

Draft 2014 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

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Executive Summary

1. Stock: species/area.

Southern Tanner crab (*Chionoecetes bairdi*) in the eastern Bering Sea (EBS).

2. Catches: trends and current levels.

Legal-sized male Tanner crab are caught and retained in the directed (male-only) Tanner crab fishery in the EBS. The directed fishery was opened in 2013/14 for the first time since 2009/10 because the stock was assessed last year as not overfished and stock metrics met the SOA criteria for opening the fishery in 2013/14. TAC was set at 1,645,000 lbs (746.2 t) for the area west of 166° W and at 1,463,000 lbs (663.6 t) for the area east of 166° W in the State of Alaska's Eastern Subdistrict of Tanner crab Registration Area J. The fisheries opened on October 15 and closed on March 31. On closing, 80.9% (603.5 t) of the TAC had been taken in the western area while 99.5% (660.6 t) had been taken in the eastern area. Prior to the closures, the retained catch averaged 770 t per year between 2005/06-2009/10.

Non-retained females and sub-legal males are caught in the directed fishery as bycatch and discarded. Total bycatch (not discounting for assumed handling mortality) in the directed fishery was 560 t. Tanner crab are also caught as bycatch in the snow crab and Bristol Bay red king crab fisheries, in the groundfish fisheries and, to a minor extent, in the scallop fishery. Over the last five years, the snow crab fishery has been the major source of Tanner crab bycatch among these fisheries, averaging 1,439 t for the 5-year period 2007/08-2011/12. Bycatch in the snow crab fishery in 2013/14 was 1,846 t. The groundfish fisheries have been the next major source of Tanner crab bycatch over the five year time period, averaging 298 t. Bycatch in the groundfish fisheries in 2013/14 was 330 t. The Bristol Bay red king crab fishery has typically been the smallest source of Tanner crab bycatch among these fisheries, averaging 104 t over the 5-year time period, with 110 t caught and discarded in 2013/14.

In order to account for mortality of discarded crab, handling mortality rates have been assumed to be 50% for Tanner crab discarded in the crab fisheries and 80% for Tanner crab discarded in the groundfish fisheries to account for differences in gear and handling procedures used in the various fisheries. A new handling mortality rate of 32.1% for Tanner crab caught in pot gear is considered as an alternative in this assessment. The author's preferred model (Alt1a) is based on the old rate of 50%.

3. Stock biomass: trends and current levels relative to virgin or historic levels

For EBS Tanner crab, spawning stock biomass is expressed as mature male biomass (MMB) at the time of mating (mid February). From the author's preferred model (Alt1a), estimated MMB for 2013/14 was 79.5 thousand t (Table 14, Figure 30). This was larger than that for 2012/13 (63.6 thousand t). The 2013 model estimate for 2012/13 MMB was 59.4 thousand t. MMB had undergone a slight downward trend since its most recent peak in 2009/10, but 2013/14 represents a return to values similar to that peak. It remains above the very low levels seen in the mid-1990s to early 2000s (1990 to 2005 average: 31.1

thousand t). However, it is considerably below historic levels in the early 1970s when MMB peaked at 328.2 thousand t (1972/73).

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

From the author's preferred model (Alt1a), the estimated male recruitment in 2014/15 (number of crab entering the population on July 1) is 99.8 million crab (Table 13, Figure 27; the number of females recruiting to the population is assumed identical to male recruitment). Recruitment is estimated to have been increasing over the past three years from a minimum of 24.2 million males in 2012.

5. Management performance

(a) Historical status and catch specifications (millions lb) for eastern Bering Sea Tanner crab.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2009/10	92.37 ^B	62.70 ^B	1.34 ^{a/}	1.32	3.62	5.00 ^A	
2010/11	91.87 ^C	58.93 ^C	0.00	0.00	1.92	3.20 ^B	
2011/12	25.13 ^D	129.17 ^D	0.00	0.00	2.73	6.06 ^C	5.47 ^C
2012/13	36.97 ^E	130.84 ^E	0.00	0.00	1.57	41.93 ^D	18.01 ^D
2013/14	37.42 ^F	117.07 ^E	3.11	2.79	6.14	55.89	39.29
2014/15		156.02 ^F				74.54 ^G	49.63 ^H

(b) Historical status and catch specifications (thousands t) for eastern Bering Sea Tanner crab.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2009/10	41.90 ^B	28.44 ^B	0.61 ^{a/}	0.6	1.64	2.27 ^A	
2010/11	41.67 ^C	26.73 ^C	0	0	0.87	1.45 ^B	
2011/12	11.40 ^D	58.59 ^D	0	0	1.24	2.75 ^C	2.48 ^C
2012/13	16.77 ^E	59.35 ^E	0	0	0.71	19.02 ^D	8.17 ^D
2013/14	16.98 ^F	53.10	1.41	1.26	2.78	25.35	17.82
2014/15		70.77 ^F				33.81 ^G	22.51 ^H

a/ Only the area east of 166°W opened in 2009/10.

A—Calculated from the assessment reviewed by the Crab Plan Team in 2009.

B—Calculated from the assessment reviewed by the Crab Plan Team in 2010.

C—Calculated from the assessment reviewed by the Crab Plan Team in 2011.

D—Calculated from the assessment reviewed by the Crab Plan Team in 2012.

E—Calculated from the assessment reviewed by the Crab Plan Team in 2013.

F—Calculated from the assessment reviewed by the Crab Plan Team in 2014.

G—Calculated by the assessment author in 2014 based on his preferred model.

H—The author's recommended ABC is based on remaining at step 2 of the 3-step staircase to ABC_{max}, using the p* ABC (33.76 thousand t) as ABC_{max}.

6. Basis for the OFL

Basis for the OFL (thousands t).

Year	Tier ^A	B _{MSY} ^A	Current MMB ^A	B/B _{MSY} (MMB) ^A	F _{OFL} ^A	Years to define B _{MSY} ^A	Natural Mortality ^{A,B}
2012/13	3a	33.45	58.59	1.75	0.61 yr ⁻¹	1982-2012	0.23 yr ⁻¹
2013/14	3a	33.54	59.35	1.77	0.73 yr ⁻¹	1982-2013	0.23 yr ⁻¹
2014/15	3a	33.95	70.77	2.08	0.58 yr ⁻¹	1982-2014	0.23 yr ⁻¹

A—Calculated from the assessment reviewed by the Crab Plan Team in 20XX of 20XX/YY or based on the author’s preferred model for 2014/15.

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

Current male spawning stock biomass (MMB) is estimated at 70.77 thousand t. B_{MSY} for this stock is calculated to be 33.95 thousand t, so MSST is 16.98 thousand t. Because current MMB > MSST, **the stock is not overfished**. Total catch mortality (retained + discard mortality in all fisheries, using a discard mortality rate of 50% for pot gear and 0.8 for trawl gear) in 2013/14 was 2.78 thousand t, which was less than the OFL for 2013/14 (25.35 thousand t); consequently **overfishing did not occur**. The OFL for 2014/15 based on the author’s preferred model is 33.81 thousand t. The ABC_{max} for 2014/15, based on the p* ABC, is 33.76 thousand t. The ABC for 2013/14 was the 2nd step of a 3-year incremental stair-step approach adopted by the SSC to set ABC for this stock. The author recommends remaining on this step for 2014/15, and consequently his recommended ABC is 2/3 x p* ABC = 22.51 thousand t.

7. Rebuilding analyses summary.

The EBS Tanner crab stock was found to be above MSST (and B_{MSY}) in the 2012 assessment (Rugolo and Turnock, 2012) and was subsequently declared rebuilt. Consequently no rebuilding analyses were conducted.

A. Summary of Major Changes

1. Changes (if any) to the management of the fishery.

The Science and Statistical Committee (SSC) of the North Pacific Fisheries Management Council (NPFMC) moved the Tanner crab stock from Tier 4 to Tier 3 for status determination and OFL setting in October 2012 based on a newly-accepted assessment model (Rugolo and Turnock, 2012a). Status determination and OFL setting for Tier 4 stocks generally depends on current survey biomass and a proxy for B_{MSY} based on survey biomass averaged over a specified time period. In Tier 3, status determination and OFL setting depend on a model-estimated value for current MMB at mating time as well as proxies for F_{MSY} and B_{MSY} based on spawning biomass-per-recruit calculations and average recruitment to the population over a specified time period. The change from Tier 4 to Tier 3 resulted in a large reduction in the B_{MSY} used for status determination from 83.33 thousand t in 2011 to 33.45 thousand t in 2012. Concurrently, the estimated assessment-year MMB increased from 26.73 thousand t in 2011 to 58.59 thousand t in 2012. As a consequence, the status of Tanner crab changed from being an overfished stock following the 2011 assessment to one that was not-overfished following the 2012 assessment. The stock was subsequently declared rebuilt and an OFL of 19.02 thousand t was set for 2012/13. Although the stock was declared rebuilt as a result of the 2012 assessment, the directed fishery for Tanner crab remained closed by the SOA on the basis of its algorithms for setting harvest levels.

In the September 2013 assessment (Stockhausen et al., 2013), the Tanner crab stock was again found to be not overfished. For the 2013/14 fishing season, the SOA opened the fisheries for Tanner crab and set Total Allowable Catch limits in the two areas in which Tanner crab is commercially fished in the eastern Bering Sea (east and west of 166° W in the Eastern Subdistrict of Tanner crab Registration Area J, see Fig. 1). TAC was set at 1,645,000 lbs (746.2 t) for the area west of 166° W and at 1,463,000 lbs (663.6 t) for the area east of 166° W. The fisheries opened on October 15 and closed on March 31. On closing, 80.9% of the TAC (603.5 t) had been taken in the western area while 99.5% (660.6 t) had been taken in the eastern area.

2. Changes to the input data

No new data sources were incorporated into this assessment. Much of the crab fishery data since 1990 has been recalculated (see Appendix 1). Retained size frequencies in the directed fishery were recalculated for 1990/91-2009/10 and updated for 2013/14. Effort data in the crab fisheries was recalculated for 1990/91-2012/13 from fish ticket data by D. Pengilly (ADFG) to better apportion it among fisheries. Effort data was also updated for 2013/14. Bycatch time series for the crab fisheries, based on at-sea crab fishery observer data, were recalculated for 1992/93-2012/13, as were annual total at-sea size compositions. Tanner crab bycatch time series in the groundfish fisheries were recalculated for 2009/10-2012/13 using new methods for expanding groundfish observer data to unobserved catch based on state statistical reporting areas (Appendix 2). New groundfish bycatch estimates for 2013/14 also use this new expansion method. Bycatch size frequencies in the groundfish fisheries were recalculated for 1973/74-2012/13 based on the crab fishing year (July 1-June 30) rather than the groundfish year (Jan. 1- Dec. 1). Abundance, biomass and size frequency estimates from the 2014 NMFS EBS bottom trawl survey were also added to the assessment. The following table summarizes existing data sources that have been updated for this assessment:

Data source	Data types	Time frame	Notes	Agency
NMFS EBS Bottom Trawl Survey	abundance, size compositions	2014	new	NMFS
Directed fishery	retained catch (numbers, biomass)	2013/14	new	ADFG
	size compositions	1990/91-2013/14	recalculated, new	ADFG
	effort	1990/91-2013/14	recalculated, new	ADFG
	total catch, discards (biomass)	1992/93-2013/14	recalculated, new	ADFG
Snow Crab Fishery	size compositions	1991/92-2013/14	recalculated, new	ADFG
	effort	1990/91-2013/14	recalculated, new	ADFG
	total catch, discards (biomass)	1992/93-2013/14	recalculated, new	ADFG
Bristol Bay Red King Crab Fishery	size compositions	1992/93-2013/14	recalculated, new	ADFG
	effort	1990/91-2013/14	recalculated, new	ADFG
	total catch, discards (biomass)	1992/93-2013/14	recalculated, new	ADFG
Groundfish Fisheries	size compositions	1992/93-2013/14	recalculated, new	ADFG
	total catch, discards (biomass)	2009/10-2013/14	recalculated, new	NMFS
	size compositions	1973/74-2013/14	recalculated, new	NMFS

Updated data sources.

3. Changes to the assessment methodology.

The major change to the assessment methodology this year is consideration of a new value for handling mortality in the crab fisheries (old value = 0.5, new value = 0.321) based on data presented at the May 2014 CPT meeting. Model runs using both values were successfully completed. In models based on the recalculated fisheries data, using the new value resulted in a 2014/15 OFL of 31.30 thousand t while using the old value resulted in a 2014/15 OFL of 33.81 thousand t.

A new assessment model is under development but has not yet been completed. The assessment methodology (i.e., a Tier 3 assessment model) remains unchanged (see Appendix 3 for a detailed description of the current model). A number of potential algorithmic changes to the existing model were

implemented (e.g., Appendix 4), but none proved satisfactory. The model that forms the basis for status determination and OFL/ABC setting is the same as in the 2013 assessment.

4. Changes to the assessment results

Results from the author's preferred model (incorporating the old handling mortality rate) are reasonably similar to those from the previous assessment, considering the large number of changes in the (primarily fisheries-related) data. Average recruitment (1982-present) was estimated at 211.9 million in last year's models, whereas it was estimated at 209.7 million in the author's preferred model this year. F_{MSY} was estimated at 0.73 yr^{-1} last year and 0.58 yr^{-1} this year. B_{MSY} was estimated at 33.5 thousand t last year, and 33.8 thousand t this year.

B. Responses to SSC and CPT Comments

1. Responses to the most recent two sets of SSC and CPT comments on assessments in general. [Note: for continuity with the previous assessment, the following includes comments prior to the most recent two sets of comments.]

September 2013 Crab Plan Team Meeting

Comment: The CPT "recommends that crab authors apply the [groundfish stock structure template] criteria for considering spatial issues in stocks."

Response: Not yet addressed.

Comment: The CPT "recommends that all assessment authors document assumptions and simulate data under those assumptions to test the ability of the model to estimate key parameters in an unbiased manner."

Response: Not yet addressed. Simulation testing will be possible with the new model under development.

Comment: The CPT "recommends that weighting factors be expressed as sigmas or CVs or effective sample sizes."

Response: This has been done.

Comment: The CPT encourages authors to "...develop approaches for accounting for this source of process error" (i.e., fitting to length-composition data accounts for sampling error but not within-year variability in selectivity).

Response: Not yet addressed.

Comment: The CPT reminds authors that "assessments should include the time series of stock estimates at the time of the survey for at least the author's recommended model in that year."

Response: This has been addressed in Tables 21 and 22.

October 2013 SSC Meeting

No general comments.

January 2014 Crab Modeling Workshop

Comment: The CPT requested "all assessment authors should provide model scenarios which mimic the September 2013 assessments by replacing the bycatch data in the crab fisheries with updated data from Bill Gaeuman using the 'simple averaging' method and by replacing the NMFS survey data with recalculated series based on updated methodologies so the CPT can evaluate the implications of these changes to the data."

Response: This was addressed for the crab bycatch data provided by W. Gaeuman at the May, 2014 CPT Meeting (see http://www.npfmc.org/wp-content/PDFdocuments/membership/PlanTeam/Crab/CrabSafe14/tanner_rev.docx). The revised NMFS time series data (abundance, biomass and size frequencies) are still being evaluated and have not yet been provided to assessment authors.

May 2014 Crab Plan Team Meeting

Comment: “For all likelihood results presented, add a row to tables showing differences in likelihoods comparing to the base models.”

Response: This has been addressed in Tables 19 and 20.

Comment: “When comparing likelihoods and model output, do not show models that cannot be compared next to each other. Make it clear which models are comparable...”

Response: Models that are not comparable are not directly compared.

Comment: “The CPT recommends that assessment authors investigate the effects of the new [NMFS trawl survey] time series on size frequencies.”

Response: Results (e.g., abundance and biomass estimates, size frequencies) for the revised NMFS trawl survey data have only recently been released in an informal manner, so there has been no time to meet this request. It is expected that the issue will be undertaken at the Crab Modeling Workshop during the winter and again at the Spring CPT meeting.

June 2014 SSC Meeting

No general comments.

2. *Responses to the most recent two sets of SSC and CPT comments specific to the assessment.* [Note: for continuity with the previous assessment, the following includes comments prior to the most recent two sets of comments.]

May 2013 Crab Plan Team Meeting

Comment: “The CPT recommended that a sensitivity analysis on handling mortality be done in the Tanner crab assessment...”

Response: The author attempted to address this request using the 2013 assessment model and data for direct comparison with last year’s OFL. However, it appears (based on the model runs done for this assessment) that the results are really not generalizable to the new data. Consequently, this request remains to be addressed.

Comment: “The CPT suggested starting the analysis from 2012 and moving backwards as alternative future evaluation [in the average recruitment analysis].”

Response: Not yet addressed.

June 2013 SSC Meeting

No specific comments.

September 2013 Crab Plan Team Meeting

Comment: “Evaluate bycatch in other fisheries, such as the scallop fishery, to determine whether it is of sufficient magnitude to be accounted for in the assessment.”

Response: In the Bering Sea, bycatch of Tanner crab in the scallop fishery was estimated to be approximately 6.7 t (15 thousand lbs, 13 thousand crab) in 2011/12. This represents a miniscule fraction of bycatch when compared with the snow crab (1.2 thousand t), BBRKC (0.1 thousand t), and groundfish (0.333 thousand t) fisheries for the same year.

Comment: “All questionable size composition data should be extracted afresh from databases and the size compositions recompiled.”

Response: W. Gaeuman (ADFG) re-extracted size composition data from the ADFG crab fisheries databases for (dockside) retained catch in the directed Tanner crab fishery and total and discarded catch in the directed, snow crab, and BBRKC fisheries. I re-extracted size frequencies for Tanner bycatch in the groundfish fisheries from the NMFS groundfish observer database and adjusted them to the crab fishery year (July 1-June 30) from the groundfish fishery year (Jan. 1-Dec.31). Results based on the new data sets

were discussed at the May 2014 CPT Meeting (see http://www.npfmc.org/wp-content/PDFdocuments/membership/PlanTeam/Crab/CrabSafe14/tanner_rev.docx).

Comment: “Fisheries should be modeled as a pulse at the midpoint of the fishery with the pulse based on the midpoint of the actual fishery.”

Response: This will be implemented in the new model code under development.

Comment: “Examine how random walks in fishery selectivity parameters are handled during periods when the fishery is closed to ensure that reasonable assumptions are being made.”

Response: The parameters describing size-at-50%-selected in the directed fishery are currently independent of one another (i.e., no autoregressive is imposed), so fishery closure periods have no effect on parameter values. This will be a issue to consider if an autoregressive structure is implemented in the future.

Comment: “The model should be fit to total biomass when that is all that is available from the survey, and fit to mature and immature biomass with separate likelihood components when both are available.”

Response: This will be implemented in the new model code.

Comment: “Maturation probabilities should be estimated on a logit scale, and the smoothing penalties should be set up so the curves are non-decreasing. A parametric curve should also be considered.”

Response: This has been implemented in the new model code.

Comment: “Collection of growth data specific to the Tanner crab stock in the EBS should be given a high research priority.”

Response: The author agrees wholeheartedly.

Comment: “Evaluate the feasibility of estimating F_{MSY} (and B_{MSY}) for the stock using the estimates of recruitment and MMB during the post-1982 period, and compare to the $F_{35\%}$ MSY proxy.”

Response: Not yet addressed.

Comment: “If time permits, apply the groundfish plan team’s stock structure template to Tanner crab to synthesize the available information on stock structure.”

Response: Time has not permitted. Not yet addressed.

October 2013 SSC Meeting

Comment: “The SSC recommends conducting a management strategy evaluation (MSE) to determining [sic] the long-term consequences of alternative harvest rates on stock status and yield under various sources of uncertainty.”

Response: It will not be feasible to address this request at least until the new model code is completed.

Comment: “The SSC continues to encourage alternative model specifications to address these patterns” [i.e., retrospective patterns in model-estimated biomass], which “inclusion of a time-varying growth function may address...”

Response: The option for time-varying growth (constant over blocks of time) has been implemented in the new model code under development.

Comment: “The SSC...encourages a thorough review and re-compilation of all data sources.”

Response: The review has been initiated and is ongoing. W. Gaeuman (ADFG) has re-extracted size composition data from the ADFG crab fisheries databases for (dockside) retained catch in the directed Tanner crab fishery and total and discarded catch in the directed, snow crab, and BBRKC fisheries. I have re-extracted size frequencies for Tanner bycatch in the groundfish fisheries from the NMFS groundfish observer database which I have adjusted to the crab fishery year (July 1-June 30) from the groundfish fishery year (Jan. 1-Dec.31). Effort in the directed Tanner crab, snow crab and BBRKC fisheries has been

painstakingly re-evaluated by D. Pengilly (ADFG), resulting in substantially revised estimates for effort in the Tanner crab fishery primarily during the early 1990s. R. Foy (NMFS) is also revising data from the NMFS trawl survey; changes, however, will not be reviewed until the 2015 Crab Modeling Workshop.

May 2014 Crab Plan Team Meeting

Comment: “The revised data sets should be used in future assessments.”

Response: The revised fisheries datasets have been incorporated in the author’s preferred model.

Comment: “Run the model using: (a) the old data set, (b) the revised data set and the composite fleet fishing mortality formula as used in Gmacs, and (c) the revised data set and bycatch fishing mortality formula as used in Gmacs.”

Response: I’m not sure I understand how the composite fleet fishing mortality formula differs from the bycatch fishing mortality formula used in Gmacs. I’ve run the model using (a) the old data set (and fishing mortality formulation) , (b’) the old data set and the Gmacs fishing mortality formulation (retained+bycatch), and (c’) the revised dataset and the Gmacs fishing mortality formulation (retained+bycatch). Unfortunately, none of the model runs using the Gmacs fishing mortality formulation had good convergence properties and were subsequently rejected as potential alternatives for the old model formulation.

Comment: “Compare actual discarded catch with model-estimated discarded catch (separately for directed fishery bycatch, snow crab bycatch, red king crab bycatch, and groundfish bycatch).”

Response: Time did not permit addressing this request.

Comment: “The CPT requested that the next Tanner crab assessment use 0.321 as handling mortality for all pot fisheries (crab and groundfish) in the base run and 0.5 as an alternative scenario.”

Response: Models with both handling mortality values. Because the 2013 assessment model used 0.5, the model using this value for handling mortality is referred to in the text as the “base” model (in contrast to the CPT’s suggestion). However, the author’s preferred model (Alt1a) is based on the old value.

June 2014 SSC Meeting

Comment: “Examine retrospective patterns of models being brought forward.”

Response: Not yet addressed.

Comment: “Use the new handling mortality rate (0.321) as recommended by the CPT.”

Response: Model runs using 0.321 as the handling mortality rate are included in this assessment. However, the author’s preferred model is based on the old value.

Comment: “...the SSC advises the assessment author to explore the buffer between ABC and OFL and asks the author and Plan Team to consider the control rule for this stock. The author and Plan Team are referred to the discussion in the SSC’s report for October, 2013.”

Response: I assume the “discussion” refers to the SSC’s recommendation for conducting an MSE for Tanner crab. It will not be feasible to address this request until the new model code is completed.

Comment: “Explore model fit to survey data using only male information.”

Response: The author requests clarification on this request. Is the request to fit a male-only model to male-only data? The current assessment model is “hard-wired” as a two-sex model. It will not be feasible to address this request until the new model code is completed.

3. Older comments that remain to be addressed:

May 2012 Crab Plan Team Meeting

Comment 2: “Plot the input effective sample sizes for the compositional data versus the effective sample sizes inferred by the fit of the model...”

Response: Not yet addressed.

Comment E: “Allow M for immature as well as mature males to change during 1980-83 (the data on changes in abundance do not suggest that only mature males declined substantially) and test whether it is necessary to allow female M to change over time.”

Response: Not yet addressed.

Comment 1 (Longer-term tasks): “Consider implementing the ability to change the penalty weight on F-deviations as a function of estimation phase...”

Response: This suggestion was implemented in the current model. Models using decreasing penalty weights as a function of estimation phase did not have good convergence properties. However, the suggestion will also be implemented in the new model code under development.

Comment 2 (Longer-term tasks): “Consider treating all of the F-deviations (except for which catch is known to be zero) as parameters, and include the fishing mortality-effort relationship as a prior—this will allow the uncertainty associated with this relationship to be reflected in the measures of uncertainty.”

Response: Not yet addressed.

Comment 3 (Longer-term tasks): “Consider different effective sample sizes for each category of survey compositional data (males+females*mature+immature).”

Response: Different effective sample sizes (EFFs) are currently used for male and female compositional survey data, but these are not broken down further. One issue with providing different EFFs for different compositional components is that they are non-additive—that is, the effective sample sizes you would get from simply summing the EFFs from the disaggregated components are not the same as those you would get by starting from the aggregated components. The solution would be to calculate the EFFs inside the assessment code directly from the compositional data at the required level of aggregation.

Comment 4 (Longer-term tasks): “Consider fitting to total biomass (by sex?) and to the compositional data rather than to mature biomass (include the fit to mature biomass by sex as a diagnostic).”

Response: Not yet addressed.

Comment 5 (Longer-term tasks): “Do not fit to male compositional data by maturity state for the years for which chela height-maturity relationships are not available.”

Response: Not yet addressed.

September 2012 Crab Plan Team Meeting

Comment: “Plot input sample sizes for LF data vs. effective sample sizes inferred by the fit of the model”

Response: Not yet addressed.

Comment: “The description of the model should be carefully checked. Two errors in model description were noted: (a) fishing mortality by the Bristol Bay red king crab and EBS snow crab fisheries is related to effort not catch; and (b) selectivity for bycatch by the EBS snow crab fishery is assumed to be dome-shaped and not asymptotic.”

Response: The current model description has been rewritten and provided as an appendix (Appendix 3).

Comment: “The seemingly anomalous values [for length at 50% selectivity] may be due to confounding among parameters and need to be explored further.”

Response: I attempted to address this issue this summer by fixing sizes at which crab were considered to be “fully selected”, as well as options for implementing ln-scale offsets to fully-selected male fishing mortality rates for females in the various fisheries. However, models implementing these changes failed to converge satisfactorily and are not discussed in detail in this chapter due to time constraints in preparing it.

Comment: “The fits to the groundfish length-frequency data (e.g. Fig. 51) and to the total catch are unexpectedly poor. Model configurations which better capture the data should be explored.”

Response: Input sample sizes associated with the male and female size compositions were found this year to have been reversed in the 2012 assessment and carried over to the 2013 assessment. Correcting this mistake has somewhat improved the fits to the groundfish size compositions, but the fits are still relatively poor.

Comment: “There is still a residual pattern in the fit to the size-composition data for the survey. This could be due to time-varying growth, which should be examined as an alternative model for May 2013.”

Response: Not yet addressed. Time-varying growth (using time blocks) is an option in the new model code under development.

Comment: “A major concern for the CPT was the inability of the model to match the magnitude of discards in the EBS snow crab and Bristol Bay red king crab fisheries...The CPT requested the analysts conduct further analyses in which mimicking the observer data was given higher weight.”

Response: Not yet addressed.

October 2012 SSC Meeting

Comment: “The SSC encourages the analysts to continue to explore alternative model formulations (variable growth, variable mortality, etc.) that may address patterns in model residuals (e.g., Fig. 37 and 39).”

Response: Time-varying growth and mortality have been implemented in the new model code under development.

Comment: “The SSC requests the assessment authors to include a plot similar to Fig. 54 of the assessment chapter in which recruitment (y-axis) is plotted against egg production indices (x-axis) from Fig. 14.”

Response: Not yet addressed.

C. Introduction

1. Scientific name.

Chionoectes bairdi. Tanner crab is one of five species in the genus *Chionoectes*. The common name “Tanner crab” for *C. bairdi* (Williams et al. 1989) was recently modified to “southern Tanner crab” (McLaughlin et al. 2005). Prior to this change, the term “Tanner crab” had also been used to refer to other members of the genus, or the genus as a whole. Hereafter, the common name “Tanner crab” will be used in reference to “southern Tanner crab”.

2. Description of general distribution

Tanner crabs are found in continental shelf waters of the north Pacific. In the east, their range extends as far south as Oregon (Hosie and Gaumer 1974) and in the west as far south as Hokkaido, Japan (Kon 1996). The northern extent of their range is in the Bering Sea (Somerton 1981a), where they are found along the Kamchatka peninsula (Slizkin 1990) to the west and in Bristol Bay to the east.

In the eastern Bering Sea (EBS), the Tanner crab distribution may be limited by water temperature (Somerton 1981a). The unit stock is that defined across the geographic range of the EBS continental shelf, and managed as a single unit (Figure 1). *C. bairdi* is common in the southern half of Bristol Bay, around the Pribilof Islands, and along the shelf break, although sub-legal sized males (≤ 138 mm CW) and ovigerous and immature females of all sizes are distributed broadly from southern Bristol Bay northwest to St. Matthew Island (Rugolo and Turnock, 2011a). The southern range of the cold water congener the snow crab, *C. opilio*, in the EBS is near the Pribilof Islands (Turnock and Rugolo, 2011b). 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 (1981a) suggests that clinal differences in some biological characteristics may exist across the range of the unit stock. These conclusions may be limited since terminal molt at maturity in this species was not recognized at the time of that analysis, nor was stock movement with ontogeny considered. Biological characteristics estimated based on comparisons of length frequency distributions across the range of the stock, or on modal length analysis over time may be confounded as a result.

Although the State of Alaska’s (SOA) harvest strategy and management controls for this stock are different east and west of 166°W, the unit stock of Tanner crab in the EBS appears to encompass both regions and comprises crab throughout the geographic range of the NMFS bottom trawl survey. Evidence is lacking that the EBS shelf is home to two distinct, non-intermixing, non-interbreeding stocks that should be assessed and managed separately.

4. Life history characteristics

a. Molting and Shell Condition

Tanner crabs, like all crustaceans, normally exhibit a hard exoskeleton of chitin and calcium carbonate. This hard exoskeleton requires individuals to grow through a process referred to as molting, in which the individual sheds its current hard shell, revealing a new, larger exoskeleton that is initially soft but which rapidly hardens over several days. Newly-molted crab in this “soft shell” phase can be particularly 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 dark yellow with many scratches and dark stains; pterygostomial and branchial spines rounded with tips sometimes worn off; dactyli very worn, sometimes flattened on tips; spines on meri and metabranchial region worn smooth, sometimes completely gone; epifauna most always present (large barnacles and bryozoans).
5	conditions described in Shell Condition 4 above much advanced; large epifauna almost completely covers crab; carapace is worn through in metabranchial regions, pterygostomial branchial spines, or on meri; dactyli flattened, sometimes worn through, mouth parts and eyes sometimes nearly immobilized by barnacles.

Although these shell classifications continue to be applied to crab in the field, it has been shown that there is little real correspondence between post-molt age and shell classifications SC 3 through 5, other than that they indicate that the individual has probably not molted within the previous year (Nevisi et al, 1996). In this assessment, crab classified into SCs 3-5 have been aggregated as “old-shell” crab, indicating that these are crab likely to have not molted within the previous year. In a similar fashion, crab classified in SCs 0-2 have been combined as “new shell” crab, indicating that these are crab have certainly (SCs 0 and 1), or are likely to have (SC 2), molted within the previous year.

b. Growth

Growth in immature Tanner crab larger than 25 mm CW proceeds by a series of annual molts, up to a final (terminal) molt to maturity (Tamone et al., 2007). Growth relationships specific to Tanner crab in the EBS are sadly lacking and in this assessment the ones used are derived from data collected near Kodiak Island in the Gulf of Alaska (Munk pers. comm., Donaldson et al. 1981). Using this data, Rugolo and Turnock (2012a) derived growth relationships for male and female Tanner crab using data on observed growth for males to approximately 140 mm carapace width (CW) and for females to approximately 115 mm CW. The relationship between pre-molt and post-molt size for males and females was modeled as two parameter exponential functions of the general form $y = ax^b$, where y is post-molt size (CW) and x is pre-molt size. The resulting parameters are:

sex	parameter	
	a	b
male	1.55	0.949
female	1.76	0.913

Rugolo and Turnock (2010) compared the resulting growth per molt (gpm) relationships with those of Stone et al. (2003) for Tanner crab in southeast Alaska in terms of the overall pattern of gpm over the size range of crab and found that the pattern of gpm for both males and females was characterized by a higher rate of growth to an intermediate size (90-100 mm CW) followed by a decrease in growth rate from that size thereafter. Similarly-shaped growth curves were found by Stone et al. (2003), Somerton (1981), and Donaldson et al. (1981).

Previous work by Somerton (1981a) estimated growth for EBS Tanner crab based on modal size frequency analysis of Tanner crab in survey data assuming no terminal molt at maturity. Somerton's approach did not directly measure molt increments and his findings are constrained by not considering that the progression of modal lengths between years was biased because crab ceased growing after their terminal molt to maturity

c. Weight at Length

Rugolo and Turnock (2012a) derived weight-at-size relationships for male (regardless of maturity state), immature female, and mature female Tanner crab in the EBS based on special collections of size and weight data during the summer bottom trawl surveys in 2006, 2007 and 2009. Power-law models of the form $w = a \cdot z^b$, where w is weight in grams and z is size in mm CW, were fit to the survey data. The resulting parameter estimates are given in the following table:

parameter	males	females	
	all	immature	mature
a	0.00016	0.00064	0.00034
b	3.136	2.794	2.956

These relationships are used in the assessment model to convert individual size to biomass.

d. Maturity and Reproduction

It is now generally accepted that both Tanner crab males (Tamone et al. 2007) and females (Donaldson and Adams 1989) undergo a terminal molt to maturity, as in most majid crabs. Females usually undergo their terminal molt from their last juvenile, or pubescent, instar while being grasped by a male (Donaldson and Adams 1989). Subsequent mating takes place annually in a hard shell state (Hilsinger 1976) and after extruding the female's clutch of eggs. While mating involving old-shell adult females has been documented (Donaldson and Hicks 1977), fertile egg clutches can be produced in the absence of males by using sperm stored in the spermathecae (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 spermatophores 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 status 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 2004a). 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 2004a).

f. Size at Maturity

Rugolo and Turnock (2012b) estimated size at 50% mature for females (all shell classes combined) from data collected in the NMFS bottom trawl survey at 68.8 mm CW, and 74.6 mm CW for new shell females. For males, Rugolo and Turnock (2012a) estimated classification lines using mixture-of-two-regressions analysis to define morphometric maturity for the unit Tanner crab stock, and for the sub-stock components east and west of 166°W, based on chela height and carapace width data collected during the 2008 NMFS bottom trawl survey. These rules were then applied to historical survey data from 1990-2007 to apportion male crab as immature or mature based on size (Rugolo and Turnock, 2012b). Rugolo and Turnock (2012a) found no significant differences between the classification lines of the sub-stock components (i.e., east and west of 166°W), or between the sub-stock components and that of the unit stock classification line. Size at 50% mature for males (all shell condition classes combined) was estimated at 91.9 mm CW, and at 104.4 mm CW for new shell males. By comparison, Zheng and Kruse (1999) used knife-edge maturity at >79 mm CW for females and >112 mm CW for males in development of the current SOA harvest strategy.

g. Mortality

Due to the lack of age information for crab, Somerton (1981a) estimated mortality separately for individual EBS cohorts of immature and adult Tanner crab. Somerton postulated that age five crab (mean CW = 95 mm) were the first cohort to be fully recruited to the NMFS trawl survey sampling gear and estimated an instantaneous natural mortality rate of 0.35 for this size class using catch curve analysis. Using this analysis with two different data sets, Somerton estimated natural mortality rates of adult male crab from the fished stock to range from 0.20 to 0.28. When using CPUE data from the Japanese fishery, estimates of M ranged from 0.13 to 0.18. Somerton concluded that estimates of M from 0.22 to 0.28 obtained from models that used both the survey and fishery data were the most representative.

Rugolo and Turnock (2011) 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 2011). 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 (2011) adopted $M=0.23$ for both male and female Tanner because the value corresponded with the range estimated by Somerton (1981a), as well as the value used in the analysis to estimate new overfishing definitions underlying Amendment 24 to the Crab Fishery Management Plan (NPFMC 2007).

5. *Brief summary of management history. A complete summary of the management history is provided in the ADF&G Area Management Report appended to the annual SAFE.*

Fisheries have historically taken place for Tanner crab throughout their range in Alaska, but currently only the fishery in the EBS is managed under a federal Fishery Management Plan (FMP; NPFMC 1998). The plan defers certain management controls for Tanner crab to the State of Alaska, with federal oversight (Bowers et al. 2008). The State of Alaska manages Tanner crab based on registration areas divided into districts. Under the FMP, the state can adjust or further subdivide districts as needed to avoid overharvest in a particular area, change size limits from other stocks in the registration area, change fishing seasons, or encourage exploration (NPFMC 1998).

The Bering Sea District of Tanner crab Registration Area J (Figure 1) includes all waters of the Bering Sea north of Cape Sarichef at 54° 36'N and east of the U.S.-Russia Maritime Boundary Line of 1991. This district is divided into the Eastern and Western Subdistricts at 173°W. The Eastern Subdistrict is further divided at the Norton Sound Section north of the latitude of Cape Romanzof and east of 168°W and the General Section to the south and west of the Norton Sound Section (Bowers et al. 2008).

In March 2011, the Alaska Board of Fisheries approved a new minimum size limit strategy for Tanner crab effective for the 2011/12 fishery. Prior to this change, the minimum legal size limit was 5.5" (138 mm CW) throughout the Bering Sea District. The new regulations established different minimum size limits east and west of 166° W. The minimum size limit for the fishery to the east of 166°W is now 4.8" (122 mm CW) and that to the west is 4.4" (112 mm CW). For economic reasons, fishers may adopt larger minimum sizes for retention of crab in both areas: above 5.5" (138 mm CW) in the east and 5" (>127 mm CW) in the west.

In this report, we will use the terms "east region" and "west region" as shorthand to refer to the regions demarcated by 166°W. We will also use the term "legal males" to refer to male crab \geq 138 mm CW, although this is not strictly correct as it now refers to the industry's "preferred" crab size in the east region.

Landings of Tanner crab in the Japanese pot and tangle net fisheries were reported in the period 1965-1978, peaking at 19.95 thousand t in 1969. The Russian tangle net fishery was prosecuted during 1965-1971 with peak landings in 1969 at 7.08 thousand t. Both the Japanese and Russian Tanner crab fisheries were displaced by the domestic fishery by the late-1970s (Table 1; Figures 2 and 3). Foreign fishing for Tanner crab ended in 1980.

The domestic Tanner crab pot fishery developed rapidly in the mid-1970s (Tables 1 and 2; Figures 2 and 3). Domestic US landings were first reported for Tanner crab in 1968 at 0.46 thousand t taken incidentally to the EBS red king crab fishery (Table 1). Tanner crab was targeted thereafter by the domestic fleet and landings rose sharply in the early 1970s, reaching a high of 30.21 thousand t in 1977/78 (Tables 1 and 2; Figure 2). Landings fell sharply after the peak in 1977/78 through the early 1980s, and domestic fishing was closed in 1985/86 and 1986/87 due to depressed stock status. In 1987/88, the fishery reopened and landings rose again in the late-1980s to a second peak in 1990/91 at 18.19 thousand t, and then fell sharply through the mid-1990s. The domestic Tanner crab fishery was closed between 1996/97 and 2004/05 as a result of conservation concerns regarding depressed stock status. It re-opened in 2005/06 and averaged 0.77 thousand t retained catch between 2005/06-2009/10 (Tables 1 and 2). For the 2010/11-2012/13 seasons, the State of Alaska closed directed commercial fishing for Tanner crab due to estimated female stock metrics being below thresholds adopted in the state harvest strategy. However, these thresholds were met in fall 2013 and the directed fishery was opened in 2013/14. TAC was set at 1,645,000 lbs (746.2 t) for the area west of 166° W and at 1,463,000 lbs (663.6 t) for the area east of 166° W in the State of Alaska's Eastern Subdistrict of Tanner crab Registration Area J. The fisheries opened on October 15 and closed on March 31. On closing, 80.9% (603.5 t) of the TAC had been taken in the

western area while 99.5% (660.6 t) had been taken in the eastern area. Prior to the closures, the retained catch averaged 770 t per year between 2005/06-2009/10.

Bycatch and discard losses of Tanner crab originate from the directed pot fishery, non-directed snow crab and Bristol Bay red king crab pot fisheries, and the groundfish fisheries (Table 3, Fig. 4). In previous assessments, discard mortalities were estimated using post-release handling mortality rates (HM) of 50% for pot fishery discards and 80% for groundfish fishery bycatch (NPFMC 2008). In this assessment, an alternative HM of 32.1% for the pot fisheries is considered based on information presented by D. Urban (AFSC) to the CPT at its May 2014 meeting. Regardless of the HM selected, the pattern of total bycatch/discard losses is similar to that of the retained catch. Bycatch was persistently high during the early-1970s; a subsequent peak mode of discard losses occurred in the early-1990s. In the early-1970s, the groundfish fisheries contributed significantly to total bycatch losses. The combined crab pot fisheries are the principal source of contemporary non-retained losses to the stock when the older value for handling mortality in the pot fisheries is used, but the groundfish fisheries remain the principal source if the new value is used.

D. Data

1. Summary of new information

No new data sources were incorporated into this assessment. Much of the crab fishery data since 1990 has been recalculated (see Appendix 1). Retained size frequencies in the directed fishery were recalculated for 1990/91-2009/10 and updated for 2013/14. Effort data in the crab fisheries was recalculated for 1990/91-2012/13 from fish ticket data by D. Pengilly (ADFG) to better apportion it among fisheries. Effort data was also updated for 2013/14. Bycatch time series for the crab fisheries, based on at-sea crab fishery observer data, were recalculated for 1992/93-2012/13, as were annual total at-sea size compositions. Tanner crab bycatch time series in the groundfish fisheries were recalculated for 2009/10-2012/13 using new methods for expanding groundfish observer data to unobserved catch based on state statistical reporting areas (Appendix 2). New groundfish bycatch estimates for 2013/14 also use this new expansion method. Bycatch size frequencies in the groundfish fisheries were recalculated for 1973/74-2012/13 based on the crab fishing year (July 1-June 30) rather than the groundfish year (Jan. 1- Dec. 1). Abundance, biomass and size frequency estimates from the 2014 NMFS EBS bottom trawl survey were also added to the assessment. The following table summarizes existing data sources that have been updated for this assessment:

Updated data sources.

Data source	Data types	Time frame	Notes	Agency
NMFS EBS Bottom Trawl Survey	abundance, size compositions	2014	new	NMFS
Directed fishery	retained catch (numbers, biomass)	2013/14	new	ADFG
	size compositions	1990/91-2013/14	recalculated, new	ADFG
	effort	1990/91-2013/14	recalculated, new	ADFG
	total catch, discards (biomass)	1992/93-2013/14	recalculated, new	ADFG
Snow Crab Fishery	size compositions	1991/92-2013/14	recalculated, new	ADFG
	effort	1990/91-2013/14	recalculated, new	ADFG
	total catch, discards (biomass)	1992/93-2013/14	recalculated, new	ADFG
Bristol Bay Red King Crab Fishery	size compositions	1992/93-2013/14	recalculated, new	ADFG
	effort	1990/91-2013/14	recalculated, new	ADFG
	total catch, discards (biomass)	1992/93-2013/14	recalculated, new	ADFG
Groundfish Fisheries	size compositions	1992/93-2013/14	recalculated, new	ADFG
	total catch, discards (biomass)	2009/10-2013/14	recalculated, new	NMFS
	size compositions	1973/74-2013/14	recalculated, new	NMFS

2. Data presented as time series

For the stock biomass and fishery data presented in this document, the convention is that ‘year’ refers to the year in which the NMFS bottom trawl survey was conducted (nominally July 1, yyyy), and fishery data are those subsequent to the survey (July 1, yyyy to June 30, yyyy+1)--e.g., 2008/09 indicates the 2008 bottom trawl survey and the winter 2008/09 fishery.

a. Total catch

Retained catch (1000’s t) in the directed fisheries for Tanner crab conducted by the foreign fisheries (Japan and Russia) and the domestic fleet, starting in 1965/66, is presented in Table 1 (and Fig.s 2, 3) by fishery year. More detailed information on retained catch in the directed domestic pot fishery is provided in Table 2, which lists total annual catches in numbers of crab and biomass (in lbs), as well as the SOA’s Guideline Harvest Level (GHL) or Total Allowable Catch (TAC), number of vessels participating in the directed fishery, and the fishery season. Information from the Community Development Quota (CDQ) is included in the totals starting in 2005/06.

b. Information on bycatch and discards

Annual discards (1000’s t) of Tanner crab by sex are provided in Table 3 (and Fig.s 4, 5) from crab observer sampling, starting in 1992/93 for the directed Tanner crab fishery, the snow crab fishery, and the BBRKC fishery. Annual discards for the groundfish fisheries are also provided starting in 1973/74, but sex is undifferentiated.

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

Retained (male) catch at size in the directed Tanner crab fishery from landings data is presented in Figure 6 by fishery region for the most recent fishery periods from 2005/06-2013/14. Size compositions of total catch (retained + discards) from at-sea crab fishery observer sampling are presented by shell condition and fishery region in Fig. 7 for male crab and in Fig. 8 for female crab. Size compositions for bycatch in the snow crab fishery from at-sea crab fishery observer sampling are presented by shell condition in Fig. 9 for male Tanner crab and in Fig. 10 for females. Figures 11 and 12 present similar information for the BBRKC fishery. Figures 13 and 14 present relative catch size composition information from groundfish observer sampling in the groundfish fisheries for undifferentiated males and females, respectively, from 1973/74 to the present. Raw sample sizes (number of individuals measured) for the various fisheries are presented in Tables 4-8.

d. Survey biomass estimates

Annual estimates (1,000’s t) of mature biomass by sex from the summertime NMFS bottom trawl survey are given in Table 9 (and plotted in Fig. 15), as is abundance (numbers) of “legal” crab (≥ 138 mm CW). Survey estimates for mature male biomass, total mature biomass, and “legal” male abundance increased from 2013 to 2014 by 23%, 17%, and 34% respectively, while estimates for mature female biomass declined by 17% (Fig. 16).

e. Survey catch-at-length

Plots of survey catch-at-size are presented for male and female crab in Fig.s 17 and 18, respectively, by shell condition and fishery region. Sample sizes for these size compositions are presented in Table 10.

f. Other time series data.

The spatial patterns of abundance in the 2010-2013 NMFS bottom trawl surveys are plotted in Fig.s 19-23 for immature males, mature males, “legal” males, immature females, and mature females, respectively. A table of annual effort (number of potlifts) is provided for the snow crab and BBRKC fisheries (Table 11).

3. Data which may be aggregated over time:

a. Growth-per-molt

Sex-specific growth curves derived by Rugolo and Turnock (2010) are presented in Fig. 24. These curves provide the basis for priors on sex-specific growth estimated within the assessment model.

b. Weight-at size

Weight-at-size curves used in the assessment model for males, immature females, and mature females are presented in Fig. 25.

c. Size distribution at recruitment

The assumed size distribution for recruits to the population in the assessment model is presented in Fig. 26.

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

None.

E. Analytic Approach

1. History of modeling approaches for this stock

Prior to the 2012 stock assessment, Tanner crab was managed as a Tier-4 stock using a survey-based assessment approach (Rugolo and Turnock 2011b). The Tier 3 Tanner Crab Stock Assessment Model (TCSAM) was developed by Rugolo and Turnock and presented for review in February 2011 to the Crab Modeling Workshop (Martel and Stram 2011), to the SSC in March 2011, to the CPT in May 2011, and to the CPT and SSC in September 2011. The model was revised after May 2011 and the report to the CPT in September 2011 (Rugolo and Turnock 2011a) described the developments in the model per recommendations of the CPT, SSC and Crab Modeling Workshop through September 2011. In January 2012, the TCSAM was reviewed at a second Crab Modeling Workshop. Model revisions were made during the Workshop based on consensus recommendations. The model resulting from the Workshop was presented to the SSC in January 2012. Review findings and recommendations by the January 2012 Workshop and 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, 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. In the process, I have found a few minor coding errors that do not appear to have had a substantial impact on model performance. A new description of the 2013 model (TCSAM2013) is presented in Appendix 3.

2. Model Description

a. Overall modeling approach

TCSAM is a stage/size-based population dynamics model that incorporates sex (male, female), shell condition (new shell, old shell), and maturity (immature, mature) as different categories into which the overall stock is divided on a size-specific basis. For details of the model, the reader is referred to Appendix 3 and Rugolo and Turnock (2012b).

In brief, crab enter the modeled population as recruits following the size distribution in Fig. 26. An equal (50:50) sex ratio is assumed at recruitment, and all recruits begin as immature, new shell crab. Within a model year, new shell, immature recruits are added to the population numbers-at-sex/shell condition/maturity state/size remaining on July 1 from the previous year. These are then projected forward to Feb. 15 ($\delta t = 0.625$ yr) and reduced for the interim effects of natural mortality. Subsequently, the various fisheries that either target Tanner crab or catch them as bycatch are prosecuted as pulse fisheries (i.e., instantaneously). Catch by sex/shell condition/maturity state/size in the directed Tanner crab, snow crab, BBRKC, and groundfish fisheries is calculated based on fishery-specific stage/size-based selectivity curves and fully-selected fishing mortalities and removed from the population. The numbers of surviving immature, new shell crab that will molt to maturity are then calculated based on sex/size-specific probabilities of maturing, and growth (via molt) is calculated for all surviving new shell crab. Crab that were new shell, mature crab become old shell, mature crab (i.e., they don't molt) and old shell crab remain old shell. Population numbers are then adjusted for the effects of maturation, growth, and change in shell condition. Finally, population numbers are reduced for the effects of natural mortality operating from Feb. 15 to July 1 ($\delta t = 0.375$ yr) to calculate the population numbers (prior to recruitment) on July 1.

Model parameters are estimated using a maximum likelihood approach, with Bayesian-like priors on some parameters and penalties for smoothness and regularity on others. Data components entering the likelihood include fits to survey biomass, survey size compositions, retained catch, retained catch size compositions, discard mortality in the bycatch fisheries, and discard size compositions in the bycatch fisheries (see Appendix 3).

b. Changes since the previous assessment.

Following the January 2014 Crab Modeling Workshop, it was realized that the equations describing fishing mortality and retention in TCSAM2013 were not the same as those being implemented in the Generalized Model for Alaskan Crab Stocks (Gmacs). Gmacs is intended to be a generalized framework for developing crab stock assessment models. Although the fishing mortality equations implemented in the current Tanner crab model (TCSAM2013) represent a workable description of the fishing mortality process, the interpretation of the retention function in the Tanner crab model and in Gmacs are inconsistent with one another. The retention function used in Gmacs represents a simple and intuitive description of the on-deck process of retention and discarding whereas the one used in the Tanner crab model does not (Appendix 4). An alternative version of the Tanner crab model implementing the Gmacs equations (TCSAM-FRev) was developed by modifying a copy of the TCSAM2013 code in Spring 2014, with results from initial model runs presented to the CPT in May. Following this, the CPT requested that model runs based on TCSAM-FRev would be presented at the September 2014 as alternative models on which to base status determination and OFL calculation.

The TCSAM2013 code has also been modified with options to: 1) provide jittering of initial parameter values (as a basis for automating the testing model convergence from multiple starting parameter value sets); 2) estimate ln-scale female offset parameters to fully-selected male fishing mortality rates, 3) “anchor” selectivity functions by fixing fully-selected sizes, and 4) implement phase-specific reductions on the weights used for various penalties in the likelihood function. These options were also incorporated in the TCSAM-FRev code. Initial model explorations using options 2-4 typically resulted in

unsatisfactory model convergence properties and are not discussed further. However, these options deserve to be more fully explored in the future.

As part of revising the size frequencies for bycatch in the groundfish fisheries, it was realized that the input sample sizes previously used for fitting these data had inadvertently been switched for males and females. This error was propagated through both the 2012 and 2013 assessments. One impact that correcting this error has on the assessment is that the parameter estimating size at 50%-selection for total selectivity on males in the directed fishery in 1996 is now driven to its lower bound. The sample sizes associated with catch size frequencies in the 1996 directed fishery are quite small (less than 3, Table 5), which means there is very little penalty in the overall likelihood for poorly fitting this data, even though it results in a very poor fit to the data and an unreasonably small value for the parameter. The error in sample sizes is included in scenarios that use the “2013 data” and corrected in scenarios that use the 2014 recalculated data.

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

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

3. Model Selection and Evaluation

a. Description of alternative model configurations

The following ten alternative model configurations were considered in this assessment:

Model Scenario	Model converged?	Handling Mortality	Data	Model Type	Model Options
Alt0a	yes	50.0%	2013 data + 2014	TCSAM2013	base model: same as 2013 model
Alt0b	yes	32.1%	2013 data + 2014	TCSAM2013	base model
Alt1a	yes	50.0%	2014 revised data	TCSAM2013	base model with sample sizes corrected for groundfish bycatch size frequencies
Alt1b	yes	32.1%	2014 revised data	TCSAM2013	base model with sample sizes corrected for groundfish bycatch size frequencies
Alt2a	no	50.0%	2014 revised data	TCSAM-FRev	options same as base TCSAM2013 model with corrected sample sizes
Alt2b	no	32.1%	2014 revised data	TCSAM-FRev	options same as base TCSAM2013 model with corrected sample sizes
Alt2c	no	50.0%	2014 revised data	TCSAM-FRev	increased weights on fitting 1996 directed fishery discards
Alt2d	no	32.1%	2014 revised data	TCSAM-FRev	increased weights on fitting 1996 directed fishery discards
Alt3a	no	50.0%	2014 revised data	TCSAM-FRev	In-scale female fishing mortality offsets estimated
Alt3b	no	32.1%	2014 revised data	TCSAM-FRev	In-scale female fishing mortality offsets estimated

Model scenario Alt0a (this year’s base model) represents last year’s accepted model (referred to subsequently as the “2013 Model”) updated with only the new data for 2013/14 (2013/14 retained catch numbers, biomass and size frequencies; 2013/14 bycatch biomass and size frequencies in the crab and groundfish fisheries; 2014 trawl survey abundance, biomass, and size frequencies). Scenario Alt0b uses the new handling mortality rate for pot fisheries to convert discard biomass to discard mortality, but is otherwise identical to Alt0a. Scenarios Alt1a and Alt1b incorporate the recalculated size frequencies from the dockside and at-sea observer sampling in the crab and groundfish fisheries, recalculated effort data in the crab fisheries, and recalculated discard biomass in the crab and groundfish fisheries as well as the new data for 2013/14. The model used to fit the data in the “Alt1-” scenarios is otherwise identical to that used to fit the “Alt 0-” scenarios (and the 2013 Model) except that the input sample sizes used for bycatch size frequencies for the groundfish fisheries have been corrected.

The “Alt2-” and “Alt3-” scenarios fit the TCSAM-FRev model, which incorporates the Gmacs fishing mortality equations, to the recalculated data with several different options. However, none of these latter scenarios resulted in converged models. Results presented at the May CPT meeting were initially encouraging, although concerns regarding model convergence were raised at the meeting. Subsequently these models displayed rather poor convergence properties and none achieved satisfactory convergence. Further modifications to the code implementing jittering of initial parameter values, In-scale offsets for

females to fully-selected male fishing mortality rates, “anchoring” selectivity functions by fixing fully-selected sizes, and phase-specific weight reductions on penalties in the likelihood function were unsuccessful at achieving converged models, as well. These results probably stem from an unsuccessful attempt to graft, as a shortcut, the Gmacs fishing mortality equations onto the TCSAM2013 model framework. Due to time constraints in preparing this SAFE chapter, results from these model runs will not be discussed further.

After careful consideration, model scenario Alt1a emerged as the author’s preferred model.

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

Parameter values from the model scenarios are compared in Table 12 for the previous assessment model (2013 Model) and the four alternative models that converged. Parameter bounds, initial estimation phase, valid indices, type and name in the corresponding TCSAM2013 code are also listed. Estimates from the 2013 Model and Alt0a (the base 2014 model) are reasonably similar (within one standard deviation of the 2013 Model estimate) for most parameters, the exceptions being the 2013 recruitment deviation (pRevDevs for 2013), the size at 50%-selected for females in the BBRKC fishery in time stanza 1 (“rkfish_disc_sel50_f1” in Table 12), the slope and size at 50% selected for females in the groundfish fisheries in the “current” time stanza (fish_disc_slope_tf3, fish_disc_sel50_tf3), and the size at 50% selected for males in the groundfish fisheries in the “current” time stanza (fish_disc_sel50_tm3). The difference in the 2013 recruitment deviation is not unexpected because there was little information (only the 2013 trawl survey) to inform this estimate last year whereas it is now based on 2 surveys.

Parameter values that were at their bounds in the 2013 Model (highlighted in Table 12) similarly hit their bounds in Alt0a. Sizes at 50%-selected also hit their bounds in Alt1a for female bycatch in the BBRKC fishery in time stanzas 1 and 2 (rk_disc_sel50_f1, rk_disc_sel50_f2).

Considering Alt0b, the following parameters were located at one of their bounds in the converged model but not in the 2013 Model or Alt0b: the scalar growth parameter for females (af1) and the ln-scale deviation to size at 50%-selected in the directed fishery corresponding to 1996 (log_sel50_dev_3, index 6). This was also the case for the Alt1a and b scenarios, as well. The af1 parameter was also fairly close to (but not at) its upper bound (0.70) for both the 2013 Model and tAlt0b (0.688) and is not really statistically different from the latter estimates (the estimated standard deviations on the latter were 0.05). The ln-scale deviation to mean size at 50%-selected was at its lower limit (-0.5). The corresponding sample sizes for the 1996 directed fishery total catch size frequencies are quite small (< 3), which puts very little constraint on this parameter in the fitting process. For the Alt1- scenarios, the change to the lower limit was traced back to correcting the legacy input sample sizes to the groundfish bycatch size frequencies for a male/female switch made prior to the 2012 assessment. That Alt0b ends up in the same place for this parameter, with only pot fishery handling mortality changed reinforces the inherent uncertainty associated with this parameter.

Parameters that were substantially different between Alt0b and Alt0a (regarded as the new base) included: the multiplier on mature female natural mortality (Mmult_f), several ln-scale deviations to total (retained+discards) mean fishing mortality in the directed fishery (pFmDevsTCF) in the early 1990s (years with substantial bycatch, which the change in handling mortality would impact as far as total mortality was concerned), several ln-scale deviations to discard mortality in the groundfish fisheries in the early 1990s (pFmDevsGTF), the average ln-scale discard mortality in the snow crab fishery (pAvgLnFmSCF), the ln-scale average (1991/92-2013/14) size at 50% selected in the directed fishery (log_avg_sel50_3), all the annual ln-scale deviations from the log_avg_sel50_3 (log_sel50_dev_3), and parameters affecting the slope and size at 50% selected for the bycatch selectivity curves in the groundfish fishery, survey q in survey time stanzas 2 and 3 (srv2_q and srv3_q), and size at 50% selected for females in the trawl survey in survey time stanza 3 (srv3_sel50_f).

Considering Alt1a, which used the revised fishery data but the old pot fishery handling mortality, it exhibited results similar to Alt0b in terms of the parameters that ended up at one of their bounds. The size at 50% selected in time stanza 1 for male bycatch in the BBRKC fishery (rkfish_disc_sel50_m1) additionally ended up at its upper bound, as did size at 50%-selected for female bycatch in time stanza 1 in the groundfish fisheries (fish_disc_sel50_tf1). However, 50% selectivity for female bycatch time stanza 2 in the groundfish fisheries (fish_disc_sel50_tf2) was estimated well inside the bounds in Alt1a as opposed to Alt0b.

Parameter values that were substantially different between Alt1a and Alt0a (regarded as the base from which to identify changes due solely to the re-calculated fishery data), parameters that were substantially different between the two included: the natural mortality multiplier for mature females during the enhanced mortality period (1980-84; mat_big[1]), ln-scale deviations to total (retained+discards) mean fishing mortality in the directed fishery (pFmDevsTCF) corresponding to the early 1990s and 1996, several ln-scale deviations to discard mortality in the groundfish fisheries in the early 1990s (pFmDevsGTF), the ln-scale mean bycatch mortality rate in the groundfish fisheries (pAvgLnFmGTF) and deviations corresponding to 1991 and 1992, the ln-scale average size at 50% selected in the directed fishery (log_avg_sel50_3), all the annual ln-scale deviations from the log_avg_sel50_3 (log_sel50_dev_3), and some of the parameters affecting the bycatch selectivity curves in the snow crab, BBRKC, and groundfish fisheries.

Finally, Alt1b exhibited results similar to Alt1a in terms of parameters that ended up at one of their bounds, except that rkfish_disc_sel50_f2 (size at 50% selected for female bycatch in time stanza 2 for the BBRKC fishery) was well-estimated in the interior of the parameter domain.

Parameter values that were substantially different between Alt1b and Alt1a (regarded as the base to distinguish changes due only to the change in handling mortality) included: ln-scale mean recruitment post 1973 (pAvgLnRec), the ln-scale mean bycatch fishing mortality in the snow crab fishery (pAvgLnFmSCF) and several associated devs (pFmDevsSCF, not unexpected given the different handling mortality values used in the two models), and some parameters influencing bycatch selectivity curves in the snow crab and BBRKC pot fisheries.

Overall, however, time series results from the four model scenarios and the 2013 Model are remarkably similar (Tables 13-18 and Figures 27-37) in most cases. Changes in the data (Alt0- scenarios vs Alt1- scenarios) and in assumed pot fishery handling mortality (Alt-a scenarios vs. Alt-b scenarios) appear to have relatively little impact on many of the estimated time series. All four model scenarios estimated somewhat lower recruitment for 2013 than the 2013 Model did, and all estimated slightly higher recruitment in 2014 than in 2013 (Fig. 27, Table 13; with the caveat that model-end estimates of recruitment are highly uncertain). Estimates of fully-selected fishing mortality (including discards) and retention rates in the directed fishery are quite similar, as well (Figures 28 and 29). Estimates of MMB (at mating time; Table 14 and Figure 30) are also quite similar across the modeled time period: the trajectories are very similar, although they differ as to the magnitude of MMB across the main peak in MMB during the mid-1970s. Final MMB differs by less than 10% across the models. Estimates of the time series of the numbers of male crab ≥ 138 mm CW in the survey (Table 15, Figure 31) differ by less than 5% over the final 20 years of the model runs.

Time series where differences are more evident occur for quantities directly related to bycatch mortality, such as the fully-selected fishing mortality rates in the snow crab (Figure 32) and groundfish fisheries (Figure 34). This is a direct consequence of different assumed pot fishery handling mortalities between the “a” and “b” models. The differences are not very apparent in the results for the BBRKC fisheries because fishing mortality for this bycatch fishery is fixed (or estimated from fishing effort) across most of the time period (Figure 33). The behavior of the fully-selected fishing mortality rate for bycatch in the

groundfish fisheries is interesting in that the models with decreased handling mortality in the pot fisheries (Alt0b, Alt1b) exhibit higher bycatch fishing mortality rates in the groundfish fisheries.

The four models follow very similar trajectories and appear to fit retained catch in the directed fishery equally well (Table 16, Figure 35), except in 1996 where all the models except Alt0a (and the 2013 Model) under-estimate the observed retained catch (0.82 thousand t) by nearly 50%. This latter deficiency presumably relates to the models' inability to estimate the size at 50% selected in the directed fishery in 1996, as well.

Fits to total mortality for males in the directed fishery are biased slightly high for all models (Table 17, Figure 36). Fits to discard mortality for females in the directed fishery are relatively poor for all models (Table 18, Figure 37). This is not terribly surprising given that annual rates of fully-selected fishing mortality on females in the directed fishery are assumed to be the same as for males (and given patterns of spatial aggregation of males and females there may be good reason not to make this assumption).

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

No such search was conducted for this assessment.

d. Convergence status and convergence criteria

Convergence in all models was assessed by running each model iteratively from a set of initial parameter configurations. Following an initial run, the final parameter estimates from the run were used as initial parameter estimates in a following run and this sequence was repeated until the final objective function value obtained was identical to that from the previous run (generally four times). The final model (with the smallest objective function value) was selected as the "converged" model if it was possible to invert the associated hessian and obtain standard deviation estimates for parameter values. For a subset of the models, this approach was checked by generating 50 randomly-chosen initial parameter settings, running the model for each setting, and checking that the minimum objective function among the 50 model runs was no smaller than that final model run selected using the iterative procedure. This latter procedure was also used to try to find convergent models for those in which the iterative procedure failed to produce a run with a valid model hessian.

e. Sample sizes assumed for the compositional data

Sample sizes assumed for compositional data used in the Alt1- models are listed in Tables 4-8 for fishery-related size compositions. Sample sizes for all survey size compositions were set to 200, which was also the maximum allowed for the fishery-related sample sizes. Otherwise, input sample sizes were scaled using

$$SS_y^{inp} = \min\left(200, \frac{SS_y}{(\overline{SS}/200)}\right)$$

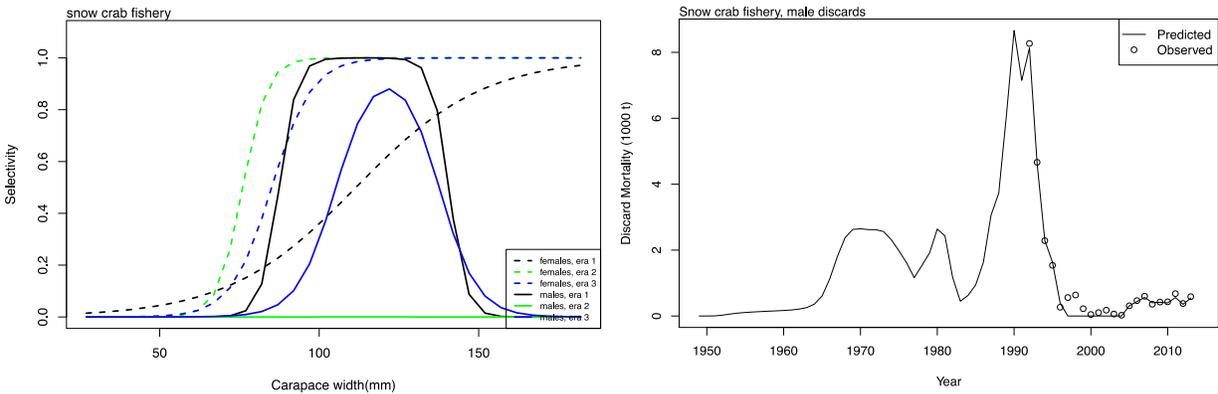
where \overline{SS} was the mean sample size for all males from dockside sampling in the directed fishery. Input sample sizes for all the Alt1- model size compositions are compared in Figure 38.

f. Parameter sensibility

Most model parameter estimates obtained from the alternative models appear to be reasonable, or at least consistent with the 2013 Model. One notable exception is the estimate for the ln-scale deviation from mean size at 50%-selected for males in the directed fishery ($\log_sel50_dev_3$, index 6) for 1996, which hits the lower bounds put on the parameter (-0.5) in models Alt0b, Alt1a, and Alt1b. This results in an unreasonably small estimate (~75 mm CW) for size at 50%-selected in 1996 in the directed fishery. The factors apparently responsible for this result are: 1) the very small input sample sizes associated with total

catch size frequencies in the directed fishery for 1996 (< 3) and 2) the incorrect input sample sizes previously used for bycatch size frequencies in the groundfish fisheries.

The other notable exception is the estimate for size at 50% selected on the downward sloping limb of the double-logistic bycatch selectivity curve for males during 1997-2004 in the snow crab fishery (snowfish_disc_sel50_m2_2) for model Alt1b. The value for this parameter is 94.9 mm CW, which is quite a bit less than the corresponding parameter for the ascending arm (snowfish_disc_sel50_m_2), which is 139 mm CW. The implications for this are illustrated in the two plots below. The lefthand plot shows the bycatch selectivity curves estimated by Alt1b for the snow crab fishery (the horizontal green line at the bottom is male bycatch selectivity during 1997-2004). The righthand plot shows the corresponding fit to the discard data (note the flat line at 0 for 1997-2004):



The result is that male bycatch in the snow crab fishery is estimated as nearly 0 during 1997-2004. To some extent, this result is due to a poor parameterization of the double-logistic which does not guarantee that the size at 50% selected on the descending limb is larger than that on the ascending limb. It may also be a consequence of formulating the likelihood for bycatch in the snow crab fishery using an assumption of normally-distributed errors with constant variance, as opposed to an assumption of lognormally distributed errors.

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

Criteria used to evaluate the alternative models included: 1) data reliability, 2) goodness of fit and likelihood criteria, 3) parameter sensibility, and 4) biological realism.

h. Residual analysis

Residual analysis for the preferred model is presented below. Residual analysis for the four alternative models is available online at the CPT archive website¹. Residuals for the author’s preferred model are discussed below under the Results section.

i. Evaluation of the model(s)

The two “Alt0-” models were not considered as possible preferred models because: 1) they were based on incorrect input sample sizes for bycatch size frequencies in the groundfish fisheries and 2) because they were fit to data that has subsequently been recalculated and revised. However, Table 19 and Figure 39, which present a comparison of components in the objective function for the two models, are included for the sake of completeness.

Considering goodness of fit and likelihood criteria, model Alt1a fits the data better in an overall sense compared with Alt1b by 6 likelihood units (Table 20, Figure 40), but not for every component in the

¹ http://legistar2.granicus.com/npfmc/meetings/2014/9/898_A_Crab_Plan_Team_14-09-15_Meeting_Agenda.pdf

objective function. Although it is not strictly valid, as was done in the table and figure, to directly compare the overall likelihoods and some of the components because they essentially involve fits to different data because different values for pot fishery handling mortality are applied to the discard data, in this case one *can* conclude that Alt1a fits the data better, and better than the difference in objective function values suggests, because it is based on the larger value for pot fishery handling mortality (and thus one would expect larger differences between observed and estimated values). Alt1a fits much better than Alt1b to size frequencies and catch mortality for retained males and all males from the directed fishery, as well as for size frequencies for immature males in the trawl survey. Alt1a fits more poorly than Alt1b for mature males, immature females and mature females for trawl survey size frequencies. It appears to fit more poorly for female bycatch mortality in the directed fishery, and for total bycatch mortality in the BBRKC fishery, but these comparisons are affected by the difference in assumed handling mortality in the pot fisheries.

The pot fishery handling mortality used in model Alt1b is presumably more biologically realistic than that in Alt1a, given that it is based on the new value of 32.1% for handling mortality in the pot fisheries—which in turn is based on a substantial body of evidence (at least regarding short term mortality). However, the author feels that Alt1a results in a better-than-moderately better fit to the data than Alt1b. Additionally, its estimated parameter values are the more reasonable of the two, given the rather nonsensical result obtained for male bycatch selectivity curves in the snow crab fishery using Alt1b (as illustrated above).

4. Results (best model(s))

Model Alt1a, which uses the recalculated data and the old estimate for handling mortality in the crab fisheries, is the author's preferred model and is considered the "best" model.

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

Input sample sizes for the various fishery-related size compositions are given in Tables 4-8 and Figure 38. Input sample sizes for all survey-related size compositions were set to 200. Weighting factors for likelihood components and penalties are listed in Table 20, as are the associated objective function values from the converged model.

b. Tables of estimates:

i. All parameters

Parameter estimates and associated standard errors, based on inversion of the converged model's Hessian, are listed in Table 12.

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

Estimates of MMB are listed in Table 14. Estimates of the number of "legal" males (≥ 138 mm CW) are listed in Table 15. Numbers at size for males and females are given by year in 5 mm CW size bins in Tables 21 and 22, respectively.

iii. Recruitment time series

The estimated recruitment time series is listed in Table 13 and plotted in Figure 27.

iv. Time series of catch divided by biomass.

Catch divided by biomass (i.e., exploitation rate) is plotted for the author's preferred model (Fig. 41).

c. Graphs of estimates

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

Model-estimated growth curves from last year's model and the author's preferred model (Alt1a) are compared with empirical curves developed from growth data on tanner crab in the GOA near Kodiak Island are shown in Figure 42. The model-estimated female growth is almost identical to that from Kodiak, while the model-estimated male growth curve suggests that molt increments are larger in the EBS than in the GOA. Model-estimated sex-specific probabilities at size of immature crab molting to maturity are compared in Figure 43. The curve for males suggests an unlikely decline at the largest sizes, but it not constrained to increase. In addition, size bins for which the curve is 1 (or 0) have corresponding parameter estimates that are on the upper (lower) boundary of the range of allowable values. This does not seem to affect model convergence or its ability to estimate standard deviations, which would ordinarily be a concern under such circumstances.

Estimates of natural mortality by sex and maturity state are shown in Figure 44. Mortality rates are assumed equal by sex for immature crab, but are allowed to be different 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 (Jie et al., 2012) and was identified as a separate period for Tanner crab in the 2012 assessment. The values estimated by the author's preferred model are similar to those estimated in the 2013 assessment model, except for mature females during the 1980-84 time period. The estimated "normal" values were 0.25 for immature crab, 0.34 for mature females and 0.25 for mature males from the previous assessment while the Alt1b model estimates were 0.25 for immature crab, 0.33 for mature females, and 0.26 for mature males. The values estimated for mature crab during the "high mortality" period from the previous assessment were 0.31 for females and 0.73 for males while the Alt1a estimates were 0.36 for females (an increase, rather than a decrease, in M) and 0.65 for males (slightly smaller, but well within the confidence bounds).

The major difference in estimated total selectivity curves for males in the directed fishery between the previous assessment and the author's preferred model is the curve for 1996, which shifted toward much smaller sizes at 50% selected in the preferred model compared with last year's assessment model (Fig. 45). Otherwise the curves are fairly similar. Comparing curves from the most recent fisheries, the 2013/14 selectivity curve is shifter to the right (larger sizes) of curves for 2005/06, 2006/07, and 2007/08 but is shifted to the left of those for 2008/09 and 2009/10. Retained selectivity shows a much narrower range over time, with only the curve for 2009/10 standing out from the rest. This may reflect the closure of the area west of 166° W to fishing in 2009/10, because crab tend to be larger in the eastern area.

Estimated bycatch selectivity curves for males and females are shown in Fig. 46 for the snow crab fishery, in Fig. 47 for the BBRKC fishery, and in Fig. 48 for the groundfish fisheries. Separate curves are estimated for 3 different time periods for each fishery, corresponding to changes in available data and fishery activity. For the snow crab fishery, separate sex-specific curves are estimated for 1989/90-1996/97, 1997/98-2004/05, and 2005/06-present. The time periods are the same for the BBRKC fishery. The directed Tanner crab fishery was closed during 1997/98-2004/05, which may have encouraged changes in how the snow crab and BBRKC fisheries were prosecuted—with associated changes in bycatch selectivity on Tanner crab. For the groundfish fisheries, the three time periods corresponding to the selectivity curves are 1973-1987, 1988-1996, and 1997-present. These correspond to changes in the groundfish fleets and Tanner crab fishery, with the curtailment of foreign and joint-venture fishing by 1988, the expansion of domestic fisheries from 1988 to 1996, and the closure of the tanner crab fishery in 1996/97.

The estimated selectivity curves for the snow crab fishery from Alt0b are similar to those from the 2013 Model for both sexes (Figure 46). The estimated selectivity curves for the BBRKC fishery are generally shifted toward the right, such that only the largest size classes for both sexes are fully selected (Figure 47). In fact, the selectivity on females is close to (but not) zero through most of the size range for females in the population. This may reflect differences in sex/size-specific bycatch fishing mortality in the BBRKC fishery such that the largest females and similarly-sized males are not subject to the same fishing mortality, as is assumed in the model by applying a fully-selected fishing mortality equally to selectivity curves for both sexes. If such were the case, the model might achieve a “better” fit to data by adjusting either the slope or location parameter (size at 50% selected) such that selectivity on females was less than 1 across the range of sizes found in the data. The other models (see online material) exhibit similar results in regards to selectivity in the BBRKC fishery. A possible solution to this confounding would be fix sex-specific sizes for “fully-selected” animals in each fishery within observed size ranges and then estimate female-specific offsets to male “fully-selected” fishing mortality.

A similar phenomenon may be occurring in the groundfish selectivity curves for Alt1a (Figure 48), but with effects seen on the slope of the curves for females rather on size at 50% selected. For Alt1a, the slopes of the female selectivity curves are such that the curves never reach 1 (fully-selected) within the model’s size range (the largest size bin corresponds to 182.5 mm CW). This did not occur in the 2013 Model, but the difference can be traced, at least in part, to the extra emphasis placed on fitting the female bycatch size compositions as a result of the switch in input sample sizes between male and female groundfish bycatch size compositions (the true male sample sizes were always several times larger than the corresponding female ones).

Estimated survey selectivity curves for males and females in three time periods (1974-1981, 1982-1987, and 1988-present) are shown in Fig. 49, together with the selectivity curves inferred from Somerton’s “underbag” experiments (Somerton and Otto, 1999). The curves are quite similar to those obtained by the 2013 Model.

iii. Estimated full selection F over time

The trajectory of full selection fishing mortality in the directed fishery (Fig. 50) estimated by Alt1a is similar to that estimated by the 2013 Model. It peaked in 1980 at a value larger than 2, then rapidly declined and was at low levels in the mid-1980s. It peaked again in 1993 and subsequently declined to low levels (when the fishery was open). Exploitation rates (catch/biomass) in the directed fishery for total catch and legal-sized males followed similar trends (Fig. 41), with exploitation rates reaching almost 80% on legal males in 1981 and 50% in 1993.

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

Time series of observed biomass of mature crab in the NMFS bottom trawl surveys are compared by sex with model-predicted values in Fig. 51. The model under-predicts mature female survey biomass in the early 1980s and 1990s. It also under-predicts mature male survey biomass in the early 1990s as well as in the mid-2000s. However, this is similar to the results obtained with the 2013 Model. The scale of the standardized log-scale residuals (Fig. 52) indicates a mediocre fit between the model and the data (the standard deviation of the residuals is ~ 2 , whereas ~ 1 would indicate a good fit).

The time series of total mature biomass in the survey is compared to the model-predicted total mature biomass in the survey in Fig. 53. Also plotted is the model-predicted total mature biomass at the time of the survey. The model consistently underestimates total mature biomass as seen in the survey.

The time series of model-predicted MMB (i.e., mature male biomass at the time of mating), mature female biomass at the time of mating, and total mature biomass at the time of mating in Fig. 54. All three time series build relatively slowly from zero in 1949 (when the model starts) until the mid-1960s, when

the spawning stock rapidly builds to a peak in 1972 and just as rapidly declines to a minimum in 1985. It rebuilds somewhat to a much lower peak in 1989 and subsequently declines to a minimum in 1999. Since 1999, MMB has increased rather steadily while mature female biomass at mating time has remained low.

iv. Estimated fishing mortality versus estimated spawning stock biomass

See Section F (Calculation of the OFL).

v. Fit of a stock-recruitment relationship, if feasible.

Not available.

e. Evaluation of the fit to the data:

i. Graphs of the fits to observed and model-predicted catches

The model fit to retained catch in the directed fishery is provided in Fig. 35. The model fit to total male (retained + discarded) catch in the directed fishery is provided in Fig. 36. The model fit to female discard mortality in the directed fishery is shown in Fig. 37. The fits are quite good for males, but less so for females.

ii. Graphs of model fits to survey numbers

Model predictions for total numbers of legal males (≥ 138 mm CW) in the population and in the survey are compared with observations from the survey in Fig. 55 (and Fig. 31). The model over-predict numbers of crab in recent years. Model-estimated numbers of males and females in the survey are compared with observed numbers in Fig. 56. The model under-predicts the decline in survey numbers of both males and females in the mid-1980s and anticipates the subsequent increase in survey numbers to 1990. More recently, the model under-estimates the numbers of both sexes in the survey. The model appears to predict survey numbers of all mature female crab (Fig. 57, bottom graph) and all mature male crab (Fig. 58, bottom graph) reasonably well, but not as sub-components broken into new shell and old shell categories. It also appears to estimate the fraction of mature crab by sex fairly well (Fig. 59).

iii. Graphs of model fits to catch proportions by length

Model-predicted proportions at size for retained males in the directed Tanner crab fishery are presented in Figs 60 and 61. The model appears to fit the observed proportions quite well, except at the smallest retained sizes in the 1980/81-1996/97 time period. The data suggests some sub-legal crab (≤ 138 mm CW) were retained in the 125-130 and 130-135 mm CW bins (although the overall proportions were quite small) and the model under-estimates these proportion relative to that observed. Conversely, the model over-estimates the proportion retained in the 135-140 mm CW size bin (the first size bin in which legal crab at the time would have been observed). This pattern is less apparent in the previous fishery period (2005/06 -2009/10), when the residuals are much smaller. For 2013/14, the model underestimates again the proportions of the smallest retained crab and overestimates the proportion of the most retained. It seems possible that the model's retention function may rise from 0 too steeply to accommodate the pattern seen in the directed fishery.

Model-predicted patterns for the proportion caught-at-size in the directed fishery for all males is shown in Figs 62 and 63. General residual patterns again indicate, but more strongly than with the retained catch, that the fishery catches a larger proportion of smaller crab than predicted by the model and catches fewer larger crab than predicted by the model. Conceivably, among other potential explanations, this pattern may indicate that an asymptotic selectivity curve is inappropriate for the selection process or that the model overestimates growth into the largest size classes for males. 1996 is the exception to this, and exhibits an extremely poor fit to the data. However, as previously noted, the relative weight (input sample size) put on fitting this weight in the likelihood is quite small. It is notable that the fit to the 1996 size composition for females taken in the directed fishery (Figs 64 and 65) is much better. The general pattern

of residuals for females is similar to the general pattern for males. It should be noted, however, that the scale of the residuals for males is larger than that for females.

iv. Graphs of model fits to survey proportions by length

Model fits to observed proportions at size in the annual NMFS trawl survey are shown for males in Figs. 66 and 67 (the latter as a bubble plot) respectively. The model appears to be suitably sensitive to relatively large cohorts recruiting to the model size range (e.g., 1997-2002), but appears to be less able to track strong cohorts through time (the mode in the model proportions at ~100 mm CW in 1982 disappears after two years, but appears to last until at least 1985 in the observed proportions). After 1982, the model tends to under-predict size proportions for males in the 70-120 mm range and over-predict the proportion of large (> 120 mm CW) males after 2000. Model fits to proportions at size in the survey for females are shown in Figs. 68 and 69. The model tends to over-predict proportions-at-size in the 65-85 mm CW range. The patterns of residuals for males and females evinced in the bubble plots (Figs. 67, 69) are almost identical to those obtained from the 2013 model in last year's assessment (Stockhausen et. al., 2013, Fig.s 66 and 68).

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

Model Alt1a-predicted marginal fits of the proportion of crab by size in the directed fishery catch (Fig. 70) are quite good at all sizes for retained males (upper graph) but underestimate the proportions caught for all males (retained and discarded, middle graph) at smaller sizes (< 130 mm CW) and over-estimate the proportion at larger sizes. A similar effect is evident for the model-predicted marginal proportion at size for female bycatch in the directed fishery (Fig. 70, lower graph).

The observed and predicted (Alt1a) marginal proportions of males taken as bycatch in the snow crab fishery are in good agreement at all sizes, while the model tends to underestimate the proportion of females taken as bycatch near the peak proportions (~80-90 mm CW) and over-estimate the proportions at larger sizes (Fig. 71, upper graph). The opposite pattern is true of the proportion-at-size of females taken as bycatch in the BBRKC fishery, where intermediate-size females are over-represented in the model predictions and under-represented at larger sizes (Fig. 71, middle graph). The pattern of model-predicted marginal proportions-at-size for males taken as bycatch in the BBRKC fishery is similar to that found for the snow crab fishery, but shifted to larger sizes by ~20 mm CW. Unfortunately, it presents a poorer fit to the observations, overestimating proportions at larger sizes and underestimating them at smaller sizes, than in the snow crab fishery. These patterns are all quite similar to those obtained with the 2013 Model in last year's assessment.

The patterns of marginal predicted proportions at size for males and females taken in the groundfish fishery (Fig. 71, lower graph) obtained by Alt1a are strikingly different from those obtained by the 2013 Model. As noted last year, the patterns for the 2013 Model "...indicate a sex-specific bias in the fits to the groundfish fisheries size compositions, given that male proportions-at-size are consistently underestimated in the model and female proportions-at-size are almost always overestimated. This may be indicative of model mis-specification or an error in the model code." As noted previously, this was traced to the input sample sizes being switched prior to the 2012 assessment and is corrected in Alt1a. The agreement of between the observed and predicted marginal distributions is much better for Alt1a than for the 2013 Model, although it certainly leaves room for improvement.

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

Not available.

vii. Tables of the RMSEs for the indices (and a comparison with the assumed values for the coefficients of variation assumed for the indices).

Not available.

viii. Quantile-quantile (q-q) plots and histograms of residuals (to the indices and compositional data) to justify the choices of sampling distributions for the data.

Not available.

f. Retrospective and historic analyses (retrospective analyses involve taking the “best” model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments).

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

As currently coded, it is not possible to perform retrospective analyses with the TCSAM in the compressed time span allowed for this assessment. This deficiency will be addressed in the future.

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

Many of the plots contained in this assessment feature comparisons between results from the 2013 assessment model and the author’s preferred model for this assessment. Most of them indicate little difference between the two models, particularly for more recent periods (e.g., since 1990), except where these were explicitly expected (as in the fits to the marginal proportions for bycatch size compositions in the groundfish fisheries).

g. Uncertainty and sensitivity analyses

Not available.

F. Calculation of the OFL and ABC

1. Status determination and OFL calculation

EBS Tanner crab was elevated to Tier 3 status following acceptance of the TCSAM by the CPT and SSC in 2012. Based upon results from the model, the stock was subsequently declared rebuilt and not overfished. Consequently, EBS Tanner crab is assessed as a Tier 3 stock for status determination and OFL setting.

The (total catch) OFL for 2013/14 was 25.35 thousand t while the total catch mortality for 2013/14 was 2.78 thousand t, based on applying discard mortality rates of 0.50 for pot fisheries and 0.8 for the groundfish fisheries to the reported catch by fleet for 2014/15 (Tables 1 and 3). Therefore overfishing did not occur.

Amendment 24 to the NPFMC fishery management plan (NPFMC 2007) revised the definitions for overfishing for EBS crab stocks. The information provided in this assessment is sufficient to estimate overfishing limits for Tanner crab under Tier 3. The OFL control rule for Tier 3 is (see Fig. 73 also):

$B, F_{35\%}, B_{35\%}$	3		
a. $\frac{B}{B_{35\%}^*} > 1$		$F_{OFL} = F_{35\%}^*$	
b. $\beta < \frac{B}{B_{35\%}^*} \leq 1$		$F_{OFL} = F_{35\%}^* \frac{\frac{B}{B_{35\%}^*} - \alpha}{1 - \alpha}$	$ABC \leq (1 - b_y) * OFL$
c. $\frac{B}{B_{35\%}^*} \leq \beta$		Directed fishery $F = 0$ $F_{OFL} \leq F_{MSY}^\dagger$	

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, $\alpha=0.1$ and $\beta=0.25$. For Tanner crab, the proxy for F_{MSY} is $F_{35\%}$, the fishing mortality that reduces the SBPR to 35% of its value for an unfished stock. Thus, if $\phi(F)$ is the SBPR at fishing mortality F , then $F_{35\%}$ is the value of fishing mortality that yields $\phi(F) = 0.35 \cdot \phi(0)$. The Tier 3 proxy for B_{MSY} is $B_{35\%}$, the equilibrium biomass achieved when fishing at $F_{35\%}$, where $B_{35\%}$ is simply 35% of the unfished stock biomass. Given an estimate of average recruitment \bar{R} , $B_{35\%} = 0.35 \cdot \bar{R} \cdot \phi(0)$.

Thus Tier 3 status determination and OFL setting for 2014/15 require estimates of $B = MMB_{2014/15}$ (the projected MMB at mating time for the coming year), $F_{35\%}$, spawning biomass per recruit in an unfished stock ($\phi(0)$), and \bar{R} . Current stock status is determined by the ratio $B/B_{35\%}$ for Tier 3 stocks. If the ratio is greater than 1, then the stock falls into Tier 3a and $F_{OFL} = F_{35\%}$. If the ratio is less than one but greater than β , then the stock falls into Tier 3b and F_{OFL} is reduced from $F_{35\%}$ following the descending limb of the control rule (Fig. 73). If the ratio is less than β , then the stock falls into Tier 3c and directed fishing must cease. In addition, if B is less than $\frac{1}{2} B_{35\%}$ (the minimum stock size threshold, MSST), the stock must be declared overfished and a rebuilding plan subsequently developed.

The estimate of B from Model Alt1b (the author’s preferred model) is 70.77 thousand t (Table 23). Spawning biomass per recruit in an unfished stock was calculated using the TCSAM population dynamics equations (Appendix 3) with total recruitment set to 1 and fishing mortality from all sources (directed fishery and all bycatch fisheries) set to 0, resulting in $\phi(0) = 0.451$ kg/recruit. Fully-selected fishing mortality and selectivity curves in the bycatch fisheries were set using the same approach as in the 2012 and 2013 assessments (Rugolo and Turnock, 2012b; Stockhausen et al., 2013), as were selectivities for all (retained+discarded) males and for retained males in the directed Tanner crab fishery (Fig. 74). The value for $F_{35\%}$ was then estimated using an iterative approach by varying the fully-selected F on males in the directed fishery until $\phi(F) = 0.35 \cdot \phi(0)$. The resulting value for $F_{35\%}$ is 0.58 yr^{-1} , which is similar to that calculated in 2012 (0.61) but smaller than that calculated last year (0.73 yr^{-1}). Changes from the 2013 assessment model to Model Alt1a in the probability of males maturing at size, bycatch selectivity in the groundfish fisheries, and bycatch selectivity in the snow crab fishery accounted for changes in the estimated value for $F_{35\%}$, as well.

The determination of $B_{MSY}=B_{35\%}$ for Tanner crab depends on the selection of an appropriate time period over which to calculate average recruitment (\bar{R}). After much discussion in 2012 and 2013, the SSC endorsed an averaging period of 1982+. Starting the average recruitment period in 1982 is consistent with a 5-6 year recruitment lag from 1976/77, when a well-known climate regime shift occurred in the EBS (Rodionov and Overland, 2005) that may have affected stock productivity. The value of \bar{R} for this period from the author’s preferred model is 209.749 million. The estimates of average recruitment are quite similar between the 2013 assessment model and the author’s preferred model (Table 23). The value of $B_{MSY}=B_{35\%}$ for \bar{R} is 33.95 thousand t. Thus, the stock is “not overfished” because $B/B_{35\%} > 0.5$ (i.e., $B > MSST$).

Once F_{OFL} is determined using the control rule (Fig. 73), the (total catch) OFL can be calculated based on projecting the population forward one year assuming that $F = F_{OFL}$. In the absence of uncertainty, the OFL would then be the predicted total catch taken when fishing at $F = F_{OFL}$. When uncertainty (e.g. assessment uncertainty, variability in future recruitment) is taken into account, the OFL is taken as the median total catch when fishing at $F = F_{OFL}$.

The total catch (biomass), including all bycatch of both sexes from all fisheries, was estimated using

$$C = \sum_f \sum_x \sum_z \frac{F_{f,x,z}}{F_{,x,z}} \cdot (1 - e^{-F_{,x,z}}) \cdot w_{x,z} \cdot [e^{-M_x \cdot \delta t} \cdot N_{x,z}]$$

where C is total catch (biomass), $F_{f,x,z}$ is the fishing mortality in fishery f on crab in size bin z by sex (x), $F_{.,x,z} = \sum_f F_{f,x,z}$ is the total fishing mortality by sex on crab in size bin z , $w_{x,z}$ is the mean weight of crab in size bin z by sex, M_x is the sex-specific rate of natural mortality, δt is the time from July 1 to the time of the fishery (0.625 yr), and $N_{x,z}$ is the numbers by sex in size bin z on July 1, 2014 as estimated by the assessment model.

Assessment uncertainty was included in the calculation of OFL using the same approach as that used for the 2012 and 2013 assessments (Rugolo and Turnock, 2012; Stockhausen et al, 2013). Basically, initial numbers at size on July 1, 2014 were randomized based on an assumed lognormal assessment error distribution and the cv of estimated MMB for 2013/14 from the assessment model, the control rule was applied to obtain F_{OFL} , and the population projected forward to next year assuming that fishing occurred consistent with F_{OFL} . This was repeated 10,000 times to generate a distribution of total catch OFLs for each of the four model scenarios. The OFL for each model scenario was taken as the median of the resulting distribution. Values for the OFLs ranged from 30.04 thousand t for model scenario Alt0b to 33.81 thousand t for scenario Alt1a (Table 23, Figure 75). **The value of OFL for 2014/15 from the author's preferred model (Alt1a) is 33.81 thousand t.**

Model Alt1a is the author's preferred model for calculating the B_{MSY} proxy as $B_{35\%}$, so $MSST = 0.5 B_{MSY} = 16.98$ thousand t. Because current $B = 70.77$ thousand t $>$ $MSST$, **the stock is not overfished**. The population state (directed F vs. MMB) is plotted for each year from 1965-2013 in Fig. 76 against the Tier 3 harvest control rule.

2. ABC calculation

Amendments 38 and 39 to the Fishery Management Plan (NPFMC 2010) established methods for the Council to set Annual Catch Limits (ACLs). The Magnuson-Stevens Act requires that ACLs be established based upon an acceptable biological catch (ABC) control rule that accounts for scientific uncertainty in the OFL such that $ACL=ABC$ and the total allowable catch (TAC) and guideline harvest levels (GHLs) be set below the ABC so as not to exceed the ACL. ABCs must be recommended annually by the Council's SSC.

Two methods for establishing the ABC control rule are: 1) a constant buffer where the ABC is set by applying a multiplier to the OFL to meet a specified buffer below the OFL; and 2) a variable buffer where the ABC is set based on a specified percentile (P^*) of the distribution of the OFL that accounts for uncertainty in the OFL. P^* is the probability that ABC would exceed the OFL and overfishing occur. In 2010, the NPFMC prescribed that ABCs for BSAI crab stocks be established at $P^*=0.49$ (following Method 2). Thus, annual $ACL=ABC$ levels should be established such that the risk of overfishing, $P[ABC>OFL]$, is 49%. For 2011/12, however, the SSC adopted a buffer of 10% on OFL for all crab stocks for calculating ABC (Method 1). Here, ABCs are provided based on both methods.

ABCs based on the $P^*=0.49$ approach were calculated from quantiles of the associated OFL distributions such that probability that the selected ABC was greater than the true OFL was 0.49. The resulting ABC for each scenario was almost identical to the associated OFL (Table 23). ABCs were also calculated using the SSC's 10% OFL buffer (Table 23).

For the author's preferred model (Alt1a), the P^* ABC_{max} is 33.76 thousand t while the 10% Buffer ABC_{max} is 30.43 thousand t. Following the 3-year incremental approach to setting ABC for this stock adopted by the CPT and SSC in 2012 after the Tier 3 model was accepted (and continued in 2013), the full ABC_{max} would be applied to the stock this year. The author remains concerned that both of these choices for ABC are overly optimistic regarding the actual productivity of the stock. Fishery-related mortality similar to these ABC levels has occurred only in the latter half of the 1970s and in 1992/93, coincident with collapses in stock biomass to low levels (Fig. 77). This suggests that $F_{35\%}$ may not be a

realistic proxy for F_{msy} and/or that MMB may not be a good proxy for reproductive success, as are the current assumptions for this stock. Given this uncertainty concerning the stock, **the author recommends not advancing this year to the final step of the 3 rung stair step used to set ABC. Consequently, using the p^* ABC as ABC_{max} , the author's recommended ABC is $2/3 \times 33.76$ thousand t = 22.51 thousand t.**

G. Rebuilding Analyses

Tanner crab is not currently under a rebuilding plan. Consequently no rebuilding analyses were conducted.

H. Data Gaps and Research Priorities

Information on growth-per-molt should be collected for the EBS Tanner crab stock. An extensive collection of data of this type exists for Tanner crab in the GOA, but assessment model results suggest that growth rates for males in the EBS are different from those in the GOA. Secondly, data on temperature-dependent effects on molting frequency would be helpful to assess potential impacts of the EBS cold pool on the stock. In addition, it would be extremely worthwhile to develop a “better” index of reproductive potential than MMB and to revisit the issue of MSY proxies for this stock.

Effort needs to continue on developing the TCSAM model code, particularly so that model output can accommodate the wide range of diagnostic and evaluation protocols requested of SAFE documents (e.g., retrospective analyses, simulation testing). In a similar vein, the model code needs to be revised so the model is more configurable using control files, rather than requiring the code itself to be altered to run different configurations, than it currently is. These issues are being addressed in the new code under development.

I. Ecosystem Considerations

Mature male biomass is currently used as the “currency” of Tanner crab spawning biomass for assessment purposes. However, its relationship to stock-level rates of egg production, perhaps an ideal measure of stock-level reproductive capacity, is unclear. Nor is it likely that mature female biomass has a clear relationship to annual egg production. For Tanner crab, the fraction of barren mature females by shell condition appears to vary on a decadal time scale (Fig. 78), suggesting a potential climatic driver. The observation that “very old shell” females have much higher rates of barrenness and are more likely to exhibit smaller clutch sizes also (Fig. 79) suggests that older females decline into senescence and it may not be as important to maintain “old, fat” female crabs as it appears to be for many species of fish. senesce. The trend in the fraction of new shell mature females (ones that mate for the first time following the molt to maturity) with clutches one-half full or is also potentially troubling (Fig. 79). Prior to 1991, this rate was similar to that for old shell (multiparous) females. After 1991, the rate increased to 20-40%, similar to that for very old shell females. Rugolo and Turnock (2010) developed an Egg Production Index (EPI) by female shell condition that incorporated observed clutch size measurements taken on the bottom trawl survey and fecundity by carapace width for 1976-2009 (Fig. 80). Figure 80 also includes estimates of male and female mature biomass relative to the shell condition class EPIs in these years. Although both male and female mature biomass increased after 2005, egg production has not increased proportionally to mature biomass. Thus use of MMB to reflect Tanner crab reproductive potential may be misleading as to stock health.

1. Ecosystem Effects on Stock

Time series trends in prey availability or abundance are generally unknown for Tanner crab because typical survey gear is not quantitative for Tanner crab prey. On the other hand, Pacific cod (*Gadus macrocephalus*) is thought to account for a substantial fraction of annual mortality on Tanner crab (Figs 81, 82; Aydin et al., 2007). Total P. cod biomass is estimated to have been slowly declining from 1990 to 2008, during the time frame of a collapse in the Tanner crab stock, but has been increasing rather rapidly

since 2008 (Thompson and Lauth, 2012). This suggests that the rates of “natural mortality” used in the stock assessment for the period post-1980 may be underestimates (and increasingly biased low if the trend in *P. cod* abundance continues). This trend is definitely one of potential concern.

2. Effects of Tanner crab fishery on ecosystem

Potential effects of the Tanner crab fishery on the ecosystem are considered in the following table:

Effects of Tanner crab fishery on ecosystem			
Indicator	Observation	Interpretation	Evaluation
<i>Fishery contribution to bycatch</i>			
Prohibited species	halibut and salmon are unlikely to be trapped inside a pot when it is pulled	unlikely to have substantial effects	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 have substantial effects	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
<i>Fishery concentration in space and time</i>	rationalization has substantially reduced fishery concentration in time	likely true of future Tanner crab fishery, as well	probably of little concern
<i>Fishery effects on amount of large size target fish</i>	Fishery selectively removes large males	May impact stock reproductive potential as large males can mate with a wider range of females	possible concern
<i>Fishery contribution to discards and offal production</i>	discarded crab suffer some mortality (assumed 32.1% in preferred model)	May impact female spawning biomass and numbers recruiting to the fishery	possible concern
<i>Fishery effects on age-at-maturity and fecundity</i>	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.
- 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.
- Foy, R. and C. Armistead. 2012. The 2012 Eastern Bering Sea Continental Shelf Bottom Trawl Survey: Results for Commercial Crab Species. NOAA Technical Memorandum NMFS-AFSC-XX 143 p.
- 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.
- Hoening, 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, University of 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. 2004a. Final Environmental Impact Statement for Bering Sea and Aleutian Islands Crab Fisheries. National Marine Fisheries Service, P.O. Box 21668, Juneau, AK 99802-1668.
- NMFS. 2004b. Alaska Groundfish Fisheries Final Programmatic Supplemental Environmental Impact Statement, DOC, NOAA, National Marine Fisheries Service, AK Region, P.O. Box 21668, Juneau, AK 99802-1668. Appx 7300 p.

- NPFMC. 1998. 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. 1999. Environmental Assessment/Regulatory Impact Review/Initial Regulatory Flexibility analysis for Amendment 11 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs. North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite, 306, Anchorage, AK 99501.
- NPFMC (North Pacific Fishery Management Council). 2000. Bering Sea snow crab rebuilding plan. Amendment 14. Bering Sea Crab Plan Team, North Pacific Fishery Management Council, Anchorage, AK, USA..
- 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, J.M., A.J. Paul, and A. Kimker. 1994. Compensatory feeding capacity of 2 brachyuran crabs, Tanner and Dungeness, after starvation periods like those encountered in pots. Alaska Fish. Res. Bull. 1:184-187.
- 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.
- 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. Turnock and E. Munk. 2008. 2008 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. Report to the North Pacific Fishery Management Council, Crab Plan Team. 59 p.
- Rugolo L,J. and B.J. Turnock. 2009. 2009 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. Report to the North Pacific Fishery Management Council, Crab Plan Team. 73 p.
- 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. 2011c. Straw Proposal for Establishing Criteria in Estimating B_{REF}. Report to the North Pacific Fishery Management Council, Crab Plan Team, June 02, 2011. 2.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.
- Rugolo, L.J., D. Pengilly, R. MacIntosh and K. Gravel. 2005. Reproductive dynamics and life-history of snow crab (*Chionoecetes opilio*) in the eastern Bering Sea. Final Completion Report to the NOAA, Award NA17FW1274, Bering Sea Snow Crab Fishery Restoration Research.
- Rathbun, M. J. 1924. New species and subspecies of spider crabs. Proceedings of U.S. Nat. Museum. 64:1-5.
- 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.
- Stevens, B. G., and R. A. MacIntosh. 1992. Cruise Results Supplement, Cruise 91-1 Ocean Hope 3: 1991 eastern Bering Sea juvenile red king crab survey, May 24-June 3, 1991., DOC, NOAA, NMFS, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, 13 p.
- 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: 2013Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 342-478.
- 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.

List of Tables

- Table 1. Retained catch (males) in directed Tanner crab fisheries.
- Table 2. Retained catch (males) in the US domestic pot fishery. Information from the Community 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.
- Table 3. Total bycatch (1000’s t) of Tanner crab in various fisheries. Discard mortality rates have not been applied.
- Table 4. Sample sizes from the recalculated fishery data for retained catch-at-size in the directed fishery. N = number of individuals. N` = scaled sample size used in assessment.
- Table 5. Sample sizes from the recalculated fishery data for total catch-at-size in the directed fishery, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.
- Table 6. Sample sizes from the recalculated fishery data for total bycatch-at-size in the snow crab fishery, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.
- Table 7. Sample sizes from the recalculated fishery data for total bycatch-at-size in the BBRKC fishery, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.
- Table 8. Sample sizes from the recalculated fishery data for total catch-at-size in the groundfish fisheries, from groundfish observer sampling. N = number of individuals. N` = scaled sample size used in the assessment.
- Table 9. Trends in mature Tanner crab biomass and abundance of legal crab (nominally defined as ≥ 138 mm CW) in the NMFS summer bottom trawl survey.
- Table 10. Sample sizes for NMFS survey catch-at-size. In the model, an effective sample size of 200 is used for all survey-related compositional data. Due to a change in software, non-zero hauls were not calculated for 2014.
- Table 11. Effort data (1000’s potlifts) in the snow crab and BBRKC fisheries (recalculated for 1990/91-2012/13).
- Table 12. Comparison of parameter estimates and approximate standard deviations from the 2013 model and 2014 alternative models. Parameter names, types, bounds, and associated indices are also given. Blue highlighting indicates the parameter estimate is at the lower bound set for the parameter, whereas red highlighting indicates the parameter estimate is at the upper bound.
- Table 13. Comparison of estimated male recruitment (in millions) from the four alternative 2014 models and the 2013 model.
- Table 14. Comparison of time series of estimated mature male biomass (1000’s t) at mating from the four alternative 2014 models and the 2013 model.
- Table 15. Comparison of time series of observed and estimated numbers of male crab ≥ 138 mmCW (millions) in the survey from the four alternative 2014 models and the 2013 model.
- Table 16. Comparison of time series of observed retained catch (1000’s t) in the directed fishery and predicted catch from the four alternative 2014 models and the 2013 model.

- Table 17. Comparison of time series of observed total male mortality (retained+discards) in the directed fishery (1000's t) with the respective predicted catch from the four alternative models and the 2013 model. Note that each 2014 model scenario has its own associated "observed" total mortality because the datasets differ between the 0 and 1 scenarios and the assumed handling mortality rates differ between the a's and b's.
- Table 18. Comparison of time series of observed female discard mortality (1000's t) in the directed fishery with the predicted catch from the 2012 assessment model and the two alternative models.
- Table 19. Comparison of the final objective function components for the alternative models Alt0a and Alt0b, which can be compared directly. Component differences greater or less than 2 units are highlighted. Positive differences (red highlighting) indicate better fits with Alt0b. Negative differences (blue highlighting) indicate better fits with Alt0a. Overall, Alt0b fits the data better, with smaller penalties, by 3.60 likelihood units compared with Alt0a.
- Table 20. Comparison of the final objective function components for the alternative models Alt1a and Alt1b, which can be compared directly. Component differences greater or less than 2 units are highlighted. Positive differences (red highlighting) indicate better fits with Alt0b. Negative differences (blue highlighting) indicate better fits with Alt0a. Overall, Alt1a fits the data better, with smaller penalties, by 6.06 likelihood units compared with Alt1b.
- Table 21. Estimated population size (thousands) for females on July 1 of year. from the author's preferred model (Alt1a).
- Table 22. Estimated population size (thousands) for males on July 1 of year. from the author's preferred model (Alt1a).
- Table 23. OFLs and ABCs for the 2013 assessment and the four alternative 2014 model scenarios. The author's preferred model is Alt1a.
- A1.Table 1. Revisions to the input data for the Tanner crab model considered in the analysis.
- A1.Table 2. Number of measured male crab in dockside sampling for retained size frequencies in the recalculated and 2013 datasets. W. Gaeuman (ADFG) did not provide recalculated size frequencies for 1995.
- A1.Table 3. Number of Tanner crab measured by at-sea observers in the directed fishery in the recalculated and 2013 datasets.
- A1.Table 4. Number of Tanner crab measured by at-sea observers in the snow crab fishery for the recalculated and 2013 datasets.
- A1.Table 5. Number of Tanner crab measured by at-sea observers in the BBRKC fishery for the recalculated and 2013 datasets.
- A1.Table 6. Number of Tanner crab measured by at-sea observers in the groundfish fisheries for the recalculated and 2013 datasets. The recalculated dataset is based on the crab fishery year (starting July 1), whereas the 2013 assessment dataset was based on the groundfish fishery year (starting Jan. 1).
- A1.Table 7. Comparison of the re-calculated annual effort (1000's of potlifts) time series in the directed Tanner crab fishery with the values used in the 2013 assessment.

List of Figures

- Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008).
- Figure 2. Retained catch (males, 1000's t) in the directed fisheries (US pot fishery [green bars], Russian tangle net fishery [red bars], and Japanese tangle net fisheries [blue bars]) for Tanner crab since 1965/66.
- Figure 3. Retained catch (males, 1000's t) in directed fishery for Tanner crab since 2001/02. The directed fishery was closed from 1996/97 to 2004/05 and from 2010/11 to 2012/13.
- Figure 4. Tanner crab discards (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Discard reporting began in 1973 for the groundfish fisheries and in 1992 for the crab fisheries.
- Figure 5. Tanner crab discards (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries since 2001.
- Figure 6. Size compositions, by 5 mm CW bins and expanded to total retained catch, for retained (male) crab in the directed Tanner crab pot fisheries since 2005/06, from dockside crab fishery observer sampling. The region west of 166°W was closed to fishing in 2009/10. The entire fishery was closed in 2010/11-2012/13.
- Figure 7. Male Tanner crab catch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling.
- Figure 8. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling.
- Figure 9. Male Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the snow crab pot fishery, from at-sea crab fishery observer sampling.
- Figure 10. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the snow crab pot fishery, from at-sea crab fishery observer sampling.
- Figure 11. Male Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the BBRKC pot fishery, from at-sea crab fishery observer sampling.
- Figure 12. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the BBRKC pot fishery, from at-sea crab fishery observer sampling.
- Figure 13. Normalized male Tanner crab bycatch size compositions in the groundfish fisheries, from groundfish observer sampling. Size compositions have been normalized to sum to 1 for each year.
- Figure 14. Normalized female Tanner crab bycatch size compositions in the groundfish fisheries, from groundfish observer sampling. Size compositions have been normalized to sum to 1 for each year.
- Figure 15. Trends in mature Tanner crab biomass and abundance of legal crab (≥ 138 mm CW) in the summer bottom trawl survey.
- Figure 16. Percent change in mature male biomass, mature female biomass, total mature biomass and number of legal male crab observed in the summer bottom trawl survey.
- Figure 17. Numbers at size (millions) for male Tanner crab, by area and shell condition, in the NMFS summer bottom trawl survey. Upper row: new shell crab. Lower row: old shell crab.
- Figure 18. Numbers at size (millions) for female Tanner crab, by area and shell condition, in the NMFS summer bottom trawl survey. Upper row: new shell crab. Lower row: old shell crab.

- Figure 19. Distribution of immature males (number/ sq. nm) in the summer trawl survey for 2010-13.
- Figure 20. Distribution of mature males (number/ sq. nm) in the summer trawl survey for 2010-13.
- Figure 21. Distribution of “legal males” (≥ 138 mm CW; number/ sq. nm) in the summer trawl survey for 2010-13.
- Figure 22. Distribution of immature females (number/ sq. nm) in the summer trawl survey for 2010-13.
- Figure 23. Distribution of mature females (number/ sq. nm) in the summer trawl survey for 2010-13.
- Figure 24. Growth of male (a) and female (b) Tanner crab as a function of premolt size. Estimated by Rugolo and Turnock (2010) based on data from Gulf of Alaska Tanner crab (Munk, unpublished data).
- Figure 25. Fitted weight-at size relationships for males (immature and mature; blue line), immature females (red line), and mature females (green line).
- Figure 26. Assumed size distribution for recruits entering the population.
- Figure 27. Comparison of model-estimated time series for (male) recruitment from the four alternative models and the 2013 model.
- Figure 28. Comparison of model-estimated time series for fully-selected total F (retained + discards) on males in the directed Tanner crab fishery from the four alternative models and the 2013 model.
- Figure 29. Comparison of model-estimated time series for fully-selected F on retained males in the directed Tanner crab fishery from the four alternative models and the 2013 model.
- Figure 30. Comparison of estimated time series for mature male biomass at mating time from the four alternative models and the 2013 model.
- Figure 31. Comparison of observed and estimated survey time series for the number of males ≥ 138 mm CW from the four alternative models and the 2013 model.
- Figure 32. Comparison of model-estimated time series for fully-selected F in the snow crab fishery from the four alternative models and the 2013 model.
- Figure 33. Comparison of model-estimated time series for fully-selected F in the BBRKC fishery from the four alternative models and the 2013 model.
- Figure 34. Comparison of model-estimated time series for fully-selected F in the groundfish fisheries from the four alternative models and the 2013 model.
- Figure 35. Comparison of estimated time series for retained (male) catch (1000's t) in the directed tanner crab fishery from the four alternative models and the 2013 model with the observed catches.
- Figure 36. Comparison of estimated time series for total male (retained+discarded) catch (1000's t) in the directed tanner crab fishery from the four alternative models and the 2013 model with the corresponding observed mortality. Note that the “observed” mortality is different for the four alternative models because ‘0’/’1’ models are based on different datasets and ‘a’/’b’ models use different rates for handling mortality.
- Figure 37. Comparison of “observed” and estimated time series for female discard mortality (1,000's t) in the directed tanner crab fishery from the four alternative models and the 2013 model. Note that the “observed” mortality is different for the four alternative models because ‘0’/’1’ models are based on different datasets and ‘a’/’b’ models use different rates for handling mortality.
- Figure 38. Input sample sizes used for the various likelihood components associated with size frequency data. The upper graph shows the sample by year for each component, the lower graph shows the mean sample size for each component. A value of 200 is used for all trawl survey components.

- Figure 39. Comparison of the components of the converged objective function values (weights \times $-\log$ -likelihood components) for models Alt0a and Alt0b. Positive values indicate better fits for Alt0b. Overall, the value of the total objective function for Alt0b is 3.60 likelihood units smaller than that for Alt0a.
- Figure 40. Comparison of the components of the converged objective function values (weights \times $-\log$ -likelihood components) for model Alt1b relative to Alt1a. Positive values indicate better fits for Alt1b. Overall, the value of the total objective function for Alt1a is 6.06 likelihood units smaller than that for Alt1b.
- Figure 41. Estimated exploitation rates in the directed fishery for total catch and legal-sized males (≥ 138 mm CW) from the 2013 model (left) and the author's preferred 2014 model, Alt1a (right).
- Figure 42. Comparison of model-estimated growth curves (solid lines, upper=males, lower=females) from the author's preferred model, Alt1a, and empirical curves ("+"=males, circles=females) developed from growth data on Tanner crab in the Gulf of Alaska near Kodiak Island.
- Figure 43. Comparison of model-estimated probability of maturing by size for new shell crab (solid line = males, dashed line = females) from the author's preferred model, Alt1a, with that used for males (dotted line) in the Amendment 24 OFL analysis (NPFMC 2007).
- Figure 44. Estimated natural mortality for immature (single time period: 1949-2013) and mature (two time periods: 1949-1979+2005-2013 and 1980-1984) crab by sex (upper graph: females; lower graph: males) from the author's preferred model, Alt1b.
- Figure 45. Estimated annual selectivity curves (solid line, pre-1991; dashed lines, 1991-2009) in the directed Tanner crab fishery for all new shell males (upper graph) and retained crab (lower graph) from the 2013 model (left column) and the author's preferred 2014 model, Alt1a (right column). The year indicated denotes the beginning of the fishery year; e.g. "2009" indicates the 2009/10 fishery year. Selectivity curves for old shell males are identical to those for new shell males.
- Figure 46. Estimated selectivity curves by sex (solid lines = males, dashed lines = females) for 3 eras in the snow crab fishery (era 1 [1989-1996] = black lines, era 2 [1997-2004] = green lines, era 3 [2005-present] = blue lines) from the 2013 model (left) and author's preferred 2014 model, Alt1a (right).
- Figure 47. Estimated selectivity curves by sex (solid lines = males, dashed lines = females) for 3 eras in the BBRKC fishery (era 1 [1989-1996] = black lines, era 2 [1997-2004] = green lines, era 3 [2005-present] = blue lines) from the 2013 model (left) and author's preferred 2014 model, Alt1a (right).
- Figure 48. Estimated selectivity curves by sex (solid lines = males, dashed lines = females) for 3 eras in the groundfish fisheries (era 1 [1973-1987] = black lines, era 2 [1988-1996] = green lines, era 3 [1997-present] = blue lines) from the 2013 model (left) and author's preferred 2014 model, Alt1a (right).
- Figure 49. Comparison of estimated sex-specific selectivity curves for the NMFS bottom trawl survey in three time periods with those obtained by Somerton and Otto (1999) in the underbag experiment. The curves for 1982-87 and 1988+ are identical. Vertical lines indicate the size corresponding to survey q for both sexes. Left column: 2013 model (left), right column: author's preferred 2014 model, Alt1a.
- Figure 50. Estimated full selection fishing mortality in the directed fishery from the 2013 model (left) and the author's preferred 2014 model, Alt1a (right).

- Figure 51. Comparison of observed survey biomass (circles with 95% CIs) and predicted survey biomass (solid line) for mature females (upper graph) and mature males (lower graph) from the 2013 model (left) and the author's preferred 2014 model, Alt1a (right).
- Figure 52. Standardized residuals (ln-scale) of mature survey biomass from the 2013 model (left) and the author's preferred 2014 model, Alt1a (right).
- Figure 53. Comparison of observed survey biomass for mature crab (circles with 95% CIs), predicted survey biomass for mature crab (solid line) and predicted spawning (males + females) biomass (dashed line) from the author's preferred model, Alt1a.
- Figure 54. Model-predicted mature biomass at mating time for males (i.e., MMB; blue line), females (green line), and total (dotted line), from the author's preferred model, Alt1a.
- Figure 55. Comparison of numbers of male crab ≥ 138 mm CW in the trawl survey with predicted total survey numbers from the author's preferred model Alt1a.
- Figure 56. Comparison of observed numbers of crab in the NMFS bottom trawl survey (circles) and predicted survey numbers (solid line) from the author's preferred model, Alt1a, for females (top graph) and males (bottom graph).
- Figure 57. Comparison of observed numbers in the NMFS bottom trawl survey for mature males by shell condition (new shell, old shell) and combined with predictions from the author's preferred model, Alt1a.
- Figure 58. Comparison of observed numbers in the NMFS bottom trawl survey for mature males by shell condition (new shell, old shell) and combined with predictions from the author's preferred model, Alt1a.
- Figure 59. Comparison of estimates of the fraction of mature crab by sex in the NMFS bottom trawl survey and as predicted by the author's preferred model, Alt1a.
- Figure 60. Comparison of predicted (solid line) and observed (circles) proportions-at-size for retained males in the directed Tanner crab fishery from the author's preferred model (Alt1a).
- Figure 61. Pearson residuals for predicted proportions at size for retained males in the directed Tanner crab fishery for the author's preferred model (Alt1a). White circles represent positive anomalies (observed > predicted), black circles represent negative anomalies.
- Figure 62. Comparison of predicted (solid line) and observed (circles) proportions-at-size for all males (retained+discarded) males in the directed Tanner crab fishery from the author's preferred model, Alt1a.
- Figure 63. Pearson residuals for predicted proportions at size for all males in the directed Tanner crab fishery from the author's preferred model (Alt1a). White circles represent positive anomalies (observed > predicted), black circles represent negative anomalies.
- Figure 64. Comparison of predicted (solid line) and observed (circles) proportions at size for females in the directed Tanner crab fishery from the author's preferred model (Alt1a).
- Figure 65. Pearson residuals for predicted proportions at size for females in the directed Tanner crab fishery from the author's preferred model (Alt1a). White circles represent positive anomalies (observed > predicted), black circles represent negative anomalies.
- Figure 66. Comparison of predicted (solid line) and observed (circles) proportions-at-size for males in the NMFS bottom trawl survey from the author's preferred model (Alt1a).

- Figure 67. Pearson residuals for predicted proportions at size for all males in the NMFS bottom trawl survey from the author's preferred model (Alt1a). White circles represent positive anomalies (observed > predicted), black circles represent negative anomalies.
- Figure 68. Comparison of predicted (solid line) and observed (circles) proportions-at-size for females in the NMFS bottom trawl survey from the author's preferred model (Alt1a).
- Figure 69. Pearson residuals for predicted proportions at size for females in the NMFS bottom trawl survey from the author's preferred model (Alt1a). White circles represent positive anomalies (observed > predicted), black circles represent negative anomalies.
- Figure 70. Comparison of marginal (mean) proportions-at-size in the directed Tanner crab fishery for retained males (upper plot) and all males (center plot) and females (lower plot) from the 2013 assessment model (left column) and the author's preferred model (Alt1a, right column). 80% confidence intervals are shown for the observed values, based on observed variance-at-size and assuming normal distributions.
- Figure 71. Comparison of marginal (mean) proportions-at-size for males and females in the snow crab fishery (upper plot), the BBRKC fishery (center plot), and the groundfish fisheries (lower plot) from the 2013 assessment model (left column) and the author's preferred model (Alt1a, right column). 80% confidence intervals are shown for the observed values, based on observed variance-at-size and assuming normal distributions.
- Figure 72. Comparison of marginal (mean) proportions-at-size in the NMFS bottom trawl survey for all (male+female) crab (upper plot), mature crab (center plot), and immature crab (lower plot) from the 2013 assessment model (left column) and the author's preferred model (Alt1a, right column). 80% confidence intervals are shown for the observed values, based on observed variance-at-size and assuming normal distributions.
- Figure 73. The F_{OFL} harvest control rule. For Tier 3 stocks such as EBS Tanner crab, F_{MSY} and B_{MSY} are based on spawning biomass per recruit proxies, where $F_{MSY} = F_{35\%}$ and $B_{MSY} = B_{35\%}$ and MMB at mating time is used as spawning biomass.
- Figure 74. Comparison of selectivity curves used in the projection model for status determination and OFL calculation in 2013 (upper plot) and the preferred model for 2014 (Alt1a, lower plot). The total (retained+ discards) selectivity curve (dark blue curve, triangles) is assumed to apply to the fisheries east and west of 166°W longitude. Retained selectivity in the fishery east of 166°W (purple curve, asterisks) is assumed to be the same as the last year of the directed fishery. Retained selectivity west of 166°W is assumed to be a left-shifted version of that east of 166°W, reflecting the smaller legal and preferred size limits there (orange curve, circles).
- Figure 75. Tier 3 OFL and ABC calculations using the empirical cumulative probability distribution (white line) for the OFL (indicated by the vertical red line) based on 10,000 1-year projection model runs. Initial (July 1, 2013) population numbers-at-size were randomized based on the CV of 2013 MMB at mating time for each alternative model (upper left: Alt0a, upper right: Alt0b, lower left: Alt1a, lower right: Alt1b). For each year, directed fishing mortality was set using $F_{msy} = F_{35\%}$ and the Tier 3 F_{OFL} control rule, and total catch was calculated. The OFL for each model is the median of the resulting distribution of catches (possible OFLs). The "p-star" ABC (indicated by the dashed blue line) is the ABC that yields $p^* = 0.49$ —i.e., the probability that the selected ABC exceeds the true OFL is 49%. $ABC_{10\%}$ (indicated by the dashed green line) is the ABC based on applying a 10% buffer to the OFL. The units for OFL and ABC are 1000's t.
- Figure 76. The Tier 3 F_{OFL} harvest control rule, with the population state for each year plotted at coordinates given by MMB at mating on the x axis and total fishing mortality on the y axis, as

estimated from the author's preferred model, Model 01. The current year (2013/14) is highlighted in red text.

Figure 77. Comparison of the OFL from the author's preferred model and the author's recommended ABC with the time series of estimated total fishery-related mortality and MMB for the Tanner crab stock.

Figure 78. Proportion of female Tanner crab with barren clutches by shell condition from survey data for 1976/77 to 2009/10.

Figure 79. Proportion of female Tanner crab with less than or equal to one-half full clutch by shell condition from survey data 1976/77 to 2009/10.

Figure 80. Tanner crab female egg production index (EPI) by shell condition, survey estimate of male mature biomass (1000 t), and survey estimate of female mature biomass (1000 t) from survey data for 1976/77 to 2009/10.

Figure 81. The fraction of annual mortality from major ecosystem components (including fisheries) on mature Tanner crab in the EBS, as estimated by a mass-balance ecosystem model for the EBS (Aydin et al., 2007).

Figure 82. The fraction of annual mortality from major ecosystem components (including fisheries) on immature Tanner crab in the EBS, as estimated by a mass-balance ecosystem model for the EBS (Aydin et al., 2007).

A1.Figure 1. Size frequencies for immature, new shell females from the 2013 AFSC trawl survey: the version used in the 2013 assessment (blue) and the corrected version (red).

A1.Figure 2. Corrected sample sizes for sex-specific (males: blue; females: red) bycatch size frequencies in the groundfish fisheries. The sexes were switched in the 2013 (and 2012) assessments.

A1.Figure 3. Numbers of measured male crab in new/old shell categories in dockside sampling for retained Tanner crab in the updated dataset (red, blue lines) and the 2013 assessment dataset (green, purple lines).

A1.Figure 4. Normalized dockside retained size frequencies from updated results (blue) and used in the 2013 assessment (red).

A1.Figure 5. Comparison of numbers of measured crab, by year and sex, in at-sea sampling in the directed Tanner crab fishery in the recalculated dataset (red and blue lines) and the 2013 assessment dataset (green and purple lines).

A1.Figure 6. Comparison of normalized size frequencies for measured male crab during selected years in at-sea sampling of the directed Tanner crab fishery in the recalculated dataset (blue lines) and the 2013 assessment dataset (dotted lines). Vertical dashed lines indicate the minimum legal sizes in the West and East regions.

A1.Figure 7. Comparison of numbers of measured Tanner crab, by year and sex, in at-sea sampling in the snow crab fishery in the recalculated dataset (red, blue lines) and the 2013 assessment (green, purple lines).

A1.Figure 8. Comparison of normalized size frequencies for measured female crab during selected years in at-sea sampling of the Tanner crab bycatch in the snow crab fishery in the recalculated dataset (blue lines) and the 2013 assessment dataset (dotted lines). Vertical dashed lines indicate the minimum legal sizes for Tanner crab in the West and East regions.

A1.Figure 9. Comparison of numbers of measured Tanner crab, by year and sex, in at-sea sampling in the BBRKC fishery in the recalculated dataset (red, blue lines) and the 2013 assessment (green, purple lines).

- A1. Figure 10. Comparison of normalized size frequencies for measured female crab during selected years in at-sea sampling of the Tanner crab bycatch in the BBRKC fishery in the recalculated dataset (blue lines) and the 2013 assessment dataset (dotted lines). Vertical dashed lines indicate the minimum legal sizes for Tanner crab in the West and East regions.
- A1. Figure 11. Comparison of numbers of measured Tanner crab, by year and sex, in at-sea sampling in the groundfish fisheries in the recalculated dataset (red, blue lines) and the 2013 assessment (green, purple lines). The recalculated dataset is based on the crab fishery year (starting July 1), whereas the 2013 assessment dataset was based on the groundfish fishery year (starting Jan. 1).
- A1. Figure 12. Comparison of normalized size frequencies for measured female crab during selected years in at-sea sampling of the Tanner crab bycatch in the groundfish fisheries in the recalculated dataset (blue lines) and the 2013 assessment dataset (dotted lines). Vertical dashed lines indicate the minimum legal sizes for Tanner crab in the West and East regions.
- A1. Figure 13. Comparison of TCSAM2013-estimated selectivity on new shell males in the directed fishery for: 1) Dataset A, the 2013 assessment data (upper graph) and 2) Dataset B, Dataset A with corrected sample sizes in the groundfish fisheries (lower graph).
- A1. Figure 14. Comparison of TCSAM2013-estimated MMB at mating time for the 5 datasets. Upper left: full time series. Lower left: recent trends. Upper right: final (2012) estimates. Lower right: % change in final estimates relative to assessment dataset (A).
- A1. Figure 15. Comparison of TCSAM2013-estimated recruitment for the 5 datasets. Upper left: full time series for males. Lower left: recent trends in males. Upper right: 1982-2013 average. Lower right: % change in 1982-2013 average relative to assessment dataset (A).
- A1. Figure 16. Comparison of TCSAM2013-estimated directed fishing mortality for the 5 datasets. Left: full time series. Right: recent trends.
- A1. Figure 17. Comparison of the re-calculated effort time series (left graph) and the resulting discard biomass (right graph) in the directed Tanner crab fishery with the values used in the 2013 assessment.
- A4. Figure 1. Comparison of models for fishing mortality in TCSAM2013 (left) and Gmacs (right). The *areas* associated with retained mortality and discard mortality are the same in both pies. r_z is the fraction of the fishing mortality pie related to retained crab. ρ_z is the fraction of the fishery capture pie related to retained crab.

Tables

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

Eastern Bering Sea <i>Chionoecetes bairdi</i> Retained Catch (1000T)				
Year	US Pot	Japan	Russia	Total
1965/66		1.17	0.75	1.92
1966/67		1.69	0.75	2.44
1967/68		9.75	3.84	13.60
1968/69	0.46	13.59	3.96	18.00
1969/70	0.46	19.95	7.08	27.49
1970/71	0.08	18.93	6.49	25.49
1971/72	0.05	15.90	4.77	20.71
1972/73	0.10	16.80		16.90
1973/74	2.29	10.74		13.03
1974/75	3.30	12.06		15.24
1975/76	10.12	7.54		17.65
1976/77	23.36	6.66		30.02
1977/78	30.21	5.32		35.52
1978/79	19.28	1.81		21.09
1979/80	16.60	2.40		19.01
1980/81	13.47			13.43
1981/82	4.99			4.99
1982/83	2.39			2.39
1983/84	0.55			0.55
1984/85	1.43			1.43
1985/86	0.00			0.00
1986/87	0.00			0.00
1987/88	1.00			1.00
1988/89	3.15			3.18
1989/90	11.11			11.11
1990/91	18.19			18.19
1991/92	14.42			14.42
1992/93	15.92			15.92
1993/94	7.67			7.67
1994/95	3.54			3.54
1995/96	1.92			1.92
1996/97	0.82			0.82
1997/98	0.00			0.00
1998/99	0.00			0.00
1999/00	0.00			0.00
2000/01	0.00			0.00
2001/02	0.00			0.00
2002/03	0.00			0.00
2003/04	0.00			0.00
2004/05	0.00			0.00
2005/06	0.43			0.43
2006/07	0.96			0.96
2007/08	0.96			0.96
2008/09	0.88			0.88
2009/10	0.60			0.60
2010/11	0.00			0.00
2011/12	0.00			0.00
2012/13	0.00			0.00
2013/14	1.26			1.26

Table 2. Retained catch (males) in the US domestic pot fishery. Information from the Community Development Quota (CDQ) fisheries is included in the table for fishery years 2005/06 to the present. Number of crabs caught and harvest includes deadloss. The “Fishery Year” YYYY/YY+1 runs from July 1, YYYY to June 30, YYYY+1. The ADF&G year (in parentheses, if different from the “Fishery Year”) indicates the year ADF&G assigned to the fishery season in compiled reports.

year (ADF&G year)	Total Crab (no.)	Total Harvest (lbs)	GHL/TAC (millions lbs)	Vessels (no.)	Season
1968/69 (1969)	353,300	1,008,900			
1969/70 (1970)	482,300	1,014,700			
1970/71 (1971)	61,300	166,100			
1971/72 (1972)	42,061	107,761			
1972/73 (1973)	93,595	231,668			
1973/74 (1974)	2,531,825	5,044,197			
1974/75	2,773,770	7,028,378		28	
1975/76	8,956,036	22,358,107		66	
1976/77	20,251,508	51,455,221		83	
1977/78	26,350,688	66,648,954		120	
1978/79	16,726,518	42,547,174		144	
1979/80	14,685,611	36,614,315	28-36	152	11/01-05/11
1980/81 (1981)	11,845,958	29,630,492	28-36	165	01/15-04/15
1981/82 (1982)	4,830,980	11,008,779	12-16	125	02/15-06/15
1982/83 (1983)	2,286,756	5,273,881	5.6	108	02/15-06/15
1983/84 (1984)	516,877	1,208,223	7.1	41	02/15-06/15
1984/85 (1985)	1,272,501	3,036,935	3	44	01/15-06/15
1985/86 (1986)	closed	closed	closed	closed	closed
1986/87 (1987)	closed	closed	closed	closed	closed
1987/88 (1988)	957,318	2,294,997	5.6	98	01/15-04/20
1988/89 (1989)	2,894,480	6,982,865	13.5	109	01/15-05/07
1989/90 (1990)	9,800,763	22,417,047	29.5	179	01/15-04/24
1990/91	16,608,625	40,081,555	42.8	255	11/20-03/25
1991/92	12,924,102	31,794,382	32.8	285	11/15-03/31
1992/93	15,265,865	35,130,831	39.2	294	11/15-03/31
1993/94	7,235,898	16,892,320	9.1	296	11/01-11/10, 11/20-01/01
1994/95 (1994)	3,351,639	7,766,886	7.5	183	11/01-11/21
1995/96 (1995)	1,877,303	4,233,061	5.5	196	11/01-11/16
1996/97 (1996)	734,296	1,806,077	6.2	196	11/01-11/05, 11/15-11/27
1997/98-2004/05	closed	closed	closed	closed	closed
2005/06	443,978	952,887	1.7	49	10/15-03/31
2006/07	927,086	2,122,589	3.0	64	10/15-03/31
2007/08	927,164	2,106,655	5.7	50	10/15-03/31
2008/09	830,363	1,939,571	4.3	53	10/15-03/31
2009/10	485,676	1,327,952	1.3	45	10/15-03/31
2010/11	closed	closed	closed	closed	closed
2011/12	closed	closed	closed	closed	closed
2012/13	closed	closed	closed	closed	closed
2013/14	1,445,768	2,786,845	3.108	32	10/15-03/31

Table 3. Total bycatch (1000's t) of Tanner crab in various fisheries. Discard mortality rates have not been applied.

Discards (1000 t) of Tanner Crab by Fishery							
Year	Tanner Crab		Snow Crab		Red King Crab		Groundfish
	Male	Female	Male	Female	Male	Female	All
1973/74							17.735
1974/75							24.449
1975/76							9.408
1976/77							4.699
1977/78							2.776
1978/79							1.869
1979/80							3.397
1980/81							2.114
1981/82							1.474
1982/83							0.449
1983/84							0.671
1984/85							0.644
1985/86							0.399
1986/87							0.649
1987/88							0.640
1988/89							0.463
1989/90							0.671
1990/91							0.943
1991/92							2.545
1992/93	6.175	1.005	25.759	1.787	1.188	0.029	2.758
1993/94	3.870	1.028	14.530	1.814	2.967	0.198	1.760
1994/95	3.130	1.270	7.124	1.271	0.000	0.000	2.096
1995/96	2.762	1.760	4.797	1.759	0.000	0.000	1.524
1996/97	0.116	0.045	0.833	0.229	0.027	0.004	1.597
1997/98	0.000	0.000	1.750	0.226	0.165	0.003	1.179
1998/99	0.000	0.000	1.989	0.175	0.119	0.003	0.934
1999/00	0.000	0.000	0.695	0.145	0.076	0.004	0.630
2000/01	0.000	0.000	0.146	0.022	0.067	0.002	0.739
2001/02	0.000	0.000	0.323	0.011	0.043	0.002	1.184
2002/03	0.000	0.000	0.557	0.037	0.062	0.003	0.721
2003/04	0.000	0.000	0.193	0.026	0.056	0.003	0.422
2004/05	0.000	0.000	0.078	0.014	0.048	0.003	0.676
2005/06	0.462	0.044	0.968	0.043	0.042	0.002	0.621
2006/07	1.370	0.355	1.462	0.169	0.026	0.003	0.717
2007/08	2.041	0.097	1.872	0.102	0.056	0.009	0.694
2008/09	0.431	0.014	1.119	0.050	0.269	0.004	0.531
2009/10	0.071	0.002	1.324	0.014	0.150	0.001	0.374
2010/11	0.000	0.000	1.344	0.016	0.033	0.001	0.231
2011/12	0.000	0.000	2.119	0.014	0.017	0.000	0.203
2012/13	0.000	0.000	1.187	0.009	0.042	0.001	0.153
2013/14	0.536	0.024	1.829	0.016	0.109	0.001	0.333

Table 4. Sample sizes from the recalculated fishery data for retained catch-at-size in the directed fishery. N = number of individuals. N' = scaled sample size used in assessment.

year	new + old shell	
	N	N'
1980/81	13,310	95.4
1981/82	11,311	81.1
1982/83	13,519	96.9
1983/84	1,675	12.0
1984/85	2,542	18.2
1988/89	12,380	88.8
1989/90	4,123	29.6
1990/91	120,676	200.0
1991/92	126,299	200.0
1992/93	125,193	200.0
1993/94	71,622	200.0
1994/95	27,658	198.3
1995/96	1,525	10.9
1996/97	4,430	31.8
2005/06	705	5.1
2006/07	2,940	21.1
2007/08	6,935	49.7
2008/09	3,490	25.0
2009/10	2,417	17.3
2013/14	5,158	37.0

Table 5. Sample sizes from the recalculated fishery data for total catch-at-size in the directed fishery, from crab observer sampling. N = number of individuals. N' = scaled sample size used in assessment.

year	N		N'	
	males	females	males	females
1991/92	31,252	5,605	200.0	40.2
1992/93	54,836	8,755	200.0	62.8
1993/94	40,388	10,471	200.0	75.1
1994/95	5,792	2,132	41.5	15.3
1995/96	5,589	3,119	40.1	22.4
1996/97	352	168	2.5	1.2
2005/06	19,715	1,107	141.3	7.9
2006/07	24,226	4,432	173.7	31.8
2007/08	61,546	3,318	200.0	23.8
2008/09	29,166	646	200.0	4.6
2009/10	17,289	147	124.0	1.1
2013/14	17,288	710	123.9	5.1

Table 6. Sample sizes from the recalculated fishery data for total bycatch-at-size in the snow crab fishery, from crab observer sampling. N = number of individuals. N' = scaled sample size used in assessment.

year	N		N'	
	males	females	males	females
1992/93	6,280	859	45.0	6.2
1993/94	6,969	1,542	50.0	11.1
1994/95	2,982	1,523	21.4	10.9
1995/96	1,898	428	13.6	3.1
1996/97	3,265	662	23.4	4.7
1997/98	3,970	657	28.5	4.7
1998/99	1,911	324	13.7	2.3
1999/00	976	82	7.0	0.6
2000/01	1,237	74	8.9	0.5
2001/02	3,113	160	22.3	1.1
2002/03	982	118	7.0	0.8
2003/04	688	152	4.9	1.1
2004/05	848	707	6.1	5.1
2005/06	9,792	368	70.2	2.6
2006/07	10,391	1,256	74.5	9.0
2007/08	13,797	728	98.9	5.2
2008/09	8,455	722	60.6	5.2
2009/10	11,057	474	79.3	3.4
2010/11	12,073	250	86.6	1.8
2011/12	9,453	189	67.8	1.4
2012/13	7,336	190	52.6	1.4
2013/14	12,935	356	92.7	2.6

Table 7. Sample sizes from the recalculated fishery data for total bycatch-at-size in the BBRKC fishery, from crab observer sampling. N = number of individuals. N' = scaled sample size used in assessment.

year	N		N'	
	males	females	males	females
1992/93	2,056	105	14.7	0.8
1993/94	7,359	1,196	52.8	8.6
1996/97	114	5	0.8	0.0
1997/98	1,030	41	7.4	0.3
1998/99	457	20	3.3	0.1
1999/00	207	14	1.5	0.1
2000/01	845	44	6.1	0.3
2001/02	456	39	3.3	0.3
2002/03	750	50	5.4	0.4
2003/04	555	46	4.0	0.3
2004/05	487	44	3.5	0.3
2005/06	983	70	7.0	0.5
2006/07	798	76	5.7	0.5
2007/08	1,399	91	10.0	0.7
2008/09	3,797	121	27.2	0.9
2009/10	3,395	72	24.3	0.5
2010/11	595	30	4.3	0.2
2011/12	344	4	2.5	0.0
2012/13	618	48	4.4	0.3
2013/14	2,110	60	15.1	0.4

Table 8. Sample sizes from the recalculated fishery data for total catch-at-size in the groundfish fisheries, from groundfish observer sampling. N = number of individuals. N' = scaled sample size used in the assessment.

year	N		N'	
	males	females	males	females
1973/74	3,155	2,277	22.6	16.3
1974/75	2,492	1,600	17.9	11.5
1975/76	1,251	839	9.0	6.0
1976/77	6,950	6,683	49.8	47.9
1977/78	10,685	8,386	76.6	60.1
1978/79	18,596	13,665	133.3	98.0
1979/80	19,060	11,349	136.7	81.4
1980/81	12,806	5,917	91.8	42.4
1981/82	6,098	4,065	43.7	29.1
1982/83	13,439	8,006	96.4	57.4
1983/84	18,363	8,305	131.7	59.5
1984/85	27,403	13,771	196.5	98.7
1985/86	23,128	12,728	165.8	91.3
1986/87	14,860	7,626	106.5	54.7
1987/88	23,508	15,857	168.5	113.7
1988/89	10,586	7,126	75.9	51.1
1989/90	59,943	41,234	200.0	200.0
1990/91	23,545	11,212	168.8	80.4
1991/92	6,817	3,479	48.9	24.9
1992/93	3,128	1,175	22.4	8.4
1993/94	1,217	358	8.7	2.6
1994/95	3,628	1,820	26.0	13.0
1995/96	3,904	2,669	28.0	19.1
1996/97	8,306	3,400	59.6	24.4
1997/98	9,949	3,900	71.3	28.0
1998/99	12,105	4,440	86.8	31.8
1999/00	11,053	4,522	79.2	32.4
2000/01	12,895	3,087	92.5	22.1
2001/02	15,788	3,083	113.2	22.1
2002/03	15,401	3,249	110.4	23.3
2003/04	9,572	2,733	68.6	19.6
2004/05	13,844	4,460	99.3	32.0
2005/06	17,785	3,709	127.5	26.6
2006/07	15,903	3,047	114.0	21.8
2007/08	16,031	3,788	114.9	27.2
2008/09	25,976	4,164	186.2	29.9
2009/10	18,842	2,611	135.1	18.7
2010/11	15,069	2,207	108.0	15.8
2011/12	16,119	4,244	115.6	30.4
2012/13	12,987	3,083	93.1	22.1
2013/14	27,490	5,773	197.1	41.4

Table 9. Trends in mature Tanner crab biomass and abundance of legal crab (nominally defined as ≥ 138 mm CW) in the NMFS summer bottom trawl survey.

Observed Survey Mature Male and Female Biomass and Legal Male Abundance				
Year	Mature Biomass (1000 t)			Male ≥ 138 mm (10^6 crab)
	Male	Female	Total	
1974	212.01	55.76	267.77	87.53
1975	259.90	48.84	308.74	278.36
1976	152.94	69.47	222.41	165.96
1977	126.93	60.11	187.04	133.73
1978	77.67	35.42	113.09	83.57
1979	47.54	23.62	71.16	55.86
1980	81.11	58.99	140.10	91.12
1981	46.51	39.62	86.13	53.48
1982	46.24	51.79	98.03	58.48
1983	27.49	22.96	50.45	36.16
1984	23.99	18.70	42.69	30.50
1985	10.89	7.60	18.49	13.07
1986	11.23	5.95	17.18	11.82
1987	20.10	14.32	34.42	24.58
1988	54.16	39.32	93.48	58.16
1989	96.14	32.63	128.77	109.58
1990	99.04	46.17	145.21	114.44
1991	102.45	55.06	157.51	123.45
1992	104.33	34.59	138.92	125.15
1993	59.48	14.20	73.68	72.68
1994	41.72	12.90	54.62	50.91
1995	31.51	16.53	48.03	41.22
1996	24.99	11.83	36.82	31.43
1997	9.64	4.24	13.88	11.60
1998	9.03	2.95	11.98	10.50
1999	8.81	4.89	13.70	9.27
2000	14.20	5.38	19.58	15.85
2001	15.72	5.73	21.45	18.53
2002	14.67	4.56	19.23	16.38
2003	19.42	7.22	26.64	22.81
2004	22.78	4.94	27.72	28.59
2005	40.29	12.54	52.82	52.69
2006	55.24	19.00	74.24	71.90
2007	64.05	16.35	80.40	81.06
2008	55.98	13.18	69.15	71.22
2009	34.95	9.63	44.58	46.00
2010	32.01	3.89	35.91	42.30
2011	38.08	4.36	42.44	47.61
2012	29.68	6.74	36.42	34.46
2013	59.61	10.93	70.53	64.04
2014	73.30	9.02	82.33	85.70

Table 10. Sample sizes for NMFS survey catch-at-size. In the model, an effective sample size of 200 is used for all survey-related compositional data. Due to a change in software, non-zero hauls were not calculated for 2014.

Year	total hauls	Females				Males			
		new shell		old shell		new shell		old shell	
		non-zero hauls	crab	non-zero hauls	crab	non-zero hauls	crab	non-zero hauls	crab
1975	136	99	2,813	40	712	127	6,800	80	398
1976	209	154	4,660	80	872	169	7,282	92	598
1977	158	88	1,964	61	748	114	3,734	79	484
1978	230	104	2,593	67	1,320	147	4,548	103	699
1979	443	146	2,263	76	728	247	5,034	156	937
1980	360	156	3,409	80	723	202	9,636	101	854
1981	348	127	2,033	112	1,433	194	6,373	150	1,085
1982	342	117	1,338	104	2,391	181	3,182	147	2,083
1983	353	128	2,700	102	2,159	166	3,870	132	1,183
1984	355	146	2,228	99	1,543	176	2,528	126	1,399
1985	355	155	1,129	65	601	178	1,513	86	459
1986	353	175	1,855	68	338	213	2,772	115	468
1987	356	200	4,780	73	387	226	6,081	103	496
1988	373	220	5,611	102	538	252	7,754	102	476
1989	416	257	7,631	134	1,018	276	12,785	170	1,222
1990	383	230	4,826	134	1,597	261	9,103	163	1,541
1991	377	192	3,623	147	2,681	233	7,341	187	3,087
1992	355	151	2,391	123	2,205	215	5,099	177	1,925
1993	389	138	1,566	127	1,445	215	3,922	188	1,949
1994	376	112	1,088	107	1,403	179	2,089	176	1,902
1995	380	122	1,105	113	1,156	159	1,438	142	1,770
1996	375	131	1,086	99	1,000	150	1,390	135	1,427
1997	376	135	1,839	85	510	165	1,965	126	588
1998	375	154	1,989	75	350	177	2,529	129	640
1999	404	156	3,318	95	542	189	4,142	136	619
2000	395	162	2,672	57	349	200	3,708	144	686
2001	375	171	4,621	72	647	213	5,173	145	817
2002	375	162	4,062	70	502	188	4,485	155	1,093
2003	380	173	4,182	85	757	208	6,062	156	1,356
2004	383	192	4,439	86	1,028	245	6,101	187	1,912
2005	373	214	4,229	76	934	255	6,030	185	1,754
2006	410	228	6,013	134	1,452	275	8,457	241	4,569
2007	412	218	4,321	148	1,463	280	7,645	229	3,215
2008	410	189	2,821	127	1,804	258	6,199	219	2,334
2009	408	194	3,207	117	1,337	227	4,726	205	2,093
2010	403	205	3,877	111	1,011	234	5,888	180	2,080
2011	396	205	6,479	104	724	222	8,136	175	2,056
2012	396	219	5,141	103	768	235	7,987	148	1,367
2013	376	178	4,880	109	1,048	208	8,850	138	1,360
2014	376		3,067		1,589		8,311		3,067

Table 11. Effort data (1000's potlifts) in the snow crab and BBRKC fisheries (recalculated for 1990/91-2012/13).

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

Table 12. Comparison of parameter estimates and approximate standard deviations from the 2013 model and 2014 alternative models. Parameter names, types, bounds, and associated indices are also given. Blue highlighting indicates the parameter estimate is at the lower bound set for the parameter, whereas red highlighting indicates the parameter estimate is at the upper bound.

name	Parameter characteristics				Alt0a		Alt0b		Model Scenarios				2013	
	type	min	max	index	value	std.dev	value	std.dev	Alt1a		Alt1b		value	std.dev
af1	'param_init_bounded_number'	0.4	0.7	1	6.88E-01	5.21E-02	7.00E-01	1.40E-04	7.00E-01	7.93E-05	7.00E-01	7.62E-05	6.82E-01	5.20E-02
bf1	'param_init_bounded_number'	0.6	1.2	1	8.87E-01	1.25E-02	8.83E-01	1.20E-03	8.83E-01	1.23E-03	8.83E-01	1.24E-03	8.88E-01	1.24E-02
am1	'param_init_bounded_number'	0.3	0.6	1	4.46E-01	2.27E-02	4.32E-01	2.23E-02	4.27E-01	2.20E-02	4.26E-01	2.19E-02	4.43E-01	2.28E-02
bm1	'param_init_bounded_number'	0.7	1.2	1	9.66E-01	5.32E-03	9.70E-01	5.26E-03	9.71E-01	5.17E-03	9.71E-01	5.18E-03	9.66E-01	5.33E-03
Mmult_imat	'param_init_bounded_number'	0.2	2	1	1.08E+00	5.14E-02	1.06E+00	5.13E-02	1.07E+00	5.13E-02	1.07E+00	5.06E-02	1.07E+00	5.13E-02
Mmultm	'param_init_bounded_number'	0.1	1.9	1	1.09E+00	4.27E-02	1.13E+00	4.28E-02	1.08E+00	4.32E-02	1.12E+00	4.28E-02	1.09E+00	4.21E-02
Mmultf	'param_init_bounded_number'	0.1	1.9	1	1.46E+00	3.65E-02	1.42E+00	3.81E-02	1.46E+00	3.73E-02	1.44E+00	3.72E-02	1.46E+00	3.63E-02
mat_big	'param_init_bounded_vector'	0.1	10	1	9.54E-01	1.05E-01	9.71E-01	1.02E-01	1.07E+00	9.75E-02	1.12E+00	9.84E-02	9.38E-01	1.05E-01
mat_big	'param_init_bounded_vector'	0.1	10	2	2.96E+00	3.79E-01	2.85E+00	3.73E-01	2.59E+00	3.52E-01	2.58E+00	3.42E-01	2.89E+00	3.70E-01
pMnLnRec	'param_init_number'	-Inf	Inf	1	1.12E+01	8.36E-02	1.11E+01	7.85E-02	1.13E+01	7.11E-02	1.12E+01	7.10E-02	1.12E+01	8.66E-02
pRecDevs	'param_init_bounded_vector'	-15	15	1974	-1.08E+00	1.83E+00	-8.16E-01	1.47E+00	-1.94E-01	7.88E-01	-1.44E-01	7.89E-01	-1.16E+00	1.93E+00
pRecDevs	'param_init_bounded_vector'	-15	15	1975	1.04E+00	2.77E-01	1.09E+00	2.69E-01	1.03E+00	2.64E-01	1.09E+00	2.59E-01	1.03E+00	2.76E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1976	1.72E+00	1.40E-01	1.79E+00	1.37E-01	1.85E+00	1.27E-01	1.87E+00	1.27E-01	1.69E+00	1.41E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1977	1.40E+00	1.76E-01	1.44E+00	1.70E-01	1.36E+00	1.67E-01	1.38E+00	1.68E-01	1.38E+00	1.78E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1978	1.28E+00	1.60E-01	1.28E+00	1.58E-01	1.20E+00	1.58E-01	1.21E+00	1.59E-01	1.25E+00	1.62E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1979	-3.64E-02	3.53E-01	-7.49E-02	3.50E-01	-2.10E-01	3.75E-01	-1.82E-01	3.73E-01	-6.95E-02	3.57E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1980	-1.56E+00	1.01E+00	-1.39E+00	8.46E-01	-1.16E+00	6.44E-01	-1.14E+00	6.44E-01	-1.62E+00	1.05E+00
pRecDevs	'param_init_bounded_vector'	-15	15	1981	-3.36E-01	2.79E-01	-3.56E-01	2.75E-01	-3.02E-01	2.50E-01	-2.77E-01	2.49E-01	-3.53E-01	2.82E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1982	-1.26E+00	4.70E-01	-1.17E+00	4.29E-01	-1.00E+00	3.83E-01	-9.92E-01	3.84E-01	-1.27E+00	4.69E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1983	9.81E-01	1.24E-01	9.94E-01	1.18E-01	9.66E-01	1.08E-01	9.72E-01	1.08E-01	9.69E-01	1.27E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1984	8.03E-01	1.85E-01	8.21E-01	1.78E-01	7.70E-01	1.59E-01	7.69E-01	1.58E-01	7.99E-01	1.87E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1985	1.59E+00	1.35E-01	1.50E+00	1.35E-01	1.43E+00	1.18E-01	1.41E+00	1.18E-01	1.57E+00	1.37E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1986	1.35E+00	1.60E-01	1.34E+00	1.52E-01	1.26E+00	1.33E-01	1.22E+00	1.33E-01	1.34E+00	1.61E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1987	1.31E+00	1.54E-01	1.21E+00	1.50E-01	1.19E+00	1.33E-01	1.13E+00	1.33E-01	1.30E+00	1.56E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1988	1.00E+00	1.59E-01	9.14E-01	1.53E-01	1.09E+00	1.25E-01	1.00E+00	1.26E-01	9.86E-01	1.61E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1989	4.02E-01	1.75E-01	3.20E-01	1.72E-01	2.61E-01	1.68E-01	1.91E-01	1.68E-01	3.95E-01	1.77E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1990	-4.49E-01	2.43E-01	-5.16E-01	2.39E-01	-5.51E-01	2.31E-01	-6.09E-01	2.31E-01	-4.56E-01	2.46E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1991	-1.15E+00	2.98E-01	-1.25E+00	3.01E-01	-1.31E+00	3.08E-01	-1.37E+00	3.10E-01	-1.15E+00	3.00E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1992	-1.40E+00	2.68E-01	-1.43E+00	2.60E-01	-1.48E+00	2.62E-01	-1.50E+00	2.61E-01	-1.40E+00	2.68E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1993	-1.60E+00	2.56E-01	-1.62E+00	2.55E-01	-1.66E+00	2.56E-01	-1.69E+00	2.57E-01	-1.58E+00	2.57E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1994	-1.62E+00	2.42E-01	-1.61E+00	2.38E-01	-1.53E+00	2.22E-01	-1.56E+00	2.24E-01	-1.61E+00	2.44E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1995	-1.27E+00	1.92E-01	-1.28E+00	1.91E-01	-1.16E+00	1.74E-01	-1.17E+00	1.75E-01	-1.27E+00	1.94E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1996	-1.15E+00	2.02E-01	-1.16E+00	2.01E-01	-1.19E+00	1.99E-01	-1.19E+00	2.00E-01	-1.15E+00	2.03E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1997	-1.98E-01	1.16E-01	-1.73E-01	1.12E-01	-1.96E-01	1.04E-01	-1.72E-01	1.04E-01	-2.02E-01	1.18E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1998	-1.06E+00	1.92E-01	-1.05E+00	1.91E-01	-1.13E+00	1.87E-01	-1.10E+00	1.87E-01	-1.06E+00	1.94E-01
pRecDevs	'param_init_bounded_vector'	-15	15	1999	6.85E-02	1.17E-01	8.75E-02	1.12E-01	1.35E-02	1.05E-01	4.33E-02	1.05E-01	6.68E-02	1.19E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2000	-4.69E-01	1.87E-01	-4.62E-01	1.86E-01	-4.84E-01	1.77E-01	-4.60E-01	1.78E-01	-4.73E-01	1.88E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2001	6.72E-01	1.09E-01	6.87E-01	1.04E-01	6.45E-01	9.68E-02	6.73E-01	9.66E-02	6.62E-01	1.11E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2002	-2.70E-01	2.00E-01	-2.71E-01	1.98E-01	-2.37E-01	1.87E-01	-2.14E-01	1.88E-01	-2.87E-01	2.01E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2003	3.03E-01	1.51E-01	3.04E-01	1.48E-01	3.47E-01	1.36E-01	3.67E-01	1.36E-01	2.88E-01	1.52E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2004	1.01E+00	1.02E-01	1.02E+00	9.74E-02	9.46E-01	9.11E-02	9.70E-01	9.11E-02	9.81E-01	1.04E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2005	-2.09E-01	2.04E-01	-2.11E-01	2.02E-01	-2.34E-01	1.95E-01	-2.12E-01	1.95E-01	-2.43E-01	2.06E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2006	-4.13E-01	2.21E-01	-4.17E-01	2.19E-01	-4.20E-01	2.08E-01	-4.00E-01	2.08E-01	-4.44E-01	2.23E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2007	-6.59E-01	2.57E-01	-6.63E-01	2.54E-01	-7.68E-01	2.57E-01	-7.55E-01	2.57E-01	-6.91E-01	2.59E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2008	-5.67E-01	2.58E-01	-5.80E-01	2.57E-01	-6.21E-01	2.50E-01	-6.15E-01	2.51E-01	-5.86E-01	2.58E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2009	1.06E+00	1.20E-01	1.06E+00	1.16E-01	1.05E+00	1.07E-01	1.07E+00	1.07E-01	9.88E-01	1.34E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2010	1.05E+00	1.27E-01	1.04E+00	1.24E-01	1.11E+00	1.14E-01	1.11E+00	1.14E-01	1.16E+00	1.40E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2011	4.48E-01	1.69E-01	4.28E-01	1.67E-01	4.25E-01	1.65E-01	4.18E-01	1.65E-01	5.42E-01	1.88E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2012	-1.06E+00	4.14E-01	-1.08E+00	4.13E-01	-1.17E+00	4.28E-01	-1.18E+00	4.28E-01	-7.92E-01	4.16E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2013	1.32E-01	2.03E-01	9.92E-02	2.00E-01	-1.76E-01	2.30E-01	-1.93E-01	2.30E-01	4.81E-01	2.40E-01
pRecDevs	'param_init_bounded_vector'	-15	15	2014	1.92E-01	2.49E-01	1.48E-01	2.47E-01	2.45E-01	2.38E-01	2.21E-01	2.38E-01		

Table 12 (cont.)

Parameter characteristics					Model Scenarios									
name	type	min	max	index	Alt0a		Alt0b		Alt1a		Alt1b		2013	
					value	std.dev	value	std.dev	value	std.dev	value	std.dev	value	std.dev
pMnLnRecEarly	'param_init_number'	-Inf	Inf	1	1.19E+01	5.05E-01	1.18E+01	5.12E-01	1.19E+01	5.08E-01	1.18E+01	5.11E-01	1.18E+01	5.04E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1949	-1.51E+00	1.61E+00	-1.51E+00	1.62E+00	-1.50E+00	1.61E+00	-1.49E+00	1.62E+00	-1.54E+00	1.61E+00
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1950	-1.51E+00	1.47E+00	-1.50E+00	1.48E+00	-1.49E+00	1.47E+00	-1.49E+00	1.48E+00	-1.54E+00	1.46E+00
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1951	-1.50E+00	1.33E+00	-1.50E+00	1.34E+00	-1.49E+00	1.33E+00	-1.48E+00	1.34E+00	-1.53E+00	1.33E+00
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1952	-1.49E+00	1.20E+00	-1.49E+00	1.21E+00	-1.47E+00	1.20E+00	-1.47E+00	1.21E+00	-1.52E+00	1.20E+00
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1953	-1.47E+00	1.08E+00	-1.47E+00	1.09E+00	-1.46E+00	1.08E+00	-1.45E+00	1.09E+00	-1.50E+00	1.08E+00
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1954	-1.44E+00	9.72E-01	-1.44E+00	9.80E-01	-1.43E+00	9.75E-01	-1.42E+00	9.79E-01	-1.47E+00	9.70E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1955	-1.39E+00	8.81E-01	-1.40E+00	8.88E-01	-1.38E+00	8.85E-01	-1.38E+00	8.87E-01	-1.42E+00	8.80E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1956	-1.33E+00	8.10E-01	-1.34E+00	8.15E-01	-1.32E+00	8.13E-01	-1.32E+00	8.14E-01	-1.36E+00	8.09E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1957	-1.23E+00	7.59E-01	-1.25E+00	7.62E-01	-1.22E+00	7.61E-01	-1.23E+00	7.62E-01	-1.26E+00	7.58E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1958	-1.09E+00	7.27E-01	-1.11E+00	7.29E-01	-1.08E+00	7.29E-01	-1.09E+00	7.30E-01	-1.12E+00	7.26E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1959	-8.75E-01	7.12E-01	-9.06E-01	7.13E-01	-8.69E-01	7.13E-01	-8.83E-01	7.14E-01	-9.01E-01	7.11E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1960	-5.37E-01	7.10E-01	-5.73E-01	7.12E-01	-5.34E-01	7.11E-01	-5.52E-01	7.12E-01	-5.52E-01	7.09E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1961	1.59E-02	7.21E-01	-3.08E-02	7.23E-01	1.36E-02	7.22E-01	-8.63E-03	7.23E-01	5.19E-04	7.19E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1962	8.12E-01	7.23E-01	7.61E-01	7.26E-01	8.05E-01	7.25E-01	7.81E-01	7.26E-01	8.02E-01	7.21E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1963	1.53E+00	7.12E-01	1.53E+00	7.13E-01	1.57E+00	7.12E-01	1.55E+00	7.13E-01	1.57E+00	7.08E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1964	1.93E+00	6.94E-01	1.86E+00	6.91E-01	1.89E+00	6.90E-01	1.88E+00	6.91E-01	1.91E+00	6.89E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1965	1.90E+00	6.93E-01	1.81E+00	6.91E-01	1.82E+00	6.87E-01	1.81E+00	6.89E-01	1.88E+00	6.90E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1966	1.72E+00	6.91E-01	1.64E+00	6.94E-01	1.62E+00	6.88E-01	1.62E+00	6.91E-01	1.72E+00	6.90E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1967	1.55E+00	6.76E-01	1.52E+00	6.80E-01	1.46E+00	6.75E-01	1.47E+00	6.78E-01	1.58E+00	6.74E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1968	1.43E+00	6.65E-01	1.50E+00	6.58E-01	1.41E+00	6.58E-01	1.44E+00	6.58E-01	1.51E+00	6.58E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1969	1.36E+00	6.80E-01	1.52E+00	6.65E-01	1.42E+00	6.62E-01	1.47E+00	6.61E-01	1.48E+00	6.74E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1970	1.12E+00	6.21E-01	1.28E+00	6.19E-01	1.24E+00	6.11E-01	1.28E+00	6.12E-01	1.20E+00	6.17E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1971	7.44E-01	5.71E-01	8.18E-01	5.76E-01	8.36E-01	5.68E-01	8.51E-01	5.71E-01	7.81E-01	5.70E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1972	6.46E-01	5.49E-01	6.94E-01	5.55E-01	6.68E-01	5.51E-01	6.71E-01	5.55E-01	6.89E-01	5.48E-01
pRecDevsEarly	'param_init_bounded_vector'	-15	15	1973	5.46E-01	5.46E-01	5.93E-01	5.52E-01	4.68E-01	5.57E-01	4.62E-01	5.60E-01	5.92E-01	5.45E-01
pAvgLnFmTCF	'param_init_number'	-Inf	Inf	1	-1.60E+00	1.04E-01	-1.61E+00	9.07E-02	-1.66E+00	8.73E-02	-1.62E+00	8.72E-02	-1.50E+00	1.07E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	1	-5.11E-01	4.96E-01	-5.14E-01	4.95E-01	-5.21E-01	4.94E-01	-5.17E-01	4.95E-01	-5.12E-01	4.96E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	2	-7.55E-01	3.85E-01	-7.57E-01	3.83E-01	-7.65E-01	3.82E-01	-7.59E-01	3.83E-01	-7.54E-01	3.84E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	3	4.03E-01	3.46E-01	4.07E-01	3.40E-01	3.98E-01	3.37E-01	4.06E-01	3.39E-01	4.10E-01	3.46E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	4	1.80E-01	3.31E-01	2.11E-01	3.24E-01	2.10E-01	3.19E-01	2.17E-01	3.21E-01	1.91E-01	3.30E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	5	2.81E-01	3.22E-01	3.40E-01	3.15E-01	3.49E-01	3.08E-01	3.56E-01	3.11E-01	2.97E-01	3.24E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	6	6.32E-02	3.13E-01	1.47E-01	3.13E-01	1.69E-01	3.02E-01	1.76E-01	3.07E-01	7.79E-02	3.18E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	7	-1.93E-01	2.84E-01	-1.05E-01	2.94E-01	-6.51E-02	2.80E-01	-6.04E-02	2.87E-01	-1.89E-01	2.94E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	8	-4.01E-01	2.26E-01	-3.37E-01	2.41E-01	-2.74E-01	2.28E-01	-2.76E-01	2.34E-01	-4.19E-01	2.37E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	9	-6.48E-01	1.47E-01	-6.34E-01	1.55E-01	-5.46E-01	1.48E-01	-5.60E-01	1.52E-01	-6.94E-01	1.52E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	10	-4.26E-01	9.72E-02	-4.61E-01	9.90E-02	-3.60E-01	9.65E-02	-3.84E-01	9.76E-02	-4.94E-01	9.92E-02
pFmDevsTCF	'param_init_bounded_vector'	-15	15	11	-1.32E-01	9.02E-02	-1.91E-01	9.08E-02	-9.45E-02	8.79E-02	-1.22E-01	8.90E-02	-2.08E-01	9.22E-02
pFmDevsTCF	'param_init_bounded_vector'	-15	15	12	6.76E-01	8.94E-02	6.08E-01	8.90E-02	6.99E-01	8.56E-02	6.76E-01	8.67E-02	6.02E-01	9.14E-02
pFmDevsTCF	'param_init_bounded_vector'	-15	15	13	1.32E+00	9.59E-02	1.25E+00	9.19E-02	1.36E+00	8.86E-02	1.35E+00	8.98E-02	1.25E+00	9.73E-02
pFmDevsTCF	'param_init_bounded_vector'	-15	15	14	1.42E+00	1.23E-01	1.35E+00	1.11E-01	1.49E+00	1.06E-01	1.50E+00	1.08E-01	1.35E+00	1.23E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	15	2.19E+00	2.19E-01	2.11E+00	1.73E-01	2.25E+00	1.60E-01	2.27E+00	1.64E-01	2.15E+00	2.23E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	16	2.35E+00	2.45E-01	2.39E+00	2.38E-01	2.35E+00	2.17E-01	2.36E+00	2.22E-01	2.30E+00	2.51E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	17	6.92E-01	1.38E-01	8.01E-01	1.55E-01	7.30E-01	1.54E-01	6.99E-01	1.50E-01	6.14E-01	1.38E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	18	-3.29E-01	1.31E-01	-3.03E-01	1.31E-01	-3.60E-01	1.28E-01	-3.72E-01	1.28E-01	-4.16E-01	1.31E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	19	-1.47E+00	2.54E-01	-1.46E+00	2.54E-01	-1.52E+00	2.50E-01	-1.51E+00	2.50E-01	-1.55E+00	2.52E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	20	-3.52E-01	1.87E-01	-3.39E-01	1.88E-01	-4.51E-01	1.81E-01	-4.28E-01	1.81E-01	-4.54E-01	1.87E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	21	-9.15E-01	2.18E-01	-9.74E-01	2.18E-01	-1.08E+00	2.16E-01	-1.07E+00	2.16E-01	-9.89E-01	2.17E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	22	-2.70E-01	1.15E-01	-2.72E-01	1.14E-01	-3.19E-01	1.10E-01	-3.20E-01	1.10E-01	-2.89E-01	1.16E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	23	8.56E-01	9.36E-02	8.20E-01	9.10E-02	7.98E-01	8.67E-02	8.11E-01	8.72E-02	7.75E-01	9.55E-02

Table 12 (cont.).

Parameter characteristics					Model Scenarios									
name	type	min	max	index	Alt0a		Alt0b		Alt1a		Alt1b		2013	
					value	std.dev	value	std.dev	value	std.dev	value	std.dev	value	std.dev
pFmDevsTCF	'param_init_bounded_vector'	-15	15	24	1.34E+00	9.82E-02	1.36E+00	9.64E-02	1.37E+00	9.16E-02	1.40E+00	9.22E-02	1.26E+00	1.00E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	25	1.26E+00	1.19E-01	1.35E+00	1.10E-01	1.39E+00	1.07E-01	1.40E+00	1.06E-01	1.16E+00	1.20E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	26	1.75E+00	1.29E-01	2.00E+00	1.48E-01	1.91E+00	1.41E-01	2.04E+00	1.55E-01	1.64E+00	1.29E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	27	1.23E+00	1.38E-01	1.43E+00	1.55E-01	1.14E+00	1.25E-01	1.24E+00	1.32E-01	1.11E+00	1.37E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	28	6.26E-01	1.53E-01	7.83E-01	1.64E-01	6.12E-01	1.45E-01	7.25E-01	1.55E-01	4.99E-01	1.52E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	29	1.06E-01	1.49E-01	1.43E-01	1.54E-01	1.18E-01	1.37E-01	1.01E-01	1.47E-01	-2.22E-02	1.49E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	30	-5.66E-01	3.78E-01	-1.14E+00	1.77E-01	-1.16E+00	1.76E-01	-1.12E+00	1.77E-01	-5.76E-01	3.69E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	31	-2.08E+00	2.22E-01	-2.07E+00	2.23E-01	-1.99E+00	2.10E-01	-2.03E+00	2.17E-01	-2.18E+00	2.22E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	32	-1.51E+00	1.50E-01	-1.56E+00	1.52E-01	-1.47E+00	1.41E-01	-1.56E+00	1.48E-01	-1.61E+00	1.53E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	33	-1.47E+00	1.38E-01	-1.56E+00	1.41E-01	-1.50E+00	1.30E-01	-1.63E+00	1.39E-01	-1.56E+00	1.41E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	34	-1.60E+00	1.79E-01	-1.61E+00	1.77E-01	-1.69E+00	1.66E-01	-1.73E+00	1.69E-01	-1.69E+00	1.81E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	35	-1.05E+00	2.81E-01	-1.07E+00	2.75E-01	-1.06E+00	2.89E-01	-1.10E+00	2.86E-01	-1.10E+00	2.88E-01
pFmDevsTCF	'param_init_bounded_vector'	-15	15	36	-2.14E+00	1.91E-01	-2.15E+00	1.93E-01	-2.12E+00	1.86E-01	-2.15E+00	1.92E-01		
pAvgLnFmGTF	'param_init_number'	-Inf	Inf	1	-4.52E+00	7.31E-02	-4.33E+00	1.08E-01	-4.26E+00	7.66E-02	-4.21E+00	7.45E-02	-4.57E+00	7.24E-02
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1973	8.22E-01	8.93E-02	7.68E-01	1.20E-01	8.07E-01	9.73E-02	7.91E-01	9.61E-02	8.79E-01	8.73E-02
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1974	1.22E+00	7.83E-02	1.19E+00	1.10E-01	1.22E+00	8.35E-02	1.20E+00	8.16E-02	1.32E+00	7.57E-02
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1975	4.68E-01	8.02E-02	3.86E-01	1.11E-01	4.15E-01	8.45E-02	4.00E-01	8.26E-02	5.19E-01	7.77E-02
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1976	-2.59E-02	9.32E-02	-9.77E-02	1.21E-01	-6.27E-02	9.66E-02	-7.46E-02	9.48E-02	2.61E-02	9.11E-02
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1977	-2.94E-01	1.22E-01	-3.28E-01	1.44E-01	-2.72E-01	1.24E-01	-2.80E-01	1.22E-01	-2.42E-01	1.20E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1978	-4.83E-01	1.60E-01	-4.72E-01	1.77E-01	-4.03E-01	1.61E-01	-4.08E-01	1.59E-01	-4.31E-01	1.59E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1979	2.04E-01	1.19E-01	2.42E-01	1.41E-01	3.12E-01	1.19E-01	3.12E-01	1.18E-01	2.60E-01	1.16E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1980	-5.91E-02	1.53E-01	1.52E-02	1.72E-01	8.24E-02	1.55E-01	8.58E-02	1.54E-01	-6.18E-03	1.51E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1981	-2.44E-01	1.93E-01	-1.79E-01	2.08E-01	-1.22E-01	1.95E-01	-1.19E-01	1.94E-01	-1.97E-01	1.92E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1982	-9.56E-01	3.86E-01	-9.25E-01	3.95E-01	-9.02E-01	3.94E-01	-8.95E-01	3.94E-01	-9.18E-01	3.88E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1983	-4.82E-01	3.46E-01	-4.56E-01	3.57E-01	-4.43E-01	3.57E-01	-4.32E-01	3.58E-01	-4.46E-01	3.47E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1984	-2.26E-01	3.69E-01	-2.26E-01	3.84E-01	-2.24E-01	3.90E-01	-2.06E-01	3.92E-01	-2.37E-01	3.71E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1985	-6.43E-01	4.50E-01	-6.05E-01	4.64E-01	-6.39E-01	4.77E-01	-6.26E-01	4.81E-01	-6.12E-01	4.52E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1986	-6.12E-01	3.64E-01	-5.75E-01	3.76E-01	-5.92E-01	3.78E-01	-5.77E-01	3.81E-01	-5.77E-01	3.66E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1987	-9.37E-01	3.53E-01	-7.35E-01	4.09E-01	-7.47E-01	3.81E-01	-7.94E-01	3.79E-01	-8.98E-01	3.54E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1988	-1.33E+00	3.79E-01	-1.14E+00	4.35E-01	-1.18E+00	4.07E-01	-1.21E+00	4.05E-01	-1.29E+00	3.81E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1989	-1.20E+00	3.21E-01	-1.00E+00	3.85E-01	-1.05E+00	3.45E-01	-1.08E+00	3.43E-01	-1.16E+00	3.22E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1990	-8.84E-01	2.63E-01	-6.61E-01	3.40E-01	-7.12E-01	2.88E-01	-7.31E-01	2.85E-01	-8.47E-01	2.64E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1991	2.16E-01	1.24E-01	4.61E-01	2.55E-01	4.13E-01	1.47E-01	4.05E-01	1.40E-01	2.51E-01	1.23E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1992	5.69E-01	1.17E-01	7.96E-01	2.54E-01	7.23E-01	1.37E-01	7.24E-01	1.31E-01	6.03E-01	1.16E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1993	4.68E-01	1.62E-01	6.59E-01	2.75E-01	5.85E-01	1.77E-01	5.81E-01	1.72E-01	4.98E-01	1.61E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1994	9.70E-01	1.41E-01	1.14E+00	2.63E-01	1.09E+00	1.55E-01	1.08E+00	1.49E-01	9.97E-01	1.40E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1995	1.01E+00	1.77E-01	1.16E+00	2.79E-01	1.13E+00	1.91E-01	1.12E+00	1.85E-01	1.04E+00	1.76E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1996	1.35E+00	1.67E-01	1.50E+00	2.69E-01	1.48E+00	1.82E-01	1.47E+00	1.76E-01	1.37E+00	1.66E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1997	1.56E+00	2.33E-01	1.42E+00	2.39E-01	1.51E+00	2.34E-01	1.56E+00	2.28E-01	1.39E+00	2.28E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1998	1.32E+00	3.25E-01	1.18E+00	3.23E-01	1.25E+00	3.22E-01	1.26E+00	3.16E-01	1.14E+00	3.20E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	1999	8.69E-01	4.81E-01	7.48E-01	4.62E-01	7.31E-01	4.84E-01	7.23E-01	4.81E-01	7.14E-01	4.60E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2000	9.56E-01	3.87E-01	8.30E-01	3.80E-01	7.92E-01	3.94E-01	7.87E-01	3.94E-01	7.94E-01	3.77E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2001	1.26E+00	2.46E-01	1.12E+00	2.52E-01	1.11E+00	2.47E-01	1.10E+00	2.47E-01	1.10E+00	2.43E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2002	5.80E-01	3.77E-01	4.55E-01	3.72E-01	4.70E-01	3.66E-01	4.70E-01	3.66E-01	4.28E-01	3.69E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2003	-6.14E-03	4.88E-01	-1.15E-01	4.73E-01	-1.09E-01	4.73E-01	-1.09E-01	4.73E-01	-1.32E-01	4.70E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2004	1.27E-01	3.70E-01	5.69E-03	3.66E-01	1.61E-02	3.61E-01	1.83E-02	3.60E-01	-1.67E-02	3.64E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2005	-1.13E-01	3.76E-01	-2.32E-01	3.72E-01	-2.48E-01	3.69E-01	-2.42E-01	3.69E-01	-2.38E-01	3.71E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2006	-8.71E-02	3.33E-01	-2.08E-01	3.33E-01	-2.34E-01	3.28E-01	-2.23E-01	3.28E-01	-2.09E-01	3.28E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2007	-2.17E-01	3.33E-01	-3.38E-01	3.32E-01	-3.68E-01	3.27E-01	-3.55E-01	3.26E-01	-3.34E-01	3.27E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2008	-5.15E-01	3.76E-01	-6.31E-01	3.72E-01	-6.69E-01	3.67E-01	-6.54E-01	3.67E-01	-6.01E-01	3.70E-01

Table 12 (cont.).

Parameter characteristics					Model Scenarios									
name	type	min	max	index	Alt0a		Alt0b		Alt1a		Alt1b		2013	
					value	std.dev	value	std.dev	value	std.dev	value	std.dev	value	std.dev
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2009	-8.07E-01	4.50E-01	-9.13E-01	4.41E-01	-8.91E-01	4.21E-01	-8.75E-01	4.22E-01	-8.68E-01	4.42E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2010	-9.04E-01	4.94E-01	-1.00E+00	4.84E-01	-1.02E+00	4.73E-01	-1.00E+00	4.75E-01	-9.57E-01	4.85E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2011	-8.88E-01	5.06E-01	-9.83E-01	4.95E-01	-1.01E+00	4.89E-01	-9.93E-01	4.92E-01	-9.51E-01	4.94E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2012	-1.09E+00	5.19E-01	-1.18E+00	5.09E-01	-1.14E+00	4.95E-01	-1.13E+00	4.98E-01	-1.16E+00	5.03E-01
pFmDevsGTF	'param_init_bounded_vector'	-15	15	2013	-9.68E-01	4.47E-01	-1.07E+00	4.41E-01	-1.10E+00	4.31E-01	-1.08E+00	4.34E-01		
pAvgLnFmSCF	'param_init_number'	-Inf	Inf	1	-3.42E+00	1.25E-01	-3.72E+00	1.40E-01	-3.54E+00	1.12E-01	-3.85E+00	1.61E-01	-3.43E+00	1.32E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1992	2.09E+00	1.41E-01	2.00E+00	1.50E-01	2.08E+00	1.07E-01	2.04E+00	1.58E-01	2.09E+00	1.46E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1993	1.87E+00	1.48E-01	1.74E+00	1.59E-01	1.84E+00	1.12E-01	1.78E+00	1.64E-01	1.87E+00	1.54E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1994	1.52E+00	1.61E-01	1.36E+00	1.81E-01	1.49E+00	1.25E-01	1.42E+00	1.83E-01	1.51E+00	1.66E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1995	1.51E+00	1.74E-01	1.35E+00	2.03E-01	1.48E+00	1.42E-01	1.42E+00	2.05E-01	1.49E+00	1.78E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1996	1.19E-01	4.31E-01	1.48E-01	5.19E-01	1.61E-01	4.10E-01	2.86E-01	5.05E-01	6.58E-02	4.41E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1997	7.18E-01	2.78E-01	6.71E-01	3.95E-01	8.03E-01	2.75E-01	-3.71E-02	8.19E-01	6.71E-01	2.81E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1998	7.79E-01	2.95E-01	5.61E-01	4.80E-01	8.16E-01	3.00E-01	-3.58E-01	7.97E-01	7.22E-01	3.01E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	1999	-3.05E-01	5.82E-01	-3.10E-01	6.92E-01	-2.74E-01	5.90E-01	-3.74E-01	7.99E-01	-3.60E-01	5.86E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2000	-7.93E-01	6.01E-01	-5.89E-01	6.66E-01	-7.65E-01	6.09E-01	-3.94E-01	7.93E-01	-8.29E-01	6.01E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2001	-7.52E-01	5.57E-01	-5.80E-01	6.32E-01	-7.11E-01	5.65E-01	-4.29E-01	7.80E-01	-7.86E-01	5.60E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2002	-6.81E-01	5.07E-01	-5.69E-01	5.97E-01	-6.19E-01	5.13E-01	-4.87E-01	7.63E-01	-7.13E-01	5.12E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2003	-1.08E+00	5.22E-01	-8.36E-01	5.82E-01	-1.02E+00	5.29E-01	-4.30E-01	7.57E-01	-1.09E+00	5.24E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2004	-1.36E+00	5.11E-01	-1.09E+00	5.61E-01	-1.32E+00	5.18E-01	-5.91E-01	7.19E-01	-1.38E+00	5.13E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2005	-5.45E-01	4.03E-01	-5.36E-01	5.14E-01	-5.76E-01	3.99E-01	-5.33E-01	5.17E-01	-5.88E-01	4.05E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2006	-2.10E-01	3.08E-01	-2.62E-01	4.30E-01	-2.57E-01	3.02E-01	-2.64E-01	4.31E-01	-2.48E-01	3.10E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2007	-1.19E-01	2.55E-01	-1.80E-01	3.62E-01	-1.69E-01	2.49E-01	-1.84E-01	3.66E-01	-1.45E-01	2.58E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2008	-6.90E-01	3.36E-01	-6.48E-01	4.32E-01	-7.40E-01	3.34E-01	-6.63E-01	4.41E-01	-7.05E-01	3.36E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2009	-5.51E-01	3.21E-01	-5.50E-01	4.30E-01	-5.96E-01	3.17E-01	-5.61E-01	4.36E-01	-5.62E-01	3.21E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2010	-4.64E-01	3.30E-01	-4.84E-01	4.50E-01	-5.00E-01	3.24E-01	-4.84E-01	4.53E-01	-4.66E-01	3.29E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2011	-4.51E-02	2.48E-01	-5.26E-02	3.68E-01	1.70E-02	2.41E-01	-3.67E-02	3.71E-01	-4.66E-02	2.49E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2012	-6.14E-01	3.62E-01	-6.20E-01	4.75E-01	-6.37E-01	3.55E-01	-6.11E-01	4.78E-01	-5.89E-01	3.57E-01
pFmDevsSCF	'param_init_bounded_vector'	-15	15	2013	-4.72E-01	2.66E-01	-5.22E-01	3.71E-01	-5.04E-01	2.58E-01	-5.01E-01	3.71E-01		
fish_fit_slope_mn1	'param_init_bounded_number'	0.25	1.001	1	7.33E-01	1.40E-01	7.30E-01	1.35E-01	7.12E-01	1.26E-01	7.28E-01	1.31E-01	7.33E-01	1.41E-01
fish_fit_se150_mn1	'param_init_bounded_number'	85	160	1	1.38E+02	4.11E-01	1.38E+02	4.00E-01	1.38E+02	4.15E-01	1.38E+02	3.94E-01	1.38E+02	4.08E-01
fish_fit_slope_mn2	'param_init_bounded_number'	0.25	2.001	1	8.25E-01	1.33E-01	8.41E-01	1.31E-01	8.44E-01	1.24E-01	8.42E-01	1.18E-01	1.02E+00	2.83E-01
fish_fit_se150_mn2	'param_init_bounded_number'	85	160	1	1.38E+02	2.43E-01	1.37E+02	2.47E-01	1.37E+02	2.63E-01	1.37E+02	3.03E-01	1.38E+02	2.42E-01
fish_slope_1	'param_init_bounded_number'	0.05	0.75	1	1.31E-01	9.97E-03	1.33E-01	9.08E-03	1.23E-01	7.10E-03	1.24E-01	6.89E-03	1.30E-01	9.95E-03
fish_slope_yr_3	'param_init_bounded_number'	0.1	0.4	1	1.37E-01	8.91E-03	1.38E-01	9.08E-03	1.35E-01	8.36E-03	1.36E-01	8.52E-03	1.34E-01	9.21E-03
log_avg_se150_3	'param_init_bounded_number'	4	5	1	4.87E+00	1.29E-02	4.83E+00	9.40E-03	4.82E+00	9.18E-03	4.83E+00	8.90E-03	4.88E+00	1.28E-02
log_se150_dev_3	'param_init_bounded_vector'	-0.5	0.5	1	1.92E-02	2.33E-02	4.89E-02	2.08E-02	5.63E-02	1.78E-02	4.71E-02	1.78E-02	1.40E-02	2.27E-02
log_se150_dev_3	'param_init_bounded_vector'	-0.5	0.5	2	7.13E-02	1.63E-02	1.31E-01	1.49E-02	1.37E-01	1.48E-02	1.45E-01	1.53E-02	6.40E-02	1.55E-02
log_se150_dev_3	'param_init_bounded_vector'	-0.5	0.5	3	4.97E-02	1.87E-02	1.12E-01	1.70E-02	9.63E-02	1.56E-02	1.05E-01	1.56E-02	4.21E-02	1.80E-02
log_se150_dev_3	'param_init_bounded_vector'	-0.5	0.5	4	3.63E-02	2.42E-02	9.79E-02	2.10E-02	7.73E-02	2.30E-02	9.81E-02	2.15E-02	2.83E-02	2.35E-02
log_se150_dev_3	'param_init_bounded_vector'	-0.5	0.5	5	-5.42E-02	3.28E-02	6.63E-03	2.84E-02	-1.79E-02	3.09E-02	-3.78E-03	2.99E-02	-6.17E-02	3.23E-02
log_se150_dev_3	'param_init_bounded_vector'	-0.5	0.5	6	-2.60E-02	1.05E-01	-4.99E-01	2.21E-02	-4.99E-01	2.02E-02	-4.99E-01	1.81E-02	2.46E-03	8.65E-02
log_se150_dev_3	'param_init_bounded_vector'	-0.5	0.5	7	-9.50E-02	2.43E-02	-6.23E-02	2.30E-02	-3.93E-02	2.01E-02	-4.64E-02	2.01E-02	-1.02E-01	2.43E-02
log_se150_dev_3	'param_init_bounded_vector'	-0.5	0.5	8	-9.29E-02	2.21E-02	-6.00E-02	2.06E-02	-4.57E-02	2.00E-02	-5.28E-02	2.00E-02	-1.00E-01	2.22E-02
log_se150_dev_3	'param_init_bounded_vector'	-0.5	0.5	9	-1.11E-01	2.01E-02	-7.64E-02	1.84E-02	-7.62E-02	1.82E-02	-8.20E-02	1.81E-02	-1.19E-01	2.01E-02
log_se150_dev_3	'param_init_bounded_vector'	-0.5	0.5	10	4.40E-02	2.00E-02	7.69E-02	1.82E-02	6.42E-02	1.67E-02	5.64E-02	1.67E-02	3.69E-02	2.02E-02
log_se150_dev_3	'param_init_bounded_vector'	-0.5	0.5	11	1.99E-01	2.07E-02	2.30E-01	1.87E-02	2.40E-01	2.09E-02	2.32E-01	2.07E-02	1.95E-01	2.14E-02
log_se150_dev_3	'param_init_bounded_vector'	-0.5	0.5	12	-4.03E-02	2.16E-02	-6.26E-03	1.99E-02	7.53E-03	1.98E-02	5.26E-04	1.98E-02		
fish_disc_slope_f	'param_init_bounded_number'	0.1	0.4	1	1.32E-01	1.06E-02	1.27E-01	1.01E-02	1.41E-01	8.94E-03	1.37E-01	8.62E-03	1.27E-01	1.06E-02
fish_disc_se150_f	'param_init_bounded_number'	80	150	1	1.15E+02	2.74E+00	1.21E+02	3.35E+00	1.17E+02	2.82E+00	1.20E+02	3.28E+00	1.16E+02	2.90E+00

Table 12 (cont.).

Parameter characteristics					Model Scenarios									
name	type	min	max	index	Alt0a		Alt0b		Alt1a		Alt1b		2013	
					value	std.dev	value	std.dev	value	std.dev	value	std.dev	value	std.dev
snowfish_disc_slope_f_1	'param_init_bounded_number'	0.05	0.5	1	5.00E-02	1.21E-05	5.00E-02	1.65E-05	5.00E-02	1.56E-05	5.00E-02	2.37E-05	5.00E-02	1.09E-05
snowfish_disc_sel50_f_1	'param_init_bounded_number'	50	150	1	1.19E+02	5.35E+00	1.15E+02	5.62E+00	1.16E+02	3.62E+00	1.12E+02	4.70E+00	1.18E+02	5.69E+00
snowfish_disc_slope_f_2	'param_init_bounded_number'	0.05	0.5	1	2.06E-01	1.19E-01	2.32E-01	1.38E-01	2.09E-01	1.06E-01	2.59E-01	1.35E-01	2.25E-01	1.34E-01
snowfish_disc_sel50_f_2	'param_init_bounded_number'	50	120	1	8.20E+01	6.28E+00	8.01E+01	5.74E+00	7.89E+01	5.64E+00	7.61E+01	4.88E+00	8.02E+01	5.80E+00
snowfish_disc_slope_f_3	'param_init_bounded_number'	0.05	0.5	1	1.27E-01	3.97E-02	1.53E-01	5.14E-02	1.33E-01	4.18E-02	1.58E-01	5.32E-02	1.30E-01	4.44E-02
snowfish_disc_sel50_f_3	'param_init_bounded_number'	50	120	1	8.98E+01	7.96E+00	8.46E+01	6.26E+00	9.01E+01	7.95E+00	8.51E+01	6.30E+00	8.90E+01	8.38E+00
snowfish_disc_slope_m_1	'param_init_bounded_number'	0.1	0.5	1	3.21E-01	9.80E-02	3.67E-01	1.16E-01	3.01E-01	9.67E-02	3.57E-01	1.27E-01	3.21E-01	9.89E-02
snowfish_disc_sel50_m_1	'param_init_bounded_number'	60	150	1	8.79E+01	1.90E+00	8.68E+01	1.66E+00	8.88E+01	1.92E+00	8.74E+01	1.77E+00	8.80E+01	1.96E+00
snowfish_disc_slope_m_2_1	'param_init_bounded_number'	0.1	0.5	1	1.39E-01	7.20E-02	1.69E-01	9.06E-02	3.22E-01	1.86E-01	3.71E-01	2.42E-01	1.28E-01	6.98E-02
snowfish_disc_sel50_m_2_1	'param_init_bounded_number'	40	200	1	1.36E+02	5.60E+00	1.37E+02	4.66E+00	1.41E+02	2.17E+00	1.41E+02	1.97E+00	1.36E+02	6.06E+00
snowfish_disc_slope_m_2	'param_init_bounded_number'	0.1	0.5	1	2.54E-01	9.10E-02	2.39E-01	8.52E-02	2.52E-01	8.15E-02	2.08E-01	6.44E-02	2.53E-01	9.03E-02
snowfish_disc_sel50_m_2	'param_init_bounded_number'	60	150	1	9.25E+01	3.01E+00	9.32E+01	3.31E+00	9.31E+01	2.77E+00	1.39E+02	6.50E+00	9.26E+01	3.02E+00
snowfish_disc_slope_m_2_2	'param_init_bounded_number'	0.1	0.5	1	1.79E-01	1.12E-01	1.63E-01	9.47E-02	1.99E-01	1.03E-01	2.10E-01	6.07E-02	1.74E-01	1.07E-01
snowfish_disc_sel50_m_2_2	'param_init_bounded_number'	40	200	1	1.42E+02	5.44E+00	1.40E+02	5.43E+00	1.42E+02	4.18E+00	9.49E+01	5.25E+00	1.42E+02	5.41E+00
snowfish_disc_slope_m_3	'param_init_bounded_number'	0.1	0.5	1	1.68E-01	1.75E-02	1.65E-01	1.75E-02	1.68E-01	1.74E-02	1.66E-01	1.74E-02	1.66E-01	1.86E-02
snowfish_disc_sel50_m_3	'param_init_bounded_number'	60	150	1	1.06E+02	1.94E+00	1.06E+02	2.09E+00	1.05E+02	1.85E+00	1.05E+02	2.00E+00	1.05E+02	2.08E+00
snowfish_disc_slope_m_2_3	'param_init_bounded_number'	0.1	0.5	1	1.92E-01	3.28E-02	1.85E-01	3.20E-02	1.76E-01	3.05E-02	1.70E-01	2.95E-02	1.96E-01	3.59E-02
snowfish_disc_sel50_m_2_3	'param_init_bounded_number'	40	200	1	1.36E+02	1.73E+00	1.36E+02	1.91E+00	1.39E+02	1.85E+00	1.38E+02	2.03E+00	1.37E+02	1.78E+00
rkfish_disc_slope_f1	'param_init_bounded_number'	0.05	0.5	1	1.70E-01	4.14E-02	1.68E-01	4.18E-02	1.72E-01	3.98E-02	1.70E-01	4.00E-02	2.52E-01	1.45E-01
rkfish_disc_sel50_f1	'param_init_bounded_number'	50	150	1	1.50E+02	1.16E+00	1.50E+02	1.16E+00	1.50E+02	1.23E+00	1.50E+02	1.14E+00	9.61E+01	1.14E+01
rkfish_disc_slope_f2	'param_init_bounded_number'	0.05	0.5	1	1.46E-01	7.48E-02	1.46E-01	7.58E-02	1.51E-01	6.91E-02	1.78E-01	1.73E-01	1.65E-01	1.74E-01
rkfish_disc_sel50_f2	'param_init_bounded_number'	50	150	1	1.50E+02	3.07E+00	1.50E+02	2.82E+00	1.50E+02	2.31E+01	1.03E+02	4.54E+01	1.04E+02	5.67E+01
rkfish_disc_slope_f3	'param_init_bounded_number'	0.05	0.5	1	1.82E-01	5.91E-02	1.84E-01	5.99E-02	1.84E-01	5.58E-02	1.85E-01	5.62E-02	1.73E-01	6.44E-02
rkfish_disc_sel50_f3	'param_init_bounded_number'	50	170	1	1.59E+02	3.83E+02	1.58E+02	3.74E+02	1.57E+02	3.60E+02	1.57E+02	3.57E+02	1.63E+02	6.18E+02
rkfish_disc_slope_m1	'param_init_bounded_number'	0.01	0.5	1	1.80E-01	7.00E-02	1.56E-01	5.90E-02	1.03E-01	1.06E-02	1.06E-01	1.08E-02	1.80E-01	6.99E-02
rkfish_disc_sel50_m1	'param_init_bounded_number'	95	150	1	1.16E+02	5.46E+00	1.20E+02	5.99E+00	1.50E+02	1.52E-03	1.50E+02	8.75E-04	1.16E+02	5.41E+00
rkfish_disc_slope_m2	'param_init_bounded_number'	0.01	0.5	1	9.09E-02	2.90E-02	8.98E-02	2.86E-02	9.57E-02	2.82E-02	9.29E-02	2.67E-02	8.95E-02	2.85E-02
rkfish_disc_sel50_m2	'param_init_bounded_number'	95	150	1	1.34E+02	1.42E+01	1.34E+02	1.44E+01	1.31E+02	1.15E+01	1.33E+02	1.21E+01	1.34E+02	1.45E+01
rkfish_disc_slope_m3	'param_init_bounded_number'	0.01	0.5	1	7.68E-02	7.34E-03	7.56E-02	7.26E-03	8.27E-02	7.20E-03	8.13E-02	7.13E-03	7.30E-02	7.94E-03
rkfish_disc_sel50_m3	'param_init_bounded_number'	95	150	1	1.50E+02	2.46E-03	1.50E+02	2.94E-03	1.50E+02	7.86E-04	1.50E+02	8.55E-04	1.50E+02	1.71E-03
fish_disc_slope_tf1	'param_init_bounded_number'	0.01	0.5	1	1.35E-01	3.05E-02	2.24E-02	8.72E-03	2.69E-02	1.68E-03	2.67E-02	1.69E-03	1.36E-01	3.03E-02
fish_disc_sel50_tf1	'param_init_bounded_number'	40	125.01	1	4.28E+01	2.10E+00	6.64E+01	1.11E+01	1.25E+02	3.17E-04	1.25E+02	2.94E-04	4.28E+01	2.09E+00
fish_disc_slope_tf2	'param_init_bounded_number'	0.005	0.5	1	1.77E-01	7.95E-02	7.68E-03	1.96E-02	1.34E-02	5.31E-03	1.20E-02	5.44E-03	1.78E-01	7.88E-02
fish_disc_sel50_tf2	'param_init_bounded_number'	40	250.01	1	4.00E+01	1.47E-04	4.00E+01	4.23E-03	1.77E+02	4.77E-01	1.78E+02	5.40E+01	4.00E+01	1.47E-04
fish_disc_slope_tf3	'param_init_bounded_number'	0.01	0.5	1	6.95E-02	7.00E-03	6.74E-02	6.84E-03	5.48E-02	8.52E-03	5.41E-02	8.49E-03	9.93E-02	1.17E-02
fish_disc_sel50_tf3	'param_init_bounded_number'	40	150.01	1	8.57E+01	3.60E+00	8.66E+01	3.70E+00	1.48E+02	1.13E+01	1.48E+02	1.14E+01	6.88E+01	2.96E+00
fish_disc_slope_tm1	'param_init_bounded_number'	0.01	0.5	1	1.48E-01	2.62E-02	1.19E-01	2.13E-02	1.13E-01	1.24E-02	1.14E-01	1.26E-02	1.48E-01	2.61E-02
fish_disc_sel50_tm1	'param_init_bounded_number'	40	120.01	1	4.74E+01	2.00E+00	5.20E+01	2.72E+00	5.42E+01	2.00E+00	5.37E+01	1.97E+00	4.74E+01	2.00E+00
fish_disc_slope_tm2	'param_init_bounded_number'	0.01	0.5	1	1.55E-01	1.19E-01	2.57E-02	2.12E-02	4.34E-02	9.56E-03	4.86E-02	1.27E-02	1.48E-01	1.15E-01
fish_disc_sel50_tm2	'param_init_bounded_number'	40	120.01	1	4.15E+01	5.08E+00	6.34E+01	2.65E+01	7.11E+01	9.80E+00	6.41E+01	8.87E+00	4.20E+01	5.27E+00
fish_disc_slope_tm3	'param_init_bounded_number'	0.01	0.5	1	7.01E-02	6.96E-03	7.05E-02	7.10E-03	7.04E-02	3.65E-03	7.10E-02	3.69E-03	7.82E-02	1.10E-02
fish_disc_sel50_tm3	'param_init_bounded_number'	40	120.01	1	9.27E+01	4.13E+00	9.22E+01	4.12E+00	9.45E+01	2.37E+00	9.38E+01	2.33E+00	8.29E+01	4.60E+00
srv2_q	'param_init_bounded_number'	0.5	1.001	1	5.07E-01	3.46E-02	5.49E-01	3.51E-02	5.35E-01	3.21E-02	5.61E-01	3.34E-02	5.13E-01	3.50E-02
srv2_selldiff	'param_init_bounded_number'	0	100	1	2.18E+01	3.56E+00	2.26E+01	3.75E+00	2.33E+01	3.76E+00	2.31E+01	3.74E+00	2.18E+01	3.57E+00
srv2_sel50	'param_init_bounded_number'	0	90	1	4.55E+01	1.93E+00	4.61E+01	2.02E+00	4.72E+01	2.03E+00	4.69E+01	2.02E+00	4.55E+01	1.93E+00
srv3_q	'param_init_bounded_number'	0.2	2	1	7.30E-01	3.63E-02	7.75E-01	3.76E-02	7.04E-01	3.52E-02	7.53E-01	3.64E-02	7.21E-01	3.64E-02
srv3_selldiff	'param_init_bounded_number'	0	100	1	5.98E+01	8.52E+00	5.75E+01	8.17E+00	5.98E+01	8.52E+00	5.68E+01	8.02E+00	6.03E+01	8.81E+00
srv3_sel50	'param_init_bounded_number'	0	69	1	2.97E+01	3.36E+00	2.83E+01	3.32E+00	2.95E+01	3.36E+00	2.82E+01	3.29E+00	3.02E+01	3.40E+00

Table 12 (cont.).

name	Parameter characteristics				Model Scenarios									
	type	min	max	index	Alt0a		Alt0b		Alt1a		Alt1b		2013	
					value	std.dev	value	std.dev	value	std.dev	value	std.dev	value	std.dev
matestf	'param_init_bounded_vector'	-15	0	1	-1.50E+01	2.63E-03	-1.50E+01	2.63E-03	-1.50E+01	2.63E-03	-1.50E+01	2.62E-03	-1.50E+01	2.71E-03
matestf	'param_init_bounded_vector'	-15	0	2	-1.37E+01	7.77E-01	-1.37E+01	7.75E-01	-1.37E+01	7.78E-01	-1.37E+01	7.78E-01	-1.37E+01	7.77E-01
matestf	'param_init_bounded_vector'	-15	0	3	-1.23E+01	1.17E+00	-1.23E+01	1.17E+00	-1.24E+01	1.17E+00	-1.24E+01	1.17E+00	-1.23E+01	1.17E+00
matestf	'param_init_bounded_vector'	-15	0	4	-1.09E+01	1.26E+00	-1.09E+01	1.26E+00	-1.09E+01	1.27E+00	-1.09E+01	1.27E+00	-1.09E+01	1.26E+00
matestf	'param_init_bounded_vector'	-15	0	5	-9.29E+00	1.12E+00	-9.29E+00	1.11E+00	-9.32E+00	1.13E+00	-9.33E+00	1.12E+00	-9.26E+00	1.12E+00
matestf	'param_init_bounded_vector'	-15	0	6	-7.50E+00	8.28E-01	-7.50E+00	8.22E-01	-7.53E+00	8.34E-01	-7.55E+00	8.33E-01	-7.47E+00	8.28E-01
matestf	'param_init_bounded_vector'	-15	0	7	-5.51E+00	4.95E-01	-5.51E+00	4.92E-01	-5.54E+00	4.99E-01	-5.56E+00	4.99E-01	-5.49E+00	4.95E-01
matestf	'param_init_bounded_vector'	-15	0	8	-3.42E+00	2.21E-01	-3.42E+00	2.19E-01	-3.45E+00	2.24E-01	-3.46E+00	2.24E-01	-3.41E+00	2.20E-01
matestf	'param_init_bounded_vector'	-15	0	9	-1.83E+00	9.87E-02	-1.84E+00	9.92E-02	-1.83E+00	1.01E-01	-1.84E+00	1.01E-01	-1.83E+00	9.92E-02
matestf	'param_init_bounded_vector'	-15	0	10	-8.72E-01	5.73E-02	-8.79E-01	5.78E-02	-8.58E-01	5.76E-02	-8.68E-01	5.81E-02	-8.81E-01	5.79E-02
matestf	'param_init_bounded_vector'	-15	0	11	-5.26E-01	4.13E-02	-5.28E-01	4.14E-02	-5.17E-01	4.13E-02	-5.24E-01	4.15E-02	-5.39E-01	4.24E-02
matestf	'param_init_bounded_vector'	-15	0	12	-3.96E-01	4.16E-02	-3.99E-01	4.09E-02	-3.85E-01	4.07E-02	-3.91E-01	4.08E-02	-4.06E-01	4.31E-02
matestf	'param_init_bounded_vector'	-15	0	13	-1.66E-01	4.10E-02	-1.72E-01	3.90E-02	-1.43E-01	3.65E-02	-1.44E-01	3.70E-02	-1.68E-01	4.18E-02
matestf	'param_init_bounded_vector'	-15	0	14	-3.98E-09	1.54E-05	-5.34E-09	2.07E-05	-2.61E-09	1.01E-05	-2.37E-09	9.19E-06	-3.98E-09	1.54E-05
matestf	'param_init_bounded_vector'	-15	0	15	-8.00E-09	3.11E-05	-2.89E-08	1.12E-04	-6.13E-03	1.10E-02	-5.61E-03	1.06E-02	-5.56E-09	2.15E-05
matestf	'param_init_bounded_vector'	-15	0	16	-1.62E-03	5.59E-03	-1.79E-03	5.70E-03	-4.17E-04	8.20E-03	-4.78E-04	7.95E-03	-8.65E-05	4.45E-03
matestmn	'param_init_bounded_vector'	-15	0	1	-1.50E+01	6.42E-03	-1.50E+01	6.49E-03	-1.50E+01	6.41E-03	-1.50E+01	6.42E-03	-1.50E+01	6.37E-03
matestmn	'param_init_bounded_vector'	-15	0	2	-1.39E+01	1.10E+00	-1.39E+01	1.10E+00	-1.39E+01	1.10E+00	-1.39E+01	1.10E+00	-1.39E+01	1.10E+00
matestmn	'param_init_bounded_vector'	-15	0	3	-1.28E+01	1.66E+00	-1.28E+01	1.66E+00	-1.27E+01	1.65E+00	-1.27E+01	1.65E+00	-1.28E+01	1.66E+00
matestmn	'param_init_bounded_vector'	-15	0	4	-1.16E+01	1.80E+00	-1.15E+01	1.80E+00	-1.15E+01	1.78E+00	-1.15E+01	1.79E+00	-1.16E+01	1.80E+00
matestmn	'param_init_bounded_vector'	-15	0	5	-1.03E+01	1.62E+00	-1.02E+01	1.61E+00	-1.02E+01	1.59E+00	-1.02E+01	1.60E+00	-1.03E+01	1.62E+00
matestmn	'param_init_bounded_vector'	-15	0	6	-8.79E+00	1.25E+00	-8.72E+00	1.24E+00	-8.67E+00	1.22E+00	-8.65E+00	1.22E+00	-8.77E+00	1.24E+00
matestmn	'param_init_bounded_vector'	-15	0	7	-7.15E+00	8.70E-01	-7.08E+00	8.58E-01	-7.02E+00	8.34E-01	-6.98E+00	8.32E-01	-7.12E+00	8.62E-01
matestmn	'param_init_bounded_vector'	-15	0	8	-5.48E+00	6.37E-01	-5.40E+00	6.23E-01	-5.34E+00	6.00E-01	-5.30E+00	5.94E-01	-5.44E+00	6.32E-01
matestmn	'param_init_bounded_vector'	-15	0	9	-4.52E+00	3.69E-01	-4.45E+00	3.62E-01	-4.44E+00	3.49E-01	-4.39E+00	3.45E-01	-4.49E+00	3.68E-01
matestmn	'param_init_bounded_vector'	-15	0	10	-3.90E+00	2.62E-01	-3.84E+00	2.60E-01	-3.85E+00	2.53E-01	-3.78E+00	2.51E-01	-3.89E+00	2.64E-01
matestmn	'param_init_bounded_vector'	-15	0	11	-3.32E+00	2.00E-01	-3.28E+00	2.00E-01	-3.28E+00	1.94E-01	-3.23E+00	1.93E-01	-3.33E+00	2.04E-01
matestmn	'param_init_bounded_vector'	-15	0	12	-2.76E+00	1.57E-01	-2.75E+00	1.57E-01	-2.78E+00	1.53E-01	-2.75E+00	1.53E-01	-2.77E+00	1.60E-01
matestmn	'param_init_bounded_vector'	-15	0	13	-2.26E+00	1.29E-01	-2.26E+00	1.29E-01	-2.32E+00	1.26E-01	-2.30E+00	1.25E-01	-2.24E+00	1.31E-01
matestmn	'param_init_bounded_vector'	-15	0	14	-1.71E+00	1.03E-01	-1.72E+00	1.02E-01	-1.80E+00	1.01E-01	-1.78E+00	9.97E-02	-1.70E+00	1.05E-01
matestmn	'param_init_bounded_vector'	-15	0	15	-1.38E+00	8.83E-02	-1.39E+00	8.69E-02	-1.44E+00	8.41E-02	-1.42E+00	8.31E-02	-1.37E+00	9.00E-02
matestmn	'param_init_bounded_vector'	-15	0	16	-1.17E+00	7.90E-02	-1.18E+00	7.84E-02	-1.18E+00	7.44E-02	-1.19E+00	7.36E-02	-1.18E+00	8.13E-02
matestmn	'param_init_bounded_vector'	-15	0	17	-1.02E+00	7.14E-02	-1.05E+00	7.21E-02	-9.86E-01	6.60E-02	-1.03E+00	6.65E-02	-1.03E+00	7.40E-02
matestmn	'param_init_bounded_vector'	-15	0	18	-7.86E-01	6.34E-02	-8.20E-01	6.45E-02	-7.36E-01	5.66E-02	-7.90E-01	5.84E-02	-8.03E-01	6.59E-02
matestmn	'param_init_bounded_vector'	-15	0	19	-5.56E-01	5.81E-02	-5.72E-01	5.94E-02	-5.12E-01	5.14E-02	-5.46E-01	5.36E-02	-5.76E-01	6.09E-02
matestmn	'param_init_bounded_vector'	-15	0	20	-2.84E-01	5.05E-02	-2.83E-01	4.97E-02	-2.55E-01	4.34E-02	-2.70E-01	4.50E-02	-2.96E-01	5.37E-02
matestmn	'param_init_bounded_vector'	-15	0	21	-1.15E-01	3.73E-02	-1.08E-01	3.38E-02	-9.47E-02	2.88E-02	-9.88E-02	2.96E-02	-1.17E-01	3.90E-02
matestmn	'param_init_bounded_vector'	-15	0	22	-6.29E-04	1.42E-02	-5.84E-05	7.46E-03	-6.02E-09	2.25E-05	-7.01E-09	2.61E-05	-9.79E-04	1.46E-02
matestmn	'param_init_bounded_vector'	-15	0	23	-2.33E-09	9.06E-06	-3.09E-09	1.18E-05	-2.23E-09	8.56E-06	-2.58E-09	9.88E-06	-2.46E-09	9.52E-06
matestmn	'param_init_bounded_vector'	-15	0	24	-1.27E-09	4.93E-06	-1.26E-09	4.89E-06	-1.15E-09	4.47E-06	-1.01E-09	4.00E-06	-1.38E-09	5.36E-06
matestmn	'param_init_bounded_vector'	-15	0	25	-1.63E-09	6.32E-06	-1.81E-09	6.99E-06	-1.82E-09	7.02E-06	-1.52E-09	5.91E-06	-1.69E-09	6.56E-06
matestmn	'param_init_bounded_vector'	-15	0	26	-1.63E-09	6.33E-06	-1.94E-09	7.50E-06	-1.74E-09	6.71E-06	-1.60E-09	6.21E-06	-1.66E-09	6.43E-06
matestmn	'param_init_bounded_vector'	-15	0	27	-2.21E-09	8.58E-06	-2.71E-09	1.05E-05	-2.25E-09	8.71E-06	-2.18E-09	8.43E-06	-2.23E-09	8.65E-06
matestmn	'param_init_bounded_vector'	-15	0	28	-3.59E-09	1.39E-05	-4.36E-09	1.68E-05	-3.48E-09	1.35E-05	-3.46E-09	1.34E-05	-3.73E-09	1.45E-05
matestmn	'param_init_bounded_vector'	-15	0	29	-8.44E-09	3.27E-05	-9.75E-09	3.77E-05	-8.30E-09	3.21E-05	-8.20E-09	3.17E-05	-9.19E-09	3.56E-05
matestmn	'param_init_bounded_vector'	-15	0	30	-4.59E-08	1.78E-04	-6.18E-08	2.39E-04	-3.76E-08	1.45E-04	-3.85E-08	1.49E-04	-5.86E-08	2.25E-04
matestmn	'param_init_bounded_vector'	-15	0	31	-6.90E-02	3.57E-01	-8.07E-02	3.14E-01	-5.05E-02	2.80E-01	-5.13E-02	2.82E-01	-6.93E-02	3.66E-01
matestmn	'param_init_bounded_vector'	-15	0	32	-1.41E-01	1.24E+00	-1.66E-01	1.20E+00	-1.04E-01	1.16E+00	-1.05E-01	1.16E+00	-1.41E-01	1.25E+00
srv2_femQ	'param_init_bounded_number'	0.5	1.001	1	7.34E-01	2.61E-01	5.81E-01	1.64E-01	6.65E-01	3.01E-01	6.03E-01	2.09E-01	6.92E-01	1.99E-01
srv2_sekliff_f	'param_init_bounded_number'	0	100	1	6.03E+01	2.27E+01	5.17E+01	2.56E+01	6.28E+01	3.13E+01	5.52E+01	2.93E+01	5.54E+01	2.01E+01
srv2_seI50_f	'param_init_bounded_number'	-200	100.01	1	6.45E+01	1.78E+01	5.43E+01	1.41E+01	6.38E+01	2.38E+01	5.70E+01	6.08E+01	1.41E+01	6.08E+01
srv3_femQ	'param_init_bounded_number'	0.2	1	1	5.51E-01	4.04E-02	5.48E-01	4.04E-02	5.22E-01	3.83E-02	5.59E-01	3.88E-02	5.61E-01	4.11E-02
srv3_sekliff_f	'param_init_bounded_number'	0	100	1	1.00E+02	7.15E-04	1.00E+02	1.23E-03	1.00E+02	6.88E-04	1.00E+02	8.30E-04	1.00E+02	6.46E-04
srv3_seI50_f	'param_init_bounded_number'	-50	69	1	-4.95E-01	1.58E+01	-1.81E+01	2.13E+01	-6.39E-01	1.49E+01	-5.29E+00	1.58E+01	4.96E+00	1.42E+01

Table 13. Comparison of estimated male recruitment (in millions) from the four alternative 2014 models and the 2013 model.

year	Alt0a	Alt0b	Alt1a	Alt1b	2013 Model	year	Alt0a	Alt0b	Alt1a	Alt1b	2013 Model
1949	31.7	30.6	32.5	31.2	29.0	1981	52.6	47.5	57.8	53.5	52.4
1950	31.8	30.7	32.5	31.3	29.1	1982	20.9	21.1	28.7	26.2	21.0
1951	32.0	30.9	32.8	31.5	29.3	1983	196.3	183.1	205.3	186.5	196.4
1952	32.4	31.2	33.2	31.9	29.7	1984	164.3	154.1	168.8	152.3	165.7
1953	33.1	31.8	33.8	32.5	30.3	1985	359.8	304.7	327.5	287.8	357.6
1954	34.1	32.7	34.8	33.4	31.2	1986	284.6	258.9	274.5	240.0	283.3
1955	35.6	34.0	36.4	34.8	32.6	1987	273.9	227.8	258.1	217.5	274.6
1956	38.0	36.2	38.8	37.1	34.8	1988	200.2	169.2	231.3	192.0	199.8
1957	41.8	39.6	42.7	40.6	38.4	1989	110.1	93.3	101.5	85.4	110.6
1958	48.2	45.4	49.1	46.6	44.3	1990	47.0	40.5	45.0	38.4	47.3
1959	59.8	55.9	60.7	57.4	55.0	1991	23.4	19.5	21.0	17.9	23.6
1960	83.9	77.7	84.9	79.9	77.4	1992	18.1	16.3	17.8	15.7	18.5
1961	145.8	134.0	146.8	137.6	135.5	1993	14.9	13.4	14.8	13.0	15.3
1962	323.0	295.9	324.0	303.1	302.0	1994	14.6	13.6	16.9	14.9	14.8
1963	698.2	638.5	696.8	653.2	650.7	1995	20.7	18.9	24.6	22.0	21.0
1964	991.4	890.2	961.4	905.2	915.3	1996	23.3	21.3	23.8	21.5	23.6
1965	962.2	848.5	897.4	850.1	888.2	1997	60.4	57.0	64.2	59.4	60.9
1966	800.3	712.6	732.3	699.1	752.6	1998	25.5	23.7	25.4	23.5	25.8
1967	673.4	631.1	626.0	605.1	656.8	1999	78.8	74.0	79.2	73.7	79.7
1968	602.5	618.6	592.4	583.3	615.8	2000	46.1	42.7	48.2	44.6	46.5
1969	560.2	632.6	599.9	602.6	592.0	2001	144.1	134.7	148.9	138.3	144.5
1970	440.2	494.6	500.3	500.9	448.7	2002	56.2	51.7	61.7	57.0	55.9
1971	301.8	313.1	333.9	325.1	295.8	2003	99.7	91.9	110.5	101.8	99.4
1972	273.7	276.7	282.5	271.4	269.7	2004	202.6	187.1	201.2	186.1	198.9
1973	247.8	250.0	231.2	220.4	244.7	2005	59.7	54.9	61.8	57.1	58.5
1974	24.9	30.0	64.4	61.1	23.3	2006	48.7	44.7	51.3	47.3	47.8
1975	208.0	201.9	218.0	209.8	208.5	2007	38.1	34.9	36.3	33.2	37.3
1976	412.1	406.5	494.6	459.2	403.6	2008	41.8	38.0	42.0	38.2	41.5
1977	298.9	284.9	304.3	279.3	295.1	2009	211.8	195.1	224.3	205.2	200.1
1978	265.4	244.9	258.3	237.7	260.5	2010	209.8	192.7	237.1	214.8	238.4
1979	71.0	62.9	63.3	58.8	69.5	2011	115.2	104.0	119.5	107.2	128.2
1980	15.5	16.9	24.5	22.6	14.8	2012	25.6	22.9	24.2	21.7	33.8
						2013	84.0	74.9	65.6	58.2	120.6
						2014	89.2	78.6	99.8	88.0	

Table 14. Comparison of time series of estimated mature male biomass (1000's t) at mating from the four alternative 2014 models and the 2013 model.

year	Alt0a	Alt0b	Alt1a	Alt1b	2013 Model
1949	0.0	0.0	0.0	0.0	0.0
1950	0.0	0.0	0.0	0.0	0.0
1951	0.2	0.1	0.2	0.2	0.1
1952	1.2	1.2	1.3	1.2	1.1
1953	4.6	4.5	4.8	4.6	4.1
1954	8.9	8.6	9.2	8.8	8.1
1955	12.4	11.9	12.7	12.1	11.3
1956	15.0	14.3	15.4	14.6	13.7
1957	17.1	16.2	17.4	16.5	15.6
1958	18.8	17.7	19.1	18.1	17.2
1959	20.3	19.0	20.6	19.5	18.6
1960	21.9	20.4	22.2	20.9	20.0
1961	23.7	22.0	24.0	22.6	21.8
1962	26.3	24.4	26.6	25.0	24.2
1963	30.6	28.2	31.0	29.0	28.1
1964	39.3	36.0	39.7	37.0	36.1
1965	57.5	52.3	57.9	53.8	52.8
1966	101.6	92.2	102.1	94.6	93.3
1967	167.8	148.1	163.8	151.6	153.2
1968	256.6	221.7	242.9	225.3	233.8
1969	322.5	271.3	293.7	272.9	293.7
1970	359.0	297.7	317.3	295.5	328.8
1971	371.9	311.0	325.1	304.2	345.5
1972	371.1	320.7	328.2	309.6	352.5
1973	360.2	326.3	327.9	312.5	349.8
1974	326.2	305.2	304.7	292.3	321.2
1975	283.1	267.4	268.3	257.6	279.9
1976	219.2	203.1	203.8	195.0	216.6
1977	148.5	131.2	128.9	122.7	146.9
1978	101.2	85.7	82.9	79.0	100.4
1979	67.8	53.6	51.6	49.0	66.8
1980	44.4	32.7	35.8	34.3	44.1

year	Alt0a	Alt0b	Alt1a	Alt1b	2013 Model
1981	48.5773	39.7859	46.4	44.5	48.7
1982	49.5313	43.9855	51.4	48.7	49.9
1983	39.6824	36.1691	43.1	40.3	40.2
1984	23.1478	21.1712	26.9	25.0	23.7
1985	21.4109	20.0808	25.5	23.9	21.7
1986	26.8208	25.7369	31.4	29.6	26.9
1987	40.2668	39.2561	45.5	43.1	40.1
1988	59.1293	56.9034	63.2	59.7	59.0
1989	70.7535	64.9185	69.9	65.7	70.6
1990	66.3634	57.4888	59.7	56.1	66.7
1991	60.6508	52.844	55.4	51.3	61.2
1992	47.3385	42.778	47.0	43.5	48.0
1993	38.4778	36.3178	40.4	37.8	39.2
1994	30.8891	29.723	32.1	30.2	31.6
1995	22.8559	22.3924	23.5	22.4	23.5
1996	18.5012	17.7947	18.7	17.5	19.1
1997	15.7434	15.0234	15.8	15.0	16.4
1998	13.8585	13.2992	14.2	13.8	14.5
1999	13.7661	13.1456	14.6	14.1	14.3
2000	15.5387	14.7048	16.7	15.9	16.0
2001	19.2094	18.159	20.6	19.4	19.6
2002	23.183	21.9193	24.5	23.2	23.6
2003	28.5593	26.9895	29.9	28.2	28.9
2004	35.8489	33.8038	37.5	35.2	36.1
2005	44.8483	42.3122	47.3	44.1	44.9
2006	50.8531	47.9885	54.0	50.3	50.9
2007	56.6765	53.5437	60.8	56.5	56.4
2008	68.4938	64.4988	72.9	67.4	67.6
2009	72.5499	67.9475	76.2	70.3	71.6
2010	66.8796	62.2956	70.0	64.4	65.9
2011	60.329	56.0701	62.9	57.8	59.3
2012	60.7291	56.302	63.6	58.1	59.4
2013	74.3676	69.1918	79.5	72.3	

Table 15. Comparison of time series of observed and estimated numbers of male crab ≥ 138 mmCW (millions) in the survey from the four alternative 2014 models and the 2013 model.

year	Observed	2014 Model Cases				2013 Model	
		Alt0a	Alt0b	Alt1a	Alt1b		
1949		0.00	0.00	0.00	0.00	0.00	
1950		0.00	0.00	0.00	0.00	0.00	
1951		0.00	0.00	0.00	0.00	0.00	
1952		0.08	0.09	0.09	0.09	0.07	
1953		0.69	0.77	0.77	0.80	0.63	
1954		1.88	2.06	2.04	2.12	1.74	
1955		2.86	3.10	3.08	3.19	2.66	
1956		3.58	3.86	3.85	3.97	3.34	
1957		4.13	4.42	4.43	4.55	3.86	
1958		4.57	4.86	4.89	5.01	4.27	
1959		4.95	5.24	5.28	5.41	4.63	
1960		5.31	5.60	5.67	5.79	4.97	
1961		5.72	6.01	6.10	6.22	5.36	
1962		6.26	6.54	6.67	6.78	5.86	
1963		7.07	7.36	7.54	7.64	6.62	
1964		8.54	8.86	9.10	9.20	8.00	
1965		11.72	12.15	12.52	12.63	11.00	
1966		19.02	19.66	20.29	20.43	17.83	
1967		35.94	37.08	38.14	38.41	33.72	
1968		57.60	57.96	59.23	59.69	53.74	
1969		79.29	78.00	79.02	79.65	73.82	
1970		88.71	85.19	85.33	86.00	82.52	
1971		90.80	86.70	85.41	86.25	85.17	
1972		89.85	87.69	84.49	85.85	85.92	
1973		87.74	89.68	84.55	86.85	86.17	
1974	90.82	83.48	89.34	83.33	86.43	83.64	
1975	153.74	72.63	79.27	74.25	77.15	73.24	
1976	89.16	60.56	66.31	62.60	64.80	61.01	
1977	69.32	43.94	47.98	44.89	46.22	44.20	
1978	40.09	24.58	26.58	24.46	24.96	24.73	
1979	22.39	14.87	16.09	15.30	15.60	14.88	
1980	29.96	13.80	14.41	13.96	14.37	13.69	
1981		10.83	14.30	13.75	14.07	14.66	14.3352
1982		7.75	23.88	23.67	22.59	23.71	23.5424
1983		5.01	21.62	21.66	20.95	21.65	21.4726
1984		6.60	13.97	14.01	14.34	14.61	14.0037
1985		3.71	8.03	8.15	9.11	9.21	8.088
1986		2.44	9.01	9.28	10.16	10.37	8.99951
1987		6.47	12.88	13.68	14.26	14.65	12.7366
1988		16.37	19.98	21.34	21.16	21.84	19.7785
1989		34.04	28.27	29.47	28.32	28.98	27.9265
1990		44.52	32.25	32.49	30.39	30.84	31.9349
1991		36.30	26.95	26.19	24.12	24.25	26.8509
1992		42.44	23.16	22.15	21.47	20.98	23.1869
1993		20.28	15.44	14.78	15.44	14.84	15.5813
1994		15.91	11.09	10.72	11.40	10.88	11.2771
1995		10.17	8.18	7.89	8.27	7.85	8.36462
1996		9.27	6.02	5.86	5.99	5.74	6.17713
1997		3.45	5.00	4.96	5.04	4.78	5.12244
1998		2.16	4.51	4.48	4.52	4.36	4.65216
1999		2.08	4.33	4.37	4.46	4.42	4.46927
2000		4.71	4.76	4.83	4.99	4.98	4.88238
2001		5.98	6.11	6.25	6.35	6.40	6.19705
2002		6.07	7.61	7.82	7.78	7.90	7.71162
2003		6.61	9.14	9.43	9.21	9.42	9.21249
2004		4.77	11.56	11.93	11.54	11.84	11.6134
2005		11.21	14.87	15.36	14.92	15.30	14.8417
2006		14.42	18.19	18.73	18.28	18.68	18.1377
2007		11.97	19.28	19.84	19.67	20.06	19.1568
2008		13.14	23.29	24.06	23.75	24.25	22.9342
2009		7.97	26.72	27.38	26.75	27.19	26.2613
2010		9.40	24.82	25.20	24.74	25.00	24.3725
2011		15.74	22.35	22.56	22.20	22.34	21.9077
2012		8.17	20.62	20.79	20.42	20.49	20.134
2013		9.02	23.98	24.34	24.14	24.21	23.1692
2014		19.55	31.70	32.28	32.56	32.64	

Table 16. Comparison of time series of observed retained catch (1000's t) in the directed fishery and predicted catch from the four alternative 2014 models and the 2013 model.

year	Observed	2014 Model Cases				2013 Model	year	Observed	2014 Model Cases				2013 Model
		Alt0a	Alt0b	Alt1a	Alt1b				Alt0a	Alt0b	Alt1a	Alt1b	
1949		0.00	0.00	0.00	0.00	0.00	1981	4.99	5.04	5.06	5.07	5.07	5.04
1950		0.00	0.00	0.00	0.00	0.00	1982	2.39	2.47	2.47	2.47	2.48	2.47
1951		0.00	0.00	0.00	0.00	0.00	1983	0.55	0.77	0.77	0.78	0.78	0.78
1952		0.00	0.01	0.01	0.01	0.00	1984	1.43	1.48	1.48	1.50	1.50	1.49
1953		0.05	0.05	0.05	0.05	0.04	1985	0.00	0.00	0.00	0.00	0.00	0.00
1954		0.13	0.14	0.14	0.14	0.12	1986	0.00	0.00	0.00	0.00	0.00	0.00
1955		0.20	0.22	0.22	0.22	0.18	1987	1.00	1.02	1.01	1.00	1.00	1.02
1956		0.26	0.27	0.28	0.27	0.23	1988	3.18	3.10	3.08	3.08	3.07	3.10
1957		0.30	0.31	0.32	0.31	0.27	1989	11.11	11.01	10.99	10.99	10.98	11.01
1958		0.33	0.34	0.35	0.35	0.30	1990	18.19	18.08	18.06	18.05	18.05	18.08
1959		0.36	0.37	0.38	0.37	0.33	1991	14.43	14.30	14.30	14.30	14.29	14.30
1960		0.38	0.40	0.41	0.40	0.35	1992	15.92	15.31	15.08	14.73	14.50	15.32
1961		0.41	0.42	0.44	0.43	0.38	1993	7.67	7.47	7.26	6.97	6.77	7.48
1962		0.45	0.46	0.48	0.47	0.41	1994	3.54	3.45	3.33	3.53	3.38	3.46
1963		0.51	0.52	0.54	0.52	0.46	1995	1.92	1.83	1.68	1.89	1.70	1.84
1964		0.61	0.62	0.65	0.63	0.56	1996	0.82	0.71	0.40	0.43	0.42	0.77
1965	1.92	1.95	1.95	1.95	1.95	1.95	1997	0.00	0.00	0.00	0.00	0.00	0.00
1966	2.45	2.47	2.47	2.47	2.47	2.47	1998	0.00	0.00	0.00	0.00	0.00	0.00
1967	13.60	13.59	13.59	13.59	13.59	13.59	1999	0.00	0.00	0.00	0.00	0.00	0.00
1968	18.00	18.00	18.00	18.00	18.00	18.00	2000	0.00	0.00	0.00	0.00	0.00	0.00
1969	27.49	27.48	27.49	27.48	27.49	27.48	2001	0.00	0.00	0.00	0.00	0.00	0.00
1970	25.49	25.49	25.49	25.49	25.49	25.49	2002	0.00	0.00	0.00	0.00	0.00	0.00
1971	20.71	20.71	20.71	20.71	20.71	20.71	2003	0.00	0.00	0.00	0.00	0.00	0.00
1972	16.91	16.90	16.90	16.90	16.90	16.90	2004	0.00	0.00	0.00	0.00	0.00	0.00
1973	13.03	13.02	13.02	13.02	13.02	13.02	2005	0.43	0.43	0.42	0.47	0.46	0.43
1974	15.24	15.23	15.23	15.23	15.23	15.23	2006	0.96	0.93	0.86	0.97	0.90	0.94
1975	17.65	17.65	17.65	17.66	17.66	17.65	2007	0.96	1.03	0.91	1.02	0.91	1.04
1976	30.02	30.01	30.01	30.01	30.01	30.01	2008	0.88	0.92	0.89	0.90	0.88	0.92
1977	35.53	35.52	35.52	35.52	35.52	35.52	2009	0.60	0.69	0.69	0.70	0.70	0.69
1978	21.09	21.09	21.09	21.08	21.08	21.09	2010	0.00	0.00	0.00	0.00	0.00	0.00
1979	19.01	18.97	18.96	18.95	18.95	18.97	2011	0.00	0.00	0.00	0.00	0.00	0.00
1980	13.43	13.43	13.44	13.46	13.46	13.43	2012	0.00	0.00	0.00	0.00	0.00	0.00
							2013	0.66	0.63	0.61	0.65	0.63	

Table 17. Comparison of time series of observed total male mortality (retained+discards) in the directed fishery (1000's t) with the respective predicted catch from the four alternative models and the 2013 model. Note that each 2014 model scenario has its own associated "observed" total mortality because the datasets differ between the 0 and 1 scenarios and the assumed handling mortality rates differ between the a's and b's.

year	observed 0a	Alt0a	2013 Model	observed 0b	Alt0b	observed 1a	Alt1a	observed 1b	Alt1b	year	observed 0a	Alt0a	2013 Model	observed 0b	Alt0b	observed 1a	Alt1a	observed 1b	Alt1b
1949		0.00	0.00		0.00		0.00		0.00	1981		8.84	8.65		10.68		11.61		10.75
1950		0.00	0.00		0.00		0.00		0.00	1982		3.79	3.73		4.32		4.62		4.37
1951		0.00	0.00		0.00		0.00		0.00	1983		1.08	1.07		1.18		1.27		1.22
1952		0.01	0.01		0.02		0.03		0.02	1984		2.02	2.00		2.21		2.39		2.31
1953		0.09	0.08		0.12		0.14		0.13	1985		0.00	0.00		0.00		0.00		0.00
1954		0.21	0.19		0.26		0.29		0.27	1986		0.00	0.00		0.00		0.00		0.00
1955		0.31	0.28		0.38		0.42		0.39	1987		1.61	1.59		1.85		1.94		1.84
1956		0.39	0.35		0.46		0.51		0.47	1988		4.86	4.77		5.52		5.84		5.54
1957		0.44	0.40		0.53		0.58		0.54	1989		17.88	17.51		20.26		21.45		20.36
1958		0.49	0.44		0.58		0.64		0.59	1990		29.36	28.82		33.31		35.24		33.78
1959		0.53	0.47		0.62		0.69		0.63	1991		23.16	23.02		22.78		23.12		23.04
1960		0.57	0.51		0.66		0.74		0.68	1992	21.42	21.74	21.74	19.45	19.98	19.01	19.80	17.90	18.89
1961		0.62	0.55		0.71		0.80		0.73	1993	11.08	11.23	11.23	9.86	10.15	9.60	10.09	8.91	9.53
1962		0.68	0.60		0.78		0.88		0.80	1994	5.10	5.23	5.23	4.54	4.74	5.10	5.18	4.54	4.71
1963		0.77	0.69		0.89		1.01		0.92	1995	3.30	3.47	3.46	2.81	3.05	3.30	3.44	2.81	3.05
1964		0.95	0.84		1.10		1.25		1.14	1996	0.94	1.23	1.19	0.90	1.29	0.88	1.27	0.86	1.28
1965		3.17	3.11		3.68		4.03		3.78	1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1966		4.20	4.11		4.93		5.42		5.07	1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1967		23.31	22.83		27.16		29.73		27.89	1999	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1968		29.78	29.23		34.29		37.27		35.10	2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1969		43.71	43.02		49.68		53.58		50.72	2001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1970		39.59	39.06		44.79		48.10		45.68	2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1971		31.75	31.38		35.93		38.51		36.64	2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1972		25.74	25.45		29.17		31.27		29.79	2004	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1973		19.69	19.43		22.23		23.90		22.76	2005	0.57	0.86	0.87	0.52	0.83	0.66	0.90	0.58	0.85
1974		22.82	22.45		25.46		27.44		26.11	2006	1.58	1.75	1.75	1.36	1.58	1.65	1.78	1.40	1.60
1975		26.44	25.96		29.18		31.46		29.90	2007	2.01	2.10	2.10	1.63	1.81	1.98	2.08	1.61	1.79
1976		46.15	45.31		50.67		54.58		51.85	2008	1.10	1.26	1.27	1.02	1.21	1.10	1.29	1.02	1.24
1977		57.98	57.00		63.03		68.33		64.93	2009	0.64	0.74	0.74	0.63	0.73	0.64	0.74	0.63	0.74
1978		37.11	36.53		39.90		44.53		42.40	2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979		43.29	42.78		47.18		54.56		51.86	2011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980		33.22	32.77		39.35		44.48		41.39	2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
										2013	0.92	1.12		0.83	1.05	0.92	1.12	0.83	1.05

Table 18. Comparison of time series of observed female discard mortality (1000's t) in the directed fishery with the predicted catch from the 2012 assessment model and the two alternative models.

year	observed 0a	Alt0a	2013 Model	observed 0b	Alt0b	observed 1a	Alt1a	observed 1b	Alt1b	year	observed 0a	Alt0a	2013 Model	observed 0b	Alt0b	observed 1a	Alt1a	observed 1b	Alt1b
1949		0.00	0.00		0.00		0.00		0.00	1981		0.70	0.71		0.52		0.50		0.36
1950		0.00	0.00		0.00		0.00		0.00	1982		0.25	0.25		0.17		0.16		0.11
1951		0.00	0.00		0.00		0.00		0.00	1983		0.07	0.07		0.04		0.04		0.03
1952		0.00	0.00		0.00		0.00		0.00	1984		0.17	0.16		0.11		0.09		0.07
1953		0.00	0.00		0.00		0.00		0.00	1985		0.00	0.00		0.00		0.00		0.00
1954		0.01	0.01		0.00		0.00		0.00	1986		0.00	0.00		0.00		0.00		0.00
1955		0.01	0.01		0.00		0.01		0.00	1987		0.08	0.08		0.04		0.04		0.03
1956		0.01	0.01		0.01		0.01		0.00	1988		0.19	0.20		0.10		0.10		0.07
1957		0.01	0.01		0.01		0.01		0.01	1989		0.68	0.71		0.37		0.38		0.27
1958		0.01	0.01		0.01		0.01		0.01	1990		1.21	1.26		0.70		0.74		0.52
1959		0.01	0.01		0.01		0.01		0.01	1991		1.09	1.11		0.68		0.75		0.52
1960		0.01	0.01		0.01		0.01		0.01	1992	0.89	1.54	1.56	0.57	1.13	0.50	1.14	0.32	0.89
1961		0.01	0.01		0.01		0.01		0.01	1993	0.91	0.71	0.72	0.58	0.51	0.51	0.43	0.33	0.33
1962		0.02	0.02		0.01		0.01		0.01	1994	0.64	0.30	0.29	0.41	0.20	0.64	0.19	0.41	0.15
1963		0.02	0.02		0.01		0.01		0.01	1995	0.88	0.13	0.13	0.56	0.08	0.88	0.09	0.56	0.06
1964		0.03	0.03		0.02		0.02		0.01	1996	0.05	0.05	0.05	0.03	0.02	0.02	0.02	0.01	0.01
1965		0.10	0.11		0.06		0.06		0.04	1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1966		0.15	0.16		0.08		0.09		0.06	1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1967		0.80	0.86		0.44		0.47		0.34	1999	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1968		0.93	1.01		0.53		0.58		0.41	2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1969		1.27	1.37		0.74		0.82		0.59	2001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1970		1.11	1.19		0.67		0.73		0.53	2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1971		0.86	0.93		0.53		0.58		0.43	2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1972		0.67	0.72		0.42		0.47		0.34	2004	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1973		0.50	0.53		0.31		0.34		0.25	2005	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01
1974		0.55	0.58		0.34		0.39		0.28	2006	0.16	0.03	0.03	0.10	0.01	0.18	0.02	0.11	0.01
1975		0.64	0.66		0.39		0.45		0.33	2007	0.05	0.03	0.03	0.03	0.02	0.05	0.02	0.03	0.01
1976		1.21	1.25		0.75		0.85		0.62	2008	0.01	0.03	0.03	0.00	0.02	0.01	0.02	0.00	0.01
1977		1.87	1.92		1.18		1.34		1.01	2009	0.00	0.06	0.06	0.00	0.03	0.00	0.04	0.00	0.02
1978		1.62	1.66		1.06		1.23		0.95	2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979		3.01	3.17		1.96		2.29		1.81	2011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980		3.49	3.69		2.55		2.52		1.92	2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
										2013	0.01	0.02		0.01	0.01	0.01	0.01	0.01	0.01

Table 19. Comparison of the final objective function components for the alternative models Alt0a and Alt0b, which can be compared directly. Component differences greater or less than 2 units are highlighted. Positive differences (red highlighting) indicate better fits with Alt0b. Negative differences (blue highlighting) indicate better fits with Alt0a. Overall, Alt0b fits the data better, with smaller penalties, by 3.60 likelihood units compared with Alt0a.

weight	sigma	Model Case		Difference a-b	Component Description
		Alt1a	Alt0b		
1.0000	1.0000	2.20	2.20	0.00	recruitment penalty
0.0000	NA	0.00	0.00	0.00	sex ratio penalty
1.0000	1.0000	1.17	1.23	-0.06	immatures natural mortality penalty
1.0000	1.0000	1.46	2.44	-0.97	mature male natural mortality penalty
1.0000	1.0000	42.00	38.19	3.81	mature female natural mortality penalty
1.0000	1.0000	4.48	1.85	2.63	survey q penalty
1.0000	1.0000	21.64	16.00	5.63	female survey q penalty
1.0000	1.0000	0.75	0.79	-0.03	prior on female growth parameter a
1.0000	1.0000	0.57	0.61	-0.04	prior on female growth parameter b
1.0000	1.0000	0.05	0.02	0.02	prior on male growth parameter a
1.0000	1.0000	0.01	0.02	0.00	prior on male growth parameter b
1.0000	1.0000	1.23	1.23	0.00	smoothing penalty on female maturity curve
0.5000	1.4142	0.40	0.41	-0.01	smoothing penalty on male maturity curve
0.0000	NA	0.00	0.00	0.00	1st difference penalty on changes in male size at 50% selectivity in directed fishery
1.0000	1.0000	46.63	48.94	-2.32	penalty on F-devs in directed fishery
0.5000	1.4142	10.14	7.99	2.15	penalty on F-devs in snow crab fishery
0.0000	NA	0.00	0.00	0.00	penalty on F-devs in BBRKC fishery
0.5000	1.4142	13.33	13.18	0.14	penalty on F-devs in groundfish fishery
1.0000	1.0000	47.47	52.33	-4.86	likelihood for directed fishery: retained males
1.0000	1.0000	56.95	69.76	-12.81	likelihood for directed fishery: total males
1.0000	1.0000	9.56	10.10	-0.54	likelihood for directed fishery: discarded females
1.0000	1.0000	40.37	40.30	0.08	likelihood for snow crab fishery: discarded males
1.0000	1.0000	13.97	13.04	0.93	likelihood for snow crab fishery: discarded females
1.0000	1.0000	27.66	27.22	0.44	likelihood for BBRKC fishery: discarded males
1.0000	1.0000	1.88	1.91	-0.02	likelihood for BBRKC fishery: discarded females
1.0000	1.0000	94.10	95.75	-1.66	likelihood for groundfish fishery
1.0000	1.0000	301.48	309.24	-7.76	likelihood for survey: immature males
1.0000	1.0000	223.15	220.68	2.47	likelihood for survey: mature males
1.0000	1.0000	253.09	247.51	5.58	likelihood for survey: immature females
1.0000	1.0000	88.72	86.44	2.28	likelihood for survey: mature females
1.0000	1.0000	186.94	187.66	-0.72	likelihood for survey: mature survey biomass
10.0000	0.3162	5.65	12.40	-6.75	likelihood for directed fishery: male retained catch biomass
10.0000	0.3162	4.51	8.97	-4.46	likelihood for directed fishery: male total catch biomass
10.0000	0.3162	11.57	6.02	5.55	likelihood for directed fishery: female catch biomass
10.0000	0.3162	13.19	9.81	3.39	likelihood for snow crab fishery: total catch biomass
10.0000	0.3162	19.27	7.63	11.64	likelihood for BBRKC fishery: total catch biomass
10.0000	0.3162	2.25	2.39	-0.14	likelihood for groundfish fishery: total catch biomass

Table 20. Comparison of the final objective function components for the alternative models Alt1a and Alt1b, which can be compared directly. Component differences greater or less than 2 units are highlighted. Positive differences (red highlighting) indicate better fits with Alt0b. Negative differences (blue highlighting) indicate better fits with Alt0a. Overall, Alt1a fits the data better, with smaller penalties, by 6.06 likelihood units compared with Alt1b.

weight	sigma	Model Case		Difference a-b	Description
		Alt1a	Alt1b		
1.0000	1.0000	2.19	2.20	-0.02	recruitment penalty
0.0000	NA	0.00	0.00	0.00	sex ratio penalty
1.0000	1.0000	0.85	0.92	-0.07	immatures natural mortality penalty
1.0000	1.0000	1.44	2.69	-1.25	mature male natural mortality penalty
1.0000	1.0000	42.70	38.99	3.71	mature female natural mortality penalty
1.0000	1.0000	6.17	3.24	2.94	survey q penalty
1.0000	1.0000	25.70	20.59	5.11	female survey q penalty
1.0000	1.0000	0.90	0.90	0.00	prior on female growth parameter a
1.0000	1.0000	0.72	0.73	-0.01	prior on female growth parameter b
1.0000	1.0000	0.09	0.12	-0.03	prior on male growth parameter a
1.0000	1.0000	0.02	0.03	0.00	prior on male growth parameter b
1.0000	1.0000	1.26	1.25	0.00	smoothing penalty on female maturity curve
0.5000	1.4142	0.43	0.43	-0.01	smoothing penalty on male maturity curve
0.0000	NA	0.00	0.00	0.00	1st difference penalty on changes in male size at 50% selectivity in directed fishery
1.0000	1.0000	49.24	51.45	-2.21	penalty on F-devs in directed fishery
0.5000	1.4142	10.02	7.40	2.62	penalty on F-devs in snow crab fishery
0.0000	NA	0.00	0.00	0.00	penalty on F-devs in BBRKC fishery
0.5000	1.4142	13.12	13.09	0.03	penalty on F-devs in groundfish fishery
1.0000	1.0000	57.82	64.72	-6.90	likelihood for directed fishery: retained males
1.0000	1.0000	93.14	102.11	-8.97	likelihood for directed fishery: total males
1.0000	1.0000	13.53	13.93	-0.40	likelihood for directed fishery: discarded females
1.0000	1.0000	42.42	41.71	0.71	likelihood for snow crab fishery: discarded males
1.0000	1.0000	13.60	12.91	0.69	likelihood for snow crab fishery: discarded females
1.0000	1.0000	22.23	22.48	-0.25	likelihood for BBRKC fishery: discarded males
1.0000	1.0000	1.83	1.93	-0.09	likelihood for BBRKC fishery: discarded females
1.0000	1.0000	150.68	154.55	-3.87	likelihood for groundfish fishery
1.0000	1.0000	289.76	300.72	-10.96	likelihood for survey: immature males
1.0000	1.0000	225.55	220.33	5.22	likelihood for survey: mature males
1.0000	1.0000	259.86	253.73	6.13	likelihood for survey: immature females
1.0000	1.0000	90.58	88.32	2.27	likelihood for survey: mature females
1.0000	1.0000	199.70	201.38	-1.68	likelihood for survey: mature survey biomass
10.0000	0.3162	22.14	32.18	-10.04	likelihood for directed fishery: male retained catch biomass
10.0000	0.3162	12.05	18.83	-6.79	likelihood for directed fishery: male total catch biomass
10.0000	0.3162	12.57	6.54	6.04	likelihood for directed fishery: female catch biomass
10.0000	0.3162	13.79	15.75	-1.96	likelihood for snow crab fishery: total catch biomass
10.0000	0.3162	24.05	9.93	14.12	likelihood for BBRKC fishery: total catch biomass
10.0000	0.3162	2.07	2.19	-0.13	likelihood for groundfish fishery: total catch biomass

Table 21. Estimated population size (thousands) for females on July 1 of year. from the author's preferred model (Alt1a).

Year	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5	147.5	152.5	157.5	162.5	167.5	172.5	177.5	182.5
1975	1.31E+04	7.61E+04	6.29E+04	4.63E+04	3.84E+04	4.04E+04	4.40E+04	5.09E+04	7.75E+04	1.25E+05	1.43E+05	1.31E+05	1.13E+05	8.36E+04	5.32E+04	2.62E+04	7.60E+03	1.19E+03	1.72E+02	2.56E+01	2.57E+00	1.79E+01	1.52E+02	3.05E+03	9.00E+04	2.78E+04	8.61E+05	2.66E+05	8.17E+06	2.58E+06	7.79E+07	2.99E+07
1976	7.58E+04	1.78E+05	1.49E+05	1.13E+05	7.59E+04	4.94E+04	3.55E+04	3.54E+04	5.82E+04	1.02E+05	1.20E+05	1.11E+05	9.66E+04	7.23E+04	4.62E+04	2.27E+04	6.59E+03	1.03E+03	1.48E+02	2.21E+01	2.21E+00	1.57E+01	1.41E+02	2.98E+03	8.87E+04	2.79E+04	8.51E+05	2.63E+05	8.10E+06	2.48E+06	7.72E+07	2.97E+07
1977	4.66E+04	1.15E+05	1.29E+05	1.44E+05	1.24E+05	9.51E+04	6.99E+04	5.32E+04	5.76E+04	8.49E+04	9.73E+04	9.02E+04	8.00E+04	6.06E+04	3.88E+04	1.90E+04	5.42E+03	8.24E+02	1.16E+02	1.69E+01	1.69E+00	1.31E+01	1.54E+02	3.72E+03	1.11E+03	3.41E+04	1.05E+04	3.23E+05	9.93E+06	9.46E+07	3.64E+07	
1978	3.96E+04	9.52E+04	9.80E+04	1.04E+05	1.00E+05	1.00E+05	9.45E+04	8.41E+04	8.39E+04	8.39E+04	9.77E+04	9.70E+04	8.20E+04	4.98E+04	3.12E+04	1.49E+04	4.09E+03	5.88E+02	7.82E+01	1.08E+01	1.05E+00	8.24E+02	1.02E+02	2.44E+03	7.06E+04	2.11E+04	6.38E+05	1.95E+05	5.94E+06	1.81E+06	5.32E+07	2.16E+07
1979	9.71E+03	2.71E+04	4.29E+04	6.48E+04	6.91E+04	7.04E+04	7.08E+04	7.43E+04	9.02E+04	1.13E+05	1.13E+05	9.21E+04	7.05E+04	4.77E+04	2.81E+04	1.26E+04	3.27E+03	4.40E+02	5.34E+01	6.87E+00	6.49E+01	5.26E+02	6.90E+03	1.65E+03	4.67E+04	1.36E+04	4.06E+05	1.23E+05	6.70E+06	1.13E+06	3.52E+07	1.35E+07
1980	3.75E+03	9.78E+03	1.31E+04	1.96E+04	2.74E+04	3.83E+04	4.58E+04	5.28E+04	7.28E+04	1.03E+05	1.10E+05	9.56E+04	7.55E+04	5.08E+04	2.91E+04	1.25E+04	3.06E+03	3.91E+02	4.23E+01	4.53E+00	4.36E+01	2.83E+02	2.14E+03	3.49E+04	8.68E+05	2.39E+05	6.87E+06	2.03E+06	6.10E+07	1.85E+07	5.70E+08	2.18E+08
1981	8.85E+03	2.04E+04	1.74E+04	1.38E+04	1.19E+04	1.31E+04	1.70E+04	2.62E+04	4.87E+04	8.25E+04	9.44E+04	8.47E+04	6.96E+04	4.84E+04	2.83E+04	1.22E+04	3.03E+03	3.99E+02	4.71E+01	6.13E+00	5.71E+01	3.45E+02	1.61E+03	1.14E+04	2.04E+05	5.17E+06	1.43E+06	4.15E+07	1.23E+07	3.69E+08	1.13E+08	4.25E+09
1982	4.40E+03	1.11E+04	1.33E+04	1.59E+04	1.40E+04	1.12E+04	9.65E+03	1.23E+04	2.77E+04	5.66E+04	7.07E+04	6.72E+04	5.89E+04	4.30E+04	2.61E+04	1.19E+04	3.10E+03	4.39E+02	5.85E+01	8.39E+00	8.19E+01	5.20E+02	2.90E+03	3.41E+04	8.67E+05	2.57E+05	7.80E+06	2.38E+06	7.26E+07	2.21E+07	6.85E+08	2.62E+08
1983	3.15E+04	7.13E+04	5.58E+04	3.50E+04	2.15E+04	1.55E+04	1.26E+04	1.25E+04	2.14E+04	4.11E+04	5.10E+04	4.89E+04	4.45E+04	3.40E+04	2.15E+04	1.02E+04	2.78E+03	4.11E+02	5.91E+01	8.92E+00	8.90E+01	5.71E+02	3.22E+03	3.91E+04	1.03E+04	3.11E+05	9.55E+06	2.94E+06	9.01E+07	2.76E+07	8.56E+08	3.26E+08
1984	2.59E+04	6.24E+04	6.43E+04	6.50E+04	5.08E+04	3.42E+04	2.21E+04	1.67E+04	2.11E+04	3.45E+04	4.04E+04	3.75E+04	3.36E+04	2.56E+04	1.63E+04	7.80E+03	2.17E+03	3.29E+02	5.00E+01	7.87E+00	8.19E+01	6.09E+02	6.11E+03	1.40E+03	4.29E+04	1.35E+04	4.24E+05	1.32E+05	4.09E+06	1.25E+06	3.92E+07	1.51E+07
1985	5.50E+04	1.16E+05	1.02E+05	8.21E+04	6.34E+04	5.24E+04	4.32E+04	3.42E+04	3.11E+04	3.59E+04	3.66E+04	3.18E+04	2.71E+04	2.01E+04	1.25E+04	5.94E+03	1.64E+03	2.47E+02	3.69E+01	5.74E+00	6.05E+01	5.02E+02	6.62E+03	1.72E+03	5.33E+04	1.68E+04	5.25E+05	1.63E+05	5.05E+06	1.55E+06	4.84E+07	1.86E+07
1986	4.21E+04	1.01E+05	1.04E+05	1.06E+05	8.79E+04	6.85E+04	5.36E+04	4.47E+04	4.40E+04	4.82E+04	4.50E+04	3.56E+04	2.69E+04	1.83E+04	1.09E+04	5.08E+03	1.40E+03	2.11E+02	3.11E+01	4.83E+00	5.36E+01	5.53E+02	1.02E+02	2.95E+03	9.34E+04	2.96E+04	9.29E+05	3.90E+05	8.97E+06	2.76E+06	8.61E+07	3.32E+07
1987	3.96E+04	9.45E+04	9.47E+04	9.53E+04	8.54E+04	7.80E+04	6.92E+04	5.95E+04	5.61E+04	5.92E+04	5.48E+04	4.36E+04	3.23E+04	2.11E+04	1.22E+04	5.48E+03	1.49E+03	2.24E+02	3.10E+01	4.61E+00	5.17E+01	5.79E+02	1.17E+02	3.46E+03	1.10E+03	3.47E+04	1.09E+04	2.90E+05	1.05E+05	3.22E+06	1.00E+06	3.86E+07
1988	3.54E+04	8.50E+04	8.60E+04	8.76E+04	7.79E+04	7.04E+04	6.45E+04	5.16E+04	6.52E+04	7.35E+04	6.88E+04	5.42E+04	3.94E+04	2.55E+04	1.47E+04	6.69E+03	1.85E+03	2.81E+02	3.79E+01	5.47E+00	5.97E+01	6.29E+02	1.20E+02	3.49E+03	1.10E+03	3.46E+04	1.08E+04	3.36E+05	1.04E+05	3.18E+06	9.90E+07	3.80E+07
1989	1.56E+04	3.97E+04	4.29E+04	6.40E+04	6.37E+04	6.15E+04	5.80E+04	5.58E+04	6.28E+04	7.70E+04	7.67E+04	6.34E+04	4.79E+04	3.15E+04	1.83E+04	8.37E+03	2.32E+03	3.54E+02	4.74E+01	6.77E+00	7.17E+01	6.89E+02	1.14E+02	3.20E+03	9.98E+04	3.12E+04	9.72E+05	3.01E+05	9.27E+06	2.84E+06	8.83E+07	3.95E+07
1990	6.90E+03	1.76E+04	2.22E+04	2.98E+04	3.44E+04	4.05E+04	4.40E+04	4.68E+04	5.77E+04	7.57E+04	7.79E+04	6.60E+04	5.16E+04	3.51E+04	2.09E+04	9.71E+03	2.71E+03	4.09E+02	5.42E+01	7.57E+00	7.58E+01	5.99E+02	7.36E+03	1.82E+03	5.50E+04	1.69E+04	5.22E+05	1.68E+05	4.92E+06	1.50E+06	4.66E+07	1.79E+07
1991	3.22E+03	8.15E+03	1.01E+04	1.33E+04	1.53E+04	1.86E+04	2.22E+04	2.84E+04	4.39E+04	6.67E+04	7.29E+04	6.37E+04	5.12E+04	3.54E+04	2.12E+04	9.83E+03	2.69E+03	3.95E+02	5.16E+01	7.10E+00	6.83E+01	4.65E+02	3.79E+03	7.20E+04	2.04E+04	6.11E+05	1.85E+05	5.63E+06	1.71E+06	5.22E+07	1.61E+07	6.17E+08
1992	2.71E+03	6.56E+03	6.76E+03	7.28E+03	7.52E+03	8.59E+03	1.02E+04	1.43E+04	2.75E+04	4.98E+04	5.91E+04	5.44E+04	4.61E+04	3.30E+04	2.01E+04	9.32E+03	2.52E+03	3.64E+02	4.71E+01	6.44E+00	6.09E+01	3.84E+02	2.31E+03	3.08E+04	7.96E+05	2.33E+05	6.96E+06	2.10E+06	6.35E+07	1.93E+07	5.94E+08	2.27E+08
1993	2.27E+03	5.47E+03	5.64E+03	5.89E+03	5.40E+03	5.18E+03	5.45E+03	5.79E+03	7.79E+03	1.75E+04	1.75E+04	1.53E+04	1.09E+04	6.25E+03	3.65E+03	1.63E+03	7.46E+02	1.05E+02	1.38E+01	1.47E+00	1.51E+01	1.29E+02	1.16E+04	2.51E+05	6.93E+06	2.01E+06	5.94E+07	1.78E+07	5.35E+08	1.65E+08	6.25E+09	
1994	2.59E+03	6.14E+03	5.88E+03	5.55E+03	4.80E+03	4.37E+03	4.23E+03	5.48E+03	1.23E+04	2.55E+04	3.17E+04	3.00E+04	2.69E+04	2.01E+04	1.24E+04	5.70E+03	1.48E+03	2.02E+02	2.67E+01	3.77E+00	3.57E+01	2.20E+02	1.12E+03	1.08E+04	2.49E+05	1.00E+06	2.10E+06	6.28E+07	1.90E+07	5.75E+08	1.77E+08	6.75E+09
1995	3.77E+03	8.83E+03	8.06E+03	6.99E+03	5.52E+03	4.50E+03	3.95E+03	4.61E+03	9.49E+03	1.91E+04	2.35E+04	2.21E+04	1.98E+04	1.49E+04	9.16E+03	4.20E+03	1.98E+03	1.47E+02	1.98E+01	2.82E+00	2.69E+01	1.70E+02	9.95E+04	1.30E+04	3.39E+05	1.00E+05	3.04E+06	9.24E+07	2.82E+07	8.58E+08	2.66E+08	1.02E+09
1996	3.65E+03	8.70E+03	8.63E+03	8.44E+03	7.00E+03	5.65E+03	4.66E+03	4.66E+03	7.94E+03	1.49E+04	1.79E+04	1.67E+04	1.48E+04	1.10E+04	6.73E+03	3.06E+03	7.87E+02	1.07E+02	1.43E+01	2.04E+00	1.95E+01	1.30E+02	1.00E+03	1.85E+04	5.32E+05	1.62E+05	4.97E+06	1.53E+06	4.68E+07	1.43E+07	4.44E+08	1.70E+08
1997	9.85E+03	2.26E+04	1.90E+04	1.40E+04	9.82E+03	7.44E+03	6.02E+03	5.53E+03	7.63E+03	1.25E+04	1.45E+04	1.31E+04	1.14E+04	8.45E+03	5.16E+03	2.36E+03	6.11E+02	8.42E+01	1.14E+01	1.64E+00	1.60E+01	1.15E+02	1.12E+03	2.51E+04	7.55E+05	2.34E+05	7.28E+06	2.25E+06	6.93E+07	2.13E+07	6.61E+08	2.53E+08
1998	3.89E+03	1.01E+04	1.31E+04	1.68E+04	1.49E+04	1.16E+04	8.69E+03	7.11E+03	8.19E+03	1.16E+04	1.26E+04	1.10E+04	9.15E+03	6.57E+03	3.98E+03	1.82E+03	4.78E+02	6.73E+01	9.29E+00	1.36E+00	1.40E+01	1.22E+02	1.83E+03	5.04E+04	1.58E+04	5.00E+05	1.57E+05	4.88E+06	1.51E+06	4.62E+07	1.44E+07	5.52E+08
1999	1.21E+04	2.78E+04	2.30E+04	1.70E+04	1.32E+04	1.16E+04	1.04E+04	1.06E+04	1.62E+04	3.25E+04	4.12E+04	3.82E+04	3.05E+04	2.19E+04	1.34E+04	6.17E+03	1.68E+03	1.58E+02	8.07E+01	1.18E+00	1.22E+01	1.09E+02	1.69E+03	4.70E+04	1.48E+04	4.67E+05	1.46E+05	4.55E+06	1.40E+06	4.30E+07	1.34E+07	5.12E+08
2000	7.38E+03	1.82E+04	2.05E+04	2.29E+04	1.93E+04	1.45E+04	1.12E+04	9.95E+03	1.14E+04	1.43E+04	1.41E+04	1.13E+04	8.47E+03	5.63E+03	3.28E+03	1.49E+03	4.05E+02	5.99E+01	8.25E+00	1.21E+00	1.33E+01	1.38E+02</										

Table 22. Estimated population size (thousands) for males on July 1 of year. from the author's preferred model (Alt1a).

Year	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5	147.5	152.5	157.5	162.5	167.5	172.5	177.5	182.5
1975	1.31E+04	7.03E+04	6.17E+04	4.26E+04	3.11E+04	2.81E+04	3.04E+04	3.16E+04	3.20E+04	3.27E+04	3.34E+04	3.68E+04	3.82E+04	4.14E+04	4.82E+04	5.17E+04	5.31E+04	5.58E+04	5.64E+04	5.74E+04	5.39E+04	4.85E+04	4.10E+04	3.47E+04	2.84E+04	2.20E+04	1.50E+04	9.77E+03	5.12E+03	2.02E+03	4.58E+02	1.64E+01
1976	7.58E+04	1.78E+05	1.46E+05	1.06E+05	7.07E+04	4.88E+04	3.17E+04	2.36E+04	2.05E+04	2.07E+04	2.33E+04	2.64E+04	2.98E+04	3.55E+04	4.09E+04	4.42E+04	4.57E+04	4.82E+04	4.86E+04	4.92E+04	4.60E+04	4.11E+04	3.44E+04	2.92E+04	2.39E+04	1.86E+04	1.32E+04	8.09E+03	4.34E+03	1.71E+03	3.89E+02	1.49E+01
1977	4.66E+04	1.12E+05	1.21E+05	1.28E+05	1.10E+05	8.82E+04	6.79E+04	5.06E+04	3.80E+04	2.96E+04	2.48E+04	2.28E+04	2.31E+04	2.47E+04	3.12E+04	3.47E+04	3.63E+04	3.86E+04	3.87E+04	3.84E+04	3.50E+04	3.06E+04	2.53E+04	2.11E+04	1.72E+04	1.32E+04	9.35E+03	5.81E+03	3.04E+03	1.20E+03	2.70E+02	1.03E+01
1978	3.96E+04	9.32E+04	9.28E+04	9.08E+04	8.21E+04	7.72E+04	7.63E+04	6.99E+04	6.11E+04	5.28E+04	4.53E+04	3.92E+04	3.49E+04	3.38E+04	3.34E+04	3.28E+04	3.12E+04	3.04E+04	2.81E+04	2.58E+04	2.17E+04	1.79E+04	1.42E+04	1.16E+04	9.34E+03	7.24E+03	5.01E+03	3.09E+03	1.60E+03	6.26E+02	1.41E+02	5.00E+00
1979	9.71E+03	2.54E+04	3.87E+04	5.48E+04	5.67E+04	5.50E+04	5.39E+04	5.12E+04	4.90E+04	4.84E+04	4.89E+04	4.82E+04	4.66E+04	4.60E+04	4.46E+04	4.20E+04	3.79E+04	3.39E+04	2.86E+04	2.34E+04	1.80E+04	1.36E+04	1.01E+04	7.73E+03	5.83E+03	4.21E+03	2.82E+03	1.68E+03	8.42E+02	3.13E+02	7.10E+01	2.34E+00
1980	3.75E+03	9.30E+03	1.38E+04	1.58E+04	1.94E+04	2.45E+04	3.10E+04	3.37E+04	3.45E+04	3.50E+04	3.60E+04	3.69E+04	3.77E+04	4.01E+04	4.17E+04	4.14E+04	3.87E+04	3.49E+04	2.91E+04	2.34E+04	1.80E+04	1.37E+04	1.03E+04	7.72E+03	5.50E+03	3.65E+03	2.19E+03	1.15E+03	5.06E+02	1.68E+02	3.36E+01	4.51E+01
1981	8.85E+03	2.02E+04	1.70E+04	1.26E+04	9.61E+03	8.79E+03	9.75E+03	1.15E+04	1.39E+04	1.69E+04	2.04E+04	2.31E+04	2.49E+04	2.71E+04	2.82E+04	2.81E+04	2.62E+04	2.36E+04	2.01E+04	1.68E+04	1.38E+04	1.14E+04	9.33E+03	7.49E+03	5.66E+03	3.93E+03	2.44E+03	1.30E+03	5.75E+02	1.90E+02	3.76E+01	1.55E+01
1982	4.40E+03	1.07E+04	1.24E+04	1.40E+04	1.24E+04	1.01E+04	8.05E+03	6.69E+03	6.21E+03	6.50E+03	7.58E+03	9.10E+03	1.08E+04	1.33E+04	1.55E+04	1.69E+04	1.72E+04	1.70E+04	1.58E+04	1.47E+04	1.31E+04	1.15E+04	9.87E+03	8.35E+03	6.74E+03	5.08E+03	3.47E+03	2.07E+03	1.04E+03	3.92E+02	8.80E+01	9.42E+01
1983	3.15E+04	7.11E+04	5.53E+04	3.37E+04	1.96E+04	1.27E+04	1.01E+04	8.56E+03	7.38E+03	6.50E+03	5.98E+03	5.80E+03	5.94E+03	6.74E+03	7.63E+03	8.40E+03	8.77E+03	9.25E+03	9.39E+03	9.66E+03	9.45E+03	8.98E+03	8.12E+03	7.26E+03	6.18E+03	4.90E+03	3.51E+03	2.20E+03	1.15E+03	4.54E+02	2.97E+02	1.05E+01
1984	2.59E+04	6.10E+04	6.12E+04	5.86E+04	4.68E+04	3.42E+04	2.31E+04	1.52E+04	1.05E+04	7.98E+03	6.86E+03	6.30E+03	5.97E+03	6.01E+03	6.08E+03	6.08E+03	5.92E+03	5.94E+03	5.89E+03	6.08E+03	6.01E+03	5.80E+03	5.29E+03	4.80E+03	4.17E+03	3.38E+03	2.49E+03	1.61E+03	8.70E+02	3.53E+02	8.23E+01	3.94E+00
1985	5.02E+04	1.15E+05	9.85E+04	7.55E+04	5.54E+04	4.36E+04	3.75E+04	3.11E+04	2.49E+04	1.95E+04	1.48E+04	1.12E+04	8.66E+03	7.17E+03	6.30E+03	5.78E+03	5.35E+03	5.11E+03	4.83E+03	4.68E+03	4.37E+03	4.01E+03	3.53E+03	3.12E+03	2.66E+03	2.12E+03	1.54E+03	9.83E+02	5.28E+02	2.13E+02	4.92E+01	2.96E+00
1986	4.21E+04	9.91E+04	8.74E+04	9.50E+04	7.84E+04	6.20E+04	4.86E+04	3.79E+04	3.06E+04	2.60E+04	2.31E+04	2.05E+04	1.78E+04	1.55E+04	1.33E+04	1.13E+04	9.48E+03	8.08E+03	6.92E+03	6.16E+03	5.41E+03	4.75E+03	4.06E+03	3.53E+03	2.98E+03	2.34E+03	1.68E+03	1.06E+03	5.65E+02	2.26E+02	5.18E+01	2.75E+00
1987	3.96E+04	9.27E+04	9.02E+04	8.47E+04	7.25E+04	6.34E+04	5.81E+04	5.06E+04	4.28E+04	3.62E+04	3.07E+04	2.61E+04	2.25E+04	2.02E+04	1.84E+04	1.69E+04	1.53E+04	1.39E+04	1.23E+04	1.09E+04	9.29E+03	7.80E+03	6.38E+03	5.27E+03	4.21E+03	3.16E+03	2.17E+03	1.32E+03	6.76E+02	2.63E+02	5.90E+01	2.64E+00
1988	3.54E+04	8.32E+04	8.18E+04	7.78E+04	6.65E+04	5.76E+04	5.22E+04	4.64E+04	4.16E+04	3.83E+04	3.61E+04	3.35E+04	3.06E+04	2.81E+04	2.57E+04	2.33E+04	2.07E+04	1.87E+04	1.67E+04	1.50E+04	1.30E+04	1.11E+04	9.26E+03	7.77E+03	6.29E+03	4.74E+03	3.26E+03	1.97E+03	1.00E+03	3.84E+02	8.61E+01	2.51E+00
1989	1.56E+04	3.81E+04	4.61E+04	5.52E+04	5.32E+04	4.95E+04	4.67E+04	4.23E+04	3.81E+04	3.51E+04	3.34E+04	3.17E+04	3.01E+04	2.94E+04	2.87E+04	2.77E+04	2.62E+04	2.47E+04	2.26E+04	2.06E+04	1.80E+04	1.53E+04	1.26E+04	1.05E+04	8.42E+03	6.29E+03	4.29E+03	2.58E+03	1.30E+03	4.98E+02	1.11E+02	3.22E+00
1990	6.90E+03	1.89E+04	2.04E+04	2.50E+04	2.66E+04	2.87E+04	3.20E+04	3.24E+04	3.15E+04	3.06E+04	3.02E+04	2.95E+04	2.84E+04	2.82E+04	2.79E+04	2.74E+04	2.62E+04	2.51E+04	2.33E+04	2.15E+04	1.88E+04	1.60E+04	1.33E+04	1.12E+04	9.09E+03	6.82E+03	4.65E+03	2.78E+03	1.39E+03	5.67E+02	1.17E+02	2.98E+00
1991	3.22E+03	7.85E+03	9.31E+03	1.12E+04	1.18E+04	1.28E+04	1.46E+04	1.60E+04	1.73E+04	1.91E+04	2.13E+04	2.28E+04	2.35E+04	2.44E+04	2.49E+04	2.49E+04	2.40E+04	2.29E+04	2.08E+04	1.82E+04	1.52E+04	1.30E+04	1.07E+04	8.97E+03	7.26E+03	5.42E+03	3.66E+03	2.16E+03	1.07E+03	4.02E+02	8.80E+01	2.20E+00
1992	2.71E+03	6.42E+03	6.40E+03	6.32E+03	5.96E+03	6.04E+03	6.69E+03	7.37E+03	8.23E+03	9.42E+03	1.11E+04	1.29E+04	1.43E+04	1.61E+04	1.77E+04	1.90E+04	1.93E+04	1.94E+04	1.82E+04	1.67E+04	1.42E+04	1.17E+04	9.57E+03	8.00E+03	6.45E+03	4.80E+03	3.24E+03	1.92E+03	9.49E+02	3.55E+02	7.76E+01	1.59E+00
1993	2.27E+03	5.35E+03	5.35E+03	5.21E+03	4.56E+03	4.07E+03	3.91E+03	4.01E+03	4.38E+03	5.05E+03	6.16E+03	7.38E+03	8.29E+03	9.48E+03	1.07E+04	1.18E+04	1.24E+04	1.30E+04	1.28E+04	1.25E+04	1.10E+04	9.40E+03	7.56E+03	5.88E+03	4.60E+03	3.35E+03	2.25E+03	1.34E+03	6.77E+02	2.58E+02	5.77E+01	8.23E+01
1994	2.59E+03	6.04E+03	5.64E+03	4.98E+03	4.10E+03	3.52E+03	3.27E+03	3.17E+03	3.26E+03	3.54E+03	4.17E+03	4.91E+03	5.39E+03	6.04E+03	6.77E+03	7.56E+03	8.05E+03	8.64E+03	8.67E+03	8.49E+03	7.50E+03	6.27E+03	5.04E+03	4.22E+03	3.39E+03	2.52E+03	1.73E+03	1.06E+03	5.43E+02	2.11E+02	4.78E+01	1.21E+00
1995	3.77E+03	8.71E+03	7.79E+03	6.38E+03	4.86E+03	3.82E+03	3.23E+03	2.91E+03	2.83E+03	2.96E+03	3.39E+03	3.88E+03	4.11E+03	4.43E+03	4.83E+03	5.31E+03	5.60E+03	6.02E+03	6.05E+03	5.96E+03	5.25E+03	4.39E+03	3.53E+03	3.00E+03	2.46E+03	1.86E+03	1.29E+03	7.95E+02	4.14E+02	1.63E+02	3.68E+01	1.28E+00
1996	3.65E+03	8.53E+03	8.24E+03	7.58E+03	6.17E+03	4.96E+03	4.07E+03	3.43E+03	3.05E+03	2.93E+03	3.34E+03	3.84E+03	3.49E+03	3.69E+03	3.96E+03	4.10E+03	4.31E+03	4.24E+03	4.09E+03	3.56E+03	2.98E+03	2.43E+03	2.13E+03	1.79E+03	1.37E+03	9.61E+02	5.95E+02	3.11E+02	1.23E+02	2.77E+01	1.14E+00	
1997	9.85E+03	2.25E+04	1.86E+04	1.31E+04	8.79E+03	6.34E+03	5.09E+03	4.26E+03	3.71E+03	3.39E+03	3.30E+03	3.29E+03	3.15E+03	3.10E+03	3.14E+03	3.25E+03	3.29E+03	3.41E+03	3.35E+03	3.25E+03	2.88E+03	2.45E+03	2.03E+03	1.78E+03	1.51E+03	1.16E+03	8.13E+02	5.04E+02	2.64E+02	1.04E+02	2.35E+01	9.80E+01
1998	3.89E+03	9.62E+03	1.21E+04	1.46E+04	1.33E+04	1.08E+04	8.33E+03	6.28E+03	4.94E+03	4.17E+03	3.85E+03	3.68E+03	3.44E+03	3.30E+03	3.22E+03	3.20E+03	3.12E+03	3.12E+03	3.00E+03	2.88E+03	2.55E+03	2.19E+03	1.82E+03	1.60E+03	1.35E+03	1.04E+03	7.32E+02	4.54E+02	2.38E+02	9.37E+01	2.12E+01	8.80E+01
1999	1.21E+04	2.76E+04	2.25E+04	1.57E+04	1.11E+04	9.31E+03	9.11E+03	8.49E+03	7.55E+03	6.58E+03	5.78E+03	5.00E+03	4.33E+03	3.91E+03	3.62E+03	3.44E+03	3.26E+03	3.18E+03	3.02E+03	2.87E+03	2.55E+03	2.19E+03	1.83E+03	1.59E+03	1.33E+03	1.02E+03	7.18E+02	4.44E+02	2.31E+02	9.06E+01	2.04E+01	8.05E+01
2000	7.38E+03	1.77E+04	1.92E+04	2.04E+04	1.74E+04	1.36E+04	1.02E+04	7.84E+03	6.52E+03	6.02E+03	6.02E+03	5.97E+03	5.89E+03	5.41E+03	5.05E+03	4.68E+03	4.27E+03	3.97E+03	3.64E+03	3.38E+03	2.97E+03											

Table 23. OFLs and ABCs for the 2013 assessment and the four alternative 2014 model scenarios. The author's preferred model is Alt1a.

Model Case	average recruitment (millions)	B (1000's t)	Fmsy	Bmsy (1000's t)	B/Bmsy	OFL (1000's t)	ABC (1000's t)	(p*)	ABC (10% buffer) (1000's t)
2013	211.9	59.35	0.73	33.54	1.77	25.35	25.31		22.82
Alt0a	206.6	63.91	0.69	32.95	1.94	32.84	32.78		29.55
Alt0b	185.4	59.65	0.61	29.12	2.05	30.04	30.00		27.04
Alt1a	209.7	70.77	0.58	33.95	2.08	33.81	33.76		30.43
Alt1b	187.0	63.37	0.61	29.51	2.15	31.35	31.30		28.21

Figures

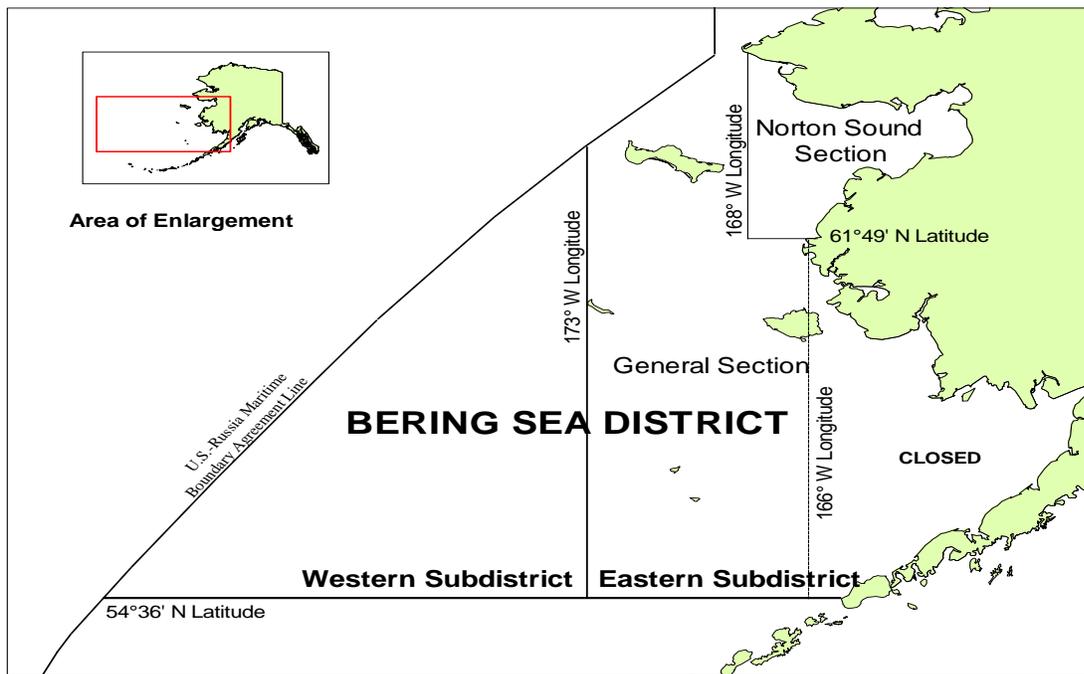


Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008).

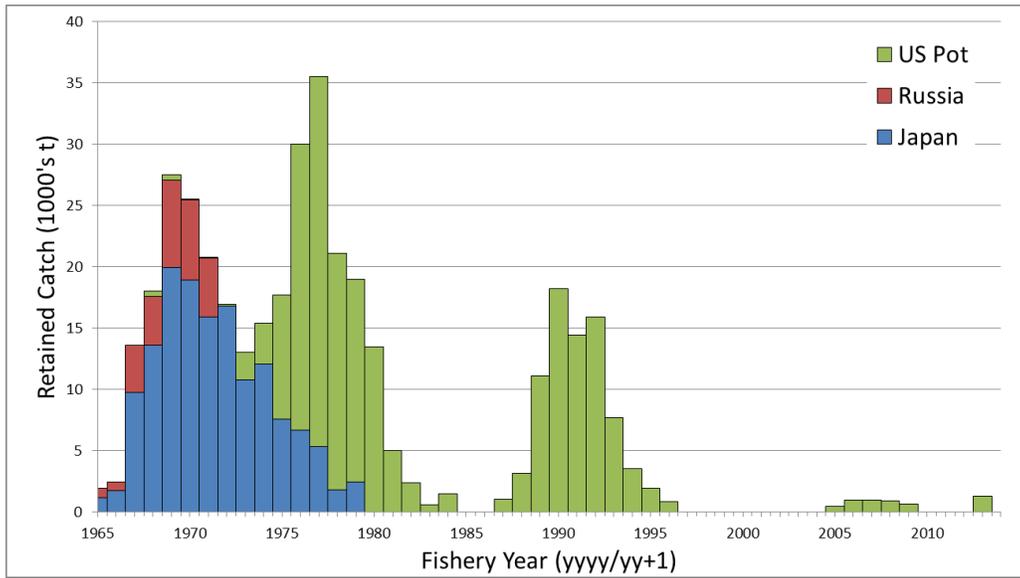


Figure 2. Retained catch (males, 1000's t) in the directed fisheries (US pot fishery [green bars], Russian tangle net fishery [red bars], and Japanese tangle net fisheries [blue bars]) for Tanner crab since 1965/66.

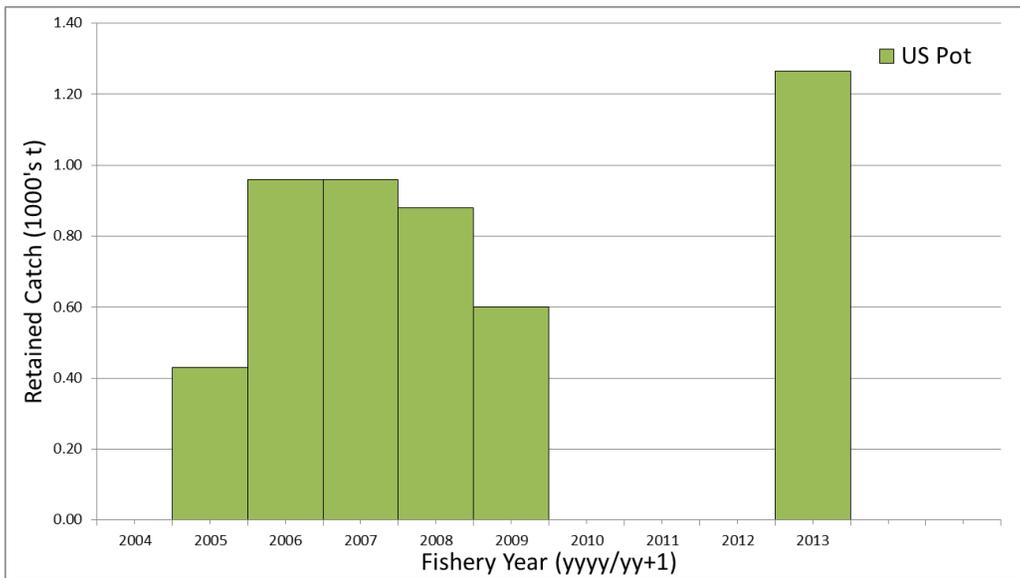


Figure 3. Retained catch (males, 1000's t) in directed fishery for Tanner crab since 2001/02. The directed fishery was closed from 1996/97 to 2004/05 and from 2010/11 to 2012/13.

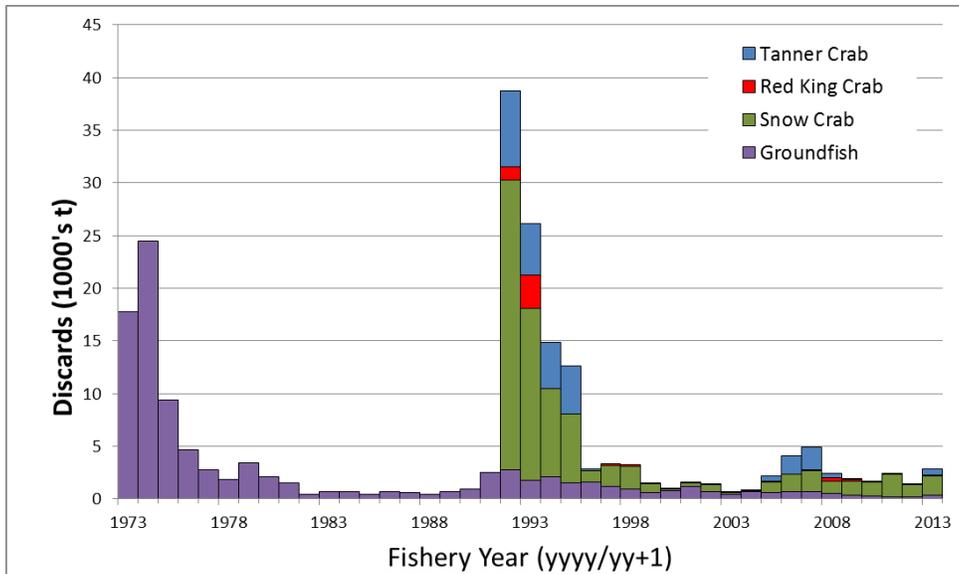


Figure 4. Tanner crab discards (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Discard reporting began in 1973 for the groundfish fisheries and in 1992 for the crab fisheries.

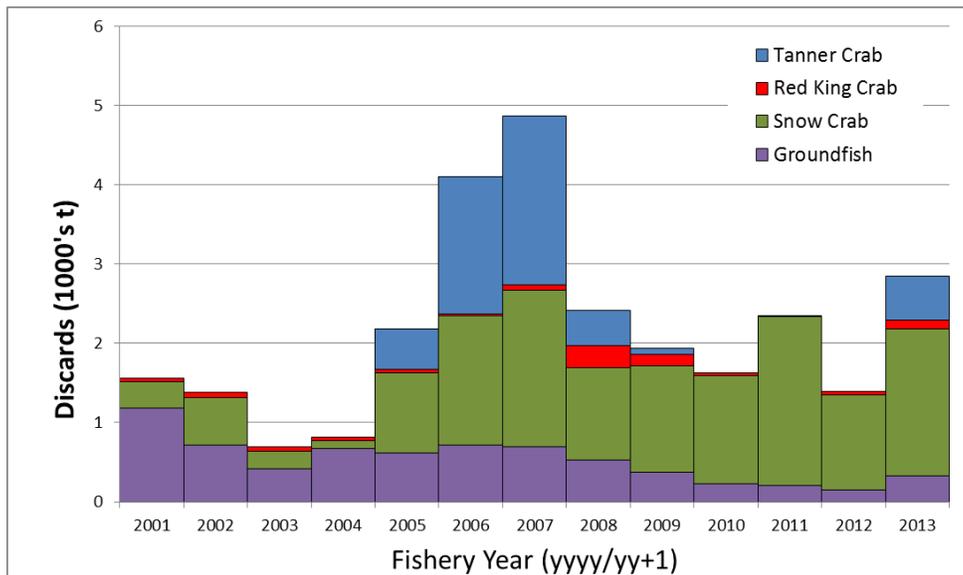


Figure 5. Tanner crab discards (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries since 2001.

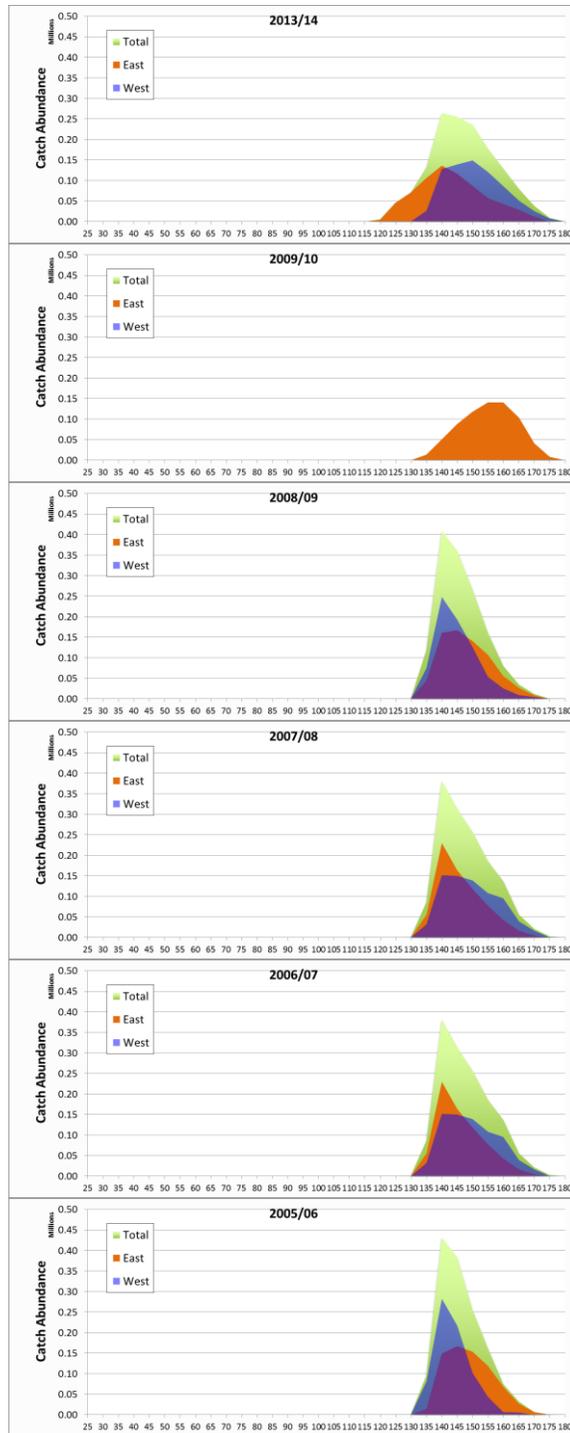


Figure 6. Size compositions, by 5 mm CW bins and expanded to total retained catch, for retained (male) crab in the directed Tanner crab pot fisheries since 2005/06, from dockside crab fishery observer sampling. The region west of 166°W was closed to fishing in 2009/10. The entire fishery was closed in 2010/11-2012/13.

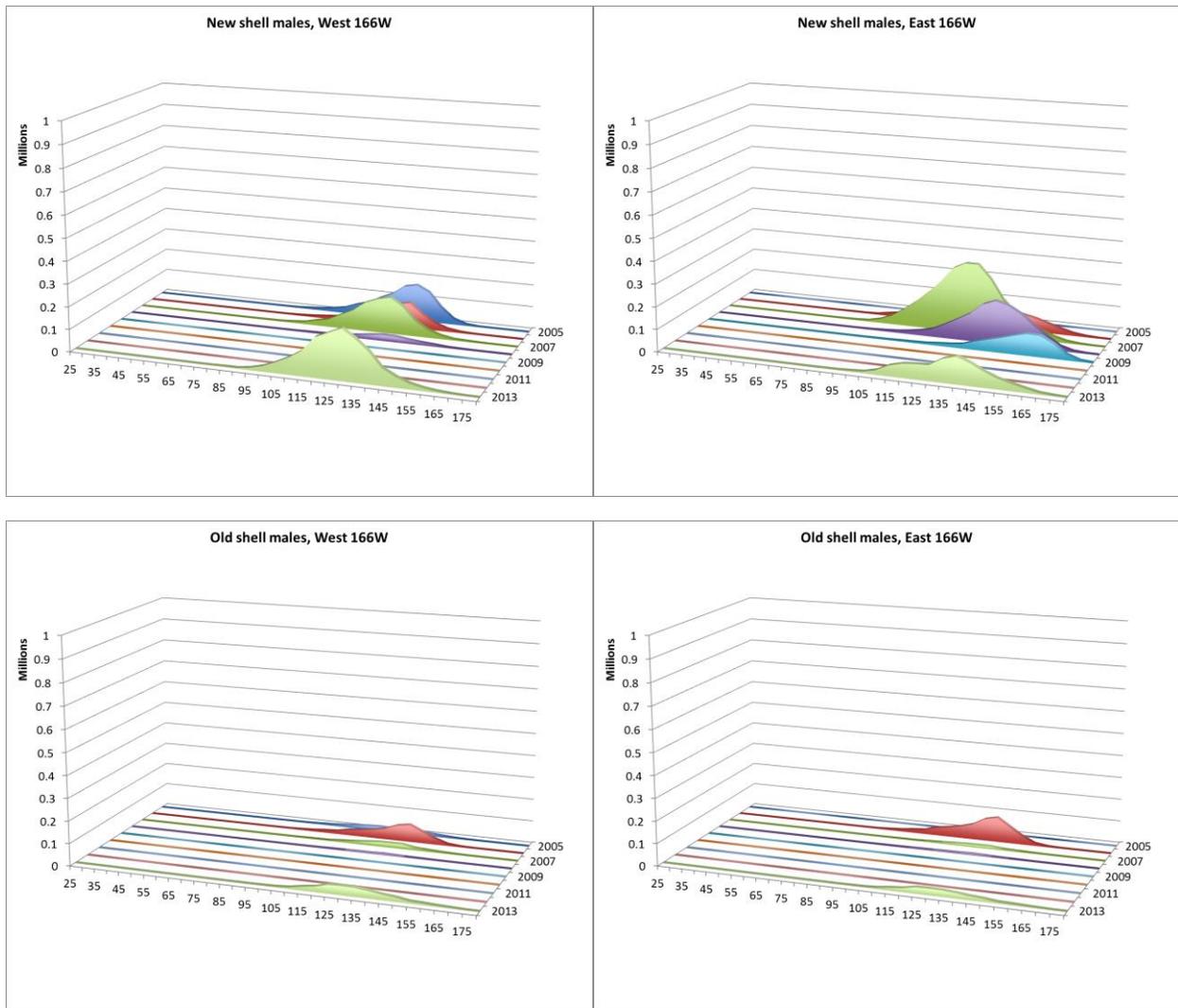


Figure 7. Male Tanner crab catch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling.

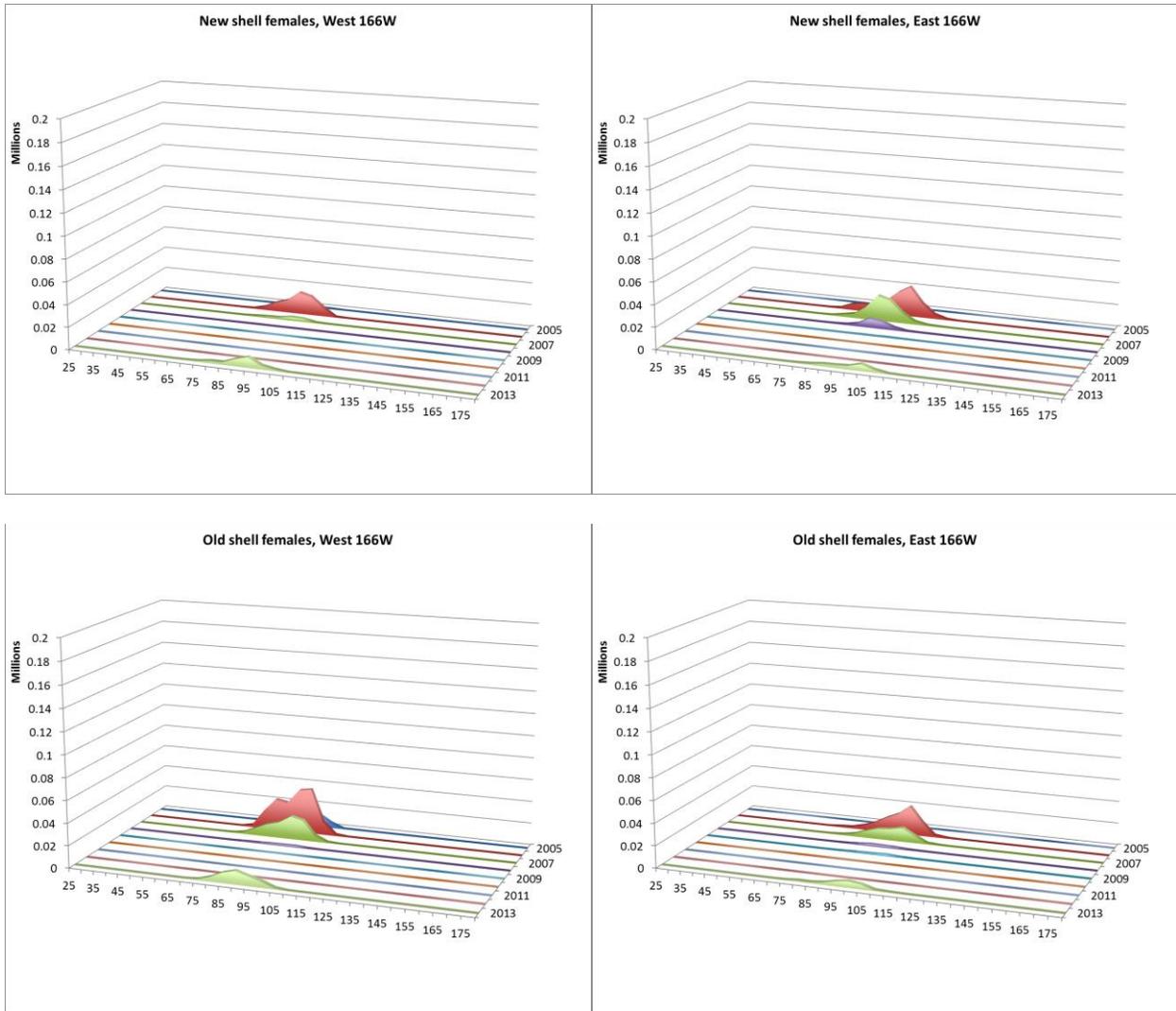


Figure 8. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling.

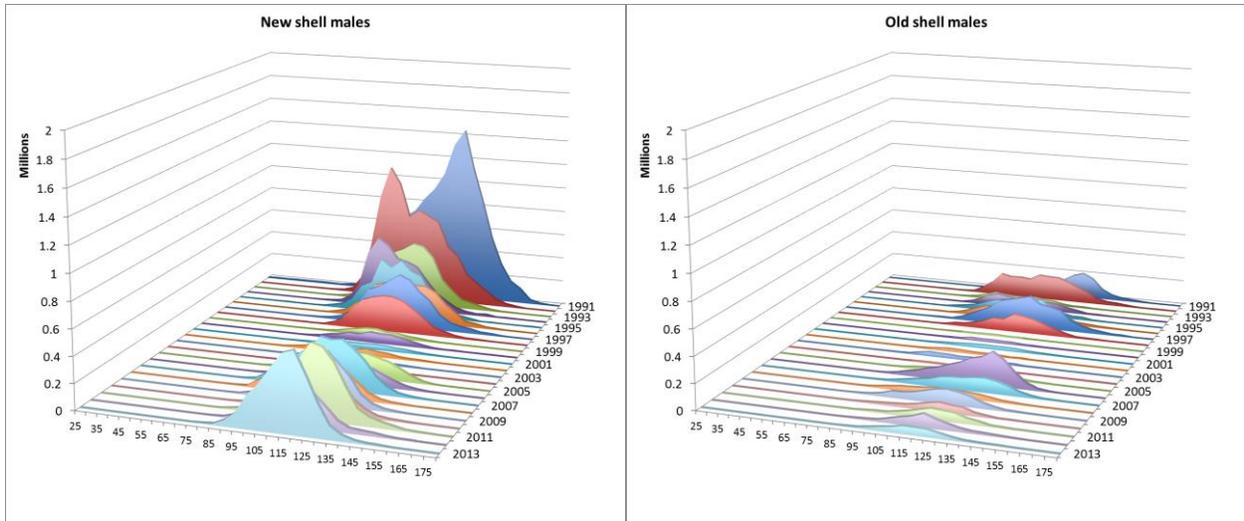


Figure 9. Male Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the snow crab pot fishery, from at-sea crab fishery observer sampling.

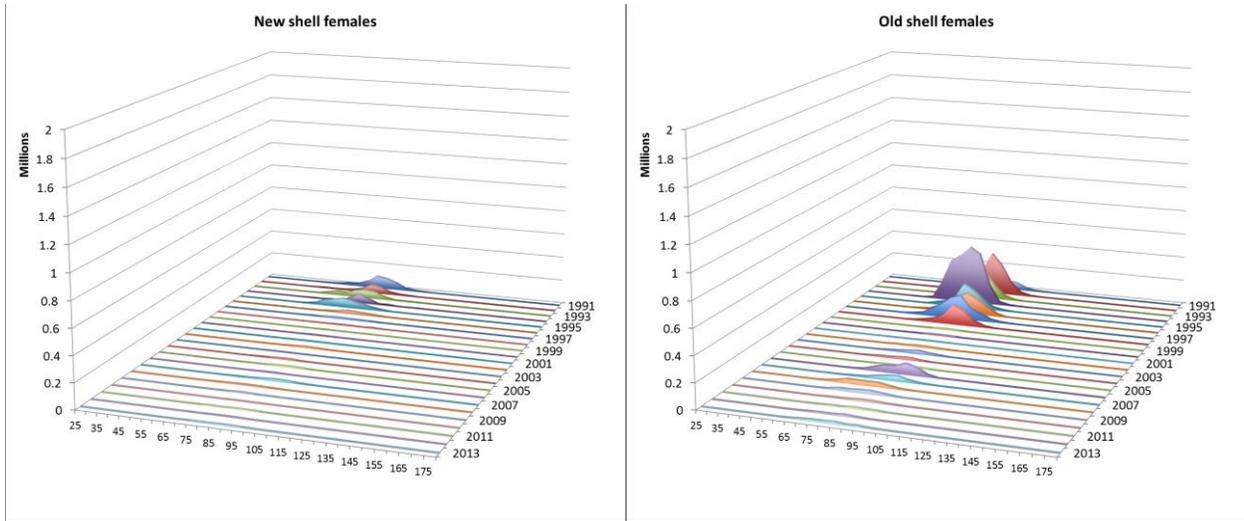


Figure 10. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the snow crab pot fishery, from at-sea crab fishery observer sampling.

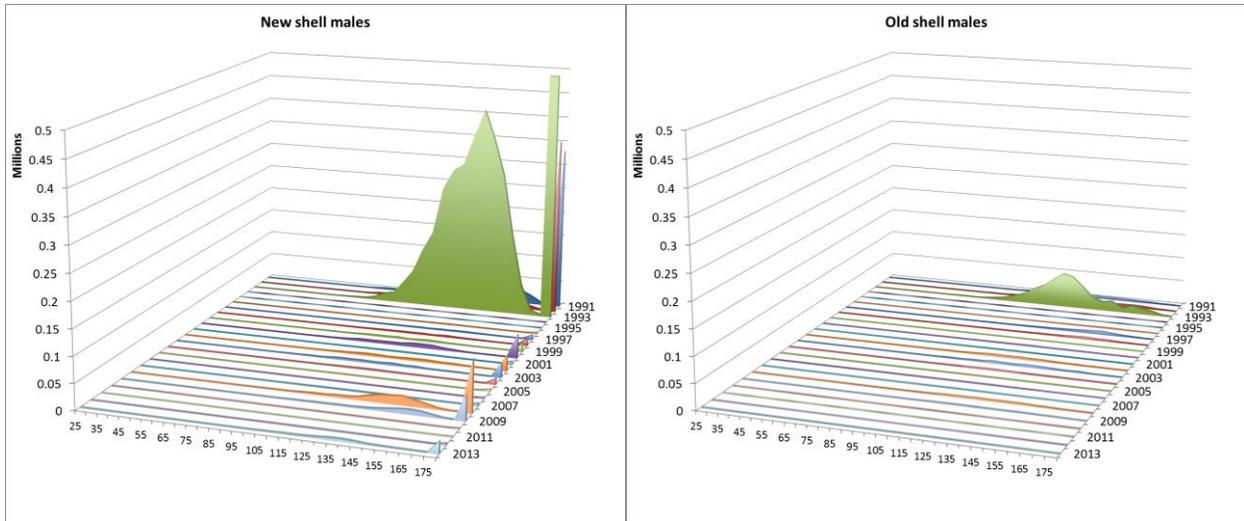


Figure 11. Male Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the BBRKC pot fishery, from at-sea crab fishery observer sampling.

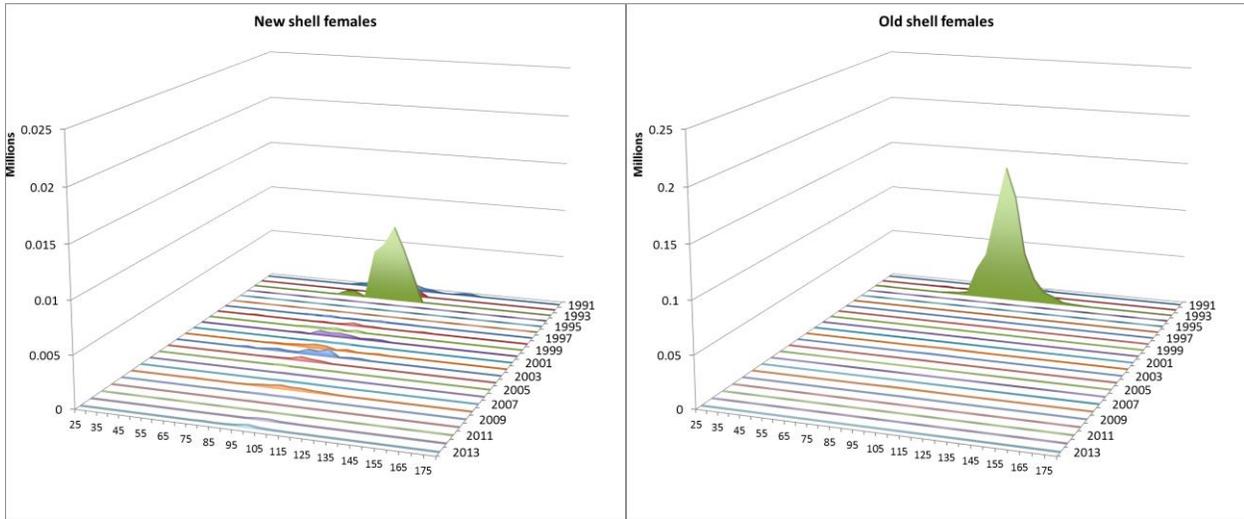


Figure 12. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the BBRKC pot fishery, from at-sea crab fishery observer sampling.

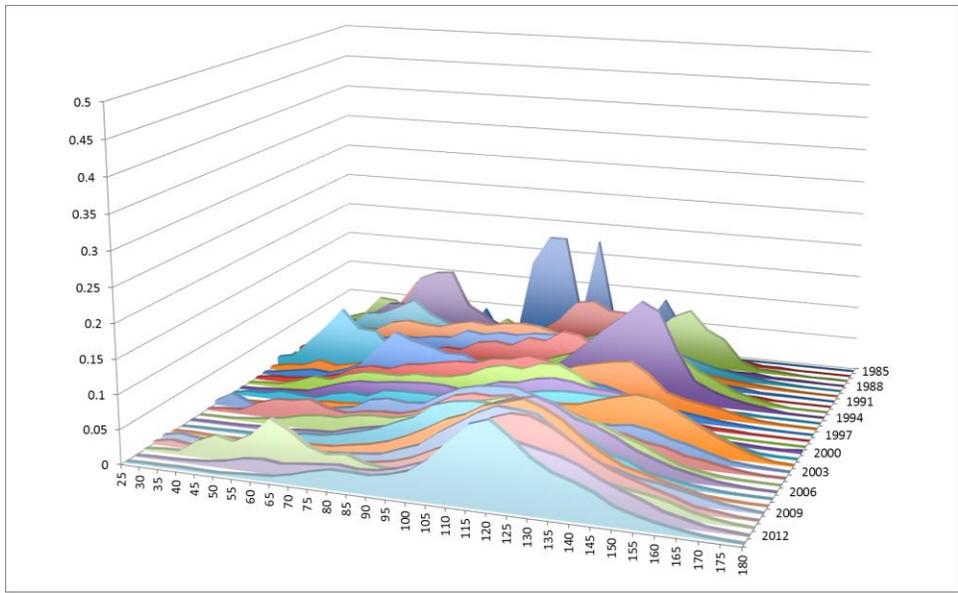


Figure 13. Normalized male Tanner crab bycatch size compositions in the groundfish fisheries, from groundfish observer sampling. Size compositions have been normalized to sum to 1 for each year.

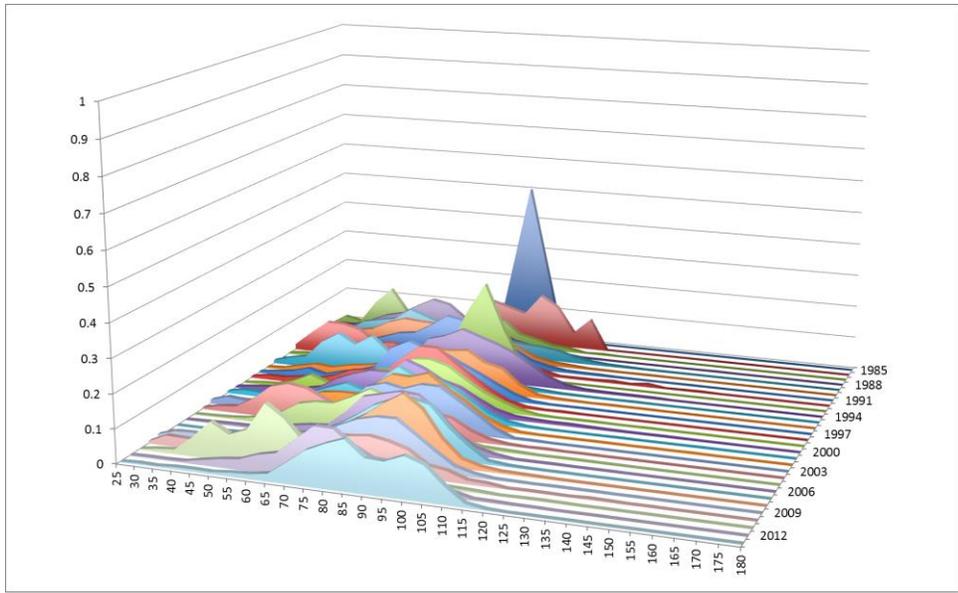


Figure 14. Normalized female Tanner crab bycatch size compositions in the groundfish fisheries, from groundfish observer sampling. Size compositions have been normalized to sum to 1 for each year.

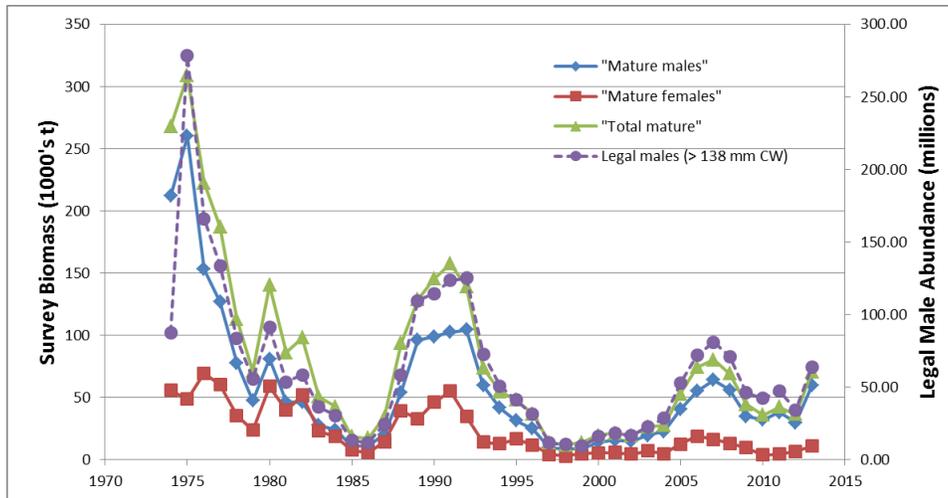


Figure 15. Trends in mature Tanner crab biomass and abundance of legal crab (≥ 138 mm CW) in the summer bottom trawl survey.

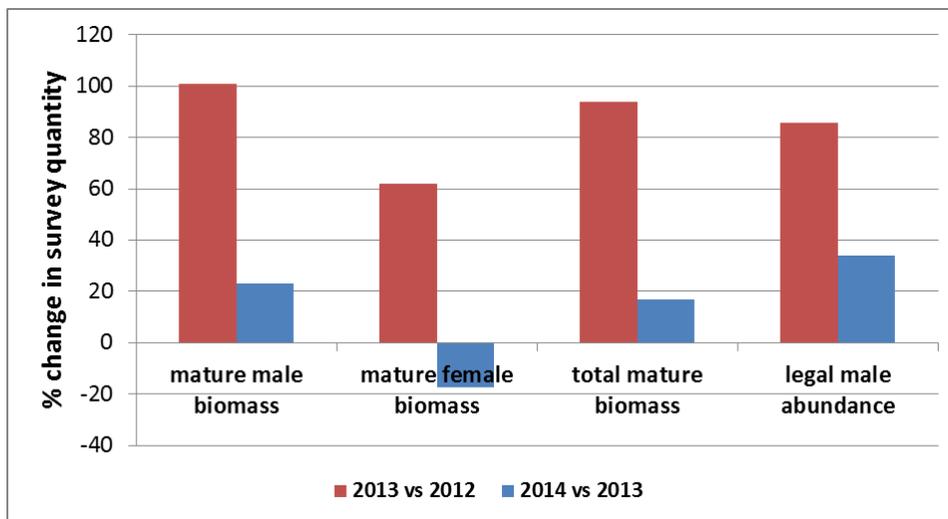


Figure 16. Percent change in mature male biomass, mature female biomass, total mature biomass and number of legal male crab observed in the summer bottom trawl survey.

West of 166° W

East of 166° W

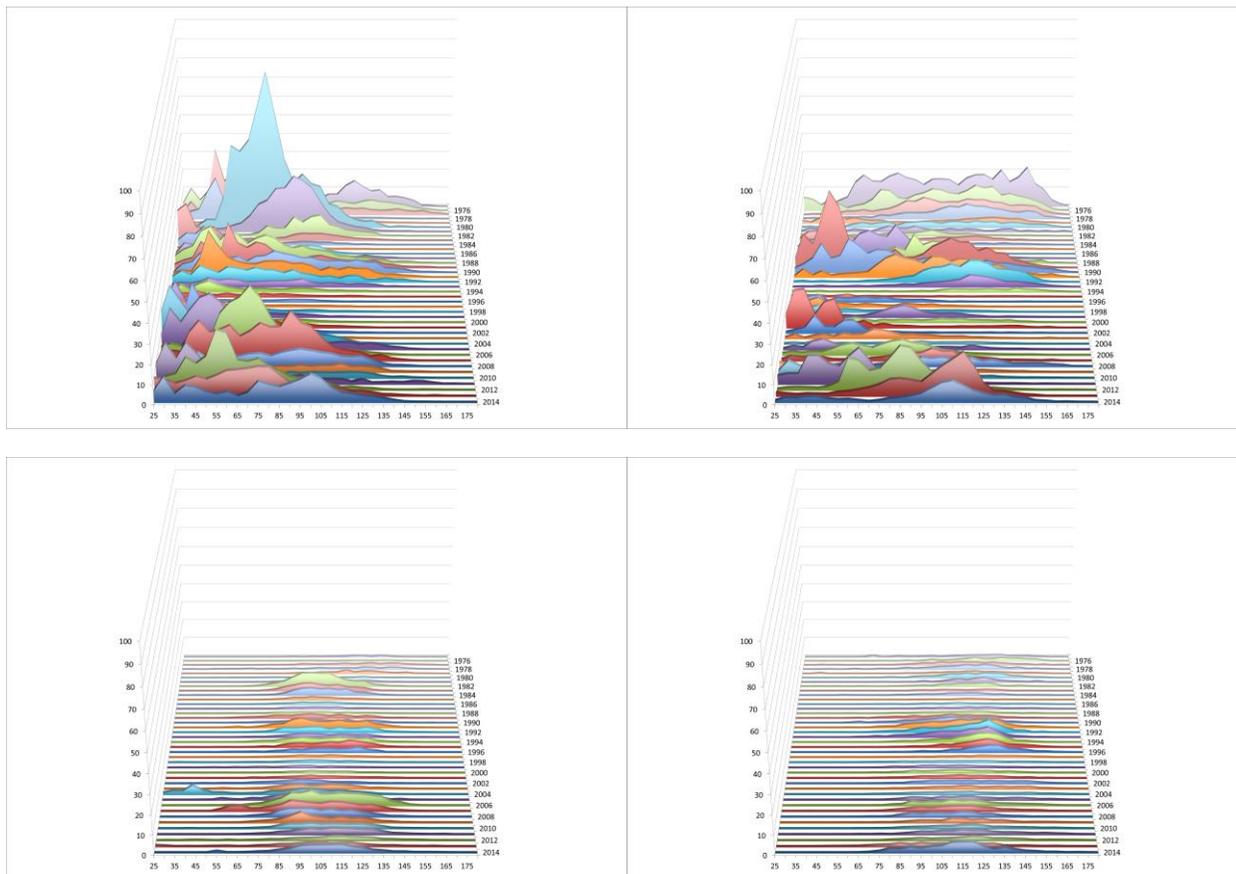


Figure 17. Numbers at size (millions) for male Tanner crab, by area and shell condition, in the NMFS summer bottom trawl survey. Upper row: new shell crab. Lower row: old shell crab.

West of 166° W

East of 166° W

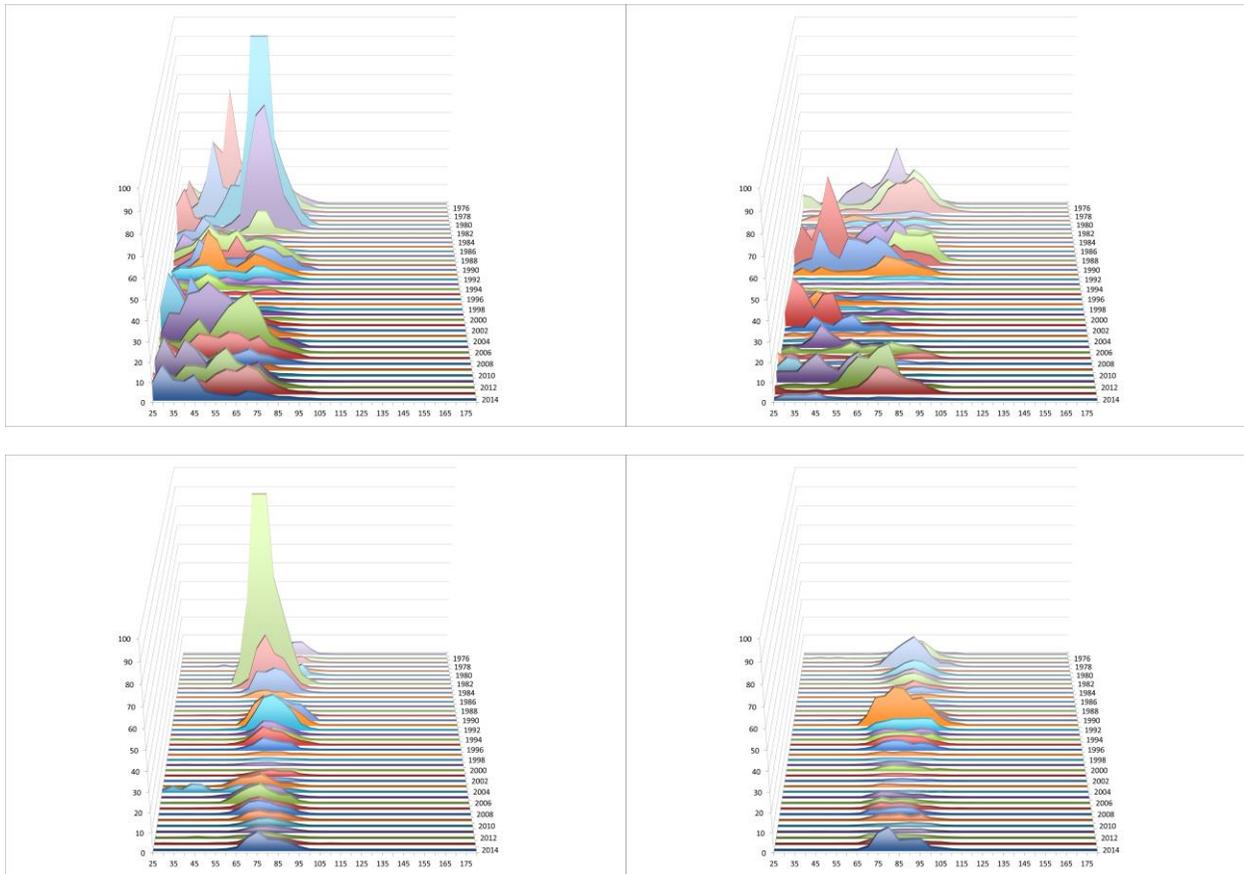


Figure 18. Numbers at size (millions) for female Tanner crab, by area and shell condition, in the NMFS summer bottom trawl survey. Upper row: new shell crab. Lower row: old shell crab.

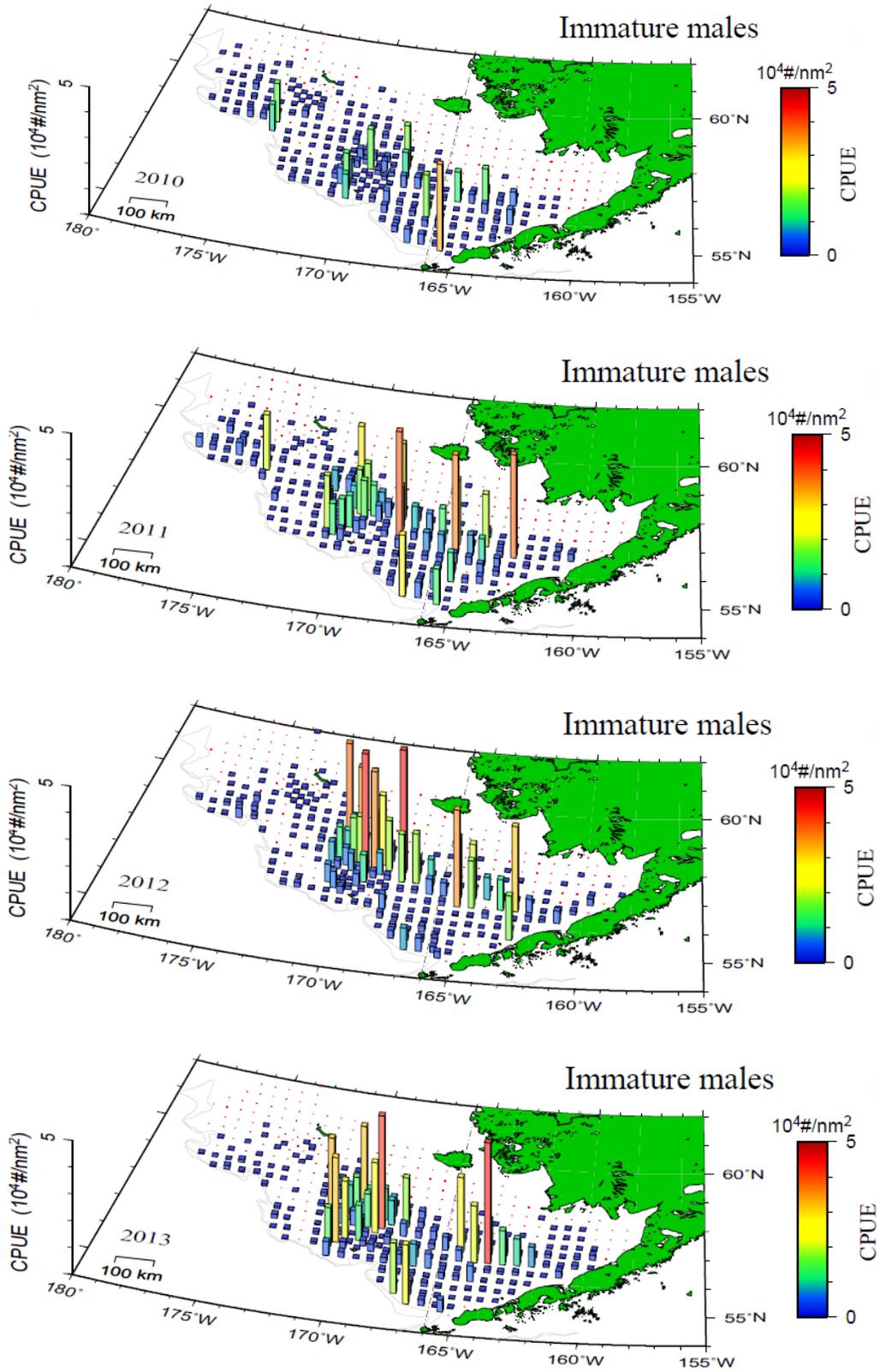


Figure 19. Distribution of immature males (number/ sq. nm) in the summer trawl survey for 2010-13.

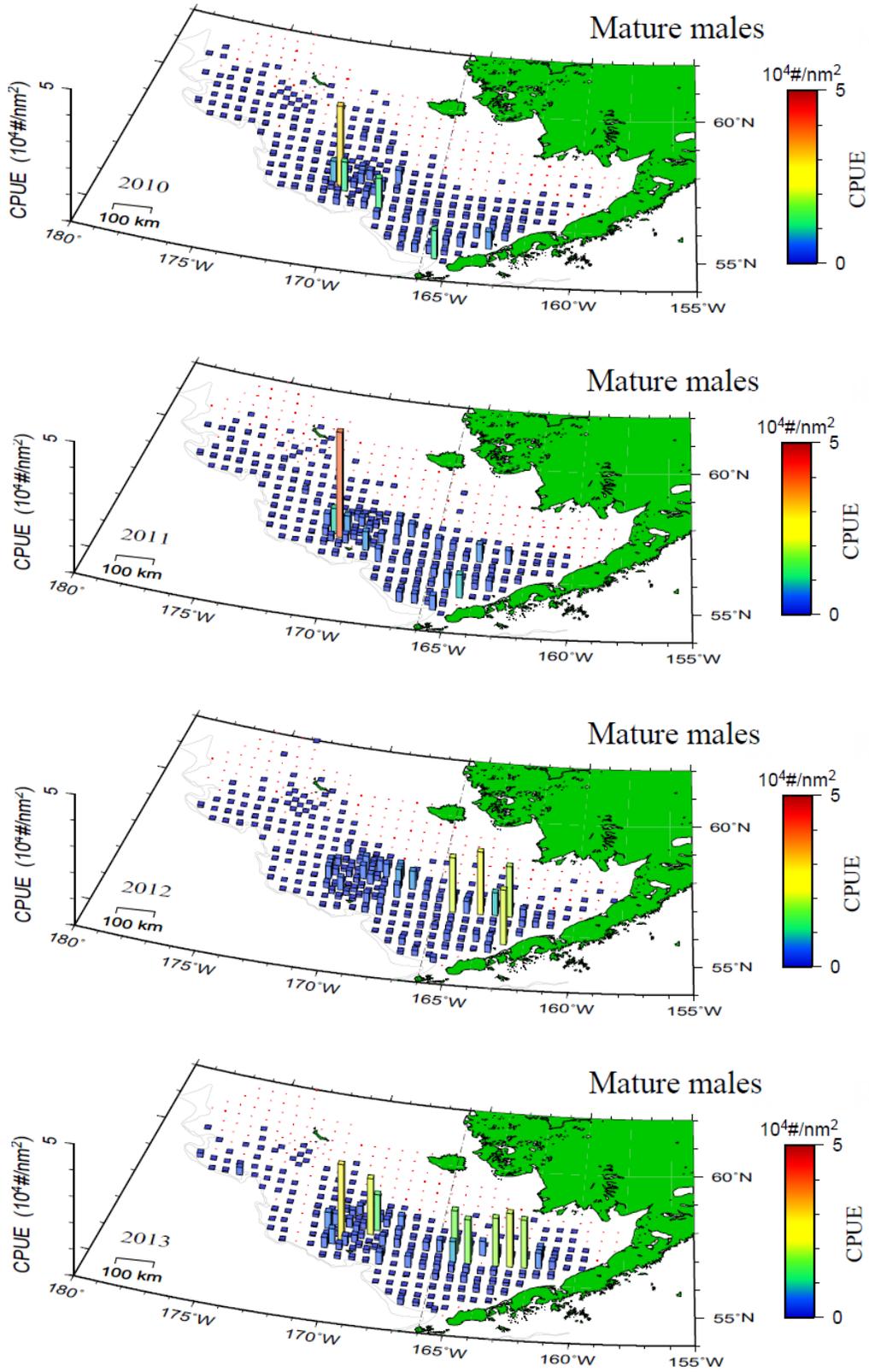


Figure 20. Distribution of mature males (number/ sq. nm) in the summer trawl survey for 2010-13.

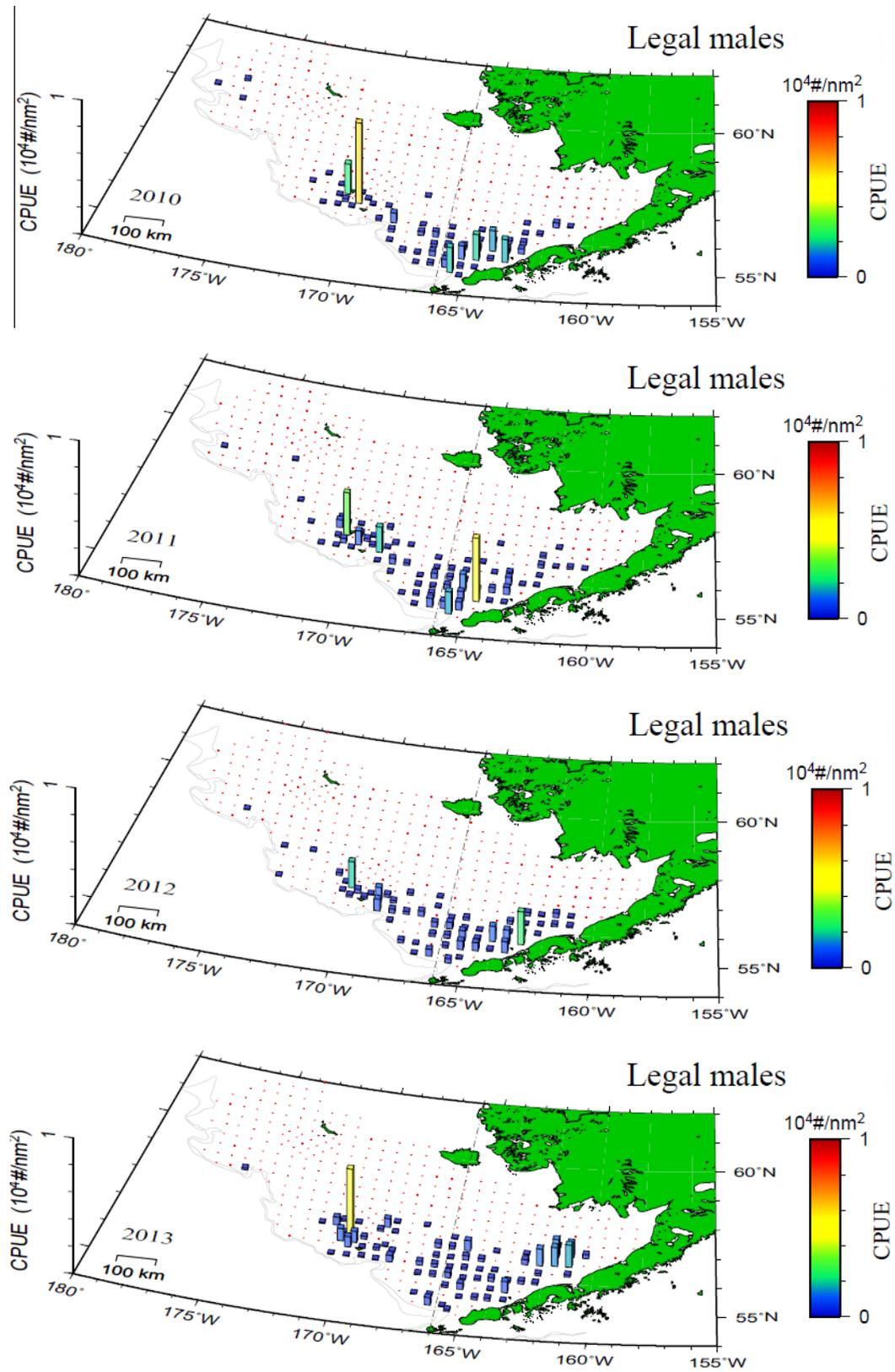


Figure 21. Distribution of “legal males” (≥ 138 mm CW; number/ sq. nm) in the summer trawl survey for 2010-13.

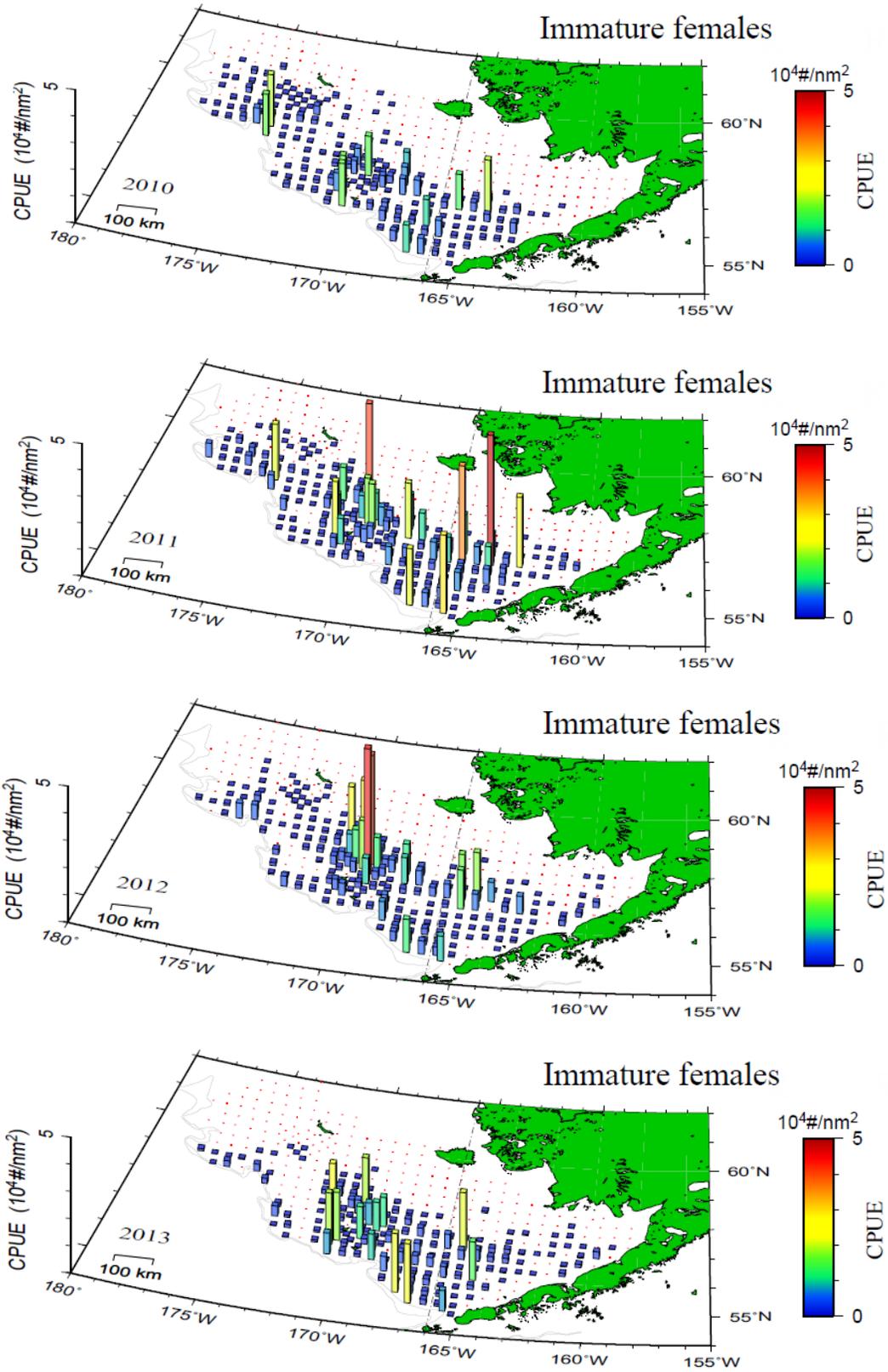


Figure 22. Distribution of immature females (number/ sq. nm) in the summer trawl survey for 2010-13.

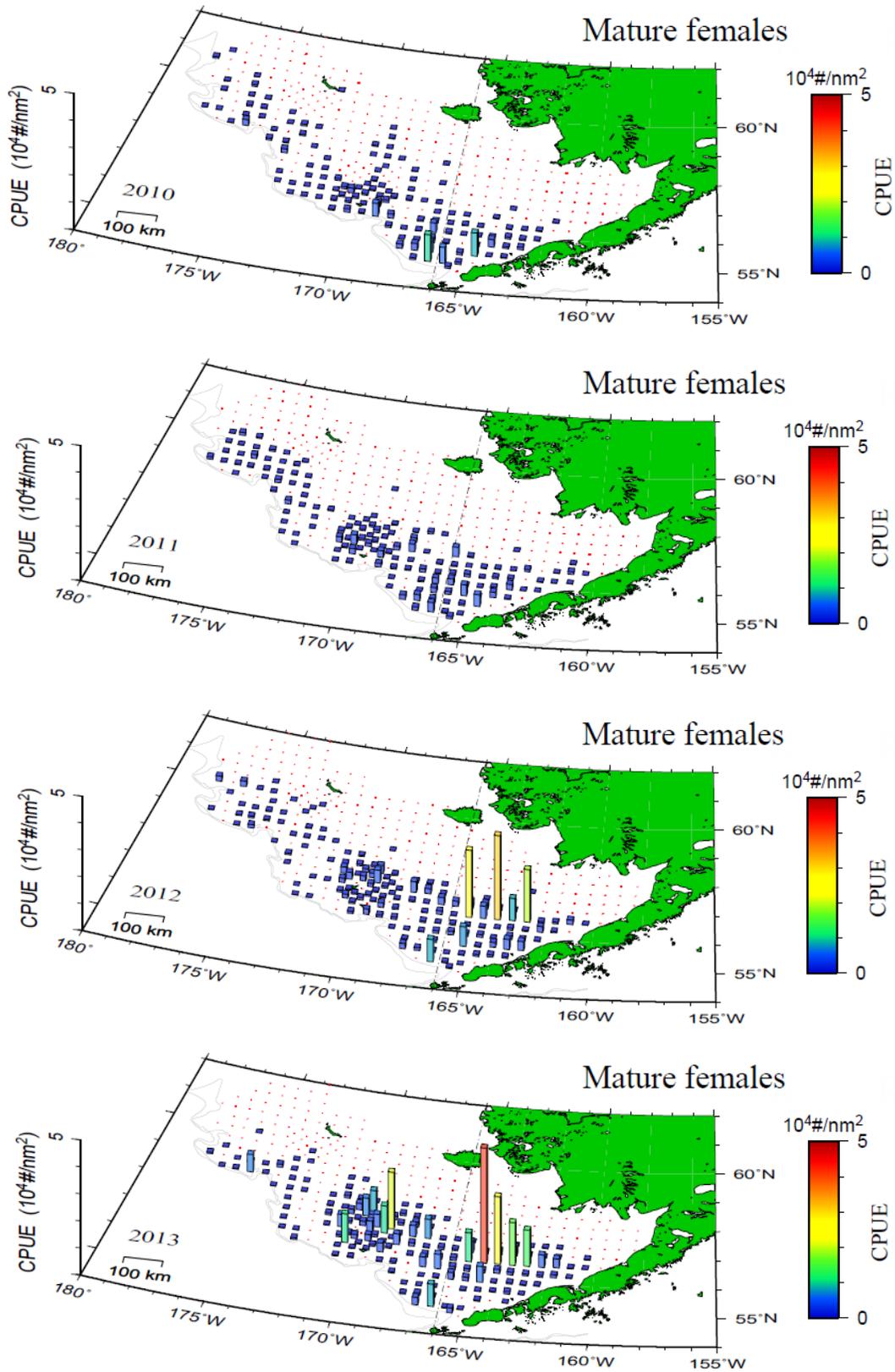
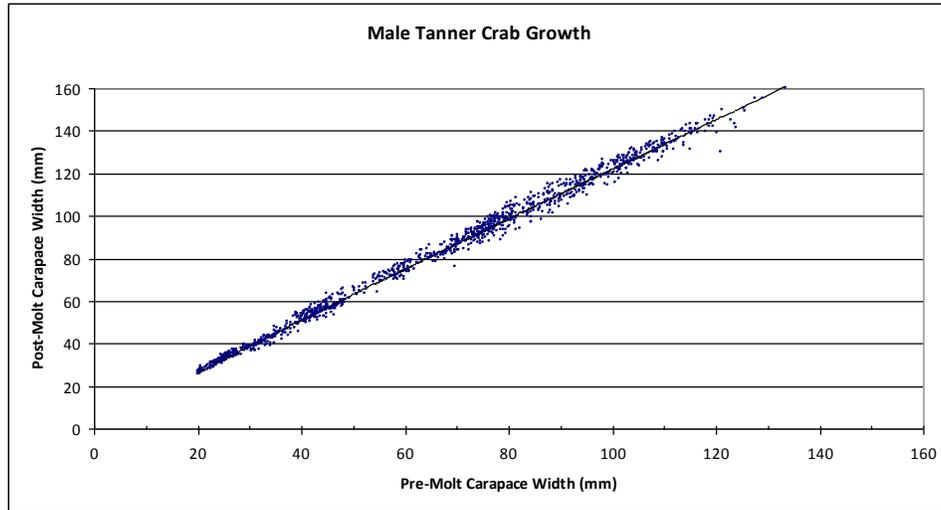


Figure 23. Distribution of mature females (number/ sq. nm) in the summer trawl survey for 2010-13.

(a)



(b)

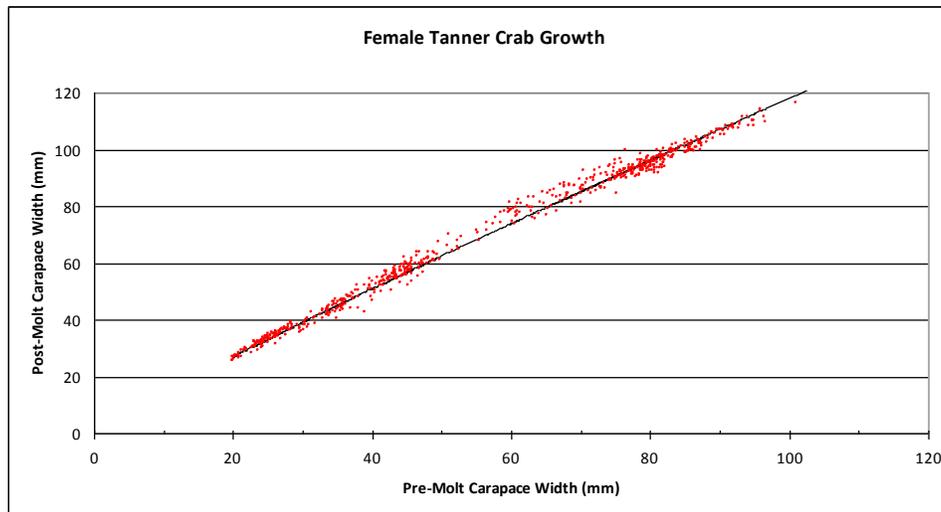


Figure 24. Growth of male (a) and female (b) Tanner crab as a function of premolt size. Estimated by Rugolo and Turnock (2010) based on data from Gulf of Alaska Tanner crab (Munk, unpublished data).

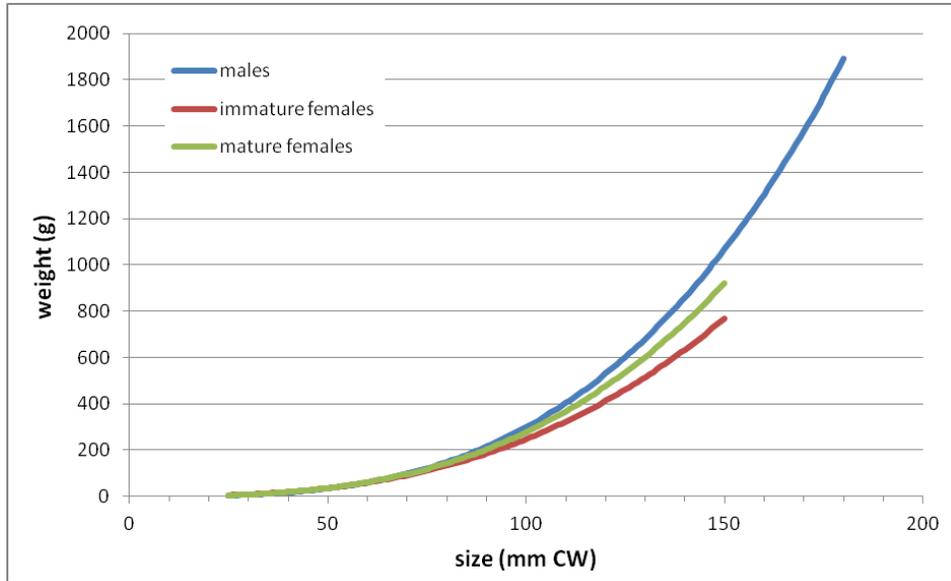


Figure 25. Fitted weight-at size relationships for males (immature and mature; blue line), immature females (red line), and mature females (green line).

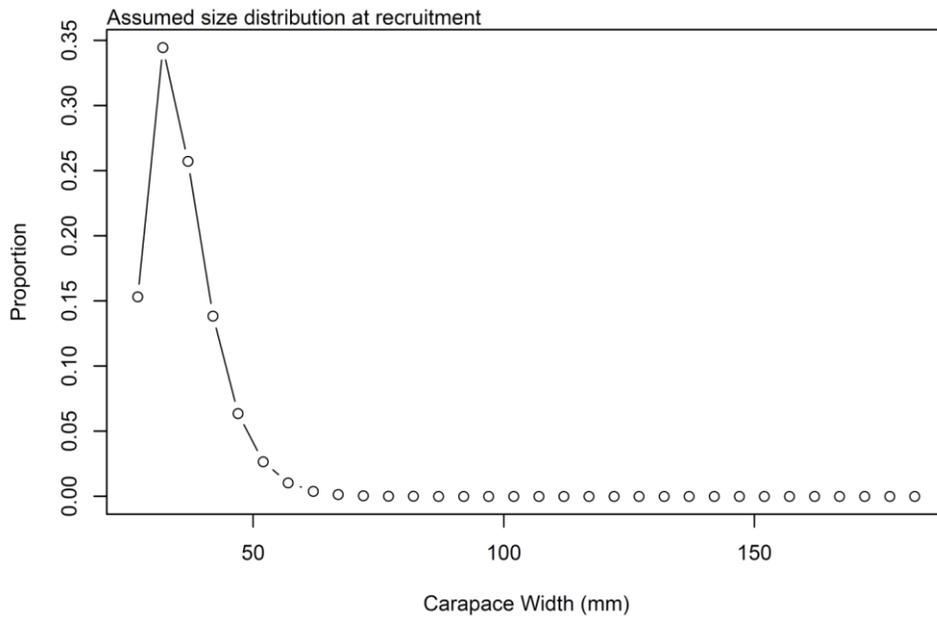


Figure 26. Assumed size distribution for recruits entering the population.

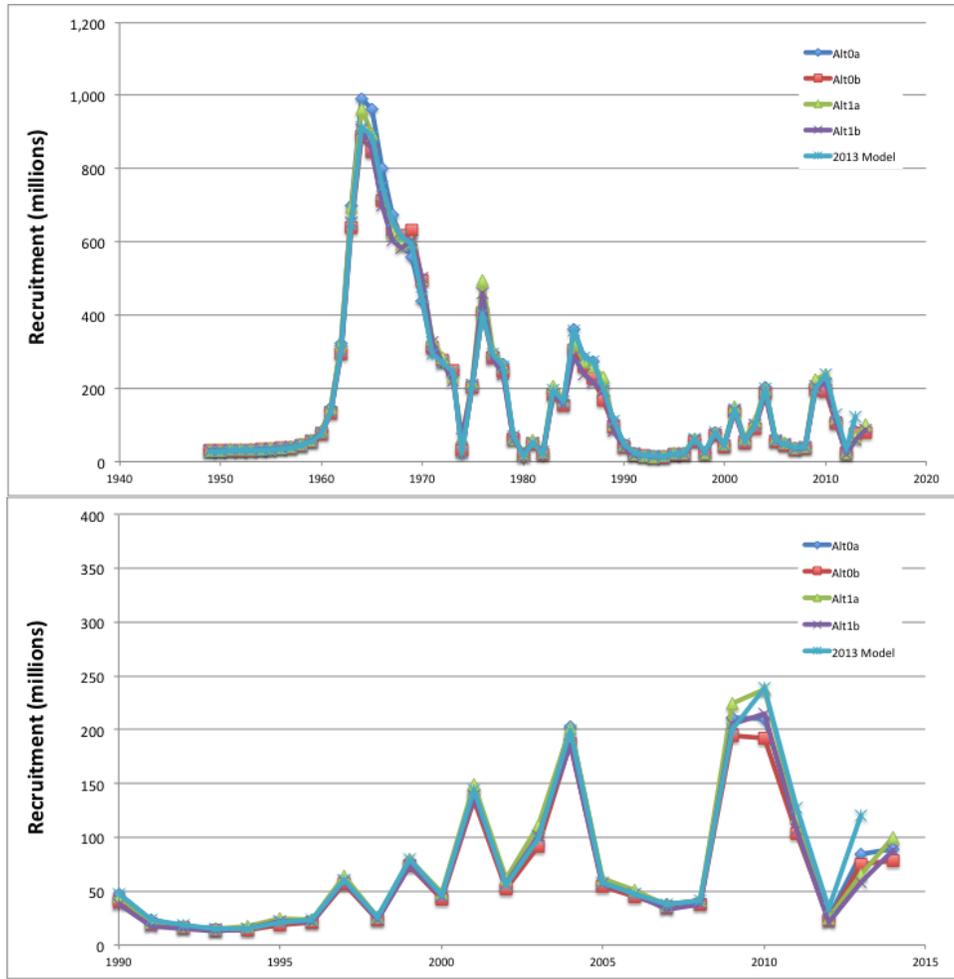


Figure 27. Comparison of model-estimated time series for (male) recruitment from the four alternative models and the 2013 model.

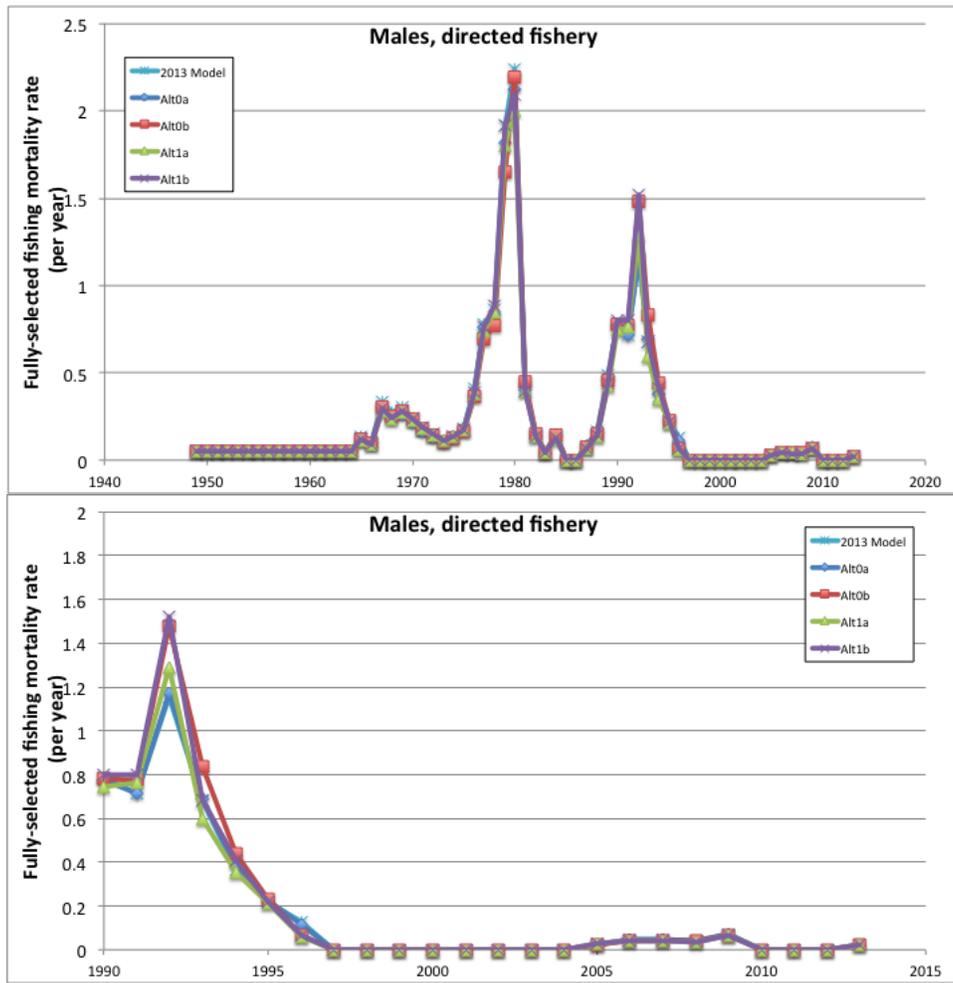


Figure 28. Comparison of model-estimated time series for fully-selected total F (retained + discards) on males in the directed Tanner crab fishery from the four alternative models and the 2013 model.

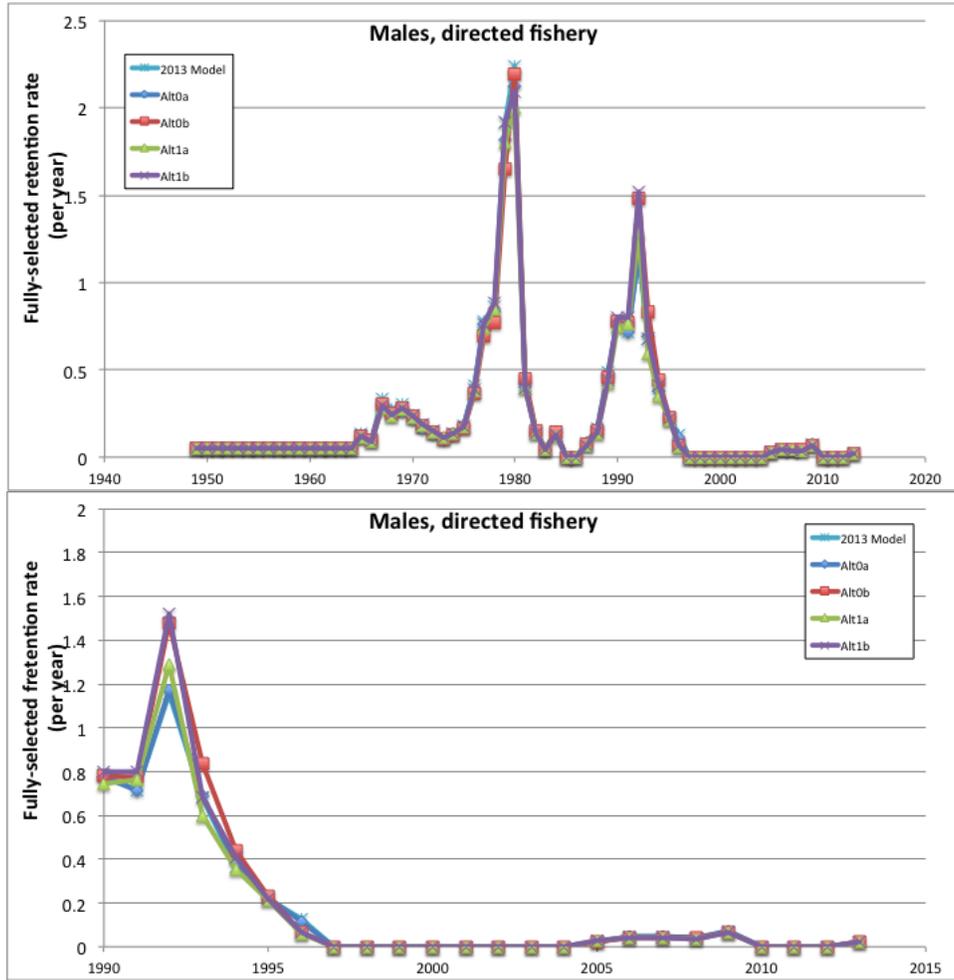


Figure 29. Comparison of model-estimated time series for fully-selected F on retained males in the directed Tanner crab fishery from the four alternative models and the 2013 model.

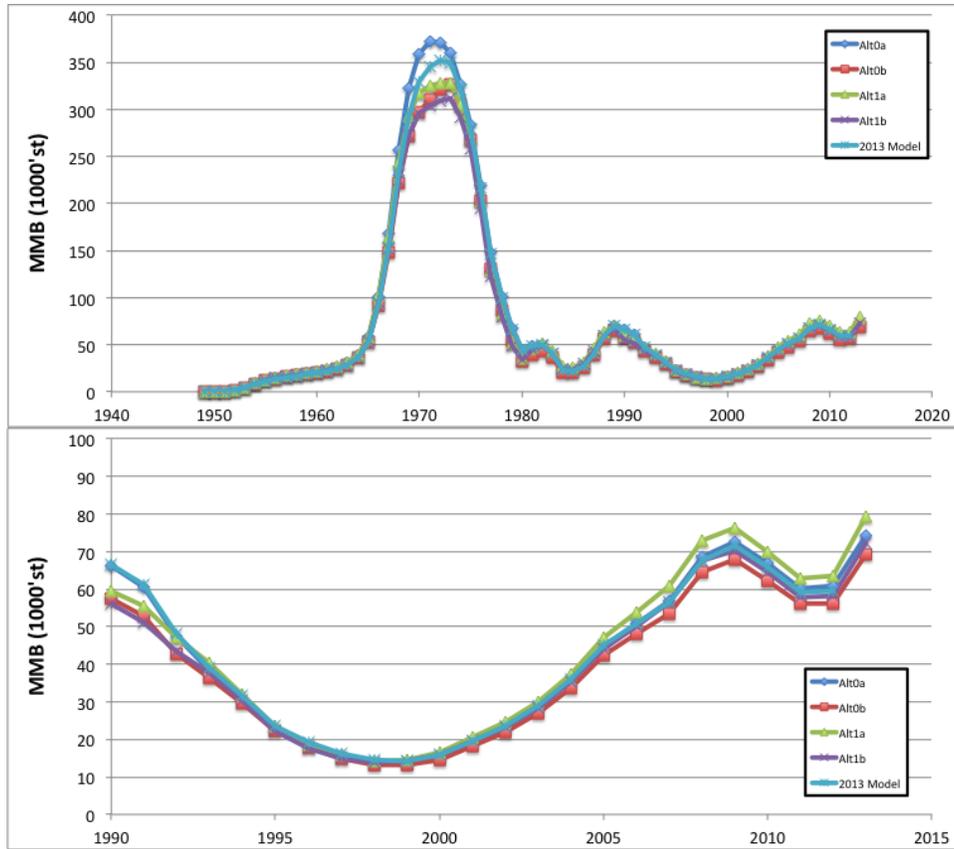


Figure 30. Comparison of estimated time series for mature male biomass at mating time from the four alternative models and the 2013 model.

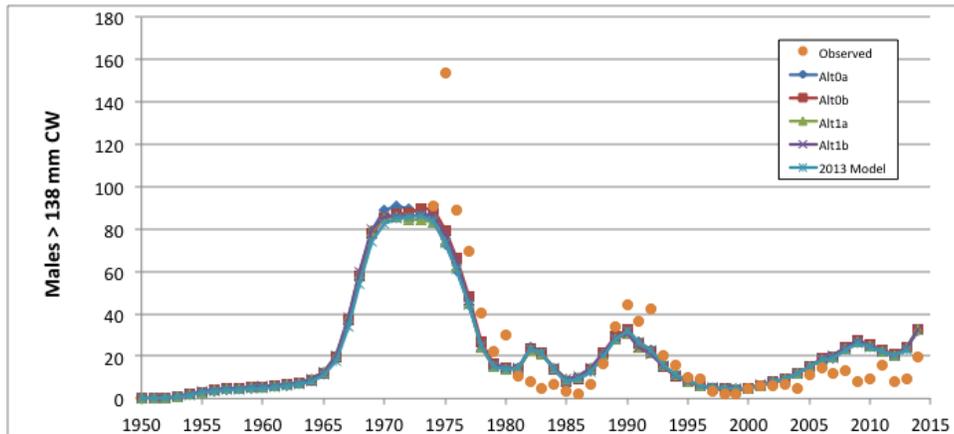


Figure 31. Comparison of observed and estimated survey time series for the number of males ≥ 138 mm CW from the four alternative models and the 2013 model.

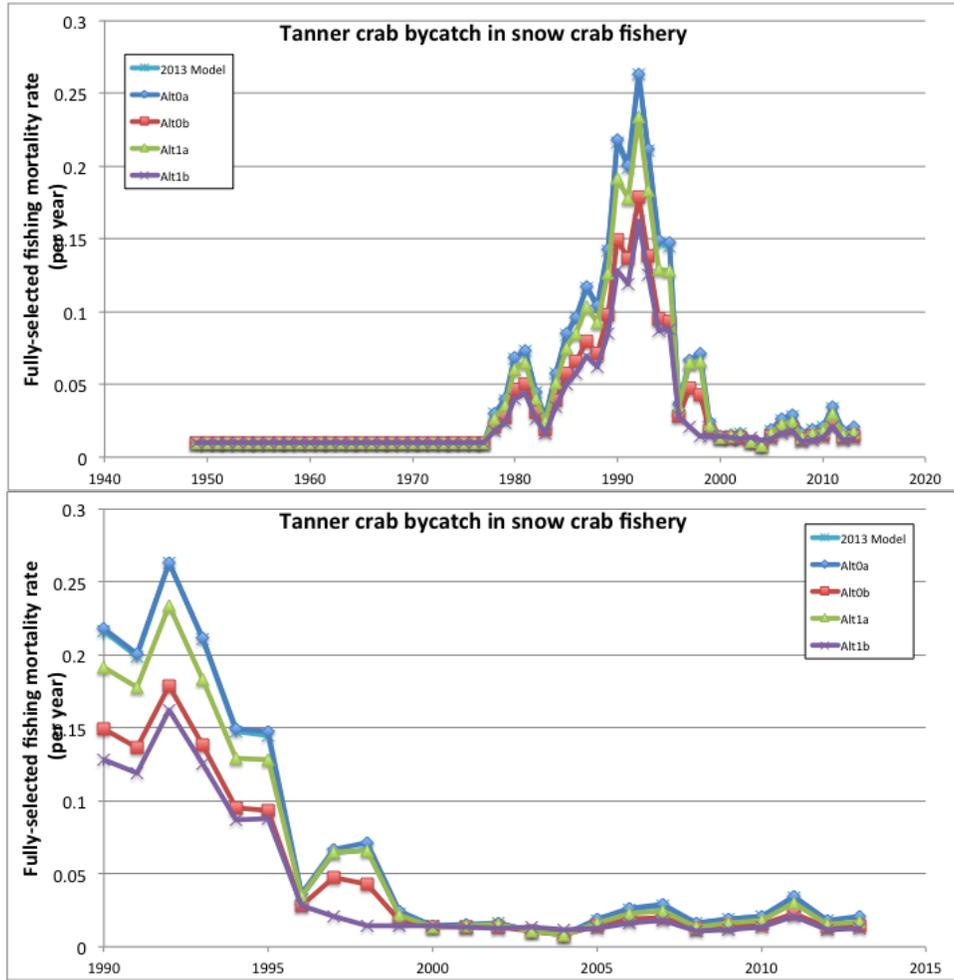


Figure 32. Comparison of model-estimated time series for fully-selected F in the snow crab fishery from the four alternative models and the 2013 model.

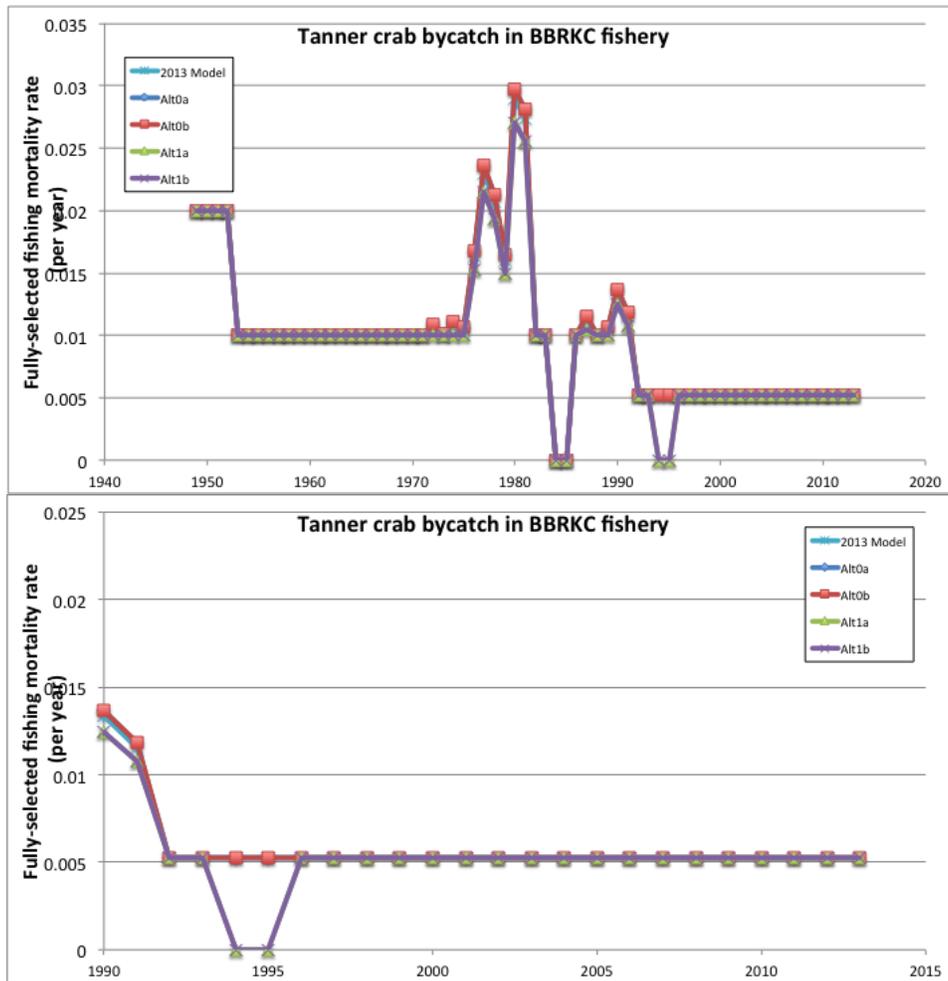


Figure 33. Comparison of model-estimated time series for fully-selected F in the BBRKC fishery from the four alternative models and the 2013 model.

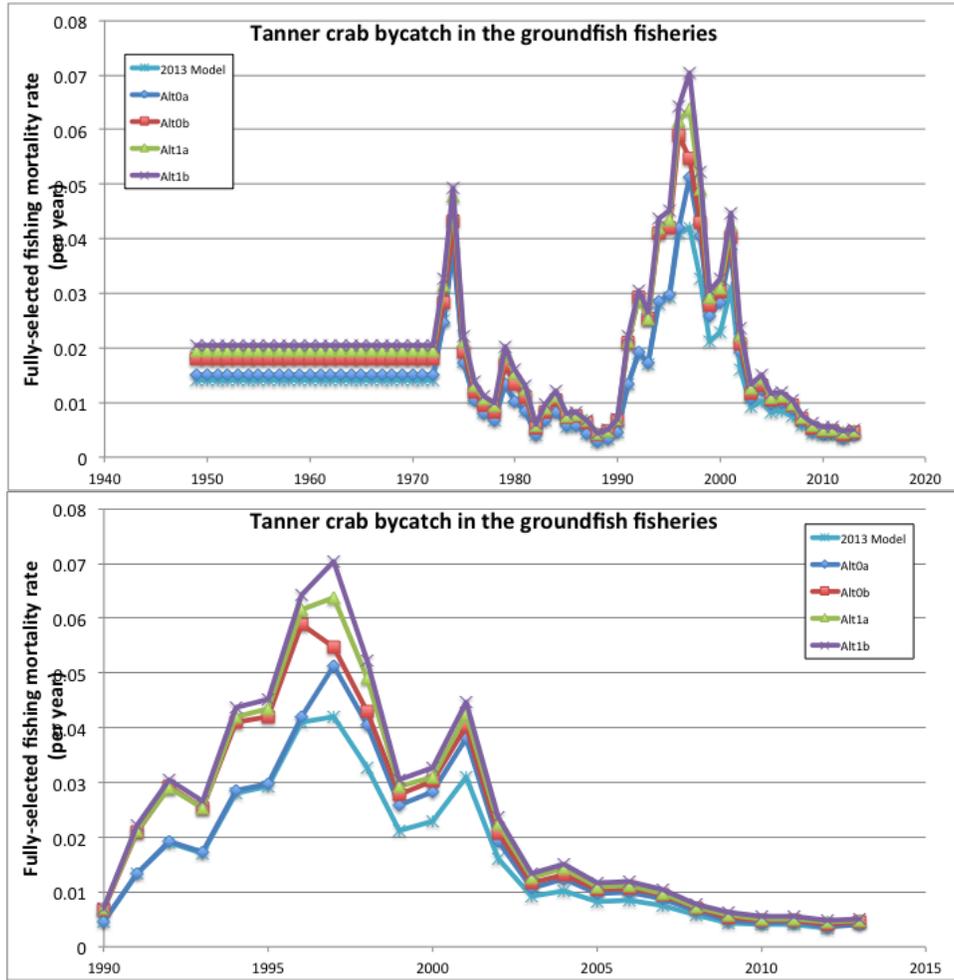


Figure 34. Comparison of model-estimated time series for fully-selected F in the groundfish fisheries from the four alternative models and the 2013 model.

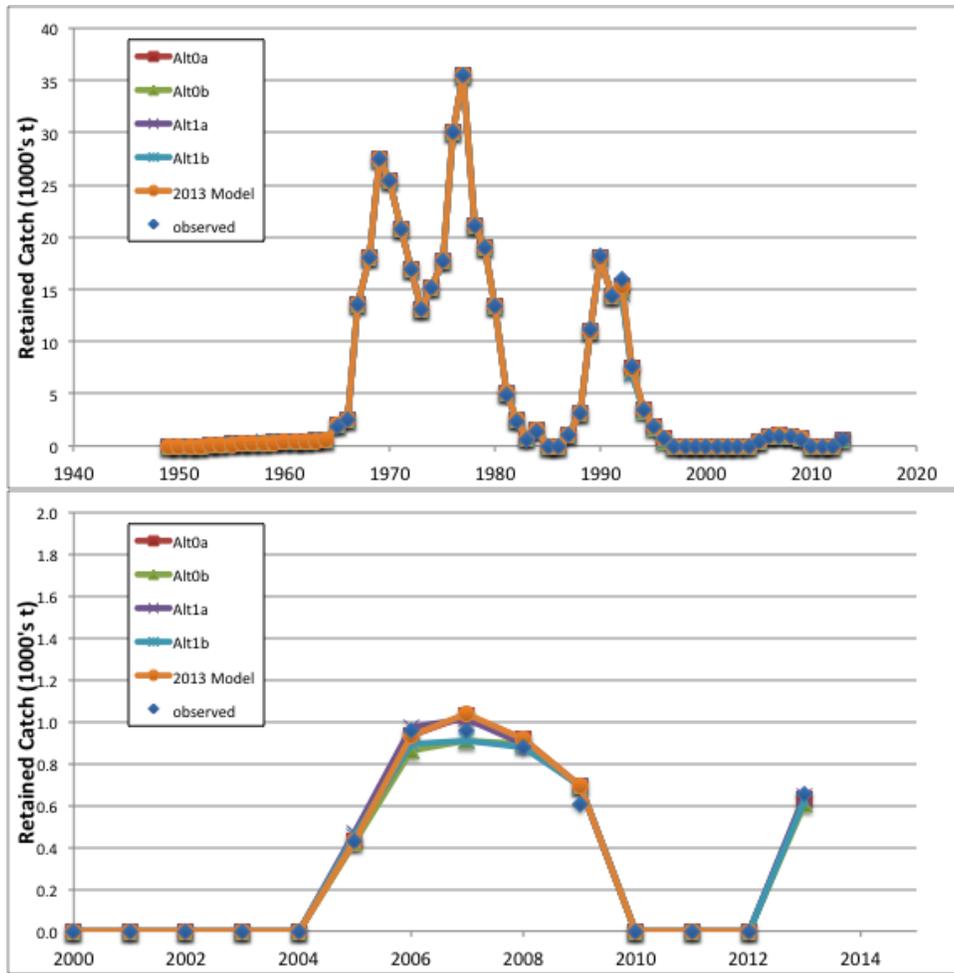


Figure 35. Comparison of estimated time series for retained (male) catch (1000's t) in the directed tanner crab fishery from the four alternative models and the 2013 model with the observed catches.

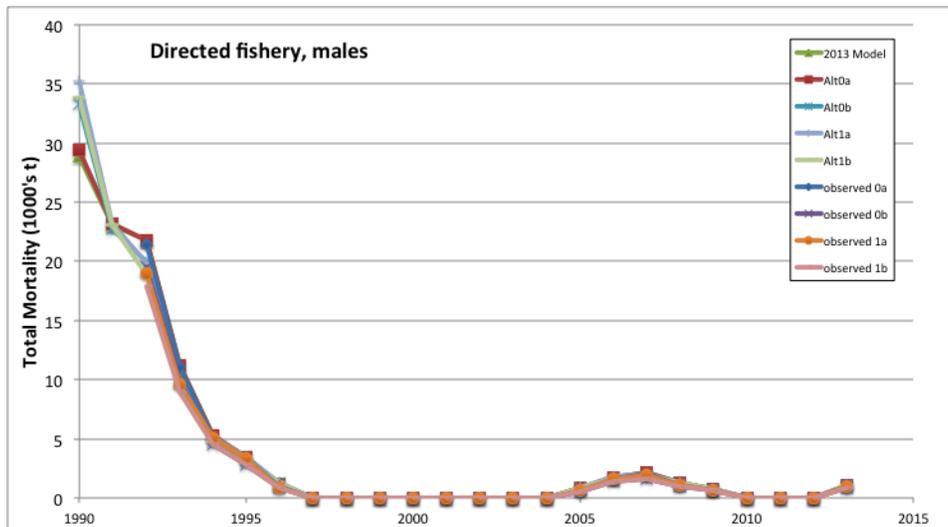
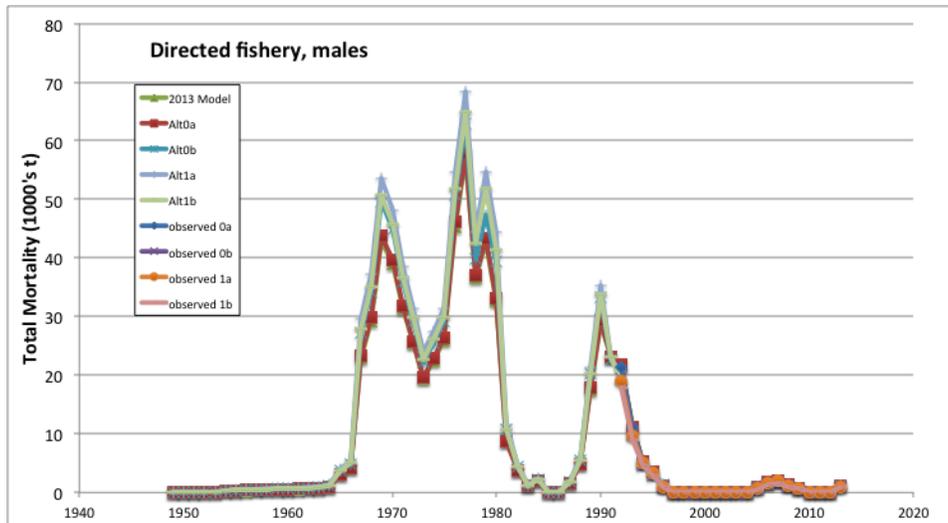


Figure 36. Comparison of estimated time series for total male (retained+discarded) catch (1000's t) in the directed tanner crab fishery from the four alternative models and the 2013 model with the corresponding observed mortality. Note that the "observed" mortality is different for the four alternative models because '0'/'1' models are based on different datasets and 'a'/'b' models use different rates for handling mortality.

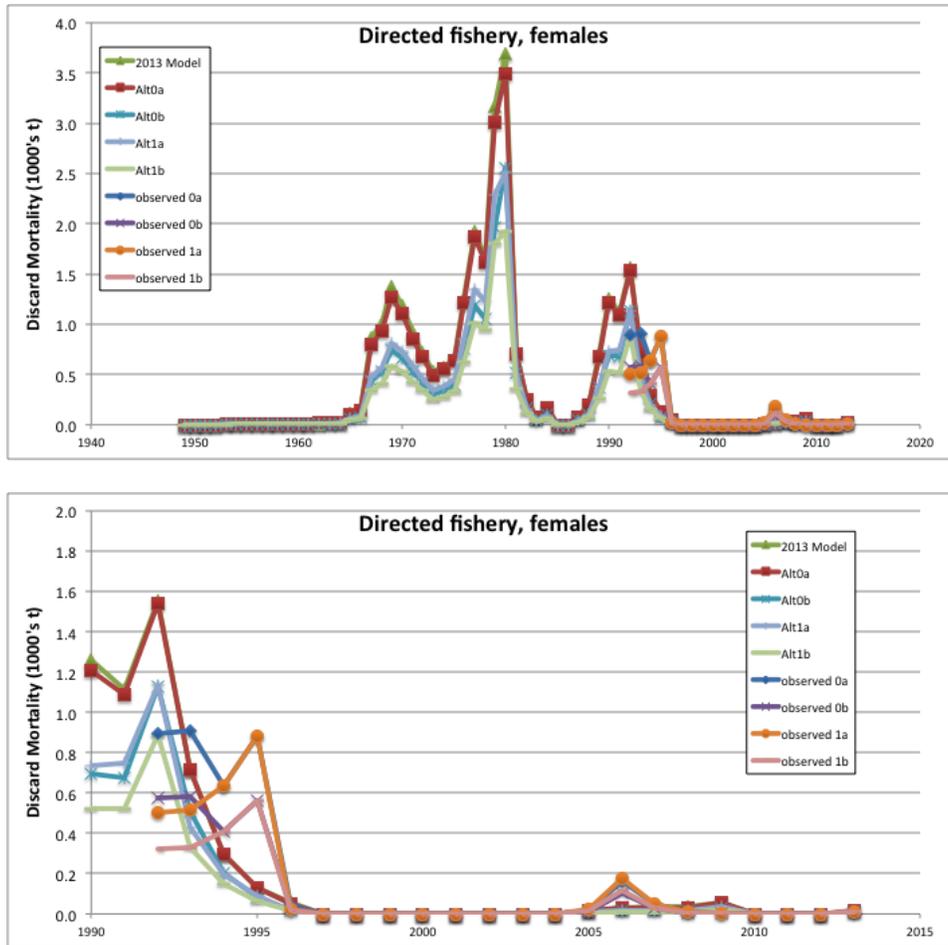


Figure 37. Comparison of “observed” and estimated time series for female discard mortality (1,000’s t) in the directed tanner crab fishery from the four alternative models and the 2013 model. Note that the “observed” mortality is different for the four alternative models because ‘0’/’1’ models are based on different datasets and ‘a’/’b’ models use different rates for handling mortality.

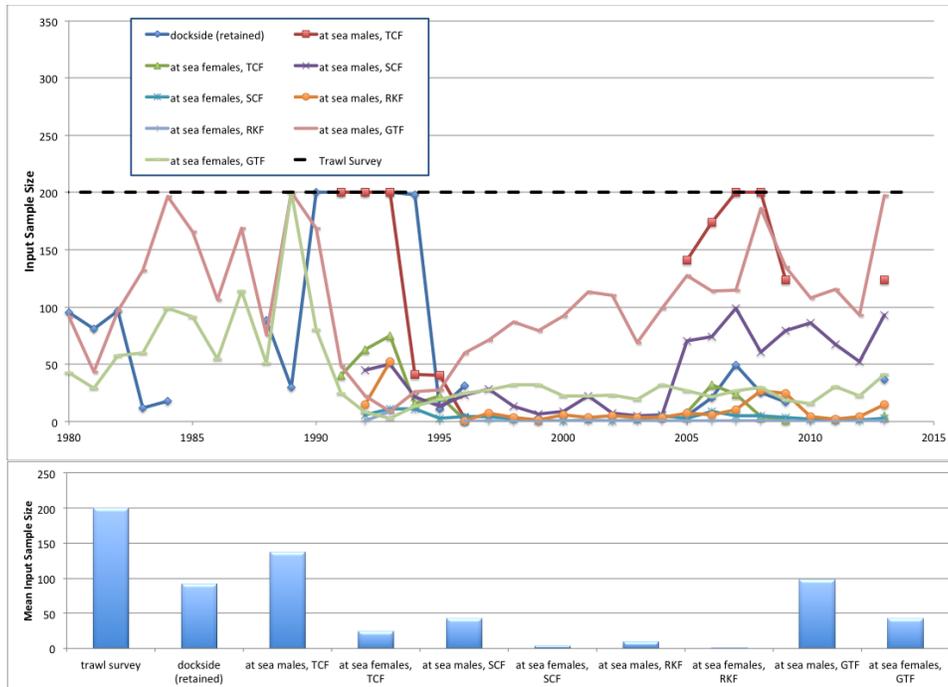


Figure 38. Input sample sizes used for the various likelihood components associated with size frequency data. The upper graph shows the sample by year for each component, the lower graph shows the mean sample size for each component. A value of 200 is used for all trawl survey components.

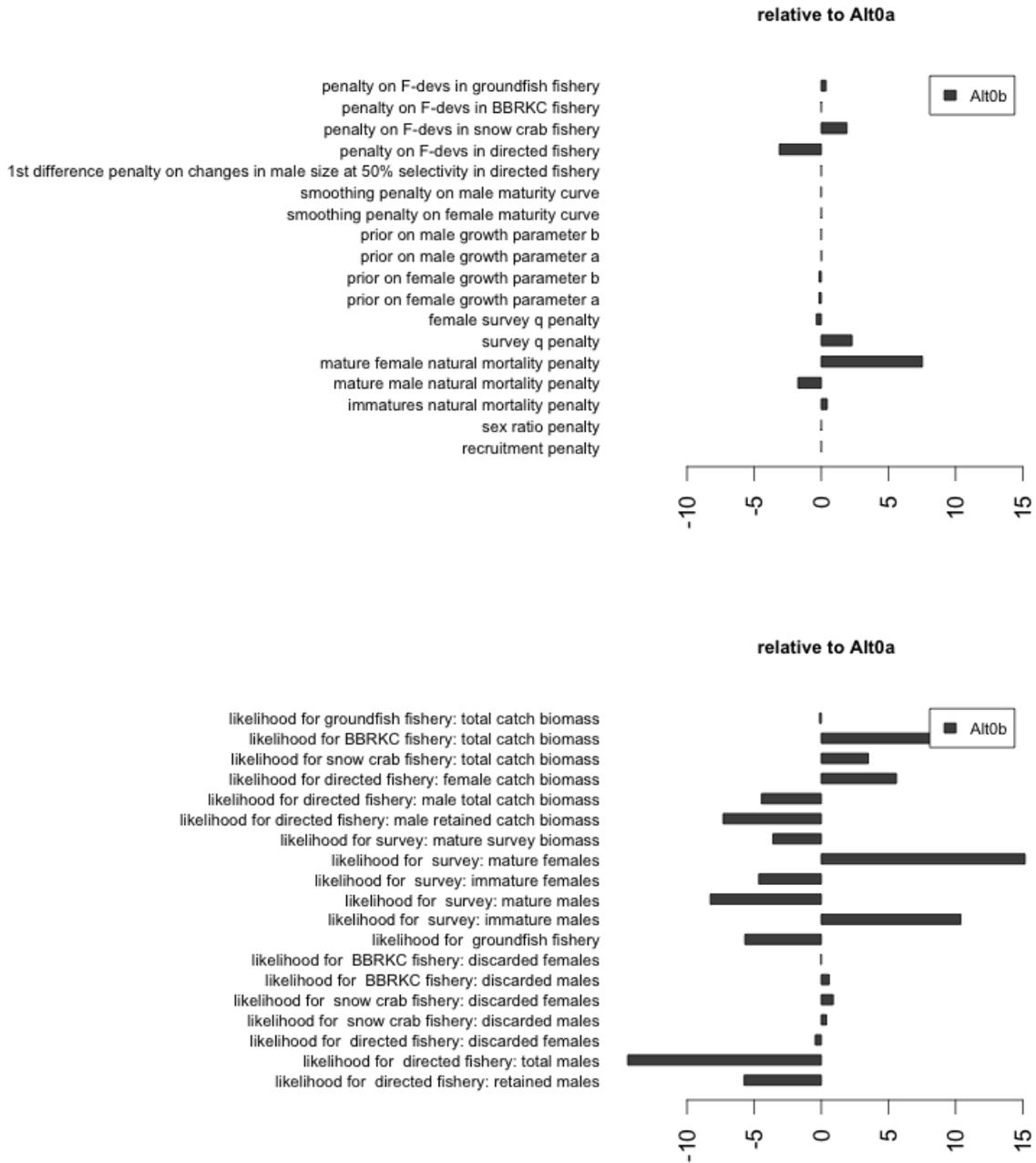


Figure 39. Comparison of the components of the converged objective function values (weights \times $-\log$ -likelihood components) for models Alt0a and Alt0b. Positive values indicate better fits for Alt0b. Overall, the value of the total objective function for Alt0b is 3.60 likelihood units smaller than that for Alt0a.

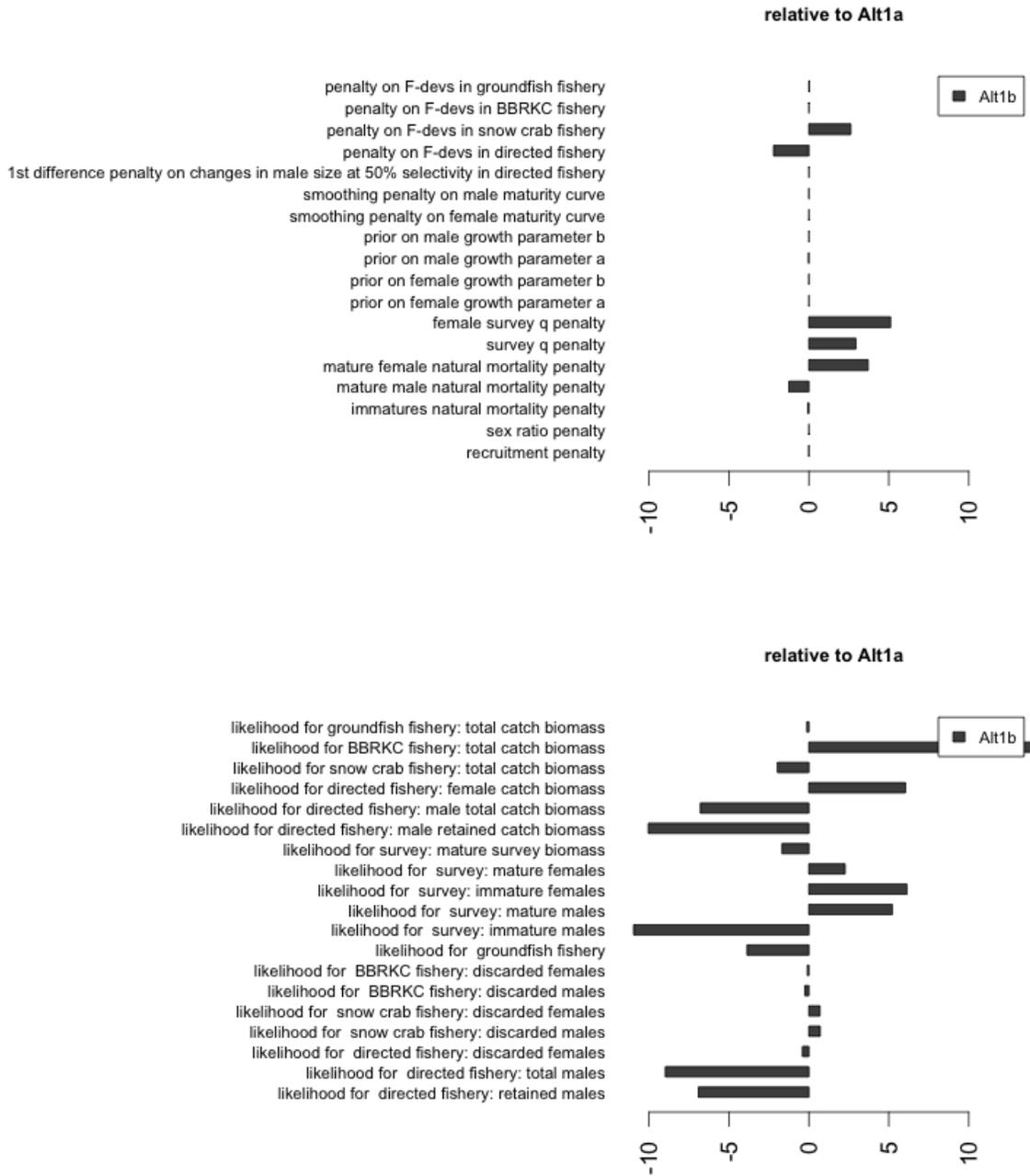
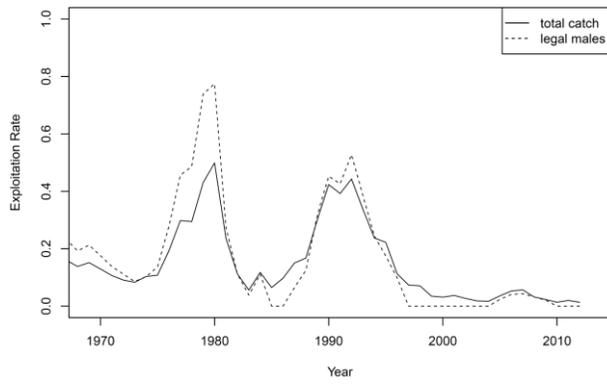


Figure 40. Comparison of the components of the converged objective function values (weights \times $-\log$ -likelihood components) for model Alt1b relative to Alt1a. Positive values indicate better fits for Alt1b. Overall, the value of the total objective function for Alt1a is 6.06 likelihood units smaller than that for Alt1b.

2013 Model



Alt1a

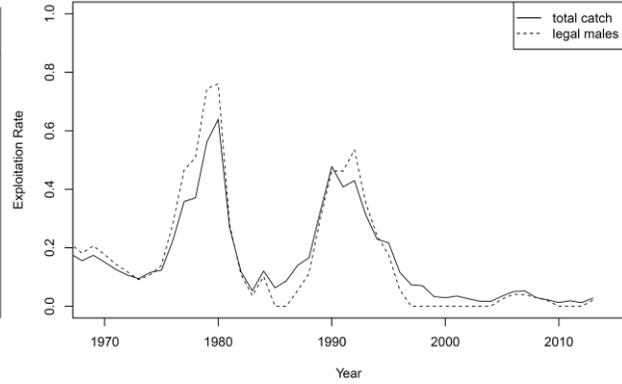
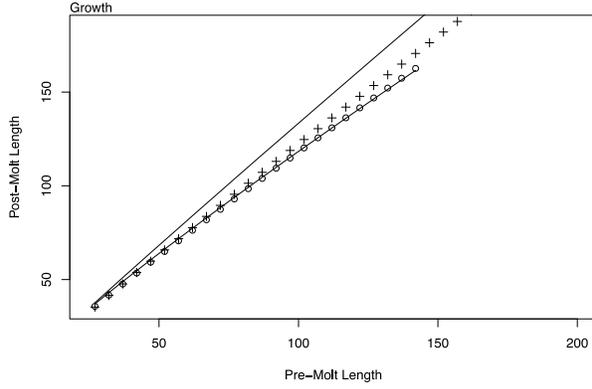


Figure 41. Estimated exploitation rates in the directed fishery for total catch and legal-sized males (≥ 138 mm CW) from the 2013 model (left) and the author's preferred 2014 model, Alt1a (right).

From 2013 Model



Model Alt1a

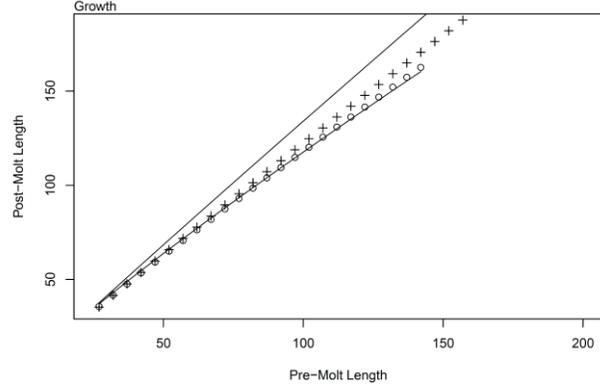
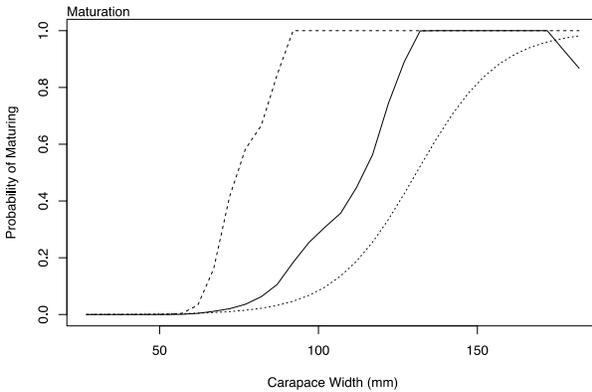


Figure 42. Comparison of model-estimated growth curves (solid lines, upper=males, lower=females) from the author's preferred model, Alt1a, and empirical curves ("+"=males, circles=females) developed from growth data on Tanner crab in the Gulf of Alaska near Kodiak Island.

From 2013 Model



Model Alt1a

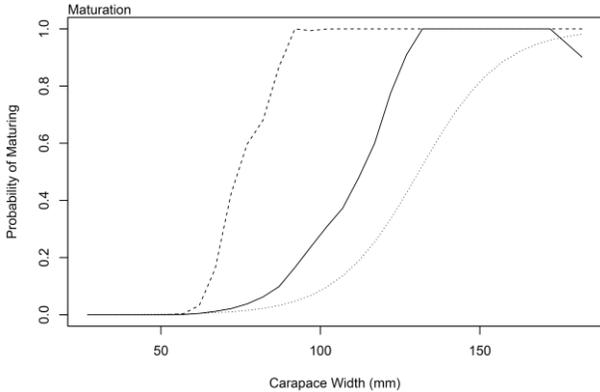


Figure 43. Comparison of model-estimated probability of maturing by size for new shell crab (solid line = males, dashed line = females) from the author's preferred model, Alt1a, with that used for males (dotted line) in the Amendment 24 OFL analysis (NPFMC 2007).

From 2013 Model

Model Alt1a

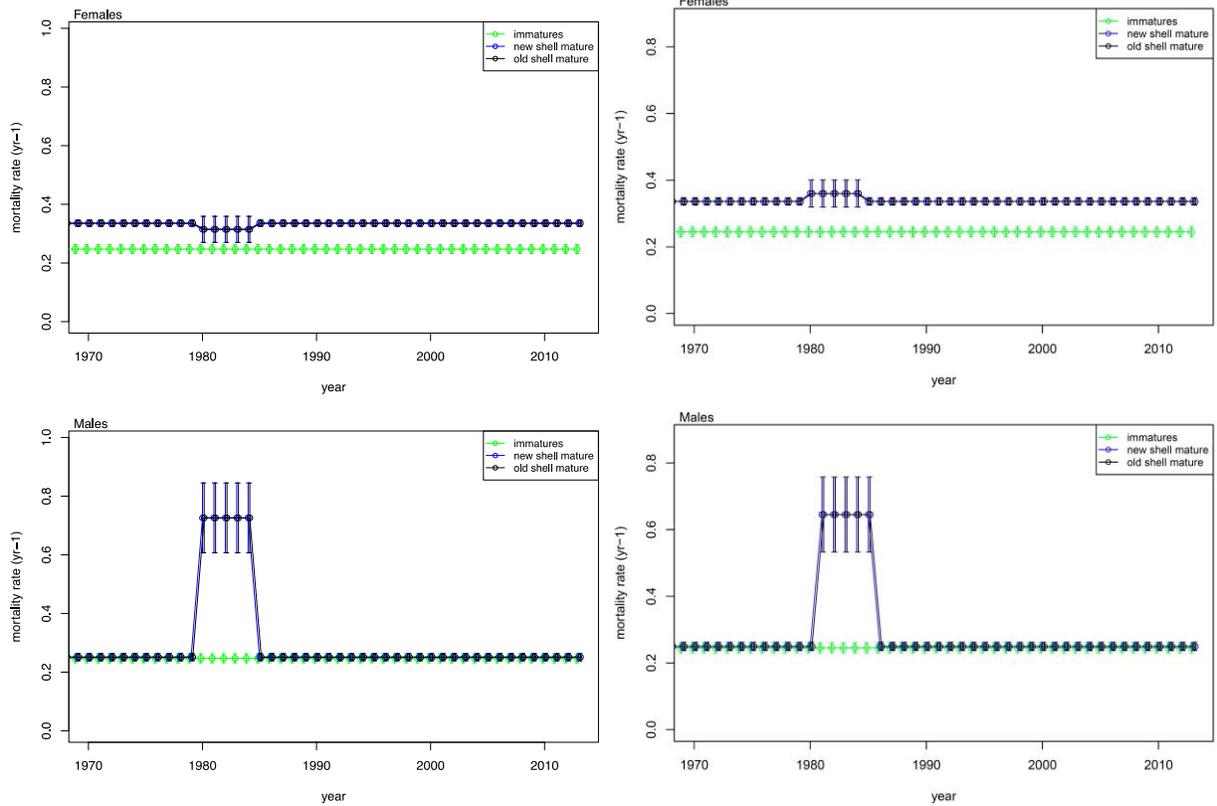


Figure 44. Estimated natural mortality for immature (single time period: 1949-2013) and mature (two time periods: 1949-1979+2005-2013 and 1980-1984) crab by sex (upper graph: females; lower graph: males) from the author's preferred model, Alt1b.

From 2013 Model

Model Alt1a

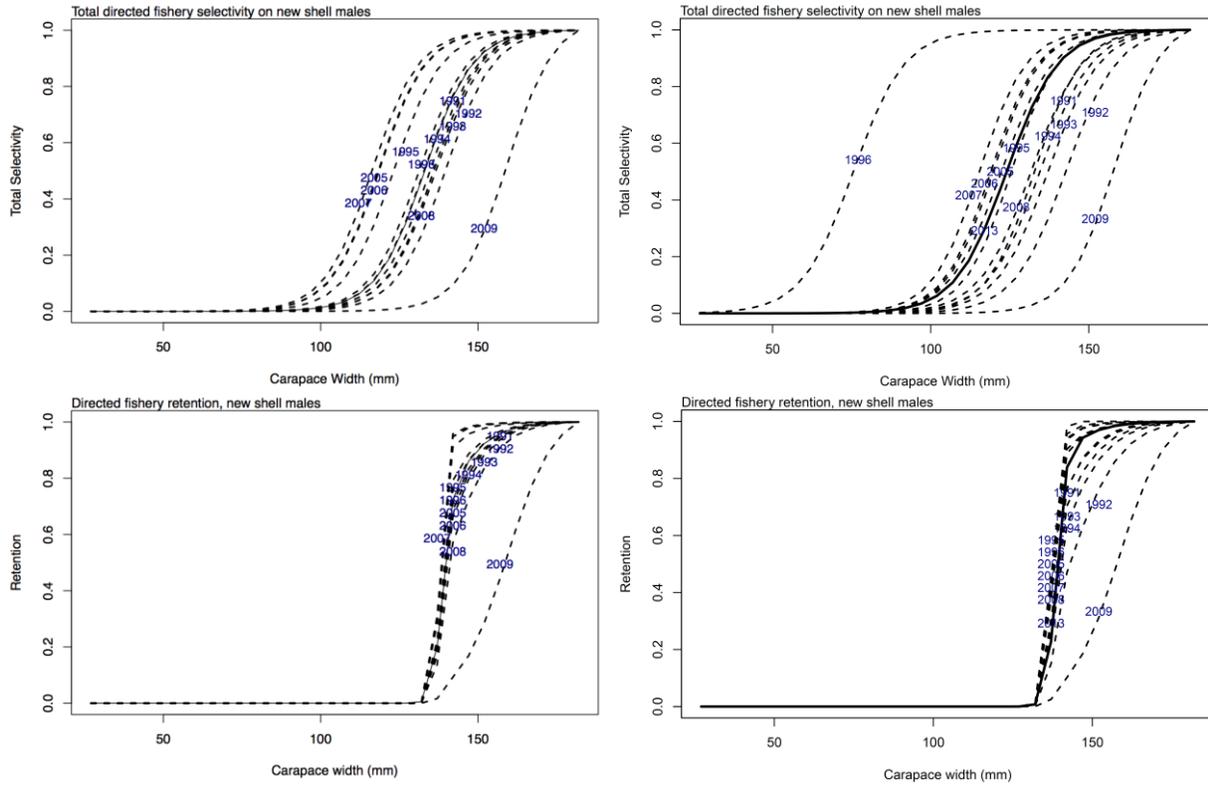


Figure 45. Estimated annual selectivity curves (solid line, pre-1991; dashed lines, 1991-2009) in the directed Tanner crab fishery for all new shell males (upper graph) and retained crab (lower graph) from the 2013 model (left column) and the author’s preferred 2014 model, Alt1a (right column). The year indicated denotes the beginning of the fishery year; e.g. “2009” indicates the 2009/10 fishery year. Selectivity curves for old shell males are identical to those for new shell males.

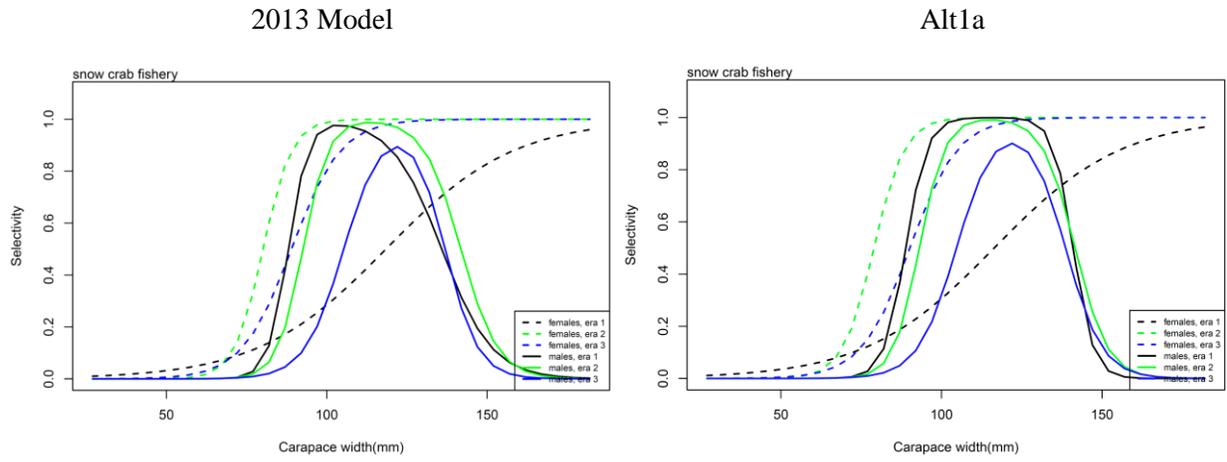


Figure 46. Estimated selectivity curves by sex (solid lines = males, dashed lines = females) for 3 eras in the snow crab fishery (era 1 [1989-1996] =black lines, era 2 [1997-2004] = green lines, era 3 [2005-present] = blue lines) from the 2013 model (left) and author's preferred 2014 model, Alt1a (right).

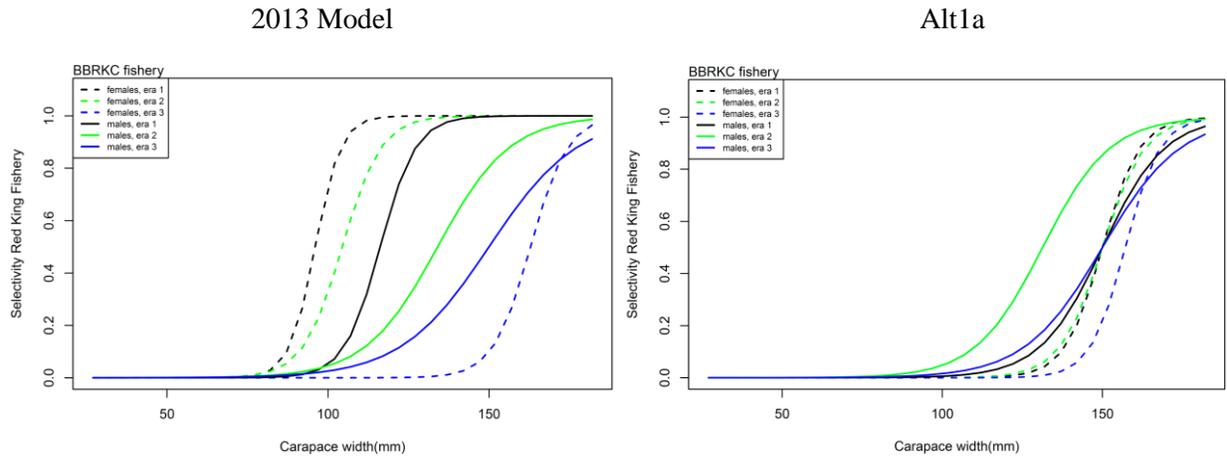


Figure 47. Estimated selectivity curves by sex (solid lines = males, dashed lines = females) for 3 eras in the BBRKC fishery (era 1 [1989-1996] =black lines, era 2 [1997-2004] = green lines, era 3 [2005-present] = blue lines) from the 2013 model (left) and author's preferred 2014 model, Alt1a (right).

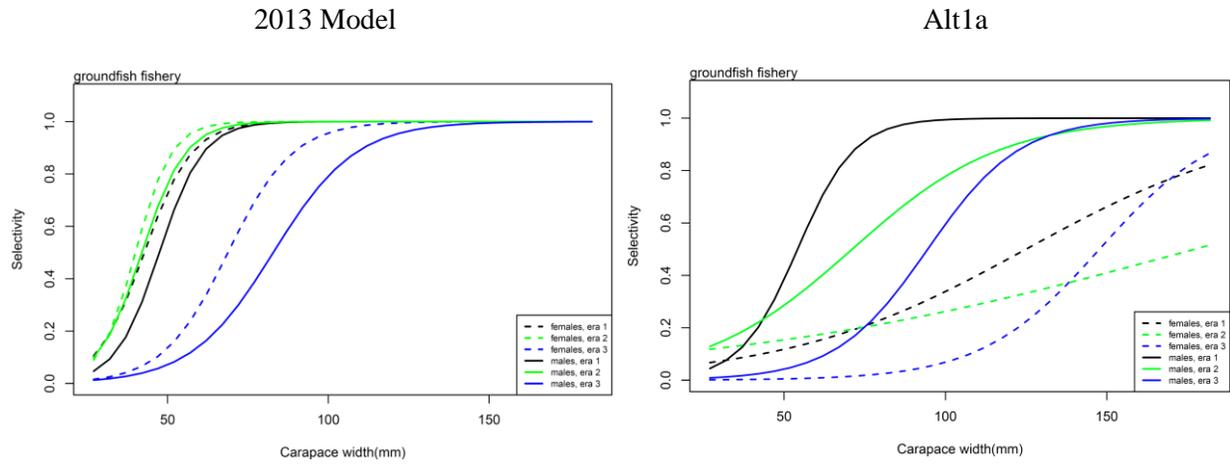


Figure 48. Estimated selectivity curves by sex (solid lines = males, dashed lines = females) for 3 eras in the groundfish fisheries (era 1[1973-1987] =black lines, era 2 [1988-1996] =green lines, era 3 [1997-present] = blue lines) from the 2013 model (left) and author's preferred 2014 model, Alt1a (right).

2013 Model

Alt1a

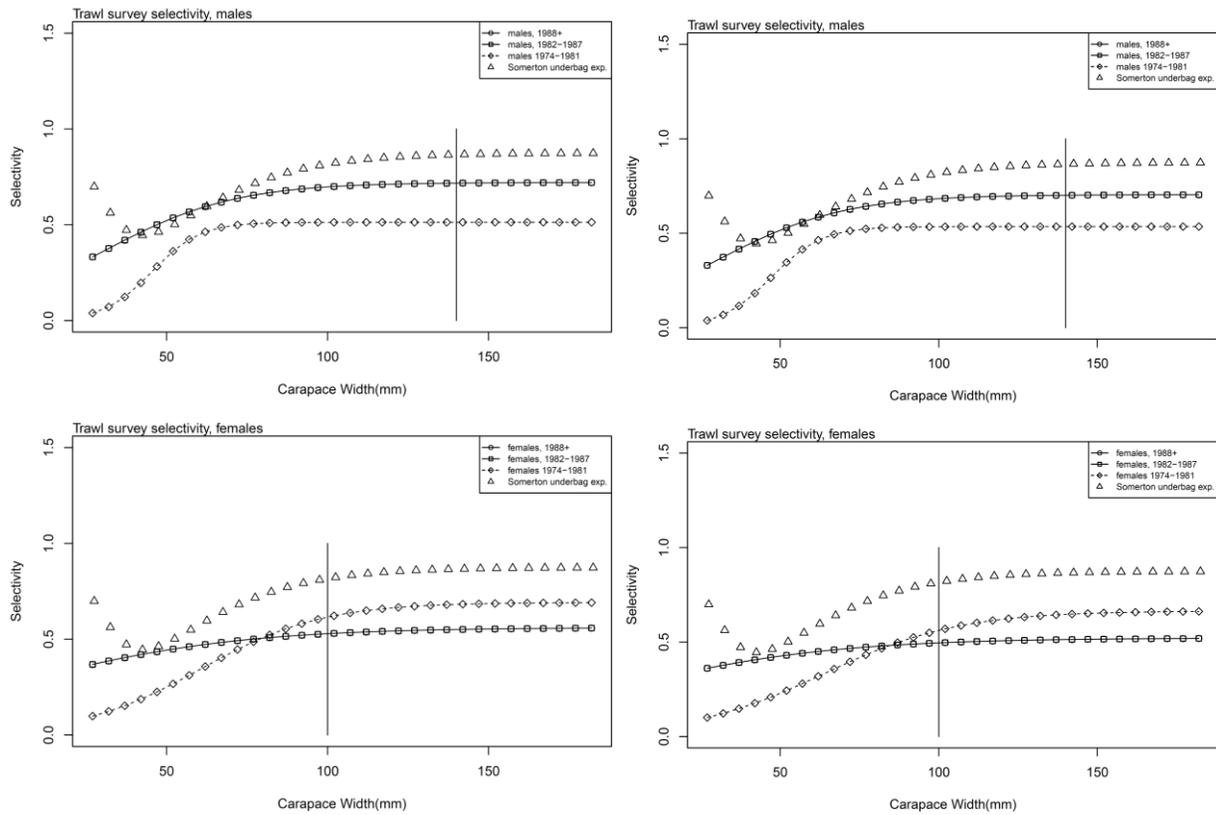
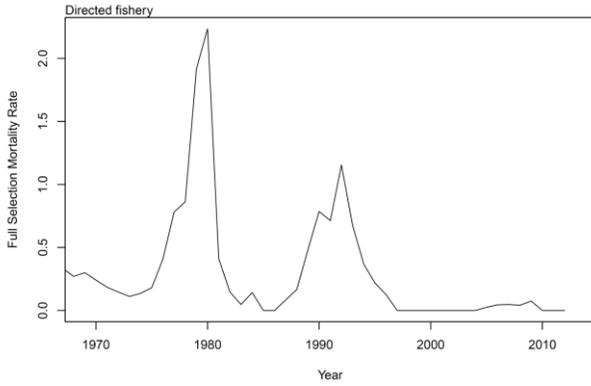


Figure 49. Comparison of estimated sex-specific selectivity curves for the NMFS bottom trawl survey in three time periods with those obtained by Somerton and Otto (1999) in the underbag experiment. The curves for 1982-87 and 1988+ are identical. Vertical lines indicate the size corresponding to survey q for both sexes. Left column: 2013 model (left), right column: author’s preferred 2014 model, Alt1a.

2013 Model



Alt1a

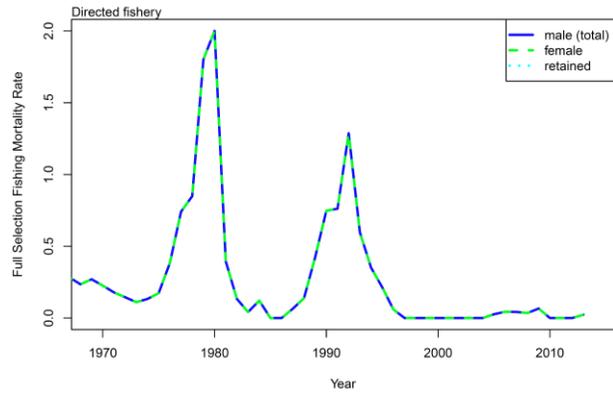


Figure 50. Estimated full selection fishing mortality in the directed fishery from the 2013 model (left) and the author's preferred 2014 model, Alt1a (right).

2013 Model

Alt1a

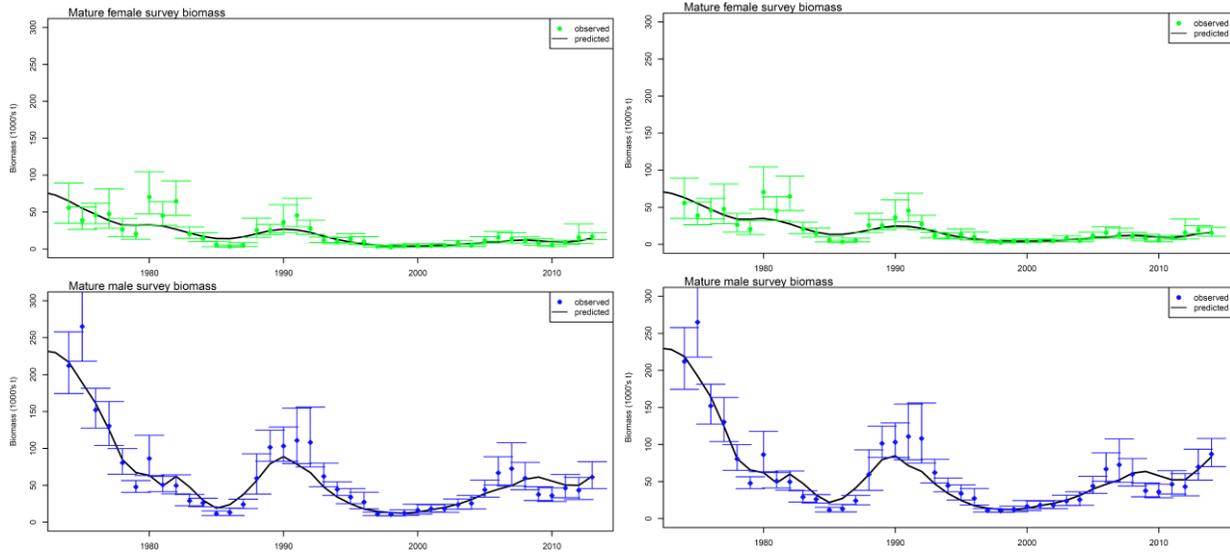


Figure 51. Comparison of observed survey biomass (circles with 95% CIs) and predicted survey biomass (solid line) for mature females (upper graph) and mature males (lower graph) from the 2013 model (left) and the author’s preferred 2014 model, Alt1a (right).

2013 Model

Alt1a

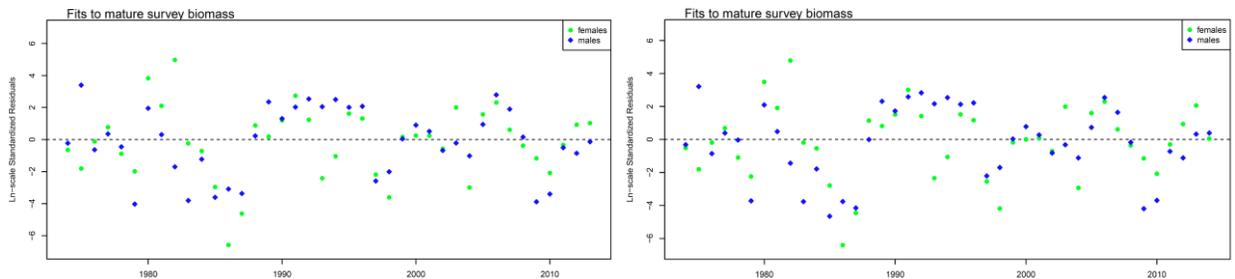


Figure 52. Standardized residuals (ln-scale) of mature survey biomass from the 2013 model (left) and the author’s preferred 2014 model, Alt1a (right).

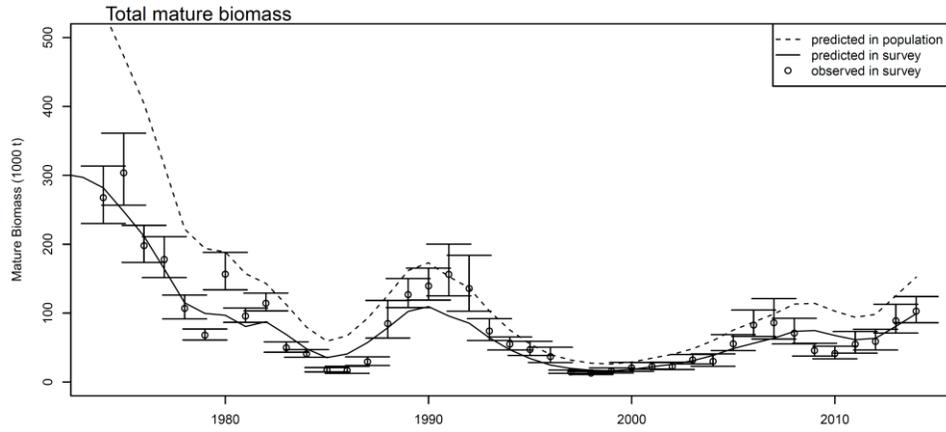


Figure 53. Comparison of observed survey biomass for mature crab (circles with 95% CIs), predicted survey biomass for mature crab (solid line) and predicted spawning (males + females) biomass (dashed line) from the author's preferred model, Alt1a.

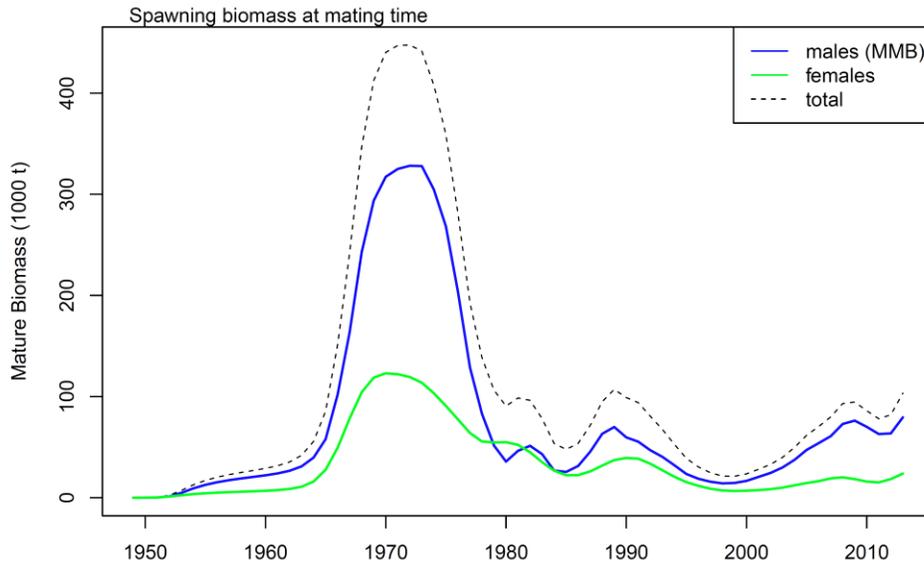


Figure 54. Model-predicted mature biomass at mating time for males (i.e., MMB; blue line), females (green line), and total (dotted line), from the author's preferred model, Alt1a.

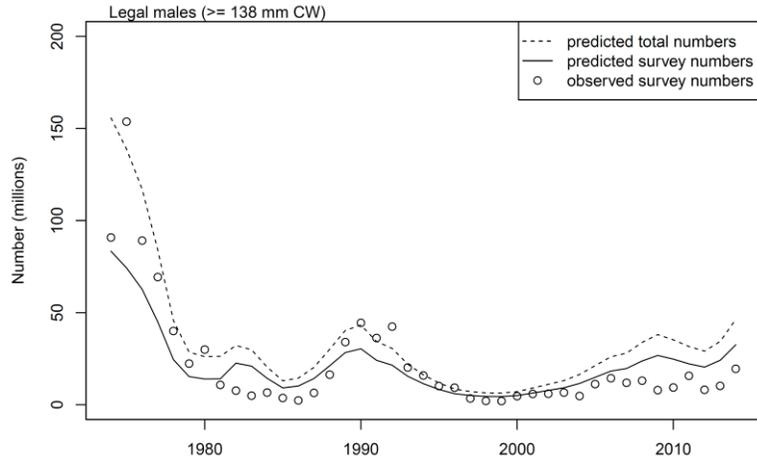


Figure 55. Comparison of numbers of male crab ≥ 138 mm CW in the trawl survey with predicted total survey numbers from the author's preferred model Alt1a.

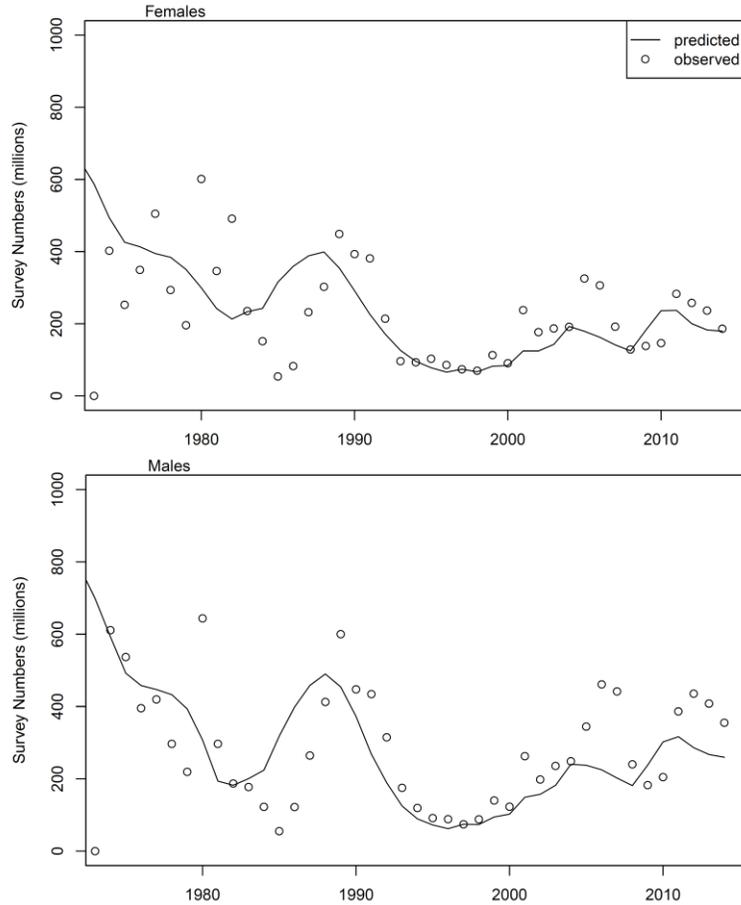


Figure 56. Comparison of observed numbers of crab in the NMFS bottom trawl survey (circles) and predicted survey numbers (solid line) from the author's preferred model, Alt1a, for females (top graph) and males (bottom graph).

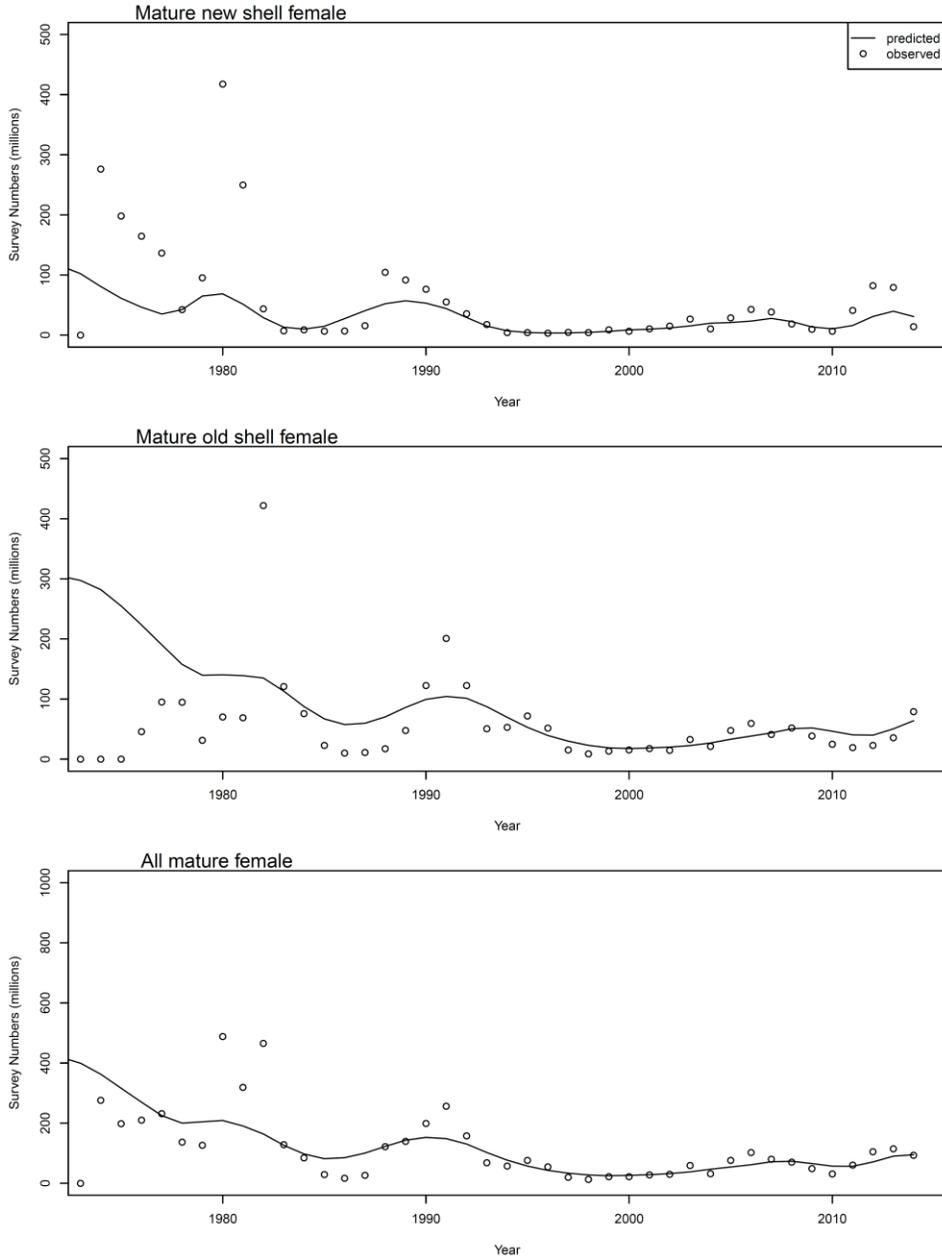


Figure 57. Comparison of observed numbers in the NMFS bottom trawl survey for mature males by shell condition (new shell, old shell) and combined with predictions from the author's preferred model, Alt1a.

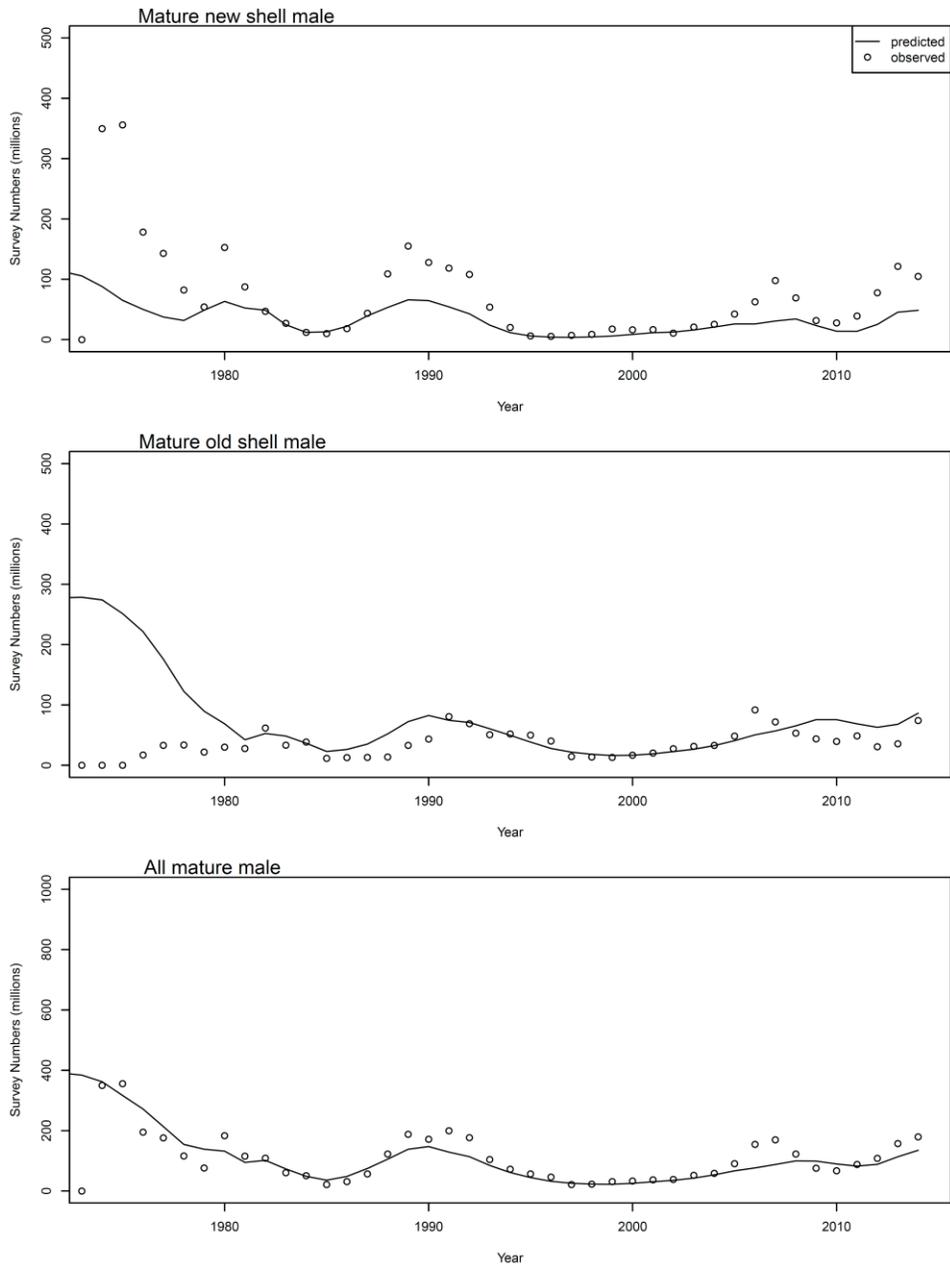


Figure 58. Comparison of observed numbers in the NMFS bottom trawl survey for mature males by shell condition (new shell, old shell) and combined with predictions from the author's preferred model, Alt1a.

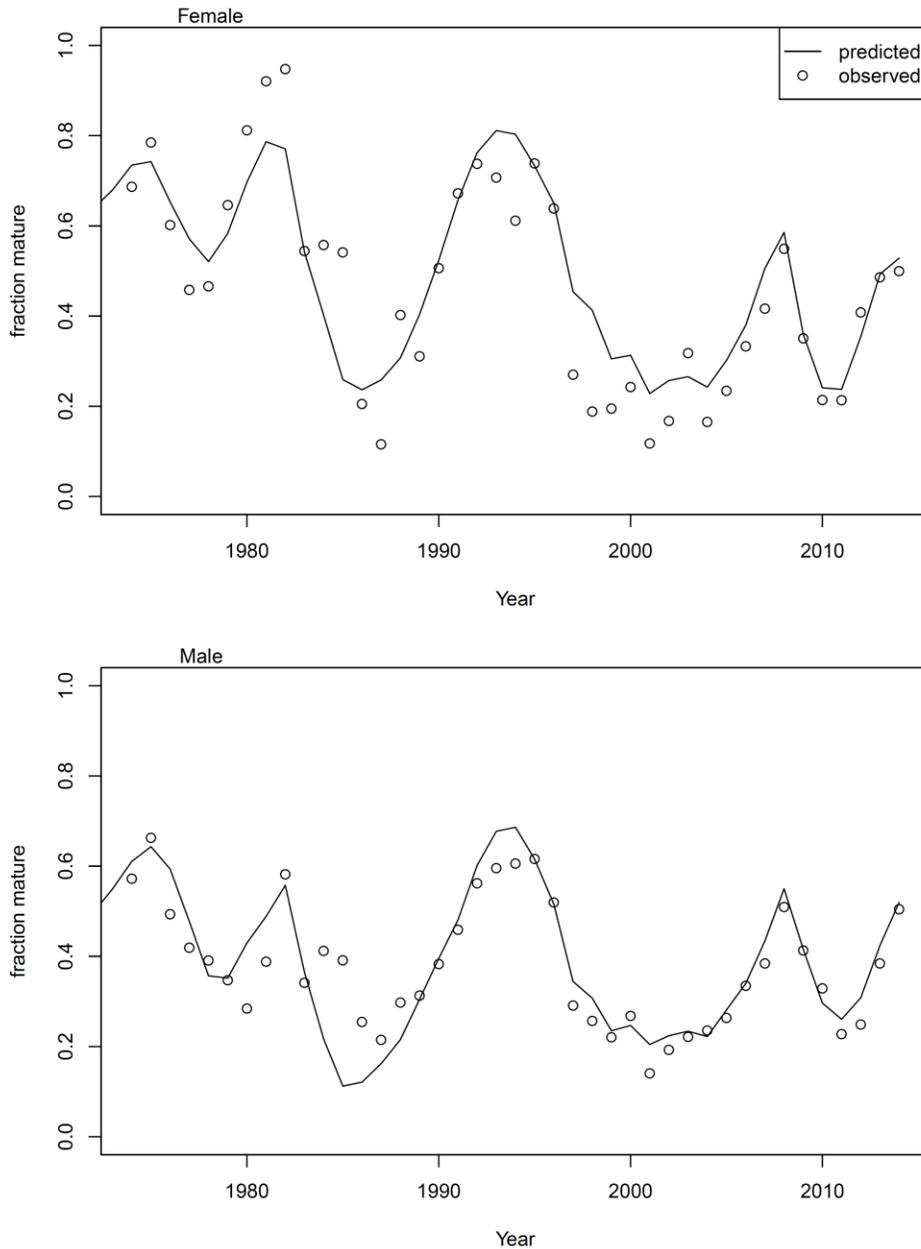


Figure 59. Comparison of estimates of the fraction of mature crab by sex in the NMFS bottom trawl survey and as predicted by the author's preferred model, Alt1a.

directed fishery, all retained males

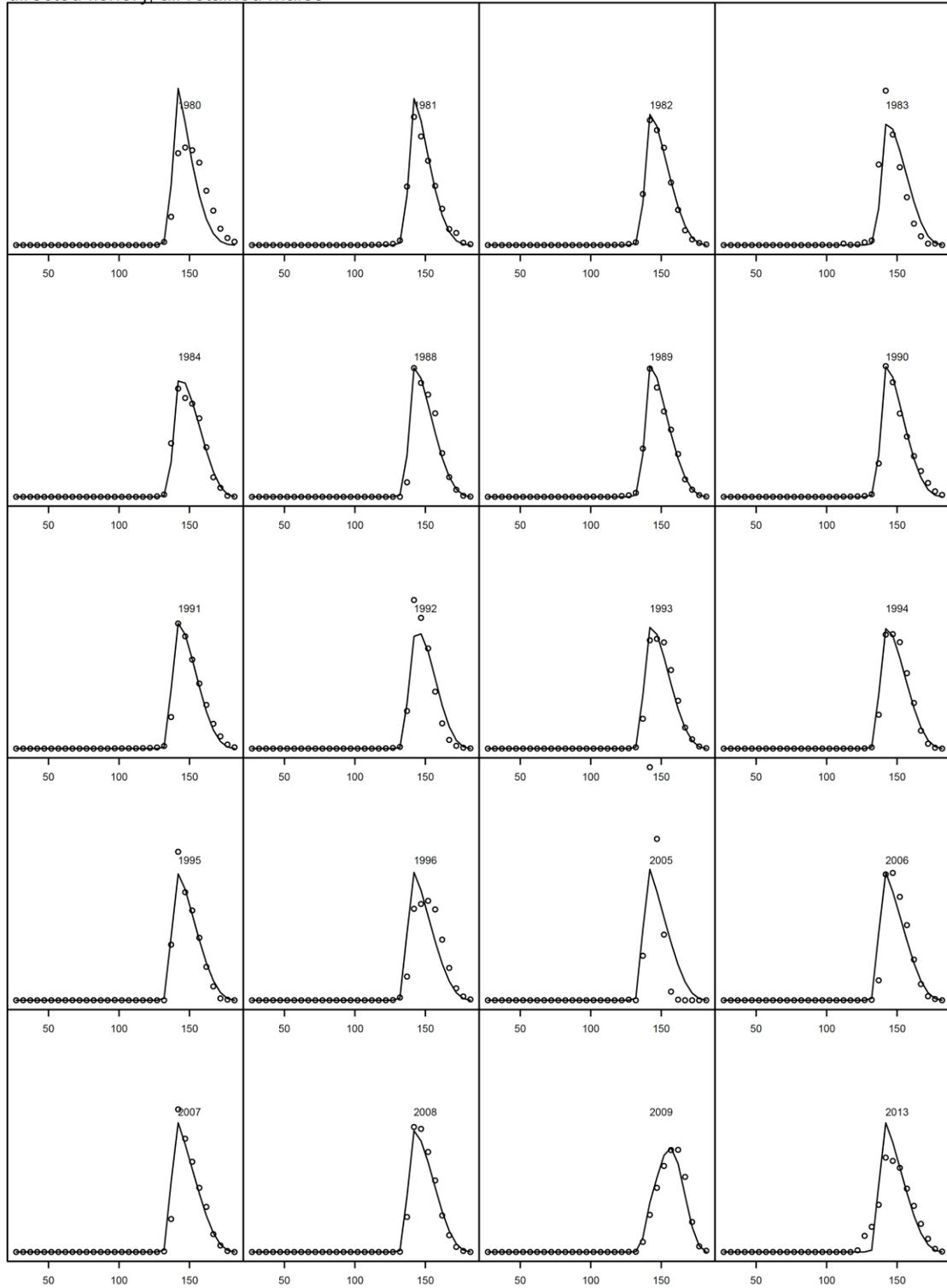


Figure 60. Comparison of predicted (solid line) and observed (circles) proportions-at-size for retained males in the directed Tanner crab fishery from the author's preferred model (Alt1a).

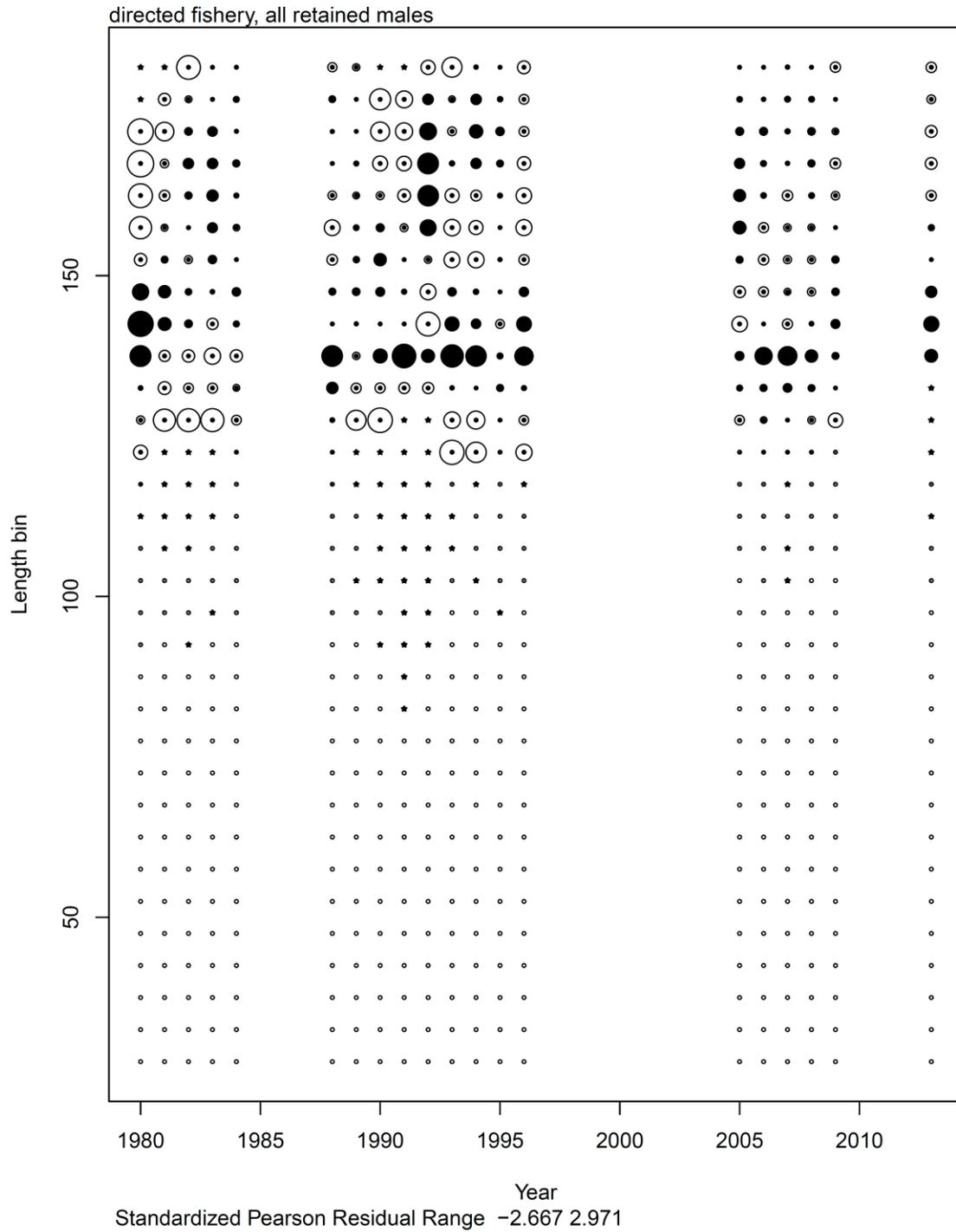


Figure 61. Pearson residuals for predicted proportions at size for retained males in the directed Tanner crab fishery for the author's preferred model (Alt1a). White circles represent positive anomalies (observed > predicted), black circles represent negative anomalies.

directed fishery, all males

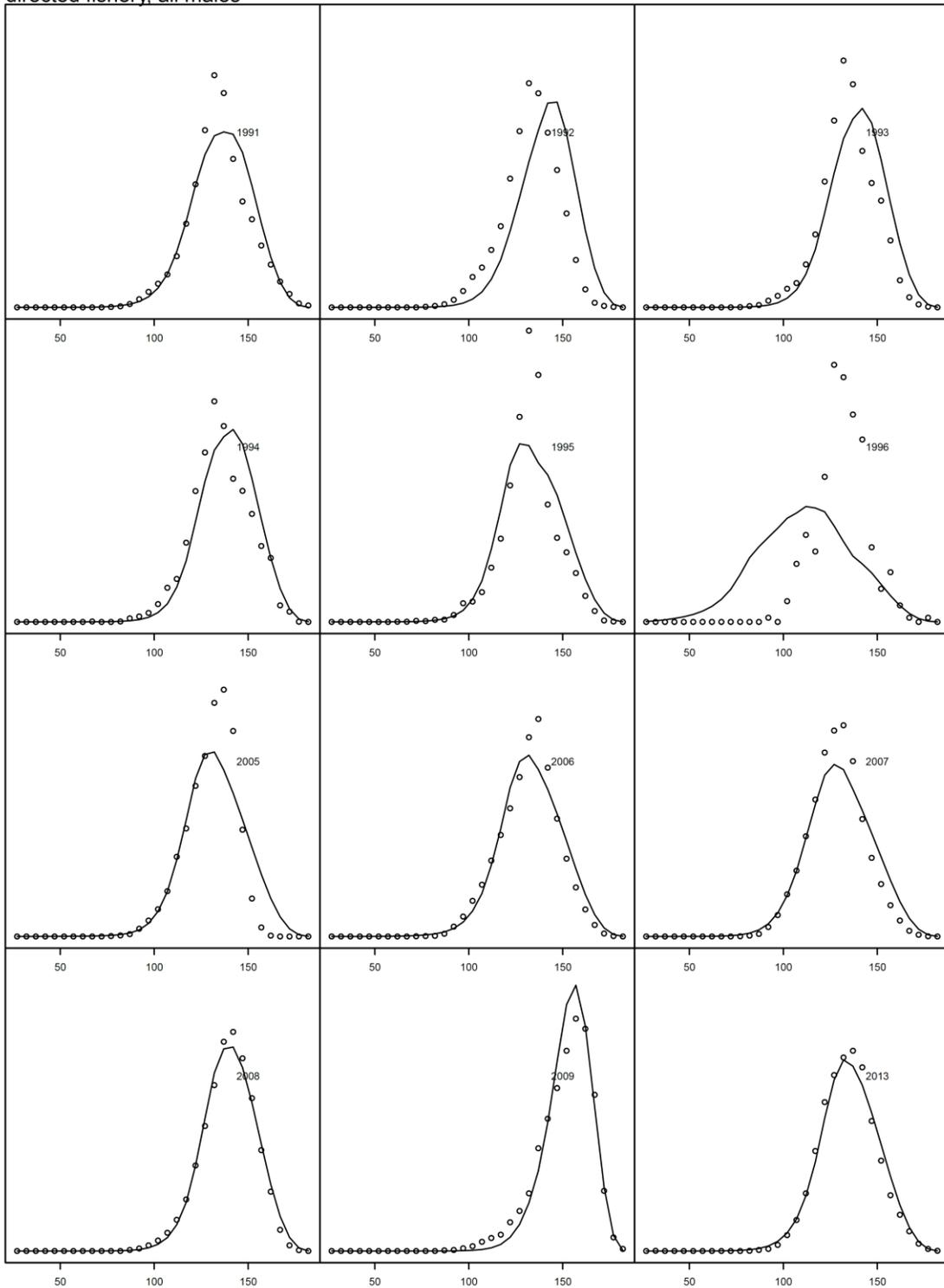


Figure 62. Comparison of predicted (solid line) and observed (circles) proportions-at-size for all males (retained+discarded) males in the directed Tanner crab fishery from the author's preferred model, Alt1a.

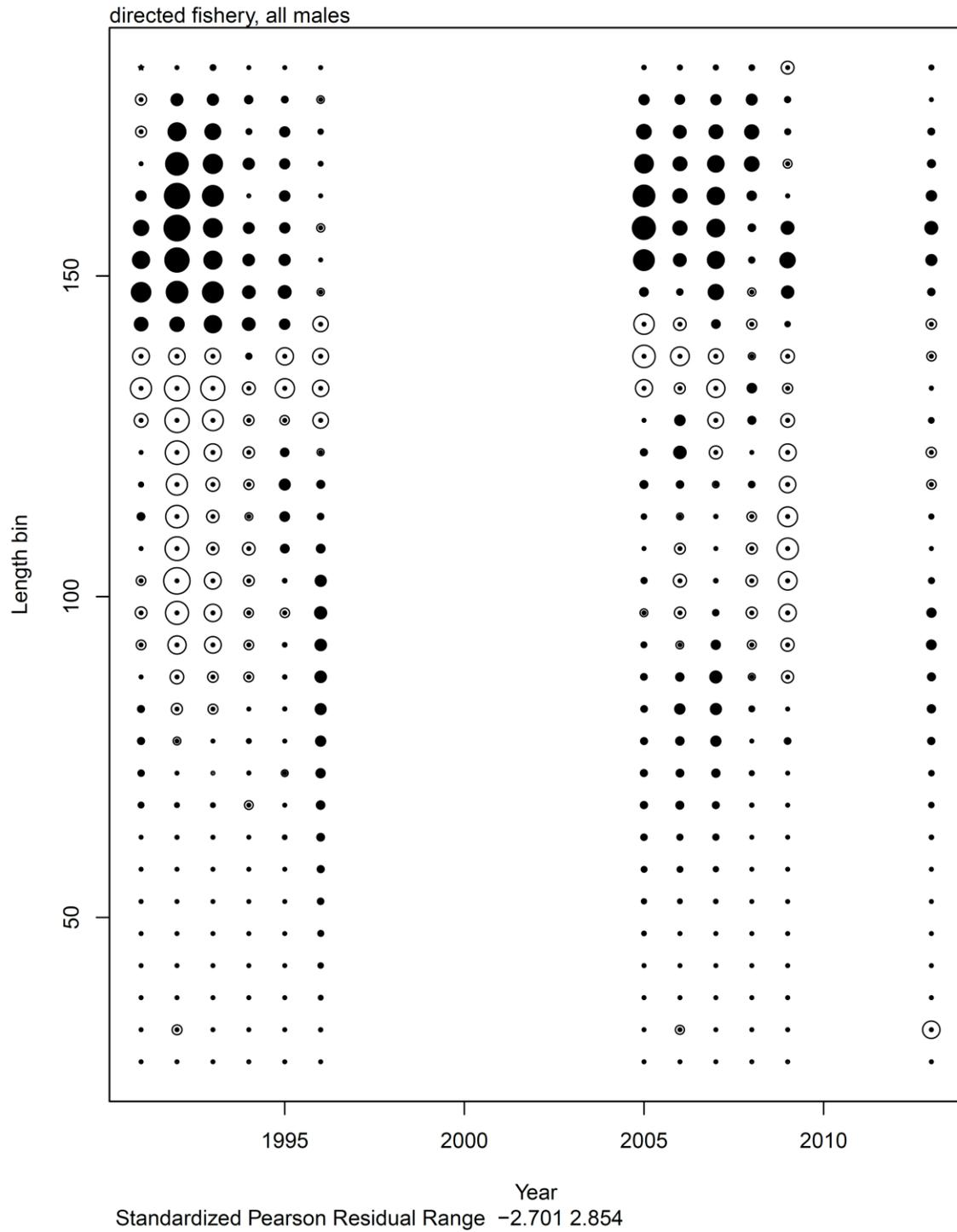


Figure 63. Pearson residuals for predicted proportions at size for all males in the directed Tanner crab fishery from the author's preferred model (Alt1a). White circles represent positive anomalies (observed > predicted), black circles represent negative anomalies.

directed fishery, all females

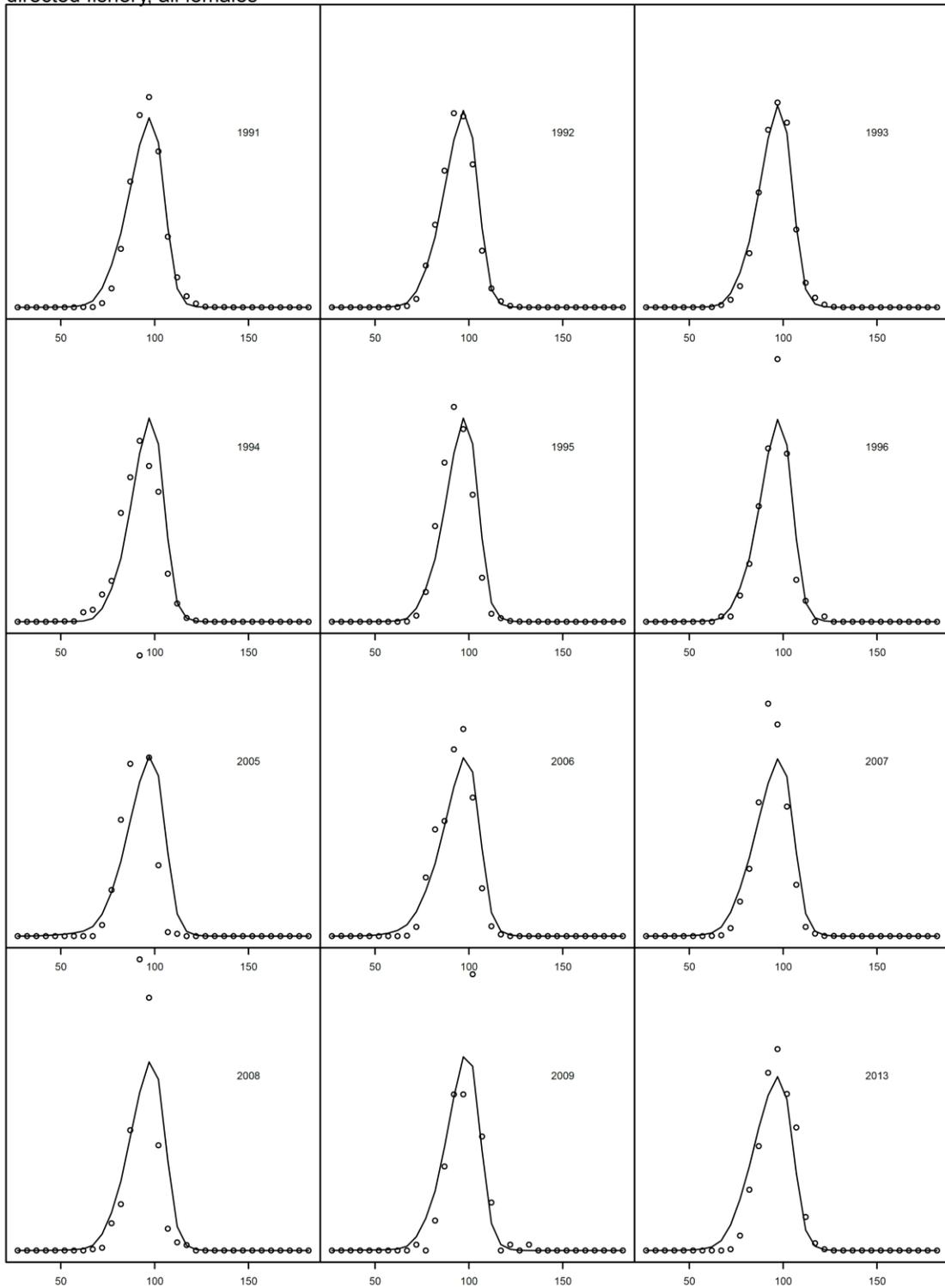


Figure 64. Comparison of predicted (solid line) and observed (circles) proportions at size for females in the directed Tanner crab fishery from the author's preferred model (Alt1a).

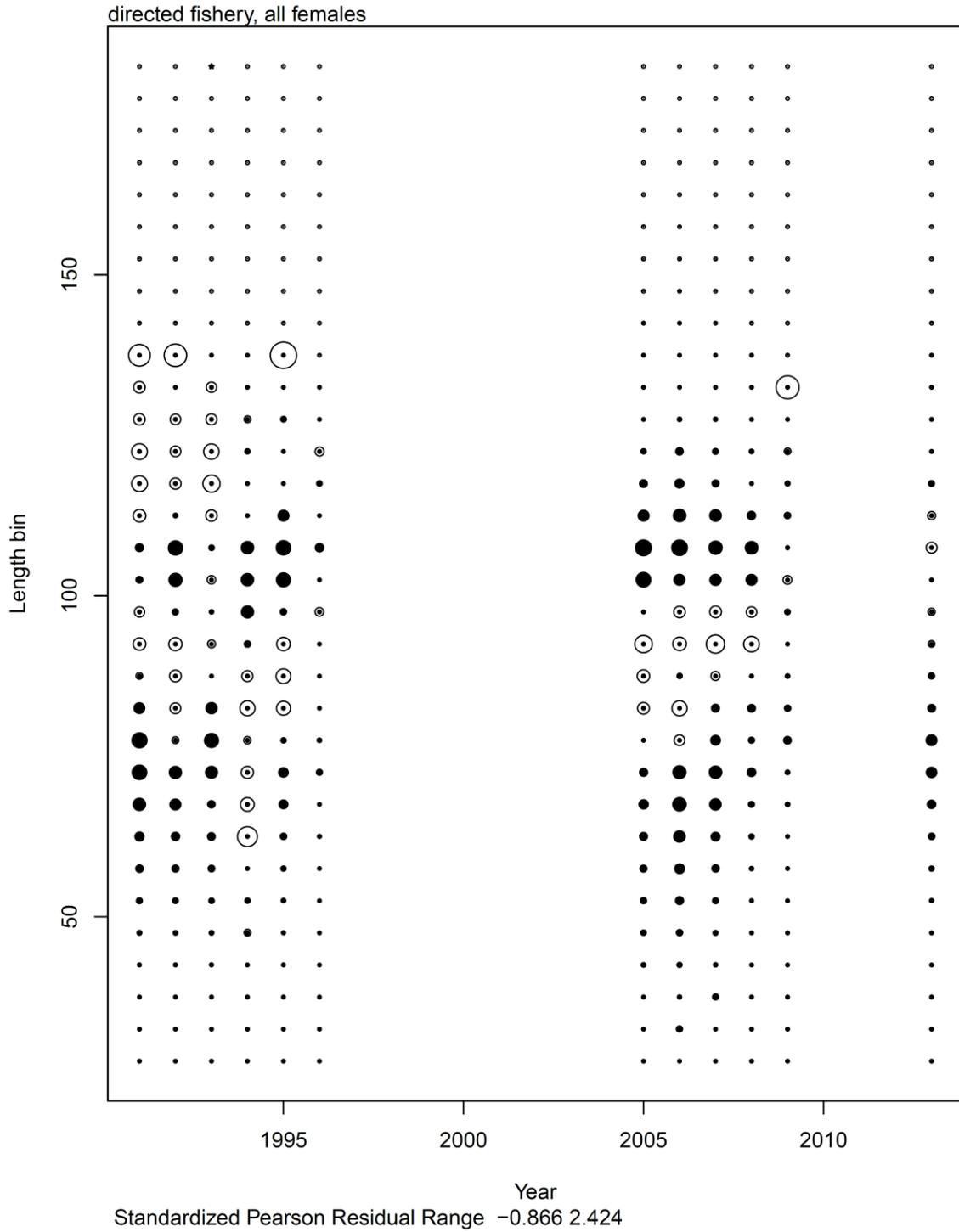


Figure 65. Pearson residuals for predicted proportions at size for females in the directed Tanner crab fishery from the author's preferred model (Alt1a). White circles represent positive anomalies (observed>predicted), black circles represent negative anomalies.

Survey proportions, males

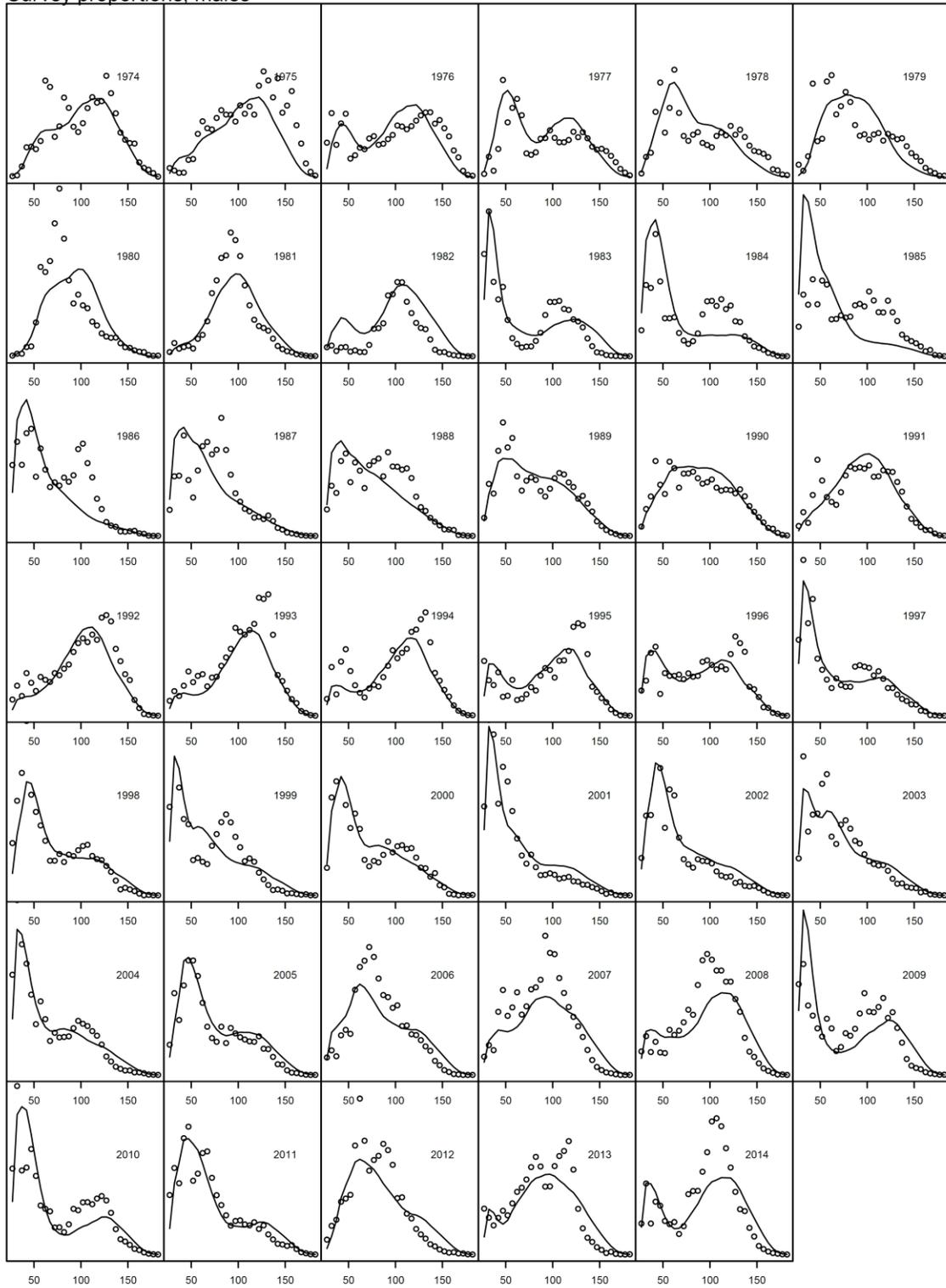


Figure 66. Comparison of predicted (solid line) and observed (circles) proportions-at-size for males in the NMFS bottom trawl survey from the author's preferred model (Alt1a).

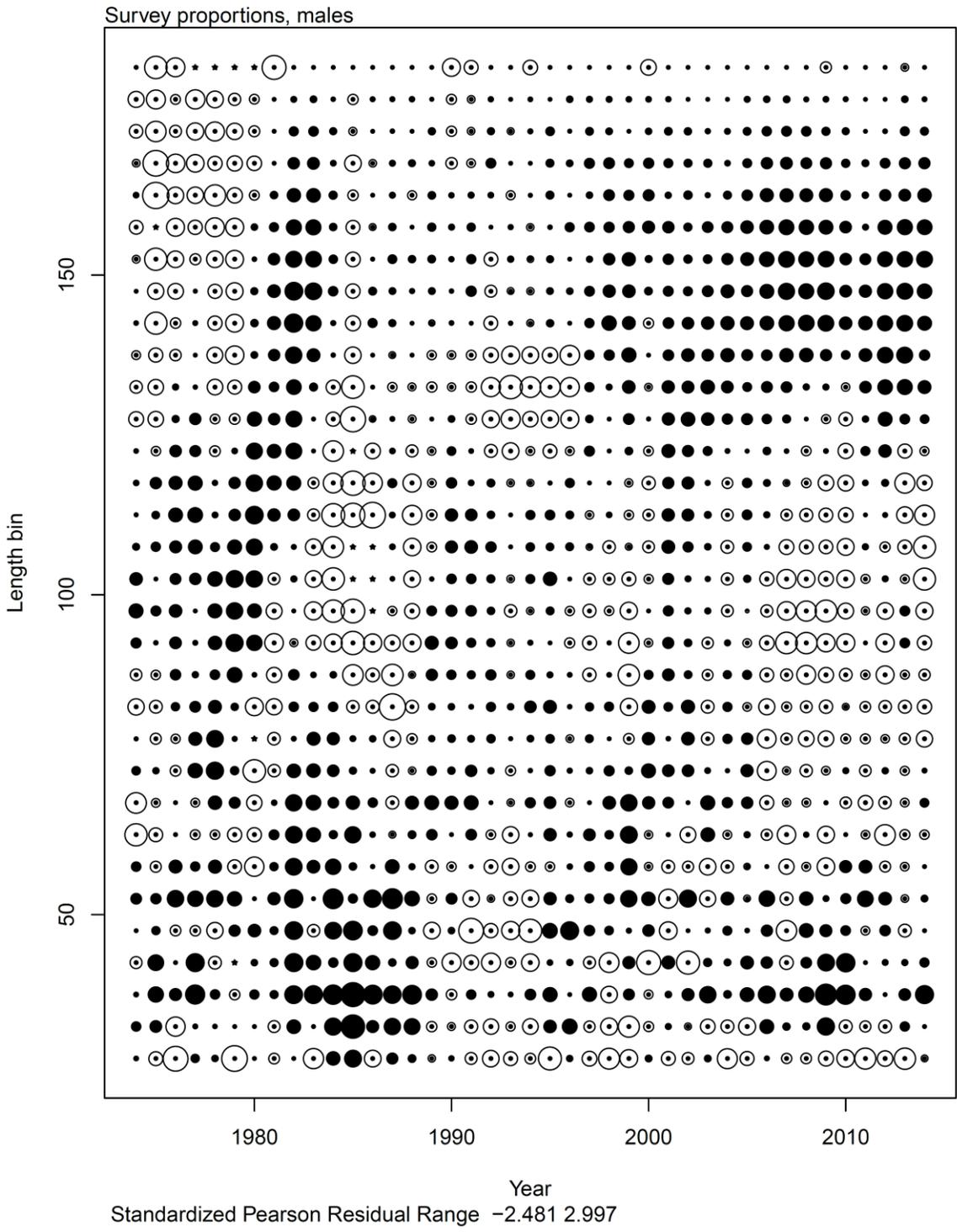


Figure 67. Pearson residuals for predicted proportions at size for all males in the NMFS bottom trawl survey from the author's preferred model (Alt 1a). White circles represent positive anomalies (observed > predicted), black circles represent negative anomalies.

Survey proportions, females

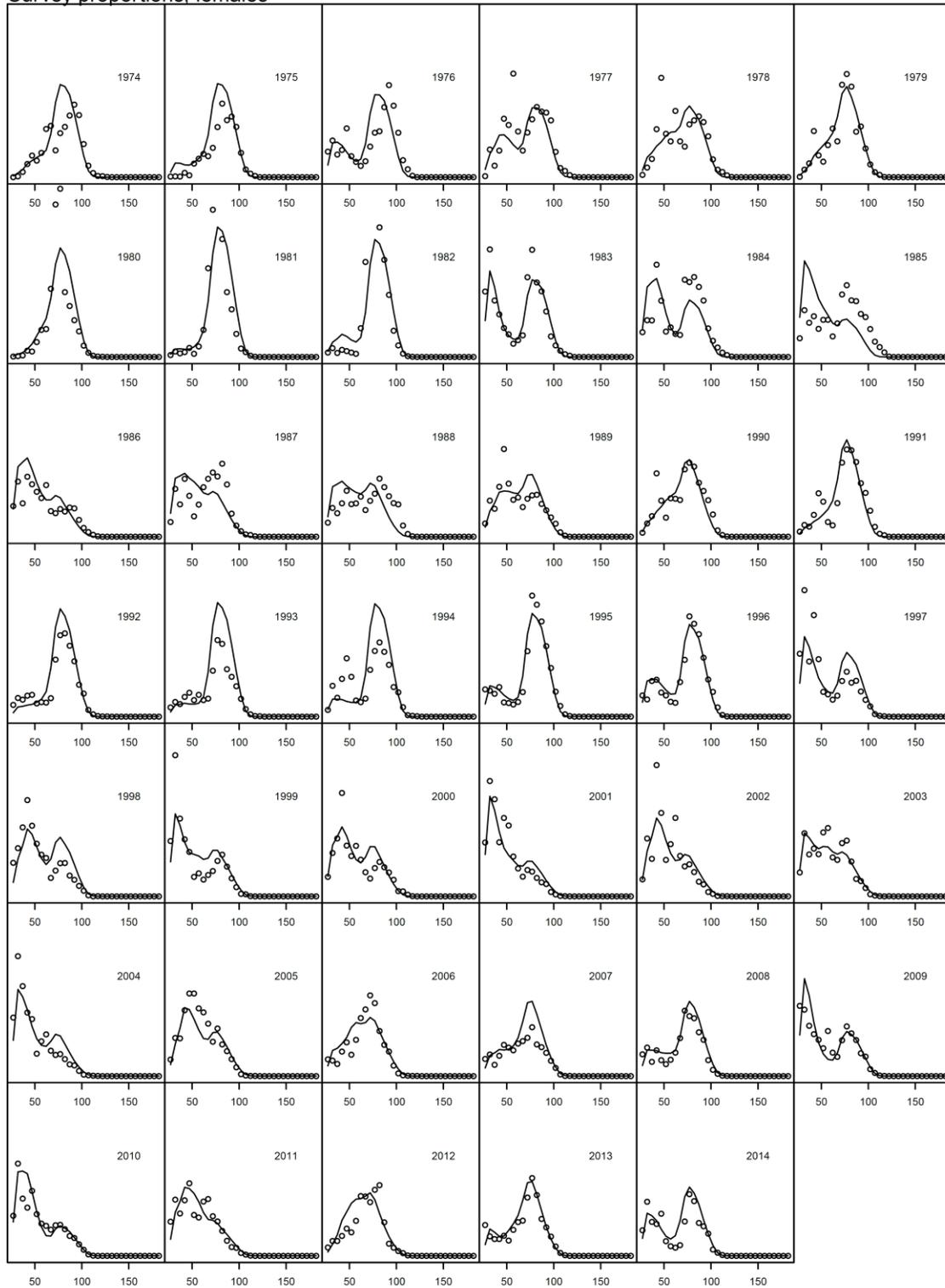


Figure 68. Comparison of predicted (solid line) and observed (circles) proportions-at-size for females in the NMFS bottom trawl survey from the author's preferred model (Alt1a).

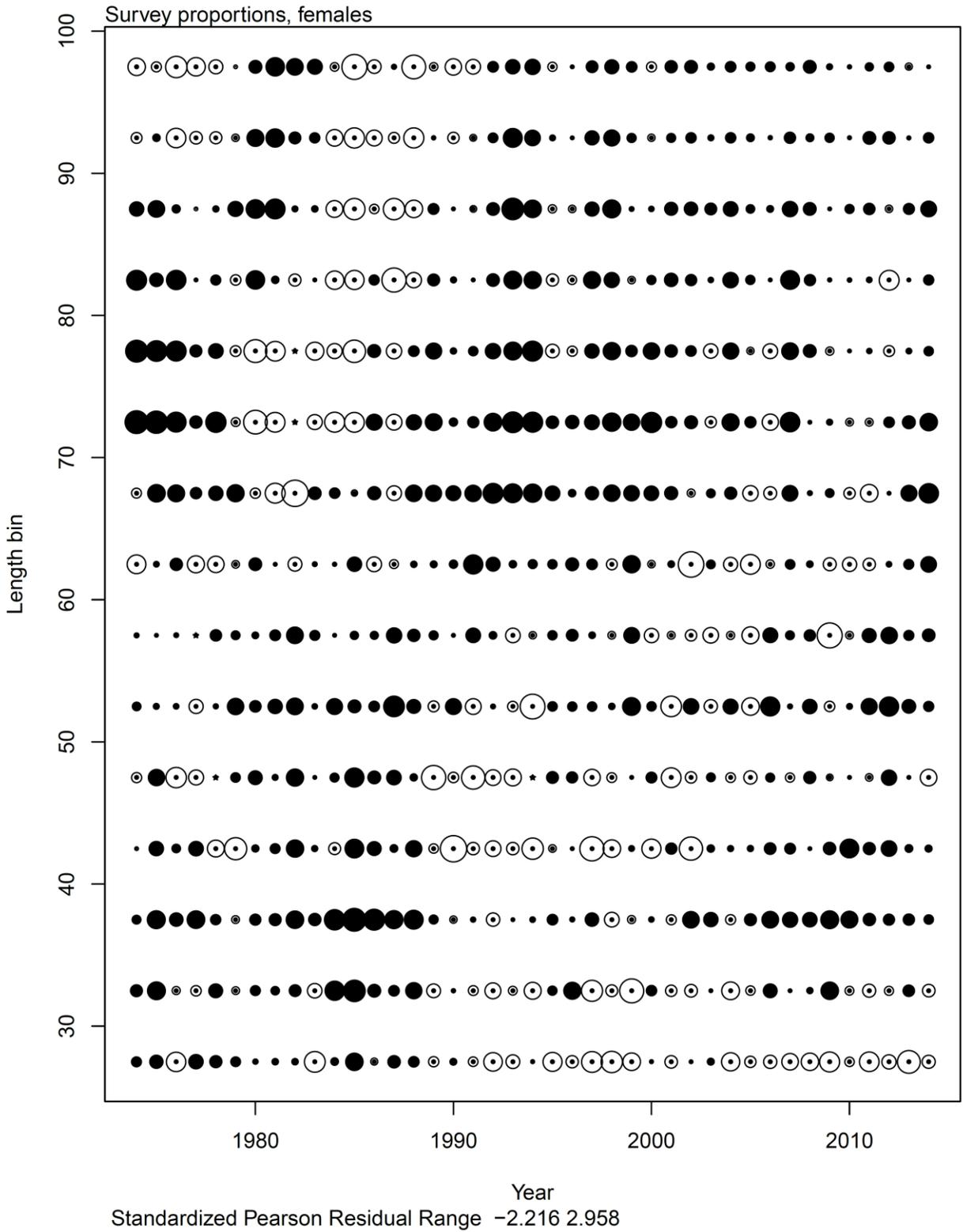


Figure 69. Pearson residuals for predicted proportions at size for females in the NMFS bottom trawl survey from the author's preferred model (Alt1a). White circles represent positive anomalies (observed > predicted), black circles represent negative anomalies.

2013 Model

Alt1a

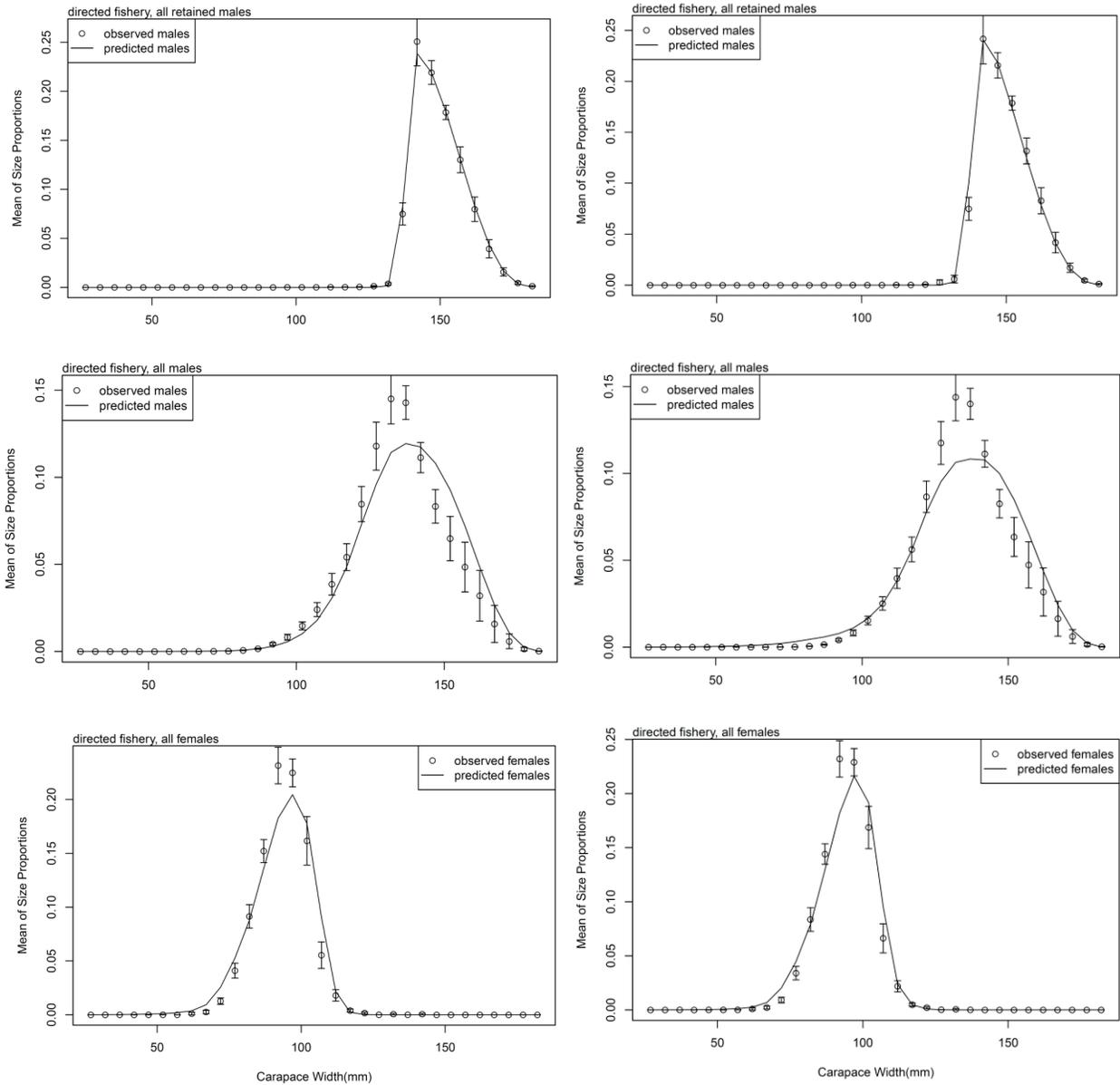


Figure 70. Comparison of marginal (mean) proportions-at-size in the directed Tanner crab fishery for retained males (upper plot) and all males (center plot) and females (lower plot) from the 2013 assessment model (left column) and the author’s preferred model (Alt1a, right column). 80% confidence intervals are shown for the observed values, based on observed variance-at-size and assuming normal distributions.

2013 Model

Alt1a

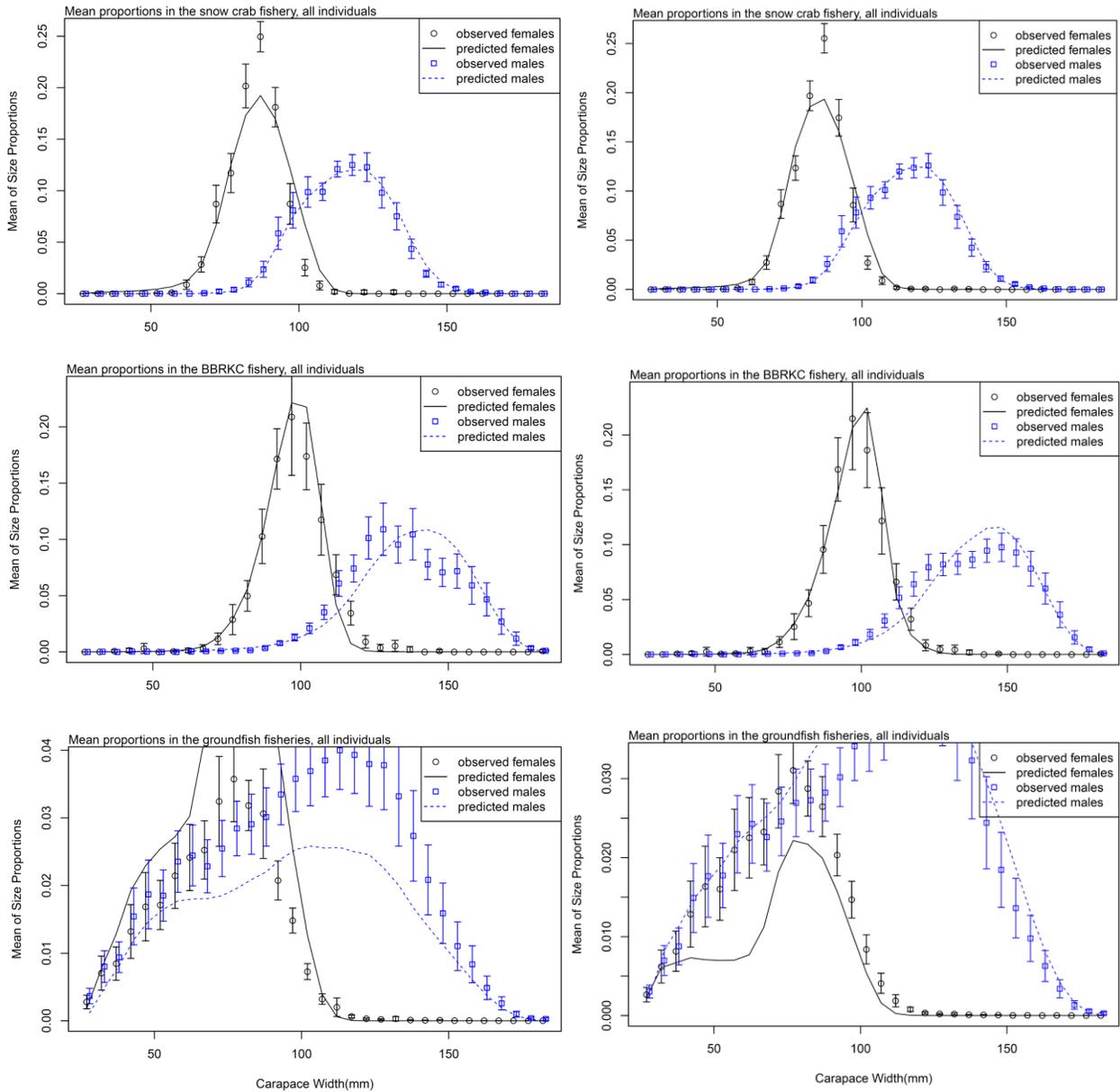


Figure 71. Comparison of marginal (mean) proportions-at-size for males and females in the snow crab fishery (upper plot), the BBRKC fishery (center plot), and the groundfish fisheries (lower plot) from the 2013 assessment model (left column) and the author’s preferred model (Alt1a, left column). 80% confidence intervals are shown for the observed values, based on observed variance-at-size and assuming normal distributions.

2013 Model

Alt1a

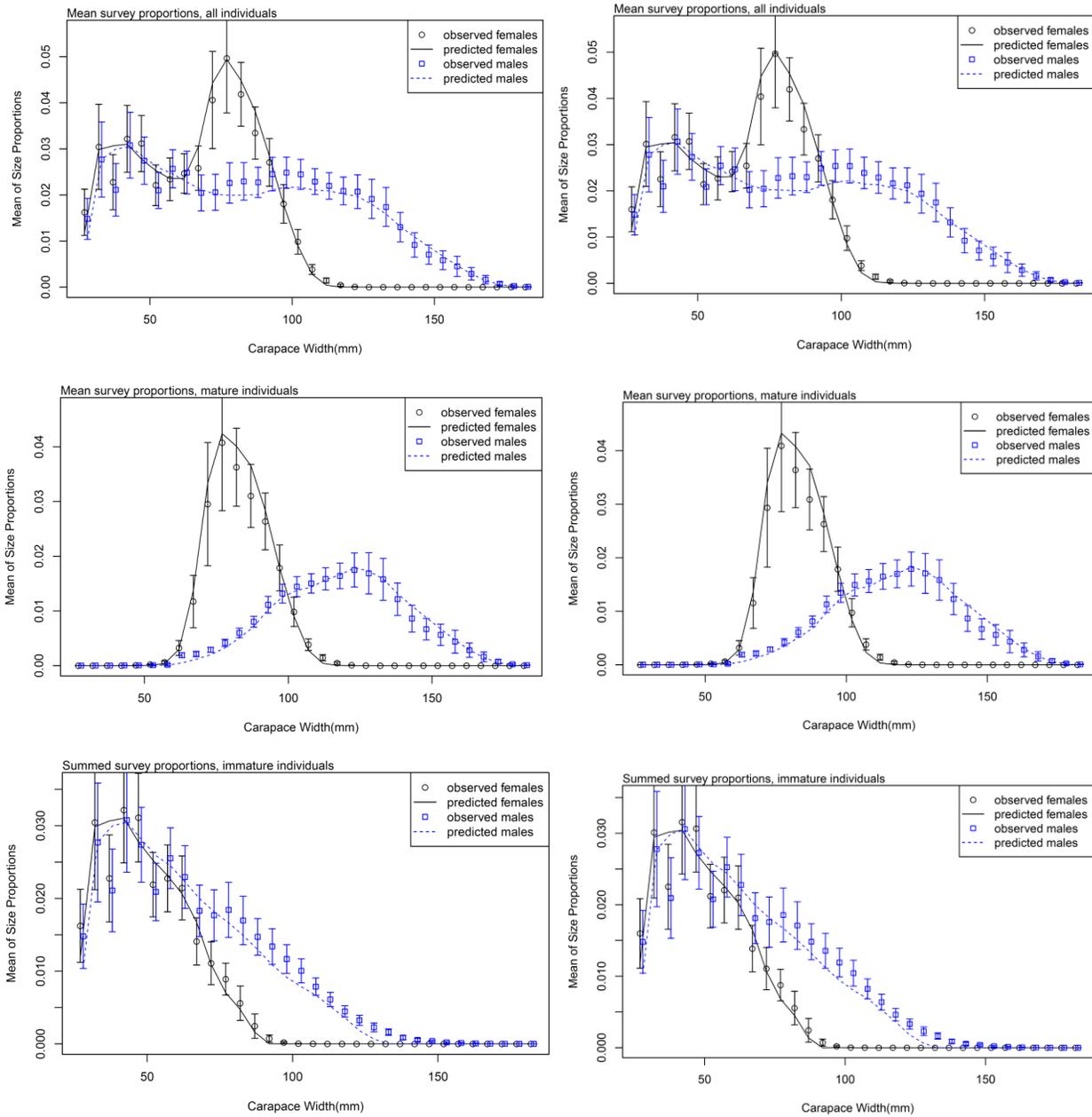


Figure 72. Comparison of marginal (mean) proportions-at-size in the NMFS bottom trawl survey for all (male+female) crab (upper plot), mature crab (center plot), and immature crab (lower plot) from the 2013 assessment model (left column) and the author’s preferred model (Alt1a, right column). 80% confidence intervals are shown for the observed values, based on observed variance-at-size and assuming normal distributions.

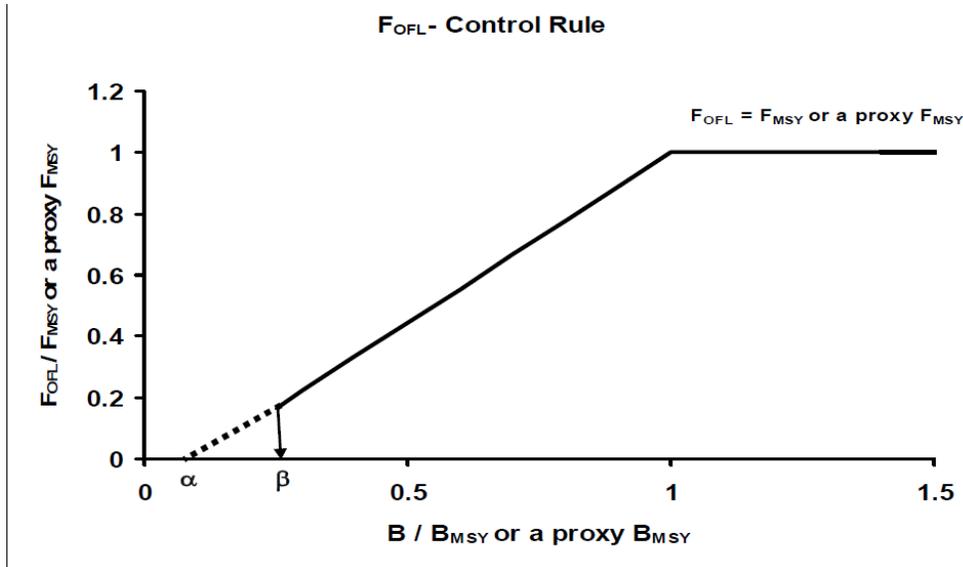


Figure 73. The F_{OFL} harvest control rule. For Tier 3 stocks such as EBS Tanner crab, F_{MSY} and B_{MSY} are based on spawning biomass per recruit proxies, where $F_{MSY} = F_{35\%}$ and $B_{MSY} = B_{35\%}$ and MMB at mating time is used as spawning biomass.

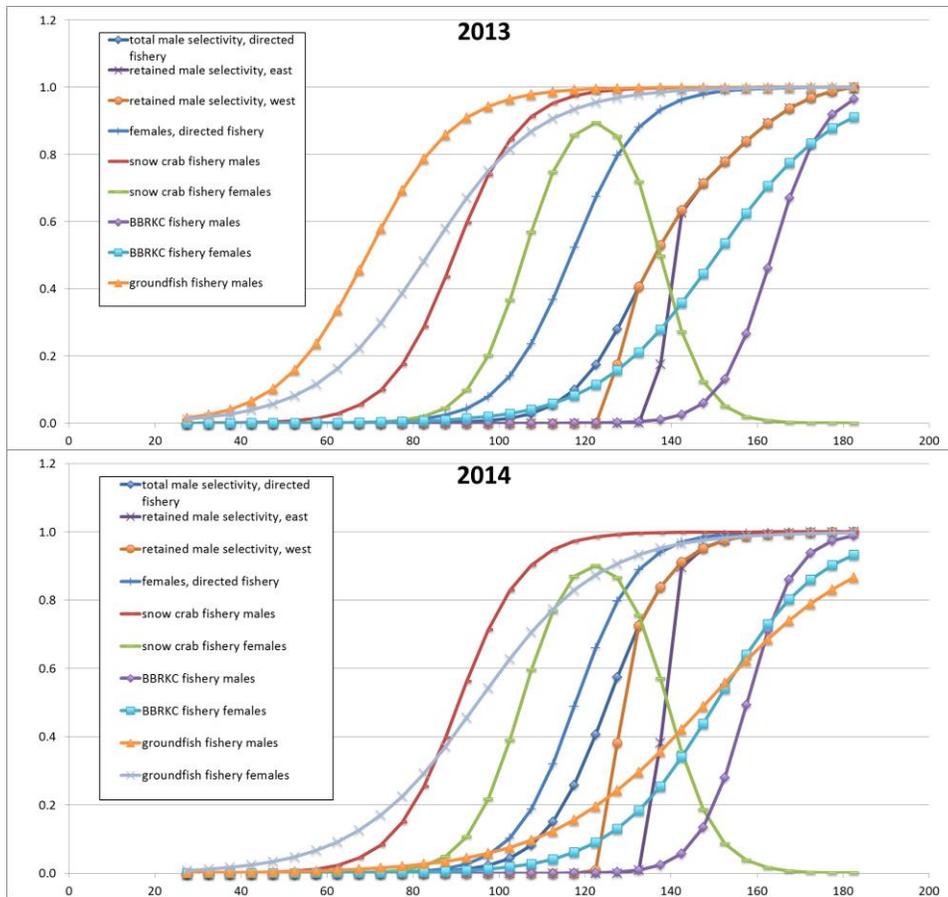


Figure 74. Comparison of selectivity curves used in the projection model for status determination and OFL calculation in 2013 (upper plot) and the preferred model for 2014 (Alt1a, lower plot). The total (retained+ discards) selectivity curve (dark blue curve, triangles) is assumed to apply to the fisheries east and west of 166°W longitude. Retained selectivity in the fishery east of 166°W (purple curve, asterisks) is assumed to be the same as the last year of the directed fishery. Retained selectivity west of 166°W is assumed to be a left-shifted version of that east of 166°W, reflecting the smaller legal and preferred size limits there (orange curve, circles).

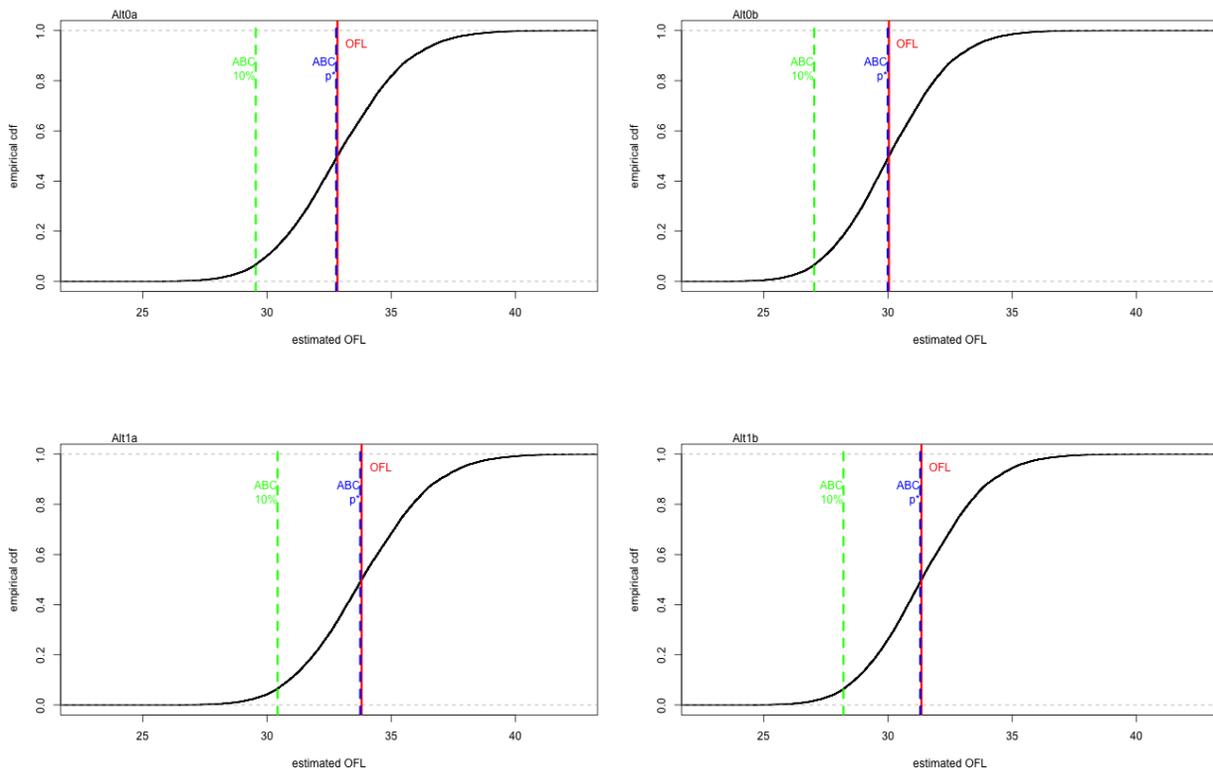


Figure 75. Tier 3 OFL and ABC calculations using the empirical cumulative probability distribution (white line) for the OFL (indicated by the vertical red line) based on 10,000 1-year projection model runs. Initial (July 1, 2013) population numbers-at-size were randomized based on the CV of 2013 MMB at mating time for each alternative model (upper left: Alt0a, upper right: Alt0b, lower left: Alt1a, lower right: Alt1b). For each year, directed fishing mortality was set using $F_{msy} = F35\%$ and the Tier 3 F_{OFL} control rule, and total catch was calculated. The OFL for each model is the median of the resulting distribution of catches (possible OFLs). The “p-star” ABC (indicated by the dashed blue line) is the ABC that yields $p^* = 0.49$ —i.e., the probability that the selected ABC exceeds the true OFL is 49%. $ABC_{10\%}$ (indicated by the dashed green line) is the ABC based on applying a 10% buffer to the OFL. The units for OFL and ABC are 1000^3 t.

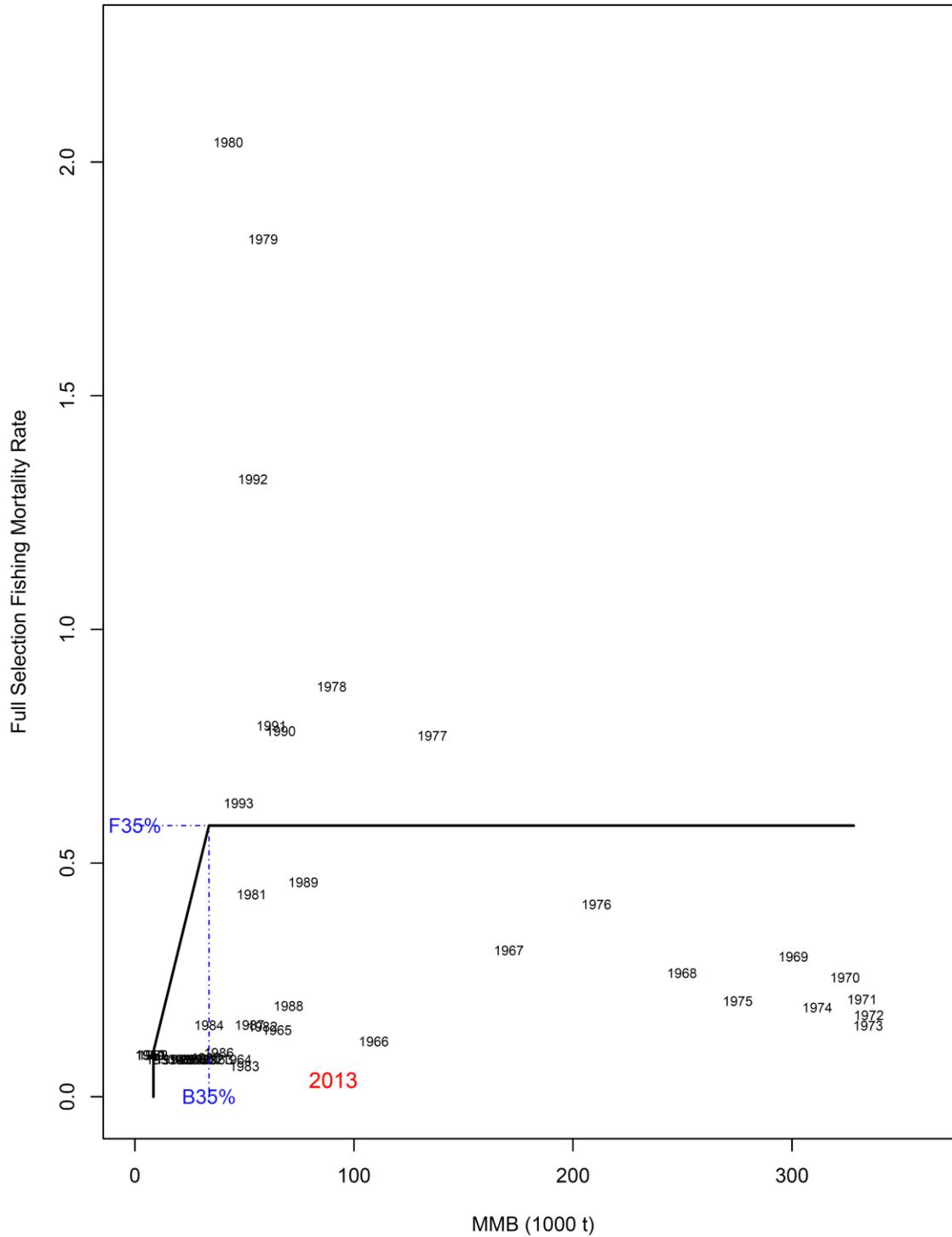


Figure 76. The Tier 3 F_{OFL} harvest control rule, with the population state for each year plotted at coordinates given by MMB at mating on the x axis and total fishing mortality on the y axis, as estimated from the author's preferred model, Model 01. The current year (2013/14) is highlighted in red text.

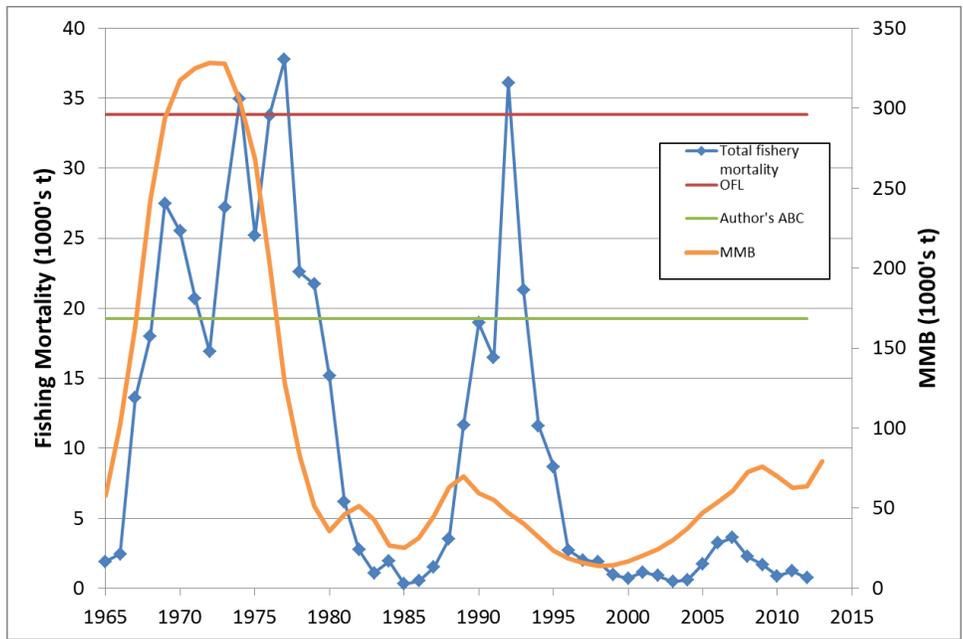


Figure 77. Comparison of the OFL from the author's preferred model and the author's recommended ABC with the time series of estimated total fishery-related mortality and MMB for the Tanner crab stock.

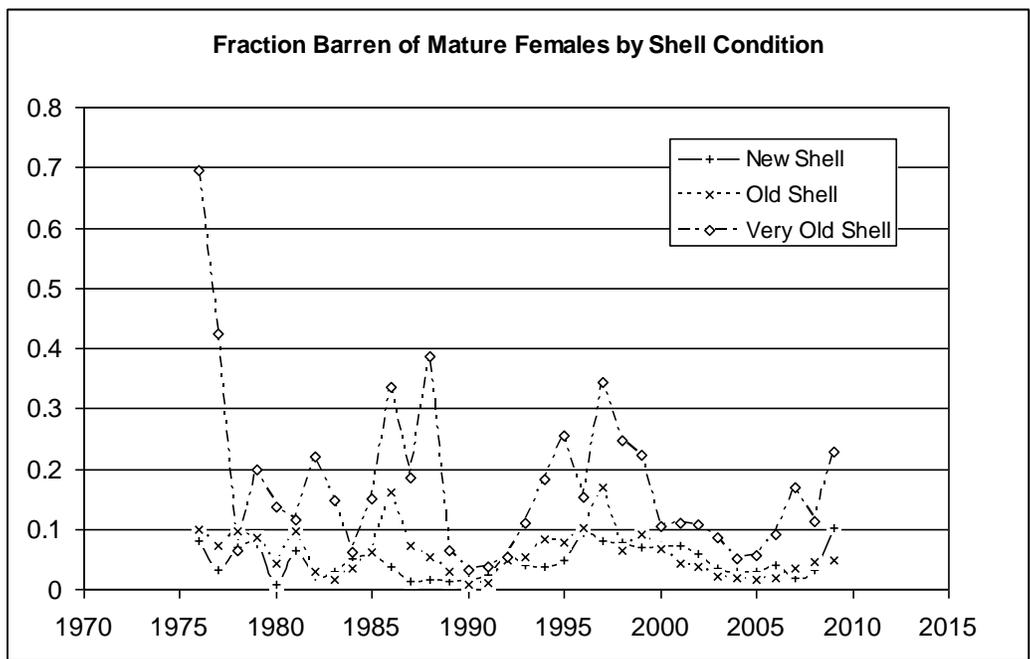


Figure 78. Proportion of female Tanner crab with barren clutches by shell condition from survey data for 1976/77 to 2009/10.

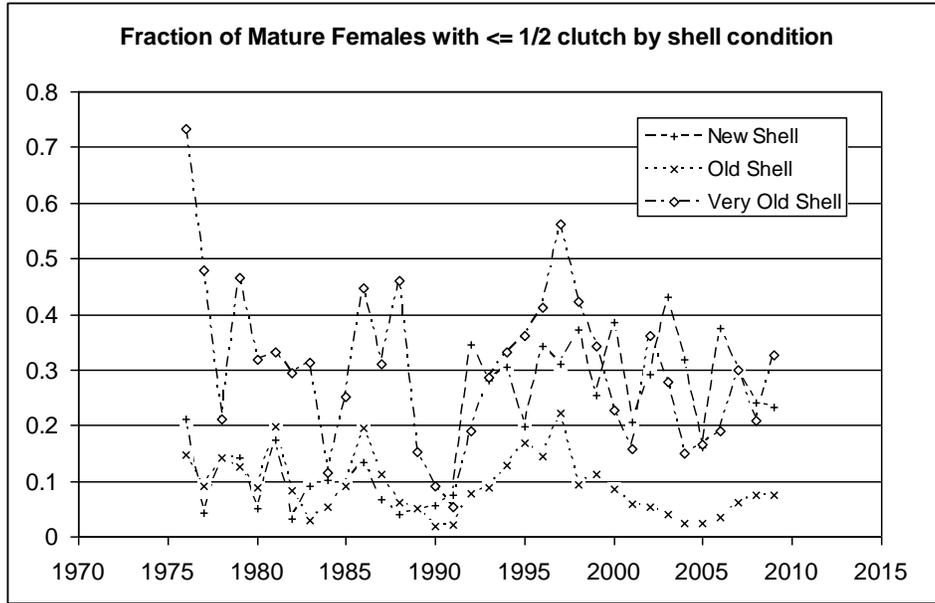


Figure 79. Proportion of female Tanner crab with less than or equal to one-half full clutch by shell condition from survey data 1976/77 to 2009/10.

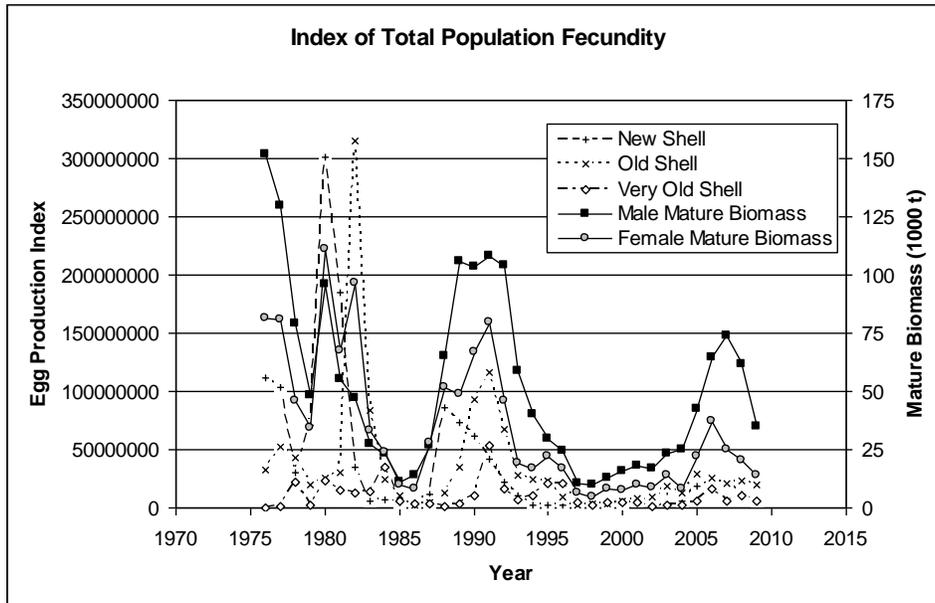


Figure 80. Tanner crab female egg production index (EPI) by shell condition, survey estimate of male mature biomass (1000 t), and survey estimate of female mature biomass (1000 t) from survey data for 1976/77 to 2009/10.

BS Bairdi mortality

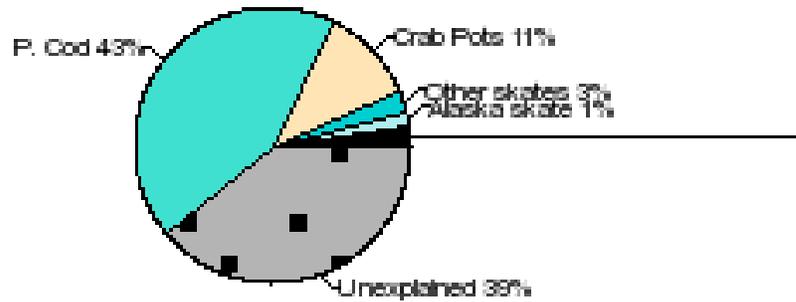


Figure 81. The fraction of annual mortality from major ecosystem components (including fisheries) on mature Tanner crab in the EBS, as estimated by a mass-balance ecosystem model for the EBS (Aydin et al., 2007).

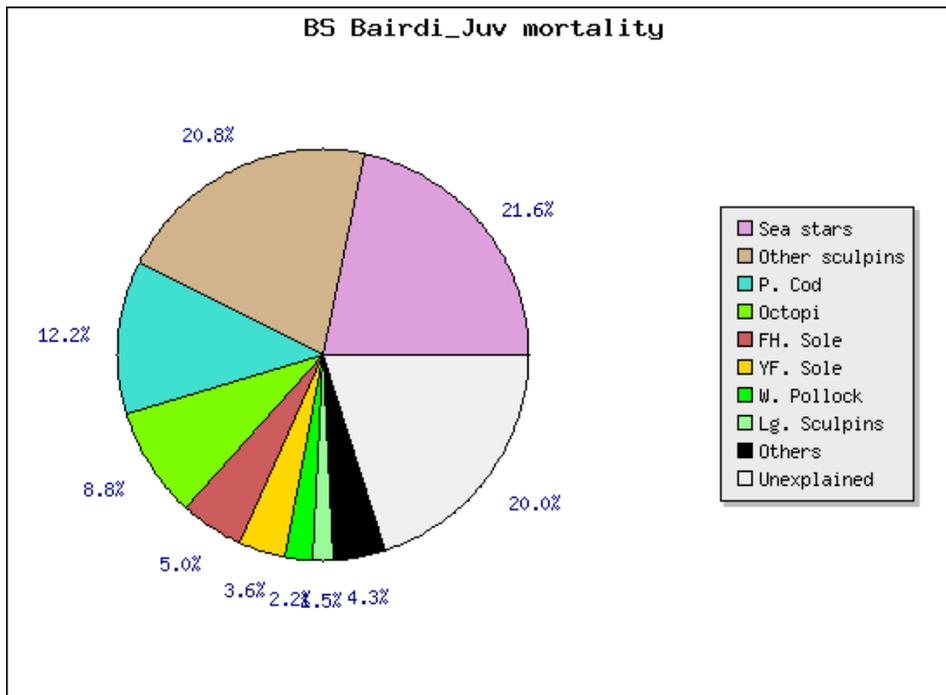


Figure 82. The fraction of annual mortality from major ecosystem components (including fisheries) on immature Tanner crab in the EBS, as estimated by a mass-balance ecosystem model for the EBS (Aydin et al., 2007).

Appendix 1: Changes to datasets since 2013 assessment

Introduction

This appendix addresses dataset issues in the Tanner crab stock assessment that have arisen subsequent to the Fall 2013 assessment. Following a discussion at the 2014 Crab Modeling Workshop (Crab Plan Team, 2014a), the Crab Plan Team (CPT) recognized that many crab assessments included "... 'legacy' data, the origins of which are uncertain...", partly as a result of changes in analysts over time and partly a result of the length of some of the data time series. The CPT requested that W. Gaeuman (ADFG) provide assessment authors with updated information on crab fishery discards (total numbers discarded, length frequencies for discards and total observed catch). The updated information for Tanner crab is reviewed here, and changes to assessment model results in light of these changes are evaluated. In addition to the new information from W. Gaeuman, two other changes to the input data to the Tanner crab assessment are also evaluated. The first change addresses the correction of two inadvertent errors in the dataset used in the 2013 Tanner crab assessment, while the second incorporates updated information on bycatch size frequencies of Tanner crab in the groundfish fisheries provided to the author by R. Foy (NMFS/AFSC). The CPT reviewed this information at its May 2014 meeting and approved incorporation of the updated datasets into the September 2014 assessment.

Finally, based on a careful re-examination of fish ticket and logbook data, annual effort data (potlifts) in the directed Tanner crab fishery have been recalculated by D. Pengilly (ADFG). This revised data has been incorporated into the assessment in the Alt1a and Alt1b model scenarios.

Revisions to the data

Five revisions to the data used in the 2013 Tanner crab assessment are presented in this appendix. Data revision B corrects two errors in the 2013 assessment data (Dataset A) that were found after the 2013 assessment was completed. In the first of these errors, the size frequency for immature, new shell females from the 2013 AFSC trawl survey was incorrectly copied into the model data file. The corrected version shows two peaks in the size frequency (in the 27.5 and 62.5 mm CW size bins) of similar size, while the version used in the assessment is more reflective of a single peak in the smallest size bin (27.5 mm CW) (A1.Figure 1). Regarding the second error, the sex-specific sample sizes (A1.Figure 2) for bycatch size frequencies in the groundfish fisheries had been inadvertently switched between males and females. This error appears to have been introduced prior to the 2012 assessment.

Data revision C incorporates retained size frequencies from dockside observer sampling for male crabs by shell condition in the directed Tanner crab fishery from 1991-2009 as recalculated by W. Gaeuman (ADFG) and provided to the author (A1.Table 2, A1.Figure 4 and A1.Figure 5). This dataset does not include size frequencies for 1995, although these had been included in the 2013 assessment, due to difficulties in re-extracting this information from the ADFG crab observer database. Comparing the new data with the old, all years agree in terms of the number of measured crab (A1.Table 2, A1.Figure 4) except for new shell males in 2008 (429 fewer crab were included in the recalculated dataset) and both shell conditions in 2009 (almost 12,000 fewer crab were included in the recalculated dataset). The differences in the resulting size frequencies are small for the 2009 new shell males, but rather substantial for the old shell males. The sources for the rather large discrepancies in total numbers sampled for 2008 and 2009 are presently unknown.

Data revision D incorporates total catch size frequencies for Tanner crab from at-sea observer sampling in the crab fisheries starting in 1990, as recalculated by W. Gaeuman and provided to the author (Tables 3-5, Fig.s 5-10). The numbers of crab sampled are substantially different in the recalculated and assessment datasets in some circumstances (e.g., ~40,000 males for 1992 in the directed fishery, A1.Table 3) but are

identical in others (e.g. 5,972 males in both datasets for 1994 in the directed fishery, A1.Table 3). On the whole, the changes in normalized size frequencies (examples of which are shown in Figs 6, 8, and 10) are relatively small. Where differences are more substantial (e.g., in 1999 for the BBRKC fishery, A1.Figure 10), the sample sizes are quite small (10-14 crabs, A1.Table 5). Once again, the sources for these large discrepancies are currently unknown.

Data revision E incorporates bycatch size frequencies for Tanner crab in the groundfish fisheries from at-sea observer sampling starting in 1973 from data files provided by R. Foy (NOAA/NMFS) that he extracted from AFSC's Groundfish Observer Program database. The numbers of crab sampled are again substantially different between the recalculated and assessment datasets (A1.Table 6, Figures 11-12). However, two sources for the differences are known. The first is that the recalculated dataset includes observer sampling from the joint venture fisheries in the late 1980s while the dataset used in the assessment does not. The second is that the recalculated dataset bases the size frequencies on the crab fishery year (July 1-June30) while the assessment dataset used the groundfish fishery year (Jan. 1-Dec. 31). The effects of the latter change can be seen in A1.Figure 12, which provides a comparison of example normalized size frequencies for measured female crab for 1985-87.

The impacts of these four changes on results from the 2013 assessment model are evaluated in a stepwise, cumulative fashion (Table 1) and discussed in the next section of this appendix.

Impacts on assessment results

Assessing the impacts of the four data revisions discussed above on the assessment was addressed by running the model used in the 2013 assessment (TCSAM2013) on each of the datasets and comparing time series of estimated mature male biomass (MMB) at mating (A1.Figure 14), recruitment (A1.Figure 15), and fully-selected fishing mortality in the directed fishery (A1.Figure 16). The resulting changes in the assessment model output are reasonably small across the time series for MMB, recruitment and directed fishing mortality. Correcting the errors to the assessment dataset (data revision B) resulted in a 12% increase in final (2012) MMB as well as 4% higher average recruitment (1982-2013), although the estimated final recruitment decreased (consistent with the correction to the 2013 trawl survey size frequency for immature, new shell females). Subsequent changes to the various size frequencies incorporated in the model data (revisions C-E) had smaller impacts on the model estimates in the terminal year of each time series.

Effort data revision

The final revision to the data used in the 2013 assessment is based on work conducted by D. Pengilly to re-calculate the time series of annual effort in the directed Tanner crab fishery (Table 7, Figure 17). This was based on a careful examination of fish ticket and logbook data. Apparently many potlifts targeting BBRKC or snow crab in their directed fisheries erroneously were assigned to the directed Tanner fishery, as well (i.e., double counted—the impact on effort in the BBRKC and snow crab fisheries was basically nonexistent). The re-calculated effort in the directed Tanner crab fishery was less than half the previously-calculated effort used in the 2013 assessment for 1991 and 1996, and still substantially different for 1990, 1992, 1993, and 2005. Because effort in the fishery is used to scale at-sea crab observer data from sampled pots up to the fishery itself, this revision had an identical (relative) impact on the time series of discard biomass in the directed fishery (Figure 17).

Recommendations

It would be worthwhile if the discrepancies (numbers of crab measured) between the size frequencies in the new datasets based on at-sea and dockside observer sampling in the various crab fisheries could be resolved with those used in previous assessments. If possible, computer codes (e.g., SQL scripts) used to generate the old and new datasets should be compared and differences identified. However, given changes in analysts over time, this may not be possible in some cases. In these cases, some double checking and

vetting of the new data should occur in order to promote confidence in its reproducibility. The CPT should identify suitable procedures and a time frame for this vetting process. In particular, stock assessment analysts will need the vetted data much sooner than the fall assessment season in order to incorporate it into each assessment.

Literature Cited

Crab Plan Team. 2014a. Crab Modeling Report.

<https://npfmc.legistar.com/View.ashx?M=F&ID=2865420&GUID=4C36935D-865B-4880-8A3A-D93CACC3C37C>

Rugolo, L.J., and B.J. Turnock. 2012. 2012 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2012 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 267-416.

Stockhausen, W.T., B.J. Turnock and L. Rugolo. 2013. 2013 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2013 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 342-449.

Tables

A1.Table 1. Revisions to the input data for the Tanner crab model considered in the analysis.

ID	Description
A	2013 assessment data
B	A + corrected sample sizes for bycatch size frequencies in the groundfish fisheries + corrected size frequencies for immature, new shell females in the 2013 AFSC trawl survey + very minor correction to sample sizes used for discard size frequencies in the crab fisheries
C	B + recalculated retained size frequencies (1991-2009) based on new results from W. Gaeuman (ADFG)
D	C + recalculated total catch size frequencies (1992-2012) in all crab fisheries based on new results from W. Gaeuman (ADFG)
E	D + recalculated bycatch size frequencies (1973-2012) in the groundfish fisheries based on new results from R. Foy (NMFS)

A1.Table 2. Number of measured male crab in dockside sampling for retained size frequencies in the recalculated and 2013 datasets. W. Gaeuman (ADFG) did not provide recalculated size frequencies for 1995.

year	Recalculated		2013 Assessment		Difference	
	new shell	old shell	new shell	old shell	new shell	old shell
1991	117,630	8,669	117,630	8,669	0	0
1992	113,319	11,874	113,319	11,874	0	0
1993	67,264	4,358	67,264	4,358	0	0
1994	25,585	2,073	25,585	2,073	0	0
1995	0	0	495	1,030	-495	-1,030
1996	2,063	2,367	2,063	2,367	0	0
2005	649	56	649	56	0	0
2006	1,053	1,887	1,053	1,887	0	0
2007	3,662	2,165	3,662	2,165	0	0
2008	2,717	344	3,146	344	-429	0
2009	2,369	48	13,903	412	-11,534	-364

A1.Table 3. Number of Tanner crab measured by at-sea observers in the directed fishery in the recalculated and 2013 datasets.

Year	Recalc'd (all shell types)		2013 Assessment		Difference	
	Females	Males	Females	Males	Females	Males
1990	34	51				
1991	5,605	31,252	2,984	13,386	2,621	17,866
1992	8,755	54,836	1,374	15,007	7,381	39,829
1993	10,470	40,388	2,871	13,511	7,599	26,877
1994	2,132	5,792	2,132	5,792	0	0
1995	3,119	5,589	3,119	5,589	0	0
1996	168	352	168	352	0	0
2005	1,107	19,715	879	15,459	228	4,256
2006	4,432	24,226	4,432	24,226	0	0
2007	3,318	61,546	1,577	26,091	1,741	35,455
2008	646	29,166	294	19,797	352	9,369
2009	147	17,289	147	16,229	0	1,060

A1.Table 4. Number of Tanner crab measured by at-sea observers in the snow crab fishery for the recalculated and 2013 datasets.

Year	Recalc'd (all shell types)		2013 Assessment		Difference	
	Females	Males	Females	Males	Females	Males
1990	478	14,032				
1991	686	11,708				
1992	859	6,280	859	6,280	0	0
1993	1,542	6,969	1,542	6,969	0	0
1994	1,523	2,982	1,523	2,982	0	0
1995	428	1,898	428	1,898	0	0
1996	662	3,265	662	3,265	0	0
1997	657	3,970	515	2,747	142	1,223
1998	324	1,911	271	870	53	1,041
1999	82	976	22	103	60	873
2000	74	1,237	38	892	36	345
2001	160	3,113	140	2,086	20	1,027
2002	118	982	49	565	69	417
2003	152	688	21	162	131	526
2004	707	848	692	686	15	162
2005	368	9,792	368	9,212	0	580
2006	1,256	10,391	1,256	9,468	0	923
2007	728	13,797	728	13,113	0	684
2008	722	8,455	722	8,435	0	20
2009	474	11,057	474	11,014	0	43
2010	250	12,073	250	12,073	0	0
2011	189	9,453	189	9,453	0	0
2012	190	7,336	270	10,998	-80	-3,662

A1. Table 5. Number of Tanner crab measured by at-sea observers in the BBRKC fishery for the recalculated and 2013 datasets.

Year	Recalc'd (all shell types)		2013 Assessment		Difference	
	Females	Males	Females	Males	Females	Males
1990	43	1,580				
1991	89	2,273				
1992	105	2,056	105	1,662	0	394
1993	1,196	7,359	1,196	2,700	0	4,659
1996	5	114	5	190	0	-76
1997	41	1,030	41	272	0	758
1998	20	457	18	219	2	238
1999	14	207	10	183	4	24
2000	44	845	36	779	8	66
2001	39	456	26	496	13	-40
2002	50	750	43	528	7	222
2003	46	555	40	592	6	-37
2004	44	487	41	480	3	7
2005	70	983	70	1,072	0	-89
2006	76	798	68	780	8	18
2007	91	1,399	89	1,139	2	260
2008	121	3,797	98	2,389	23	1,408
2009	72	3,395	70	2,153	2	1,242
2010	30	595	28	510	2	85
2011	4	344	4	324	0	20
2012	48	618	48	503	0	115

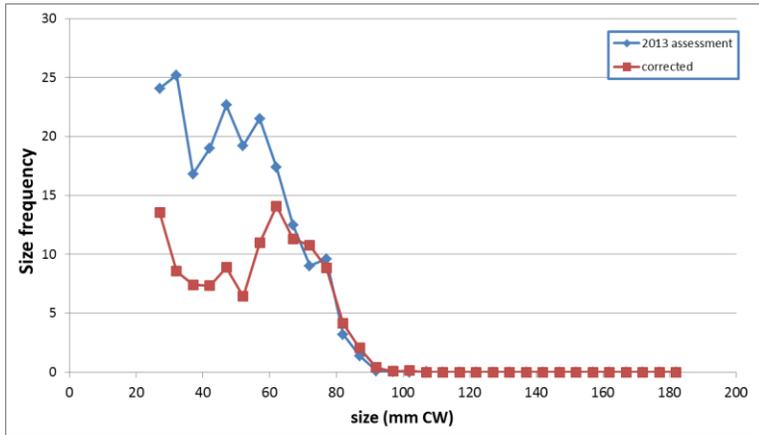
A1. Table 6. Number of Tanner crab measured by at-sea observers in the groundfish fisheries for the recalculated and 2013 datasets. The recalculated dataset is based on the crab fishery year (starting July 1), whereas the 2013 assessment dataset was based on the groundfish fishery year (starting Jan. 1).

Crab Fishery Year	Recalculated		2013 Assessment		Difference	
	Females	Males	Females	Males	Females	Males
1973	2,279	3,155	1,212	1,604	1,067	1,551
1974	1,624	2,500	2,789	4,155	-1,165	-1,655
1975	839	1,254	24	16	815	1,238
1976	6,709	6,984	2,526	2,928	4,183	4,056
1977	8,401	10,703	9,803	10,873	-1,402	-170
1978	13,801	18,699	8,105	11,724	5,696	6,975
1979	11,360	19,075	16,953	24,924	-5,593	-5,849
1980	5,984	12,890	5,598	10,424	386	2,466
1981	4,127	6,122	6,817	12,956	-2,690	-6,834
1982	8,161	13,681	5,694	7,690	2,467	5,991
1983	8,335	18,404	7,983	14,112	352	4,292
1984	14,288	27,849	10,589	24,303	3,699	3,546
1985	12,823	23,290	12,765	26,334	58	-3,044
1986	7,664	14,922	1,776	3,222	5,888	11,700
1987	15,967	23,620	1,689	3,308	14,278	20,312
1988	7,199	10,658	1,922	3,082	5,277	7,576
1989	41,315	60,089	2,190	2,814	39,125	57,275
1990	11,558	24,652	1,983	3,017	9,575	21,635
1991	3,494	6,828	6,155	14,432	-2,661	-7,604
1992	1,183	3,134	1,749	4,903	-566	-1,769
1993	369	1,258	279	1,148	90	110
1994	1,832	3,706	328	854	1,504	2,852
1995	2,675	3,946	2,248	4,404	427	-458
1996	3,410	8,370	2,364	3,458	1,046	4,912
1997	3,912	9,972	5,314	12,176	-1,402	-2,204
1998	4,448	12,150	4,282	10,139	166	2,011
1999	4,528	11,066	4,399	12,037	129	-971
2000	3,097	12,931	3,701	12,391	-604	540
2001	3,100	15,821	2,485	12,910	615	2,911
2002	3,252	15,418	3,232	15,498	20	-80
2003	2,763	9,613	3,292	13,542	-529	-3,929
2004	4,479	13,876	2,788	11,110	1,691	2,766
2005	3,711	17,796	4,097	13,424	-386	4,372
2006	3,050	15,916	3,498	17,129	-448	-1,213
2007	3,588	15,552	3,150	17,513	438	-1,961
2008	3,869	23,997	2,832	10,658	1,037	13,339
2009	2,493	17,642	1,973	6,435	520	11,207
2010	1,571	6,323	2,096	5,952	-525	371
2011	3,515	7,042	697	2,055	2,818	4,987
2012	1,850	3,538	1,845	3,478	5	60

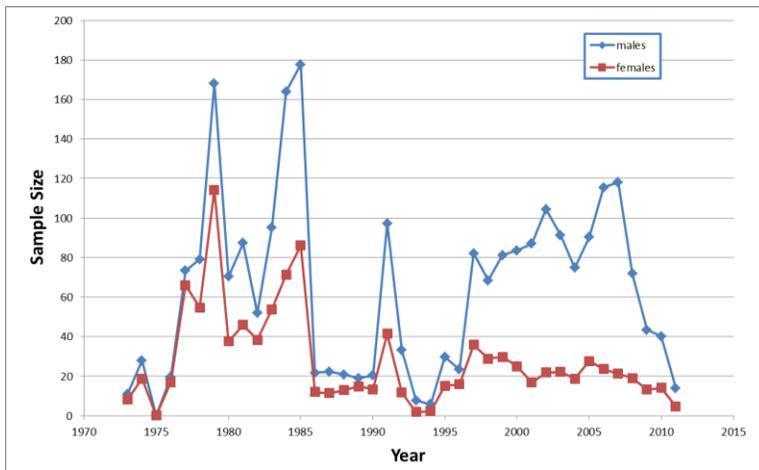
A1.Table 7. Comparison of the re-calculated annual effort (1000's of potlifts) time series in the directed Tanner crab fishery with the values used in the 2013 assessment.

Year	re-calc'd effort	2013 effort	% difference
1990	494.299	883.441	-78.7
1991	500.914	1,224.959	-144.5
1992	675.592	1,201.900	-77.9
1993	326.720	576.662	-76.5
1994	249.536	249.536	0.0
1995	248.442	248.442	0.0
1996	73.522	149.289	-103.1
1997	0.000	0.000	0.0
1998	0.000	0.000	0.0
1999	0.000	0.000	0.0
2000	0.000	0.000	0.0
2001	0.000	0.000	0.0
2002	0.000	0.000	0.0
2003	0.000	0.000	0.0
2004	0.000	0.000	0.0
2005	6.346	3.926	38.1
2006	19.790	17.950	9.3
2007	33.709	34.689	-2.9
2008	21.737	21.737	0.0
2009	6.635	6.635	0.0
2010	0.000	0.000	0.0
2011	0.000	0.000	0.0
2012	0.000	0.000	0.0

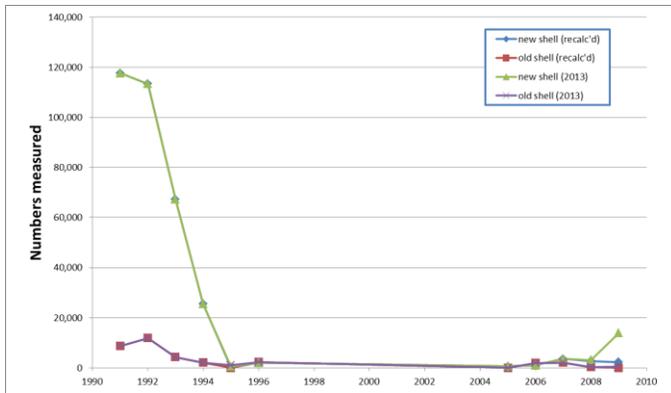
Figures



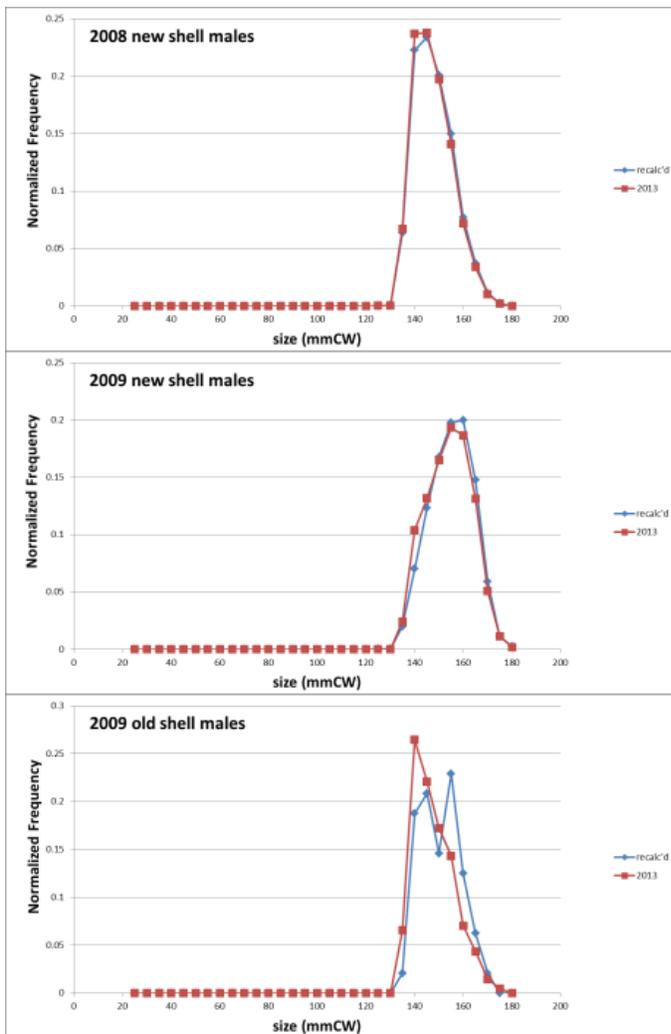
A1. Figure 1. Size frequencies for immature, new shell females from the 2013 AFSC trawl survey: the version used in the 2013 assessment (blue) and the corrected version (red).



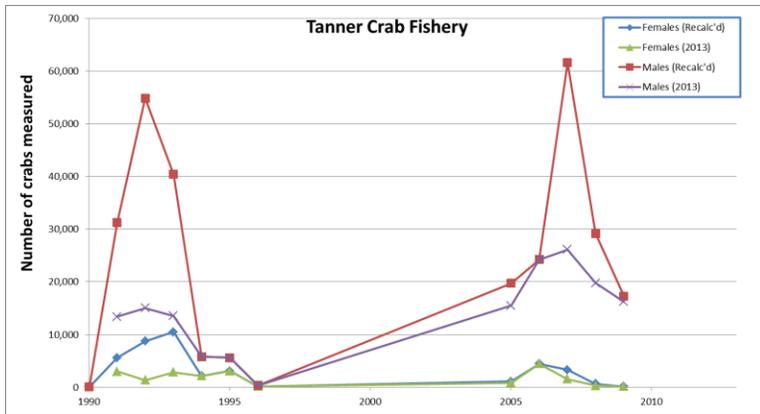
A1. Figure 2. Corrected sample sizes for sex-specific (males: blue; females: red) bycatch size frequencies in the groundfish fisheries. The sexes were switched in the 2013 (and 2012) assessments.



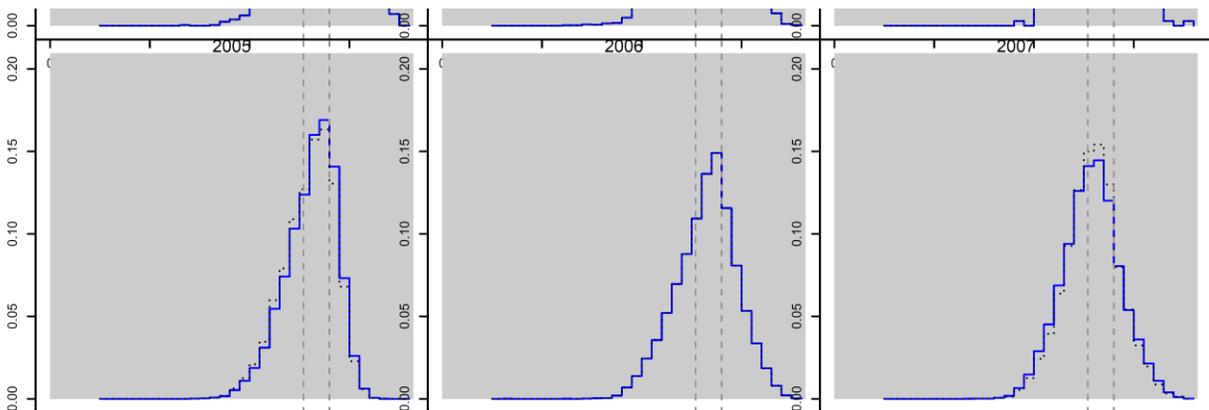
A1. Figure 3. Numbers of measured male crab in new/old shell categories in dockside sampling for retained Tanner crab in the updated dataset (red, blue lines) and the 2013 assessment dataset (green, purple lines).



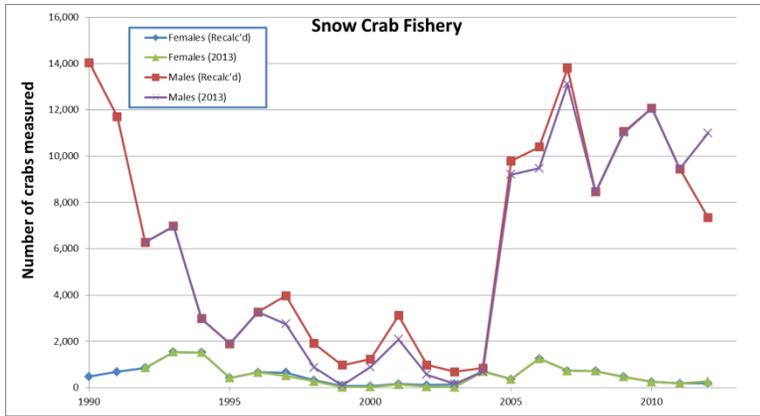
A1. Figure 4. Normalized dockside retained size frequencies from updated results (blue) and used in the 2013 assessment (red).



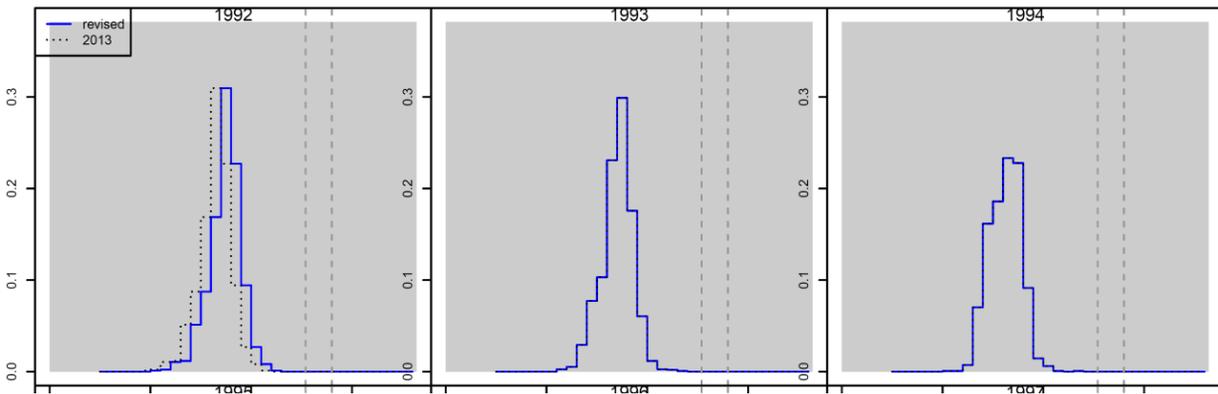
A1. Figure 5. Comparison of numbers of measured crab, by year and sex, in at-sea sampling in the directed Tanner crab fishery in the recalculated dataset (red and blue lines) and the 2013 assessment dataset (green and purple lines).



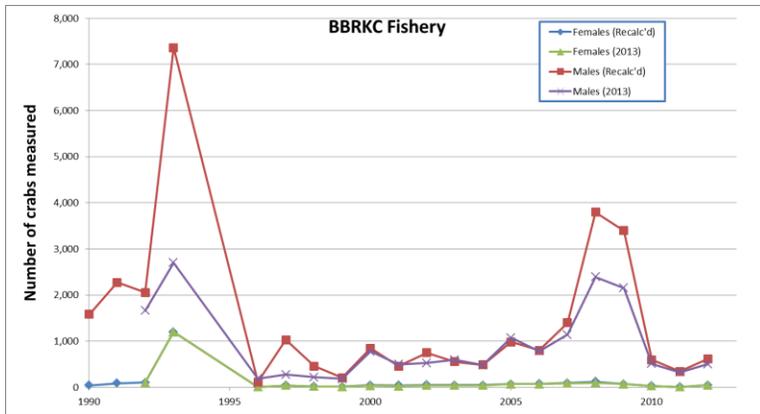
A1. Figure 6. Comparison of normalized size frequencies for measured male crab during selected years in at-sea sampling of the directed Tanner crab fishery in the recalculated dataset (blue lines) and the 2013 assessment dataset (dotted lines). Vertical dashed lines indicate the minimum legal sizes in the West and East regions.



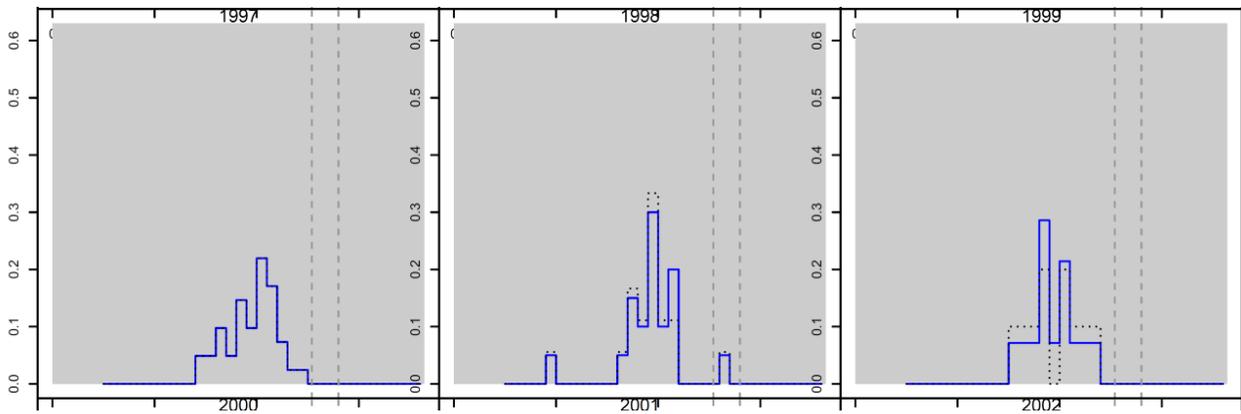
A1. Figure 7. Comparison of numbers of measured Tanner crab, by year and sex, in at-sea sampling in the snow crab fishery in the recalculated dataset (red, blue lines) and the 2013 assessment (green, purple lines).



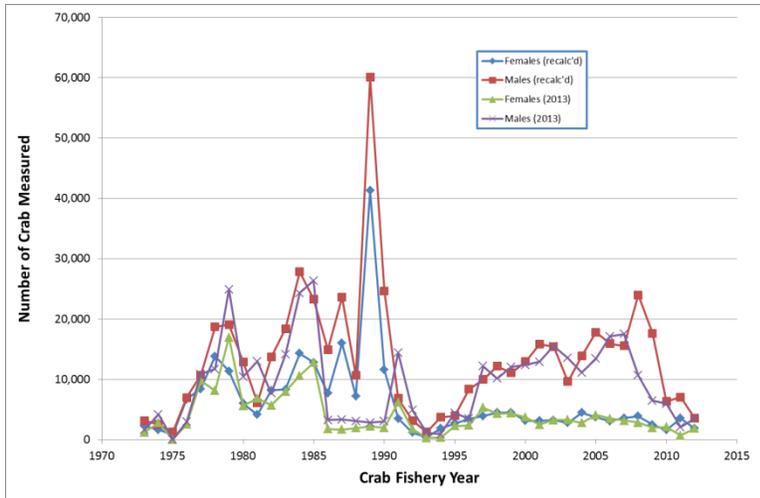
A1. Figure 8. Comparison of normalized size frequencies for measured female crab during selected years in at-sea sampling of the Tanner crab bycatch in the snow crab fishery in the recalculated dataset (blue lines) and the 2013 assessment dataset (dotted lines). Vertical dashed lines indicate the minimum legal sizes for Tanner crab in the West and East regions.



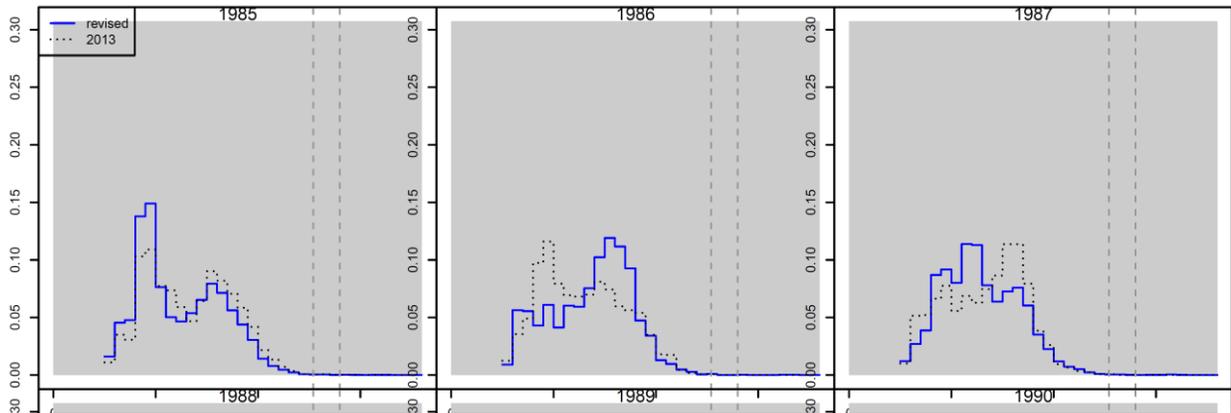
A1. Figure 9. Comparison of numbers of measured Tanner crab, by year and sex, in at-sea sampling in the BBRKC fishery in the recalculated dataset (red, blue lines) and the 2013 assessment (green, purple lines).



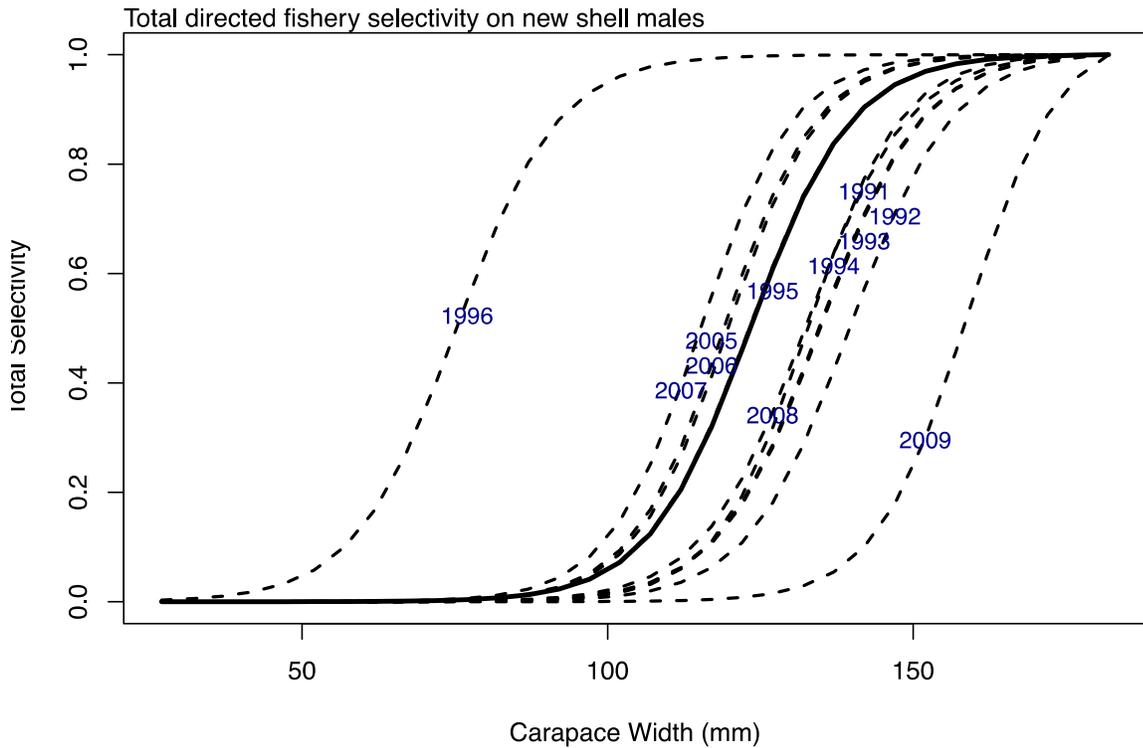
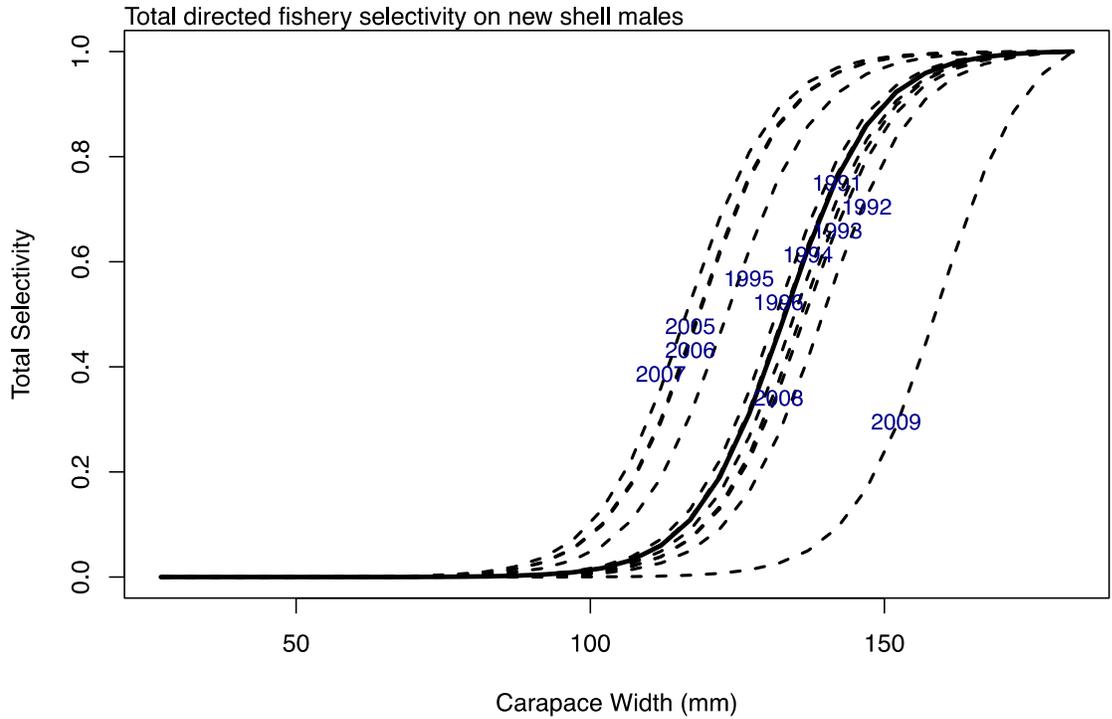
A1. Figure 10. Comparison of normalized size frequencies for measured female crab during selected years in at-sea sampling of the Tanner crab bycatch in the BBRKC fishery in the recalculated dataset blue lines) and the 2013 assessment dataset (dotted lines). Vertical dashed lines indicate the minimum legal sizes for Tanner crab in the West and East regions.



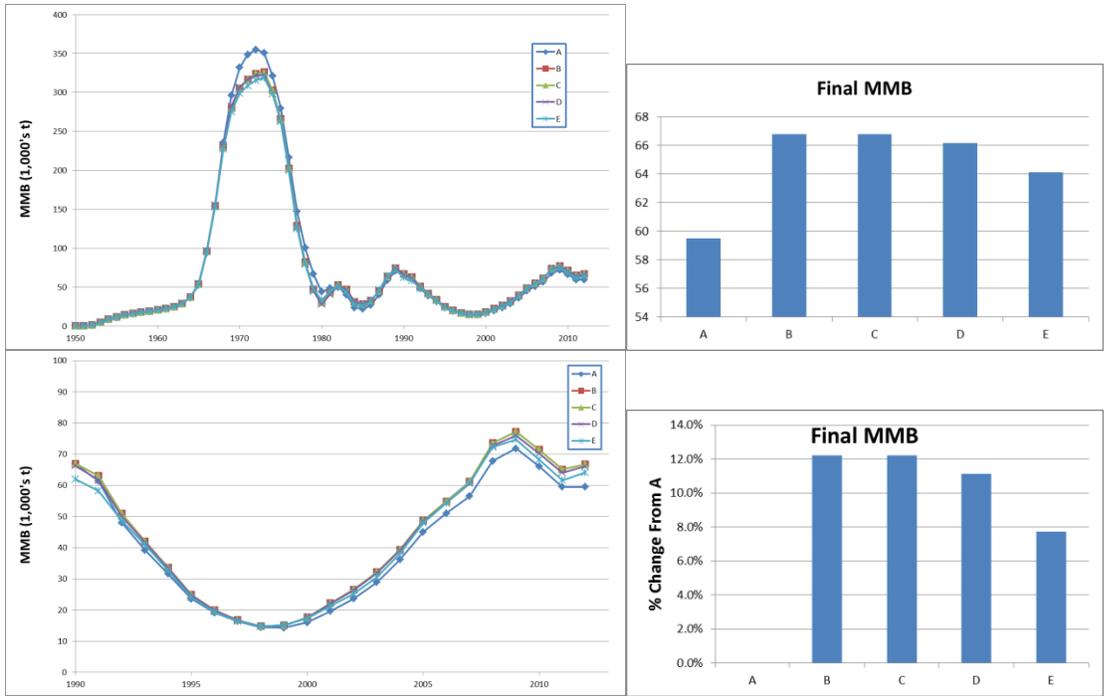
A1. Figure 11. Comparison of numbers of measured Tanner crab, by year and sex, in at-sea sampling in the groundfish fisheries in the recalculated dataset (red, blue lines) and the 2013 assessment (green, purple lines). The recalculated dataset is based on the crab fishery year (starting July 1), whereas the 2013 assessment dataset was based on the groundfish fishery year (starting Jan. 1).



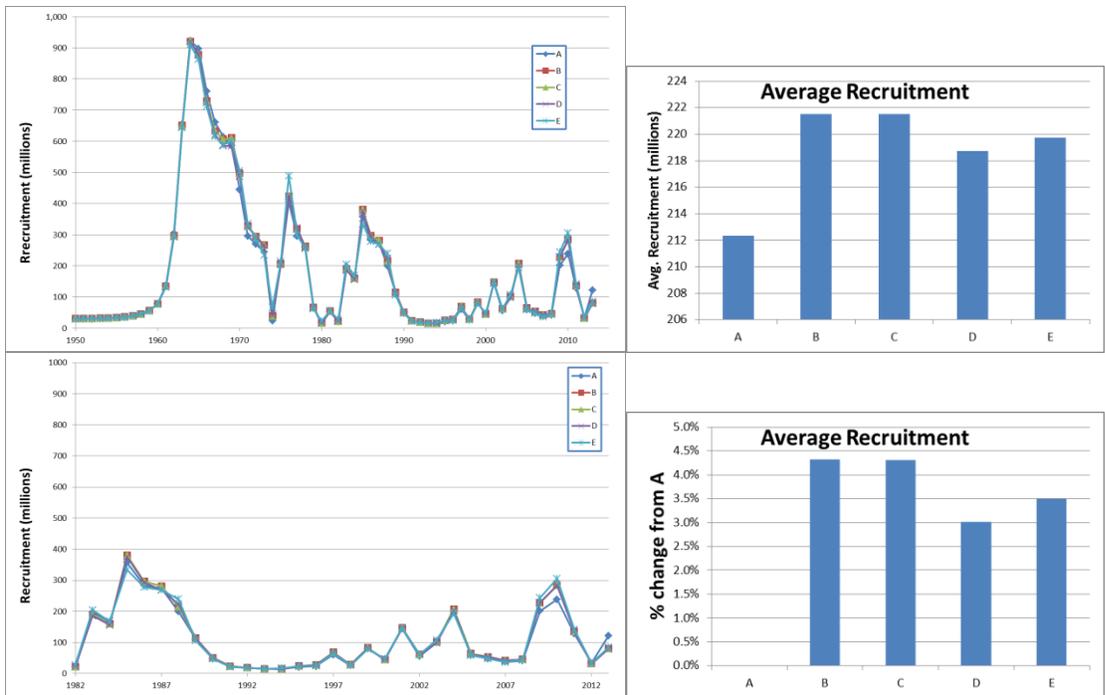
A1. Figure 12. Comparison of normalized size frequencies for measured female crab during selected years in at-sea sampling of the Tanner crab bycatch in the groundfish fisheries in the recalculated dataset (blue lines) and the 2013 assessment dataset (dotted lines). Vertical dashed lines indicate the minimum legal sizes for Tanner crab in the West and East regions.



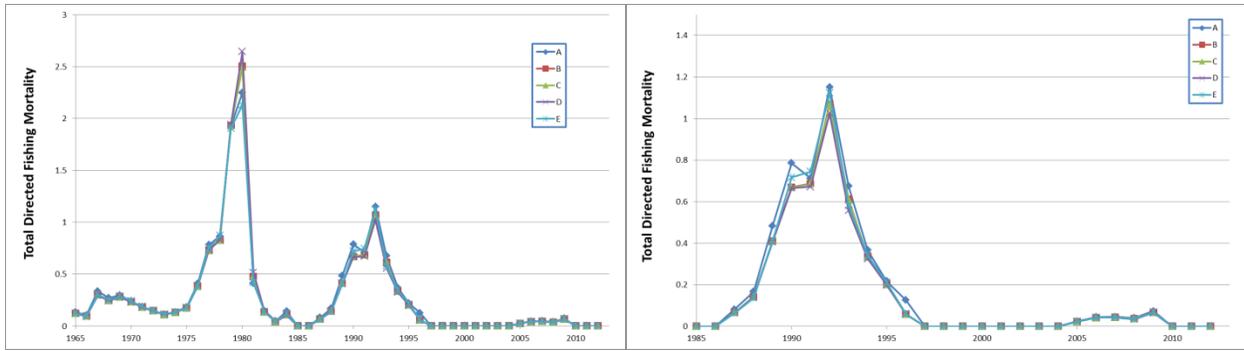
A1. Figure 13. Comparison of TCSAM2013-estimated selectivity on new shell males in the directed fishery for: 1) Dataset A, the 2013 assessment data (upper graph) and 2) Dataset B, Dataset A with corrected sample sizes in the groundfish fisheries (lower graph).



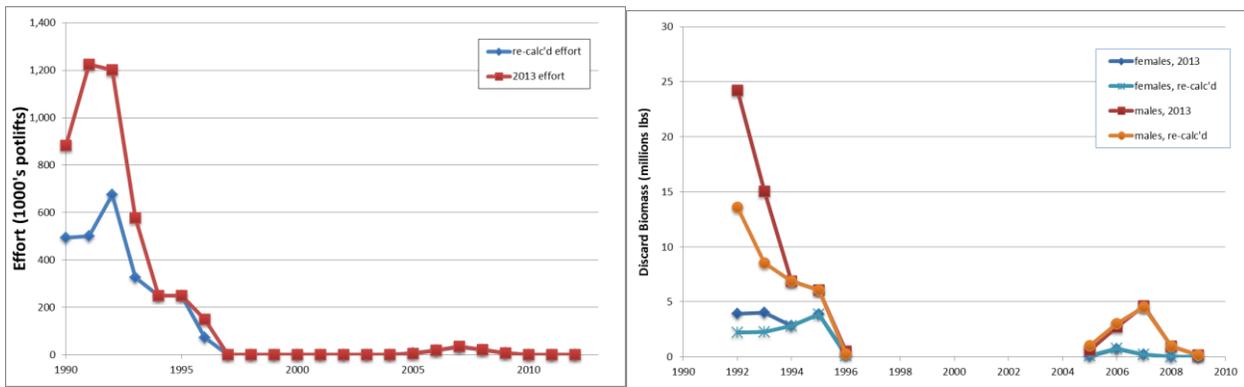
A1. Figure 14. Comparison of TCSAM2013-estimated MMB at mating time for the 5 datasets. Upper left: full time series. lower left: recent trends. Upper right: final (2012) estimates. Lower right: % change in final estimates relative to assessment dataset (A).



A1. Figure 15. Comparison of TCSAM2013-estimated recruitment for the 5 datasets. Upper left: full time series for males. Lower left: recent trends in males. Upper right: 1982-2013 average. Lower right: % change in 1982-2013 average relative to assessment dataset (A).



A1. Figure 16. Comparison of TCSAM2013-estimated directed fishing mortality for the 5 datasets. Left: full time series. Right: recent trends.



A1. Figure 17. Comparison of the re-calculated effort time series (left graph) and the resulting discard biomass (right graph) in the directed Tanner crab fishery with the values used in the 2013 assessment.

Appendix 2: Estimating crab bycatch in the groundfish fisheries

This appendix provides a brief overview regarding estimation of crab bycatch in the groundfish fisheries, as conducted by the NMFS Alaska Regional Office (AKRO) and the Alaska Fisheries Information Network (AKFIN). It represents a merging of two memos provided by J. Gaspar (AKRO) discussing these details.

Data availability:

Pre 1991: Data available in INPFC reports only.

1991-December 2002: Bycatch estimates use the “blend method”. The blend process combined data from industry production reports and observer reports to make the best, comprehensive accounting of groundfish catch. For shoreside processors, Weekly Production Reports (WPR) submitted by industry were the best source of data for retained groundfish landings. All fish delivered to shoreside processors were weighed on scales, and these weights were used to account for retained catch. Observer data from catcher vessels provided the best data on at-sea discards of groundfish by vessels delivering to shoreside processors. Discard rates from these observer data were applied to the shoreside groundfish landings to estimate total at-sea discards from both observed and unobserved catcher vessels. For observed catcher/processors and motherships, the WPR and the Observer Reports recorded estimates of total catch (retained catch plus discards). If both reports were available, one of them were selected during the “blend” process for incorporation into the catch database. If the vessel was unobserved, only the WPR was available.

January 2003 –December 2007: A new database structure named the Catch Accounting System (CAS) led to large method change. Bycatch estimates were derived from a combination of observer and landing (catcher vessels/production data). Production data included CPs and catcher vessels delivering to motherships. To obtain fishery level estimates, CAS uses a ratio estimator derived from observer data (counts of crab/kg groundfish) that is applied to production/landing information (see <http://www.afsc.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-205.pdf>). Estimates of crab are in numbers because the Prohibited Species Catch (PSC) is managed on numbers. There were two issues with this dataset that required estimation work outside of CAS:

- 1) The estimated number of crab had to be converted to weights. An average weight was calculated using groundfish observer data. This weight was specific to crab year, crab species, and fixed or trawl gear. This average was applied to the estimated number of crab for crab year by federal reporting area.
- 2) In some situations crab estimates were identified and grouped in the observed data to the genus level. These crabs were apportioned to the species level using the identified crab.

January 2008-2012: The observer program changed the method in which they speciate crab to better reflect their hierarchal sampling method and to account for broken crab that in the past were only identified to genus. In addition, haul-level weights collected by the observers were used to estimate the weight of crab through CAS instead of applying an annual (global) weight factor. Spatial resolution was at the federal reporting area.

NEW Data January 2009 – 2013: A new data set was made available in August 2013. The level of spatial resolution in CAS was formerly at the federal reporting area because this was the highest spatial resolution at which observer data was aggregated to create bycatch rates. The federal reporting area does not follow crab stock boundaries, particular for species with small stock areas such as the Pribilof Islands or St. Matthew Island stocks, so the new data was provided at the State reporting areas. This method uses a weight-based ratio estimator (weight crab/weight groundfish) applied to groundfish reported on

production/landing reports. Where possible, this dataset aggregates observer data to the stock area level to create bycatch estimates at the stock area. There are instances where no observer data is available and aggregation could go outside of a stock area, but this practice is greatly reduced compared with the pre-2009 data, which at-best was at the Federal reporting area level.

AKFIN/AKR created this new data set using observer data and eLandings information: landing reports and production reports. 2009 is the start of the data set because it is the first year that identification of state statistical areas was required on groundfish production reports. This allowed the use of a ratio estimator created from observer data to be applied to state statistical area landings/production.

Changes in 2014

Changes in estimates of crab bycatch in the groundfish fisheries, beginning in 2009, occurred between spring 2013 and fall of 2014 due to improvements made to the database and methods.

Background

The Alaska Region historically provided estimates of crab bycatch in groundfish fisheries at the federal reporting area level. Ratio estimation (weight of crab/total groundfish) methods were used to estimate crab catch by species. Generally speaking, there are two steps in this estimation method: 1) a ratio estimator is created by post-stratifying (aggregating) observer information; and 2) the ratio estimator is then applied to landings or production information that have the same post-strata characteristics as in 1 (e.g., both the landings and observer data were collected from area 541 for pot gear during the same week). Details on the estimation routines used in the Catch Accounting System (CAS) are in Cahalan et al. (2010), with an updated Technical Memorandum currently in review.

Spatial scale is an important component in the post-strata criteria. There are two spatial scales associated with industry reports of groundfish catch: 1) the federal reporting area and 2) the groundfish FMP area; the latter being an aggregation of federal reporting areas. Estimates of crab bycatch from CAS are specific to a federal reporting area if at-sea observer data is available; however, in federal reporting areas that have commercial landings and no corresponding observer data (defined by the post-stratification criteria), the ratio estimator is derived from an aggregation of observer information across the entire Bering Sea and Aleutian Islands FMP area. These post-stratification procedures result in bycatch estimates that may include at-sea observer information from outside a crab stock area².

Changes to estimation

In 2013, the NMFS Alaska Regional Office (AKRO) and Alaska Fisheries Information Network (AKFIN) created a new estimation method to generate estimates crab catch (in weight) in the groundfish fisheries by crab stock area. This required modifying the CAS Prohibited Species Catch (PSC) calculation methods so that the post-strata definitions were specific to a crab stock area and crab species (or state statistical area within a crab stock area). ***The stock-area specific estimates (in weight) are available through AKFIN starting in the 2009/2010 crab year.***

A flaw in the estimation method was identified in 2013 after the September Plan Team. This flaw allowed observer data from outside a stock area boundary to be used for stock-area specific estimation if there was little observer data available within the stock area. Correcting this issue was especially important for crab

² Note that post-strata definitions also including gear, vessel, week ending date, trip target, and observer selection method (based on deployment rates in the ADP). The intent of this appendix is not to provide detail on the estimation methods, but instead to highlight large changes in methodology.

stocks that bisect reporting areas, such as the Pribilof Islands, St. Mathews Islands, and Bristol Bay, but it also affected the estimates for most stocks throughout the Bering Sea and Aleutian Islands. As expected, large changes were observed for the St. Mathews and the Pribilof Islands stock areas since observer data had incorrectly been aggregated across these areas. For example, observer information from the St. Mathew stock area was used in the ratio estimators for the Pribilof Islands.

In 2014, AKFIN and AKRO staff conducted further review of the crab estimation routines. This review resulted in several programming changes that affected some estimates:

- There were errors in the mapping of State of Alaska statistical areas with the crab stock area boundaries that were found and corrected. This correction affected some estimates, particularly Pribilof Island estimates where the eastern extension of the stock area boundary for blue king crab was incorrectly applied to red and golden king crab (which also changed the Bristol Bay area slightly).
- The procedures used to determine if a trip has corresponding observer data were improved. This improvement results in a lower percentage of trips that are incorrectly marked as unobserved, which means more estimates are specific to observed trips. The impact on estimation due to this change was minor.
- A post stratum was added to the estimation process. This post stratum is only used when observer data are unavailable for landings of a specific gear type (with the exception of jig gear since it is never observed), stock area, and calendar year. The impact on crab estimates due to this change was minor (mainly a few vessels in the Aleutian Islands): nearly all ratio estimates use observer data that is of the same gear type as the vessels making a landing.

In addition, updates to observer information occur when observers are debriefed and data quality verified. Debriefings can result in changes to data values or cause deletions of incorrectly collected data.

References

Cahalan J., Mondragon J., and J. Gasper. 2010. Catch sampling and estimation in the federal groundfish fisheries off Alaska. NOAA Tech. Mem. NMFS AFSC-205. 42 pp.

Appendix 3: TCSAM (Tanner Crab Stock Assessment Model) 2013 Description

Introduction

The Tanner crab stock assessment model (TCSAM) is an integrated assessment model developed in C++ using AD Model Builder (Fournier et al., 2012) libraries that is fit to multiple data sources. The model described herein is the version used in the Sept. 2013 assessment (Stockhausen et al., 2013) and will be referred to as TCSAM2013. Except for some minor corrections to the code, this model was identical to that used in the Sept. 2012 assessment (Rugolo and Turnock, 2012).

Model parameters in TCSAM2013 are estimated using a maximum likelihood approach, with Bayesian-like priors on some parameters and penalties for smoothness and regularity on others. Data components entering the likelihood include fits to survey biomass, survey size compositions, retained catch, retained catch size compositions, discard mortality in the bycatch fisheries, and discard size compositions in the bycatch fisheries. Population abundance at the start of year y in the model, $n_{y,x,m,s,z}$, is characterized by sex x (male, female), maturity state m (immature, mature), shell condition s (new shell, old shell), and size z (carapace width, CW). Changes in abundance due to natural mortality, molting and growth, maturation, fishing mortality and recruitment are tracked on an annual basis. Because the principal crab fisheries occur during the winter, the model year runs from July 1 to June 30 of the following calendar year.

A. Calculation sequence

Step A1: Survival prior to fisheries

Natural mortality is applied to the population from the start of the model year (July 1) until just prior to prosecution of the pulse fisheries for year y at δt_y^F . The numbers surviving at δt_y^F in year y are given by:

$n_{y,x,m,s,z}^1 = e^{-M_{y,x,m,s,z} \cdot \delta t_y^F} \cdot n_{y,x,m,s,z}$	A1
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where M represents the annual rate of natural mortality in year y on crab classified as x, m, s, z .

Step A2: Prosecution of the fisheries

The directed fishery and bycatch fisheries are modeled as pulse fisheries occurring at δt_y^F in year y . The numbers that remain after the fisheries are prosecuted are given by:

$n_{y,x,m,s,z}^2 = \left(1 - e^{-F_{y,x,m,s,z}^T}\right) \cdot n_{y,x,m,s,z}^1$	A2
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where F^T represents total (across all fisheries) annual fishing mortality in year y on crab classified as x, m, s, z .

Step A3: Survival after fisheries to time of molting/mating

Natural mortality is again applied to the population from just after the fisheries to the time at which molting/mating occurs for year y at δt_y^m . The numbers surviving at δt_y^m in year y are then given by:

$n_{y,x,m,s,z}^3 = e^{-M_{y,x,m,s,z}(\delta t_y^m - \delta t_y^F)} \cdot n_{y,x,m,s,z}^2$	A3
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where, as above, M represents the annual rate of natural mortality in year y on crab classified as x, m, s, z . In the 2012 and 2013 assessments, molting and mating were taken to occur on Feb. 15 each year ($\delta t_y^m = 0.625$), and the pulse fisheries were taken to occur just prior to this ($\delta t_y^F = 0.625$, also), so the term in the exponent in eq. A3 was 0 for all years.

Step A4: Molting, growth, and maturation

The changes in population structure due to molting, growth and maturation of immature (new shell) crab, as well as the change in shell condition for new shell mature crab due to aging, are given by:

$n_{y,x,MAT,NS,z}^4 = \sum_{z'} \Theta_{y,x,z,z'}^{MAT} \cdot \phi_{y,x,z'} \cdot n_{y,x,IMM,NS,z'}^3$	A4a
$n_{y,x,IMM,NS,z}^4 = \sum_{z'} \Theta_{y,x,z,z'}^{IMM} \cdot (1 - \phi_{y,x,z'}) \cdot n_{y,x,IMM,NS,z'}^3$	A4b
$n_{y,x,MAT,OS,z}^4 = n_{y,x,MAT,OS,z}^3 + n_{y,x,MAT,NS,z}^3$	A4c

where $\phi_{y,x,z}$ is the probability that an immature (new shell) crab of sex x and size z will undergo its terminal molt to maturity and $\Theta_{y,x,z,z'}^m$ is the growth transition matrix from size z' to z for that crab, which may depend on whether ($m=MAT$; eq. A.4a) or not ($m=IMM$; eq. A.4b) the terminal molt to maturity occurs. Additionally, crabs that underwent their terminal molt to maturity the previous year are assumed to change shell condition from new shell (NS) to old shell (OS ; A.4c). Note that the numbers of immature, old shell crab are identically zero in the current model because immature crab are assumed to molt each year until they undergo the terminal molt to maturity; consequently, an equation for $m=IMM, s=NS$ above is unnecessary.

Step A5: Survival to end of year, recruitment, and update to start of next year

Finally, population abundance at the start of year $y+1$ due to recruitment of immature new shell crab at the end of year y ($r_{y,x,z}$) and natural mortality on crab from the time of molting in year y until the end of the model year (June 30) are given by:

$r_{y,x,z} = R_y \cdot \rho_{y,x} \cdot \eta_z$	A5a
$n_{y+1,x,m,s,z} = \begin{cases} e^{-M_{y,x,IMM,NS,z} \cdot (1-\delta t_y^m)} \cdot n_{y,x,IMM,NS,z}^4 + r_{y,x,z} & m = IMM, s = NS \\ e^{-M_{y,x,m,s,z} \cdot (1-\delta t_y^m)} \cdot n_{y,x,m,s,z}^4 & otherwise \end{cases}$	A5b

B. Model processes: natural mortality

Natural mortality rates in TCSAM2013 vary across 3 year blocks (model start-1979, 1980-1984, 1985-model end) within which they are sex- and maturity state-specific but do not depend on shell condition or size. They are parameterized in the following manner:

$M_{y,x,m,s,z} = \begin{cases} M_{x,m,s}^{base} \cdot \delta M_{x,m} & 1980 \leq y \leq 1984 \\ M_{x,m,s}^{base} \cdot \delta M_{x,m} \cdot \delta M_{x,m}^T & otherwise \end{cases}$	natural mortality rates	B1
		B2

where y is year, x is sex, m is maturity state and s is shell condition, the $M_{x,m,s}^{base}$ are user constants (not estimated), and the $\delta M_{x,m}$ and $\delta M_{x,m}^T$ are parameters (although not all are estimated).

Priors are imposed on the $\delta M_{x,m}$ parameters in the likelihood using:

$\Pr(\delta M_{x,m}) = e^{-\frac{(\delta M_{x,m} - \mu_{x,m})^2}{2 \cdot \sigma_{x,m}^2}}$	Prior probability function for $\delta M_{x,m}$	B3
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The μ 's and σ^2 , along with bounds, initial values and estimation phases used for the parameters, as well as the values for the constants, used in the 2013 model are:

parameters/constants	$\mu_{x,m}$	$\sigma_{x,m}^2$	lower bound	upper bound	initial value	phase	code name
$M_{MALE,IMM,NS}^{base}$	--	--	--	--	0.23	NA	M_in(MALE)
$M_{FEMALE,IMM,NS}^{base}$	--	--	--	--	0.23	NA	M_in(FEMALE)
$M_{MALE,MAT,NS}^{base}$	--	--	--	--	0.23	NA	M_matn_in(MALE)
$M_{FEMALE,MAT,NS}^{base}$	--	--	--	--	0.23	NA	M_matn_in(FEMALE)
$M_{MALE,MAT,OS}^{base}$	--	--	--	--	0.23	NA	M_mato_in(MALE)
$M_{FEMALE,MAT,OS}^{base}$	--	--	--	--	0.23	NA	M_mato_in(FEMALE)
$\delta M_{x,IMM}$	1.0	0.05	0.2	2.0	1.1	7	M_mult_imat
$\delta M_{MALE,MAT}$	1.0	0.05	0.1	1.9	1.0	7	Mmultm
$\delta M_{FEMALE,MAT}$	1.0	0.05	0.1	1.9	1.0	7	Mmultf
$\delta M_{MALE,IMM}^T$	--	--	--	--	1.0	NA	NA
$\delta M_{FEMALE,IMM}^T$	--	--	--	--	1.0	NA	NA
$\delta M_{MALE,MAT}^T$			0.1	10.0	1.0	7	mat_big(MALE)
$\delta M_{FEMALE,MAT}^T$			0.1	10.0	1.0	7	mat_big(FEMALE)

where constants have phase = NA and estimated parameters have phase > 0. When no corresponding variable exists in the model (code name = NA), the effective value of the parameter/constant is given.

C. Model processes: growth

Growth of immature crab in the 2013 TCSAM model is based on sex-specific transition matrices that specify the probability that crab in pre-molt size bin z grow to post-molt size bin z' . The sex-specific growth matrix $\Theta_{x,z,z'}$ (i.e., the array `len_len[sex,ilen,ilen]` in the model code) is related to the sex-specific parameters a_x , b_x , and β_x by the following equations:

$\Theta_{x,z,z'} = c_{x,z} \cdot \Delta_{z,z'}^{\alpha_{x,z}-1} \cdot e^{-\frac{\Delta_{z,z'}}{\beta_x}}$	Sex-specific (x) transition matrix for growth from pre-molt z to post-molt z' , with $z' \geq z$	C1
$c_{x,z} = \left[\sum_{z'} \Delta_{z,z'}^{\alpha_{x,z}-1} \cdot e^{-\frac{\Delta_{z,z'}}{\beta_x}} \right]^{-1}$	Normalization constant so $1 = \sum_{z'} \Theta_{x,z,z'}$	C2
$\Delta_{z,z'} = z' - z$	Actual growth increment	C3
$\alpha_{x,z} = [\bar{z}_{x,z} - z] / \beta_x$	Mean molt increment, scaled by β_x	C4
$\bar{z}_{x,z} = e^{a_x} \cdot z^{b_x}$	Mean size after molt, given pre-molt size z	C5

$\Theta_{x,z,z'}$ is used to update the numbers-at-size for immature crab following molting using:

$n_{x,z'}^+ = \sum_z n_{x,z} \cdot \Theta_{x,z,z'}$		C6
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where z is the pre-molt size and z' is the post-molt size.

Sex-specific priors are imposed on the estimated values \hat{a}_x and \hat{b}_x for the a_x and b_x parameters using:

$\Pr(\hat{a}_x) = e^{-\frac{(\hat{a}_x - \mu_{a_x})}{2 \cdot \sigma_{a_x}^2}}$	Prior probability function for a 's	C7
$\Pr(\hat{b}_x) = e^{-\frac{(\hat{b}_x - \mu_{b_x})}{2 \cdot \sigma_{b_x}^2}}$	Prior probability function for b 's	C8

The μ 's and σ^2 , along with the bounds, initial values and estimation phases used for the parameters in the 2013 TCSAM are:

parameter	sex (x)	μ_x	σ_x^2	lower bound	upper bound	initial value	phase	code name
a_x	female	0.56560241	0.100	0.4	0.7	0.55	8	af1

	male	0.43794100	0.025	0.3	0.6	0.45	8	am1
b_x	female	0.9132661	0.025	0.6	1.2	0.90	8	bf1
	male	0.9487000	0.100	0.7	1.2	0.95	8	bm1
β_x	both	NA	NA	0.75000	0.75001	0.750005	-2	growth_beta

Note that the β_x are treated as constants because the associated estimation phases are negative.

D. Model processes: maturity

Maturation of immature crab in TCSAM2013 is based on sex- and size-specific probabilities of maturation, $\phi_{x,z}$, where size z is pre-molt size. After molting, but before assessing growth, the numbers of crab remaining immature, $n_{x,IMM,NS,z}^+$, and those maturing, $n_{x,MAT,NS,z}^+$, at pre-molt size z are given by:

$n_{x,IMM,NS,z}^+ = (1 - \phi_{x,z}) \cdot n_{x,IMM,NS,z}$		D1a
$n_{x,MAT,NS,z}^+ = \phi_{x,z} \cdot n_{x,IMM,NS,z}$		D1b

where $n_{x,IMM,NS,z}$ is the number of immature, new shell crab of sex x at pre-molt size z .

The sex- and size-specific probabilities of maturing, $\phi_{x,z}$, are related to the model parameters $p_{x,z}^{mat}$ by:

$\phi_{FEMALE,z} = \begin{cases} e^{p_{FEMALE,z}^{mat}} & z \leq 100 \text{ mm CW} \\ 1 & z > 100 \text{ mm CW} \end{cases}$	female probabilities of maturing at pre-molt size z	D2a
$\phi_{MALE,z} = e^{p_{MALE,z}^{mat}}$	male probabilities of maturing at pre-molt size z	D2b

where each $p_{FEMALE,z}^{mat}$ is an estimated parameter (16 parameters), as is each $p_{MALE,z}^{mat}$ (32 parameters).

Second difference penalties, P_x^{mat} , on the parameter estimates are applied in the model's objective function to promote relatively smooth changes with size. These penalties are of the form

$P_x^m = \sum_z [\nabla(\nabla p_{x,z}^{mat})]^2$	2 nd -difference (smoothness) likelihood penalty	D3
$\nabla p_{x,z}^{mat} = p_{x,z}^{mat} - p_{x,z-1}^{mat}$	first difference	D4

The bounds, initial values and estimation phases used for the parameters in the 2013 model are:

parameters	lower bound	upper bound	initial value	phase	code name
$p_{MALE,z}^{mat}$	-16	0	-1.0	5	matestm

$p_{FEMALE,z}^{mat}$	-16	0	-1.0	5	matestf
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E. Model processes: recruitment

Recruitment of immature (new shell) crab in TCSAM2013 has the functional form:

$R_{y,x,z} = \dot{R}_{y,x} \cdot \ddot{R}_z$	recruitment of immature, new shell crab	E1
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where y is year, x is sex, and z is size. $\dot{R}_{y,x}$ represents total sex-specific recruitment in year y and \ddot{R}_z represents the size distribution of recruits, which is assumed identical for males and females.

Sex-specific recruitment, $\dot{R}_{y,x}$, is parameterized as

$\dot{R}_{y,x} = \begin{cases} e^{pLnR^H + \delta R_y^H} & y \leq 1973 \\ e^{pLnR + \delta R_y} & 1974 \leq y \end{cases}$	sex-specific recruitment of immature, new shell crab	E2
--	--	----

where the sex ratio at recruitment is assumed to be 1:1 and the δR_y and δR_y^H are “devs” parameter vectors, with the constraint that the elements of a “devs” vector sums to zero. Independent parameter sets are used for the “historic” period during model spin-up (1949-1973) and the “current” period (1974-2013).

The size distribution for recruits, \ddot{R}_z , is based on a gamma-type distribution and is parameterized as

$\ddot{R}_z = c^{-1} \cdot \Delta_z^{\frac{\alpha}{\beta}-1} \cdot e^{-\frac{\Delta_z}{\beta}}$	size distribution of recruiting crab	E3
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where α and β are parameters, $\Delta_z = z + 2.5 - z_{min}$, and $c = \sum_z \Delta_z^{\frac{\alpha}{\beta}-1} \cdot e^{-\frac{\Delta_z}{\beta}}$ is a normalization constant so that $1 = \sum_z \ddot{R}_z$. z_{min} is the smallest model size bin (27 mm) and the constant 2.5 represents one-half the size bin spacing.

Penalties are imposed on the “devs” parameter vectors δR_y and δR_y^H in the objective function as follows:

$P(\delta R) = \sum_y \delta R_y^2$	Penalty function on δR_y	E4
$P(\delta R^H) = \sum_y (\delta R_y^H - \delta R_{y-1}^H)^2$	1 st difference penalty function on δR_y^H	E5

The bounds, initial values and estimation phases used for the parameters used in the 2013 model are:

parameters	lower bound	upper bound	initial value	phase	code name
$pLnR^H$	--	--	0.0	1	pMnLnRecEarly

$pLnR$	--	--	11.4	1	pMnLnRec
δR_y^H	-15	15	0	1	pRecDevsEarly
δR_y	-15	15	0	1	pRecDevs
α	11.49	11.51	11.50	-8	alpha1_rec
β	3.99	4.01	4.00	-8	beta_rec

where parameters with phase < 0 are not estimated (i.e., treated as constants).

F. Model processes: fisheries

Four fisheries that catch Tanner crab are included in TCSAM2013: 1) the directed Tanner crab fishery, 2) the snow crab fishery, 3) the BBRKC fishery and 4) the various groundfish fisheries (lumped as one bycatch fishery). Crab (males only) are assumed to be retained exclusively in the directed fishery. Bycatch of non-retained Tanner crab (males and females) is assumed to occur in all four fisheries; discard mortality fractions for the (discarded) bycatch are assumed to differ between the crab and groundfish fisheries due to the differences in gear used (pots vs. primarily bottom trawl).

The predicted number of crab killed in fishery f by year in TCSAM2013 model has the functional form:

$m_{y,x,m,s,z}^f = \frac{F_{y,x,m,s,z}^f}{F_{y,x,m,s,z}^T} \cdot [1 - e^{-F_{y,x,m,s,z}^T}] \cdot n_{y,x,m,s,z}^1$	estimated crab mortality in fishery f	F1
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where y is year, x is sex, m is maturity state, s is shell condition and z is size, $F_{y,x,m,s,z}^f$ is sex/maturity state/shell condition/size-specific fishing mortality in year y , and $F_{y,x,m,s,z}^T = \sum_f F_{y,x,m,s,z}^f$ is total fishing mortality sex x crab in maturity state m and shell condition s at size z at the time the fisheries occur in year y . Note that $m_{y,x,m,s,z}^f$ represents the estimated *mortality* in numbers associated with fishery f , not the numbers *captured* (i.e., brought on deck). These differ because discard mortality is not 100% in the fisheries).

The total fishing mortality rate for each fishery is decomposed into two multiplicative components: 1) the mortality rate on fully-selected crab, FM_y^f , and 2) a size-specific selectivity function $S_{y,x,m,s,z}^f$, as follows:

$F_{y,x,m,s,z}^f = FM_y^f \cdot S_{y,x,m,s,z}^f$	fishing mortality rate in fishery f	F2
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Fully-selected fishing mortality

The manner in which the fully-selected fishing mortality rate is further decomposed is time-dependent and specific to each fishery. Consequently, this decomposition is discussed below specific to each fishery.

Considering Tanner crab total fishing mortality (retained + discards) in the directed Tanner crab fishery (TCF) first, the fully-selected fishing mortality is modeled differently in three time periods:

$FM_y^{TCF} = \begin{cases} 0.05 & y < 1965 \\ 0 & 1965 \leq y, \text{ fishery closed} \\ e^{p\overline{LnF}^{TCF} + \delta F_y^{TCF}} & 1965 \leq y, \text{ fishery open} \end{cases}$	fully-selected fishing mortality rate in the directed Tanner crab fishery	F3
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where $p\overline{LnF}^{TCF}$ is a parameter representing the mean ln-scale fishing mortality in the Tanner crab fishery since 1964 (catch data for this fishery begins in 1965) and δF_y^{TCF} represents a “devs” parameter vector with elements defined for each year the fishery was open. Prior to 1965, a small directed fishing mortality rate (0.05) is assumed.

For Tanner crab bycatch in the snow crab fishery (SCF), the fully-selected discard fishing mortality is modeled differently in three time periods using:

$FM_y^{SCF} = \begin{cases} 0.01 & y < 1978 \\ r^{SCF} \cdot E_y^{SCF} & 1978 \leq y \leq 1991 \\ e^{p\overline{LnF}^{SCF} + \delta F_y^{SCF}} & 1992 \leq y \end{cases}$	fully-selected discard fishing mortality rate in the snow crab fishery	F4
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where $p\overline{LnF}^{SCF}$ is a parameter representing the mean ln-scale bycatch fishing mortality in the snow crab fishery since 1992 (when reliable observer-based Tanner crab discard data in the snow crab fishery first became available) and δF_y^{SCF} represents a “devs” parameter vector with elements defined for each year in this time period. Prior to 1978, a small annual discard mortality rate associated with this fishery (0.01) is assumed. Annual effort data (total potlifts, E_y^{SCF}) is used to extend predictions of Tanner crab discard mortality in this fishery into the period 1978-1991. To do this, the assumption is made that effort in the snow crab fishery is proportional to Tanner crab discard fishing mortality and estimate the proportionality constant, r^{SCF} , using a ratio estimator between effort and discard mortality in the period 1992-present:

$r^{SCF} = \frac{\left\{ \frac{1}{N} \sum_{y=1992}^{present} FM_y^{SCF} \right\}}{\left\{ \frac{1}{N} \sum_{y=1992}^{present} E_y^{SCF} \right\}}$	ratio estimator relating fishing mortality rate to effort in the snow crab fishery	F5
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where N is the number of years, 1992-present.

For Tanner crab bycatch in the BBRKC fishery (RKF), the fully-selected discard fishing mortality when the fishery was open is modeled differently in three time periods using:

$FM_y^{RKF} = \begin{cases} 0.02 & y < 1953 \\ \max\{0.01, -\ln[1 - r^{RKF} \cdot E_y^{RKF}]\} & 1953 \leq y \leq 1991 \\ e^{p\overline{LnF}^{RKF} + \delta F_y^{RKF}} & 1992 \leq y \end{cases}$	fully-selected discard fishing mortality rate in the BBRKC fishery	F6
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where $p\overline{LnF}^{RKF}$ is a parameter representing the mean ln-scale bycatch fishing mortality in the BBRKC fishery since 1992 (when observer-based Tanner crab discard data in the BBRKC fishery first became available) and δF_y^{RKF} represents a “devs” parameter vector with elements defined for each year in this period that the fishery was open. Prior to 1953, a small annual discard mortality rate associated with this fishery (0.02) was assumed. Annual effort data (total potlifts, E_y^{RKF}) was used to extend predictions of Tanner crab discard mortality in this fishery into the period 1953-1991. To do this, we made the assumption that effort in the BBRKC fishery is proportional to Tanner crab discard fishing mortality and estimate the proportionality constant, r^{RKF} , using a ratio estimator between effort and discard mortality in the period 1992-present:

$r^{RKF} = \frac{\left\{ \frac{1}{N} \sum_{y=1992}^{present} \left[1 - e^{-FM_y^{RKF}} \right] \right\}}{\left\{ \frac{1}{N} \sum_{y=1992}^{present} E_y^{RKF} \right\}}$	ratio estimator relating fishing mortality rate to effort in the BBRKC fishery	F7
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where N is the number of years, 1992-present, when the BBRKC fishery was open. For any year that the BBRKC fishery was closed, FM_y^{RKF} was set to 0.

Finally, for Tanner crab bycatch in the groundfish fisheries (GTF), the fully-selected discard fishing mortality in the fishery was modeled differently in two time periods using:

$FM_y^{GTF} = \begin{cases} \frac{1}{N} \sum_{y=1992}^{present} e^{p\overline{LnF}^{GTF} + \delta F_y^{GTF}} & y < 1973 \\ e^{p\overline{LnF}^{GTF} + \delta F_y^{GTF}} & 1973 \leq y \end{cases}$	fully-selected discard fishing mortality rate in the groundfish trawl fisheries	F8
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where $p\overline{LnF}^{GTF}$ is a parameter representing the mean fully-selected ln-scale bycatch fishing mortality in the groundfish fisheries since 1973 (when observer-based Tanner crab discard data in the groundfish fisheries first became available) and δF_y^{GTF} is a “devs” parameter vector with elements representing the annual ln-scale deviation from the mean. Prior to 1973, the fully-selected discard mortality rate associated with these fisheries was assumed to be constant and equal to the mean over the 1973-present period.

The bounds (when set), initial values and estimation phases used for the fully-selected fishing mortality parameters and devs vectors in the 2013 model were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\overline{LnF}^{TCF}$	--	--	-0.7	1	pAvgLnFmTCF
δF_y^{TCF}	-15	15	0	2	pFmDevsTCF
$p\overline{LnF}^{SCF}$	--	--	-3.0	3	pAvgLnFmSCF
δF_y^{SCF}	-15	15	0	4	pFmDevsSCF
$p\overline{LnF}^{RKF}$	-5.25	-5.25	-5.25	-4	pAvgLnFmRKF
δF_y^{RKF}	-15	15	0	-5	pFmDevsRKF
$p\overline{LnF}^{GTF}$	--	--	-4.0	2	pAvgLnFmGTF
δF_y^{GTF}	-15	15	0	3	pFmDevsGTF

where all parameters and parameter vectors were estimated (phase > 0), except for those associated with the BBRKC fishery.

Fishery selectivity

The manner in which fishery selectivity is parameterized is also time-dependent and specific to each fishery, as with the fully-selected fishing mortality. However, the time periods used to define selectivity are not necessarily those used for the fully-selected fishing mortality.

In the directed Tanner crab fishery (TCF), total selectivity (retained + discards) is modeled using sex-specific ascending logistic functions. For males, in addition, total selectivity is parameterized differently in three time periods, corresponding to differences in information about the fishery (pre-/post-1991) and differences in the fishery itself (pre-/post-rationalization in 2005):

$S_{y,FEMALE,m,s,z}^{TCF} = \left\{ 1 + e^{-p\beta_{FEMALE}^{TCF} \cdot (z - pZ_{50,FEMALE}^{TCF})} \right\}^{-1}$	total selectivity for females in the directed Tanner crab fishery	F9
$S_{y,MALE,m,s,z}^{TCF} = \begin{cases} \left\{ 1 + e^{-p\beta_{MALE}^{TCF(1)} \cdot (z - \bar{z}_{50,MALE}^{TCF})} \right\}^{-1} & y \leq 1990 \\ \left\{ 1 + e^{-p\beta_{MALE}^{TCF(1)} \cdot (z - z_{50,y,MALE}^{TCF})} \right\}^{-1} & 1991 \leq y \leq 1996 \\ \left\{ 1 + e^{-p\beta_{MALE}^{TCF(2)} \cdot (z - z_{50,y,MALE}^{TCF})} \right\}^{-1} & 2005 \leq y \leq 2009 \end{cases}$	total selectivity for males in the directed Tanner crab fishery	F10

where the $p\beta_x^{TCF(t)}$ are parameters controlling the slopes of the associated logistic selectivity curves, $pZ_{50,FEMALE}^{TCF}$ is the parameter controlling the size of females at 50% selection, $\bar{z}_{50,MALE}^{TCF}$ controls the size of 50%-selected males in the pre-1991 period, and $z_{50,y,MALE}^{TCF}$ controls the size of 50%-selected males in the post-1990 period. The latter three quantities are functions of estimable parameters as described in the following:

$\bar{z}_{50,MALE}^{TCF} = \frac{1}{6} \sum_{y=1991}^{1996} z_{50,y,MALE}^{TCF}$	male size at 50%-selected used in pre-1991 period	F11
$z_{50,y,MALE}^{TCF} = e^{pLnZ_{50,MALE}^{TCF} + \delta Z_{50,y,MALE}^{TCF}}$	male size at 50%-selected used in post-1990 period	F12

where $pLnZ_{50,MALE}^{TCF}$ is a parameter controlling the ln-scale mean male size at 50% selectivity post-1990 and $\delta Z_{50,y,MALE}^{TCF}$ is a parameter vector controlling annual ln-scale deviations in male size at 50% selectivity post-1990. As formulated, selectivity in the directed fishery is not a function of maturity state or shell condition.

The bounds, initial values and estimation phases used in the 2013 model for the 5 parameters describing total selectivity in the directed Tanner crab fishery were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta_{FEMALE}^{TCF}$	0.1	0.4	0.25	3	fish_disc_slope_f
$pZ_{50FEMALE}^{TCF}$	80	150	115	3	fish_disc_sel50_f
$p\beta_{MALE}^{TCF(1)}$	0.05	0.75	0.4	3	fish_slope_1
$p\beta_{MALE}^{TCF(2)}$	0.1	0.4	0.25	3	fish_slope_yr_3
$pLnZ_{50MALE}^{TCF}$	4.0	5.0	4.5	3	log_avg_sel50_3

where all parameters were estimated. The bounds, initial values and estimation phase used in the 2013 model for the ln-scale “devs” parameter vector $\delta Z_{50y,MALE}^{TCF}$ describing annual deviations in male size at 50%-selected (1991-1996, 2005-2009) were:

parameters	lower bound	upper bound	initial value	phase	code name
$\delta Z_{50y,MALE}^{TCF}$	-0.5	0.5	0	3	log_sel50_dev_3

In the snow crab fishery (SCF), bycatch (discard) selectivity is modeled using three time periods (model start to 1996, 1997-2004, 2005 to present). Male selectivity is described using dome-shaped (double logistic) functions in each period, with:

$S_{y,MALE,m,s,z}^{SCF} = \begin{cases} S_{MALE,z}^{SCF(1)} & y \leq 1996 \\ S_{MALE,z}^{SCF(2)} & 1997 \leq y \leq 2004 \\ S_{MALE,z}^{SCF(3)} & 2005 \leq y \end{cases}$	male selectivity in the snow crab fishery	F13
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where the double logistic functions $S_{MALE,z}^{SCF(t)}$ are parameterized using:

$S_{MALE,z}^{SCF(t)} = \left\{ 1 + e^{-p\beta_{MALE}^{SCF(ta)} \cdot (z - pZ_{50MALE}^{SCF(ta)})} \right\}^{-1} \cdot \left\{ 1 + e^{+p\beta_{MALE}^{SCF(td)} \cdot (z - pZ_{50MALE}^{SCF(td)})} \right\}^{-1}$	dome-shaped selectivity	F14
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where $p\beta_x^{SCF(ta)}$ and $pZ_{50x}^{SCF(ta)}$ are the 6 parameters controlling the ascending limb of the double logistic function and $p\beta_x^{SCF(td)}$ and $pZ_{50x}^{SCF(td)}$ are the 6 parameters controlling the descending limb for each period t .

Female selectivity is described using ascending logistic functions in each period, with:

$S_{y,FEMALE,m,s,z}^{SCF} = \begin{cases} S_{FEMALE,z}^{SCF(1)} & y \leq 1996 \\ S_{FEMALE,z}^{SCF(2)} & 1997 \leq y \leq 2004 \\ S_{FEMALE,z}^{SCF(3)} & 2005 \leq y \end{cases}$	female selectivity in the snow crab fishery	F15
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where the ascending logistic functions $S_{FEMALE,z}^{SCF(t)}$ are parameterized using:

$S_{FEMALE,z}^{SCF(t)} = \left\{ 1 + e^{-p\beta_{FEMALE}^{SCF(t)} \cdot (z - pZ_{50}^{SCF(t)})} \right\}^{-1}$	ascending logistic selectivity	F16
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where the $p\beta_x^{SCF(p)}$ are the 3 parameters controlling the slopes of the associated logistic selectivity curves and the $pZ_{50}^{SCF(p)}$ are the 3 parameters controlling size at 50%-selection.

As formulated, selectivity in the snow crab fishery is not a function of maturity state or shell condition.

The bounds, initial values and estimation phases used in the 2013 model for the 12 parameters describing male selectivity in the snow crab fishery were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta_{MALE}^{SCF(1a)}$	0.01	0.50	0.255	4	snowfish_disc_slope_m_1
$pZ_{50MALE}^{SCF(1a)}$	60	150	122.5	4	snowfish_disc_sel50_m_1
$p\beta_{MALE}^{SCF(1d)}$	0.01	0.50	0.255	4	snowfish_disc_slope_m2_1
$pZ_{50MALE}^{SCF(1d)}$	40	200	120	4	snowfish_disc_sel50_m2_1
$p\beta_{MALE}^{SCF(2a)}$	0.01	0.50	0.255	4	snowfish_disc_slope_m_2
$pZ_{50MALE}^{SCF(2a)}$	60	150	122.5	4	snowfish_disc_sel50_m_2
$p\beta_{MALE}^{SCF(2d)}$	0.01	0.50	0.255	4	snowfish_disc_slope_m2_2
$pZ_{50MALE}^{SCF(2d)}$	40	200	120	4	snowfish_disc_sel50_m2_2
$p\beta_{MALE}^{SCF(3a)}$	0.01	0.50	0.255	4	snowfish_disc_slope_m_3
$pZ_{50MALE}^{SCF(3a)}$	60	150	122.5	4	snowfish_disc_sel50_m_3
$p\beta_{MALE}^{SCF(3d)}$	0.01	0.50	0.255	4	snowfish_disc_slope_m2_3
$pZ_{50MALE}^{SCF(3d)}$	40	200	120	4	snowfish_disc_sel50_m2_3

where all parameters were estimated.

The bounds, initial values and estimation phases used in the 2013 model for the 6 parameters describing female selectivity in the snow crab fishery were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta_{FEMALE}^{SCF(1)}$	0.05	0.5	0.275	4	snowfish_disc_slope_f1
$pZ_{50FEMALE}^{SCF(1)}$	50	150	100	4	snowfish_disc_sel50_f1
$p\beta_{FEMALE}^{SCF(2)}$	0.05	0.5	0.275	4	snowfish_disc_slope_f2
$pZ_{50FEMALE}^{SCF(2)}$	50	120	85	4	snowfish_disc_sel50_f2
$p\beta_{FEMALE}^{SCF(3)}$	0.05	0.5	0.275	4	snowfish_disc_slope_f3
$pZ_{50FEMALE}^{SCF(3)}$	50	120	85	4	snowfish_disc_sel50_f3

where all parameters were estimated.

In the BBRKC fishery (RKF), bycatch (discard) selectivity is also modeled using the three time periods used to model selectivity in the snow crab fishery (model start to 1996, 1997-2004, 2005 to present), with sex-specific parameters estimated in each period. All sex/period combinations are modeled using ascending logistic functions:

$S_{y,x,m,s,z}^{RKF} = \begin{cases} \left\{ 1 + e^{-p\beta_x^{RKF(1)} \cdot (z - pZ_{50x}^{RKF(1)})} \right\}^{-1} & y \leq 1996 \\ \left\{ 1 + e^{-p\beta_x^{RKF(2)} \cdot (z - pZ_{50x}^{RKF(2)})} \right\}^{-1} & 1997 \leq y \leq 2004 \\ \left\{ 1 + e^{-p\beta_x^{RKF(3)} \cdot (z - pZ_{50x}^{RKF(3)})} \right\}^{-1} & 2005 \leq y \end{cases}$	selectivity in the BBRKC fishery	F17
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where the $p\beta_x^{RKF(p)}$ are 6 parameters controlling the slopes of the associated logistic selectivity curves and the $pZ_{50x}^{RKF(p)}$ are 6 parameters controlling size at 50%-selection. As formulated, selectivity in the BBRKC fishery is not a function of maturity state or shell condition.

The bounds, initial values and estimation phases used in the 2013 model for the 12 parameters describing male selectivity in the BBRKC fishery were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta_{MALE}^{RKF(1)}$	0.01	0.50	0.255	3	rkfish_disc_slope_m1
$pZ_{50MALE}^{RKF(1)}$	95	150	122.5	3	rkfish_disc_sel50_m1
$p\beta_{MALE}^{RKF(2)}$	0.01	0.50	0.255	3	rkfish_disc_slope_m2
$pZ_{50MALE}^{RKF(2)}$	95	150	122.5	3	rkfish_disc_sel50_m2
$p\beta_{MALE}^{RKF(3)}$	0.01	0.50	0.255	3	rkfish_disc_slope_m3
$pZ_{50MALE}^{RKF(3)}$	95	150	122.5	3	rkfish_disc_sel50_m3

where all parameters were estimated.

The bounds, initial values and estimation phases used in the 2013 model for the 6 parameters describing female selectivity in the BBRKC fishery were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta_{FEMALE}^{RKF(1)}$	0.005	0.50	0.2525	3	rkfish_disc_slope_f1
$pZ_{50FEMALE}^{RKF(1)}$	50	150	100	3	rkfish_disc_sel50_f1
$p\beta_{FEMALE}^{RKF(2)}$	0.005	0.50	0.255	3	rkfish_disc_slope_f2
$pZ_{50FEMALE}^{RKF(2)}$	50	150	100	3	rkfish_disc_sel50_f2
$p\beta_{FEMALE}^{RKF(3)}$	0.01	0.50	0.255	3	rkfish_disc_slope_f3
$pZ_{50FEMALE}^{RKF(3)}$	50	170	110	3	rkfish_disc_sel50_f3

where all parameters were estimated.

In the groundfish fisheries (GTF), bycatch (discard) selectivity is also modeled using three time periods (model start to 1986, 1987-1996, 1997 to present), but these are different from those used in the snow

crab and BBRKC fisheries. Sex-specific parameters are estimated in each period; all sex/period combinations are modeled using ascending logistic functions:

$S_{y,x,m,s,z}^{GTF} = \begin{cases} \left\{1 + e^{-p\beta_x^{GTF(1)} \cdot (z - pZ_{50x}^{GTF(1)})}\right\}^{-1} & y \leq 1986 \\ \left\{1 + e^{-p\beta_x^{GTF(2)} \cdot (z - pZ_{50x}^{GTF(2)})}\right\}^{-1} & 1987 \leq y \leq 1996 \\ \left\{1 + e^{-p\beta_x^{GTF(3)} \cdot (z - pZ_{50x}^{GTF(3)})}\right\}^{-1} & 1997 \leq y \end{cases}$	selectivity in the groundfish fisheries	F18
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where the $p\beta_x^{GTF(p)}$ are 6 parameters controlling the slopes of the associated logistic selectivity curves and the $pZ_{50x}^{GTF(p)}$ are 6 parameters controlling size at 50%-selection. As formulated, selectivity in the groundfish fisheries is not a function of maturity state or shell condition.

The bounds, initial values and estimation phases used in the 2013 model for the 12 parameters describing male selectivity in the groundfish fisheries were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta_{MALE}^{GTF(1)}$	0.01	0.50	0.255	3	fish_disc_slope_tm1
$pZ_{50MALE}^{GTF(1)}$	40	120.01	80.005	3	fish_disc_sel50_tm1
$p\beta_{MALE}^{GTF(2)}$	0.01	0.50	0.255	3	fish_disc_slope_tm2
$pZ_{50MALE}^{GTF(2)}$	40	120.01	80.005	3	fish_disc_sel50_tm2
$p\beta_{MALE}^{GTF(3)}$	0.01	0.50	0.255	3	fish_disc_slope_tm3
$pZ_{50MALE}^{GTF(3)}$	40	120.01	80.005	3	fish_disc_sel50_tm3

where all parameters were estimated.

The bounds, initial values and estimation phases used in the 2013 model for the 6 parameters describing female selectivity in the groundfish fisheries were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta_{FEMALE}^{GTF(1)}$	0.01	0.50	0.255	3	fish_disc_slope_tf1
$pZ_{50FEMALE}^{GTF(1)}$	40	125.01	82.505	3	fish_disc_sel50_tf1
$p\beta_{FEMALE}^{GTF(2)}$	0.005	0.50	0.255	3	fish_disc_slope_tf2
$pZ_{50FEMALE}^{GTF(2)}$	40	250.01	145.005	3	fish_disc_sel50_tf2
$p\beta_{FEMALE}^{GTF(3)}$	0.01	0.50	0.255	3	fish_disc_slope_tf3
$pZ_{50FEMALE}^{GTF(3)}$	40	150.01	95.005	3	fish_disc_sel50_tf3

where all parameters were estimated.

Retention in the directed fishery

Retention of male crab in the directed fishery is modeled as a multiplicative size-specific process “on top” of total (retention + discards) fishing selectivity. The number of crab (males only) retained in the directed Tanner crab fishery is given by

$r_{y,m,s,z}^{TCF} = \frac{R_{y,m,s,z}^{TCF}}{F_{y,MALE,m,s,z}^T} \cdot [1 - e^{-F_{y,MALE,m,s,z}^T}] \cdot n_{y,MALE,m,s,z}^1$	retained male crab (numbers) in the directed fishery	F19
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where $R_{y,m,s,z}^{TCF}$ is the retained mortality rate associated with retention, which is related to the total fishing mortality rate on male crab in the directed fishery, $F_{y,MALE,m,s,z}^{TCF}$, by

$R_{y,m,s,z}^{TCF} = \rho_{y,m,s,z}^{TCF} \cdot F_{y,MALE,m,s,z}^{TCF} = FM_y^{TCF} \cdot \rho_{y,m,s,z}^{TCF} \cdot S_{y,MALE,m,s}^{TCF}$	retained mortality rate in the directed fishery	F20
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where $\rho_{y,m,s,z}^{TCF}$ represents size-specific retention of male crab. Retention at size, $\rho_{y,m,s,z}^{TCF}$, in the directed fishery is modeled as an ascending logistic function, with different parameters in two time periods, as follows:

$\rho_{y,m,s,z}^{TCF} = \begin{cases} \left\{1 + e^{-p\beta^{TCFR(1)} \cdot (z - pZ_{50}^{TCFR(1)})^{-1}}\right\}^{-1} & y \leq 1990 \\ \left\{1 + e^{-p\beta^{TCFR(2)} \cdot (z - pZ_{50}^{TCFR(2)})^{-1}}\right\}^{-1} & 1991 \leq y \end{cases}$	size-specific retention in the directed fishery	F21
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where $p\beta^{TCFR(t)}$ is the parameter controlling the slope of the function in the each period ($t=1,2$) and $pZ_{50}^{TCFR(t)}$ is the parameter controlling the size at 50%-selected. As formulated, retention is not a function of maturity state or shell condition.

The bounds, initial values and estimation phases used for the size-specific retention parameters in the 2013 model were:

parameters	lower bound	upper bound	initial value	phase	code name
$p\beta^{TCFR(1)}$	0.25	1.01	0.63	3	fish_fit_slope_mn1
$pZ_{50}^{TCFR(1)}$	85	160	122.5	3	fish_fit_sel50_mn1
$p\beta^{TCFR(2)}$	0.25	2.01	1.13	3	fish_fit_slope_mn2
$pZ_{50}^{TCFR(2)}$	85	160	122.5	3	fish_fit_sel50_mn2

where all parameters were estimated.

G. Model indices: surveys

The predicted number of crab caught in the survey by year in the 2013 TCSAM model has the functional form:

$n_{y,x,m,s,z}^{STV} = q_{y,x} \cdot S_{y,x,z} \cdot n_{y,x,m,s,z}$	predicted number of crab caught in survey	G1
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where y is year, x is sex, m is maturity state, s is shell condition and z is size, $q_{y,x}$ is sex-specific survey catchability in year y , $S_{y,x,z}$ is sex-specific size selectivity in year y , and $n_{y,x,m,s,z}$ is the number of sex x crab in maturity state m and shell condition s at size z at the time of the survey in year y .

Three time periods that were used to test hypotheses regarding changes in catchability and selectivity in the survey over time are defined in the model. These periods are defined as: 1) $y < 1982$, 2) $1982 \leq y \leq 1987$, and 3) $1988 \leq y$. As parameterized in the 2013 model, catchabilities in periods 2 and 3 were assumed to be identical, so only two sets of sex-specific parameters reflecting catchability were used in the model. In terms of the three time periods, catchability was parameterized using the sex-specific parameters q_x^I and q_x^{II} in the following manner:

$q_{y,x} = \begin{cases} q_x^I & y < 1982 \\ q_x^{II} & 1982 \leq y \leq 1987 \\ q_x^{II} & 1988 \leq y \end{cases}$	survey catchability	G2
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The bounds, initial values and estimation phases used for these parameters in the 2013 model were:

parameters	lower bound	upper bound	initial value	phase	code name
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q_{MALE}^I	0.50	1.001	0.7505	4	srv2_q
q_{FEMALE}^I	0.50	1.001	0.7505	4	srv2_femQ
q_{MALE}^{II}	0.20	2.00	1.1	4	srv3_q
q_{FEMALE}^{II}	0.20	1.00	0.6	4	srv3_femQ

where all parameters were estimated (phase > 0).

Similarly, survey selectivity in periods 2 and 3 was assumed identical and only two sets of sex-specific parameters were used to describe survey selectivity using logistic functions:

$S_{y,z} = \begin{cases} \left\{ 1 + e^{-[\ln(19) \cdot (z - z_{50}^I) / \delta z_{95}^I]} \right\}^{-1} & y < 1982 \\ \left\{ 1 + e^{-[\ln(19) \cdot (z - z_{50}^{II}) / \delta z_{95}^{II}]} \right\}^{-1} & 1982 \leq y \leq 1987 \\ \left\{ 1 + e^{-[\ln(19) \cdot (z - z_{50}^{II}) / \delta z_{95}^{II}]} \right\}^{-1} & 1987 \leq y \end{cases}$	survey selectivity	G3
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where the z_{50} 's are parameters reflecting the inflection point of the logistic curve (i.e., size at 50% selected) and the δz_{95} 's are parameters reflecting the difference the sizes at 50% and 95% selected.

The bounds, initial values and estimation phases used for the selectivity parameters used in the 2013 model were:

parameters	lower bound	upper bound	initial value	phase	code name
$Z_{50}^I_{MALE}$	0	90	45	4	srv2_sel150
$Z_{50}^I_{FEMALE}$	-200	100.01	-49.005	4	srv2_sel150_f
$\delta Z_{95}^I_{MALE}$	0	100	50	4	srv2_seldiff
$\delta Z_{95}^I_{FEMALE}$	0	100	50	4	srv2_seldiff_f
$Z_{50}^{II}_{MALE}$	0	69	34.5	4	srv3_sel150
$Z_{50}^{II}_{FEMALE}$	-50	69	9.5	4	srv3_sel150_f
$\delta Z_{95}^{II}_{MALE}$	0	100	50	4	srv3_seldiff
$\delta Z_{95}^{II}_{FEMALE}$	0	100	50	4	srv3_seldiff_f

where all parameters were estimated (phase > 0).

H. Model fitting: objective function equations

The TCSAM2013 model is fit by minimizing an objective function, σ , with additive components consisting of: 1) several penalty functions, 2) several negative log-likelihood functions based on assumed prior probability distributions for model parameters, and 3) several negative log-likelihood functions based on input data components, of the form:

$\sigma = \sum_f \lambda_f \cdot \mathcal{F}_f - 2 \sum_p \lambda_p \cdot \ln(\wp_p) - 2 \sum_l \lambda_l \cdot \ln(\mathcal{L}_l)$	model objective function	H1
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where \mathcal{F}_f represents the f th penalty function, \wp_p represents the p th prior probability function, \mathcal{L}_l represents the l th likelihood function, and the λ 's represent user-adjustable weights for each component.

Penalty Functions

The penalty functions associated with various model quantities are identified in the section (B-F) concerning the associated process.

Prior Probability Functions

The prior probability functions associated with various model parameters are identified in the section (B-F) concerning the associated parameter.

Likelihood Functions

The model's objective function includes likelihood components based on 1) retained catch size frequencies (i.e., males only) in the directed fishery from dockside observer sampling; 2) total catch (retained + discarded) size frequencies by sex in each fishery from at-sea observer sampling; 3) size frequencies for immature males, mature males, immature females, and mature females, respectively, from trawl survey data; 4) dockside retained catch biomass (i.e., males only) in the directed fishery from fish ticket data; 5) estimated total catch (retained + discarded) mortality in biomass by sex in the crab and groundfish fisheries from at-sea observer sampling; and 6) estimated mature biomass by sex from trawl survey data. As discussed in more detail below, size frequency-related likelihood components are based on the multinomial distribution while those related to biomass are based on either the normal or lognormal distributions.

Size frequency components

Fishery-related (log-scale) likelihood components involving sex-specific size frequencies are based on the following equation for multinomial sampling:

$\ln(\mathcal{L}^M)_x^f = \sum_y n_{y,x}^f \cdot \sum_z p_{y,x,z}^{obs.f} \cdot \ln(p_{y,x,z}^{mod.f} + \delta) - p_{y,x,z}^{obs.f} \cdot \ln(p_{y,x,z}^{obs.f} + \delta)$	multinomial log-likelihood	H2
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where f indicates the fishery, x indicates sex, the y 's are years for which data exists, $n_{y,x}^f$ is the sex-specific effective sample size for year y , $p_{y,x,z}^{obs.f}$ is the observed size composition in size bin z (i.e., the size frequency normalized to sum to 1 across size bins for each year), $p_{y,x,z}^{mod.f}$ is the corresponding model estimate, and δ is a small constant.

Size compositions for retained catch (male only) in the directed Tanner crab fishery are obtained from dockside observer sampling and calculated from shell condition-specific size frequencies $r_{y,MALE,s,z}^{obs.TCF}$ using:

$p_{y,MALE,z}^{obs.TCF} = \frac{\sum_s r_{y,MALE,s,z}^{obs.TCF}}{\sum_s \sum_z r_{y,MALE,s,z}^{obs.TCF}}$	retained size compositions for the directed fishery from dockside observer sampling	H3
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where s indicates shell condition (new shell, old shell) and z indicates the size bin. The corresponding model size compositions are calculated from the predicted numbers retained in the directed fishery $r_{y,MALE,m,s,z}^{mod.TCF}$ using

$p_{y,MALE,z}^{mod.TCF} = \frac{\sum_m \sum_s r_{y,MALE,m,s,z}^{mod.TCF}}{\sum_m \sum_s \sum_z r_{y,MALE,m,s,z}^{mod.TCF}}$	model-predicted retained catch size compositions for the directed fishery	H4
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where, additionally, m is maturity state (immature, mature).

Size compositions for total (retained + discarded) catch in fishery f ($f = 1-4$) are sex-specific and are calculated from sex/shell condition-specific size frequencies $r_{y,x,s,z}^{obs.f} + d_{y,x,s,z}^{obs.f}$ obtained from at-sea observer sampling using:

$p_{y,x,z}^{obs.f} = \frac{\sum_s [r_{y,x,s,z}^{obs.f} + d_{y,x,s,z}^{obs.f}]}{\sum_s \sum_z [r_{y,x,s,z}^{obs.f} + d_{y,x,s,z}^{obs.f}]}$	sex-specific size compositions for total catch for fishery f from at-sea observer sampling	H5
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where s indicates shell condition (new shell, old shell) and z indicates the size bin. In the above equation, $d_{y,x,s,z}^{obs.f}$ has *not* been discounted for discard survival (i.e., it's consistent with setting discard mortality to 100%). The corresponding model size compositions are calculated from the predicted total fishing mortality (numbers) in each fishery f , $m_{y,x,m,s,z}^{mod.f} (= r_{y,x,m,s,z}^{mod.f} + \delta_f \cdot d_{y,x,m,s,z}^{mod.f})$, using

$p_{y,x,z}^{mod.f} = \frac{\sum_m \sum_s m_{y,x,m,s,z}^{mod.f}}{\sum_m \sum_s \sum_z m_{y,x,m,s,z}^{mod.f}}$	model-predicted total catch mortality size compositions for fishery f	H6
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where, again, the subscript m is maturity state (immature, mature). In eq. H6, $m_{y,x,m,s,z}^{mod.f}$ does not assume any particular value for discard mortality.

Log-scale likelihood components for the trawl survey involve size frequencies that are sex- and maturity state-specific, and thus are based on the following equation for multinomial sampling:

$\ln(\mathcal{L}^M)_{x,m}^{srv} = \sum_y n_{y,x,m}^{srv} \cdot \sum_z \{p_{y,x,m,z}^{obs.srv} \cdot \ln(p_{y,x,m,z}^{mod.srv} + \delta) - p_{y,x,m,z}^{obs.srv} \cdot \ln(p_{y,x,m,z}^{obs.srv} + \delta)\}$	multinomial log-likelihood	H7
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where x indicates sex, the y 's are years for which data exists, $n_{y,x,m}^{srv}$ is the sex- and maturity-state specific effective sample size for year y , $p_{y,x,z}^{obs.srv}$ is the observed size composition in size bin z (i.e., the size frequency normalized to sum to 1 across size bins for each year), $p_{y,x,z}^{mod.srv}$ is the corresponding model estimate, and δ is a small constant.

Fishery biomass components

Likelihood components related to fishery biomass totals are based on the assumption of normally-distributed sampling, and generally have the simple form:

$\ln(\mathcal{L}^N)_x^f = - \sum_y [b_{y,x}^{obs.f} - b_{y,x}^{mod.f}]^2$	normal log-likelihood	H8
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where $b_{y,x}^{obs.f}$ is the sex-specific catch mortality (as biomass) in fishery f for year y and $b_{y,x}^{mod.f}$ is the corresponding value predicted by the model. Components of this sort are calculated for retained biomass in the directed fishery, total (retained + discard) sex-specific fishery-related mortality in the model crab fisheries, and discard-related (not sex-specific) mortality in the groundfish fishery. The observed components of discard-related mortality for each fishery are obtained by multiplying the observed discard biomass by the assumed discard mortality fraction.

Survey biomass components

Likelihood components related to survey biomass are based on the assumption of lognormally-distributed sampling errors, and have the form:

$\ln(\mathcal{L}^N)_x^{srv} = - \sum_y \frac{[\ln(b_{y,x}^{obs.srv} + \delta) - \ln(b_{y,x}^{mod.srv} + \delta)]^2}{2 \cdot \ln(1 + cv_{y,x}^2)}$	lognormal log-likelihood	H9
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where $b_{y,x}^{obs.srv}$ is sex-specific mature biomass estimated from the trawl survey data for year y , $b_{y,x}^{mod.srv}$ is the corresponding value predicted by the model, and $cv_{y,x}$ is the cv of the observation. Survey numbers-at-

size $n_{y,x,m,s,z}^{obs.srv}$, classified by sex, shell condition and maturity state, are combined with sex- and maturity state-specific weight-at-size relationships $w_{x,m,z}$ to estimate sex-specific mature biomass $b_{y,x}^{obs.srv}$ using

$b_{y,x}^{obs.srv} = \sum_s \sum_z n_{y,x,MATURE,s,z}^{obs.srv} \cdot w_{x,MATURE,z}$	mature biomass	H10
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An equivalent equation is used to calculate $b_{y,x}^{mod.srv}$.

Literature cited

- Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. *Optim. Methods Softw.* 27:233-249.
- Rugolo, L.J., and B.J. Turnock. 2012. 2012 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2012 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 267-416.
- Stockhausen, W.T., B.J. Turnock and L. Rugolo. 2013. 2013 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2013 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 342-449.
- Whitten, A.R., A.E. Punt, J.N. Ianelli. 2013. Gmacs: Generalized Modeling for Alaskan Crab Stocks. http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/crab/Whitten%20et%20al%202014%20-%20Gmacs%20Model%20Description.pdf

Appendix 4: TCSAM-FRev revisions to TCSAM2013

Introduction

This appendix addresses an issue in the Tanner crab stock assessment that concerns a logical inconsistency in the manner in which fishing mortality was modeled in the 2013 stock assessment (hereafter referred to as TCSAM2013). As part of an effort to improve the assessment, I wrote a new description of the Tanner crab model used in the 2013 assessment (see Appendix 3). In the course of writing the new description, I realized that the equations used to estimate total fishing mortality and retained mortality were not consistent with those used in Gmacs (the Generic Model for Alaskan Crab Stocks), a generic modeling framework for crab assessments being developed by A. Whitten, J. Ianelli and A. Punt (Whitten et al., 2014). To resolve this, I derived a set of equations describing fishing mortality on crab stocks from first principles (see below). The resulting equations are the same that are used in Gmacs. These equations indicate that the interpretation of the estimated “retention curve” in TCSAM2013 as directly reflecting the on-deck process of sorting crab into retained and discarded components is incorrect. I have consequently revised the TCSAM2013 code to reflect the corrected equations (TCSAM-FRev).

Model revisions

The model used in the 2013 assessment, TCSAM2103, assumes that the rate of mortality on crab due to retaining them in the directed fishery is proportional to the rate of total fishing mortality (retained + discarded mortality) in that fishery (see Appendix 3 for details). Using a slightly simplified description, TCSAM2013 models the rate of fishing mortality on male crab of size z due to retention, $r_{y,z}$, as

$$r_{y,z} = r_z \cdot F_{y,z}$$

where $F_{y,z}$ is the total fishing mortality rate (retained + discard mortality) in year y on male crabs of size z and r_z is the size-specific “retention function”, which takes values between 0 (no retention) and 1 (complete retention). In TCSAM2013, the retention function r_z is modeled using an increasing 2-parameter logistic function (retention is 0 for “small” crab and 100% for “large” crab) and the two parameters are estimated as part of the model fitting process. This is fine, as far as it goes, because it simply represents a somewhat non-standard model for retained fishing mortality. However, the expectation has been that r_z reflects the process of sorting and retaining legal crab on deck, and thus it represents the fraction of crab caught at size z that were retained. If this were the case, r_z would be independent of handling mortality because what’s retained is not affected by what’s discarded (rather it’s the other way around: what’s discarded is simply what’s left over after crab to be retained have been selected). However, **this is not the correct interpretation of r_z** as it is used in TCSAM2013 and the equation above. Rather, as illustrated in Fig. 1, r_z simply reflects the fraction of crab killed at size z that were killed because they were retained, as opposed to being killed as part of the discard process. As such, it is actually a function of the assumed handling mortality on discarded crab whereas the function that describes the on-deck sorting process is not. As an illustration to make this point, if handling mortality were 0 then all fishing mortality $F_{y,z}$ would be due to retention ($r_{y,z} = F_{y,z}$) and r_z would be identically 1 irrespective of any sorting process that occurred on deck (e.g., all sub-legals being discarded). In Fig. 1, this would be equivalent to the “fishing mortality pie” shrinking in size but turning completely red, while the only change to the “fishing capture pie” would be that the discard mortality slice turns blue (all discards survive). The fraction of the latter pie representing retention would not change.

In the Tanner crab assessment, we are concerned with fitting the *retained* (R_f) and *discarded* (D_f) components of the total catch ($C_f = R_f + D_f$) of Tanner crab on an annual basis in several fisheries (the directed Tanner crab fishery, the snow crab fishery, the Bristol Bay red king crab fishery, and the groundfish fisheries), as well as accounting for the associated mortality in the population dynamics for the Tanner crab stock. As a clarification of terminology, C_f is the total number of crab *captured* (i.e.,

brought on board) in fishery f , and D_f is the number of crab discarded (i.e. released overboard), not the numbers killed. Unlike many fish species, crabs captured at sea and brought on deck experience little barotrauma and, while some fraction of those subsequently discarded overboard die as a result, the remaining discarded crab survive and continue to contribute to the stock. Experimental lab and observational field studies suggest that discard mortality on Tanner crab captured in the crab fisheries is moderate; a value of 50% has been used in past assessments as the discard mortality fraction for these fisheries. Discard mortality in the groundfish fisheries is assumed to be higher because of gear differences (trawl vs. pot); we use 80% as the discard mortality fraction for Tanner crab in the groundfish fisheries. Total mortality, M_f , of Tanner crab in fishery f is then given by $M_f = R_f + \delta_f \cdot D_f$, where δ_f is the discard (i.e., “handling”) mortality fraction in the fishery. So the number of crabs captured by a fishery is more than the number of crabs killed, because discard mortality is not 100%. Because capture, retention and discard processes in the fisheries are sex- and size-dependent, as well as being dependent on shell condition and maturity state, the TCSAM model applies these concepts to individual components of the population (e.g. mature, new shell males between 100 and 105 mm CW) and then sums up the individual contributions to obtain stock-level and fishery-level totals.

For some component (e.g. mature, new shell males between 100 and 110 mm CW) of a population experiencing mortality from several fisheries, the short term change in numbers, N , can be described by the following differential equation:

$\frac{dN}{dt} = - \left(m + \sum_f F_f \right) \cdot N(t)$	Rate of change of N over a short period of time	1
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where m represents the rate of natural mortality and F_f represents the fishing mortality rate associated with the f th fishery on this component of the population (i.e., F_f includes size-dependent selectivity). The solution to this equation, assuming that m and the F_f 's are constant over the period, is

$N(t) = e^{-(m+F_T) \cdot t} \cdot N_0$	Change in N with time	2
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where $F_T = \sum_f F_f$ is the rate of total fishing mortality experienced by population component. The cumulative numbers killed by each fishery, M_f , are described by the equation

$\frac{dM_f}{dt} = F_f \cdot N(t) = F_f \cdot e^{-(m+F_T) \cdot t} \cdot N_0$	Rate of change of the numbers killed by fishery f	3
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which has the solution

$M_f(t) = \frac{F_f}{m + F_T} \cdot [1 - e^{-(m+F_T) \cdot t}] \cdot N_0$	Cumulative numbers killed by fishery f	4
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As discussed above, in fisheries that discard part of the catch, and part of that discarded catch may survive, the numbers *captured* (i.e., brought on board) by the fishery are different from those actually

killed by the fishery. Letting ϕ_f denote the *capture rate* associated with fishery f , the cumulative numbers captured in this fishery, C_f , are described by

$\frac{dC_f}{dt} = \phi_f \cdot N = \phi_f \cdot e^{-(m+F_T) \cdot t} \cdot N_0$	Rate of change of the numbers captured by fishery f	5
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which has the solution

$C_f(t) = \frac{\phi_f}{m + F_T} \cdot [1 - e^{-(m+F_T) \cdot t}] \cdot N_0$	Numbers captured by fishery f	6
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where ϕ_f is the fishery capture rate. Of course, $C_f(t) = R_f(t) + D_f(t)$ (number captured = number retained plus number discarded) and $M_f(t) = R_f(t) + \delta_f \cdot D_f(t)$ (number killed = number retained plus number discarded that die due to handling) for this component of the population.

Letting ρ_f denote the fraction of $C_f(t)$ that is retained, then

$R_f(t) = \rho_f \cdot C_f(t)$	Numbers retained by fishery f	7
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and

$D_f(t) = (1 - \rho_f) \cdot C_f(t)$	Numbers discarded by fishery f	8
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so, substituting eq.s 7 and 8 into the equation for M_f , one obtains

$\begin{aligned} M_f(t) &= \rho_f \cdot C_f(t) + \delta_f \cdot (1 - \rho_f) \cdot C_f(t) \\ M_f(t) &= [\rho_f + \delta_f \cdot (1 - \rho_f)] \cdot C_f(t) \end{aligned}$	Numbers killed by fishery f	9
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Substituting eq.s 4 and 6 into eq. 9 and eliminating similar terms from both sides, one finds that the fishing mortality rate in the f th fishery is related to the capture rate ϕ_f in that fishery by:

$F_f = [\rho_f + \delta_f \cdot (1 - \rho_f)] \cdot \phi_f$	Fishing mortality rate for fishery f	10
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The above equations are based on continuous time models for the fishing and natural mortality processes. To convert these equations to those appropriate for a set of pulse fisheries conducted simultaneously (as used in the Tanner crab model), one takes the limit of the above equations as $t \rightarrow 0$ and the ϕ_f 's gets large such that $\phi_f \cdot t$ and ϕ_f / F_T remains constant, for each f . Letting $\phi_f \equiv \lim_{\substack{t \rightarrow 0 \\ \phi_f \rightarrow \infty}} \{\phi_f \cdot t\}$ for all

fisheries simultaneously, one obtains the following equations for a set of pulse fisheries in terms of ϕ_f , ρ_f , and δ_f :

$F_f = [\rho_f + \delta_f \cdot (1 - \rho_f)] \cdot \phi_f$	fishing <i>mortality</i> rate in fishery <i>f</i>	11
$F_T = \sum_f F_f$	Total fishing <i>mortality</i> rate	12
$N^+ = e^{-F_T} \cdot N_0$	Population numbers after fisheries	13
$C_f = \frac{\phi_f}{F_T} \cdot [1 - e^{-F_T}] \cdot N_0$	Numbers captured in fishery <i>f</i>	14
$R_f = \rho_f \cdot C_f = \frac{\rho_f \cdot \phi_f}{F_T} \cdot [1 - e^{-F_T}] \cdot N_0$	Numbers retained in fishery <i>f</i>	15
$D_f = (1 - \rho_f) \cdot C_f = \frac{(1 - \rho_f) \cdot \phi_f}{F_T} \cdot [1 - e^{-F_T}] \cdot N_0$	Numbers discarded in fishery <i>f</i>	16
$M_f = R_f + \delta_f \cdot D_f = [\rho_f + \delta_f \cdot (1 - \rho_f)] \cdot C_f$	Total mortality in fishery <i>f</i>	17
$DM_f = \delta_f \cdot (1 - \rho_f) \cdot C_f$	Discard mortality in fishery <i>f</i>	18

It is important to remember that all terms in eq.s 11-18 apply to individual components of the population, and not the entire population, on an annual basis. The TCSAM model decomposes the population by sex, maturity state, shell condition, and size. Thus, each of the quantities above, other than discard mortality δ_f (which is assumed to apply equally to all components of the discarded catch), can have additional subscripts *x* (sex), *m* (maturity), *s* (shell condition), *z* (size) (and *y*, year, to make the temporal component explicit).

On fitting the TCSAM2103 model

The TCSAM2013 model is parameterized, in part, based on annual fully-selected fishing mortality rates $F_{f,y,x,m,s}$, selectivity functions $S_{f,y,x,z}$ and retention functions $\rho_{f,y,x,z}$ (the latter non-zero only for males in the directed fishery, of course). The total (size selective) fishing mortality rate is given by

$F_{f,y,x,m,s,z} = F_{f,y,x,m,s} \cdot S_{f,y,x,z}$	Total mortality rate (retained+discard) for fishery <i>f</i>	19
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from which total annual fishing mortality (in biomass) estimated by the model is compared to the observed total fishing mortality (observed discard biomass discounted by assumed discard mortality added to the retained biomass) in the model's objective function.

The retained mortality *rate* in the model is given by

$r_{f,y,x,m,s,z} = \rho_{f,y,x,z} \cdot F_{f,y,x,m,s,z}$	Total retained mortality rate for fishery <i>f</i> (TCSAM2013)	20
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However, eq. 15 implies that the retained mortality rate is given by

$r_{f,y,x,m,s,z} = \rho_{f,y,x,z} \cdot \phi_{f,y,x,m,s,z}$	Total retained mortality rate for fishery f (TCSAM-FRev)	21
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The simplest way to see that eq. 20 is inconsistent with the previous description of “retention” is to consider a fishery with no discard mortality, so that the only fishing mortality is due to retention. In this case, using eq. 11 with $\delta_f = 0$, one finds that the total fishing mortality rate is related to the capture rate by $F_{f,y,x,m,s,z} = \rho_{f,y,x,z} \cdot \phi_{f,y,x,m,s,z}$, so that applying eq. 20 to obtain the retention mortality rate yields $r_{f,y,x,m,s,z} = \rho_{f,y,x,z}^2 \cdot \phi_{f,y,x,m,s,z}$ in eq. 21—the retention function is doubly-applied.

However, the overall effect in terms of model fit and parameter estimation is probably small. It depends on the steepness of the rise of the retention curve $\rho_{f,y,x,z}$, and is smaller for steeper curves. While not step functions, the retention curves for Tanner crab tend to be fairly steep.

TCSAM-FRev thus models the size-specific fishing mortality rate in the directed fishery using

$$F_{y,z} = (h \cdot [1 - \rho_z] + \rho_z) \cdot \phi_{y,z}$$

where h is handling mortality, ρ_z is the size-specific “retention function” that reflects the on-board sorting process, and $\phi_{y,z}$ is the fishery capture rate for crab of size z in year y . In this formulation, $\phi_{y,z}$ reflects the rate at which crab are brought on deck, ρ_z is the fraction of crab captured (not killed) that are retained (and thus die), and h is the fraction of discarded crab ($[1 - \rho_z]$) that die due to handling. The equation that describes the fishing mortality rate due to retention is simply

$$r_{y,z} = \rho_z \cdot \phi_{y,z}$$

The fishery capture rate $\phi_{y,z}$ in the revised model is treated with the same assumptions that $F_{y,z}$ is treated with in TCSAM2013: it is modeled as a separable function of size and year

$$\phi_{y,z} = \phi_y \cdot S_z$$

where ϕ_y is the “fully-selected” capture rate in year y and S_z is the size-specific capture selectivity. ϕ_y is parameterized in a similar fashion to the fully-selected fishing mortality rate F_y in TCSAM2013. The capture selectivity S_z and retention function ρ_z are also parameterized in the same way as selectivity and the retention function r_z in TCSAM2013.

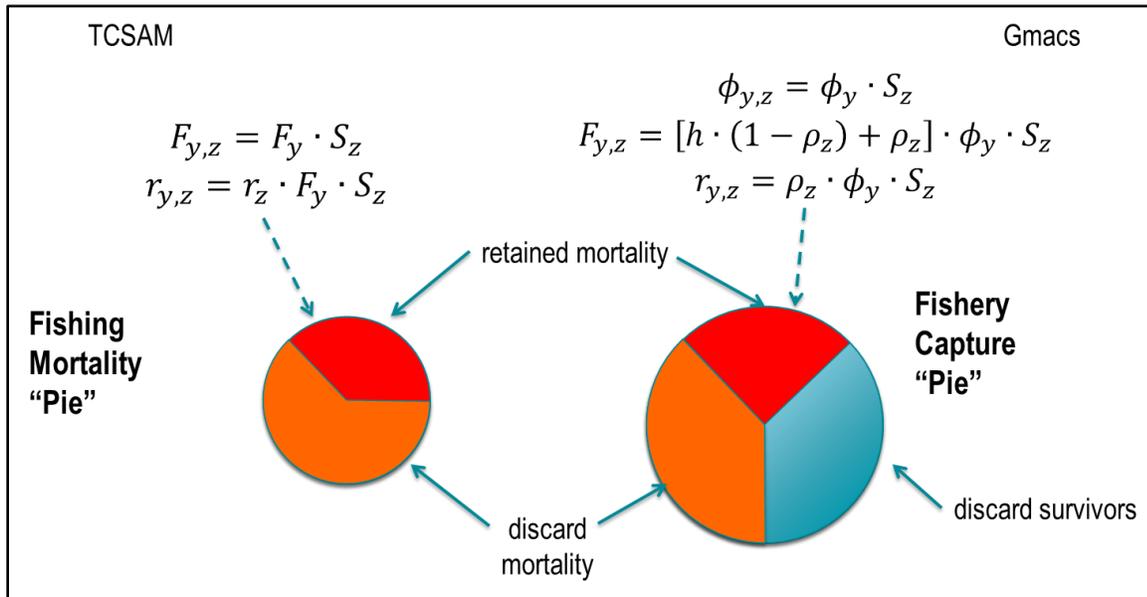
Literature Cited

Crab Plan Team. 2014. Crab Modeling Report.

<https://npsfmc.legistar.com/View.ashx?M=F&ID=2865420&GUID=4C36935D-865B-4880-8A3A-D93CACC3C37C>

Whitten, A.R., A.E. Punt, J.N. Ianelli. 2014. Gmacs: Generalized Modeling for Alaskan Crab Stocks. http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/crab/Whitten%20et%20al%202014%20-%20Gmacs%20Model%20Description.pdf

Figures



A4. Figure 1. Comparison of models for fishing mortality in TCSAM2013 (left) and Gmacs (right). The *areas* associated with retained mortality and discard mortality are the same in both pies. r_z is the fraction of the fishing mortality pie related to retained crab. ρ_z is the fraction of the fishery capture pie related to retained crab.