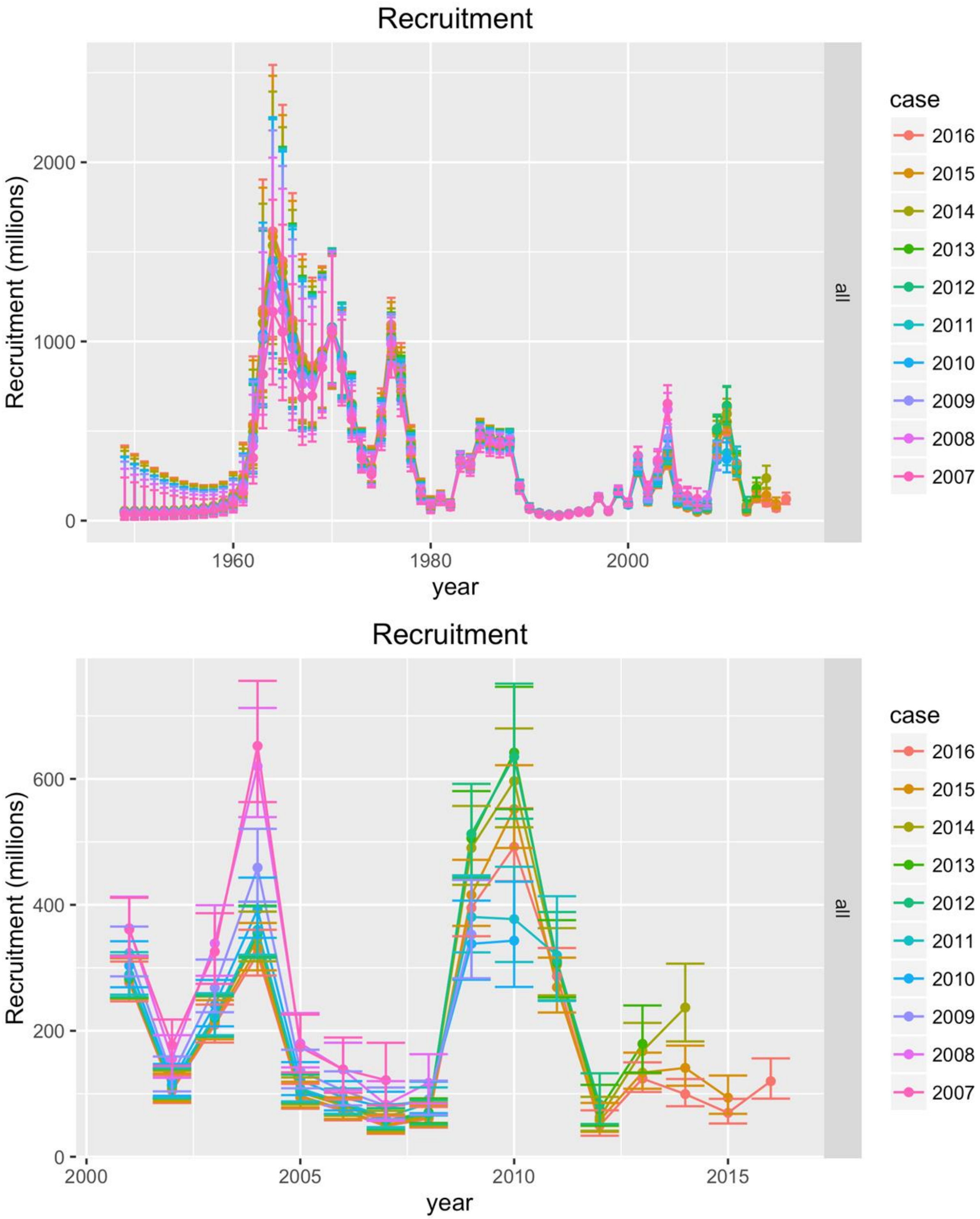


Figure 87. Retrospective analysis for estimated recruitment from the author's preferred model (Model C). Model C was run for each case as though the assessment were conducted in the year indicated by the case name. Upper plot: full model time series; lower plot: recent time period.

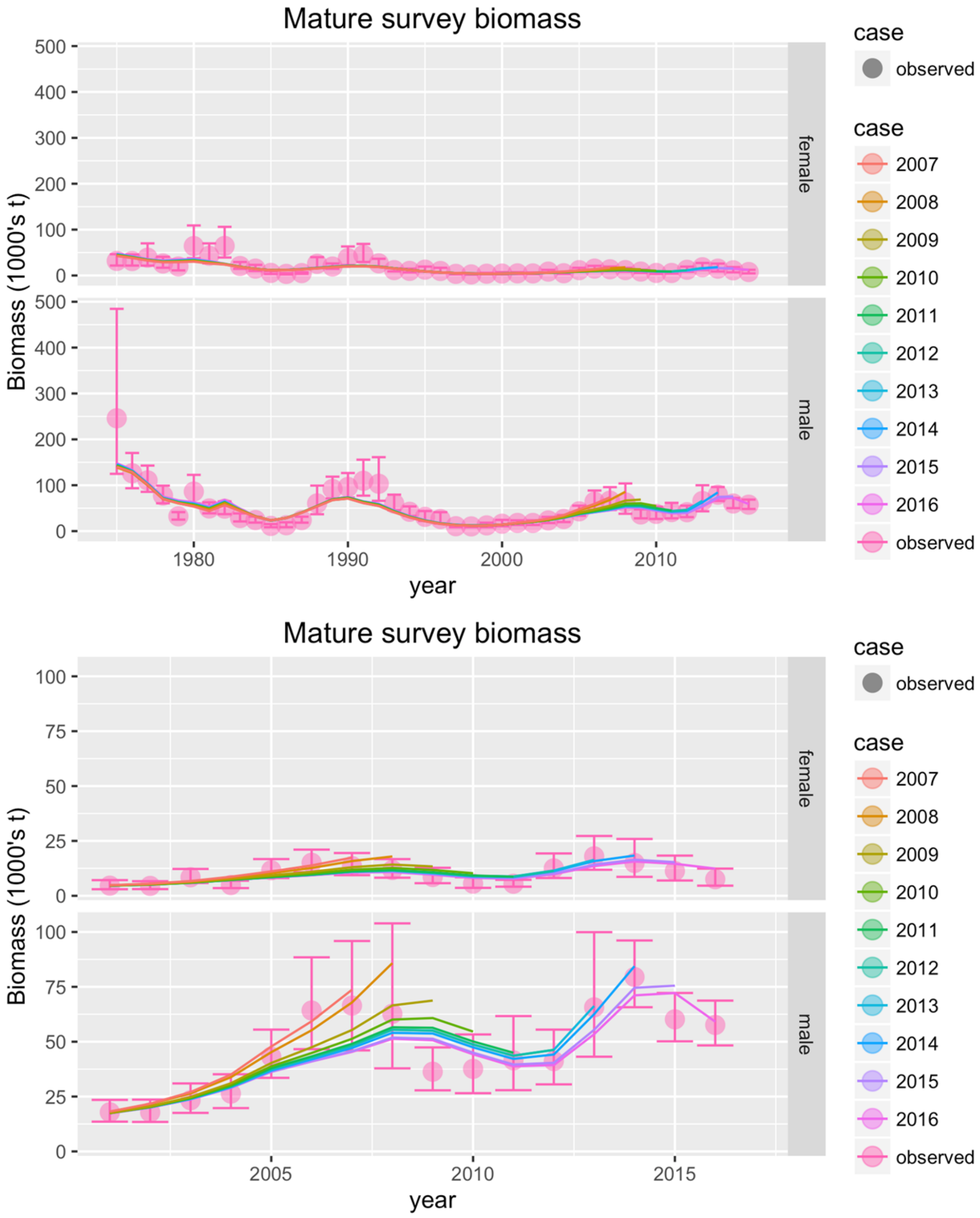


Figure 88. Retrospective analysis for fits to mature survey biomass from the author's preferred model (Model C). Observed: symbols and error bars; lines: predicted. Model C was run for each case as though the assessment were conducted in the year indicated by the case name. Upper plot: full model time series; lower plot: recent time period.

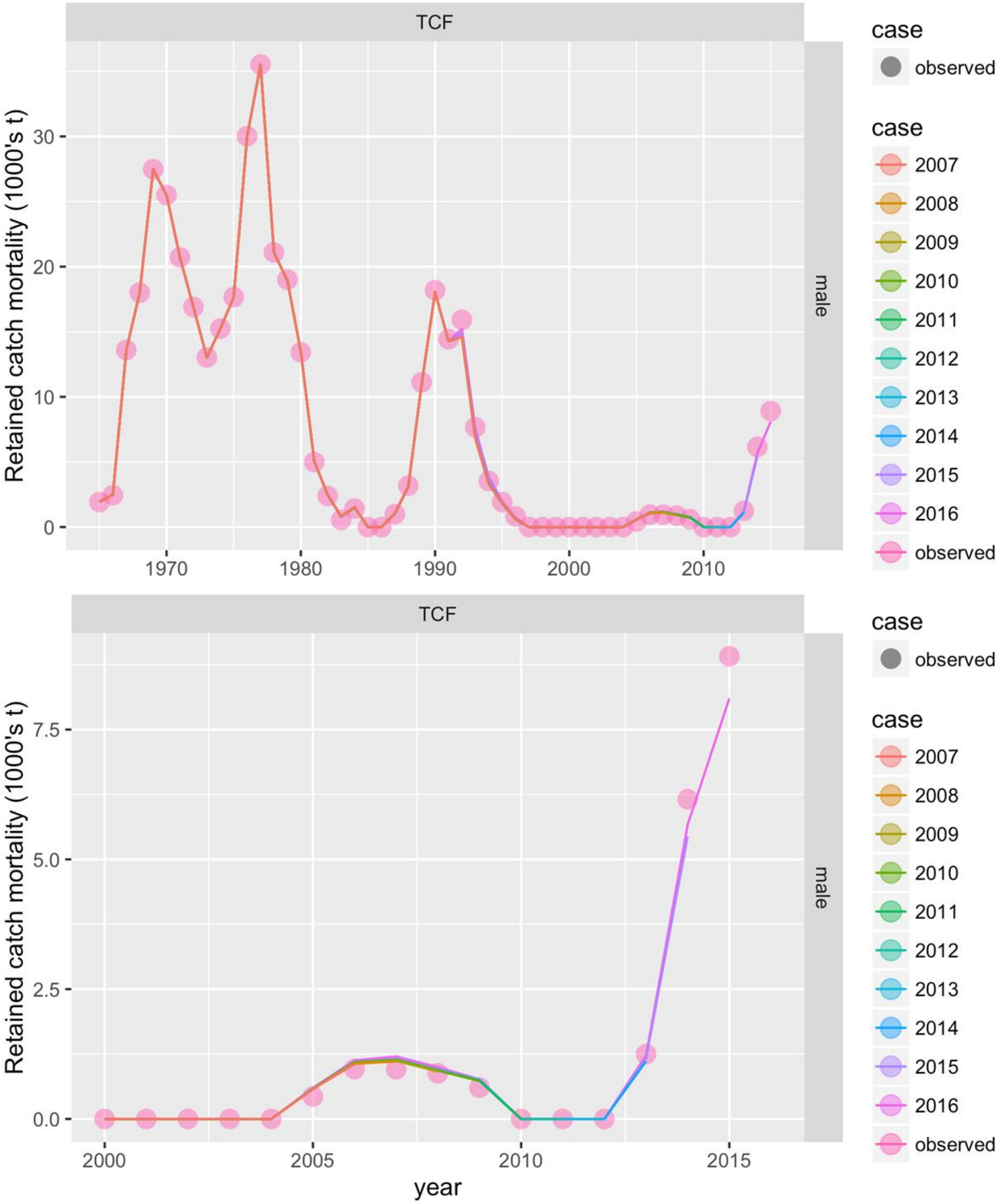


Figure 89. Retrospective analysis for fits to retained catch from the author's preferred model (Model C). Observed: symbols and error bars; lines: predicted. Model C was run for each case as though the assessment were conducted in the year indicated by the case name. Upper plot: full model time series; lower plot: recent time period.

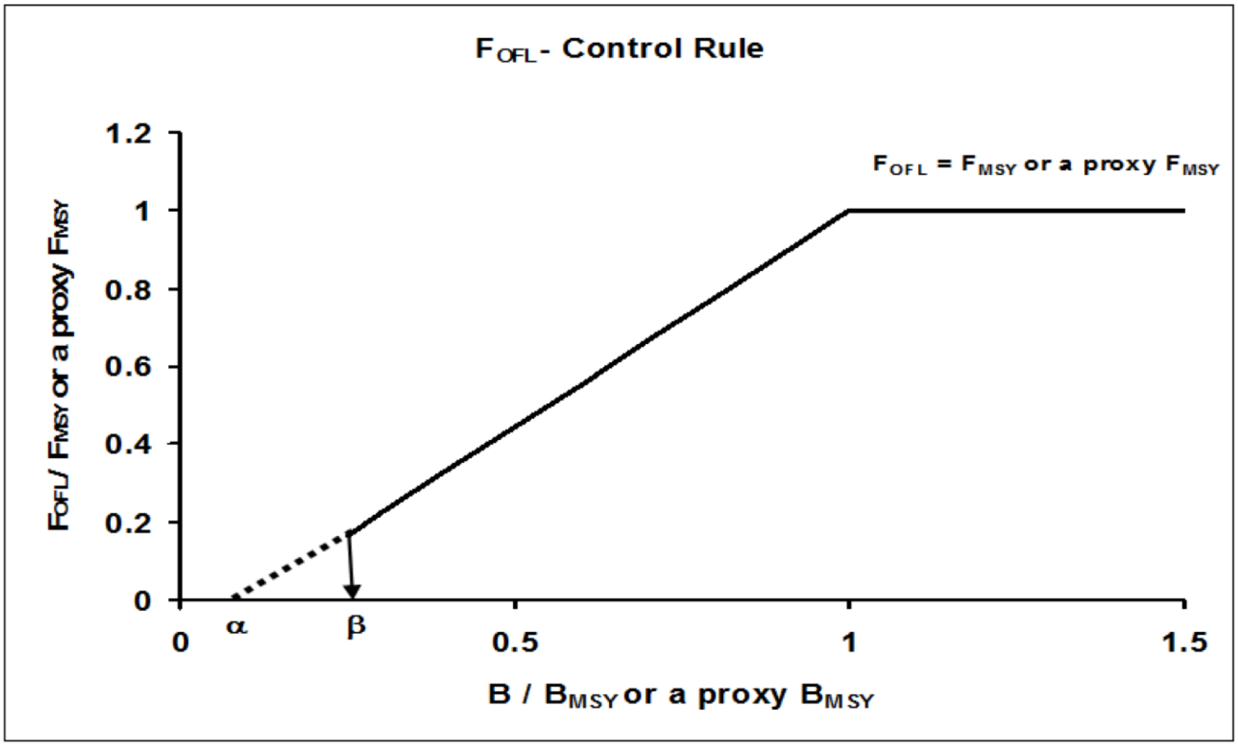


Figure 90. The F_{OFL} harvest control rule. For Tier 3 stocks such as EBS Tanner crab, F_{MSY} and B_{MSY} are based on spawning biomass per recruit proxies, where $F_{MSY} = F_{35\%}$, B_{MSY} = B35%, and MMB at mating time is used as a surrogate for egg production/spawning biomass.

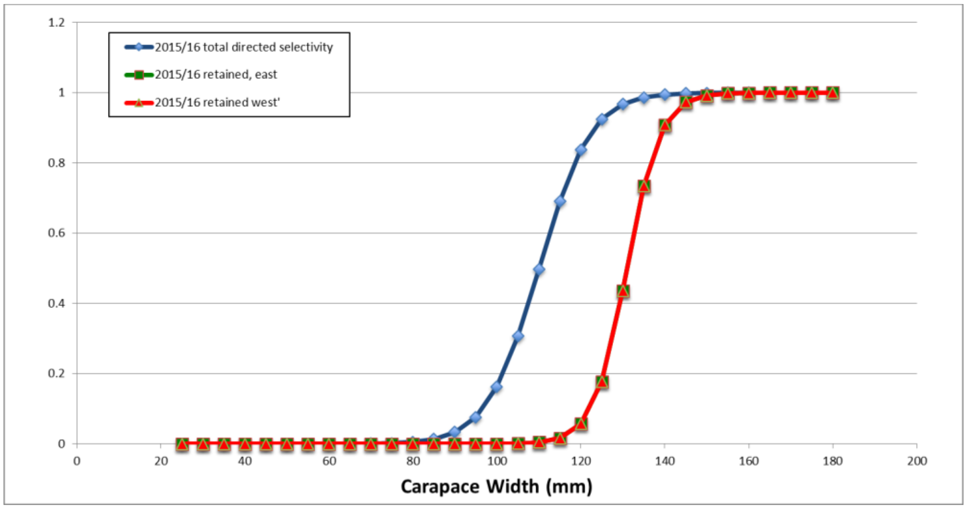


Figure 91. The selectivity and retention curves for males in the directed fishery used to calculate the OFL.

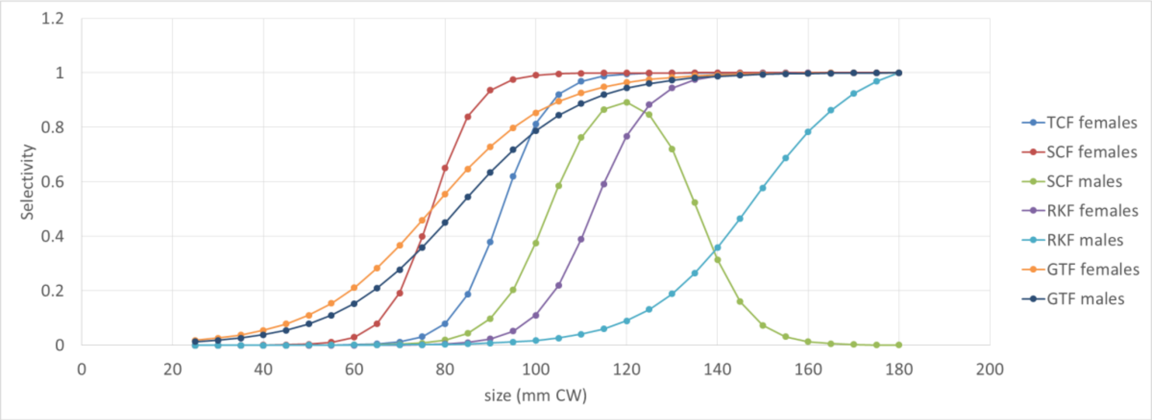


Figure 92. Bycatch fishery selectivity curves used to calculate the OFL.

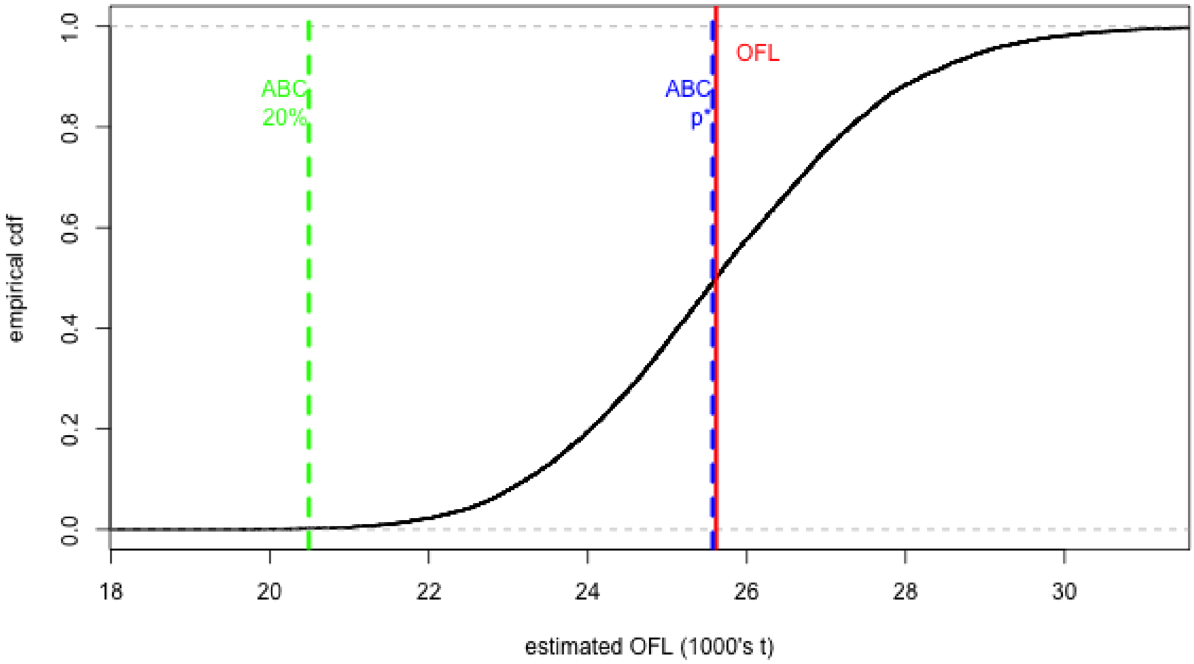


Figure 93. Distribution of OFL, illustrating the estimated p* ABC and 20%-buffer ABC, for Model C.

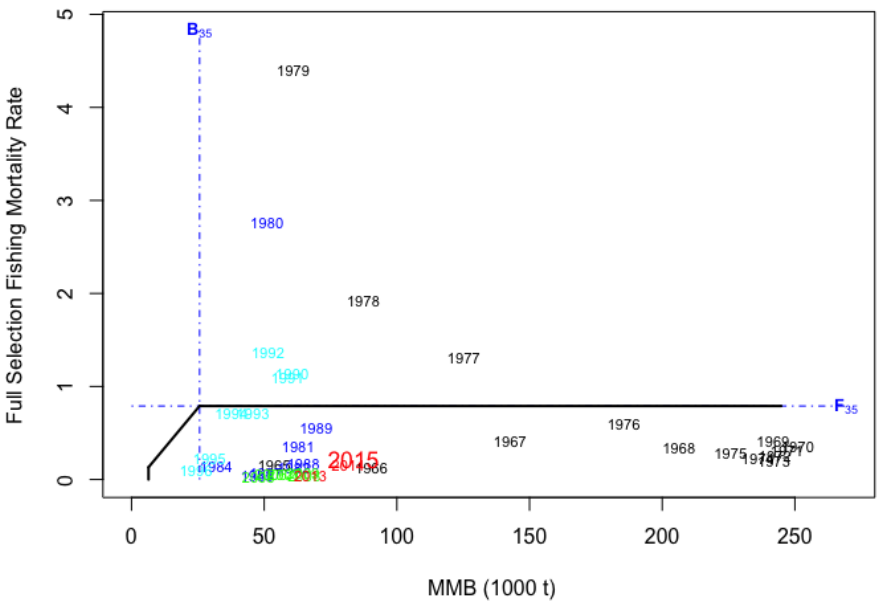


Figure 94. Tier 3 quad plot for the author's preferred model, Model A (Dataset D). Colors indicate different time periods. Black: 1965-1979; blue: 1980-1989; cyan: 1990-1999; green: 2000-2009; red: 2010-2015.

Appendix A:
Comparison of Models 2015AMO, 2015AMR, 2015AMN, 2015AM

William T. Stockhausen
Alaska Fisheries Science Center
6 September 2016

THIS INFORMATION IS DISTRIBUTED SOLELY FOR THE PURPOSE OF PREDISSEMINATION PEER REVIEW UNDER APPLICABLE INFORMATION QUALITY GUIDELINES. IT HAS NOT BEEN FORMALLY DISSEMINATED BY NOAA FISHERIES/ALASKA FISHERIES SCIENCE CENTER AND SHOULD NOT BE CONSTRUED TO REPRESENT ANY AGENCY DETERMINATION OR POLICY

Introduction

This appendix summarizes the comparison of models 2015AMO, 2015AMR, 2015AMN, and 2015AM to document changes in progressing from the 2015 assessment model (2015AMO here) to the base model for the 2016 assessment (Model B). 2015AMR is a better-converged version of 2015AMO, with convergence evaluated using 200 runs with jittered initial parameter values. 2015AMN uses the 2015 data, but with the "new" cv's for mature survey biomass. 2015AM uses the 2016 data. Models 2015AMN and 2015AM were also evaluated for convergence using 200 runs with jittered initial parameter values.

Evaluation

Objective function values

Direct comparison among the four models on the basis of objective function value is not valid for drawing inferences because 2015AMO was not converged to the global minimum, uncertainties for mature survey biomass differ between 2015AMR and 2015AMN, and the 2016 data is added to 2015AM.

Population processes

One effect of the "new" cv's was to lower estimates of natural mortality on mature crab during the "enhanced mortality" period (1980-1984). Estimated natural mortality rates were similar among the models outside the "enhanced mortality" time period, but differed for mature crab among models during this period (Fig. 1), with 2015AMO and 2015AMR exhibiting the highest rates for both mature males and females. The estimated rates on mature males during this period also increased slightly with the addition of the 2016 data. Otherwise, functions governing population processes (molt-to-maturity, growth) for all four models (Fig.s 2, 3).

Figure 1. Comparison of estimates of natural mortality from the four models.

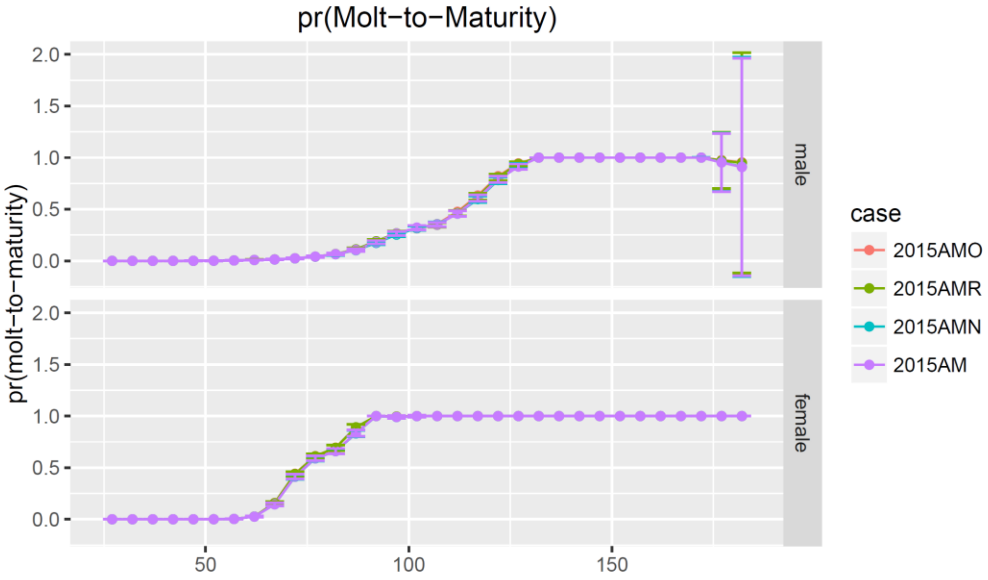


Figure 2. Comparison of estimates of the size-specific probability of undergoing terminal molt-to-maturity from the four models.

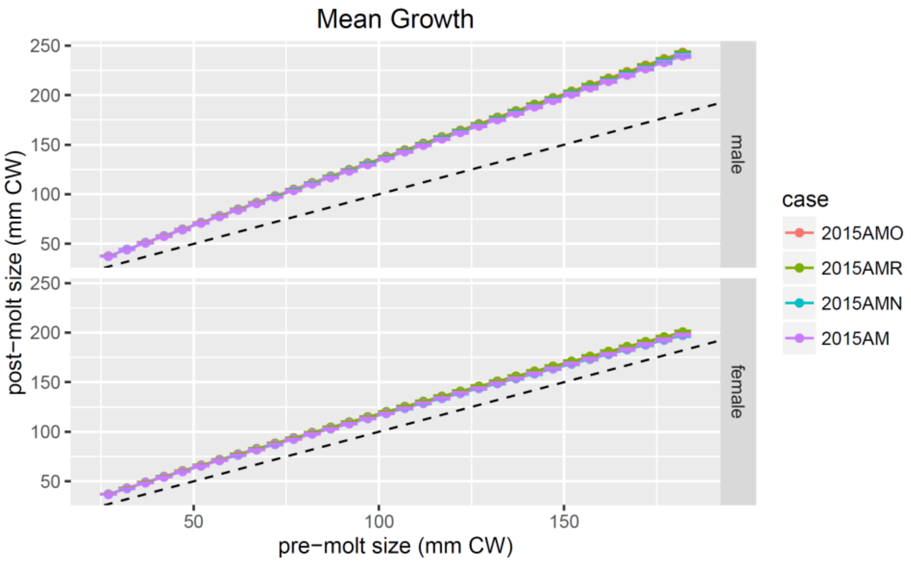


Figure 3. Estimates of the mean post-molt size as a function of pre-molt size from the four models.

Population quantities

Estimated trends in recruitment were quite similar for the four models (Fig.s 4, 5). The model estimates differed slightly when recruitment high for short periods, but oscillations were in-phase across models and all peaks occurred in the same year. At peaks in recruitment, the models with the “new” cv’s for mature survey biomass (2015AMN, 2015AM) yielded slightly higher estimated recruitment compared with the models with the “old” cv’s.Trends in population abundance were also similar for the four models, although some differences between models were discernible when the population reached its maximum abundance in the early 1970s, and again during the “enhanced mortality” period, 1980-1984. During the last 15 years, 2015AMN estimated abundance at somewhat higher levels than the other models, while 2015AMO and 2015AMR estimated abundance at the lowest levels (Fig. 6, 7). One effect of the “new” cv’s was obviously to increase recruitment and population abundance estimates, while adding the 2016 data (2015AM) led to slightly decreased estimates of recruitment and abundance vis-à-vis 2015AMN after 2008 (Fig.s 5, 7). Similar conclusions hold for mature biomass-at-mating (Fig.s 8, 9).

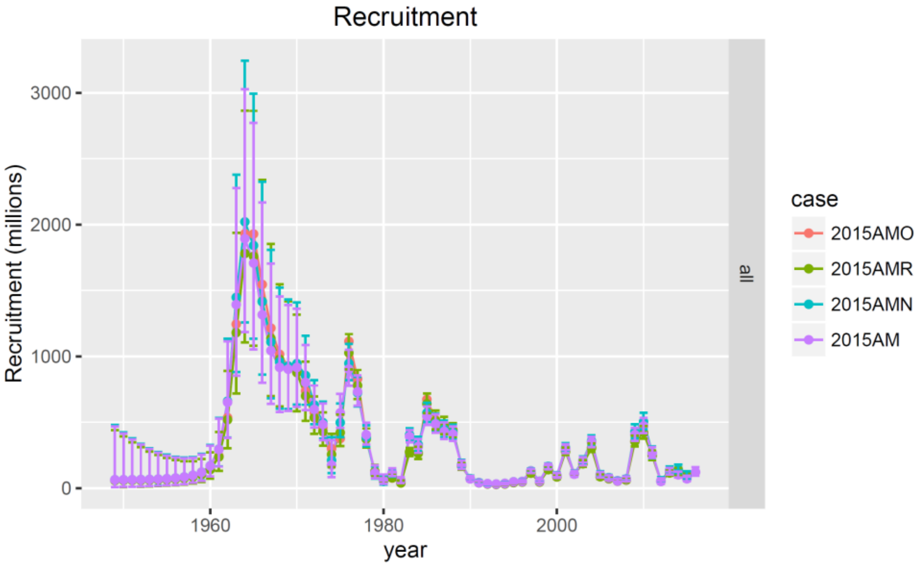


Figure 4. Estimated time series of recruitment from the four models.

Figure 5. Estimated time series of recruitment from the four models.

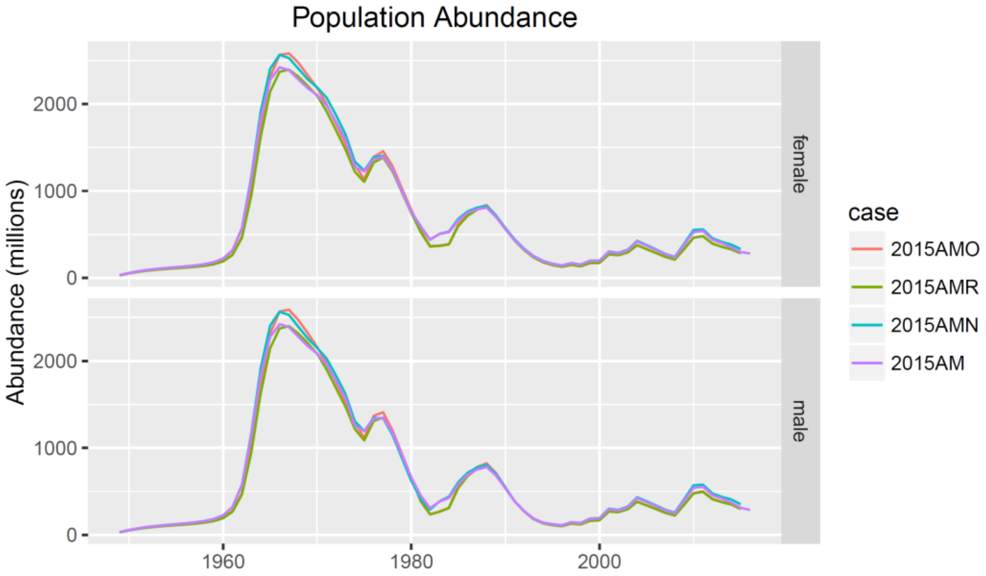


Figure 6. Estimated time series of population abundance from the four models.

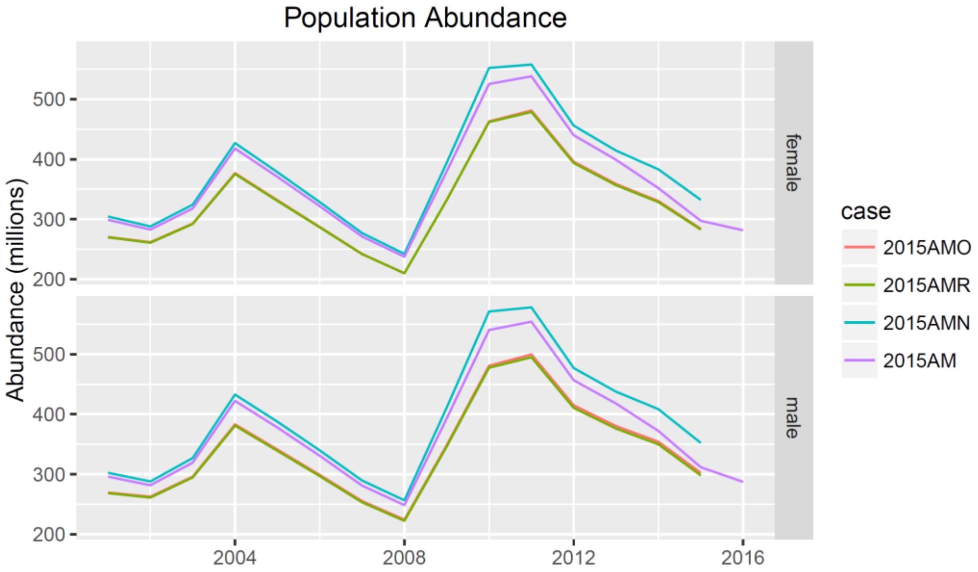


Figure 7. Estimated time series of population abundance from the four models.

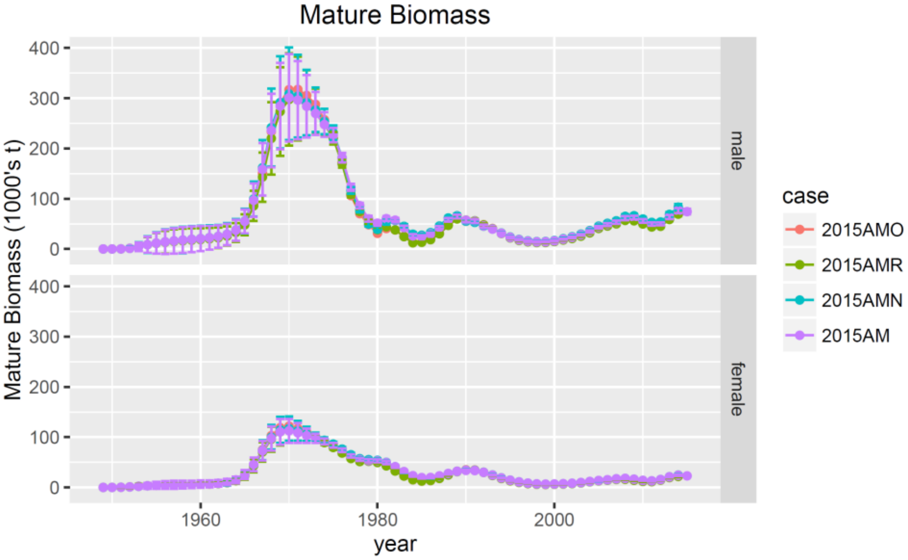


Figure 8. Estimated time series of mature biomass-at-mating from the four models.

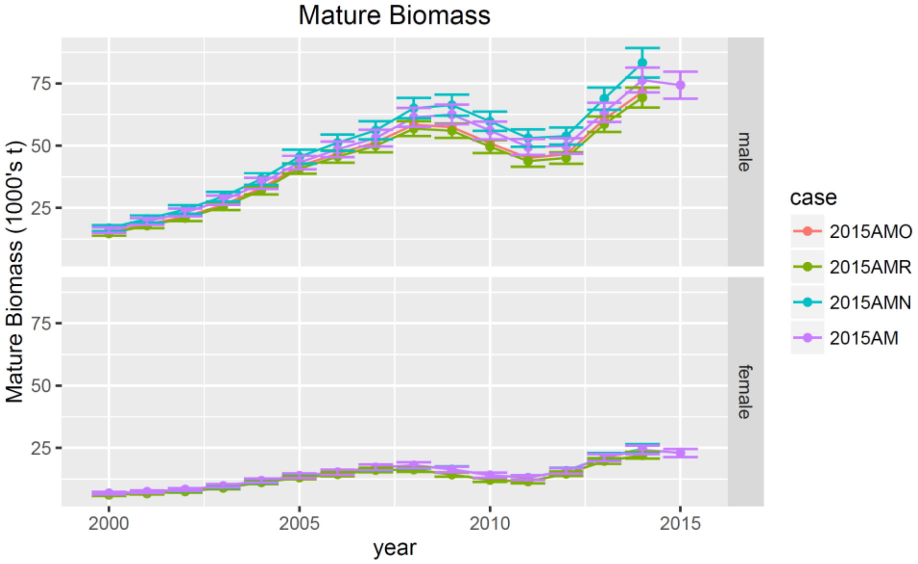


Figure 9. Estimated time series of mature biomass-at-mating from the four models.

Survey selectivity functions

The four models estimated almost identical survey selectivity curves and survey q's for both sexes during selectivity time period 1 (pre-1982), while in time period two the selectivity curves were similar across models but survey q's differed (with higher q's for the models using the "old" mature survey biomass cv's).

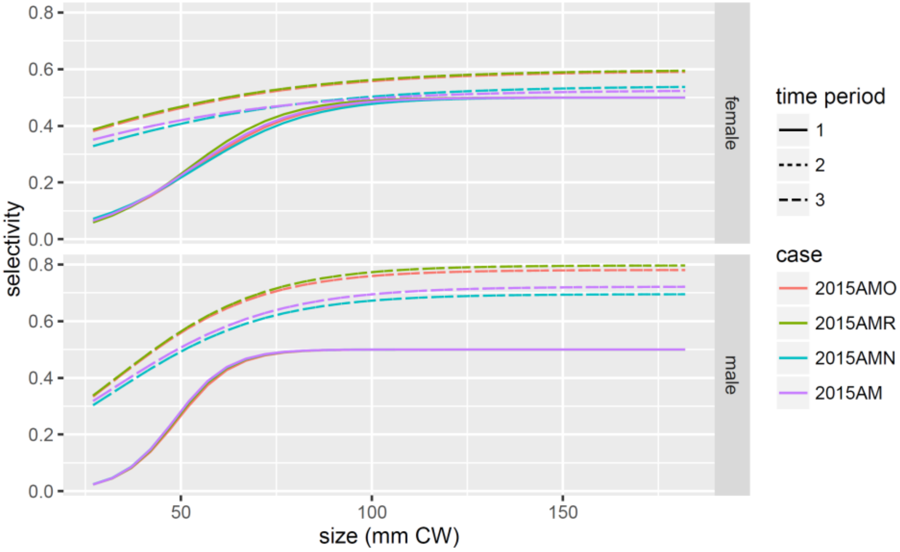


Figure 10. Comparison of estimated survey selectivity functions for the four models.

Fishery selectivity functions

Estimated fishery retention functions were identical for the four models during the pre-1991 time period, as were those post-1990 for the 3 models using 2015 data (2015AMO, 2015AMR, 2015AMN; Fig. 11). The retention function estimated by 2015AM, using 2016 data, was left-shifted 5 mm toward smaller sizes. This may reflect accumulating evidence for shift to retention of somewhat smaller (but still legal-sized) crab by industry since the fishery re-opened in 2013/14.

Estimated female selectivity in the directed fishery was essentially identical across the four models (Fig. 12). Estimated male selectivity curves before 1991 fell into two categories: those from 2015AMO and 2015AMN were left-shifted to smaller sizes by ~10 mm relative to those from 2015AMR and 2015AM (Fig. 12). This result is rather curious, because it does not track with the change in calculated mature survey biomass cv's.

The estimated annual male selectivity curves in the directed fishery post-1990 (Fig. 13) are rather illuminating. For the years in which the directed fishery was prosecuted during this time period (1991/92-1996/97, 2005/06-2009/10, 2013/14-present), except 1996/97, the curves are very for all four models (only 2015AM estimates the 2015/16 curve, of course). In fact, they are practically identical in 2005/06-2009/10 and 2013/14-2014/15. However, they differ substantially for 1996/97, with curves from 2015AMO and 2015AMN substantially left-shifted relative to 2015AMR and 2015AM. This results in the pattern across models for the male selectivity curves pre-1991 (Fig. 12), or more likely the pattern for 1996/97 is a result of the pre-1991 pattern, because the size at 50%-selected (z50) parameter in the logistic function used to describe pre-1991 male selectivity in the directed fishery is the average of the annual z50's for 1991/2-1996/97. It would be worthwhile to see how the model responds when 1996/97 is removed from the averaging time period.

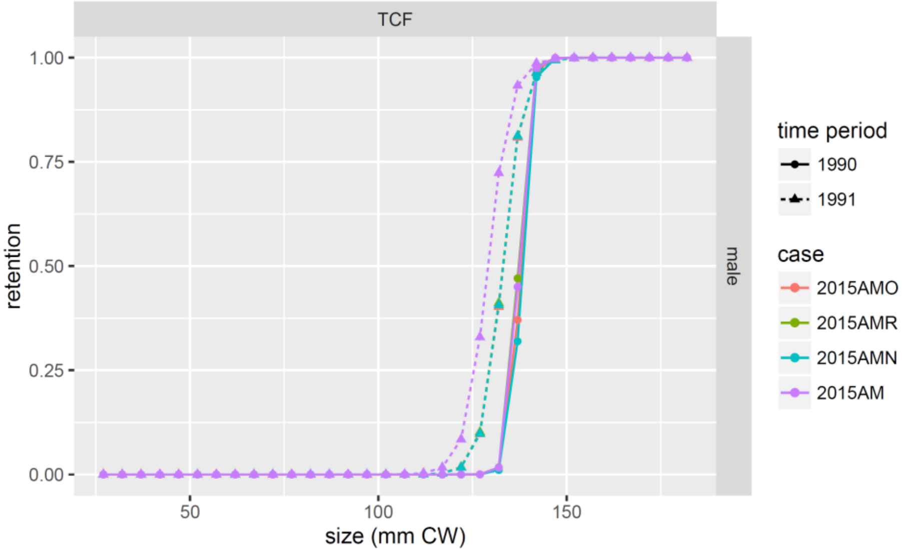


Figure 11. Comparison of estimated retention functions in the directed fishery for the four models.

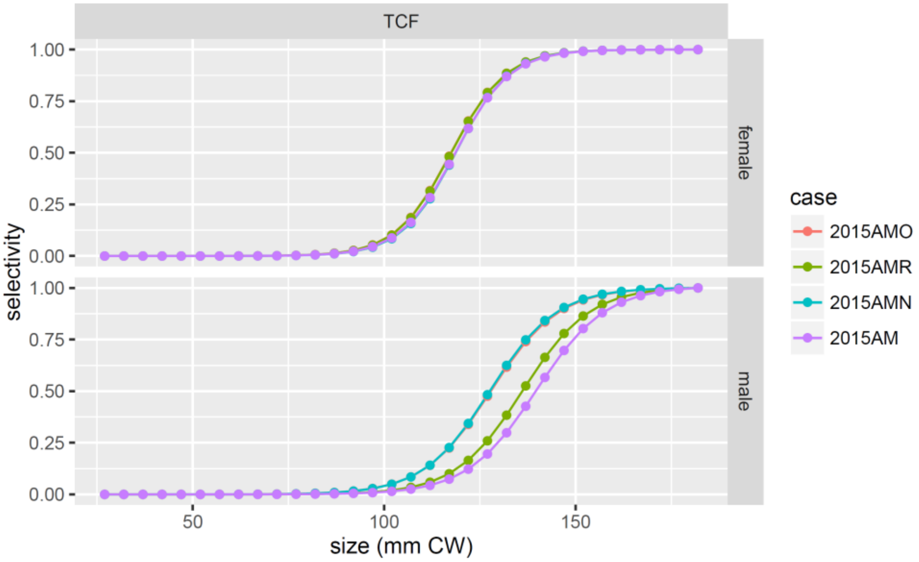


Figure 12. Comparison of estimated female selectivity functions and pre-1991 male total catch mortality selectivity functions in the directed fishery for the four models.

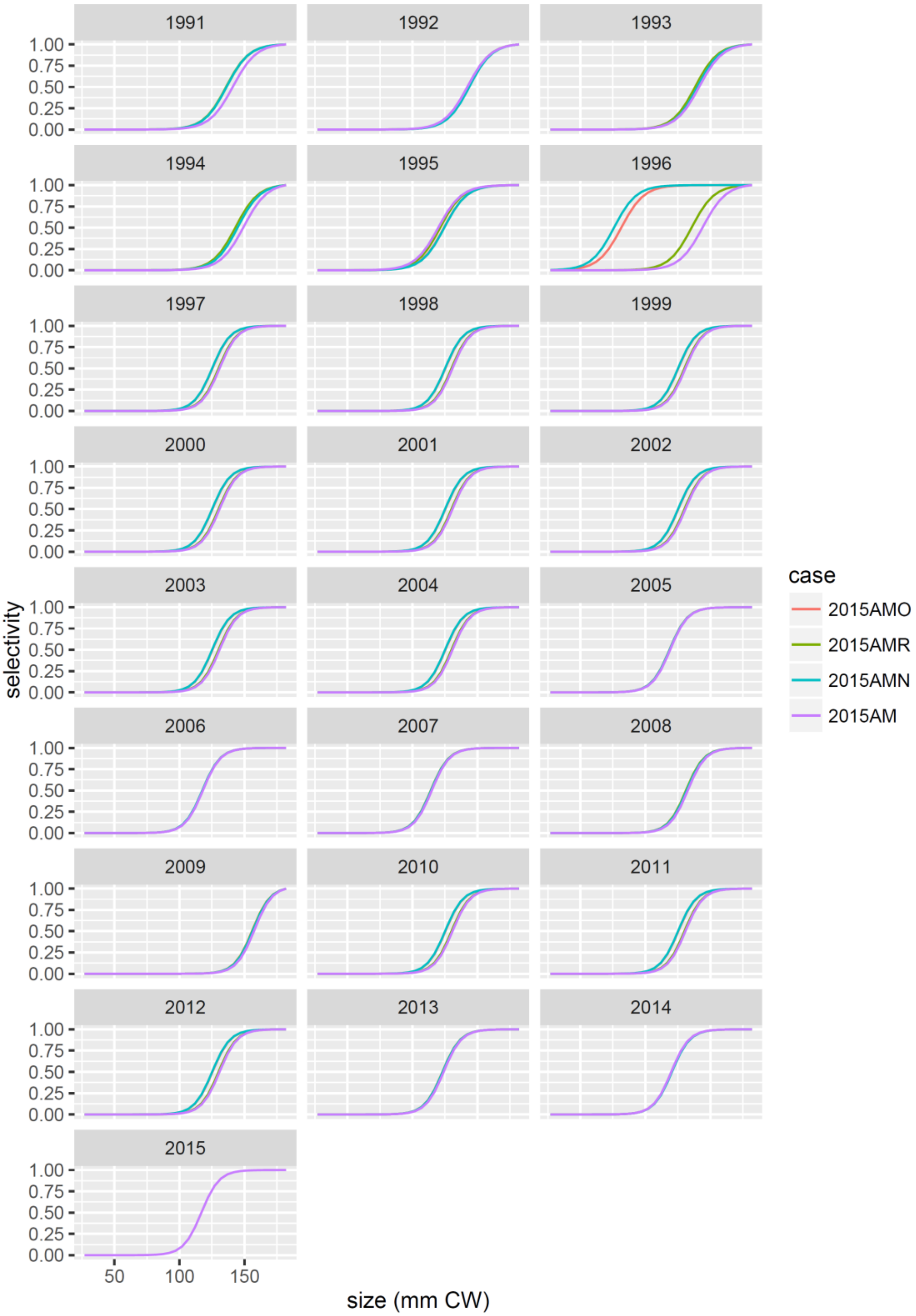


Figure 13. Comparison of estimated annual (post-1990) male total catch mortality selectivity functions in the directed fishery for the four models. The directed fishery was closed during 1997/98-2004/05 and 2010/11-2012/13. The mean selectivity function for 1991-present from

which annual deviations are taken is shown during the closures.

Appendix B:
Comparison of Models 2015AM and Model B (the CPT's Base Model)

William T. Stockhausen
Alaska Fisheries Science Center
6 September 2016

THIS INFORMATION IS DISTRIBUTED SOLELY FOR THE PURPOSE OF PREDISSEMINATION PEER REVIEW UNDER APPLICABLE INFORMATION QUALITY GUIDELINES. IT HAS NOT BEEN FORMALLY DISSEMINATED BY NOAA FISHERIES/ALASKA FISHERIES SCIENCE CENTER AND SHOULD NOT BE CONSTRUED TO REPRESENT ANY AGENCY DETERMINATION OR POLICY

Introduction

This appendix summarizes the comparison of models 2015AM and Model B to finish documenting changes in progressing from the 2015 assessment model (2015AMO) to the base model for the 2016 assessment (Model B). The progression for 2015AMO to 2015AM is discussed in Appendix A. The rationale for Model B, the CPT's base model, was discussed at the May 2016 CPT meeting. It includes a suite of changes that were evaluated in an incremental fashion by the author as part of that meeting. Model B embodies the following changes relative to the 2015AM model (which incorporates the "new" cv's for mature survey biomass and the 2016 data):

Change	Description
A	start "current" recruitment estimation in 1975, instead of 1974
B	normalize groundfish fishery size comps using original sample sizes, not input sample sizes
C	estimate log-scale fishing mortality/capture rate offsets for female crab
E	turn on fishing mortality/capture rate estimation for BBRKC
G	estimate probability of molt-to-maturity using logit-scale parameterization
I	enforce logistic selectivity = 1 in largest size bin
J	use GMACS fishing mortality model

The letter designations above refer to the suite of potential changes reviewed at the May meeting.

Evaluation

Objective function values

Direct comparison between the two models on the basis of objective function value is not valid for drawing inferences in a likelihood framework because model change B above essentially changes the bycatch size composition data for the groundfish fisheries. However, comparison of individual components of the objective function can give a sense of the size of relative fits to data, as well as the impact of penalty functions and assumed priors. In this sense, the objective function components are interpreted more as indicators of mean-squared error, in some sense.

In this regard, the size of the penalties applied in the objective function (Fig. 1) are quite similar for the two models, with perhaps the exception that the penalty on the estimate of natural mortality on mature males is larger for Model B than for 2015AM.Similarly, the size of the prior probabilities in the objective function are also similar (Fig. 2), although the prior for female catchability (*q*) in the NMFS trawl survey is somewhat larger in Model B than in 2015AM.

Comparing the multinomial component values to the objective function from size fishery and survey compositions (Fig. 3), three components stand out with much larger values for Model B: the groundfish fisheries bycatch size compositions, the retained catch size compositions, and the total-catch size compositions in the directed fishery. The first of these is a non-starter, because the extended size compositions in the two models differ substantially in a number of years. It is a bit disappointing, however, that Model B does not fit the retained catch and ale total-catch size compositions better than 2015AM. This suggests there is room for improvement in the specification of selectivity and retention functions for the directed fishery, possibly in terms of allowing retention curves to vary annually as the selectivity curves are allowed to do (post-1991).

However, Model B fits the retained biomass and male total-catch biomass somewhat better than 2015AM (Fig. 4). Fitting catch biomass data at the expense of size composition data is generally considered a reasonable tradeoff, so the poorer fits to the retained catch and total-catch size composition data by Model B relative to 2015AM can be discounted in terms of overall model suitability.

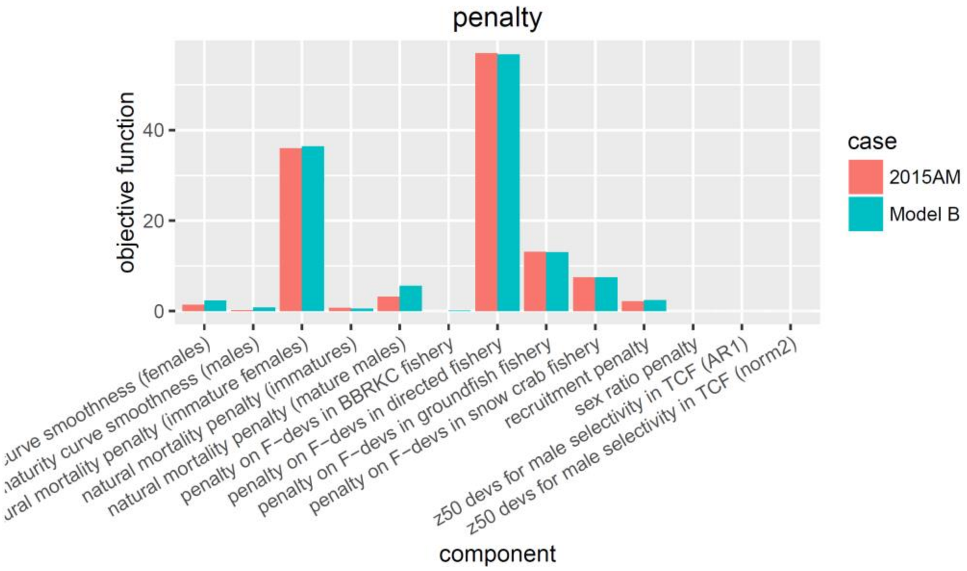


Figure 1. Comparison of penalty components to the model objective function for the two models.

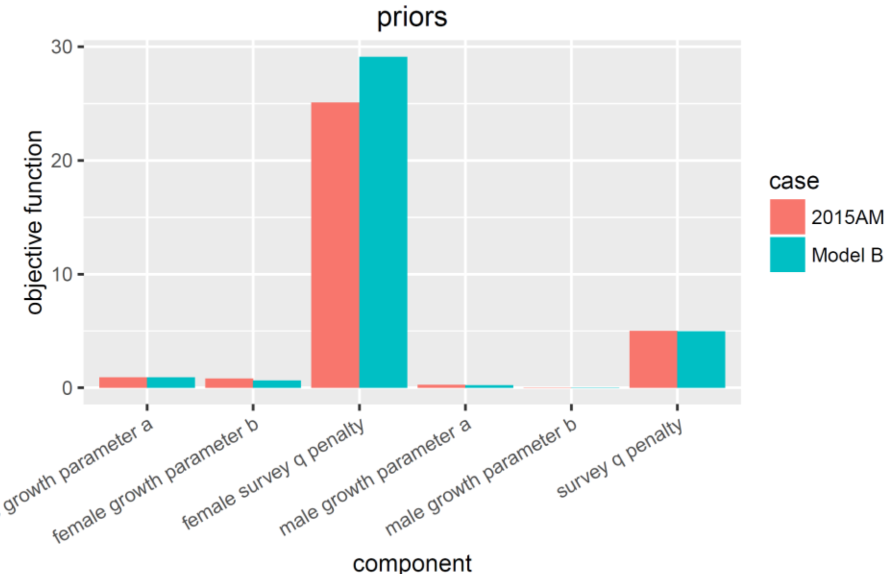


Figure 2. Comparison of prior probability components to the model objective function for the two models.

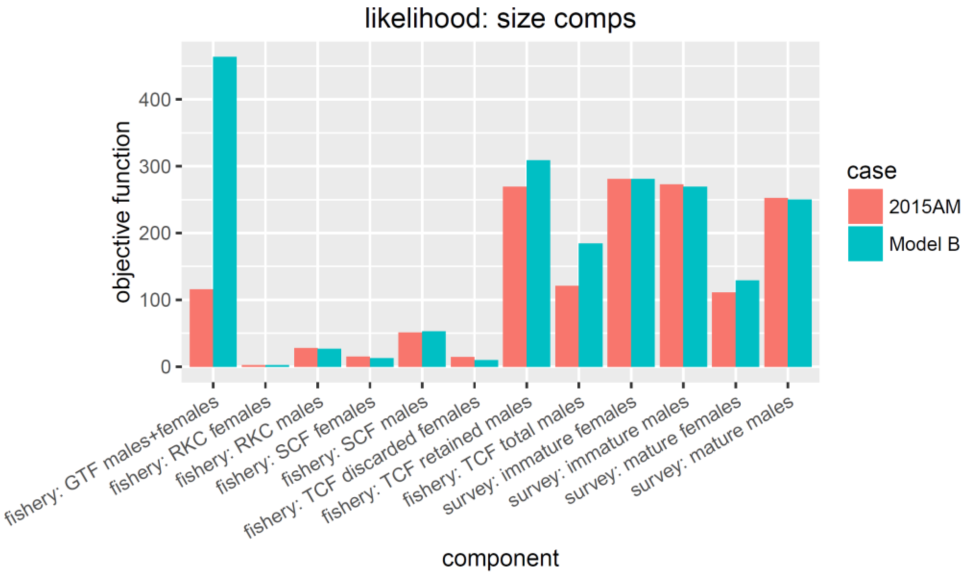


Figure 3. Comparison of multinomial components to the model objective function for the two models.

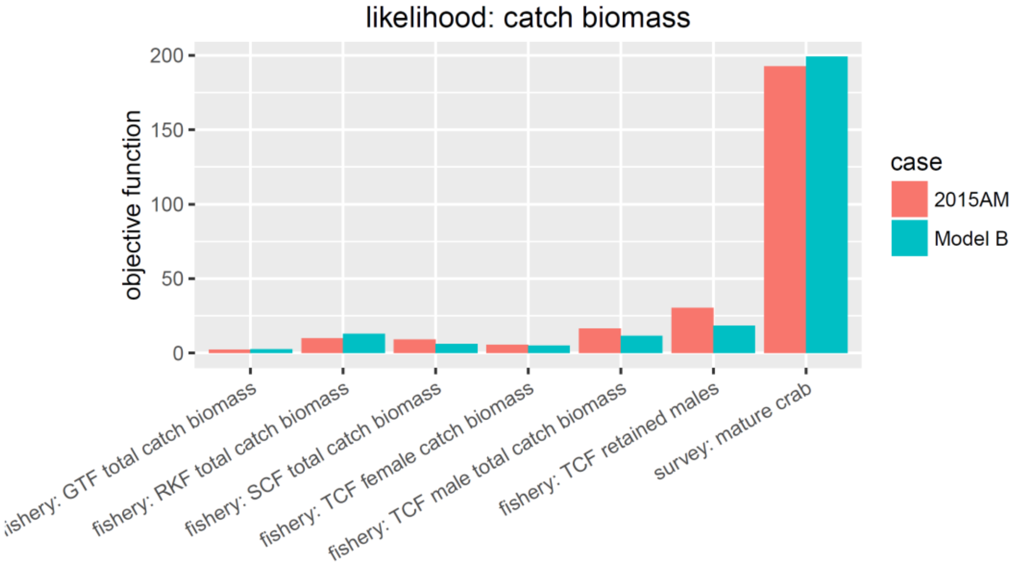


Figure 4. Comparison of biomass components to the model objective function for the two models.

Population processes

One effect of introducing the “new” cv’s in 2015AMN was to lower estimates of natural mortality on mature crab during the “enhanced mortality” period (1980-1984; Appendix A). 2015AM, with the 2016 data, had slightly higher estimated rates than 2015AMN with only the 2015 data. Model B estimates very slightly larger rates, relative to 2015AM, for mature males outside the “enhanced mortality” period and slightly higher rates for mature males and females during the “enhanced mortality” period (Fig. 5).

The size-specific probability of undergoing the terminal molt to maturity is parameterized differently in the two models considered here: parameters (one for each size bin) are estimated on a ln-scale (with max 0) in 2015AM while they are estimated on a logit scale (no need to impose a maximum) in Model B. The resulting estimates, however, are remarkably similar (Fig. 6), except for the slight dip at large size for males in 2015AM (which does not seem credible, in any case).

Estimated patterns of mean growth-per-molt are almost identical for both models (Fig. 7). However, growth parameters in both models essentially hit their imposed upper bounds (as is also true of every other model considered in this assessment).

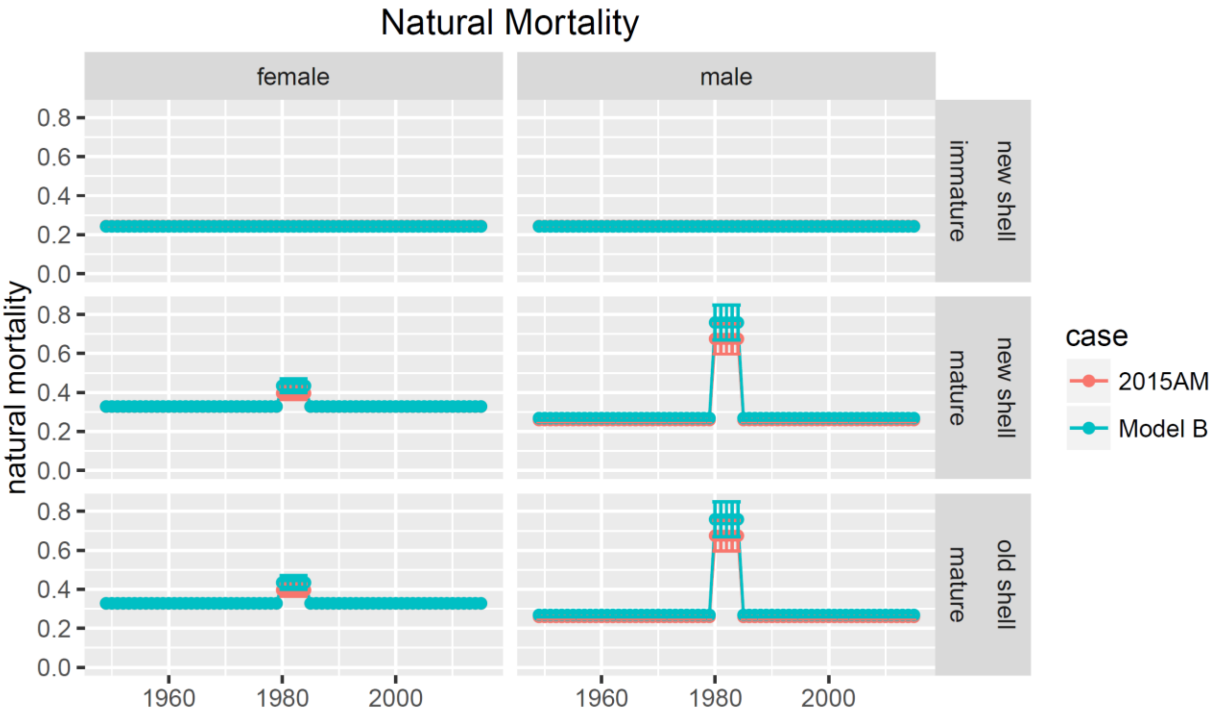


Figure 5. Comparison of estimates of natural mortality from the two models.

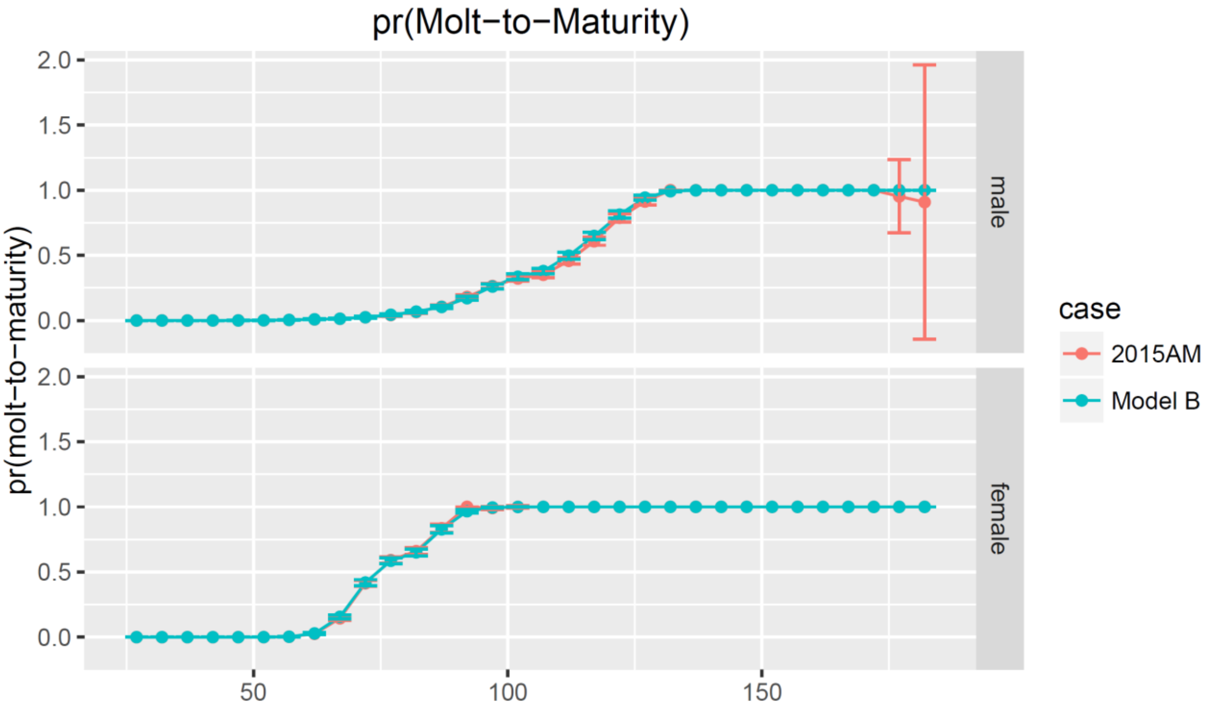


Figure 6. Comparison of estimates of the size-specific probability of undergoing terminal molt-to-maturity for from the four models.

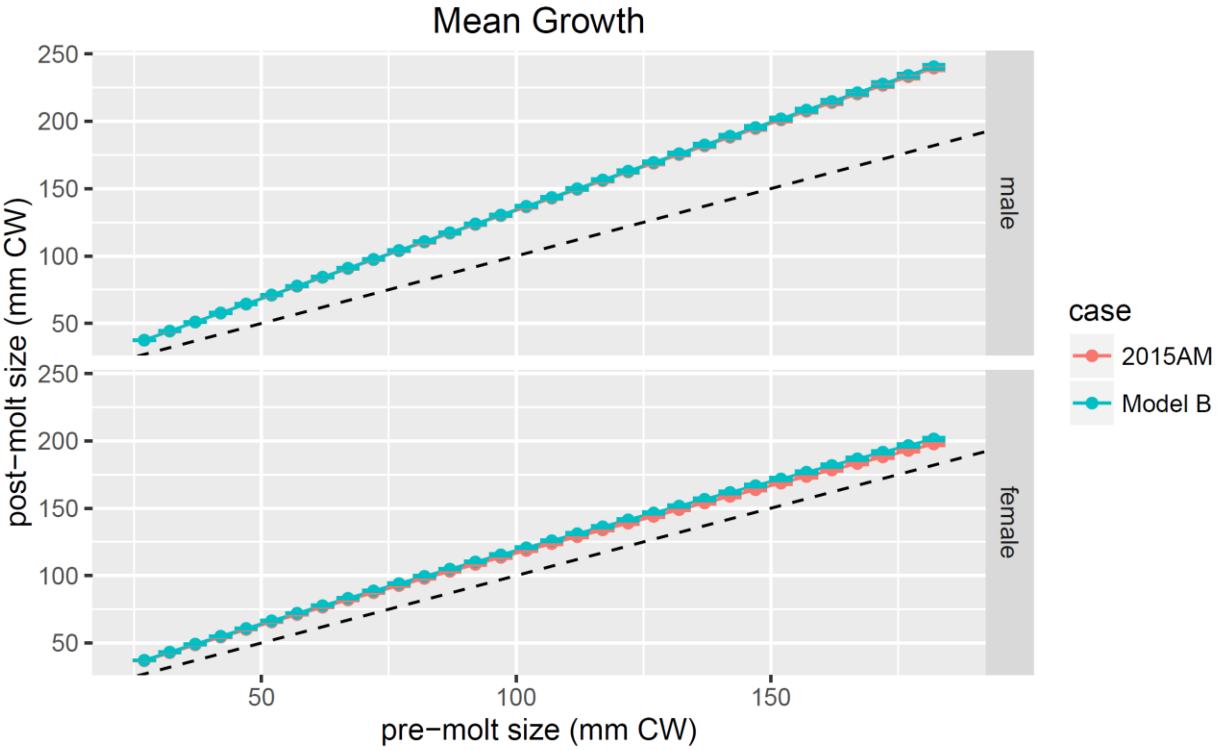


Figure 7. Estimates of the mean post-molt size as a function of pre-molt size from the four models.

Population quantities

While estimated recruitment differs somewhat in the mid-1960s between the two models (Fig. 8), the estimates are almost identical after 1980 and certainly after 2000 (Fig. 9). Similarly, the two models differ somewhat in estimated mature biomass-at-mating during the late 1960s and early 1970s (following the maturation of the recruits in the mid-1960s; Fig. 10), the estimated time series after 1980 are again very similar. During 2005-2012 (Fig. 11), estimates from 2015AM are slightly higher for males relative to Model B, but they are almost identical in 2014 and 2015. In contrast, estimates from 2015AM are slightly smaller relative to Model B during the past two years. Population abundance trends from the two models also converge to very similar values, after differing somewhat in before 1980 (Fig. 12).

Figure 8. Estimated time series of recruitment from the four models.

Figure 9. Estimated time series of recruitment from the four models.

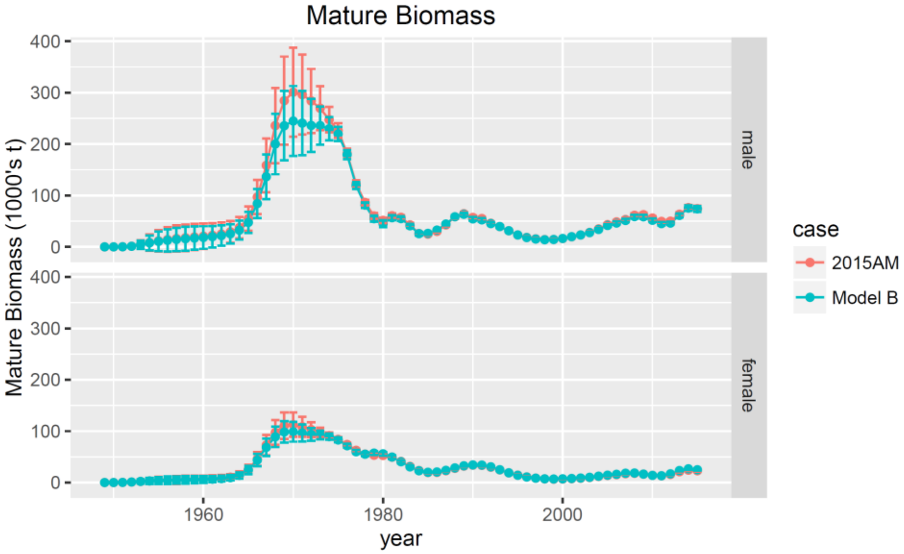


Figure 10. Estimated time series of mature biomass-at-mating from the four models.

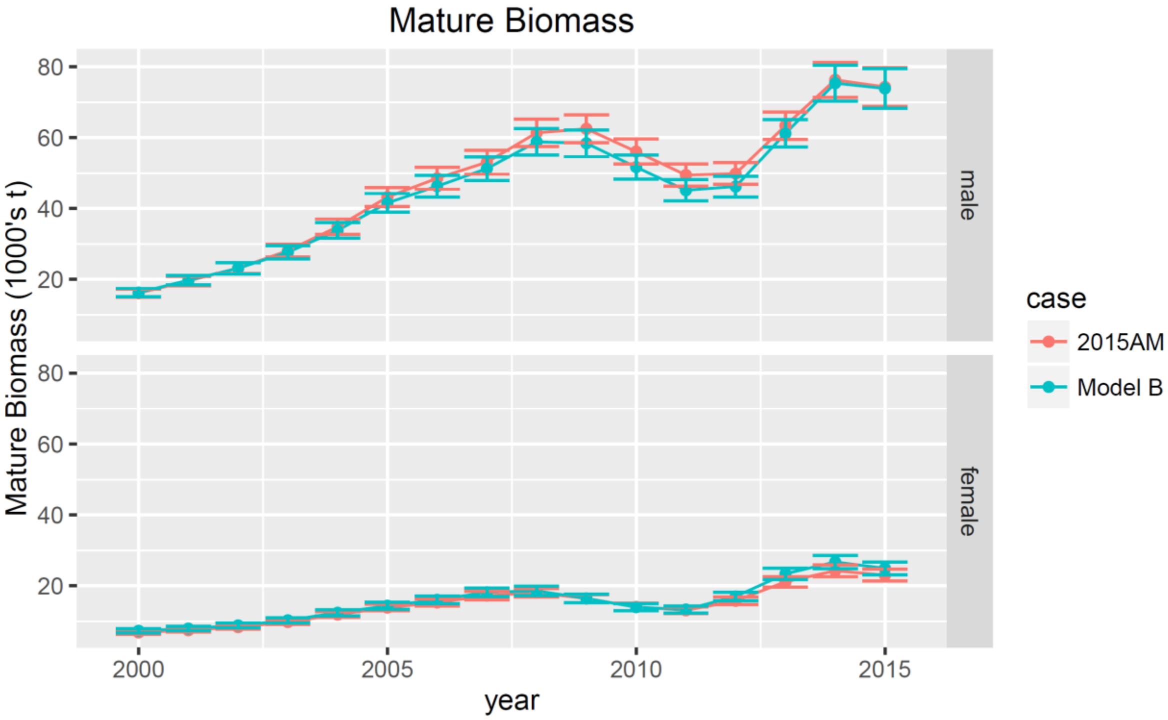


Figure 11. Estimated time series of mature biomass-at-mating from the two models.

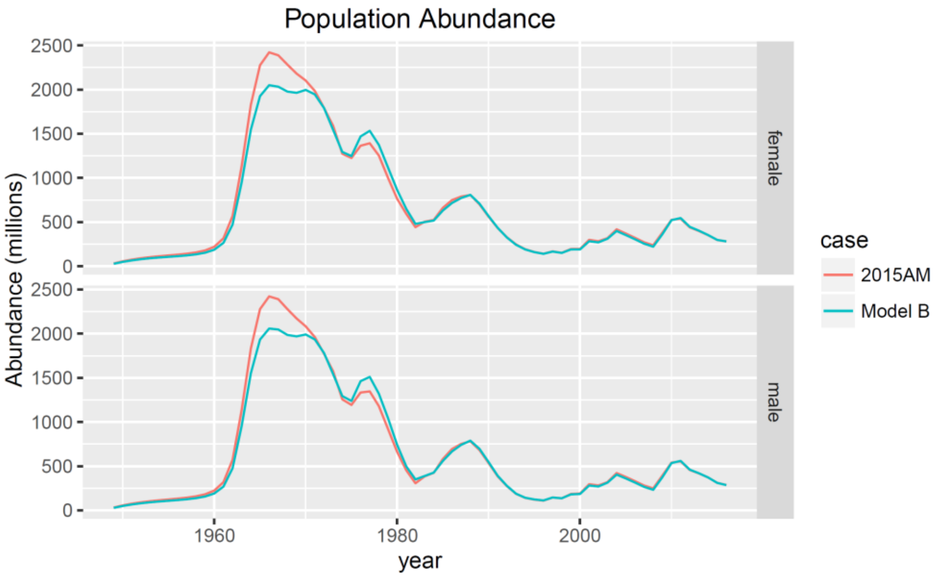


Figure 12. Estimated population abundance time series from the two models.

Survey selectivity functions

Estimated survey selectivity functions were nearly identical for the two models.

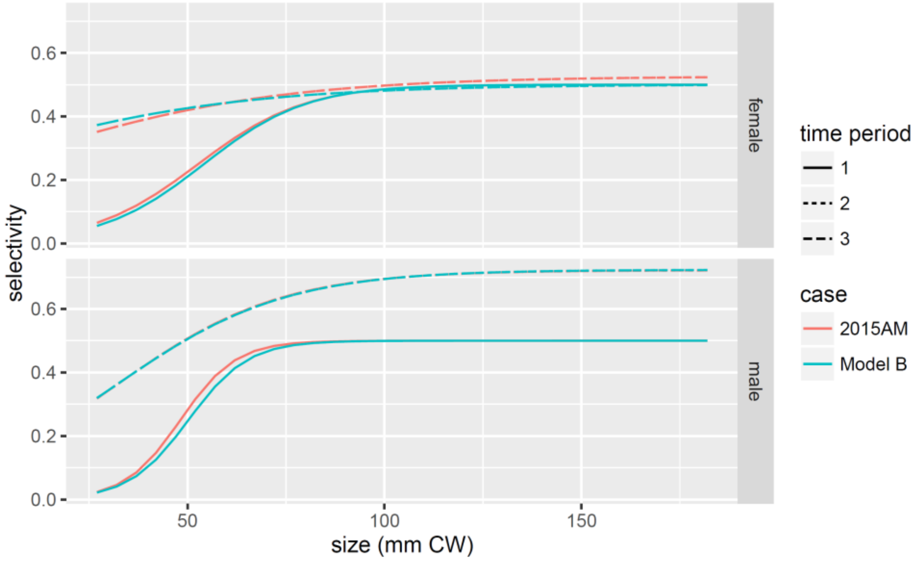


Figure 13. Comparison of estimated survey selectivity functions for the two models.

Fishery selectivity functions

The estimated retention curves from the two models are nearly identical for the period before 1991, while the curve for 2015AM is shifted to slightly smaller sizes, relative to Model B, for the period after 1990 (Fig. 14). The estimated (bycatch) selectivity function for females in the directed fishery is substantially left-shifted to smaller sizes in Model B, relative to 2015AM (Fig. 15). This is a result of estimating a female-specific offset to male fishing mortality in the directed fishery (the size-specific fishing mortality rates are comparable). The estimated selectivity curves from the two models for males in the directed fishery should not be directly compared (despite doing so here) because they are different "beasts". The selectivity curve in 2015AM represents size-specific fishing *mortality* rates (retained + discard mortality: i.e., bycatch after handling mortality has been applied) while that in Model B represents size-specific *capture* rates (retained + bycatch before handling mortality is applied). Including handling mortality in the selectivity curve from Model B would right-shift it back toward larger sizes. Similar considerations hold for the annually-varying (1991-present) selectivity curves shown in Fig. 16, although it does not account for the really large difference between the curves in 1996. The left-shifted curve for 1996 from Model B is the result of: 1) a very small sample size for the male total-catch size composition in 1996 (with the consequence that mis-fitting this size composition has little impact on the overall objective function) and 2) the size at 50%-selected (z_{50}) parameter for the pre-1991 selectivity curve is the average of the z_{50} 's for the 1991-1996 annually-varying selectivity functions. The small weight on fitting the 1996 size composition implies the 1996 z_{50} is essentially a free parameter driven by determining the z_{50} for the pre-1991 selectivity curve that best minimizes the overall objective function, rather than by the size composition in 1996. The value of z_{50} for the 1996 male total-catch appears to be extremely sensitive to other details of the model.

The estimated bycatch selectivity curves for males in the snow crab (Fig. 17), BBRKC (Fig. 18) and groundfish (Fig. 19) fisheries are very similar for the two models. The selectivity curves for females are substantially left-shifted to smaller sizes in Model B relative to 2015AM for two reasons: 1) female offsets to fully-selected male fishing mortality rates are estimated in Model B, but not in 2015AM; and 2) the selectivity curves are forced to equal 1 in the maximum model size bin in Model B but not in 2015AM (particularly important for the groundfish fisheries female bycatch selectivity curves).

The impact of estimating female offsets to fully-selected male fishing mortality rates in Model B vis-à-vis 2015AM is illustrated in Fig. 20, where fully-selected rates on females are identical to those estimated for males in the directed fishery in 2015AM (reaching a maximum value of > 4) whereas the rates are much smaller for Model B.

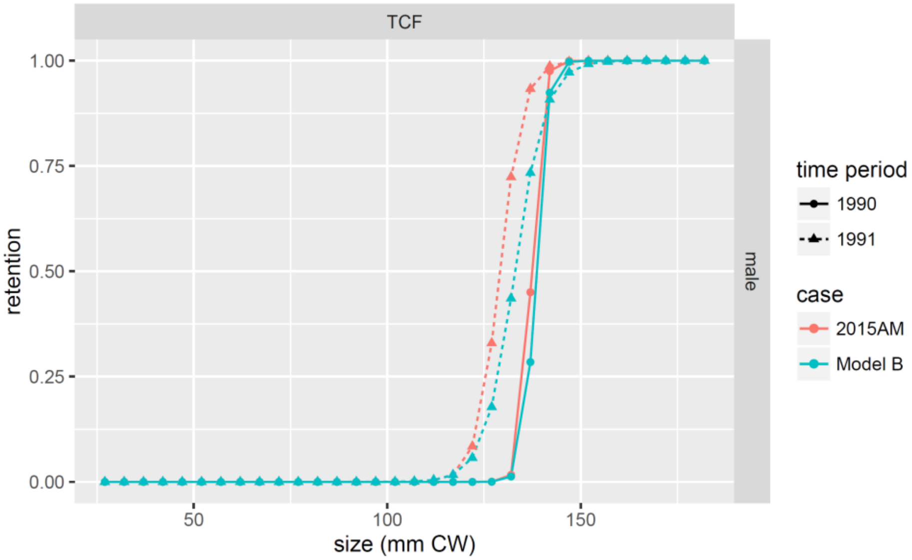


Figure 14. Comparison of estimated retention functions in the directed fishery for the two models.

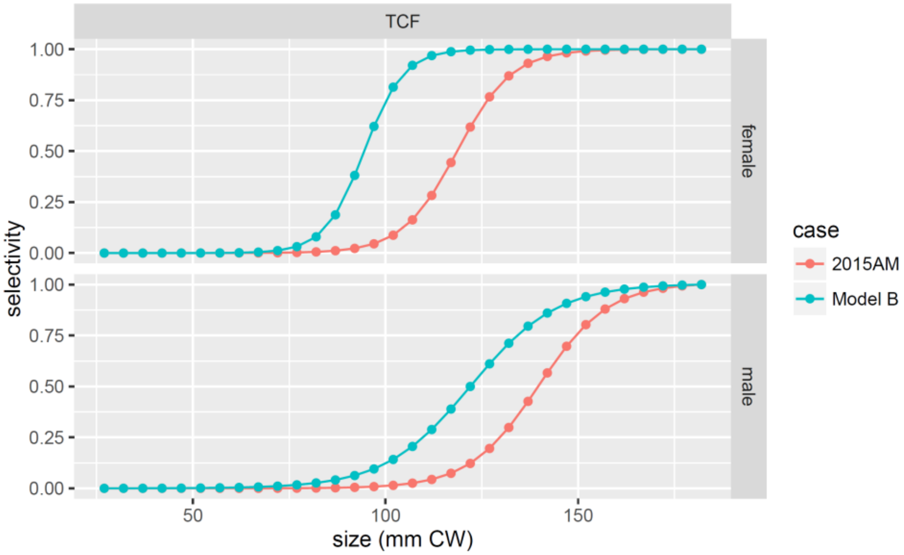


Figure 15. Comparison of estimated female bycatch selectivity and male selectivity prior to 1990 in the directed fishery for the two models.

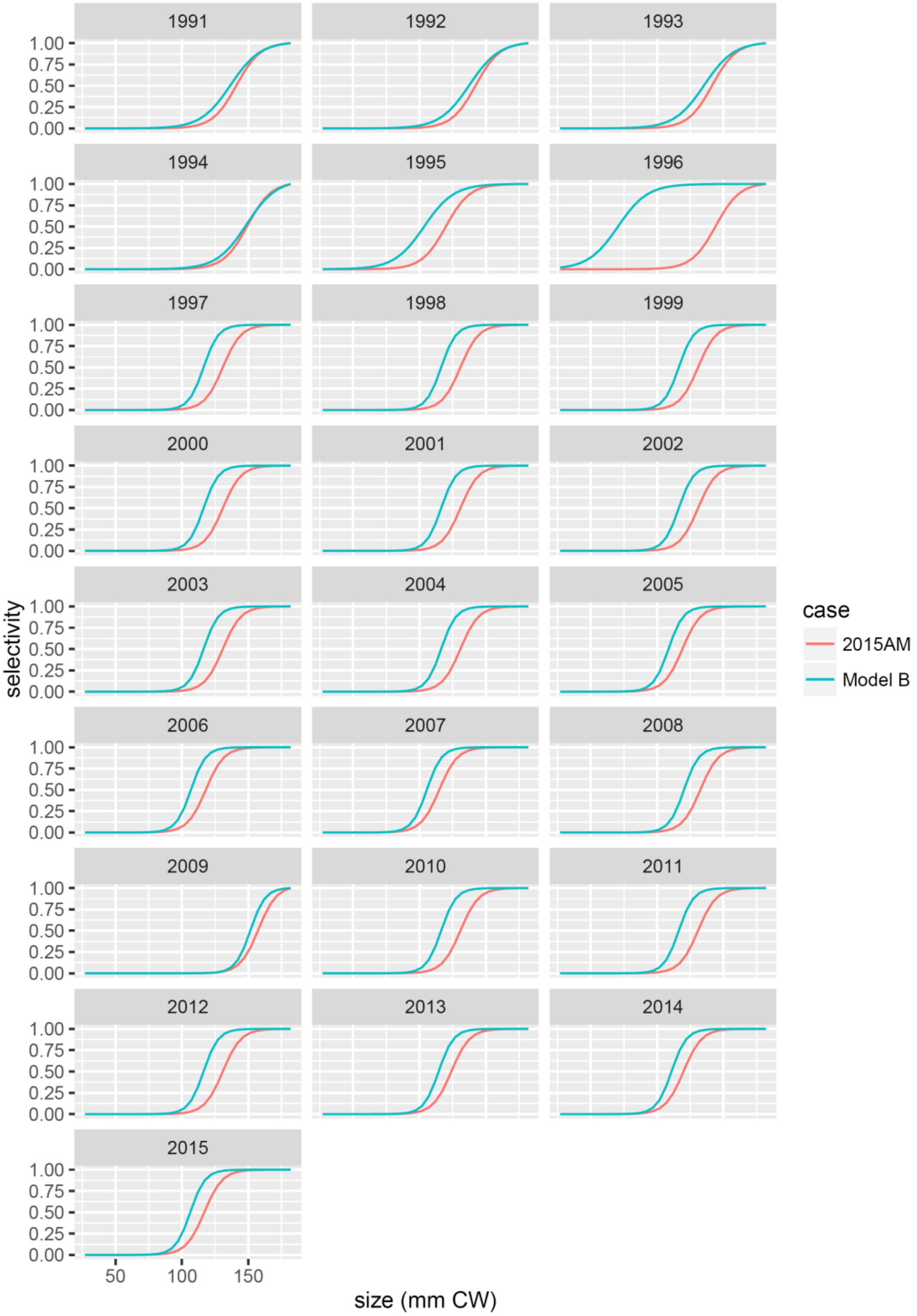


Figure 16. Comparison of estimated annual selectivity functions in the directed fishery for the two models.

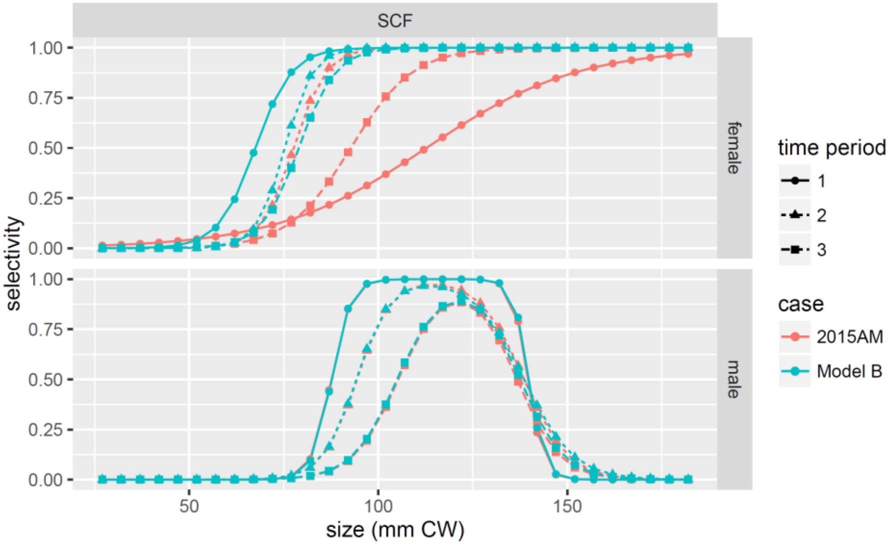


Figure 17. Comparison of estimated bycatch selectivity functions in the snow crab fishery for the two models.

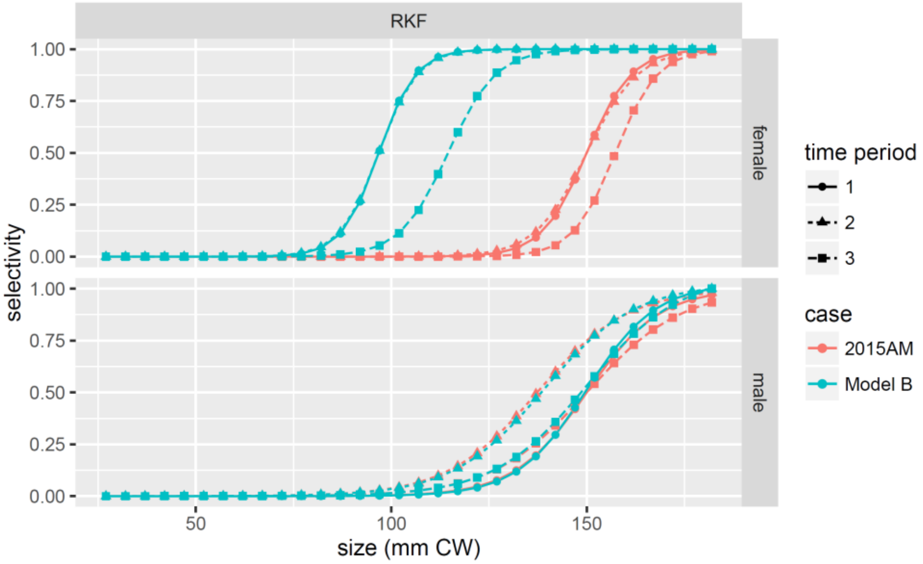


Figure 18. Comparison of estimated bycatch selectivity functions in the BBRKC fishery for the two models.

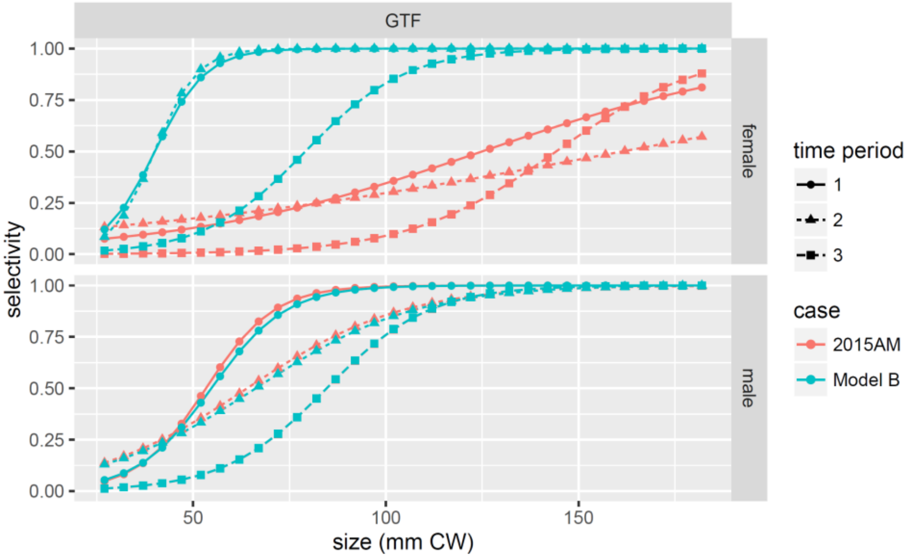


Figure 19. Comparison of estimated bycatch selectivity functions in the groundfish fisheries for the two models.

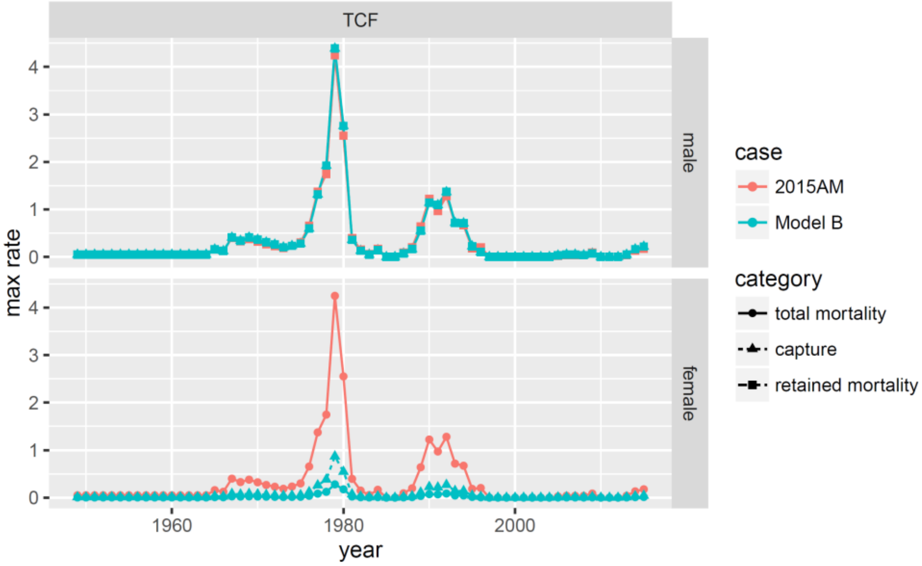


Figure 20. Comparison of estimated mean selectivity functions in the directed fishery for the two models.

Appendix C:
Comparison of Model B and Model C

William T. Stockhausen
Alaska Fisheries Science Center
6 September 2016

THIS INFORMATION IS DISTRIBUTED SOLELY FOR THE PURPOSE OF PREDISSEMINATION PEER REVIEW UNDER APPLICABLE INFORMATION QUALITY GUIDELINES. IT HAS NOT BEEN FORMALLY DISSEMINATED BY NOAA FISHERIES/ALASKA FISHERIES SCIENCE CENTER AND SHOULD NOT BE CONSTRUED TO REPRESENT ANY AGENCY DETERMINATION OR POLICY

Introduction

This appendix summarizes the comparison of Models B and C from the 2016 Tanner crab assessment. Model C builds on Model B by eliminating the constraint imposed on bycatch F rates in the BBRKC fishery that required estimated F's to be above a minimum threshold value. Any F's that fell below this threshold were replaced by the minimum. This constraint was non-differentiable and may have complicated model convergence.

Evaluation

Because Model C eliminated a non-differentiable constraint in the model, it would in almost any case have been preferred to Model B as a better model in terms of being consistent with AD Model Builder's minimization algorithms.

However, results for Model C were also almost identical to Model B, as indicated by very small differences in all objective function components (see below), so the constraint did not interfere with model minimization. The only "substantial" differences between the models were in some of the estimated bycatch capture rates in the BBRKC fishery:

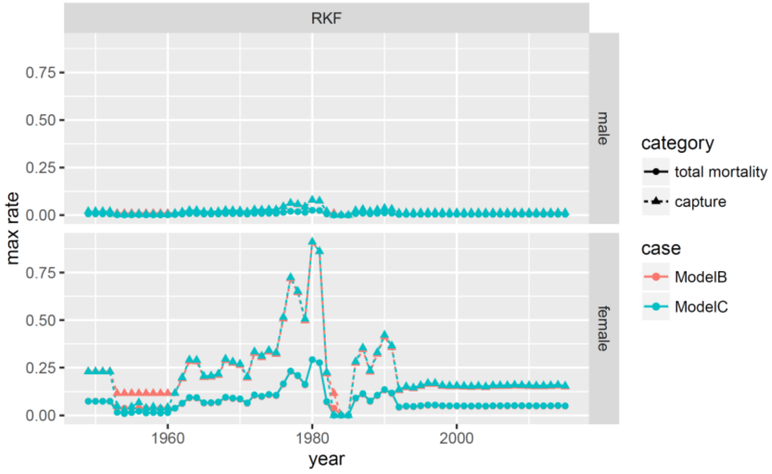


Figure 1. Fully-selected fishery capture/mortality rates in the BBRKC fishery for Models B and C.

Consequently, there was no issue to adopting Model C as the preferred model over B.

Objective function values

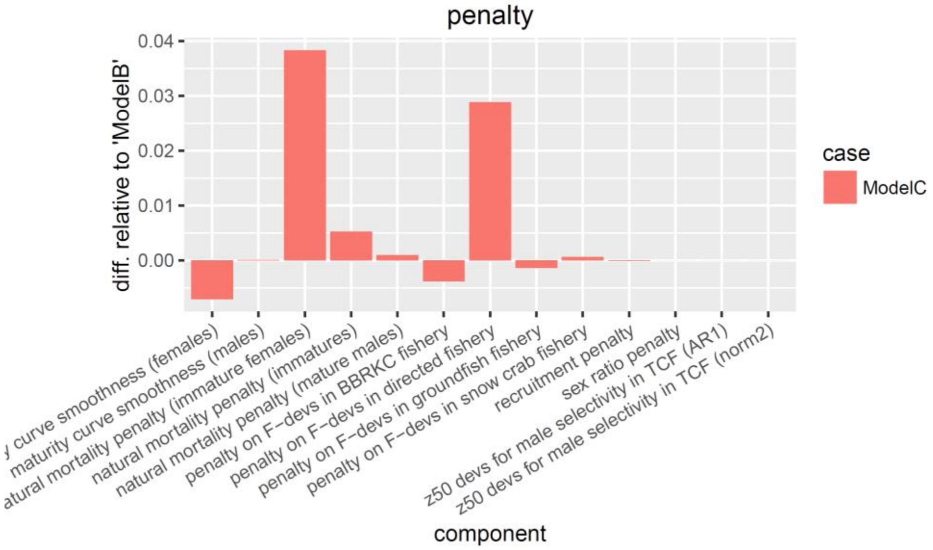


Figure 2. Differences for Model C vis-à-vis Model B (C-B) in penalty components to the model objective function.

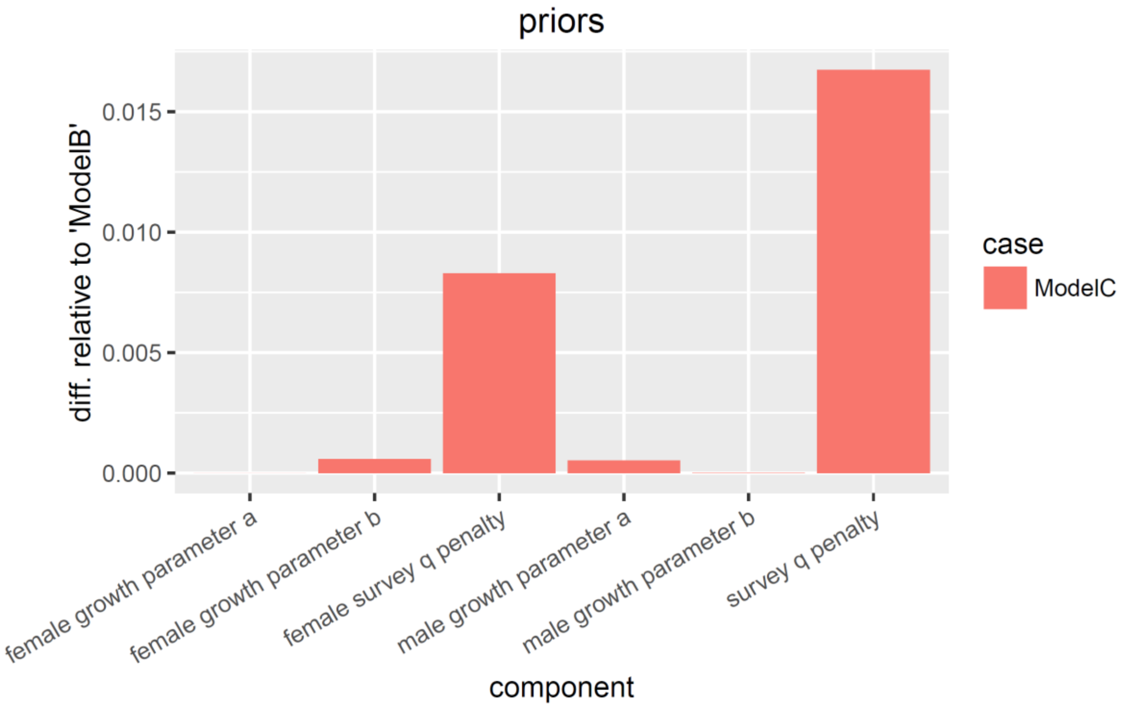


Figure 3. Differences for Model C vis-à-vis Model B (C-B) in prior probability components to the model objective function.

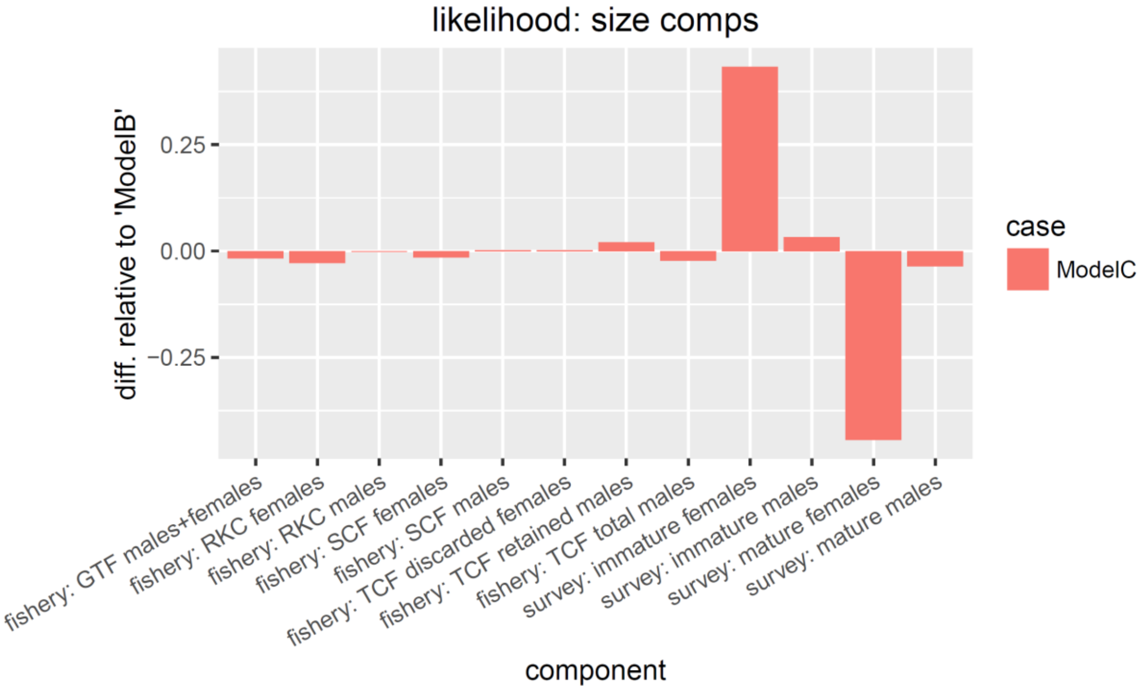


Figure 4. Differences for Model C vis-à-vis Model B (C-B) in prior probability components to the model objective function.

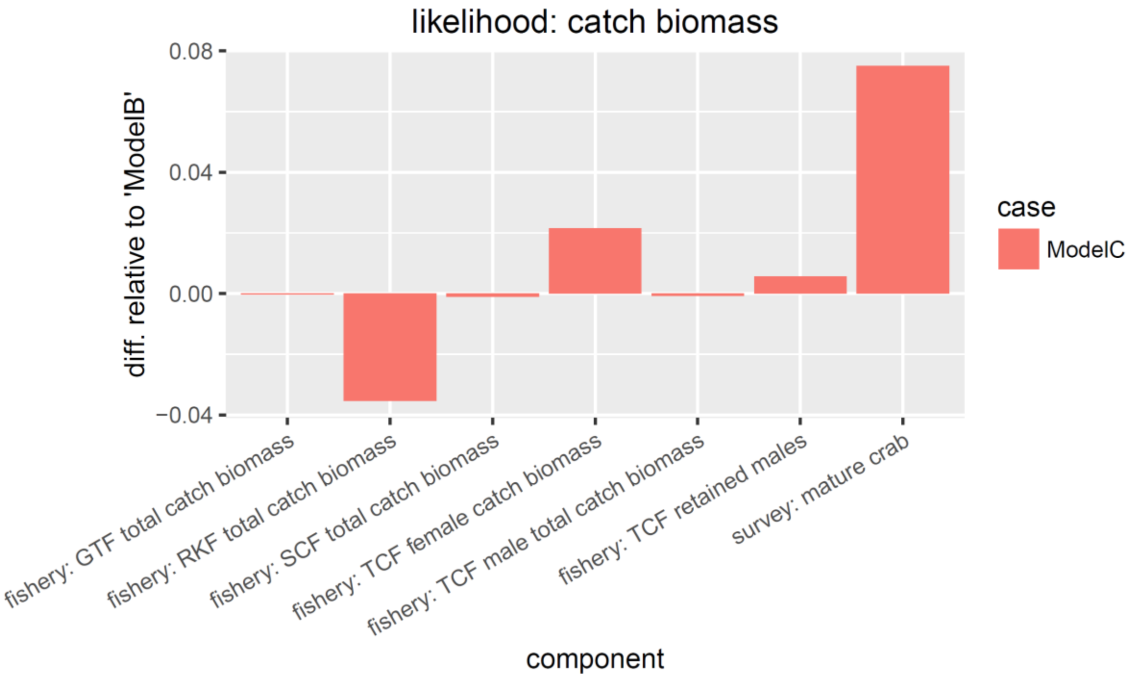


Figure 5. Differences for Model C vis-à-vis Model B (C-B) in prior probability components to the model objective function.

Population processes

Figure 6. Estimates of natural mortality for Models B and C.

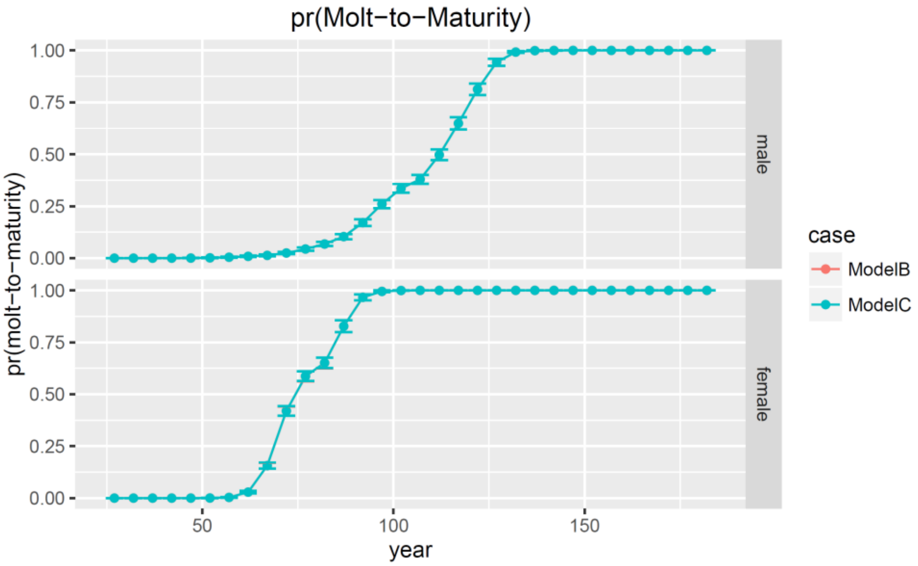


Figure 7. Estimates of the size-specific probability of undergoing terminal molt-to-maturity for Models B and C.

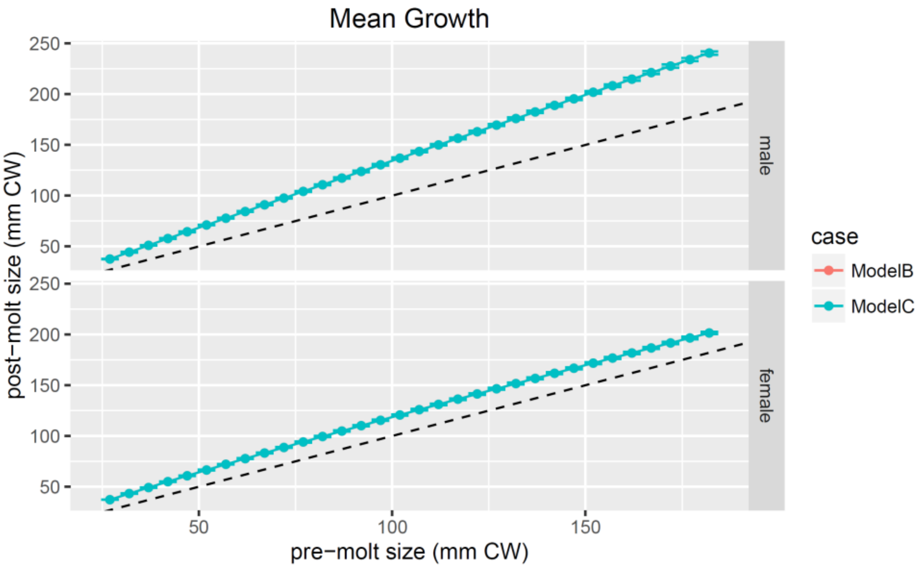


Figure 8. Estimates of the mean post-molt size as a function of pre-molt size for Models B and C.

Population quantities

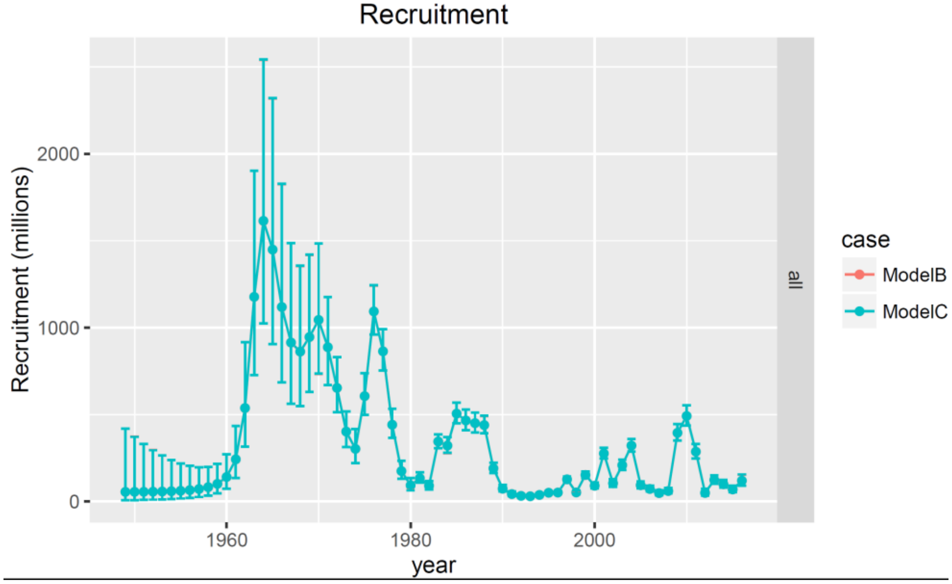


Figure 9. Estimated time series of recruitment from Models B and C.

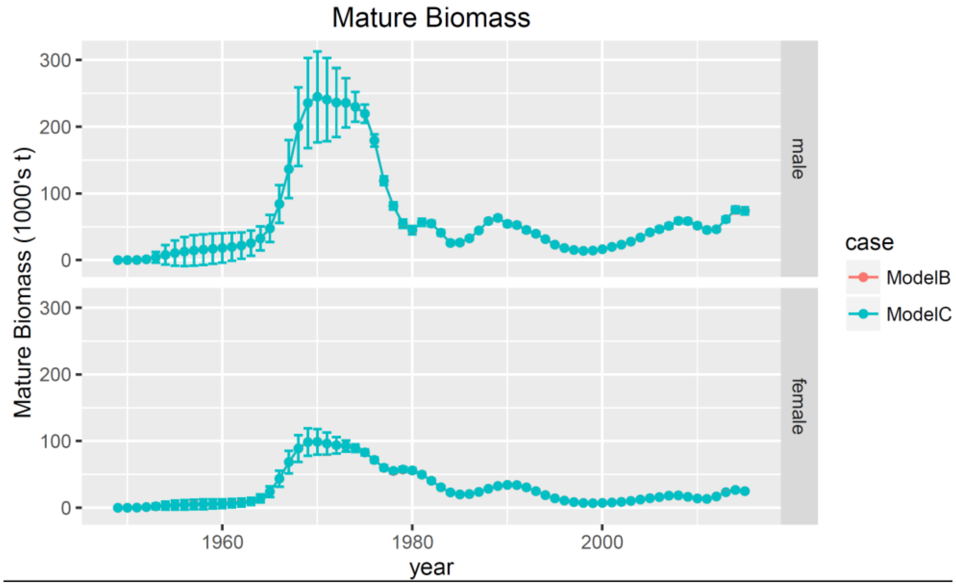


Figure 10. Estimated time series of mature biomass-at-mating from Models B and C.

Appendix D:
Comparison of Models C, D, E, F, G

William T. Stockhausen
Alaska Fisheries Science Center
6 September 2016

THIS INFORMATION IS DISTRIBUTED SOLELY FOR THE PURPOSE OF PREDISSEMINATION PEER REVIEW UNDER APPLICABLE INFORMATION QUALITY GUIDELINES. IT HAS NOT BEEN FORMALLY DISSEMINATED BY NOAA FISHERIES/ALASKA FISHERIES SCIENCE CENTER AND SHOULD NOT BE CONSTRUED TO REPRESENT ANY AGENCY DETERMINATION OR POLICY

Introduction

This appendix summarizes the comparison of Models C, D, E, F, and G from the 2016 Tanner crab assessment. Model D builds on Model C by adding two parameters, one for the snow crab fishery and one for the BBRKC fishery, to estimate fishery q's for these fisheries to convert effort (potlifts) to fishery capture rates. Model E builds on D by reducing penalties on F-devs with each estimation phase in the model convergence algorithm, then eliminating the penalties completely in the final estimation phase. Model F builds on Model D by incorporating lognormal likelihoods for catch data in all fisheries, and Model G does the same with Model E as its base (rather than Model D).

Evaluation

Unfortunately, the (ln-scale) estimates for the fishery q parameters introduced in Model D were unreasonably small:

	Model D	Model E	Model F	Model G
BBRKC	-18.46	-19.78	-19.28	-19.77
snow crab fishery	-17.82	-19.83	-19.83	-19.82

Table 36. Ln-scale estimates of fishery q's (F=qE) for bycatch in the BBRKC and snow crab fisheries from Models D-G.

which resulted in essentially bycatch rates of 0 in the snow crab and BBRKC fisheries prior to 1992, when at-sea crab fishery observers first provided usable estimates of Tanner crab bycatch in those fisheries (Fig.s 1 and 2):

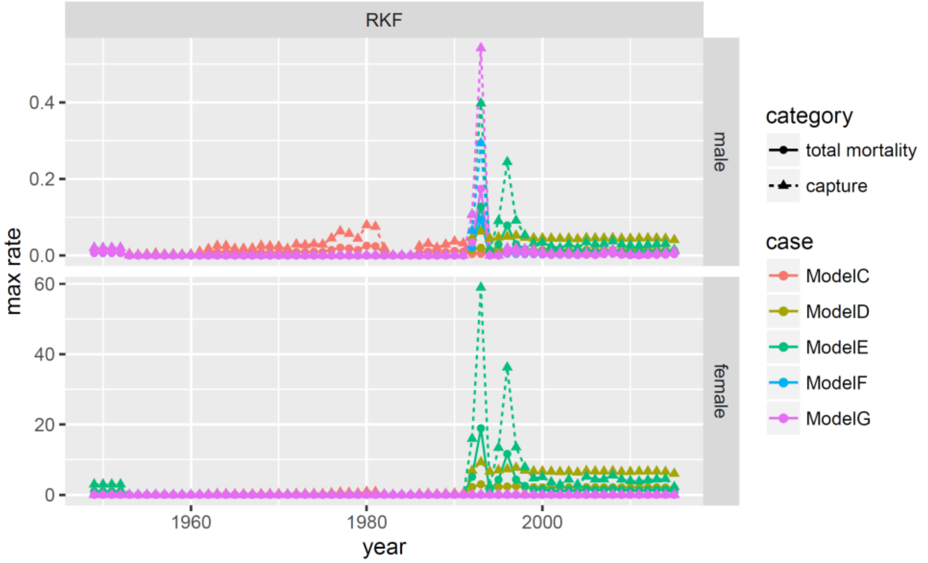


Figure 1. Fully-selected fishery capture/mortality rates in the BBRKC fishery for Models C-G.

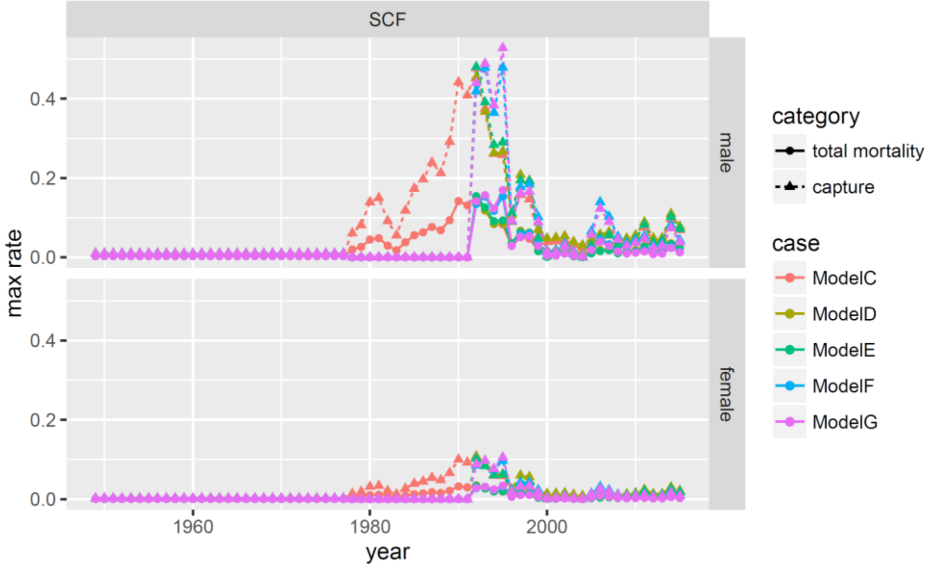


Figure 2. Fully-selected fishery capture/mortality rates in the snow crab fishery for Models C-G.

The fishery q's in Model C are not estimated parameters, but instead are based on the ratio of mean(fishing capture rate)/mean(effort) over the period 1992-present in the two respective fisheries. This approach at least appears to give reasonable estimates of historical (pre-1992) max capture rates (see Appendix C). Thus, Model C was selected over Models D-G as the preferred model for this assessment.