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

2016 Final Crab SAFE

Compiled by

The Plan Team for the King and Tanner Crab Fisheries
of the Bering Sea and Aleutian Islands

With Contributions by

K. Bush, M. Dorn, G. Eckert, R.J. Foy,
B. Garber-Yonts, T. Hamazaki, J. N. Ianelli, A.E. Punt,
L. Rugolo, M.S.M. Siddeek, W. Stockhausen, L. Slater, D. Stram,
C. Szuwalski, B. J. Turnock, D. Weber and J. Zheng

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North Pacific Fishery Management Council
605 W. 4th Avenue, #306
Anchorage, AK 99501

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

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2016 Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries in the Bering Sea and Aleutian Islands

Introduction

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

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

The Crab Plan Team (CPT) annually assembles the SAFE report with contributions from ADF&G and the NMFS. This SAFE report is presented to the North Pacific Fishery Management Council (NPFMC) and is available to the public on the NPFMC web page at: http://fakr.noaa.gov/npfmc/membership/plan_teams/CRAB_team.htm. Under a revised process modified to accommodate specific fishery and data availability needs to determine overfishing level (OFL) determinations, and annual catch limit (ACL) requirements the CPT reviews assessments in a staggered time frame. The CPT reviews one assessment in January (Norton Sound red king crab), three assessments in May (Aleutian Islands golden king crab, WAI red king crab and Pribilof Islands golden king crab) and the remaining assessments (Bristol Bay red king crab, EBS snow crab, EBS Tanner crab, Saint Matthew blue king crab, Pribilof Island red king crab and Pribilof Island blue king crab) in September (Table 1).

Table 1 Ten BSAI crab stocks and the schedule for annual review by the CPT and SSC

Stock	*CPT review and recommendations to SSC*	*SSC review and recommendations to Council*
Norton Sound red king crab (NSRKC)	January	February
Aleutian Is. golden king crab (AIGKC)	May	June
Pribilof Is. golden king crab (PIGKC)	May	June
Western Aleutian Is. red king crab (WAIRKC)	May	June
EBS snow crab	September	October
Bristol Bay red king crab(BBRKC)	September	October
EBS Tanner crab	September	October
Pribilof Is. red king crab (PIRKC)	September	October
Pribilof Is. blue king crab (PIBKC)	September	October
Saint Matthew blue king crab (SMBKC)	September	October

The CPT provides recommendations on OFL, acceptable biological catch (ABC) and stock status specifications for review by the NPFMC Science and Statistical Committee (SSC) in February (NSRKC) and June (AIGKC, WAIRKC, PIGKC) and October (BBRKC, EBS Snow crab, EBS Tanner crab, SMBKC, PIRKC, PIBKC). The rationale for this staggered review process is the following: The stocks with summer fisheries as well as those established on catch data only have specifications set in June. The stocks which employ data from the EBS NMFS trawl survey thus cannot be assessed until survey data are available in early September. Summer catch data for NSRKC however are not available in time for fall specifications, nor is assessing this stock with the June timing feasible as the CDQ fishery can open as early as May thus this stock is assessed in the winter. Additional information on the OFL and ABC determination process is contained in this report.

The CPT met from September 20-23, 2016 in Seattle, WA to review the final stock assessments as well as additional related issues, in order to provide the recommendations and status determinations contained in this SAFE report. This final 2016 Crab SAFE report contains all recommendations for all 10 stocks including those whose OFL and ABC were previously determined in February and June 2016. This SAFE report will be presented to the NPFMC in October for their annual review of the status of BSAI Crab stocks. Members of the team who participated in this review include the following: Bob Foy (Chair), Karla Bush (Vice-Chair), Laura Slater, Miranda Westphal, Brian Garber-Yonts, Ginny Eckert, Gretchen Harrington, André Punt, Buck Stockhausen, Martin Dorn, Shareef Siddeek, Jack Turnock and Diana Stram.

Stock Status Definitions

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

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

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

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

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

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

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

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

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

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

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

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

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

Status Determination Criteria

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

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

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

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

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

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

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

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

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

<u>Five-Tier System</u>

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

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

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

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

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

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

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

Stock assessment documents shall:

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

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

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

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

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

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

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

Tiers 1 through 3

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

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

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

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

Tier 4

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

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

If the information necessary to determine total catch OFLs and ACLs is available for a Tier 4 stock, then the OFL and ACL will be total catch limits comprised of three catch components: (1) non-directed fishery discard losses; (2) directed fishery discard losses; and (3) directed fishery retained catch. If the information necessary to determine total catch OFLs and ACLs is not available for a Tier 4 stock, then the OFL and

ACL are determined for retained catch. In the future, as information improves, data would be available for some stocks to allow the formulation and use of selectivity curves for the discard fisheries (directed and non-directed losses) as well as the directed fishery (retained catch) in the models. The resulting OFL and ACL from this approach, therefore, would be the total catch OFL and ACL.

Tier 5

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

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

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

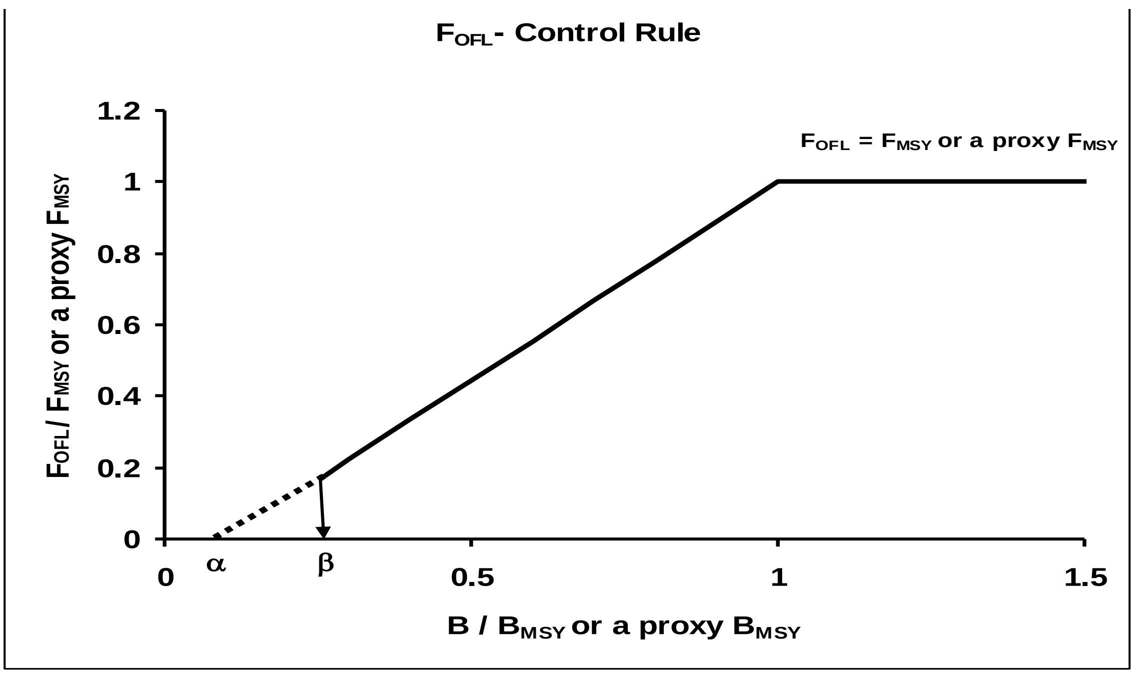

Table 1 Five-Tier System for setting overfishing limits (OFLs) and Acceptable Biological Catches (ABCs) for crab stocks. The tiers are listed in descending order of information availability. Table 2 contains a guide for understanding the five-tier system.

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

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

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

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

Crab Plan Team Recommendations

Table 3 lists the team's recommendations for 2016/2017 on Tier assignments, model parameterizations, time periods for reference biomass estimation or appropriate catch averages, OFLs and ABCs. The team recommends three stocks be placed in Tier 3 (EBS snow crab, Bristol Bay red king crab and EBS Tanner crab), four stocks in Tier 4 (St. Matthew blue king crab, Pribilof Islands blue king crab, Pribilof Islands red king crab, and Norton Sound red king crab) and three stocks in Tier 5 (AI golden king crab, Pribilof Islands golden king crab, and Adak red king crab). Table 4 lists those stocks for which the team recommends an ABC less than the maximum permissible ABC for 2016/17. Stock status in relation to status determination criteria are evaluated in this report (Table 5). Status of stocks in relation to status determination criteria for stocks in Tiers 3 and 4 are shown in Figure 2. EBS Tanner crab and Pribilof Island red king crab are estimated to be above B_{MSY} for 2016/17 while snow crab, Bristol Bay red king crab, Saint Matthew blue king crab and Norton Sound red king crab are estimated below B_{MSY}. Pribilof Islands blue king crab stock remains overfished and estimated to be well below its MSST.

The CPT has general recommendations for all assessments and specific comments related to individual assessments. All recommendations are for consideration for the 2017 assessments. The general comments are listed below while the comments related to individual assessments are contained within the summary of CPT deliberations and recommendations contained in the stock specific summary section. Additional details regarding recommendations are contained in the Crab Plan Team Report (September 2016 CPT Report).

General recommendations for all assessments

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

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

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

Stock Status Summaries

1 Eastern Bering Sea Snow crab

Fishery information relative to OFL setting

Total catch mortality in 2015/16 was 21,400 t (with discard mortality rates applied), while the retained catch in the directed fishery was 18,400 t. This was below the 2015/16 OFL of 61,500 t. Snow crab bycatch occurs in the directed fishery and to a lesser extent in the groundfish trawl fisheries. Estimates of trawl bycatch in recent years are less than 1% of the total snow crab catch. Estimates of stock status were above the B_{MSY} proxy for this stock ($B_{35\%}$) in 2010/11-2012/13, but below the B_{MSY} proxy more recently. For 2016/17, the ratio of projected MMB (91.6 t) fishing at the F_{OFL} to B_{MSY} (151,800 t) remains less than 1 but above 0.5.

Data and assessment methodology

The stock assessment is based on a size- and sex-structured model in which crabs are categorized into immature or mature and new or old shell. The model is fitted to abundance and size frequency data from the NMFS trawl survey, total catch data from the directed fishery, bycatch data from the trawl fishery, size frequency data for male retained catch in the directed fishery, and male and female bycatch in the directed and trawl fisheries. The model is also fitted to biomass estimates and size frequency data from the 2009 and 2010 BSFRF surveys. Updated data in the model include biomass and length frequency data from the 2016 NMFS Eastern Bering Sea trawl survey, retained and discard catch and length frequencies from the 2015/16 directed fishery, and discard catch and length frequencies from the 2015/16 groundfish fisheries, and five new observations of individual crab molt increments. Weight-at-size relationships were also updated, reflecting a re-analysis of previously-collected data from the NMFS trawl survey.

The model estimation structure did not change from the 2015 assessment, but the status determination and OFL calculations were incorporated directly within the model code. This allowed the author to employ a Bayesian approach to determining OFL, by using Markov Chain Monte Carlo (MCMC) techniques to sample the posterior distributions of relevant quantities that more fully incorporated model uncertainty than was possible with the methods used previously.

The assessment author examined six model scenarios in this assessment. Model 0 was equivalent to the September 2015 assessment model. Model 1 included a number of changes from Model 0, including: 1) estimating average F for the groundfish bycatch (it was previously specified), 2) removing penalties on F for 1992-present, 3) estimating a separate vector of F-devs for 1978-1990 and 1991-present, and 4) estimating a constant of proportionality between fishing effort and F for females in the directed fishery. Model 2 included all changes in Model 1 and additionally removed the priors on the sex/size-specific probabilities of molting-to-maturity (i.e., undergoing terminal molt). Model 3 included all changes in Model 2, but also increased the weight on the smoothness penalty for the probabilities of molt-to-maturity and estimated the 50%-selected parameter for female discards. Model 3a decreased effective sample sizes for survey composition data by applying the Francis weighting methodology, but was otherwise similar to Model 3. Model 3b included all the changes in Model 3, but also increased the weighting in the female growth likelihood component and decreased the variance for the prior on natural mortality.

The author rejected Models 1, 2 and 3 based primarily on poor fits to the growth data. Model 0 was rejected because it had the worst fit to MMB in the terminal year. Although Model 3a fit the terminal year MMB the best of all the models, the author rejected this model because it did not fit the male growth data, fit the survey size composition data poorly in some years, and estimated high directed Fs in recent years. The author selected Model 3b as the preferred model because the penalties on the 1992–present fishing mortality rates were removed (these penalties have been shown to result in bias), the model fit the growth data as well or better than the other models, and it was the only model other than Model 0 that did not hit the bounds for its value on natural mortality. Values for OFL and projected MMB-at-mating were quite similar between Model 3b and Model 0. While $F_{35\%}$ and F_{OFL} for Model 3b were substantially larger than those for Model 0, the former were consistent with values from previous assessments. The CPT concurred with the author's recommendation, as well as his recommendation to use the median of the posterior distributions as values for 2016/17 $F_{35\%}$, $B_{35\%}$, projected MMB-at-mating, and OFL.

Stock biomass and recruitment trends

Observed survey mature male biomass decreased from 167,100 t in 2011 to 97,500 t in 2013, increased to 163,500 t in 2014, then fell to 80,000 t in 2015 and 63,200 t in 2016. The 2016 model estimates of mature male biomass showed trends similar to survey biomass during 2011–2016, except that the model failed to match the 1-year spike in survey biomass observed in 2014. Observed survey mature female biomass rose quickly from 52,200 t in 2009 to 175,800 t in 2011, its highest value since 1991, then decreased steadily to 55,400 t in 2016. Although the model matches the observed mature female survey biomass fairly well in 2016, the model estimates do not follow the observed rise and fall that started in 2009; instead, they indicate that mature female biomass was fairly constant across the 2009-2016 time period. The model estimates a 3-year trend of increasing recruitment starting in 2014, with very high values for 2016 (> 6 million). This is supported by the associated NMFS EBS survey size compositions, particularly for males.

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

The CPT recommends that the EBS snow crab is a Tier 3 stock so the OFL will be determined by the F_{OFL} control rule using $F_{35\%}$ as the proxy for F_{MSY}. The proxy for B_{MSY} ($B_{35\%}$) is the mature male biomass at mating (151.8 thousand t) based on average recruitment over 1978 to present. Consequently, the minimum stock size threshold (MSST) is 75.8 thousand t. The CPT recommends that the ABC be less than maximum permissible ABC. The CPT recommends using the standard buffer for Tier 3 stocks (10%) for setting the 2016/17 ABC due to model uncertainties and contradictions between model trends and survey and fishery observations.

Historical status and catch specifications for snow crab (thousand t). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2012/13	77.1	170.1[A]	30.1	30.1	32.4	67.8	61.0
2013/14	71.5	126.5[A]	24.5	24.5	28.1	78.1	70.3
2014/15	78.9	168.0[A]	30.8	30.8	34.3	69.0	62.1
2015/16	75.8	91.6	18.4	18.4	21.4	83.1	62.3
2016/17		96.1				23.7	21.3

Historical status and catch specifications for snow crab (million lb). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and *are not updated except for total and retained catch.*

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2012/13	170.0	375.0	66.4	66.4	71.4	149.5	134.5
2013/14	157.6	279.0	54.0	54.0	62.0	172.2	155.0
2014/15	173.9	370.4	67.9	67.9	75.4	152.1	137.0
2015/16	167.1	302.0	40.6	40.6	47.2	183.2	137.4
2016/17		201.9				52.2	47.0

2 Bristol Bay Red King Crab

Fishery information relative to OFL setting.

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

The current SOA harvest strategy allows a maximum harvest rate of 15% of mature-sized (≥120 mm CL) males, but also incorporates a maximum harvest rate of 50% of legal males and a threshold of 8.4 million mature-sized (≥90 mm CL) females and 14.5 million lb (6.6 thousand t) of effective spawning biomass (ESB), to prosecute a fishery. Annual non-retained catch of female and sublegal male RKC during the fishery averaged less than 3.9 million lb (8.6 thousand t) since data collection began in 1990. Total catch (retained and bycatch mortality) increased from 16.9 million lb (7.6 thousand t) in 2005/06 to 23.4 million lb (10.6 thousand t) in 2007/08, but has decreased since then; retained catch in 2015/16 was 10.17 million lb (4.61 thousand t) and total catch was 11.77 million lb (5.34 thousand t).

Data and assessment methodology

The stock assessment model is a sex- and size-structured population dynamics model incorporating data from the NMFS eastern Bering Sea trawl survey, the Bering Sea Fisheries Research Foundation (BSFRF) trawl survey, landings of commercial catch, at-sea observers, and dockside samplers. In the model recommended by the CPT, annual stock abundance was estimated for male and female crabs ≥ 65-mm carapace length from 1975 to the time of the 2016 survey and mature male (males ≥120 mm CL) biomass was projected to 15 February 2017. Catch data (retained catch numbers, retained catch weight, and pot lifts by statistical area and landing date) from the directed fishery, which targets males ≥ 135 mm (6.5 in carapace length), were obtained from ADF&G fish tickets and reports, red king crab and Tanner crab fisheries bycatch data from the ADF&G observer database, and groundfish trawl bycatch data from the NMFS trawl observer database. NMFS trawl survey data were updated with data from the 2016 survey and new estimates of survey variance provided by NMFS; catch and bycatch data were updated with data from the 2015/16 crab fishery year.

Three alternative models were evaluated in the 2016 assessment: model 1, the accepted model for the 2015 assessment, and two new models that explored alternative ways to incorporate recent BSFRF survey data (2013-2016) into the assessment. Model 1n is a straightforward addition of new survey data to the BSFRF survey time series for 2013-2016, which was modeled as independent time series, as in previous BBRKC assessments. Model 2 adopted the approach used in the snow crab assessment for modeling the BSFRF survey, in which the BSFRF survey provides information on availability of crab in the area covered by both surveys, and the NMFS survey is modeled with a selectivity pattern and a catchability parameter that reflects the proportion of the crab in the surveyed area that are captured by the NMFS trawl. This approach makes more extensive use of the BSFRF survey data, and relies on the assumption that the BSFRF survey captures all of the crab in front of the net. The CPT selected model 2 as its recommended model as the basis for status determination and OFL setting. The rationale for selecting model 2 was following. First, the overall fit to the data (particularly the NMFS survey length composition) was improved with model 2. Second, the approach was consistent with how the BSFRF survey data has been used in the snow crab model. Finally, the estimated selectivity/availability curves for the BSFRF survey were considered more plausible for model 2.

Stock biomass and recruitment trends

Model (scenario 2) estimates of total survey biomass increased from 252.3 thousand t in 1975 to 300.2 thousand t in 1977, fell to 34.9 thousand t in 1985, generally increased to 91.7 thousand t in 2007, and subsequently declined to 65.7 thousand t in 2016. Estimated recruitment was high during the 1970s and early 1980s and has been generally low since 1985. The near-term outlook for this stock is a continued gradual declining trend. Recruitment has been poor (less than the mean from 1984-2016) since 2006. The 2011 survey produced a high catch of juvenile males and females <65 mm CL in one survey tow but that catch did not track into the 2012−2016 surveys. The survey area-swept estimates for abundance and biomass in 2015-2016 were more consistent with previous surveys, in comparison to 2014, when the estimates were anomalously high.

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

Bristol Bay red king crab is in Tier 3. Based on the author's discussion regarding an apparent reduction in stock productivity associated with the 1976/77 climate regime shift in the EBS, the CPT continues to recommend computing average recruitment based on model recruitment using the time period 1984 (corresponding to fertilization in 1977) to the last year of the assessment. The estimated $B_{35\%}$ is 25.8 thousand t). MMB projected for 2016/17 is 24.0 thousand t, 93% of $B_{35\%}$. Consequently, the BBRKC stock is in Tier 3b in 2016/17.

The team recommends that the OFL for 2016/17 be set according to model scenario 2, for which the calculated OFL is 6.64 thousand t (14.63 million lb). The team recommends that the ABC for 2016/17 be set below the maximum permissible ABC. The team recommends that a 10% buffer from the OFL be used to set the ABC at 5.97 thousand t (13.17 million lb).

MMB for 2015/16 was estimated to be 27.68 thousand t and above MSST (12.89 thousand t); hence the stock was not overfished in 2015/16. The total catch in 2015/16 (5.34 thousand t) was less than the 2015/16 OFL (6.73 thousand t); hence overfishing did not occur in 2015/16. The stock at 2016/17 time of mating is projected to be above the MSST and 93% of $B_{35\%}$ (see above); hence the stock is not projected to be in overfished condition in 2016/17.

Historical status and catch specifications for Bristol Bay red king crab (thousand t). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical *assessments and are not updated except for total and retained catch.*

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2012/13	13.19	29.05	3.56	3.62	3.90	7.96	7.17
2013/14	12.85	27.12	3.90	3.99	4.56	7.07	6.36
2014/15	13.03	27.25	4.49	4.54	5.44	6.82	6.14
2015/16	12.89	27.68	4.52	4.61	5.34	6.73	6.06
2016/17		24.00				6.64	5.97

Historical status and catch specifications for Bristol Bay red king crab (million lb). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2012/13	29.1	64.0	7.85	7.98	8.59	17.55	15.80
2013/14	28.3	59.9	8.60	8.80	10.05	15.58	14.02
2014/15	28.7	60.1	9.99	10.01	11.99	15.04	13.53
2015/16	28.4	61.0	9.97	10.17	11.77	14.84	13.36
2016/17		52.9				14.63	13.17

3 Eastern Bering Sea Tanner crab

Fishery information relative to OFL setting.

Eastern Bering Sea (EBS) Tanner crabs are caught in a directed Tanner crab fishery, and as bycatch in the groundfish fisheries, scallop fisheries, the directed Tanner crab fishery (mainly as non-retained females and sublegal males), and other crab fisheries (notably, eastern Bering Sea snow crab and, to a lesser extent, Bristol Bay red king crab). A single OFL is set for Tanner crab in the EBS. Under the Crab Rationalization Program, ADF&G sets separate TACs for directed fisheries east and west of 166° W longitude. Both fisheries were closed from 1997 to 2004 due to low abundance. In 2005/06, abundance increased to a level to support a fishery in the area west of 166° W longitude. ADF&G opened both fisheries for the 2006/07 to 2008/09 crab fishing years, and to the area east of 166° W longitude only in 2009/10.

The mature male biomass was estimated to be below the Minimum Stock Size Threshold ($0.5B_{MSY}$) in February 2010 (the assumed time of mating) based on trends in mature male biomass from the survey, and NMFS declared the stock overfished in September 2010. The directed fisheries were closed from 2010/11 through 2012/13 crab fishery years. NMFS determined the stock was not overfished in 2012 based on a new assessment model with a revised estimate of B_{MSY}. The fishery was opened for the 2013/14 season with total allowable catch (TAC) of 746.2 t (1,645,000 lb) for the area west of 166° W longitude and 663.6 t (1,463,000 lb) for the area east of 166° W longitude (combined = 1.41 thousand t ; 3.11 million lb,) and for the 2014/15 season with TAC of 2,328.7 t (6,625,000 lb) for the area west of 166° W longitude and 3,829.3 t (8,480,000 lb) for the area east of 166° W longitude (6.85 thousand t ; 15.10 million lb,). Total retained catch in the 2014/15 season was 6.16 thousand t (13.58 million lb): 2.33 thousand t (6.63 million lb) from the area west of 166° W longitude and 3.83 thousand t (8.48 million lb) from the area east of 166° W longitude. The total retained catch in 2015/16 (8,910 t) was the largest taken in the fishery since 1992/93.

Data and assessment methodology

The SSC accepted the stock assessment model for use in harvest specifications in 2012 and classified the EBS Tanner stock as a Tier 3 stock. The current model structure, based on crab size, sex, shell condition, and maturity, is the same as in the 2015 assessment. The model uses available data on the magnitude and size-composition from: the NMFS trawl survey; landings and discards by the directed fishery; bycatch in the Bristol Bay red king crab, EBS snow crab, and groundfish fisheries. The model includes prior distributions on parameters related to natural mortality and catchability, and penalties on changes in recruitment and in the proportion maturing. New input data were added to the time series for the 2016 assessment and updates or corrections to previously used data were made: the current “standard” dataset for crab from the NMFS EBS trawl survey, 1975−2016, with use of current standard NMFS estimator for weight-from-width; a correction to the 2014/15 fishery data used in the 2015 assessment; the retained catch, bycatch, and size composition data from the 2015/16 crab fisheries; and data on Tanner crab bycatch in the groundfish fisheries in 2015/16.

Stock biomass and recruitment trends

The MMB at the time of mating is estimated to have been highest early in the early 1970s (approximately 300 thousand t), with secondary peaks in 1989 (60 thousand t) and 2008 – 2009 (57 – 58 thousand t). The estimated MMB at time of mating in 2015 is 73.93 thousand t and the projection for the 2016 time of mating is 45.34 thousand t. Estimates of recruitment since 1999 have been generally low relative to the peaks estimated for the period prior to 1990 and estimates of recruitment in the last four years are below the 1982 – 2016 average.

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

The team recommends the OFL for this stock be based on the Tier 3 control rule. Application of the Tier 3 control rule requires a set of years for defining R_{MSY}, the mean recruitment corresponding to B_{MSY} under prevailing environmental conditions. The recommended time period for defining R_{MSY} is 1982 – 2016; the 1982-and-onwards time period has been used in previous OFL determination and follows the most-recent recommendation of the SSC.

Based on the estimated biomass at 15 February 2017, the stock is at Tier 3 level a. The F_{MSY} proxy ($F_{35\%}$) is 0.58 yr^{-1}, and the 2015/16 F_{OFL} is 0.58 yr^{-1} under the Tier 3 level a OFL Control Rule, which results in a total male and female OFL of 25.61 thousand t. The CPT recommends a 20% buffer to account for model uncertainty and stock productivity uncertainty be applied to the OFL, to set ABC = 20.49 thousand t. The 2016/17 OFL is estimated from an updated model. The 20% buffer is the same that the SSC recommended for determination of the 2015/16 ABC.

Historical status and catch specifications for Eastern Bering Sea Tanner crab (thousand t). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2012/13	16.77	59.35	0	0	0.71	19.02	8.17
2013/14	16.98	72.70	1.41	1.26	2.78	25.35	17.82
2014/15	13.40	71.57	6.85	6.16	9.16	31.48	25.18
2015/16	12.82	73.93	8.92	8.91	11.38	27.19	21.75
2016/17		45.34				25.61	20.49

Historical status and catch specifications for Eastern Bering Sea Tanner crab (million lb). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2012/13	36.97	130.84	0.00	0.00	1.57	41.93	18.01
2013/14	37.43	160.28	3.12	2.78	6.13	55.89	39.29
2014/15	29.53	157.78	15.10	13.58	20.19	69.40	55.51
2015/16	28.27	162.99	19.67	19.64	25.09	59.94	47.95
2016/17		99.95				56.46	45.17

4 Pribilof Islands red king crab

Fishery information relative to OFL setting

The Pribilof Islands red king crab fishery began in 1973 as bycatch during the blue king crab fishery. In 1993 and 1994 the red king crab fishery was open to directed fishing and blue king crab was closed. From 1995 through 1998, combined Pribilof Islands red and blue king crab GHLs were used. Declines in crab abundance of both red and blue king crab stocks from 1996 to 1998 resulted in poor fishery performance with annual harvests below the GHLs. The Pribilof red king crab fishery has been closed since 1999 due to uncertainty in estimated red king crab abundance and concerns for bycatch mortality of blue king crab, which is overfished and severely depressed. Fishery closures near the Pribilof Islands have resulted in low bycatch, recent catches have been well below the OFL, ranging from <0.001 to 0.029 t (0.32 to 13.1 million pounds; 2011/12–2015/16).

Data and assessment methodology

The 2016 assessment is based on trends in male mature biomass (MMB) at the time of mating inferred from NMFS bottom trawl survey from 1975-2016 and commercial catch and observer data from 1973/74 to 2015/16. Four assessment methods were presented for evaluation: one calculated an annual index of MMB derived as the 3-yr running average using inverse variance weighting; the second was a random effects model; the third was an integrated length-based assessment model using tier 3 harvest control rules; and the fourth was an integrated length-based assessment model using tier 4 harvest control rules. The running average method with a tier 4 HCR was selected in 2016 by the CPT as the model to determine the OFL and ABC based on concerns around lack of convergence of the random effects model using Francis weighting at low values (further work evaluating process error or universal weighting for measurement error was recommended) and different trends over the last decade between the integrated model and the running average and the lack of fit of the integrated model to survey abundance data.

Stock biomass and recruitment trends

Male and female abundance varies widely over the history of the survey time series and uncertainty around area-swept estimates of abundance are large due to relatively low sample sizes.
Recruitment for this stock is episodic, and has been low in recent years. Numbers at length vary dramatically from year to year; however, two (possibly three) cohorts can be seen moving through the length frequencies over time. MMB_{mating} increased over 2011 to 2015. Estimates for the 3-year moving average for MMB_{mating} have recently returned to levels exceeding those estimated during the early 1990s, peaking in 2015 at 13,685 t (30.2 million pounds).

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

The assessment included the status quo approach (a 3-year inverse-variance running average) as well as multiple scenarios using a random effects model and an integrated length-based assessment model. The CPT recommended using the 3-year inverse-variance running average assessment, and to remain in Tier 4 for stock status level determination. For 2016/17 the B_{MSY} = 5,512 t derived as the mean MMB_{mating} from 1991/92 to 2015/16. Male mature biomass at the time of mating for 2016/17 was estimated at 6,980 t. The B/B_{MSY} = 1.25 and F_{OFL}=0.18. $B/B_{MSY\ Proxy}$ is > 1, therefore the stock status level is *a*. For the 2016/17 fishery, the OFL is 1,462 t (3.2 million lb).

The CPT recommended a 25% buffer for an ABC from the OFL.

Historical status and catch specifications for Pribilof Islands red king crab (t). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2012/13	2,609	4,025	0	0	13.1	569	455
2013/14	2,582	4,679	0	0	2.25	903	718
2014/15	2,871	8,894	0	0	1.06	1,359	1,019
2015/16	2,756	9,062				2,119	1,467
2016/17		6,980				1,462	1,096

Historical status and catch specifications for Pribilof Islands red king crab (million lb). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2012/13	5.75	8.87	0	0	0.029	1.25	1.00
2013/14	5.66	10.32	0	0	0.005	1.99	1.58
2014/15	6.33	19.61	0	0	0.002	3.00	2.25
2015/16	6.08	19.98				4.67	3.23
2016/17		15.39				3.22	2.42

The stock was above MSST in 2015/16 and is hence not overfished. Overfishing did not occur during the 2015/16 fishing year.

5 Pribilof Islands blue king crab

Fishery information relative to OFL setting.

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

The stock was declared overfished in 2002 and a rebuilding plan implemented in 2004. The rebuilding plan closed directed fishing for Pribilof blue king crab until the stock was rebuilt. In 2009, NMFS determined the stock would not meet its 10-year rebuilding horizon. Subsequently, Amendment 43 to the King and Tanner Crab FMP and Amendment 103 to the BSAI Groundfish FMP were approved by the Secretary of Commerce in 2014. This action, a revised rebuilding plan, closed the Pribilof Island Habitat Conservation Zone to Pacific cod pot fishing, which accounts for the highest recent rates of bycatch of this stock. This area was already closed to groundfish trawl fishing. To prevent overfishing in the future, ADF&G will implement closure areas for the western Tanner crab fishery to reduce the blue king crab bycatch. NMFS recently implemented a procedure to account for blue king crab bycatch in the groundfish fisheries inseason and will take inseason action to prevent overfishing.

Data and assessment methodology

The calculation of the 2016/17 survey biomass uses the stock area definition established in 2012/13 that includes an additional 20 nm strip east of the Pribilof District. This assessment changes the method used to project MMB and calculate B_{MSY}. Prior to this assessment, MMB for the current year was estimated from the NMFS EBS bottom trawl survey using a three-year running average weighted by the inverse of the variance of the area-swept estimate. The CPT recommended a new method to calculate MMB and B_{MSY} that uses a random effects model to smooth the survey time series. This model smooths the MMB estimates without low abundance estimates having undue influence. Differences in abundance estimates from the two methods were largest during periods of high inter-annual variability. Differences between the methods were small in recent years. Results from this method are shown in the 2015/16 MMB and 2016/2017 projected MMB.

In 2015/2016, bycatch increased to 1.184 t and exceeded the OFL. Most female and male bycatch mortality occurred in the hook-and-line fishery for Pacific cod and groundfish non-pelagic trawl fishery (1.018t). A small amount of PIBKC bycatch occurred in the Tanner crab fishery (0.166t). Appendix B to the PIBKC stock assessment provides additional analyses of bycatch data.

Stock biomass and recruitment trends

The 2016/17 MMB at mating is projected to be 233 t, which is approximately 6% of the proxy for B_{MSY}. The Pribilof blue king crab stock biomass continues to be low with no indication of recruitment.

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

This stock is recommended for placement into Tier 4. B_{MSY} was estimated using the time periods 1980/81 -1984/85 and 1990/91-1997/98. This range was chosen because it eliminates periods of extremely low abundance that may not be representative of the production potential of the stock. B_{MSY} is estimated at 4,116 t (9.07 million pounds) for 2016/17.

Because the projected 2016/17 estimate of MMB is less than 25% B_{MSY}, the stock is in stock status c and the directed fishery F is 0. However, an F_{OFL} must be determined for the non-directed catch. Ideally this should be based on the rebuilding strategy. For this stock the F_{OFL} is based on average groundfish bycatch between 1999/00 and 2005/06. The recommended OFL for 2016/17 is 1.16 t (0.003 million lb).

The CPT recommended setting the ABC less than the maximum permissible by employing a 25% buffer on the OFL. This recommendation was based upon continuing concerns with stock status and consistency with relative buffer levels for other stocks for which the OFL is based upon average catch.

Historical status and catch specifications for Pribilof Islands blue king crab (t). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2012/13	1,994	579	Closed	0	0.61	1.16	1.04
2013/14	2,001	225	Closed	0	0.03	1.16	1.04
2014/15	2,055	344	Closed	0	0.07	1.16	0.87
2015/16	2,058	361	Closed	0	1.18	1.16	0.87
2016/17		233				1.16	0.87

Historical status and catch specifications for Pribilof Islands blue king crab (million lb). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2012/13	4.39	1.28	Closed	0	0.0013	0.003	0.002
2013/14	4.41	0.50	Closed	0	0.0001	0.003	0.002
2014/15	4.53	0.76	Closed	0	0.0002	0.003	0.002
2015/16	4.54	0.79	Closed	0	0.0026	0.003	0.002
2016/17		0.51				0.003	0.002

The total catch for 2015/16 (1.18 t, 0.003 million lb) was slightly larger than the 2015/16 OFL (1.16 t, 0.003 million lb) so overfishing did occur during 2015/16. The 2016/17 projected MMB estimate of 233 t (0.51 million lb) is below the proxy for MSST (MMB/B_{MSY} = 0.06) so the stock is projected to continue to be in an overfished condition.

6 St. Matthew blue king crab

Fishery information relative to OFL setting

The fishery was prosecuted as a directed fishery from 1977 to 1998. Harvests peaked in 1983/84 when 4,288 t (9.454 million lb) were landed by 164 vessels. Harvest was fairly stable from 1986/87 to 1990/91, averaging 568 t (1.252 million lb) annually. Harvest increased to a mean catch of 1,496 t (3.297 million lb) during the 1991/92 to 1998/99 seasons until the fishery was declared overfished and closed in 1999 when the stock size estimate was below the MSST. In November of 2000, Amendment 15 to the FMP was approved to implement a rebuilding plan for the St. Matthew Island blue king crab stock. The rebuilding plan included a harvest strategy established in regulation by the Alaska Board of Fisheries, an area closure to control bycatch, and gear modifications. In 2008/09 and 2009/10, the MMB was estimated to be above B_{MSY} for two years and the stock declared rebuilt in 2009.

The fishery re-opened in 2009/10 with a TAC of 529 t (1.167 million lb) and 209 t (0.461 million lb) of retained catch were harvested. The 2010/11 TAC was 726 t (1.600 million lb) and the fishery reported a retained catch of 573 t (1.264 million lb). The 2011/12 harvest of 853 t (1.881 million lb) represented 80% of the 1,152 t (2.539 million lb) TAC. In 2012/13, by contrast, harvesters landed 99% (733 t ,1.616 million lb) of a reduced TAC of 740 t (1.630 million lb), though fishery efficiency, at about 10 crab per pot, was little changed from what it had been in each of the previous three years. The directed fishery was closed in 2013/14 due to declining trawl survey estimates of abundance and concerns about the health of the stock. The directed fishery resumed again in 2014/15 with a TAC of 300 t (0.655 million pounds), but the fishery performance was relatively poor with the retained catch of 140 t (0.309 million pounds). The TAC in 2015/16 was 190 t (0.410 million pounds) with a retained catch of 50 t (0.105 million pounds). Bycatch of non-retained blue king crab has been observed in the St. Matthew blue king crab fishery, the eastern Bering Sea snow crab fishery, and trawl and fixed-gear groundfish fisheries. Based on limited observer data, bycatch of sublegal male and female crabs in the directed blue king crab fishery off St. Matthew Island was relatively high when the fishery was prosecuted in the 1990s, and total bycatch (in terms of number of crabs captured) was often twice as high or higher than total catch of legal crabs.

Data and assessment methodology

This assessment is done using GMACS which was accepted for use by the CPT in May 2016 and the SSC in June 2016. The model is based upon the 3-stage length-based assessment model first presented in May 2011 by Bill Gaeuman and accepted by the CPT in May 2012. There are several differences between the GMACS assessment model and the previous model. One of the major differences being that natural and fishing mortality are continuous within 5 discrete seasons (using the "correct" catch equation rather than being applied as a pulse). Season length in Gmacs is controlled by changing the proportion of natural mortality that is applied during each season.

The GMACS is used to assess the male crab ≥90 mm CL. The three size categories are: 90–104 mm CL; 105–119 mm CL; and ≥120 mm CL. Males ≥ 105 are used as a proxy to identify mature males, and males ≥ 120 mm CL are used as a proxy to identify legal males. The model incorporates the following data: (1) commercial catch data from 1978/79 -1998/99, 2009/10- 2012/13, 2015/16; (2) annual trawl survey data from 1978 to 2016; (3) triennial pot survey data from 1995 to 2016; (4) bycatch data in the groundfish trawl and groundfish fixed-gear fisheries from 1991 to 2015; and (5) ADF&G crab-observer composition data for the years 1990/91–1998/99, 2009/10–2012/13, 2015/16.

Trawl survey data are from the NMFS summer trawl survey for stations within the St. Matthew Section. The pot survey data originate from the ADF&G triennial pot surveys that occurred during July and August in 1995, 1998, 2001, 2004, 2007, 2010, 2013, 2015 and 2016. The pot survey samples areas of high-relief habitat important to blue king crab (particularly females) that the NMFS trawl survey cannot sample. Data used are from only the 96 stations fished in common during each of the six pot survey years. The CPUE (catch per pot lift) indices from those 96 stations for the male categories listed above were used in the assessment.

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

Stock biomass and recruitment trends

Following a period of low numbers (below 30% of the 1978-2016 mean of 5,865 t) after the stock was declared overfished in 1999, trawl-survey indices of SMBKC stock abundance and biomass generally increased to well above average from 2007-2012. In 2013 the survey biomass estimate was low (~40% of the mean value) but was followed by average biomass estimates in 2014 and 2015 (with sampling CVs of 77% and 45%, respectively). The 2016 survey biomass estimate was 3,500 t (7.7 million lb with a CV of 39%). This value represents about 60% of the long term mean with the most recent 3-year average surveys at 87% of the mean value. This suggests a general decline in biomass compared to the recent peak survey estimate of nearly twice the average. The assessment model estimates dampen the interannual variability observed in the survey biomass and suggest that the stock (in survey biomass units) is presently at about 45% of the long term model-predicted survey biomass average. The trend from these values suggest a slight decline.

Because little information about the abundance of small crab is available for this stock, recruitment has been assessed in terms of the number of male crab within the 90-104 mm carapace length (CL) size class in each year. The 2013 trawl-survey area-swept estimate of 0.335 million male SMBKC in this size class marked a three-year decline and was the lowest since 2005. That decline did not continue as the 2014 survey estimate was 0.723 million. Survey recruitment was 0.992 million in 2015, but the majority of this survey estimate is from one tow with a great deal of uncertainty. In 2016, survey recruitment declined to 0.535 million.

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

The stock assessment examines 6 model configurations: 1) the September 2015 model; 2) Match model is the GMACS model with selectivity parameters fixed to match the September 2015 model; 3) GMACS base model with selectivities estimated; 4) M scenario is the GMACS base scenario removing the large natural mortality applied in 1998 (i.e. constant M over time); 5)Francis scenario is the GMACS M model using the Francis method to estimate effective sample sizes; and 6) Force model is the Francis scenario adding increased weight on the likelihood for the pot survey (2.0) and trawl survey biomass (1.5).

The CPT recommends the use of GMACS base scenario for stock status determination. This stock is in Tier 4. The CPT recommended model uses the full assessment period (1978/79-2015/16) to define the proxy for B_{MSY} in terms of average estimated MMB_{mating}. The projected MMB estimated for 2016/17 under the recommended model is 2,230 t (4.91 million lb) and the F_{MSY} proxy is the natural mortality rate (0.18^{-1} year) and F_{OFL} is 0.09, resulting in a mature male biomass OFL of 140 t (0.310 million lb). The MMB/B_{MSY} ratio is 0.61. The author recommended and the CPT concurred with a 20% buffer on the OFL for the ABC which was consistent with the approach used last year. The ABC based on this buffer is 110 t (0.250 million lb).

BSAI Crab SAFE **Introduction**

Historical status and catch specifications for Saint Matthew blue king crab (thousand t). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Male Catch	OFL	ABC
2012/13	1.80	2.85	0.74	0.73	0.82	1.02	0.92
2013/14	1.50	3.01	0	0	0.0003	0.56	0.45
2014/15	1.86	2.48	0.30	0.14	0.15	0.43	0.34
2015/16	1.84	2.11	0.19	0.05	0.05	0.28	0.22
2016/17		2.23				0.14	0.11

Historical status and catch specifications for Saint Matthew blue king crab (million lb). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Male Catch	OFL	ABC
2012/13	4.0	6.29	1.630	1.616	1.81	2.24	2.02
2013/14	3.4	6.64	0	0	0.0006	1.24	0.99
2014/15	4.1	5.47	0.655	0.309	0.329	0.94	0.75
2015/16	4.0	4.65	0.41	0.105	0.105	0.62	0.49
2016/17		4.91				0.31	0.25

The stock was above MSST in 2015/16 and is hence not overfished. The total catch was less than the OFL in 2015/16 and hence overfishing did not occur.

Additional Plan Team recommendations

Include likelihood equations and the Francis weighting equation in the document. Each model scenario should have only one change to facilitate evaluating results. The CPT made no specific recommendations on model scenarios for the May 2017 meeting.

7 Norton Sound Red King Crab

Fishery information relative to OFL setting

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

Data and assessment methodology

Four types of surveys have occurred periodically during the last three decades: summer trawl, summer pot, winter pot, and preseason summer pot, but none of these surveys have been conducted every year. To improve abundance estimates, a male-only length-based model of male crab abundance was previously developed that combines multiple sources of data. A maximum likelihood approach was used to estimate abundance, recruitment, and selectivity and catchability of the commercial pot gear. The model has been updated to include the following data: 1980–2012 winter pot survey; 2013/2015 winter commercial and subsistence catches; revised commercial catch CPUE for 1977-2015; and the 1976–2015 triennial trawl survey data. The current model assumes a constant $M=0.18yr^{-1}$ for all length classes except the length classes of > 123mmCL, which had an estimated value of $0.641yr^{-1}$. Logistic functions are used to describe fishery and survey selectivities, except for a dome-shaped function examined for the winter pot fishery. The model timeline was also revised to have the assessment year start February 1.

The author summarized fifteen model run alternatives, in conjunction with the base model (Model 0). The author recommended, and the CPT selected, Model 5 as the recommended configuration. This model contains an estimated multiplier from the baseline natural mortality rate for the length bins of greater than 123mm CL, expanded length classes from the previous configuration of 6 length classes from 74 to >123mm CL to 8 length classes from 64 to >133mm, but the same 10 mmlength interval. Other attributes were similar to the base model from the previous assessment. Model 5 had the best retrospective pattern and the lowest Mohn's rho compared with the other configurations.

Stock biomass and recruitment trends

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

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

The team recommended Tier 4, stock status a, for Norton Sound red king crab. The estimated abundance and biomass in 2016 using Model 5 are: Mature male biomass on Feb. 1: 5.87million lb (2.66 thousand t).

The $B_{MSY\ \mathrm{proxy}}$, calculated as the average of mature male biomass on Feb. 1 during 1980-2016, was $B_{MSY\ \mathrm{proxy}}$ = 4.53 million lb. The $F_{MSY\ \mathrm{proxy}}$ is M =0.18 yr^{-1} and the F_{OFL}=0.18yr^{-1}, because the 2016 mature male biomass is larger than $B_{MSY\ \mathrm{proxy}}$ with the CPT choosing the default of gamma =1.0.

The maximum permissible ABC would be 0.71 million lb, based on projected retained catch on July 1. The CPT recommended an ABC less than the maximum permissible due to concerns with model specification, lack of bycatch data as well as issues noted with the M employed for the largest length group. The CPT recommended an ABC = 80% of the OFL (20% buffer) of 0.568 million lb.

Historical status and catch specifications for Norton Sound red king crab (thousand t). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2012/13	0.80	1.93	0.21	0.21	0.21	0.24	0.22
2013/14	0.93	2.27	0.23	0.16	0.16	0.26	0.24
2014/15	0.96	1.68	0.17	0.18	0.18	0.21	0.19
2015	1.09	2.33	0.18	0.18	0.24	0.33	0.26
2016	1.03	2.66	TBD	TBD	TBD	0.32	0.26

Historical status and catch specifications for Norton Sound red king crab (million lb). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2012/13	1.76	4.59	0.47	0.47	0.47	0.53	0.48
2013/14	2.06	5.00	0.50	0.35	0.35	0.58	0.52
2014/15	2.11	3.71	0.38	0.39	0.39	0.46	0.42
2015	2.41	5.13	0.39	0.40	0.52	0.72	0.58
2016	2.26	5.87	TBD	TBD	TBD	0.71	0.57

Total catch in 2015/16 did not exceed the OFL for this stock, thus overfishing is not occurring. Stock biomass is above MSST; thus, the stock is not overfished.

Additional Plan Team recommendations

The CPT has the following recommendations for the next assessment:

- Calculate OFL by including length class wise M from Feb 1 to July 1.
- Provide OFL values calculated assuming:
  - The winter fishery will take 8% of the OFL
  - The winter fishery will take X% of the OFL, where X = the average fraction taken by the winter fishery over the last few (e.g., 5) years.
- Evaluate whether using a growth function that "slows" growth prior to the largest size bins can improve overestimation of abundance of large crab

    - Consider a piece-wise linear model (like that used for snow crab)
    - Consider treating molting probability using random walk parameters
- Evaluate applying the natural mortality multiplier ‘ms’ to only the largest size bin, not all bins > 123 mm.
- Evaluate estimating selectivity in the summer pot fishery in two time periods: before and after the change in buyers’ preferred size (2005)
- For time series plots that include $B_{MSY\ proxy}$, do not extend the line indicating $B_{MSY\ proxy}$ beyond the temporal extent used to calculate it

8 Aleutian Islands Golden King Crab

Fishery information relative to OFL setting

The directed fishery has been prosecuted annually since the 1981/82 season. Retained catch peaked in 1986/87 at 14.7 million lb and averaged 11.9 million lb over the 1985/86-1989/90 seasons. Average harvests dropped sharply from 1989/90 to 1990/91 to a level of 6.9 million lb for the period 1990/91–1995/96. Management based on a formally established GHL began with the 1996/97 season. The 5.9 million lb GHL established for the 1996/97 season, which was based on the previous five-year average catch, was subsequently reduced to 5.7 million lb beginning in 1998/99. The GHL (or TAC, since 2005/06) remained at 5.700 million lb for 2007/08, but was increased to 5.985 million lb for the 2008/09-2011/12 seasons, and to 6.290 million lb starting with the 2012/13 season. Average annual retained catch for the period 1996/97–2007/08 was 5.62 million lb and 5.96 million lb for the period 2008/09-2012/13. The retained catch for 2013/14 was 6.38 million lb. This fishery is rationalized under the Crab Rationalization Program. The 2014/15 season ends by regulation on 15 May 2015.

Non-retained bycatch occurs mainly in the directed fishery, and to a minor extent in other crab fisheries. Bycatch also occurs in fixed-gear and trawl groundfish fisheries although that bycatch is low relative to bycatch in the directed fishery. Total annual non-retained catch of golden king crab during crab fisheries decreased relative to the retained catch after the 1990s. Bycatch in the post-rationalized fishery (2005/06-2013/14) has ranged from 2.5 million lb in 2005/06 (46% of the retained catch) to 3.2 million lb for 2013/14 (50% of the retained catch). Estimated total mortality (retained catch plus bycatch in crab and groundfish fisheries) ranged from 5.8 to 9.4 million lb since 1995/96. Estimated total mortality in 2013/14 was 7.0 million lb.

Data and assessment methodology

Available data used in the Tier 5 assessment are from ADF&G fish tickets, size-frequencies from samples of landed crabs, at-sea observations from pot lifts sampled during the fishery, and bycatch estimates from the groundfish fisheries. These data are available through the 2013/14 season; complete data from the 2014/15 fishery season, which ends on 15 May 2015, are not currently available. Most of the available data were obtained from the directed fishery which targets legal-size (≥6-inch CW) males. A new survey and assessment model are currently being developed for this stock.

Stock biomass and recruitment trends

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

Summary of major changes

Fishery data that have been updated with the results for 2013/14 include: retained catch for the directed fishery and bycatch estimates for the directed fishery, non-directed crab fisheries, and groundfish fisheries.

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

The CPT recommends that this stock be managed as a Tier 5 stock in 2015/16. The B_{MSY} and MSST are not estimated for this stock. Observer data on bycatch from the directed fishery and groundfish fisheries provide the estimate of total bycatch mortality. Bycatch data from the directed fishery for the 1990/91 – 1995/96 seasons (excluding 1993/94 and 1994/95 seasons due to insufficient data) and from the groundfish fisheries from the 1993/94 – 2008/09 seasons were used. There are no directed fishery observer data prior to the 1988/89 season and observer data are lacking or confidential for four seasons in at least one management area in the Aleutian Islands during 1988/89–1994/95.

This assessment author recommended using the same approach for determining the 2015/16 total catch

OFL as has been used to determine the total catch OFL since 2012/13. This approach uses data for 1985/86–1995/96 to estimate the mean retained catch in the crab fisheries, and bycatch data for 1990/91-95/96 to estimate the mean bycatch rate (0.363):

$$OFL_{2015/16} = (1+R_{90/91\text{-}95/96})\bullet RET_{85/86\text{-}95/96} + BM_{GF,93/94\text{-}08/09} = 12{,}533{,}570 \text{ lb}$$

where,

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

The assessment author recommended a 25% buffer between the OFL and ABC, which is the same buffer used to set the 2014/15 ABC. There remains uncertainty regarding the time-period that represents productivity. The CPT agrees with the assessment author’s recommendation and notes that this is consistent with considering uncertainty in other crab stocks. The CPT recommended ABC is 9,400,178 lb.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch[a]	Total Catch[a]	OFL	ABC
2011/12	N/A	N/A	2.72	2.71	2.95	5.17	4.66
2012/13	N/A	N/A	2.85	2.84	3.12	5.69	5.12
2013/14	N/A	N/A	2.85	2.89	3.19	5.69	5.12
2014/15	N/A	N/A	2.85	2.77	3.08	5.69	4.26
2014/15	N/A	N/A	2.85			5.69	4.27

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

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC
2011/12	N/A	N/A	5.99	5.96	6.51	11.40	10.26
2012/13	N/A	N/A	6.29	6.27	6.87	12.54	11.28
2013/14	N/A	N/A	6.29	6.38	7.04	12.54	11.28
2014/15	N/A	N/A	6.29	6.11	6.79	12.53	9.40
2015/16	N/A	N/A	6.29			12.53	9.40

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

Overfishing did not occur during 2014/15 because the estimated total catch did not exceed the Tier 5 overfishing limit (OFL) of 12.53-million lb (5.69 kt). The total catch did not exceed the ABC established for 2014/15 (9.40-million lb, or 4.26 kt). The OFL and ABC values for 2015/16 are the values recommended by the SSC in June 2015. The 2015/16 TAC was established by ADF&G on 15 July 2015. The TACs for 2013/14 – 2014/15 do not include landings towards a cost-recovery fishing goal of $300,000 to cover costs of observer deployments in the fishery or landings towards a cost-recovery fishing goal of $200,000 in 2014/15 to support Aleutians king crab research; however, the catch totals for 2013/14 and 2014/15 include the catch towards the cost-recovery fishery.

Additional Plan Team recommendations

The CPT reviewed progress on the assessment model for Aleutian Islands golden king crab. Detailed comments and recommendations for the model are contained in the CPT report.

9 Pribilof District Golden King Crab

Fishery information relative to OFL setting

The Pribilof District golden king crab fishery began in the 1981/82 season. The directed fishery mainly occurs in Pribilof Canyon of the continental slope. Peak directed harvest was 0.856-million lb (388 t) by 50 vessels during the 1983/84 season; fishery participation has since been sporadic and retained catches vary from 0 to 0.342-million lb (155 t). The fishing season is based on a calendar year. A guideline harvest level (GHL) was first established in 1999 at 0.200-million lb (91 t) and the fishery has been managed with a GHL of 0.150-million lb (68 t) since 2000; a GHL for 2015 has not yet been set. No directed fishery occurred during 2006–2009. One vessel landed catch in 2010, two vessels landed catch in 2011, and one vessel landed catch each year from 2012 to 2014. The 2015 season is ongoing and no vessels have participated so far. Data from the directed fishery since 2003 cannot be reported under state confidentiality regulations; however, the GHL has not been reached. Non-retained bycatch occurs in the directed fishery and can occur in the eastern Bering Sea snow crab fishery, Bering Sea grooved Tanner crab fishery, and Bering Sea groundfish fisheries. Estimated fishing mortality from 2001 to 2014 due to directed and non-directed crab fisheries ranged from 0 to 0.160 million lb (73 t). Bycatch mortality in the groundfish fisheries ranged from <0.001 million lb (< 1 t) to 0.019 million lb (12 t) from 1991/92 to 2013/14.

Data and assessment methodology

There is no assessment model for this stock. Fish ticket and observer data are available, size-frequency data from samples of landed crabs, and pot lifts sampled during the fishery, and from the groundfish fisheries. Much of the directed fishery data are confidential due to low participation levels.

Stock biomass and recruitment trends

There is no stock biomass data used in this Tier 5 assessment.

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

The CPT recommends this stock be managed under Tier 5 in 2016. The CPT concurs with the author’s recommended status quo OFL of 0.20 million lb and an ABC of 0.15 million lb. The ABC was derived by applying a 25% buffer of the OFL, ABC = 0.75 * OFL, the same buffer used for other Tier 5 stocks with similar levels of concern. The 2016 OFL calculation is the same as recommended by the SSC for 2012−2015:

$$OFL_{2016} = (1+R_{2001\text{–}2010})*RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,1992/93\text{–}1998/99}$$

where,

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

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

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2012	N/A	N/A	68	Conf.	Conf.	91	82
2013	N/A	N/A	68	Conf.	Conf.	91	82
2014	N/A	N/A	68	Conf.	Conf.	91	82
2015	N/A	N/A	TBA			91	68
2016	N/A	N/A				93	70

N/A = not available

Conf. = confidential

TBA = to be announced

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

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2012	N/A	N/A	0.15	Conf.	Conf.	0.20	0.18
2013	N/A	N/A	0.15	Conf.	Conf.	0.20	0.18
2014	N/A	N/A	0.15	Conf.	Conf.	0.20	0.18
2015	N/A	N/A	TBA			0.20	0.15
2016	N/A	N/A				0.21	0.15

N/A = not available

Conf. = confidential

TBA = to be announced

10 Western Aleutian Islands red king crab

Fishery information relative to OFL and ABC setting

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

Retained catch from 1985/86 to 1994/95 averaged 0.94 million lb, but the retained catch during the 1995/96 season dropped to 0.04 million lb. Most of the catch since the 1990/91 season was harvested in the Petrel Bank area (between 179° W longitude and 179° E longitude) and the last two commercial fishery seasons (2002/03 and 2003/04) were opened only in the Petrel Bank area. Retained catches in those two seasons were 0.51 million lb (2002/03) and 0.48 million lb (2003/04).

Non-retained catch of red king crabs occurs in both the directed red king crab fishery, the Aleutian Islands golden king crab fishery, and in groundfish fisheries. Estimated bycatch mortality during the 1995/96 to 2013/14 seasons averaged 0.002 million lb in crab fisheries and 0.018 million lb in groundfish fisheries. Estimated annual total fishing mortality from 1995/96 to 2013/14 averaged 0.087 million lb. The average retained catch during that period was 0.066 million lb. This fishery is rationalized under the Crab Rationalization Program only for the area west of 179° W longitude.

Data and assessment methodology

The 1960/61 to 2007/08 time series of retained catch (number and pounds of crabs), effort (vessels, landings and pot lifts), average weight and average carapace length of landed crabs, and catch-per-unit effort (number of crabs per pot lift) are available. Bycatch from crab fisheries from 1995/96 to 2013/14 and from groundfish fisheries from 1993/94 to 2013/14 are available. There is no assessment model for this stock. The standardized surveys of the Petrel Bank area conducted by ADF&G in 2006 and 2009 and the ADF&G-Industry Petrel Bank surveys conducted in 2001 were too limited in geographic scope and too infrequent for reliable estimation of abundance for the entire western Aleutian Islands area.

Stock biomass and recruitment trends

Estimates of stock biomass are not available for this stock. Estimates of recruitment trends and current levels relative to virgin or historic levels are not available. The fishery has been closed since 2003/04 due to apparent poor recruitment. A 2009 survey conducted by ADF&G in the Petrel Bank area encountered an ageing population of legal male crab occurring in a more limited area and at lower densities than were found in a 2006 survey and provided no expectations for recruitment. A test fishery conducted by a commercial vessel during October-December 2009 in the area west of Petrel Bank yielded only one legal male red king crab.

Industry is working with ADF&G to conduct a “reconnaissance survey” in the Adak Island area in September 2015. No red king crab will be retained in the survey, but handling mortality is expected and will be accounted for.

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

The CPT recommends that this stock be managed under Tier 5 for the 2015/16 season. The CPT concurs with the assessment author's recommendation of an OFL based on the 1995/96–2007/08 average total catch following the recommendation of the SSC in June 2010 to set the time period for computing the OFL at 1995/96–2007/08. The CPT recommends an OFL for 2015/16 of 0.12 million lb.

The CPT continues to have concerns regarding the depleted condition of this stock. Groundfish bycatch in recent years has accounted for the majority of the total catch. The CPT recommends an ABC of 0.074 million lb for 2015/16, which is below the maximum permissible ABC of 0.11 million lb; equivalent to a 40% buffer.

Status and catch specifications t of Western Aleutian Islands red king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC
2011/12	N/A	N/A	Closed	0	1	56	12
2012/13	N/A	N/A	Closed	0	<1	56	34
2013/14	N/A	N/A	Closed	0	<1	56	34
2014/15	N/A	N/A	Closed	0	<1	56	34
2015/16	N/A	N/A	Closed			56	34

a. Includes bycatch mortality of discarded bycatch.

Status and catch specifications (millions lb) of Western Aleutian Islands red king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC
2011/12	N/A	N/A	Closed	0	0.002	0.12	0.03
2012/13	N/A	N/A	Closed	0	<0.001	0.12	0.07
2013/14	N/A	N/A	Closed	0	<0.001	0.12	0.07
2014/15	N/A	N/A	Closed	0	<0.001	0.12	0.07
2015/16	N/A	N/A	Closed			0.12	0.07

a. Includes bycatch mortality of discarded bycatch.

Overfishing did not occur during 2014/15; the estimated total catch did not exceed the Tier 5 OFL of 0.12-million lb (56 t). The total catch did not exceed the ABC established for 2014/15 (0.7-million lb, or 34 t). The OFL and ABC values for 2015/16 in the tables below are the values recommended by the SSC in June 2015.

Figures and Tables

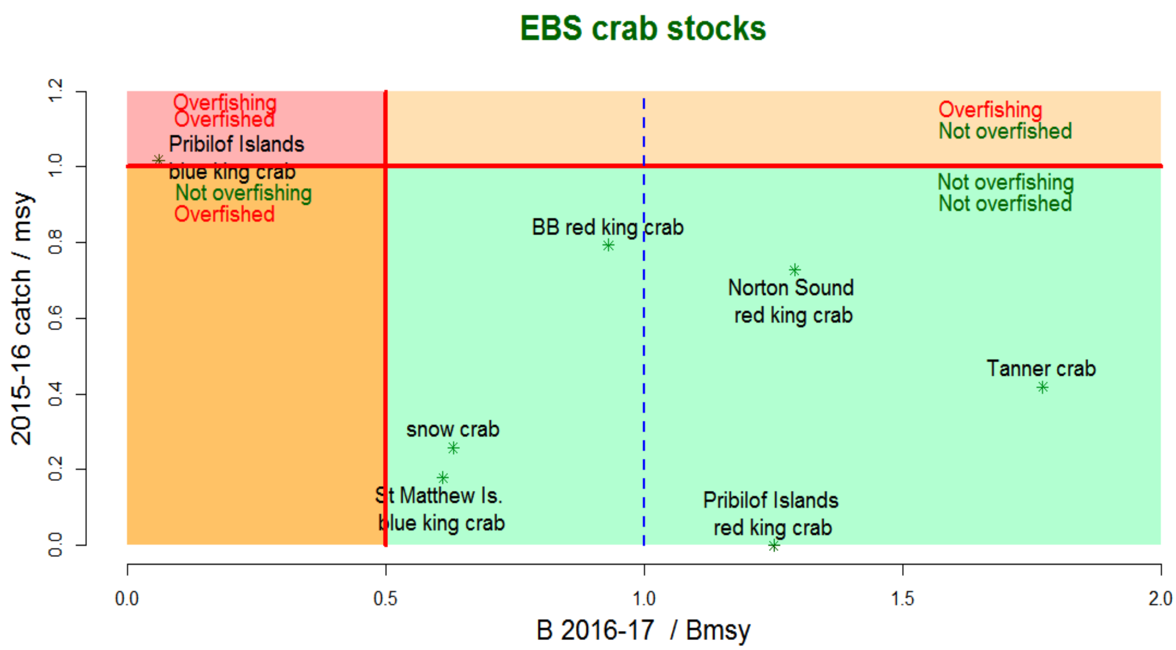

Figure 1. Status of 7 Bering Sea crab stocks in relation to status determination criteria (B_{MSY}, MSST, overfishing). Note that information is insufficient to assess Tier 5 stocks according to these criteria (WAIRKC, AIGKC, PIGKC).

BSAI Crab SAFE Introduction

Table 3 Crab Plan Team recommendations for September 2016 (stocks 1-6). Note that recommendations for stocks 7, 8, 9, 10 represent those final values recommended by the SSC in February and June 2016. Note diagonal fill indicates parameters are not applicable for that tier. Biomass units are 1000 t.

Chapter	Stock	Tier	Status (a,b,c)	F_{OFL}	B_{MSY} or $B_{MSYproxy}$	Years[1] (biomass or catch)	2016/17[2] MMB	2016 MMB / MMB_{MSY}	γ	Mortality (M)	2016/17 OFL	2016/17 ABC	ABC buffer (%)
1	EBS snow crab	3	b	1.14	151.6	1979-current [recruitment]	96.1	0.63		0.23(females) 0.417 (imm) 0.259 (mat males)	23.71	21.34	10%
2	BB red king crab	3	b	0.27	25.78	1984-current [recruitment]	24.00	0.93		Variable[3]	6.64	5.97	10%
3	EBS Tanner crab	3	a	0.79	25.65	1982-current [recruitment]	45.34	1.77		Variable[4]	25.61	20.49	20%
4	Pribilof Islands red king crab	4	a	0.18	5.51	1991-current	6.98	1.25	1.0	0.18	1.46	1.10	25%
5	Pribilof Islands blue king crab	4	c	0.18	4.12	1980-1984 1990-1997	0.233	0.06	1.0	0.18	0.00116	0.00087	25%
6	St. Matthew Island blue king crab	4	b	0.09	3.67	1978-current	2.23	0.61	1.0	0.18	0.14	0.11	20%
7	Norton Sound red king crab	4	a	0.18	2.06	1980-current [model estimate]	2.66	1.29	1.0	0.18 (≤123 mm) 0.648 (>123 mm)	0.32	0.26	20%
8	Aleutian Islands golden king crab	5				See intro chapter					5.69	4.27	25%
9	Pribilof Islands golden king crab	5				See intro chapter					0.093	0.070	25%
10	Adak red king crab	5				1995/96–2007/08					0.056	0.034	40%

[1] For Tiers 3 and 4 where B_{MSY} or $B_{MSYproxy}$ is estimable, the years refer to the time period over which the estimate is made. For Tier 5 stocks the years refer to the time period over which catch is averaged for the OFL.
[2] MMB as projected on 02/01/2016 for Norton Sound red king crab and 2/15/2017 for remaining stocks.
[3] Mortality is 0.18 except where noted: Male M = 0.64 (1980-1984); Female M = 0.99 (1980-1984) and 0.27 (1976-1979 and 1985-1993).
[4] Mortality is estimated: Immature M = 0.24 (all years); Male M = 0.27 (1949-1979 and 1985-2015) and 0.76 (1980-1984); Female M = 0.33 (1949-1979 and 1985-2013) and 0.44 (1980-1984).

Table 4 Maximum permissible ABCs for 2016/17 and Crab Plan Team recommended ABCs for those stocks where the Plan Team recommendation is below the maximum permissible ABC as defined by Amendment 38 to the Crab FMP. Note that the rationale is provided in the individual introduction chapters for recommending an ABC less than the maximum permissible for these stocks.

Stock	Tier	2016/17 *Max*ABC (1000 t)	2016/17 ABC (1000 t)
EBS Snow Crab	3	23.69	21.34
Bristol Bay red king crab	3	*	5.97
EBS Tanner Crab	3	25.57	20.49
Pribilof Islands red king crab	4	1.44	1.10
Pribilof Islands blue king crab	4	*	0.00087
Saint Matthew blue king crab	4	*	0.11
Norton Sound red king crab	4	*	0.26
Aleutian Islands golden king crab	5	5.12	4.27
Pribilof Islands golden king crab [1]	5	0.08	0.07
WAI red king crab	5	0.05	0.03

[1] Pribilof Islands golden king crab assessment is on 2017 calendar year instead of the 2016-2017 crab fishing year.
* not available in the stock assessment

Table 5. Stock status in relation to status determination criteria for 2015/16 as estimated in September 2016. (Note diagonal fill indicates parameters not applicable for this tier level).

Chapter	Stock	Tier	MSST	B_{MSY} or $B_{MSYproxy}$	2015/16[1] MMB	2015/16 MMB / MMB_{MSY}	2015/16 OFL 1000 t	2015/16 Total catch	Rebuilding Status
1	EBS snow crab	3	75.8	151.6	91.6	0.60	83.1	21.4	
2	BB red king crab	3	12.89	25.78	27.68	1.07	6.73	5.34	
3	EBS Tanner crab	3	12.82	25.64	73.93	2.88	27.19	11.38	
4	Pribilof Islands red king crab	4	2.76	5.52	9.06	1.64	2.12	0.00032	
5	Pribilof Islands blue king crab	4	2.06	4.12	0.36	0.09	0.00116	0.00118[2]	overfished
6	St. Matthew Island blue king crab	4	1.84	3.68	2.11	0.57	0.28	0.05	
7	Norton Sound red king crab	4	1.09	2.18	2.33	1.07	0.33 	0.24	
8	Aleutian Islands golden king crab	5					5.69	Confidential[3]	
9	Pribilof Islands golden king crab	5					0.09	0.001	
10	Adak red king crab	5					0.05	0.002	

[1] For stocks 1-6 MMB on 2/15/2016 is estimated using the current assessment in September 2016. For Norton Sound red king crab MMB on 2/1/2016 is estimated using the current assessment in January 2016.

[2]Overfishing occurred in 2015/16.

[3]Confidential under State of Alaska Statute Sec. 16.05.815. TAC not attained.

BRISTOL BAY RED KING CRAB STOCK ASSESSMENT IN FALL 2016

J. Zheng and M.S.M. Siddeek
Alaska Department of Fish and Game
Division of Commercial Fisheries
P.O. Box 115526
Juneau, AK 99811-5526, USA
Phone: (907) 465-6102
Fax: (907) 465-2604
Email: jie.zheng@alaska.gov

Executive Summary

1. Stock: red king crab (RKC), *Paralithodes camtschaticus,* in Bristol Bay, Alaska.
2. Catches: The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lbs (58,943 t). The catch declined dramatically in the early 1980s and remained at low levels during the last three decades. Catches during recent years until 2010/11 were among the high catches in last 15 years. The retained catch in 2015/16 was about 10 million lbs (4,500 t), similar to the catch in 2014/15. The magnitude of bycatch from groundfish trawl fisheries has been stable and small relative to stock abundance during the last 10 years.
3. Stock biomass: Estimated mature biomass increased dramatically in the mid 1970s and decreased precipitously in the early 1980s. Estimated mature crab abundance had increased during 1985-2009 with mature females being about three times more abundant in 2009 than in 1985 and mature males being about two times more abundant in 2009 than in 1985. Estimated mature abundance has steadily declined since 2009.
4. Recruitment: Estimated recruitment was high during 1970s and early 1980s and has generally been low since 1985 (1979 year class). During 1984-2016, only in 1984, 1986, 1995, 1999, 2002 and 2005 were estimated recruitments above the historical average for 1976-2016. Estimated recruitment was extremely low during the last nine years.
5. Management performance:

Status and catch specifications (1,000 t) (scenario 2):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2012/13	13.19[A]	29.05[A]	3.56	3.62	3.90	7.96	7.17
2013/14	12.85[B]	27.12[B]	3.90	3.99	4.56	7.07	6.36
2014/15	13.03[C]	27.25[C]	4.49	4.54	5.44	6.82	6.14
2015/16	12.89[D]	27.68[D]	4.52	4.61	5.34	6.73	6.06
2016/17		24.00[D]				6.64	5.97

The stock was above MSST in 2015/16 and hence was not overfished. Overfishing did not occur.

Status and catch specifications (million lbs):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2012/13	29.1[A]	64.0[A]	7.85	7.98	8.59	17.55	15.80
2013/14	28.3[B]	59.9[B]	8.60	8.80	10.05	15.58	14.02
2014/15	28.7[C]	60.1[C]	9.99	10.01	11.99	15.04	13.53
2015/16	28.4[D]	61.0[D]	9.97	10.17	11.77	14.84	13.36
2016/17		52.9[D]				14.63	13.17

Notes:
A – Calculated from the assessment reviewed by the Crab Plan Team in September 2013
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2014
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2015
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2016

6. Basis for the OFL: All table values are in 1000 t (Scenario 2):

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2012/13	3b	27.5	26.3	0.96	0.31	1984-2012	0.18
2013/14	3b	26.4	25.0	0.95	0.27	1984-2013	0.18
2014/15	3b	25.7	24.7	0.96	0.28	1984-2014	0.18
2015/16	3b	26.1	24.7	0.95	0.27	1984-2015	0.18
2016/17	3b	25.8	24.0	0.93	0.27	1984-2016	0.18

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

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2012/13	3b	60.7	58.0	0.96	0.31	1984-2012	0.18
2013/14	3b	58.2	55.0	0.95	0.27	1984-2013	0.18
2014/15	3b	56.7	54.4	0.96	0.28	1984-2014	0.18
2015/16	3b	57.5	54.4	0.95	0.27	1984-2015	0.18
2016/17	3b	56.8	52.9	0.93	0.27	1984-2016	0.18

A. Summary of Major Changes

1. Change to management of the fishery: None.

2. Changes to the input data:

a. The new 2016 NMFS trawl survey data and BSFRF side-by-side trawl survey data during 2013-2016 were used.

b. Catch and biomass data were updated to include the 2015/16 information.

c. Total NMFS survey biomass CVs were updated and they are slightly different from those in 2015 for some years.

3. Changes to the assessment methodology:

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

Scenario 1: the same as Scenario 1 in the SAFE report in September 2015 using BSFRF survey data in 2007 and 2008. The BSFRF survey is treated as an independent survey, and no assumption is made about the capture probabilities of the BSFRF survey. In effect, survey selectivities for both surveys are estimated separately and directly in the model. A survey capture probability for a length group is simply defined as the proportion of the crab in the length group within the area-swept that is caught by the survey net.

Scenario 1n: the same as scenario 1 plus additional BSFRF survey data in 2013-2016.

Scenario 2: the same as scenario 1n except for the assumption that BSFRF survey capture probabilities are 1.0 for all length groups. Under this assumption, NMFS survey selectivities are the products of crab availabilities (equal to BSFRF survey selectivities) and NMFS survey capture probabilities.

b. A jittering approach is used to find the optimum.

4. Changes to assessment results:

The population biomass estimates in 2016 are slightly lower than those in 2015. Among the three scenarios, model estimated relative survey biomasses are very similar. The absolute population biomass estimates are slightly higher for scenario 2 than for scenario 1n. Scenario 1n is higher than scenario 1 during recent years, due to use of the BSFRF survey data (2013-2016) for scenarios 1n and 2.

B. Responses to SSC and CPT Comments

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

None.

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

Response to CPT Comments (from September 2015)

"The CPT recommends that size composition and biomass estimates from the 2013-2015 BSFRF side-by-side surveys be included in the assessment model. Sufficient data from these surveys are now available to help inform catchability of the NMFS trawl survey. The CPT identified several approaches, such as considering these surveys as an extension of the BSFRF surveys in 2007 and 2008, which are already used in the model. The earlier surveys did not use the side-by-side design, so technical aspects considerations of this approach would need to be evaluated. Another approach would be to drop the 2007 and 2008 surveys, and to add the 2013-2015 surveys. Since size composition data were collected during 2013-2015 surveys, it should be possible to evaluate survey selectivity, which needed to be assumed for 2007-2008 surveys. Due to the amount of analysis required to incorporate a new survey time series into the model, Jie did not think that this would be ready for review at the May 2016 CPT meeting."

These comments were addressed in May 2016.

Response to CPT Comments (from January 2016)

"CPT requests to the Bristol Bay red king crab assessment authors for May 2016 meeting: The CPT requested two assessments in which data from the 2007 and 2008 BSFRF surveys and the 2013–2015 BSFRF side-by-side are used to estimate trawl survey selectivity using the aforementioned snow crab model "separate survey" approach: one assessment without a prior for survey Q from the Otto-Somerton double-bag study; one assessment with a prior for survey Q from the double-bag study. The CPT also recommended that an approach be developed where the paired design of 2013-2015 BSFRF surveys is used to directly estimate selectivity. This would involve adding size-structured tow-by-tow data in new likelihood component in the assessment model, and was considered as a project for model development. There was no expectation by the CPT that such a model would be a candidate base model for review at the May CPT meeting."

These comments were addressed in May 2016.

Response to CPT Comments (from May 2016)

"The CPT had several comments about this approach. First, it was noted at NMFS/BSRF ratios were highly variable, and that a better approach would be to consider the ratio of the NMFS survey to the sum of two surveys NMFS/(NMFS+BSFRF). Second, an attempt should be made to fit actual tow-by-tow data rather than survey aggregates. Finally, catchability for the NMFS survey was estimated to be greater than one for some model runs (this only occurred when the prior was omitted).It was suggested that catchability could be limited to values less than one by parameterizing catchability on a logit scale. The CPT concluded that these issues needed to be addressed before scenario 3 could be adopted."

The ratio of the NMFS survey to the sum of two surveys NMFS/(NMFS+BSFRF) was also evaluated in May 2016 and the results were not presented to the CPT meeting but were added to the final draft report. We agree that this approach is better than the NMFS/BSRF ratios.

Due to very small amount of crab caught in each tow, it is not feasible to fit the actual tow-by-tow data.

We will examine the approach to parameterize catchability on a logit scale so that it is less or equal to 1.0 in the future work (May 2017).

"The CPT requests that the following models be brought forward in September 2016: scenario 1 (status quo), scenario 1n, and scenario 2. Since results from the 2016 BSFRF survey will be available on the same timetable as the 2016 NMFS survey, these data should be incorporated into scenarios 1n and 2."

These three scenarios are presented in the September 2016 SAFE report.

Response to SSC Comments specific to this assessment (from October 2015)

"The SSC reiterates its previous concern that improvement in model fit by increasing M is not a sufficient condition for accepting Model 1. The SSC reiterates its previous recommendation that the author should test the hypothesis that natural mortality varies annually due to environmental change by running a research model with a random walk on M and then statistically evaluating relationships between time trends in estimated M relative to plausible mechanisms influencing M. We agree that this model should not be used for setting biological reference points, however it may provide useful information on the appropriate time stanzas for time varying M. Mechanistic explanations for the resulting time stanzas could then be explored.

The SSC agrees with the CPT that the author should explore a model that incorporates the 2013-2015 side-by-side BSFRF data."

The side-by-side data were evaluated in May 2016. We have spent considerable time over last 20 years to identify mechanisms for change in natural mortality over time but without much success. It is a very complex problem and many factors might have played a role on it. We will continue to work on this issue in the future.

Response to SSC Comments specific to this assessment (from June 2016):

"The SSC supports the CPT recommendation to bring forward three scenarios for the stock assessment in fall 2016: (1) scenario 1, which is the status quo (2015) using BSFRF data from 2007 ad 2008 in which the two surveys are treated as independent surveys and survey selectivities are estimated separately and directly in the model; (2) scenario 1n, which is the same as scenario 1 but also includes the 2013-2015 BSFRF survey data, and (3) scenario 2, which is the same as scenario 1n but assumes that the BSFRF survey has capture probabilities of 1.0 for all length groups.

When these scenarios are presented, the terms "capture probabilities" and "selectivity" should be clearly defined. In the report, their descriptions seemed somewhat confusing and contradictory. For instance, Figure 6 implies catchabilities at small sizes in the BSFRF survey that are less than 1.0 for all scenarios, but from the text, this should not be the case. It is important that the definitions and procedures are clearly described."

We reported the results of these three scenarios in this SAFE report and cleaned up the confusion of terms "capture probabilities" and "selectivity" throughout the report.

C. Introduction

1. Species

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

2. General distribution

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

3. Stock Structure

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

4. Life History

Red king crab have a complex life history. Fecundity is a function of female size, ranging from several tens of thousands to a few hundreds of thousands (Haynes 1968; Swiney et al. 2012). The eggs are extruded by females, fertilized in the spring, and held by females for about 11 months (Powell and Nickerson 1965). Fertilized eggs are hatched in the spring, most during April-June (Weber 1967). Primiparous females are bred a few weeks earlier in the season than multiparous females.

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

5. Fishery

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

6. Fisheries Management

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

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

D. Data

1. Summary of New Information

The NMFS and BSFRF trawl survey data were updated to include the survey data in 2016.

Catch and biomass data were updated to 2015/16.

Data types and ranges are illustrated in Figure 2.

2. Catch Data

Data on landings of Bristol Bay RKC by length and year and catch per unit effort from 1960 to 1973 were obtained from annual reports of the International North Pacific Fisheries Commission (Hoopes et al. 1972; Jackson 1974; Phinney 1975) and from the ADF&G from 1974 to 2015. Bycatch data are available starting from 1990 and were obtained from the ADF&G observer database and reports (Gaeuman 2013). Sample sizes for catch by length and shell condition are summarized in Table 2. Relatively large samples were taken from the retained catch each year. Sample sizes for trawl bycatch were the annual sums of length frequency samples in the National Marine Fisheries Service (NMFS) database.

(i). Catch Biomass

Retained catch and estimated bycatch biomasses are summarized in Table 1 and illustrated in Figure 2. Retained catch and estimated bycatch from the directed fishery include the general, open-access fishery (prior to rationalization), or the individual fishery quota (IFQ) fishery (after rationalization), as well as the Community Development Quota (CDQ) fishery and the ADF&G cost-recovery harvest. Starting in 1973, the fishery generally occurred during the late summer and fall. Before 1973, a small portion of retained catch in some years was caught from April to June. Because most crab bycatch from the groundfish trawl fisheries occurred during the spring, the years in Table 1 are one year less than those from the NMFS trawl bycatch database to approximate the annual bycatch for reporting years defined as June 1 to May 31; e.g., year 2002 in Table 1 for trawl bycatch corresponds to what is reported for year 2003 in the NMFS database. Catch biomass is shown in Figure 3. Bycatch data for the cost-recovery fishery before 2006 were not available. In this report, pot fisheries include both the directed fishery and RKC bycatch in the Tanner crab pot fishery and trawl fisheries are groundfish trawl fisheries.

(ii). Catch Size Composition

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

(iii). Catch per Unit Effort

Catch per unit effort (CPUE) is defined as the number of retained crab per tan (a unit fishing effort for tanglenets) for the Japanese and Russian tanglenet fisheries and the number of retained crab per potlift for the U.S. fishery (Table 1). Soak time, while an important factor influencing CPUE, is difficult to standardize. Furthermore, complete historical soak time data from the U.S. fishery are not available. Based on the approach of Balsiger (1974), all fishing effort from Japan, Russia, and U.S. were standardized to the Japanese tanglenet from 1960 to 1971, and the CPUE was standardized as crab per tan. Except for the peak-to-crash years of late 1970s and early 1980s the correspondence between U.S. fishery CPUE and area-swept survey abundance is poor (Figure 4). Due to the difficulty in estimating commercial fishing catchability and crab availability to the NMFS annual trawl survey data, commercial CPUE data were not used in the model.

3. NMFS Survey Data

The NMFS has performed annual trawl surveys of the eastern Bering Sea since 1968. Two vessels, each towing an eastern otter trawl with an 83 ft headrope and a 112 ft footrope, conducted this multispecies, crab-groundfish survey during the summer. Stations were sampled in the center of a systematic 20 X 20 nm grid overlaid in an area of ≈140,000 nm^2. Since 1972, the trawl survey has covered the full stock distribution except in nearshore waters. The survey in Bristol Bay occurs primarily during late May and June. Tow-by-tow trawl survey data for Bristol Bay RKC during 1975-2016 were provided by NMFS.

Abundance estimates by sex, carapace length, and shell condition were derived from survey data using an area-swept approach (Figures 5a and 5b). Spatial distributions of crab from the standard trawl surveys during recent years are shown in Appendix B. Until the late 1980s, NMFS used a post-stratification approach, but subsequently treated Bristol Bay as a single stratum; the estimates shown for Bristol Bay in Figures 4 and 5 were made without post-stratification. If multiple tows were made for a single station in a given year, the average of the abundances from all tows within that station was used as the estimate of abundance for that station. The new time series since 2015 discards all "hot spot" tows. We used the new area-swept estimates provided by NMFS in 2016.

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

4. Bering Sea Fisheries Research Foundation Survey Data

The BSFRF conducted trawl surveys for Bristol Bay RKC in 2007 and 2008 with a small-mesh trawl net and 5-minute tows. The surveys occurred at similar times as the NMFS standard surveys and covered about 97% of the Bristol Bay area. Few Bristol Bay RKC were found outside of the BSFRF survey area. Because of the small mesh size, the BSFRF surveys were expected to catch more of RKC within the swept area. Crab abundances of different size groups were estimated by the kriging method. Mature male abundances were estimated to be 22.331 in 2007 and 19.747 million in 2008 with respective CVs of 0.0634 and 0.0765. BSFRF also conducted side-by-side survey with NMFS trawl survey during 2013-2016 in Bristol Bay.

E. Analytic Approach

1. History of Modeling Approaches

To reduce annual measurement errors associated with abundance estimates derived from the area-swept method, ADF&G developed a length-based analysis (LBA) in 1994 that incorporates multiple years of data and multiple data sources in the estimation procedure (Zheng et al. 1995a). Annual abundance estimates of the Bristol Bay RKC stock from the LBA have been used to manage the directed crab fishery and to set crab bycatch limits in the groundfish fisheries since 1995 (Figure 1). An alternative LBA (research model) was developed in 2004 to include small size groups for federal overfishing limits. The crab abundance declined sharply during the early 1980s. The LBA estimated natural mortality for different periods of years, whereas the research model estimated additional mortality beyond a basic constant natural mortality during 1976-1993. In this report, we present only the research model that was fit to the data from 1975 to 2016.

2. Model Description

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

a-f. See appendix A.

g. Critical assumptions of the model:

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

ii. Survey and fisheries selectivities are a function of length and were constant over shell condition. Selectivities are also a function of sex except for trawl bycatch selectivities, which are the same for both sexes. Two different survey selectivities were estimated: (1) 1975-1981 and (2) 1982-2016, based on modifications to the trawl gear used in the assessment survey.

iii. Growth is a function of length and is assumed to not change over time for males. For females, growth-per-molt increments as a function of length were estimated for three periods (1975-1982, 1983-1993, and 1994-2016) based on sizes at maturity. Once mature, female red king crab grow with a much smaller growth increment per molt.

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

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

vi. The prior of survey catchability (*Q*) was estimated to be 0.896, based on a trawl experiment by Weinberg et al. (2004) with a standard deviation of 0.025. *Q* is assumed to be constant over time and is estimated in the model.

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

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

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

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

3. Model Selection and Evaluation

a. Alternative model configurations (scenarios):

1. The base scenario in September 2015. Scenario 1 includes:

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

(2) Including BSFRF survey data in 2007 and 2008. The BSFRF survey is treated as an independent survey, and no assumption is made about the capture probabilities of the BSFRF survey. In effect, survey selectivities for both surveys are estimated separately and directly in the model.

(3) NMFS survey catchability is estimated in the model and is assumed to be constant over time. BSFRF survey catchability is assumed to be 1.0.

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

(5) Estimating effective sample size from observed sample sizes. Effective sample sizes are estimated as min(0.5*observed-size, N) for trawl surveys and min(0.1* observed-size, N) for catch and bycatch, where N is the maximum sample size (200 for trawl surveys, 100 for males from the pot fishery and 50 for females from pot fishery and both males and females from the trawl fisheries. There is a justification for enforcing a maximum limit to effective sample sizes because the number of length measurements is large (Fournier at al. 1998). The effective sample sizes are plotted against the implied effective sample sizes in Figures 6 and 7, where the implied effective sample sizes are estimated as follows:

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

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

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

(7) Estimating initial year length compositions.

1n. Same as scenario 1 plus additional BSFRF survey data in 2013-2016.

For scenarios 1 and 1n, survey abundances $\hat{N}^{b}_{s,y,l}$ (BSFRF survey) and $\hat{N}^{n}_{s,y,l}$ (NMFS survey) by sex s and in year y and length group l are computed as follows:

$$\begin{aligned} \hat{N}^{b}_{s,y,l} &= N_{s,y,l}\, s^{b}_{s,l}, \\ \hat{N}^{n}_{s,y,l} &= N_{s,y,l}\, s^{n}_{s,l}, \end{aligned} \qquad (2)$$

where $s^{b}_{s,l}$ and $s^{n}_{s,l}$ are survey selectivities for BSFRF and NMFS surveys by sex s and in length group l, respectively, and $N_{s,y,l}$ is the population abundance by sex s and in year y and length group l. The NMFS (1982-2016) and BSFRF survey selectivities are computed as

$$\begin{aligned} s^{n}_{s,l} &= \frac{Q}{1+e^{-\beta^{n}_{s}\,(l-L^{n}_{50,s})}}, \\ s^{b}_{s,l} &= \frac{1}{1+e^{-\beta^{b}_{s}\,(l-L^{b}_{50,s})}}, \end{aligned} \qquad (3)$$

where β and L_{50} are parameters and Q is the NMFS survey catchability. Survey selectivity for the first length group (67.5 mm) was assumed to be the same for both males and females, so only three parameters (β, $L50$ for females and $L50$ for males) were estimated in the model for each survey. Q is estimated in the model with or without a prior from the double-bag experiment, depending on scenarios. The BSFRF survey catchability is assumed to be 1.0.

2. Same as scenario 1n except for making an assumption that the BSFRF survey capture probabilities are 1.0 for all length groups. Under this assumption, NMFS survey selectivities are the products of crab availabilities (equal to BSFRF survey selectivities) and NMFS survey capture probabilities (p):

$$s^{n}_{s,l} = p_{s,l}\, s^{b}_{s,l}. \qquad (4)$$

Therefore, the model estimates NMFS survey capture probabilities and BSFRF survey selectivities and computes NMFS survey selectivities from these estimates. NMFS survey capture probabilities are computed as

$$p_{s,l} = \frac{Q}{1+e^{-\beta_s \ (l-L_{50,s})}}, \tag{5}$$

where β and $L50$ are parameters and similar to the survey selectivities, only three parameters (β, $L50$ for females and $L50$ for males) were estimated in the model for each sex.

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

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

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

e. Sample sizes for length composition data: observed sample sizes are summarized in Table 2, and estimated implied sample sizes and effective sample sizes are illustrated in Figures 6 and 7.

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

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

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

i. Model evaluation is provided under Results, below.

j. Jittering: the Stock Synthesis Approach is used to do jittering to find the optimum:

The *Jitter* factor of 0.1 is multiplied by a random normal deviation $rdev=N(0,1)$, to a transformed parameter value based upon the predefined parameter:

$$temp = 0.5 \ rdev \ Jitter \ \ln\left(\frac{P_{\max} - P_{\min} + 0.0000002}{P_{val} - P_{\min} + 0.0000001} - 1\right), \tag{6}$$

with the final jittered starting parameter value backtransformed as:

$$P_{new} = P_{\min} + \frac{P_{\max} - P_{\min}}{1.0 + \exp(-2.0 \ temp)}, \tag{7}$$

where P_{max} and P_{min} are upper and lower bounds of parameters and P_{val} is the estimated parameter value before the jittering. The jittering results are summarized in Table 3 for three scenarios. Most runs converge to the highest log likelihood values.

4. Results

a. Effective sample sizes and weighting factors.

i. The effective sample sizes are:

(1) Trawl surveys: 200 for males and females except for females: 184 in 1986, 180 in 1992, and 133 in 1994, and except for males 187 in 2016.
(2) Retained catch: 100.
(3) Pot male discard: 100 except 87 in 1990 and 23 in 1996.
(4) Pot female discard: 50 except 38 in 1991, 1 in 1996, 4 in 1999, and 30 in 2002.
(5) Trawl bycatch: 50 for males and females except for males 44 in 1988, 21 in 1991 and 1992, 33 in 1994, 10 in 1995, and for females 28 in 1986 and 1988, 19 in 1989, 40 in 1991, 11 in 1992, 25 in 1994, 5 in 1995, 48 in 1997.
(6) Tanner fishery bycatch: 50 for males and females except for males 28 in 1992, 23 in 1993, 22 in 2013, and 26 inn 2014, and for females 27 in 1993 and 38 in 2014.

(7) BSFRF survey:

Year:	2007	2008	2013	2014	2015	2016
Females:	200	200	56	103	92	116
Males:	200	200	95	109	106	56

For scenario 1, effective sample sizes are illustrated in Figures 6 and 7.

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

iii. Initial trawl survey catchability (*Q*) is estimated to be 0.896 with a standard deviation of 0.025 (CV about 0.03) based on the double-bag experiment results. These values are used as a prior for estimating *Q* in the model.

b. Tables of estimates.

i. Parameter estimates for scenarios 1, 1n and 2 are summarized in Tables 4 and 5.

ii. Abundance and biomass time series are provided in Table 6 for scenarios 1, 1n and 2.

iii. Recruitment time series for scenarios 1, 1n and 2 are provided in Table 6.

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

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

c. Graphs of estimates.

i. Selectivities and molting probabilities by length are provided in Figures 8 and 9 for scenarios 1, 1n and 2.

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

For scenarios 1 and 1n, estimated molting probabilities during 1975-2016 (Figure 9) were generally lower than those estimated from the 1954-1961 and 1966-1969 tagging data (Balsiger 1974). Lower molting probabilities mean more oldshell crab, possibly due to changes in molting probabilities over time or shell aging errors. Overestimates or underestimates of oldshell crab will result in lower or higher estimates of male molting probabilities.

ii. Estimated total survey biomass and mature male and female abundances are plotted in Figure 10. Absolute mature male biomasses are illustrated in Figure 11.

Model estimated relative survey biomasses are very similar among the three scenarios and fit the survey data quite well. The absolute population biomass estimates are slightly higher for scenario 2 than for scenarios 1 and 1n during recent years due to a slightly lower estimate of trawl survey selectivities for scenario 2 and additional BSFRF survey data for scenarios 1n and 2.

Although the model did not fit the mature crab abundances directly, trends in the mature abundance estimates agree well with observed survey values except in 2014 (Figure 10b). Estimated mature crab abundance increased dramatically in the mid 1970s then decreased precipitously in the early 1980s. Estimated mature crab abundance had increased during 1985-2009 with mature females being about 3 times more abundant in 2009 than in 1985 and mature males being about 2 times more abundant in 2009 than in 1985. Estimated mature abundance has declined since 2009 (Figure 10b). Model estimates of both male and female mature abundances have steadily declined since the late 2000s. Absolute mature male biomasses for scenarios 1, 1n and 2 have a similar trend over time (Figure 11).

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

iii. Estimated recruitment time series are plotted in Figure 12 for scenarios 1, 1n and 2.

iv. Estimated fishing mortality rates are plotted against mature male biomass in Figure 13 for scenarios 1, 1n and 2.

The average of estimated male recruits from 1984 to 2016 (Figure 12) and mature male biomass per recruit were used to estimate $B_{35\%}$. Alternative periods of 1976-present and 1976-1983 were compared in our report. The full fishing mortalities for the directed pot fishery at the time of fishing were plotted against mature male biomass on Feb. 15 (Figure 13). Estimated fishing mortalities in most years before the current harvest strategy was adopted in 1996 were above $F_{35\%}$ (Figure 13). Under the current harvest strategy, estimated fishing mortalities were at or above the $F_{35\%}$ limits in 1998, 2005, 2007-2009 for three scenarios but below the $F_{35\%}$ limits in the other post-1995 years. The estimated higher survey selectivities with scenarios 1 and 1n result in relatively higher fishing mortalities than those with scenario 2.

For scenario 1, estimated full pot fishing mortalities ranged from 0.00 to 1.56 during 1975-2015, with estimated values over 0.40 during 1975-1981, 1986-1987 and 2008 (Table 5, Figure 13). For scenario 1n, estimated full pot fishing mortalities ranged from 0.00 to 1.56 during 1975-2015, with estimated values over 0.40 during 1975-1981, 1986-1987 and 2008 (Figure 13). Estimated fishing mortalities for pot female and trawl bycatches were generally less than 0.06.

v. Estimated mature male biomass and recruitment are plotted to illustrate their relationships with scenario 1 (Figure 14a). Annual stock productivities are illustrated in Figure 14b.

Stock productivity (recruitment/mature male biomass) was generally lower during the last 20 years (Figure 14c).

Egg clutch data collected during summer surveys may provide information about mature female reproductive conditions. Although egg clutch data are subject to rating errors as well as sampling errors, data trends over time may be useful. Proportions of empty clutches for newshell mature females >89 mm CL were high in some years before 1990, but have been low since 1990 (Figure 15). The highest proportion of empty clutches (0.2) was in 1986, and primarily involved soft shell females (shell condition 1). Clutch fullness fluctuated annually around average levels during two periods: before 1991 and after 1990 (Figure 15). The average clutch fullness was similar for these two periods (Figure 15).

d. Graphic evaluation of the fit to the data.

i. Observed vs. estimated catches are plotted in Figure 16.

ii. Model fits to total survey biomass are shown in Figure 10 with a standardized residual plot in Figure 17.

iii. Model fits to catch and survey proportions by length are illustrated in Figures 18-24 and residual bubble plots are shown in Figures 25-26.

The model (three scenarios) fit the fishery biomass data well and the survey biomass reasonably well (Figures 10 and 16). Because the model estimates annual fishing mortality for directed pot male catch, undirected pot male bycatch, pot female bycatch, and trawl bycatch, the deviations of observed and predicted (estimated) fishery biomass are mainly due to size composition differences.

The model also fit the length composition data well (Figures 18-24). The model also fit the length proportions of the pot male bycatch well with two simple linear selectivity functions (Figure 21). We explored a logistic selectivity function, but due to the long left tail of the pot male bycatch selectivity, the logistic selectivity function did not fit the data well.

Modal progressions are tracked well in the trawl survey data, particularly beginning in the mid-1990s (Figures 18 and 19). Cohorts first seen in the trawl survey data in 1975, 1986, 1990, 1995, 1999, 2002 and 2005 can be tracked over time. Some cohorts can be tracked over time in the pot bycatch as well (Figure 21), but the bycatch data did not track the cohorts as well as the survey data. Groundfish trawl bycatch data provide little information to track modal progression (Figures 23 and 24).

Standardized residuals of total survey biomass and proportions of length are plotted to examine their patterns. Residuals were calculated as observed minus predicted and standardized by the estimated standard deviation. Standardized residuals of total survey biomass did not show any consistent patterns (Figure 17). Standardized residuals of proportions of survey males appear to be random over length and year (Figure 25). There is an interesting pattern for residuals of proportions of survey females. Residuals were generally negative for large-sized mature females during 1975-1987 for scenarios 1 and 1n (Figure 26). Changes in growth over time or increased mortality may cause this pattern. The inadequacy of the model can be corrected by adding parameters to address these factors or with improved growth data.

e. Retrospective and historic analyses.

Two kinds of retrospective analyses were conducted for this report: (1) the 2016 model (scenario 1) hindcast results and (2) historical results. The 2016 model results are based on sequentially excluding one-year of data to evaluate the current model performance with fewer data. The historical results are the trajectories of biomass and abundance from previous assessments that capture both new data and changes in methodology over time. Treating the 2016 estimates as the baseline values, we can also evaluate how well the model had done in the past.

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

The performance of the 2016 model includes sequentially excluding one-year of data. The model with scenario 1 performed reasonably well during 2008-2015 with a lower terminal year estimates in 2012 and 2013 and higher estimates during 2008-2010 (Figures 27-28).

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

The model first fit the data from 1985 to 2004 in the terminal year of 2004. Thus, sequentially incrementing the terminal year provided 10 historical assessments for comparison with the 2016 assessment model results (Figure 29). The main differences of the 2004 model were weighting factors and effective sample sizes for the likelihood functions. In 2004, the weighting factors were 1,000 for survey biomass, 2,000 for retained catch biomass and 200 for bycatch biomasses. The effective sample sizes were set to be 200 for all proportion data but weighting factors of 5, 2, and 1 were also respectively applied to retained catch proportions, survey proportions and bycatch proportions. Estimates of time series of abundance in 2004 were generally higher than those estimated after 2004 (Figure 29).

In 2005, to improve the fit for retained catch data, the weight for retained catch biomass was increased to 3,000 and the weight for retained catch proportions was increased to 6. All other weights were not changed. In 2006, all weights were re-configured. No weights were used for proportion data, and instead, effective sample sizes were set to 500 for retained catch, 200 for survey data, and 100 for bycatch data. Weights for biomasses were changed to 800 for retained catch, 300 for survey and 50 for bycatch. The weights in 2007 were the same as 2006. Generally, estimates of time series of abundance in 2005 were slightly lower than in 2006 and 2007, and there were few differences between estimates in 2006 and 2007 (Figure 29).

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

During 2009-2013, the model was extended to the data through 1968. No weight factors were used for the NMFS survey biomass during 2009-2013 assessments. Since 2013, the model has fitted the data only back to 1975 for consistence of trawl survey data. Two levels of molting probabilities over time were used, shell conditions for males were combined, and length composition data of the BSFRF survey were used as well. In 2014 and 2015, the trawl survey time series were re-estimated and a trawl survey catchability was estimated for some scenarios.

Overall, both historical results (historic analysis) and the 2016 model results (retrospective analysis) performed reasonably well. No great overestimates or underestimates occurred as was observed in assessments for Pacific halibut (*Hippoglossus stenolepis*) (Parma 1993) and some eastern Bering Sea groundfish stocks (Zheng and Kruse 2002; Ianelli et al. 2003). Since the most recent model was not used to set TAC or overfishing limits until 2009, historical implications for management from the stock assessment errors cannot be evaluated at the current time. However, management implications of the ADF&G stock assessment model were evaluated by Zheng and Kruse (2002).

f. Uncertainty and sensitivity analyses

i. Estimated standard deviations of parameters are summarized in Table 5 for scenarios 1, 1n and 2. Estimated standard deviations of mature male biomass are listed in Table 6.

ii. Probabilities for trawl survey catchability *Q* are illustrated in Figure 30 for scenarios 1, 1n and 2 using the mcmc approach; estimated *Q*s are generally less than 1.0. Probabilities for mature male biomass and OFL in 2016 are illustrated in Figure 31 for scenarios 1, 1n and 2 using the mcmc appproach. The confidence intervals are quite narrow.

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

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

g. Comparison of alternative model scenarios

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

In this report (September 2016), three scenarios are compared. Model estimated relative survey biomasses are very similar among the scenarios. The absolute population biomass estimates are slightly higher for scenarios 1n and 2 than for scenario 1 during recent years due to additional BSFRF survey data during 2013-2016. A slightly lower estimate of NMFS trawl survey selectivities for scenario 2 also results in slightly higher absolute biomass during recent years for scenario 2 than for scenario 1n. Overall, the results for all three scenarios are similar.

F. Calculation of the OFL and ABC

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

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

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

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

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

Where

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

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

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

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

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

Because trawl bycatch fishing mortality was not related to pot fishing mortality, average trawl bycatch fishing mortality during 2006 to 2015 was used for the per recruit analysis as well as for projections in the next section. Pot female bycatch fishing mortality was set equal to pot male fishing mortality times 0.02, an intermediate level during 1990-2015. Some discards of legal males occurred since the IFQ fishery started in 2005, but the discard rates were much lower during 2007-2013 than in 2005 after the fishing industry minimized discards of legal males. However, due to the high proportion of large oldshell males, the discard rate increased greatly in 2014. The average of retained selectivities and discard male selectivities during 2013-2015 were used to represent current trends for per recruit analysis and projections. Average molting probabilities during 2006-2015 were used for per recruit analysis and projections.

Average recruitments during three periods were used to estimate $B_{35\%}$: 1976-1983, 1976-2016, and 1984-2016 (Figure 12). Estimated $B_{35\%}$ is compared with historical mature male biomass in Figure 13a. We recommend using the average recruitment during 1984-present, corresponding to the 1976/77 regime shift. Note that recruitment period 1984-present has been used since 2011 to set the overfishing limits. Several factors support our recommendation. First, estimated recruitment was lower after 1983 than before 1984, which corresponded to brood years 1978 and later, after the 1976/77 regime shift. Second, high recruitments during the late 1960s and 1970s generally occurred when the spawning stock was primarily located in the southern Bristol Bay, whereas the current spawning stock is mainly in the middle of Bristol Bay. The current flows favor larvae hatched in the southern Bristol Bay (see the section on Ecosystem Considerations for SAFE reports in 2008 and 2009). Finally, stock productivity (recruitment/mature male biomass) was higher before the 1976/1977 regime shift.

If we believe that differences in productivity and other population characteristics before 1978 were caused by fishing, not by the regime shift, then we should use the recruitment from 1976-1983 (corresponding to brood years before 1978) as the baseline to estimate B35%. If we believe that the regime shift during 1976/77 caused the productivity differences, then we should select the recruitments from period 1984-2016 as the baseline.

The control rule is used for stock status determination. If total catch exceeds OFL estimated at B, then "overfishing" occurs. If B equals or declines below 0.5 B_{MSY} (i.e., MSST), the stock is "overfished." If B equals or declines below β*B_{MSY} or β*a proxy B_{MSY}, then the stock productivity is severely depleted and the fishery is closed.

The estimated probability distribution of MMB in 2016 is illustrated in Figure 30. Based the SSC suggestion in 2011, ABC = 0.9*OFL is used to estimate ABC.

Status and catch specifications (1,000 t) (scenario 2):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2012/13	13.19[A]	29.05[A]	3.56	3.62	3.90	7.96	7.17
2013/14	12.85[B]	27.12[B]	3.90	3.99	4.56	7.07	6.36
2014/15	13.03[C]	27.25[C]	4.49	4.54	5.44	6.82	6.14
2015/16	12.89[D]	27.68[D]	4.52	4.61	5.34	6.73	6.06
2016/17		24.00[D]				6.64	5.97

The stock was above MSST in 2015/16 and is hence not overfished. Overfishing did not occur.

Status and catch specifications (million lbs):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2012/13	29.1[A]	64.0[A]	7.85	7.98	8.59	17.55	15.80
2013/14	28.3[B]	59.9[B]	8.60	8.80	10.05	15.58	14.02
2014/15	28.7[C]	60.1[C]	9.99	10.01	11.99	15.04	13.53
2015/16	28.4[D]	61.0[D]	9.97	10.17	11.77	14.84	13.36
2016/17		52.9[D]				14.63	13.17

Notes:

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2013
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2014
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2015
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2016

4. Based on the $B_{35\%}$ estimated from the average male recruitment during 1984-2016, the biological reference points and OFL were estimated as follows:

	Scenario 1		Scenario 1n		Scenario 2	
	1,000t	Mill. lbs	1,000t	Mill. lbs	1,000t	Mill. lbs
$B_{35\%}$	24.777	54.624	24.907	54.910	25.785	56.846
$F_{35\%}$	0.29		0.29		0.29	
MMB_{2016}	22.381	49.341	23.014	50.736	23.999	52.908
OFL_{2016}	6.040	13.316	6.385	14.076	6.637	14.633
ABC_{2016}	5.436	11.984	5.746	12.668	5.937	13.169

5. Based on the 10% buffer rule used last year, ABC = 0.9*OFL. If P*=49% is used, the ABC will be higher.

G. Rebuilding Analyses

NA.

H. Data Gaps and Research Priorities

1. The following data gaps exist for this stock:
   a. Information about changes in natural mortality in the early 1980s;
   b. Un-observed trawl bycatch in the early 1980s;
   c. Natural mortality;
   d. Crab availability to the trawl surveys;
   e. Juvenile crab abundance;
   f. Female growth per molt as a function of size and maturity;
   g. Changes in male molting probability over time.

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2. Research priorities:
   a. Estimating natural mortality;
   b. Estimating crab availability to the trawl surveys;
   c. Surveying juvenile crab abundance in nearshore;
   d. Studying environmental factors that affect the survival rates from larvae to recruitment.

I. Projections and Future Outlook

1. Projections

Future population projections primarily depend on future recruitment, but crab recruitment is difficult to predict. Therefore, annual recruitment for the projections was a random selection from estimated recruitments during 1984-2016. Besides recruitment, the other major uncertainty for the projections is estimated abundance in 2016. The 2016 abundance was randomly selected from the estimated normal distribution of the assessment model output for each replicate. Three scenarios of fishing mortality for the directed pot fishery were used in the projections:

(1) No directed fishery. This was used as a base projection.

(2) $F_{40\%}$. This fishing mortality creates a buffer between the limits and target levels.

(3) $F_{35\%}$. This is the maximum fishing mortality allowed under the current overfishing definitions.

Each scenario was replicated 1,000 times and projections made over 10 years beginning in 2016 (Table 7).

As expected, projected mature male biomasses are much higher without the directed fishing mortality than under the other scenarios. At the end of 10 years, projected mature male biomass is above $B_{35\%}$ for all scenarios (Table 7; Figure 32). Projected retained catch for the $F_{35\%}$ scenario is higher than those for the $F_{40\%}$ scenario (Table 7, Figure 33). Due to the poor recruitment in recent years, the projected biomass and retained catch are expected to decline during the next few years.

2. Near Future Outlook

The near future outlook for the Bristol Bay RKC stock is a declining trend. The three recent above-average year classes (hatching years 1990, 1994, and 1997) had entered the legal population by 2006 (Figure 34). Most individuals from the 1997 year class will continue to gain weight to offset loss of the legal biomass to fishing and natural mortalities. The above-average year class (hatching year 2000) with lengths centered around 87.5 mm CL for both males and females in 2006 and with lengths centered around 112.5-117.5 mm CL for males and around 107.5 mm CL for females in 2008 has largely entered the mature male population in 2009 and the legal population by 2014 (Figure 34). No strong cohorts have been observed in the survey data after this cohort through 2010 (Figure 34). There was a huge tow of juvenile crab of size 45-55 mm in 2011, but these juveniles were not observed during 2012-2016 surveys. This single tow is unlikely to be an indicator for a strong cohort. The high survey abundance of large males and mature females in 2014 cannot be explained by the survey data during the previous years and were not followed with the 2015-2016 survey results (Figure 34). Due to lack of recruitment, mature and legal crab should continue to decline next year. Current crab abundance is still low relative to the late 1970s, and without favorable environmental conditions, recovery to the high levels of the late 1970s is unlikely.

J. Acknowledgements

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Table 1a. Bristol Bay red king crab annual catch and bycatch mortality biomass (t) from June 1 to May 31. A handling mortality rate of 20% for the directed pot, 25% for the Tanner fishery, and 80% for trawl was assumed to estimate bycatch mortality biomass.

Year	Retained Catch				Pot Bycatch		Trawl Bycatch	Tanner Fishery Bycatch	Total Catch
	U.S.	Cost-Recovery	Foreign	Total	Males	Females			
1953	1331.3		4705.6	6036.9					6036.9
1954	1149.9		3720.4	4870.2					4870.2
1955	1029.2		3712.7	4741.9					4741.9
1956	973.4		3572.9	4546.4					4546.4
1957	339.7		3718.1	4057.8					4057.8
1958	3.2		3541.6	3544.8					3544.8
1959	0.0		6062.3	6062.3					6062.3
1960	272.2		12200.7	12472.9					12472.9
1961	193.7		20226.6	20420.3					20420.3
1962	30.8		24618.7	24649.6					24649.6
1963	296.2		24930.8	25227.0					25227.0
1964	373.3		26385.5	26758.8					26758.8
1965	648.2		18730.6	19378.8					19378.8
1966	452.2		19212.4	19664.6					19664.6
1967	1407.0		15257.0	16664.1					16664.1
1968	3939.9		12459.7	16399.6					16399.6
1969	4718.7		6524.0	11242.7					11242.7
1970	3882.3		5889.4	9771.7					9771.7
1971	5872.2		2782.3	8654.5					8654.5
1972	9863.4		2141.0	12004.3					12004.3
1973	12207.8		103.4	12311.2					12311.2
1974	19171.7		215.9	19387.6					19387.6
1975	23281.2		0	23281.2					23281.2
1976	28993.6		0	28993.6			682.8		29676.4
1977	31736.9		0	31736.9			1249.9		32986.8
1978	39743.0		0	39743.0			1320.6		41063.6
1979	48910.0		0	48910.0			1331.9		50241.9
1980	58943.6		0	58943.6			1036.5		59980.1
1981	15236.8		0	15236.8			219.4		15456.2
1982	1361.3		0	1361.3			574.9		1936.2
1983	0.0		0	0.0			420.4		420.4
1984	1897.1		0	1897.1			1094.0		2991.1
1985	1893.8		0	1893.8			390.1		2283.8
1986	5168.2		0	5168.2			200.6		5368.8
1987	5574.2		0	5574.2			186.4		5760.7
1988	3351.1		0	3351.1			597.8		3948.9
1989	4656.0		0	4656.0			174.1		4830.1
1990	9236.2	36.6	0	9272.8	526.9	651.5	247.6		10698.7
1991	7791.8	93.4	0	7885.1	407.8	75.0	316.0	1401.8	10085.7
1992	3648.2	33.6	0	3681.8	552.0	418.5	335.4	244.4	5232.2
1993	6635.4	24.1	0	6659.6	763.2	637.1	426.6	54.6	8541.0
1994	0.0	42.3	0	42.3	3.8	1.9	88.9	10.8	147.8
1995	0.0	36.4	0	36.4	3.3	1.6	194.2	0.0	235.5
1996	3812.7	49.0	0	3861.7	164.6	1.0	106.5	0.0	4133.9
1997	3971.9	70.2	0	4042.1	244.7	19.6	73.4	0.0	4379.8
1998	6693.8	85.4	0	6779.2	959.7	864.9	159.8	0.0	8763.7
1999	5293.5	84.3	0	5377.9	314.2	8.8	201.6	0.0	5902.4
2000	3698.8	39.1	0	3737.9	360.8	40.5	100.4	0.0	4239.5

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2001	3811.5	54.6	0	3866.2	417.9	173.5	164.6	0.0	4622.1
2002	4340.9	43.6	0	4384.5	442.7	7.3	155.1	0.0	4989.6
2003	7120.0	15.3	0	7135.3	918.9	430.4	172.3	0.0	8656.9
2004	6915.2	91.4	0	7006.7	345.5	187.0	119.6	0.0	7658.8
2005	8305.0	94.7	0	8399.7	1359.5	498.3	155.2	0.0	10412.8
2006	7005.3	137.9	0	7143.2	563.8	37.0	116.7	3.8	7864.4
2007	9237.9	66.1	0	9303.9	1001.3	186.1	138.5	1.8	10631.6
2008	9216.1	0.0	0	9216.1	1165.5	148.4	159.5	4.0	10693.5
2009	7226.9	45.5	0	7272.5	888.1	85.2	103.7	1.6	8351.2
2010	6728.5	33.0	0	6761.5	797.5	122.6	85.3	0.0	7767.0
2011	3553.3	53.8	0	3607.1	395.0	24.0	68.8	0.0	4094.9
2012	3560.6	61.1	0	3621.7	205.2	12.3	61.2	0.0	3900.5
2013	3901.1	89.9	0	3991.0	310.6	99.8	136.2	28.5	4566.0
2014	4530.0	8.6	0	4538.6	584.7	86.2	221.9	42.0	5473.4
2015	4522.3	91.4	0	4613.7	266.1	222.9	149.4	84.2	5336.3

Table 1b. Annual retained catch (millions of crab) and catch per unit effort of the Bristol Bay red king crab fishery.

Year	Japanese Tanglenet		Russian Tanglenet		U.S. Pot/Trawl		Standardized
	Catch	Crab/tan	Catch	Crab/tan	Catch	Crab/Potlift	Crab/tan
1960	1.949	15.2	1.995	10.4	0.088		15.8
1961	3.031	11.8	3.441	8.9	0.062		12.9
1962	4.951	11.3	3.019	7.2	0.010		11.3
1963	5.476	8.5	3.019	5.6	0.101		8.6
1964	5.895	9.2	2.800	4.6	0.123		8.5
1965	4.216	9.3	2.226	3.6	0.223		7.7
1966	4.206	9.4	2.560	4.1	0.140	52	8.1
1967	3.764	8.3	1.592	2.4	0.397	37	6.3
1968	3.853	7.5	0.549	2.3	1.278	27	7.8
1969	2.073	7.2	0.369	1.5	1.749	18	5.6
1970	2.080	7.3	0.320	1.4	1.683	17	5.6
1971	0.886	6.7	0.265	1.3	2.405	20	5.8
1972	0.874	6.7			3.994	19	
1973	0.228				4.826	25	
1974	0.476				7.710	36	
1975					8.745	43	
1976					10.603	33	
1977					11.733	26	
1978					14.746	36	
1979					16.809	53	
1980					20.845	37	
1981					5.308	10	
1982					0.541	4	
1983					0.000		
1984					0.794	7	
1985					0.796	9	
1986					2.100	12	
1987					2.122	10	
1988					1.236	8	
1989					1.685	8	
1990					3.130	12	
1991					2.661	12	
1992					1.208	6	
1993					2.270	9	
1994					0.015		
1995					0.014		
1996					1.264	16	
1997					1.338	15	
1998					2.238	15	
1999					1.923	12	
2000					1.272	12	
2001					1.287	19	
2002					1.484	20	
2003					2.510	18	
2004					2.272	23	
2005					2.763	30	
2006					2.477	31	
2007					3.154	28	
2008					3.064	22	
2009					2.553	21	
2010					2.410	18	
2011					1.298	28	
2012					1.176	30	
2013					1.272	27	
2014					1.501	26	
2015					1.527	31	

Table 2. Annual sample sizes (>64 mm CL) in numbers of crab for trawl surveys, retained catch and pot and trawl fishery bycatch of Bristol Bay red king crab.

Year	Trawl Survey		Retained Catch	Pot Bycatch		Trawl Bycatch		Tanner Fishery Bycatch	
	Males	Females		Males	Females	Males	Females	Males	Females
1975	2,943	2,139	29,570						
1976	4,724	2,956	26,450			2,327	676		
1977	3,636	4,178	32,596			14,014	689		
1978	4,132	3,948	27,529			8,983	1,456		
1979	5,807	4,663	27,900			7,228	2,821		
1980	2,412	1,387	34,747			47,463	39,689		
1981	3,478	4,097	18,029			42,172	49,634		
1982	2,063	2,051	11,466			84,240	47,229		
1983	1,524	944	0			204,464	104,910		
1984	2,679	1,942	4,404			357,981	147,134		
1985	792	415	4,582			169,767	30,693		
1986	1,962	367	5,773			1,199	284		
1987	1,168	1,018	4,230			723	927		
1988	1,834	546	9,833			437	275		
1989	1,257	550	32,858			3,147	194		
1990	858	603	7,218	873	699	761	1,570		
1991	1,378	491	36,820	1,801	375	208	396	885	2,198
1992	513	360	23,552	3,248	2,389	214	107	280	685
1993	1,009	534	32,777	5,803	5,942			232	265
1994	443	266	0	0	0	330	247		
1995	2,154	1,718	0	0	0	103	35		
1996	835	816	8,896	230	11	1,025	968		
1997	1,282	707	15,747	4,102	906	1,202	483		
1998	1,097	1,150	16,131	11,079	9,130	1,627	915		
1999	764	540	17,666	1,048	36	2,154	858		
2000	731	1,225	14,091	8,970	1,486	994	671		
2001	611	743	12,854	9,102	4,567	4,393	2,521		
2002	1,032	896	15,932	9,943	302	3,372	1,464		
2003	1,669	1,311	16,212	17,998	10,327	1,568	1,057		
2004	2,871	1,599	20,038	8,258	4,112	1,689	1,506		
2005	1,283	1,682	21,938	55,019	26,775	1,815	1,872		
2006	1,171	2,672	18,027	32,252	3,980	1,481	1,983		
2007	1,219	2,499	22,387	59,769	12,661	1,011	1,097		
2008	1,221	3,352	14,567	49,315	8,488	1,867	1,039		
2009	830	1,857	16,708	52,359	6,041	1,482	870		
2010	705	1,633	20,137	36,654	6,868	734	846		
2011	525	994	10,706	20,629	1,920	600	1,069		
2012	580	707	8,956	7,206	561	1,577	1,752		
2013	633	560	10,197	13,828	6,048	4,681	4,198	218	596
2014	1,106	1,255	9,618	13,040	1,950	1,966	2,580	256	381
2015	600	677	11,746	8,037	5,889	1,126	3,704	726	2163
2016	374	803							

Table 3(1). Summary of jittering results for scenario 1. Run 51 is used for initial conditions. Runs with "NA" are not converging. Jittering factor is 0.1. Biomass and OFL are in t.

Run	Neg.log.liklihood	Max.gradient	B35%	B2016	OFL2016
1	-54160.6	0.00038	24405.3	21753.8	5776.2
2	NA	NA	NA	NA	NA
3	-54163.0	0.00149	24776.9	22380.5	6040.0
4	NA	NA	NA	NA	NA
5	-54160.6	0.00183	24405.3	21753.8	5776.2
6	-54163.0	0.00108	24776.9	22380.5	6040.0
7	-54162.6	0.00064	24752.2	22243.8	5965.6
8	-54163.0	0.00051	24776.9	22380.5	6040.0
9	-54163.0	0.00051	24776.9	22380.5	6040.0
10	NA	NA	NA	NA	NA
11	-54163.0	0.00259	24776.9	22380.5	6040.0
12	NA	NA	NA	NA	NA
13	-54163.0	0.00069	24776.9	22380.5	6040.0
14	-54163.0	0.00106	24776.9	22380.5	6040.0
15	-54160.6	0.00057	24405.3	21753.8	5776.2
16	-54163.0	0.00096	24776.9	22380.5	6040.0
17	-54163.0	0.00019	24776.9	22380.5	6040.0
18	-54163.0	0.00076	24776.9	22380.5	6040.0
19	NA	NA	NA	NA	NA
20	NA	NA	NA	NA	NA
21	-54163.0	0.00010	24776.9	22380.5	6040.0
22	-54163.0	0.00033	24776.9	22380.5	6040.0
23	-54163.0	0.00052	24776.9	22380.5	6040.0
24	-54160.6	0.00088	24405.3	21753.8	5776.2
25	-54163.0	0.00125	24776.9	22380.5	6040.0
26	NA	NA	NA	NA	NA
27	-54163.0	0.00076	24776.9	22380.5	6040.0
28	-54163.0	0.00012	24776.9	22380.5	6040.0
29	NA	NA	NA	NA	NA
30	-54163.0	0.00249	24776.9	22380.5	6040.0
31	NA	NA	NA	NA	NA
32	-54160.6	0.00025	24405.3	21753.8	5776.2
33	-54160.6	0.00044	24405.3	21753.8	5776.2
34	NA	NA	NA	NA	NA
35	-54160.6	0.00039	24405.3	21753.8	5776.2
36	-54163.0	0.00040	24776.9	22380.5	6040.0
37	-54160.6	0.00106	24405.3	21753.8	5776.2
38	-54163.0	0.00104	24776.9	22380.5	6040.0
39	-54163.0	0.00067	24776.9	22380.5	6040.0
40	NA	NA	NA	NA	NA
41	-54163.0	0.00066	24776.9	22380.5	6040.0
42	-54163.0	0.00115	24776.9	22380.5	6040.0
43	-54163.0	0.00179	24776.9	22380.5	6040.0
44	NA	NA	NA	NA	NA
45	-54163.0	0.00079	24776.9	22380.5	6040.0
46	-54160.6	0.00280	24405.3	21753.8	5776.2
47	NA	NA	NA	NA	NA
48	-54160.6	0.00237	24405.3	21753.8	5776.2
49	-54163.0	0.00061	24776.9	22380.5	6040.0
50	-54163.0	0.00143	24776.9	22380.5	6040.0
51	**-54163.0**	**0.00007**	**24776.9**	**22380.5**	**6040.0**
52	-54160.6	0.00050	24405.3	21753.8	5776.2
53	-54163.0	0.00324	24776.9	22380.5	6040.0
54	-54163.0	0.00058	24776.9	22380.5	6040.0
55	-54160.6	0.00198	24405.3	21753.8	5776.2
56	-54163.0	0.00174	24776.9	22380.5	6040.0
57	NA	NA	NA	NA	NA
58	NA	NA	NA	NA	NA
59	-54163.0	0.00050	24776.9	22380.5	6040.0
60	-54163.0	0.00059	24776.9	22380.5	6040.0
61	-54163.0	0.00032	24776.9	22380.5	6040.0
62	-54160.2	0.00063	24385.6	21630.2	5709.3
63	-54160.6	0.00216	24405.3	21753.8	5776.2
64	-54163.0	0.00029	24776.9	22380.5	6040.0
65	NA	NA	NA	NA	NA

66	-54163.0	0.00120	24776.9	22380.5	6040.0
67	-54163.0	0.00075	24776.9	22380.5	6040.0
68	-54160.6	0.00153	24405.3	21753.8	5776.2
69	-54163.0	0.00083	24776.9	22380.5	6040.0
70	-54163.0	0.00116	24776.9	22380.5	6040.0
71	-54163.0	0.00178	24776.9	22380.5	6040.0
72	-54163.0	0.00038	24776.9	22380.5	6040.0
73	NA	NA	NA	NA	NA
74	-54160.6	0.00175	24405.3	21753.8	5776.2
75	-54163.0	0.00013	24776.9	22380.5	6040.0
76	-54163.0	0.00131	24776.9	22380.5	6040.0
77	-54160.6	0.00021	24405.3	21753.8	5776.2
78	-54160.6	0.00038	24405.3	21753.8	5776.2
79	-54163.0	0.00480	24776.9	22380.5	6040.0
80	NA	NA	NA	NA	NA
81	-54162.6	0.00014	24752.2	22243.8	5965.6
82	-54163.0	0.00103	24776.9	22380.5	6040.0
83	NA	NA	NA	NA	NA
84	-54160.6	0.00069	24405.3	21753.8	5776.2
85	-54163.0	0.00083	24776.9	22380.5	6040.0
86	-54163.0	0.00098	24776.9	22380.5	6040.0
87	-54163.0	0.00289	24776.9	22380.5	6040.0
88	NA	NA	NA	NA	NA
89	-54160.6	0.00041	24405.3	21753.8	5776.2
90	NA	NA	NA	NA	NA
91	-54160.6	0.00205	24405.3	21753.8	5776.2
92	-54163.0	0.00205	24776.9	22380.5	6040.0
93	-54163.0	0.00028	24776.9	22380.5	6040.0
94	-54163.0	0.00141	24776.9	22380.5	6040.0
95	NA	NA	NA	NA	NA
96	-54163.0	0.00056	24776.9	22380.5	6040.0
97	NA	NA	NA	NA	NA
98	-54163.0	0.00078	24776.9	22380.5	6040.0
99	-54163.0	0.00153	24776.9	22380.5	6040.0
100	-54160.6	0.00047	24405.3	21753.8	5776.2

Table 3(1n). Summary of jittering results for scenario 1n. Run 18 is used for initial conditions. Runs with “NA” are not converging. Jittering factor is 0.1. Biomass and OFL are in t.

Run	Neg.log.liklihood	Max gradient	B35%	B2016	OFL2016
1	-54446.8	4223.20000	25390.3	23206.2	6280.9
2	-54577.6	0.00081	24906.6	23013.6	6384.8
3	NA	NA	NA	NA	NA
4	-54577.6	0.00062	24906.6	23013.6	6384.8
5	NA	NA	NA	NA	NA
6	-54577.6	0.00020	24906.6	23013.6	6384.8
7	-54577.6	0.00027	24906.6	23013.6	6384.8
8	-54577.6	0.00037	24906.6	23013.6	6384.8
9	NA	NA	NA	NA	NA
10	-54577.6	0.00222	24906.7	23013.6	6384.8
11	-54577.6	0.00028	24906.6	23013.6	6384.8
12	NA	NA	NA	NA	NA
13	NA	NA	NA	NA	NA
14	-54577.6	0.00030	24906.6	23013.6	6384.8
15	-54577.6	0.00188	24906.6	23013.6	6384.8
16	-54571.8	0.00188	24613.9	22706.1	6289.1
17	-54577.6	0.00028	24906.6	23013.6	6384.8
18	**-54577.6**	**0.00008**	**24906.6**	**23013.6**	**6384.8**
19	NA	NA	NA	NA	NA
20	-54577.6	0.00135	24906.6	23013.6	6384.8
21	NA	NA	NA	NA	NA
22	-54577.6	0.00050	24906.6	23013.6	6384.8
23	NA	NA	NA	NA	NA
24	NA	NA	NA	NA	NA
25	NA	NA	NA	NA	NA
26	-54577.6	0.00043	24906.6	23013.6	6384.8
27	-54577.6	0.00032	24906.6	23013.6	6384.8
28	-54577.6	0.00091	24906.6	23013.6	6384.8
29	NA	NA	NA	NA	NA
30	-54577.6	0.00074	24906.6	23013.6	6384.8
31	-54577.6	0.00006	24906.6	23013.6	6384.8
32	NA	NA	NA	NA	NA
33	-54577.6	0.00045	24906.7	23013.6	6384.8
34	NA	NA	NA	NA	NA
35	-54577.6	0.00049	24906.6	23013.6	6384.8
36	-54577.6	0.00232	24906.7	23013.6	6384.8
37	-54577.6	0.00017	24906.6	23013.6	6384.8
38	-54577.6	0.00008	24906.6	23013.6	6384.8
39	NA	NA	NA	NA	NA
40	-54577.6	0.00036	24906.6	23013.6	6384.8
41	-54577.6	0.00069	24906.6	23013.6	6384.8
42	NA	NA	NA	NA	NA
43	NA	NA	NA	NA	NA
44	-54577.6	0.00131	24906.7	23013.6	6384.8
45	-54577.6	0.00056	24906.6	23013.6	6384.8
46	-54577.6	0.00247	24906.6	23013.6	6384.8
47	NA	NA	NA	NA	NA
48	-54577.6	0.00017	24906.6	23013.6	6384.8
49	-54577.6	0.00026	24906.6	23013.6	6384.8
50	NA	NA	NA	NA	NA
51	-54577.6	0.00026	24906.6	23013.6	6384.8
52	NA	NA	NA	NA	NA
53	-54577.6	0.00114	24906.6	23013.6	6384.8
54	-54577.6	0.00022	24906.6	23013.6	6384.8
55	NA	NA	NA	NA	NA
56	NA	NA	NA	NA	NA
57	-54577.6	0.00046	24906.6	23013.6	6384.8
58	NA	NA	NA	NA	NA
59	NA	NA	NA	NA	NA
60	-54577.6	0.00326	24906.7	23013.6	6384.8
61	-54577.6	0.00009	24906.6	23013.6	6384.8
62	NA	NA	NA	NA	NA
63	NA	NA	NA	NA	NA
64	-54577.6	0.00215	24906.6	23013.6	6384.8
65	NA	NA	NA	NA	NA

66	-54577.6	0.00178	24906.7	23013.6	6384.8
67	NA	NA	NA	NA	NA
68	-54577.6	0.00191	24906.6	23013.6	6384.8
69	-54577.6	0.00026	24906.6	23013.6	6384.8
70	-54577.6	0.00057	24906.6	23013.6	6384.8
71	-54577.6	0.00272	24906.6	23013.6	6384.8
72	NA	NA	NA	NA	NA
73	NA	NA	NA	NA	NA
74	NA	NA	NA	NA	NA
75	-54577.6	0.00078	24906.6	23013.6	6384.8
76	-54577.6	0.00223	24906.7	23013.6	6384.8
77	-54577.6	0.00071	24906.6	23013.6	6384.8
78	-54577.6	0.00119	24906.7	23013.6	6384.8
79	-54577.6	0.00053	24906.6	23013.6	6384.8
80	NA	NA	NA	NA	NA
81	-54577.6	0.00104	24906.7	23013.6	6384.8
82	-54577.6	0.00090	24906.7	23013.6	6384.8
83	-54577.6	0.00033	24906.6	23013.6	6384.8
84	NA	NA	NA	NA	NA
85	-54577.6	0.00033	24906.6	23013.6	6384.8
86	NA	NA	NA	NA	NA
87	-54577.6	0.00083	24906.6	23013.6	6384.8
88	-54577.6	0.00131	24906.6	23013.6	6384.8
89	-54577.6	0.00009	24906.6	23013.6	6384.8
90	-54577.6	0.00014	24906.6	23013.6	6384.8
91	-54577.6	0.00522	24906.7	23013.6	6384.8
92	-54577.6	0.00130	24906.6	23013.6	6384.8
93	-54577.6	0.00166	24906.6	23013.6	6384.8
94	-54577.6	0.00049	24906.6	23013.6	6384.8
95	-54577.6	0.00166	24906.7	23013.6	6384.8
96	NA	NA	NA	NA	NA
97	NA	NA	NA	NA	NA
98	-54577.6	0.00127	24906.6	23013.6	6384.8
99	NA	NA	NA	NA	NA
100	-54577.6	0.00109	24906.6	23013.6	6384.8

Table 3(2). Summary of jittering results for scenario 2. Run 60 is used for initial conditions. Runs with “NA” are not converging. Jittering factor is 0.1. Biomass and OFL are in t.

Run	Neg.log.liklihood	Max gradient	B35%	B2016	OFL2016
1	-54581.2	0.00145	25785.1	23998.7	6637.2
2	-54581.2	0.00093	25785.1	23998.7	6637.2
3	-54581.2	0.00014	25785.1	23998.7	6637.2
4	-54581.2	0.00044	25785.1	23998.7	6637.2
5	-54581.2	0.00131	25785.1	23998.7	6637.2
6	-54581.2	0.00018	25785.1	23998.7	6637.2
7	-54581.2	0.00172	25785.1	23998.7	6637.2
8	-54581.2	0.00100	25785.1	23998.7	6637.2
9	NA	NA	NA	NA	NA
10	-54581.2	0.00052	25785.1	23998.7	6637.2
11	NA	NA	NA	NA	NA
12	NA	NA	NA	NA	NA
13	-54581.2	0.00126	25785.1	23998.7	6637.2
14	-54581.2	0.00023	25785.1	23998.7	6637.2
15	NA	NA	NA	NA	NA
16	-54581.2	0.00023	25785.1	23998.7	6637.2
17	-54581.2	0.00068	25785.1	23998.7	6637.2
18	-54581.2	0.00130	25785.1	23998.7	6637.2
19	-54581.2	0.00148	25785.1	23998.7	6637.2
20	NA	NA	NA	NA	NA
21	-54581.2	0.00154	25785.1	23998.7	6637.2
22	-54581.2	0.00087	25785.1	23998.7	6637.2
23	-54581.2	0.00022	25785.1	23998.7	6637.2
24	-54581.2	0.00031	25785.1	23998.7	6637.2
25	-54581.2	0.00226	25785.1	23998.7	6637.2
26	-54581.2	0.00135	25785.1	23998.7	6637.2
27	NA	NA	NA	NA	NA
28	NA	NA	NA	NA	NA
29	-54576.5	0.00027	25757.0	23644.3	6410.8
30	-54581.2	0.00047	25785.1	23998.7	6637.2
31	-54581.2	0.00140	25785.1	23998.7	6637.2
32	-54581.2	0.00045	25785.1	23998.7	6637.2
33	-54581.2	0.00109	25785.1	23998.7	6637.2
34	NA	NA	NA	NA	NA
35	NA	NA	NA	NA	NA
36	-54581.2	0.00128	25785.1	23998.7	6637.2
37	-54581.2	0.00033	25785.1	23998.7	6637.2
38	-54581.2	0.00036	25785.1	23998.7	6637.2
39	-54581.2	0.00030	25785.1	23998.7	6637.2
40	NA	NA	NA	NA	NA
41	-54581.2	0.00070	25785.1	23998.7	6637.2
42	-54581.2	0.00041	25785.1	23998.7	6637.2
43	NA	NA	NA	NA	NA
44	-54581.2	0.00210	25785.1	23998.7	6637.2
45	-54581.2	0.00016	25785.1	23998.7	6637.2
46	NA	NA	NA	NA	NA
47	-54581.2	0.00082	25785.1	23998.7	6637.2
48	-54581.2	0.00030	25785.1	23998.7	6637.2
49	-54581.2	0.00026	25785.1	23998.7	6637.2
50	-54581.2	0.00056	25785.1	23998.7	6637.2
51	-54581.2	0.00116	25785.1	23998.7	6637.2
52	NA	NA	NA	NA	NA
53	-54581.2	0.00123	25785.1	23998.7	6637.2
54	-54581.2	0.00138	25785.1	23998.7	6637.2
55	-54576.5	0.00013	25757.0	23644.3	6410.8
56	-54581.2	0.00154	25785.1	23998.7	6637.2
57	-54581.2	0.00123	25785.1	23998.7	6637.2
58	NA	NA	NA	NA	NA
59	-54581.2	0.00060	25785.1	23998.7	6637.2
60	**-54581.2**	**0.00008**	**25785.1**	**23998.7**	**6637.2**
61	NA	NA	NA	NA	NA
62	-54581.2	0.00106	25785.1	23998.7	6637.2
63	-54581.2	0.00063	25785.1	23998.7	6637.2
64	-54580.4	0.00005	25756.8	23829.2	6542.9
65	-54581.2	0.00073	25785.1	23998.7	6637.2

66	-54581.2	0.00031	25785.1	23998.7	6637.2
67	-54581.2	0.00072	25785.1	23998.7	6637.2
68	-54576.5	0.00058	25757.0	23644.3	6410.8
69	NA	NA	NA	NA	NA
70	-54581.2	0.00077	25785.1	23998.7	6637.2
71	NA	NA	NA	NA	NA
72	-54581.2	0.00076	25785.1	23998.7	6637.2
73	-54581.2	0.00057	25785.1	23998.7	6637.2
74	-54581.2	0.00074	25785.1	23998.7	6637.2
75	NA	NA	NA	NA	NA
76	-54581.2	0.00038	25785.1	23998.7	6637.2
77	-54580.4	0.00080	25756.8	23829.2	6542.9
78	-54581.2	0.00048	25785.1	23998.7	6637.2
79	-54581.2	0.00135	25785.1	23998.7	6637.2
80	NA	NA	NA	NA	NA
81	-54581.2	0.00048	25785.1	23998.7	6637.2
82	NA	NA	NA	NA	NA
83	-54581.2	0.00060	25785.1	23998.7	6637.2
84	-54581.2	0.00092	25785.1	23998.7	6637.2
85	-54581.2	0.00049	25785.1	23998.7	6637.2
86	-54581.2	0.00021	25785.1	23998.7	6637.2
87	-54581.2	0.00054	25785.1	23998.7	6637.2
88	-54581.2	0.00138	25785.1	23998.7	6637.2
89	-54581.2	0.00150	25785.1	23998.7	6637.2
90	-54581.2	0.00194	25785.1	23998.7	6637.2
91	-54581.2	0.00299	25785.1	23998.7	6637.2
92	-54581.2	0.00059	25785.1	23998.7	6637.2
93	-54581.2	0.00126	25785.1	23998.7	6637.2
94	NA	NA	NA	NA	NA
95	-54581.2	0.00122	25785.1	23998.7	6637.2
96	-54581.2	0.00028	25785.1	23998.7	6637.2
97	-54581.2	0.00055	25785.1	23998.7	6637.2
98	-54580.4	0.00163	25756.8	23829.2	6542.9
99	NA	NA	NA	NA	NA
100	NA	NA	NA	NA	NA

Table 4a. Number of parameters and the list of likelihood components for the model (Scenarios 1, 1n and 2).

Parameter counts	**Scenarios 1, 1n and 2**
Fixed growth parameters	9
Fixed recruitment parameters	2
Fixed length-weight relationship parameters	6
Fixed mortality parameters	4
Fixed survey catchability parameter	1
Fixed high grading parameters	11
Total number of fixed parameters	33
Free survey catchability parameter	1
Free growth parameters	6
Initial abundance (1975)	1
Recruitment-distribution parameters	2
Mean recruitment parameters	1
Male recruitment deviations	41
Female recruitment deviations	41
Natural and fishing mortality parameters	4
Pot male fishing mortality deviations	43
Bycatch mortality from the Tanner crab fishery	11
Pot female bycatch fishing mortality deviations	28
Trawl bycatch fishing mortality deviations	42
Initial (1975) length compositions	35
BSFRF survey extra CV	1
Free selectivity parameters	22
Total number of free parameters	279
Total number of fixed and free parameters	312

Negative log likelihood components (see table 4b)

Length compositions---retained catch
Length compositions---pot male discard
Length compositions---pot female discard
Length compositions---survey
Length compositions---trawl discard
Length compositions---Tanner crab discards
Pot discard male biomass
Retained catch biomass
Pot discard female biomass
Trawl discard
Survey biomass
Recruitment variation
Total

Table 4b. Negative log likelihood components for scenarios 1, 1n, and 2 and differences in negative log-likelihood components among model scenarios.

	Scenario					
Negative log likelihood	1	1n	2	1 – 1n	1 - 2	1n – 2
R-variation	89.21	88.59	86.87	0.63	2.34	1.72
Length-like-retained	-1006.52	-1006.30	-1005.17	-0.22	-1.35	-1.13
Length-like-discmale	-1047.63	-1047.10	-1047.20	-0.53	-0.43	0.10
Length-like-discfemale	-2408.40	-2408.56	-2409.54	0.16	1.14	0.98
Length-like-survey	-47401.20	-47400.40	-47409.90	-0.80	8.70	9.50
Length-like-disctrawl	-2076.26	-2075.56	-2075.02	-0.70	-1.24	-0.54
Length-like-discTanner	-463.67	-464.55	-465.88	0.88	2.21	1.33
Length-like-bsfrfsurvey	-238.03	-650.31	-646.36	412.28	408.33	-3.95
Catchbio_retained	48.80	48.63	48.59	0.17	0.21	0.04
Catchbio_discmale	227.46	227.56	227.80	-0.11	-0.34	-0.24
Catchbio-discfemale	0.13	0.14	0.13	0.00	0.00	0.00
Catchbio-disctrawl	0.90	0.91	0.92	0.00	-0.02	-0.01
Catchbio-discTanner	0.14	0.14	0.12	0.00	0.02	0.02
Biomass-trawl survey	94.80	94.91	97.75	-0.11	-2.95	-2.84
Biomass-bsfrfsurvey	-4.62	-7.75	-8.07	3.13	3.45	0.32
Q-trawl survey	1.10	1.22	2.76	-0.12	-1.66	-1.54
Others	20.79	20.84	21.00	-0.05	-0.21	-0.16
Total	-54163.00	-54577.60	-54581.20	414.60	418.20	3.60
Free parameters	279	279	279	0	0	0

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Table 5(1). Summary of estimated model parameter values and standard deviations and limits for scenario 1 for Bristol Bay red king crab. All values are on a log scale. Male recruit in year *t* is exp($mean+males_t$), and female recruit in year *t* is exp($mean+males_t+females_t$).

Year	Recruits				F for Directed Pot Fishery				F for Trawl	
	Females	SD	Males	SD	Males	SD	Females	SD	Estimate	SD
Mean	15.826	0.025	15.826	0.025	-1.986	0.042	0.012	0.001	-5.324	0.062
Limits↑	13,18		13,18		-3.0,0.0		.001,0.1		-8.5,-1.0	
Limits↓	-15,15		-15,15		-15,2.43		-6.0,3.5		-10,10	
1975					1.112	0.100				
1976	0.086	0.257	0.814	0.143	1.113	0.071			0.173	0.107
1977	0.527	0.160	0.729	0.104	1.112	0.061			0.700	0.105
1978	0.449	0.135	0.948	0.086	1.321	0.056			0.695	0.104
1979	0.721	0.102	1.222	0.077	1.593	0.052			0.733	0.104
1980	0.238	0.116	1.416	0.078	2.395	0.048			0.777	0.104
1981	0.110	0.148	0.594	0.105	2.425	0.007			0.338	0.104
1982	0.005	0.050	2.219	0.050	0.566	0.047			2.052	0.106
1983	-0.043	0.071	1.499	0.052	-10.25	0.743			1.933	0.105
1984	0.422	0.059	1.479	0.052	0.929	0.057			2.897	0.103
1985	0.134	0.187	-0.600	0.124	1.027	0.064			1.838	0.105
1986	0.517	0.058	0.743	0.048	1.551	0.063			0.768	0.105
1987	-0.063	0.137	-0.141	0.074	1.158	0.059			0.456	0.104
1988	0.263	0.170	-0.826	0.107	0.208	0.051			1.435	0.102
1989	0.074	0.151	-0.680	0.089	0.308	0.047			0.032	0.102
1990	-0.083	0.068	0.453	0.046	0.916	0.043	2.011	0.099	0.329	0.102
1991	-0.106	0.095	-0.010	0.056	0.893	0.045	-0.120	0.100	0.667	0.103
1992	-0.424	0.370	-1.748	0.171	0.375	0.047	2.180	0.100	0.842	0.103
1993	-0.302	0.100	-0.232	0.056	1.021	0.049	2.062	0.100	1.094	0.103
1994	-0.232	0.413	-2.116	0.200	-4.122	0.049	1.435	0.128	-0.368	0.104
1995	-0.015	0.039	1.326	0.036	-4.458	0.045	1.550	0.133	0.269	0.103
1996	-0.657	0.240	-0.506	0.114	0.091	0.043	-3.652	0.151	-0.436	0.103
1997	-0.826	0.386	-1.365	0.170	0.200	0.043	-0.995	0.102	-0.819	0.103
1998	-0.319	0.123	-0.105	0.068	0.894	0.044	2.080	0.098	-0.100	0.102
1999	0.040	0.061	0.724	0.044	0.447	0.043	-2.051	0.104	0.118	0.102
2000	-0.098	0.143	-0.245	0.082	0.076	0.043	-0.252	0.099	-0.634	0.102
2001	0.674	0.184	-0.888	0.140	0.099	0.042	1.112	0.098	-0.182	0.102
2002	0.199	0.055	1.161	0.041	0.204	0.042	-2.220	0.104	-0.278	0.101
2003	0.040	0.237	-0.620	0.149	0.728	0.042	1.184	0.099	-0.215	0.101
2004	-0.189	0.151	0.150	0.083	0.589	0.042	0.389	0.098	-0.562	0.102
2005	0.316	0.061	1.063	0.047	1.013	0.043	0.907	0.098	-0.333	0.101
2006	-0.674	0.161	0.447	0.066	0.732	0.043	-1.506	0.100	-0.622	0.102
2007	-0.323	0.157	-0.104	0.084	1.060	0.043	-0.285	0.099	-0.503	0.102
2008	0.102	0.158	-0.569	0.103	1.155	0.046	-0.603	0.099	-0.369	0.102
2009	0.264	0.140	-0.577	0.098	0.860	0.047	-0.834	0.100	-0.813	0.103
2010	-0.022	0.101	0.016	0.065	0.723	0.049	-0.298	0.100	-1.035	0.104
2011	0.108	0.105	-0.063	0.072	0.049	0.050	-1.229	0.101	-1.235	0.105
2012	-0.065	0.145	-0.391	0.088	-0.052	0.052	-1.772	0.103	-1.357	0.106
2013	-0.608	0.198	-0.591	0.092	0.129	0.055	0.168	0.100	-0.547	0.105
2014	-0.137	0.357	-1.889	0.196	0.375	0.059	-0.162	0.102	-0.032	0.106
2015	-0.151	0.216	-1.085	0.133	0.338	0.064	0.904	0.103	-0.373	0.108
2016	0.049	0.341	-1.652	0.203						

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Table 5(1) (continued). Summary of estimated model parameter values and standard deviations and limits for scenario 1 for Bristol Bay red king crab. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

				Initial Length Composition 1975			
Parameter	Value	SD	Limits	Length	Value	SD	Limits
Mm80-84	0.467	0.016	0.184, 1.0	68	1.155	0.103	-5, 5
Mf80-84	0.807	0.021	0.276, 1.5	73	1.188	0.089	-5, 5
Mf76-79,85-93	0.085	0.006	0.0, 0.108	78	0.523	0.108	-5, 5
log_betal, females	0.243	0.054	-0.67, 1.32	83	0.597	0.090	-5, 5
log_betal, males	0.673	0.080	-0.67, 1.32	88	0.407	0.089	-5, 5
log_betar, females	-0.601	0.062	-1.14, 0.5	93	0.215	0.094	-5, 5
log_betar, males	-0.614	0.051	-1.14, 0.5	98	0.220	0.093	-5, 5
Bsfrf_CV	0.031	0.055	0.00, 0.40	103	0.005	0.105	-5, 5
moltp_slope, 75-78	0.134	0.021	0.01, 0.259	108	0.082	0.103	-5, 5
moltp_slope, 79-14	0.106	0.004	0.01, 0.259	113	0.213	0.101	-5, 5
log_moltp_L50, 75-78	4.970	0.013	4.445, 5.52	118	0.013	0.119	-5, 5
log_moltp_L50, 79-14	4.950	0.004	4.445, 5.52	123	0.054	0.124	-5, 5
log_N75	19.997	0.033	15.0, 21.0	128	-0.028	0.139	-5, 5
log_avg_L50_ret	4.920	0.002	4.467, 5.51	133	-0.040	0.148	-5, 5
ret_fish_slope	0.538	0.032	0.05, 0.70	138	-0.145	0.139	-5, 5
pot disc.males, φ	-0.343	0.014	-0.40, 0.00	143	-0.257	0.143	-5, 5
pot disc.males, κ	0.004	0.000	0.0, 0.005	148	-0.442	0.154	-5, 5
pot disc.males, γ	-0.016	0.001	-0.025, 0.0	153	-0.783	0.189	-5, 5
pot disc.fema., slope	0.204	0.064	0.05, 0.43	158	-1.315	0.263	-5, 5
log_pot disc.fema., L50	4.432	0.023	4.20, 4.666	163	-1.335	0.277	-5, 5
trawl disc slope	0.065	0.004	0.01, 0.20	68	1.604	0.105	-5, 5
log_trawl disc L50	4.922	0.028	4.50, 5.40	73	1.510	0.102	-5, 5
log_srv_L50, m, bsfrf	4.398	0.045	3.59, 5.48	78	1.481	0.094	-5, 5
srv_slope, f, bsfrf	0.012	0.005	0.01, 0.435	83	1.320	0.093	-5, 5
log_srv_L50, f, bsfrf	5.305	0.509	4.09, 5.54	88	1.275	0.086	-5, 5
log_srv_L50, m, 75-81	4.351	0.011	4.09, 4.554	93	0.816	0.101	-5, 5
srv_slope, f, 75-81	0.069	0.004	0.01, 0.303	98	0.442	0.124	-5, 5
log_srv_L50, f, 75-81	4.483	0.017	4.09, 4.70	103	0.148	0.148	-5, 5
log_srv_L50, m, 82-14	4.490	0.010	4.09, 5.10	108	-0.001	0.153	-5, 5
srv_slope, f, 82-14	0.060	0.002	0.01, 0.30	113	-0.250	0.179	-5, 5
log_srv_L50, f, 82-14	4.519	0.011	4.09, 4.90	118	-0.826	0.278	-5, 5
TC_slope, females	0.382	0.139	0.02, 0.40	123	-0.936	0.316	-5, 5
log_TC_L50, females	4.532	0.014	4.24, 4.90	128	-1.210	0.408	-5, 5
TC_slope, males	0.248	0.102	0.05, 0.90	133	-2.120	0.883	-5, 5
log_TC_L50, males	4.569	0.019	4.25, 5.14	138	-2.127	0.968	-5, 5
Q	0.933	0.021	0.59, 1.2	143	NA	NA	
log_TC_F, males, 91	-4.162	0.086	-10.0, 1.00				
log_TC_F, males, 92	-6.133	0.087	-10.0, 1.00				
log_TC_F, males, 93	-6.857	0.089	-10.0, 1.00				
log_TC_F, males, 13	-8.249	0.095	-10.0, 1.00				
log_TC_F, males, 14	-7.378	0.094	-10.0, 1.00				
log_TC_F, males, 15	-6.957	0.097	-10.0, 1.00				
log_TC_F, females, 91	-2.907	0.086	-10.0, 1.00				
log_TC_F, females, 92	-4.557	0.085	-10.0, 1.00				
log_TC_F, females, 93	-6.444	0.087	-10.0, 1.00				
log_TC_F, females, 13	-7.692	0.084	-10.0, 1.00				
log_TC_F, females, 14	-7.543	0.084	-10.0, 1.00				
log_TC_F, females, 15	-6.507	0.082	-10.0, 1.00				

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Table 5(1n). Summary of estimated model parameter values and standard deviations and limits for scenario 1n for Bristol Bay red king crab. All values are on a log scale. Male recruit in year t is $\exp(\mathit{mean}+\mathit{males}_t)$, and female recruit in year t is $\exp(\mathit{mean}+\mathit{males}_t+\mathit{females}_t)$.

Year	Recruits				F for Directed Pot Fishery				F for Trawl	
	Females	SD	Males	SD	Males	SD	Females	SD	Estimate	SD
Mean	15.833	0.024	15.833	0.024	-1.985	0.041	0.012	0.001	-5.323	0.061
Limits↑	13,18		13,18		-3.0,0.0		.001,0.1		-8.5,-1.0	
Limits↓	-15,15		-15,15		-15,2.43		-6.0,3.5		-10,10	
1975					1.112	0.099				
1976	0.087	0.259	0.803	0.144	1.112	0.071			0.171	0.107
1977	0.527	0.160	0.724	0.104	1.111	0.061			0.698	0.105
1978	0.450	0.136	0.943	0.086	1.320	0.056			0.693	0.104
1979	0.722	0.102	1.218	0.077	1.591	0.052			0.730	0.104
1980	0.236	0.116	1.412	0.078	2.393	0.048			0.775	0.104
1981	0.107	0.148	0.590	0.105	2.425	0.007			0.339	0.104
1982	0.004	0.050	2.215	0.050	0.570	0.047			2.057	0.106
1983	-0.045	0.071	1.491	0.051	-10.24	0.741			1.940	0.105
1984	0.421	0.059	1.473	0.052	0.941	0.057			2.906	0.103
1985	0.133	0.188	-0.615	0.124	1.042	0.064			1.848	0.105
1986	0.518	0.058	0.733	0.047	1.566	0.063			0.777	0.104
1987	-0.061	0.138	-0.154	0.074	1.172	0.059			0.464	0.104
1988	0.261	0.171	-0.839	0.108	0.219	0.050			1.443	0.102
1989	0.071	0.152	-0.690	0.090	0.318	0.047			0.039	0.102
1990	-0.082	0.068	0.443	0.046	0.925	0.043	2.006	0.099	0.335	0.102
1991	-0.104	0.095	-0.023	0.056	0.903	0.045	-0.125	0.100	0.674	0.103
1992	-0.430	0.371	-1.759	0.171	0.386	0.046	2.175	0.100	0.851	0.103
1993	-0.304	0.100	-0.242	0.056	1.033	0.049	2.056	0.100	1.103	0.103
1994	-0.241	0.414	-2.129	0.200	-4.111	0.048	1.429	0.128	-0.358	0.104
1995	-0.014	0.039	1.317	0.036	-4.450	0.045	1.546	0.133	0.276	0.103
1996	-0.659	0.241	-0.519	0.115	0.098	0.043	-3.652	0.151	-0.430	0.103
1997	-0.839	0.388	-1.375	0.170	0.208	0.043	-0.996	0.102	-0.813	0.103
1998	-0.323	0.123	-0.111	0.068	0.901	0.044	2.075	0.098	-0.094	0.102
1999	0.039	0.061	0.718	0.044	0.453	0.043	-2.056	0.104	0.123	0.102
2000	-0.097	0.143	-0.253	0.082	0.082	0.043	-0.254	0.099	-0.630	0.102
2001	0.669	0.186	-0.896	0.141	0.104	0.042	1.109	0.098	-0.179	0.102
2002	0.199	0.054	1.157	0.041	0.208	0.042	-2.224	0.104	-0.276	0.101
2003	0.034	0.239	-0.628	0.150	0.731	0.042	1.183	0.099	-0.213	0.101
2004	-0.192	0.151	0.149	0.083	0.591	0.042	0.386	0.098	-0.561	0.102
2005	0.312	0.061	1.066	0.047	1.014	0.043	0.904	0.098	-0.333	0.101
2006	-0.670	0.160	0.449	0.066	0.731	0.043	-1.507	0.100	-0.623	0.102
2007	-0.325	0.157	-0.100	0.084	1.056	0.043	-0.285	0.099	-0.506	0.102
2008	0.105	0.157	-0.559	0.102	1.148	0.045	-0.602	0.099	-0.374	0.102
2009	0.270	0.139	-0.558	0.097	0.849	0.047	-0.830	0.100	-0.820	0.103
2010	-0.018	0.100	0.038	0.064	0.708	0.048	-0.292	0.100	-1.045	0.104
2011	0.106	0.105	-0.046	0.071	0.032	0.049	-1.223	0.101	-1.247	0.104
2012	-0.053	0.142	-0.368	0.086	-0.072	0.051	-1.765	0.103	-1.371	0.105
2013	-0.626	0.194	-0.558	0.089	0.106	0.053	0.176	0.100	-0.563	0.105
2014	-0.099	0.347	-1.879	0.194	0.347	0.057	-0.151	0.102	-0.051	0.106
2015	-0.135	0.204	-1.020	0.128	0.306	0.062	0.918	0.103	-0.396	0.107
2016	0.047	0.331	-1.617	0.202						

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Table 5(1n) (continued). Summary of estimated model parameter values and standard deviations and limits for scenario 1n for Bristol Bay red king crab. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

				Initial Length Composition 1975			
Parameter	Value	SD	Limits	Length	Value	SD	Limits
Mm80-84	0.470	0.016	0.184, 1.0	68	1.157	0.103	-5, 5
Mf80-84	0.810	0.021	0.276, 1.5	73	1.190	0.089	-5, 5
Mf76-79,85-93	0.086	0.006	0.0, 0.108	78	0.524	0.108	-5, 5
log_betal, females	0.255	0.054	-0.67, 1.32	83	0.598	0.090	-5, 5
log_betal, males	0.683	0.080	-0.67, 1.32	88	0.408	0.090	-5, 5
log_betar, females	-0.599	0.062	-1.14, 0.5	93	0.215	0.094	-5, 5
log_betar, males	-0.613	0.051	-1.14, 0.5	98	0.220	0.093	-5, 5
Bsfrf_CV	0.000	0.000	0.00, 0.40	103	0.005	0.105	-5, 5
moltp_slope, 75-78	0.135	0.022	0.01, 0.259	108	0.081	0.103	-5, 5
moltp_slope, 79-14	0.106	0.004	0.01, 0.259	113	0.212	0.101	-5, 5
log_moltp_L50, 75-78	4.971	0.013	4.445, 5.52	118	0.012	0.119	-5, 5
log_moltp_L50, 79-14	4.951	0.004	4.445, 5.52	123	0.053	0.124	-5, 5
log_N75	19.998	0.033	15.0, 21.0	128	-0.029	0.139	-5, 5
log_avg_L50_ret	4.920	0.002	4.467, 5.51	133	-0.042	0.149	-5, 5
ret_fish_slope	0.539	0.032	0.05, 0.70	138	-0.147	0.139	-5, 5
pot disc.males, φ	-0.343	0.014	-0.40, 0.00	143	-0.259	0.143	-5, 5
pot disc.males, κ	0.004	0.000	0.0, 0.005	148	-0.444	0.154	-5, 5
pot disc.males, γ	-0.016	0.001	-0.025, 0.0	153	-0.785	0.189	-5, 5
pot disc.fema., slope	0.195	0.062	0.05, 0.43	158	-1.317	0.263	-5, 5
log_pot disc.fema., L50	4.435	0.023	4.20, 4.666	163	-1.336	0.277	-5, 5
trawl disc slope	0.065	0.004	0.01, 0.20	68	1.608	0.105	-5, 5
log_trawl disc L50	4.921	0.027	4.50, 5.40	73	1.514	0.101	-5, 5
log_srv_L50, m, bsfrf	4.357	0.040	3.59, 5.48	78	1.483	0.094	-5, 5
srv_slope, f, bsfrf	0.011	0.003	0.01, 0.435	83	1.321	0.093	-5, 5
log_srv_L50, f, bsfrf	5.396	0.426	4.09, 5.54	88	1.275	0.086	-5, 5
log_srv_L50, m, 75-81	4.352	0.011	4.09, 4.554	93	0.816	0.101	-5, 5
srv_slope, f, 75-81	0.069	0.004	0.01, 0.303	98	0.442	0.124	-5, 5
log_srv_L50, f, 75-81	4.484	0.017	4.09, 4.70	103	0.148	0.148	-5, 5
log_srv_L50, m, 82-14	4.494	0.010	4.09, 5.10	108	-0.002	0.153	-5, 5
srv_slope, f, 82-14	0.060	0.002	0.01, 0.30	113	-0.249	0.179	-5, 5
log_srv_L50, f, 82-14	4.523	0.011	4.09, 4.90	118	-0.826	0.278	-5, 5
TC_slope, females	0.382	0.139	0.02, 0.40	123	-0.935	0.316	-5, 5
log_TC_L50, females	4.532	0.014	4.24, 4.90	128	-1.210	0.408	-5, 5
TC_slope, males	0.247	0.100	0.05, 0.90	133	-2.119	0.881	-5, 5
log_TC_L50, males	4.570	0.019	4.25, 5.14	138	-2.128	0.968	-5, 5
Q	0.935	0.021	0.59, 1.2	143	NA	NA	
log_TC_F, males, 91	-4.150	0.086	-10.0, 1.00				
log_TC_F, males, 92	-6.121	0.087	-10.0, 1.00				
log_TC_F, males, 93	-6.844	0.089	-10.0, 1.00				
log_TC_F, males, 13	-8.272	0.093	-10.0, 1.00				
log_TC_F, males, 14	-7.406	0.092	-10.0, 1.00				
log_TC_F, males, 15	-6.990	0.094	-10.0, 1.00				
log_TC_F, females, 91	-2.898	0.085	-10.0, 1.00				
log_TC_F, females, 92	-4.547	0.085	-10.0, 1.00				
log_TC_F, females, 93	-6.434	0.087	-10.0, 1.00				
log_TC_F, females, 13	-7.702	0.083	-10.0, 1.00				
log_TC_F, females, 14	-7.554	0.083	-10.0, 1.00				
log_TC_F, females, 15	-6.520	0.081	-10.0, 1.00				

Table 5(2). Summary of estimated model parameter values and standard deviations and limits for scenario 2 for Bristol Bay red king crab. All values are on a log scale. Male recruit in year t is exp($mean$+$males_t$), and female recruit in year t is exp($mean$+$males_t$+$females_t$).

Year	Recruits				F for Directed Pot Fishery				F for Trawl	
	Females	SD	Males	SD	Males	SD	Females	SD	Estimate	SD
Mean	15.843	0.024	15.843	0.024	-1.971	0.041	0.012	0.001	-5.300	0.062
Limits↑	13,18		13,18		-3.0,0.0		.001,0.1		-8.5,-1.0	
Limits↓	-15,15		-15,15		-15,2.43		-6.0,3.5		-10,10	
1975					1.123	0.101				
1976	-0.003	0.277	0.813	0.137	1.117	0.071			0.183	0.107
1977	0.531	0.161	0.697	0.103	1.109	0.061			0.707	0.105
1978	0.466	0.137	0.904	0.086	1.316	0.055			0.701	0.104
1979	0.741	0.103	1.178	0.077	1.587	0.052			0.739	0.104
1980	0.247	0.117	1.374	0.076	2.384	0.048			0.783	0.104
1981	0.092	0.150	0.565	0.102	2.425	0.007			0.354	0.104
1982	0.089	0.059	2.138	0.051	0.571	0.047			2.077	0.106
1983	0.018	0.075	1.458	0.051	-10.21	0.713			1.954	0.105
1984	0.465	0.061	1.476	0.049	0.929	0.056			2.914	0.103
1985	0.125	0.199	-0.631	0.122	1.037	0.064			1.863	0.105
1986	0.581	0.064	0.720	0.047	1.596	0.063			0.796	0.105
1987	-0.051	0.144	-0.159	0.074	1.212	0.058			0.485	0.104
1988	0.301	0.176	-0.851	0.107	0.246	0.050			1.461	0.102
1989	0.103	0.158	-0.710	0.089	0.335	0.047			0.051	0.102
1990	-0.025	0.073	0.435	0.046	0.938	0.043	1.996	0.099	0.344	0.102
1991	-0.061	0.098	-0.025	0.056	0.916	0.045	-0.133	0.100	0.683	0.103
1992	-0.586	0.433	-1.771	0.170	0.397	0.046	2.170	0.100	0.859	0.103
1993	-0.249	0.103	-0.257	0.056	1.046	0.048	2.051	0.101	1.111	0.103
1994	-0.464	0.486	-2.116	0.197	-4.100	0.048	1.428	0.128	-0.349	0.104
1995	0.033	0.046	1.311	0.036	-4.444	0.045	1.547	0.133	0.282	0.103
1996	-0.823	0.286	-0.514	0.114	0.102	0.042	-3.650	0.151	-0.428	0.103
1997	-0.916	0.431	-1.381	0.167	0.211	0.043	-0.998	0.102	-0.812	0.103
1998	-0.306	0.127	-0.120	0.068	0.908	0.044	2.070	0.098	-0.093	0.102
1999	0.085	0.064	0.708	0.043	0.462	0.043	-2.064	0.104	0.126	0.102
2000	-0.092	0.148	-0.237	0.081	0.087	0.042	-0.260	0.099	-0.628	0.102
2001	0.673	0.189	-0.890	0.138	0.105	0.042	1.106	0.098	-0.181	0.102
2002	0.236	0.059	1.156	0.041	0.208	0.042	-2.227	0.104	-0.279	0.101
2003	-0.038	0.255	-0.590	0.143	0.732	0.041	1.180	0.099	-0.217	0.101
2004	-0.190	0.159	0.145	0.083	0.591	0.042	0.381	0.098	-0.566	0.102
2005	0.351	0.065	1.072	0.047	1.012	0.043	0.901	0.099	-0.339	0.101
2006	-0.716	0.175	0.468	0.065	0.728	0.042	-1.510	0.100	-0.630	0.102
2007	-0.264	0.161	-0.100	0.083	1.051	0.043	-0.288	0.099	-0.515	0.102
2008	0.151	0.161	-0.558	0.101	1.140	0.045	-0.603	0.099	-0.385	0.102
2009	0.288	0.142	-0.541	0.096	0.838	0.047	-0.830	0.100	-0.832	0.103
2010	0.026	0.103	0.059	0.064	0.692	0.048	-0.289	0.100	-1.060	0.104
2011	0.142	0.107	-0.013	0.071	0.010	0.049	-1.215	0.101	-1.267	0.105
2012	-0.068	0.148	-0.327	0.085	-0.099	0.051	-1.754	0.103	-1.395	0.105
2013	-0.588	0.200	-0.513	0.089	0.076	0.054	0.189	0.100	-0.591	0.105
2014	-0.179	0.386	-1.817	0.190	0.311	0.057	-0.136	0.102	-0.082	0.106
2015	-0.114	0.211	-0.982	0.126	0.264	0.062	0.938	0.103	-0.431	0.107
2016	-0.011	0.367	-1.570	0.198						

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Table 5(2) (continued). Summary of estimated model parameter values and standard deviations and limits for scenario 2 for Bristol Bay red king crab. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

				Initial Length Composition 1975			
Parameter	Value	SD	Limits	Length	Value	SD	Limits
Mm80-84	0.460	0.016	0.184, 1.0	68	1.148	0.103	-5, 5
Mf80-84	0.807	0.021	0.276, 1.5	73	1.176	0.089	-5, 5
Mf76-79,85-93	0.091	0.007	0.0, 0.108	78	0.514	0.108	-5, 5
log_betal, females	0.312	0.058	-0.67, 1.32	83	0.592	0.089	-5, 5
log_betal, males	0.634	0.081	-0.67, 1.32	88	0.405	0.089	-5, 5
log_betar, females	-0.618	0.061	-1.14, 0.5	93	0.215	0.094	-5, 5
log_betar, males	-0.599	0.052	-1.14, 0.5	98	0.222	0.093	-5, 5
Bsfrf_CV	0.000	0.000	0.00, 0.40	103	0.010	0.105	-5, 5
moltp_slope, 75-78	0.134	0.022	0.01, 0.259	108	0.087	0.103	-5, 5
moltp_slope, 79-14	0.099	0.004	0.01, 0.259	113	0.217	0.101	-5, 5
log_moltp_L50, 75-78	4.972	0.013	4.445, 5.52	118	0.017	0.119	-5, 5
log_moltp_L50, 79-14	4.948	0.004	4.445, 5.52	123	0.057	0.124	-5, 5
log_N75	19.994	0.034	15.0, 21.0	128	-0.027	0.140	-5, 5
log_avg_L50_ret	4.921	0.002	4.467, 5.51	133	-0.041	0.149	-5, 5
ret_fish_slope	0.533	0.031	0.05, 0.70	138	-0.142	0.139	-5, 5
pot disc.males, φ	-0.330	0.014	-0.40, 0.00	143	-0.266	0.144	-5, 5
pot disc.males, κ	0.004	0.000	0.0, 0.005	148	-0.454	0.155	-5, 5
pot disc.males, γ	-0.015	0.001	-0.025, 0.0	153	-0.797	0.190	-5, 5
pot disc.fema., slope	0.189	0.062	0.05, 0.43	158	-1.332	0.265	-5, 5
log_pot disc.fema., L50	4.439	0.025	4.20, 4.666	163	-1.354	0.279	-5, 5
trawl disc slope	0.064	0.004	0.01, 0.20	68	1.628	0.105	-5, 5
log_trawl disc L50	4.932	0.028	4.50, 5.40	73	1.529	0.101	-5, 5
log_srv_L50, m, bsfrf	4.338	0.026	3.59, 5.48	78	1.491	0.094	-5, 5
srv_slope, f, bsfrf	0.037	0.006	0.01, 0.435	83	1.324	0.093	-5, 5
log_srv_L50, f, bsfrf	4.475	0.044	4.09, 5.54	88	1.273	0.086	-5, 5
log_srv_L50, m, 75-81	4.348	0.010	4.09, 4.554	93	0.814	0.102	-5, 5
srv_slope, f, 75-81	0.069	0.004	0.01, 0.303	98	0.443	0.125	-5, 5
log_srv_L50, f, 75-81	4.482	0.017	4.09, 4.70	103	0.151	0.149	-5, 5
log_srv_L50, m, 82-14	4.301	0.079	4.09, 5.10	108	-0.004	0.155	-5, 5
srv_slope, f, 82-14	0.064	0.009	0.01, 0.30	113	-0.238	0.180	-5, 5
log_srv_L50, f, 82-14	4.246	0.029	4.09, 4.90	118	-0.824	0.280	-5, 5
TC_slope, females	0.379	0.135	0.02, 0.40	123	-0.924	0.315	-5, 5
log_TC_L50, females	4.532	0.014	4.24, 4.90	128	-1.205	0.408	-5, 5
TC_slope, males	0.245	0.099	0.05, 0.90	133	-2.113	0.880	-5, 5
log_TC_L50, males	4.571	0.019	4.25, 5.14	138	-2.132	0.977	-5, 5
Q	0.955	0.021	0.59, 1.2	143	NA	NA	
log_TC_F, males, 91	-4.137	0.085	-10.0, 1.00				
log_TC_F, males, 92	-6.111	0.087	-10.0, 1.00				
log_TC_F, males, 93	-6.835	0.089	-10.0, 1.00				
log_TC_F, males, 13	-8.301	0.094	-10.0, 1.00				
log_TC_F, males, 14	-7.442	0.093	-10.0, 1.00				
log_TC_F, males, 15	-7.032	0.095	-10.0, 1.00				
log_TC_F, females, 91	-2.921	0.087	-10.0, 1.00				
log_TC_F, females, 92	-4.566	0.087	-10.0, 1.00				
log_TC_F, females, 93	-6.451	0.089	-10.0, 1.00				
log_TC_F, females, 13	-7.743	0.085	-10.0, 1.00				
log_TC_F, females, 14	-7.597	0.085	-10.0, 1.00				
log_TC_F, females, 15	-6.564	0.083	-10.0, 1.00				

Table 6(1). Annual abundance estimates (millions of crab), mature male biomass (MMB, 1000 t), and total survey biomass (1000 t) for red king crab in Bristol Bay estimated by length-based analysis (scenario 1) from 1975-2016. Mature male biomass for year *t* is on Feb. 15 of year *t*+1. Size measurements are mm carapace length.

Year (t)	Males				Females	Total Recruits	Trawl Survey Biomass	
	Mature (>119 mm)	Legal (>134 mm)	MMB (>119 mm)	SD MMB	Mature (>89 mm)		Model Est. (>64 mm)	Area-Swept
1975	55.912	29.211	82.166	5.334	74.669		247.826	202.731
1976	61.279	35.558	91.657	4.546	112.602	35.223	284.661	331.868
1977	62.869	38.173	94.811	3.814	140.725	41.696	295.008	375.661
1978	69.046	39.232	97.799	3.156	134.285	49.488	286.963	349.545
1979	65.087	40.771	83.460	2.644	116.916	77.457	264.966	167.627
1980	46.701	33.640	24.812	0.998	106.784	69.769	229.387	249.322
1981	14.569	8.500	8.340	0.463	49.346	28.639	94.525	132.669
1982	7.383	3.151	8.200	0.423	22.948	137.720	52.269	143.740
1983	6.600	3.079	8.620	0.405	14.589	65.434	44.987	49.320
1984	6.241	3.083	6.523	0.379	14.847	82.759	44.990	155.311
1985	7.535	2.547	10.663	0.561	13.710	8.781	37.098	34.535
1986	12.354	4.892	15.736	0.856	20.131	42.015	49.546	48.158
1987	15.786	7.047	22.334	1.051	23.859	12.573	56.492	70.263
1988	16.579	9.448	28.327	1.153	28.634	7.520	60.739	55.372
1989	18.007	11.272	32.008	1.210	26.305	7.860	63.996	55.941
1990	18.195	12.272	29.868	1.233	22.537	22.565	64.120	60.321
1991	14.792	11.008	24.904	1.212	20.387	14.036	58.362	85.055
1992	11.705	8.855	22.730	1.161	20.104	2.150	52.320	37.687
1993	12.260	8.016	20.145	1.135	18.021	10.293	50.473	53.703
1994	12.066	7.404	25.597	1.164	14.895	1.613	44.770	32.335
1995	12.507	9.216	28.324	1.132	14.411	55.849	51.165	38.396
1996	12.492	9.806	26.230	1.075	19.600	6.836	58.472	44.649
1997	11.733	8.833	24.313	1.026	28.382	2.742	62.829	85.277
1998	15.993	8.532	26.541	1.113	26.532	11.611	66.143	85.176
1999	17.616	10.151	31.070	1.225	23.193	31.417	65.855	65.604
2000	15.649	11.547	30.901	1.211	25.464	11.141	67.870	68.342
2001	14.570	11.002	29.648	1.161	29.445	9.100	70.306	53.188
2002	16.164	10.474	31.390	1.153	29.113	52.923	74.670	69.786
2003	16.835	11.262	29.935	1.135	34.500	8.203	79.288	116.794
2004	14.973	10.662	27.711	1.087	41.783	15.860	80.938	131.910
2005	17.222	10.066	27.807	1.102	40.030	51.287	85.803	107.341
2006	17.409	10.567	29.627	1.152	43.780	17.620	88.653	95.676
2007	16.783	11.073	26.745	1.167	50.629	11.598	93.512	104.841
2008	18.254	10.218	27.654	1.292	47.589	8.909	93.241	114.430
2009	19.304	10.923	31.151	1.474	43.184	9.656	90.221	91.673
2010	18.233	12.043	31.189	1.578	39.598	15.005	87.118	81.642
2011	15.660	11.591	31.195	1.599	37.390	14.828	82.855	67.053
2012	14.192	11.056	29.868	1.580	36.571	9.781	81.254	61.248
2013	13.821	10.262	28.536	1.587	35.395	6.387	79.173	62.410
2014	13.794	9.778	27.127	1.636	32.455	2.115	75.270	114.103
2015	13.005	9.354	25.723	1.684	28.464	4.694	69.453	64.240
2016	11.760	8.842	22.381	1.345	24.672	2.935	62.960	61.231

Table 6(1n). Annual abundance estimates (million crab), mature male biomass (MMB, 1000 t), and total survey biomass (1000t) for red king crab in Bristol Bay estimated by length-based analysis (scenario 1n) from 1975-2016. Mature male biomass for year *t* is on Feb. 15, year *t*+1. Size measurements are mm carapace length.

Year (t)	Males				Females	Total Recruits	Total Survey Biomass	
	Mature (>119 mm)	Legal (>134mm)	MMB (>119 mm)	SD MMB	Mature (>89 mm)		Model Est. (>64 mm)	Area-Swept (>64 mm)
1975	55.868	29.186	82.085	5.327	74.725		248.224	202.731
1976	61.241	35.540	91.584	4.542	112.801	35.096	285.230	331.868
1977	62.850	38.158	94.761	3.810	140.909	41.765	295.647	375.661
1978	69.059	39.232	97.805	3.151	134.387	49.594	287.590	349.545
1979	65.122	40.793	83.524	2.640	116.942	77.709	265.551	167.627
1980	46.754	33.680	24.796	0.991	106.776	69.986	229.913	249.322
1981	14.546	8.497	8.294	0.453	49.236	28.673	94.507	132.669
1982	7.341	3.136	8.127	0.415	22.848	138.043	51.867	143.740
1983	6.541	3.053	8.522	0.396	14.534	65.378	44.539	49.320
1984	6.177	3.049	6.420	0.370	14.765	82.813	44.491	155.311
1985	7.444	2.511	10.502	0.548	13.638	8.706	36.618	34.535
1986	12.222	4.831	15.489	0.838	20.018	41.914	48.982	48.158
1987	15.623	6.958	22.019	1.029	23.738	12.515	55.872	70.263
1988	16.414	9.339	27.989	1.129	28.472	7.471	60.105	55.372
1989	17.844	11.158	31.664	1.183	26.147	7.824	63.395	55.941
1990	18.036	12.157	29.528	1.205	22.383	22.514	63.548	60.321
1991	14.647	10.895	24.579	1.184	20.241	13.979	57.797	85.055
1992	11.575	8.748	22.428	1.134	19.957	2.138	51.765	37.687
1993	12.137	7.918	19.859	1.109	17.883	10.257	49.950	53.703
1994	11.946	7.314	25.316	1.138	14.774	1.599	44.289	32.335
1995	12.397	9.129	28.065	1.108	14.294	55.711	50.685	38.396
1996	12.393	9.726	25.997	1.053	19.490	6.793	57.966	44.649
1997	11.645	8.759	24.104	1.005	28.235	2.723	62.309	85.277
1998	15.891	8.467	26.319	1.090	26.406	11.602	65.657	85.176
1999	17.508	10.084	30.840	1.200	23.081	31.444	65.402	65.604
2000	15.553	11.478	30.693	1.187	25.365	11.134	67.445	68.342
2001	14.489	10.936	29.470	1.137	29.352	9.068	69.917	53.188
2002	16.098	10.417	31.242	1.128	29.032	53.125	74.317	69.786
2003	16.784	11.220	29.818	1.109	34.455	8.168	78.971	116.794
2004	14.937	10.631	27.629	1.062	41.763	15.939	80.672	131.910
2005	17.205	10.047	27.764	1.072	40.026	51.687	85.615	107.341
2006	17.412	10.565	29.632	1.117	43.836	17.814	88.561	95.676
2007	16.812	11.088	26.814	1.128	50.750	11.728	93.558	104.841
2008	18.342	10.256	27.838	1.242	47.759	9.073	93.465	114.430
2009	19.455	11.009	31.470	1.411	43.376	9.942	90.645	91.673
2010	18.419	12.177	31.615	1.505	39.844	15.482	87.745	81.642
2011	15.863	11.753	31.692	1.523	37.737	15.178	83.666	67.053
2012	14.417	11.229	30.432	1.502	37.018	10.137	82.245	61.248
2013	14.096	10.453	29.198	1.509	35.906	6.604	80.337	62.410
2014	14.121	10.005	27.904	1.556	32.989	2.190	76.584	114.103
2015	13.369	9.622	26.594	1.605	28.958	5.081	70.900	64.240
2016	12.145	9.138	23.014	1.285	25.162	3.057	64.495	61.231

Table 6(2). Annual abundance estimates (million crab), mature male biomass (MMB, 1000 t), and total survey biomass (1000t) for red king crab in Bristol Bay estimated by length-based analysis (scenario 2) from 1975-2016. Mature male biomass for year *t* is on Feb. 15, year *t*+1. Size measurements are mm carapace length.

Year (t)	Males				Females	Total Recruits	Total Survey Biomass	
	Mature (>119 mm)	Legal (>134mm)	MMB (>119 mm)	SD MMB	Mature (>89 mm)		Model Est. (>64 mm)	Area-Swept (>64 mm)
1975	55.363	28.789	80.956	5.290	74.312		252.302	202.731
1976	60.873	35.220	90.717	4.492	112.493	34.194	290.193	331.868
1977	62.507	37.943	94.074	3.762	139.728	41.164	300.239	375.661
1978	68.634	39.040	97.136	3.126	132.567	48.616	291.471	349.545
1979	64.702	40.612	82.947	2.620	114.820	76.346	268.500	167.627
1980	46.356	33.515	24.784	0.982	104.447	68.362	231.675	249.322
1981	14.470	8.418	8.313	0.450	48.423	28.014	95.515	132.669
1982	7.333	3.107	8.158	0.411	22.560	134.830	48.635	143.740
1983	6.568	3.036	8.593	0.394	14.566	65.834	42.064	49.320
1984	6.196	3.053	6.491	0.372	15.011	86.115	42.207	155.311
1985	7.350	2.503	10.386	0.533	14.183	8.616	34.935	34.535
1986	12.034	4.699	15.127	0.797	20.795	43.495	46.709	48.158
1987	15.533	6.724	21.636	0.990	24.640	12.627	53.470	70.263
1988	16.373	9.106	27.636	1.097	29.468	7.620	57.663	55.372
1989	17.809	10.966	31.317	1.153	26.952	7.869	61.050	55.941
1990	17.986	11.983	29.178	1.173	22.963	23.158	61.475	60.321
1991	14.599	10.734	24.245	1.154	20.744	14.367	56.069	85.055
1992	11.519	8.618	22.124	1.107	20.488	2.011	50.161	37.687
1993	12.078	7.804	19.574	1.082	18.315	10.447	48.331	53.703
1994	11.889	7.186	25.045	1.110	15.066	1.490	42.788	32.335
1995	12.356	8.997	27.809	1.081	14.565	57.298	49.244	38.396
1996	12.360	9.619	25.767	1.029	20.032	6.533	56.623	44.649
1997	11.612	8.671	23.898	0.984	29.120	2.671	60.605	85.277
1998	15.888	8.377	26.162	1.067	27.161	11.693	63.652	85.176
1999	17.509	9.956	30.664	1.174	23.696	32.191	63.493	65.604
2000	15.582	11.344	30.535	1.166	26.075	11.449	65.773	68.342
2001	14.526	10.858	29.357	1.122	30.261	9.228	68.265	53.188
2002	16.123	10.361	31.147	1.115	29.959	54.649	72.578	69.786
2003	16.825	11.138	29.742	1.099	35.601	8.259	77.323	116.794
2004	15.016	10.559	27.614	1.057	43.179	16.037	78.862	131.910
2005	17.336	10.011	27.848	1.076	41.329	53.682	83.666	107.341
2006	17.578	10.537	29.786	1.128	45.331	18.047	86.734	95.676
2007	17.022	11.085	27.042	1.151	52.581	12.141	91.696	104.841
2008	18.618	10.295	28.195	1.282	49.502	9.395	91.644	114.430
2009	19.808	11.071	31.981	1.470	45.048	10.314	89.142	91.673
2010	18.806	12.288	32.224	1.577	41.437	16.315	86.783	81.642
2011	16.233	11.918	32.350	1.599	39.332	16.129	83.272	67.053
2012	14.779	11.429	31.140	1.581	38.760	10.595	82.268	61.248
2013	14.489	10.672	30.002	1.593	37.704	7.071	80.661	62.410
2014	14.578	10.247	28.843	1.649	34.671	2.266	77.179	114.103
2015	13.893	9.903	27.680	1.707	30.473	5.380	71.787	64.240
2016	12.715	9.475	23.999	1.379	26.482	3.142	65.697	61.231

Table 7(1). Comparison of projected mature male biomass (1000 t) on Feb. 15, retained catch (1000 t), their 95% limits, and mean fishing mortality with no directed fishery, $F_{40\%}$, and $F_{35\%}$ harvest strategy with $F_{35\%}$ constraint during 2016-2025. Parameter estimates with scenario 1 are used for the projection.

Year	MMB	95% LCI	95% UCI	Catch	95% LCI	95% UCI
			No Directed Fishery			
2016	27.795	23.685	31.675	0.000	0.000	0.000
2017	28.031	23.887	31.945	0.000	0.000	0.000
2018	27.251	23.222	31.057	0.000	0.000	0.000
2019	26.377	22.672	30.238	0.000	0.000	0.000
2020	27.930	22.652	38.240	0.000	0.000	0.000
2021	32.105	22.900	50.850	0.000	0.000	0.000
2022	37.112	23.803	60.698	0.000	0.000	0.000
2023	42.086	24.922	71.806	0.000	0.000	0.000
2024	46.729	26.277	78.660	0.000	0.000	0.000
2025	50.898	27.400	84.352	0.000	0.000	0.000
			$F_{40\%}$			
2016	23.115	20.212	25.954	4.701	3.489	5.747
2017	20.157	17.942	22.255	3.666	2.825	4.545
2018	17.522	15.781	19.135	2.757	2.183	3.335
2019	15.726	14.313	17.239	2.127	1.731	2.551
2020	16.540	13.273	24.508	2.043	1.469	3.411
2021	19.487	13.050	33.166	2.511	1.321	4.863
2022	22.532	13.565	39.730	3.278	1.365	6.481
2023	24.943	14.273	44.348	4.020	1.479	7.879
2024	26.696	14.914	47.210	4.599	1.687	8.835
2025	27.925	15.537	48.924	4.987	1.875	9.294
			$F_{35\%}$			
2016	22.411	19.680	24.916	5.408	4.023	6.790
2017	19.183	17.169	20.989	4.001	3.116	4.864
2018	16.489	14.934	17.864	2.919	2.339	3.471
2019	14.725	13.457	16.094	2.216	1.823	2.623
2020	15.559	12.403	23.327	2.134	1.521	3.618
2021	18.409	12.222	31.301	2.692	1.369	5.489
2022	21.235	12.720	37.385	3.567	1.425	7.229
2023	23.361	13.458	41.594	4.377	1.564	8.693
2024	24.827	14.117	43.196	4.974	1.784	9.682
2025	25.796	14.627	44.707	5.360	1.986	10.155

Table 7(1n). Comparison of projected mature male biomass (1000 t) on Feb. 15, retained catch (1000 t), their 95% limits, and mean fishing mortality with no directed fishery, $F_{40\%}$, and $F_{35\%}$ harvest strategy with $F_{35\%}$ constraint during 2016-2025. Parameter estimates with scenario 1n are used for the projection.

Year	MMB	95% LCI	95% UCI	Catch	95% LCI	95% UCI
No Directed Fishery						
2016	28.741	24.615	32.637	0.000	0.000	0.000
2017	28.999	24.835	32.930	0.000	0.000	0.000
2018	28.231	24.177	32.058	0.000	0.000	0.000
2019	27.355	23.624	31.253	0.000	0.000	0.000
2020	28.862	23.560	39.163	0.000	0.000	0.000
2021	32.975	23.767	51.747	0.000	0.000	0.000
2022	37.923	24.598	61.485	0.000	0.000	0.000
2023	42.843	25.675	72.519	0.000	0.000	0.000
2024	47.435	26.918	79.339	0.000	0.000	0.000
2025	51.559	28.059	84.964	0.000	0.000	0.000
$F_{40\%}$						
2016	23.802	20.895	26.738	4.962	3.737	5.928
2017	20.694	18.491	22.838	3.863	3.003	4.788
2018	17.978	16.250	19.614	2.896	2.312	3.497
2019	16.135	14.731	17.658	2.234	1.832	2.673
2020	16.886	13.618	24.802	2.132	1.547	3.511
2021	19.773	13.350	33.446	2.586	1.378	4.930
2022	22.773	13.815	40.098	3.343	1.419	6.544
2023	25.152	14.481	44.631	4.078	1.520	7.957
2024	26.880	15.055	47.202	4.650	1.713	8.888
2025	28.091	15.696	49.236	5.033	1.895	9.358
$F_{35\%}$						
2016	23.051	20.330	25.668	5.718	4.305	7.003
2017	19.669	17.675	21.528	4.204	3.306	5.121
2018	16.898	15.362	18.301	3.059	2.472	3.636
2019	15.092	13.832	16.465	2.322	1.925	2.743
2020	15.868	12.712	23.587	2.223	1.602	3.722
2021	18.662	12.493	31.507	2.768	1.430	5.560
2022	21.445	12.981	37.669	3.633	1.484	7.289
2023	23.542	13.625	41.742	4.435	1.604	8.776
2024	24.986	14.250	43.391	5.026	1.802	9.732
2025	25.939	14.762	44.797	5.406	2.011	10.166

Table 7(2). Comparison of projected mature male biomass (1000 t) on Feb. 15, retained catch (1000 t), their 95% limits, and mean fishing mortality with no directed fishery, $F_{40\%}$, and $F_{35\%}$ harvest strategy with $F_{35\%}$ constraint during 2016-2025. Parameter estimates with scenario 2 are used for the projection.

Year	MMB	95% LCI	95% UCI	Catch	95% LCI	95% UCI
			No Directed Fishery			
2016	29.955	25.862	33.821	0.000	0.000	0.000
2017	30.270	26.134	34.176	0.000	0.000	0.000
2018	29.516	25.482	33.325	0.000	0.000	0.000
2019	28.617	24.898	32.505	0.000	0.000	0.000
2020	30.065	24.788	40.330	0.000	0.000	0.000
2021	34.074	24.953	52.124	0.000	0.000	0.000
2022	38.903	25.615	62.270	0.000	0.000	0.000
2023	43.715	26.626	73.162	0.000	0.000	0.000
2024	48.215	27.666	79.749	0.000	0.000	0.000
2025	52.264	28.763	85.190	0.000	0.000	0.000
			$F_{40\%}$			
2016	24.824	21.933	27.762	5.155	3.947	6.087
2017	21.618	19.425	23.767	4.037	3.179	4.962
2018	18.806	17.085	20.448	3.041	2.457	3.645
2019	16.875	15.474	18.405	2.352	1.949	2.794
2020	17.542	14.267	25.365	2.225	1.638	3.597
2021	20.342	13.916	33.692	2.651	1.456	4.943
2022	23.279	14.297	40.077	3.378	1.465	6.511
2023	25.622	14.895	44.978	4.094	1.567	7.893
2024	27.332	15.476	47.566	4.658	1.722	8.860
2025	28.532	16.086	49.502	5.039	1.905	9.277
			$F_{35\%}$			
2016	24.038	21.337	26.663	5.945	4.546	7.192
2017	20.548	18.565	22.414	4.393	3.498	5.312
2018	17.677	16.147	19.087	3.212	2.626	3.793
2019	15.783	14.531	17.161	2.444	2.047	2.866
2020	16.480	13.326	24.114	2.317	1.696	3.817
2021	19.195	12.983	31.769	2.833	1.507	5.569
2022	21.926	13.457	37.667	3.665	1.529	7.259
2023	23.998	14.020	41.777	4.447	1.646	8.753
2024	25.433	14.607	43.592	5.030	1.810	9.682
2025	26.383	15.133	45.362	5.410	2.018	10.147

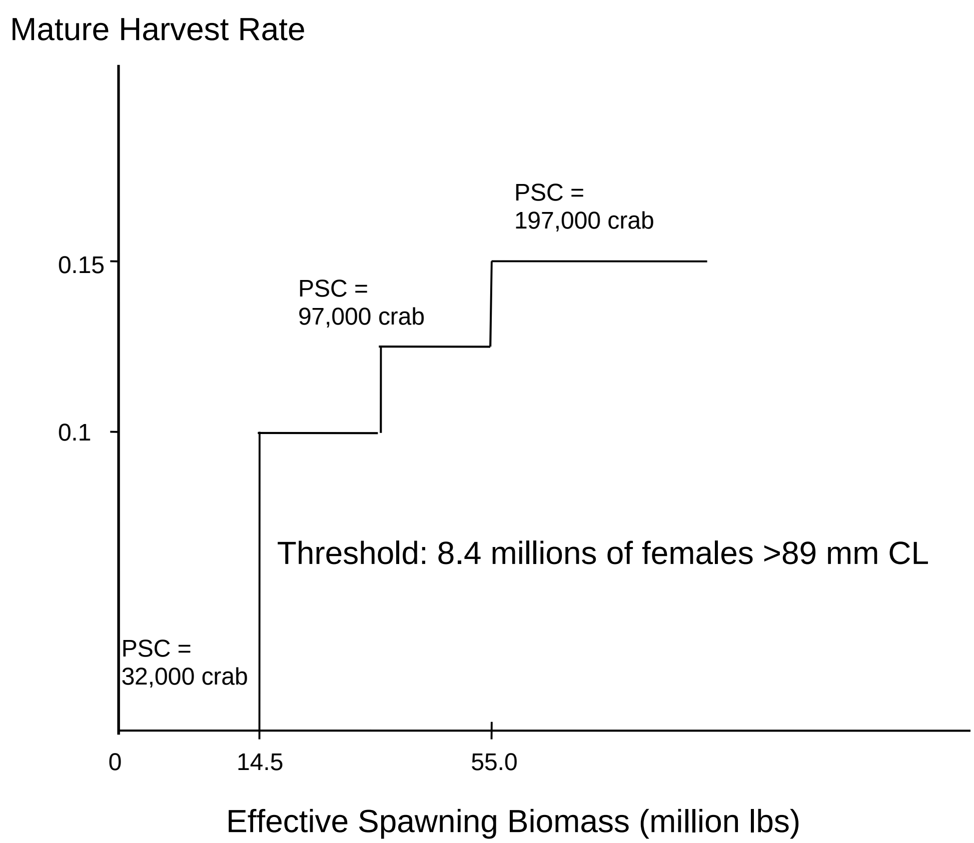

Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and annual prohibited species catch (PSC) limits (numbers of crab) of Bristol Bay red king crab in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates of effective spawning biomass (ESB), whereas PSC limits apply to previous-year ESB.

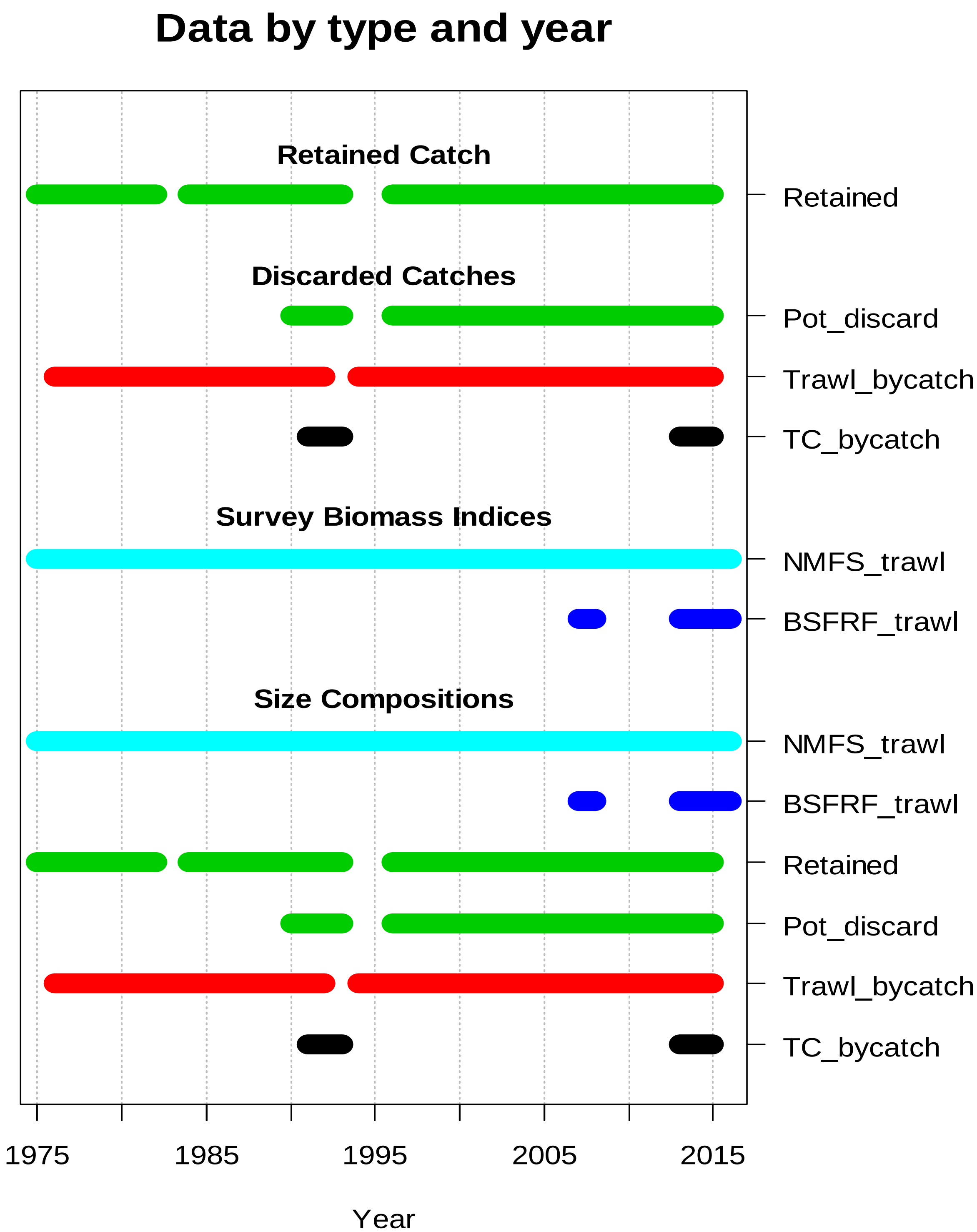

Figure 2. Data types and ranges used for the stock assessment.

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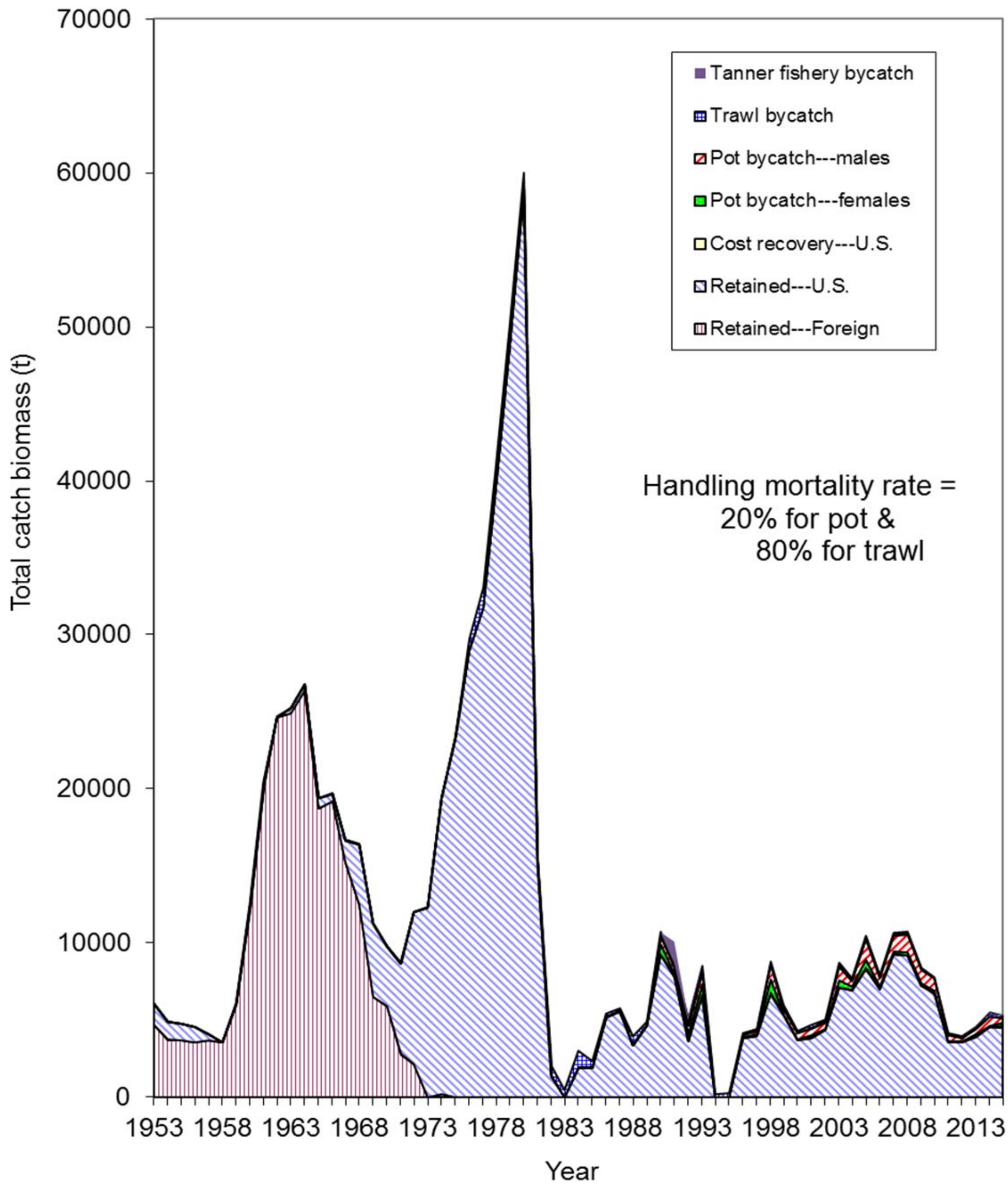

Figure 3. Retained catch biomass and bycatch mortality biomass (t) for Bristol Bay red king crab from 1953 to 2015. Handling mortality rates were assumed to be 0.2 for the directed pot fishery 0.25 for the Tanner crab fishery and 0.8 for the trawl fisheries.

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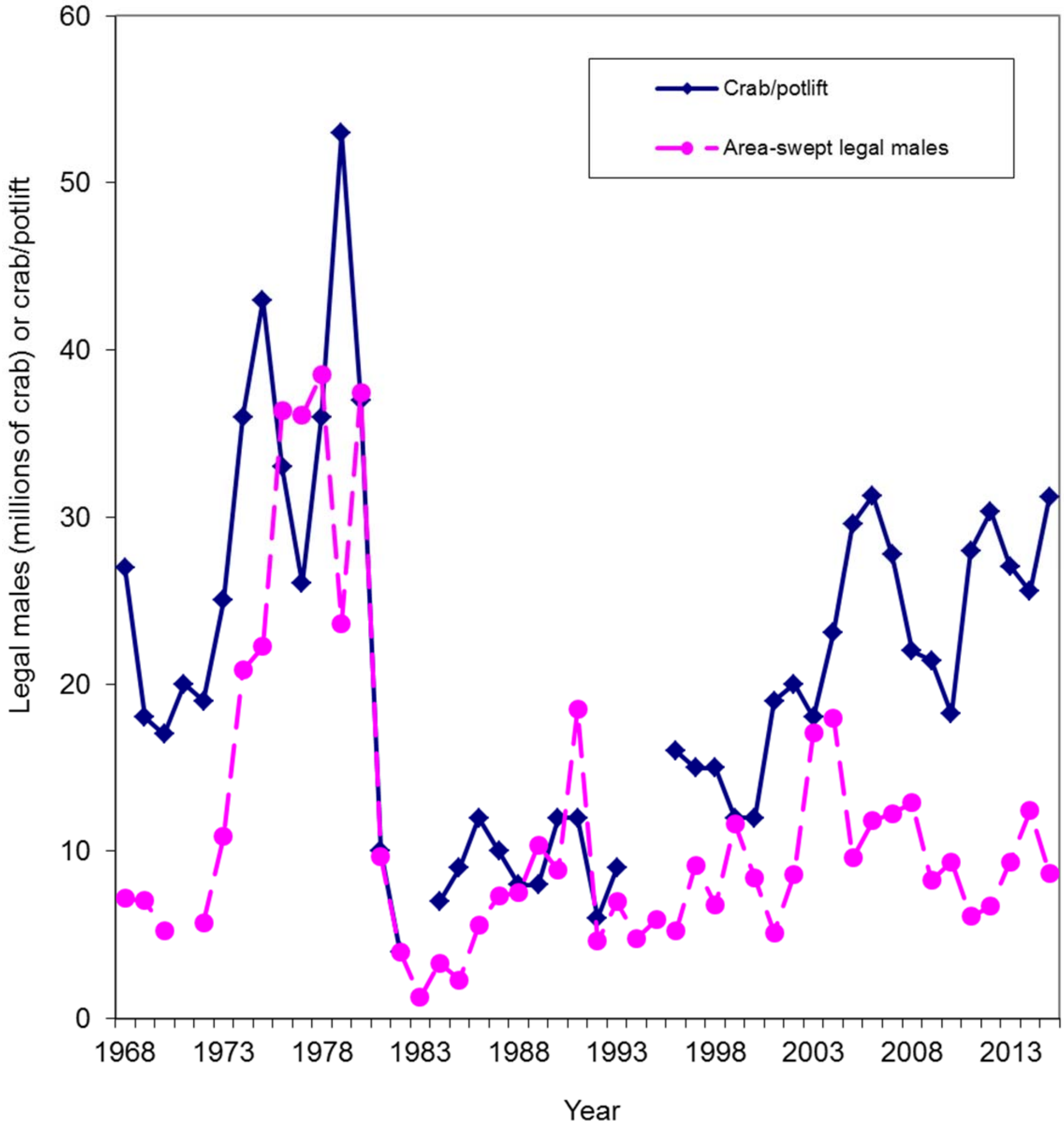

Figure 4. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2015.

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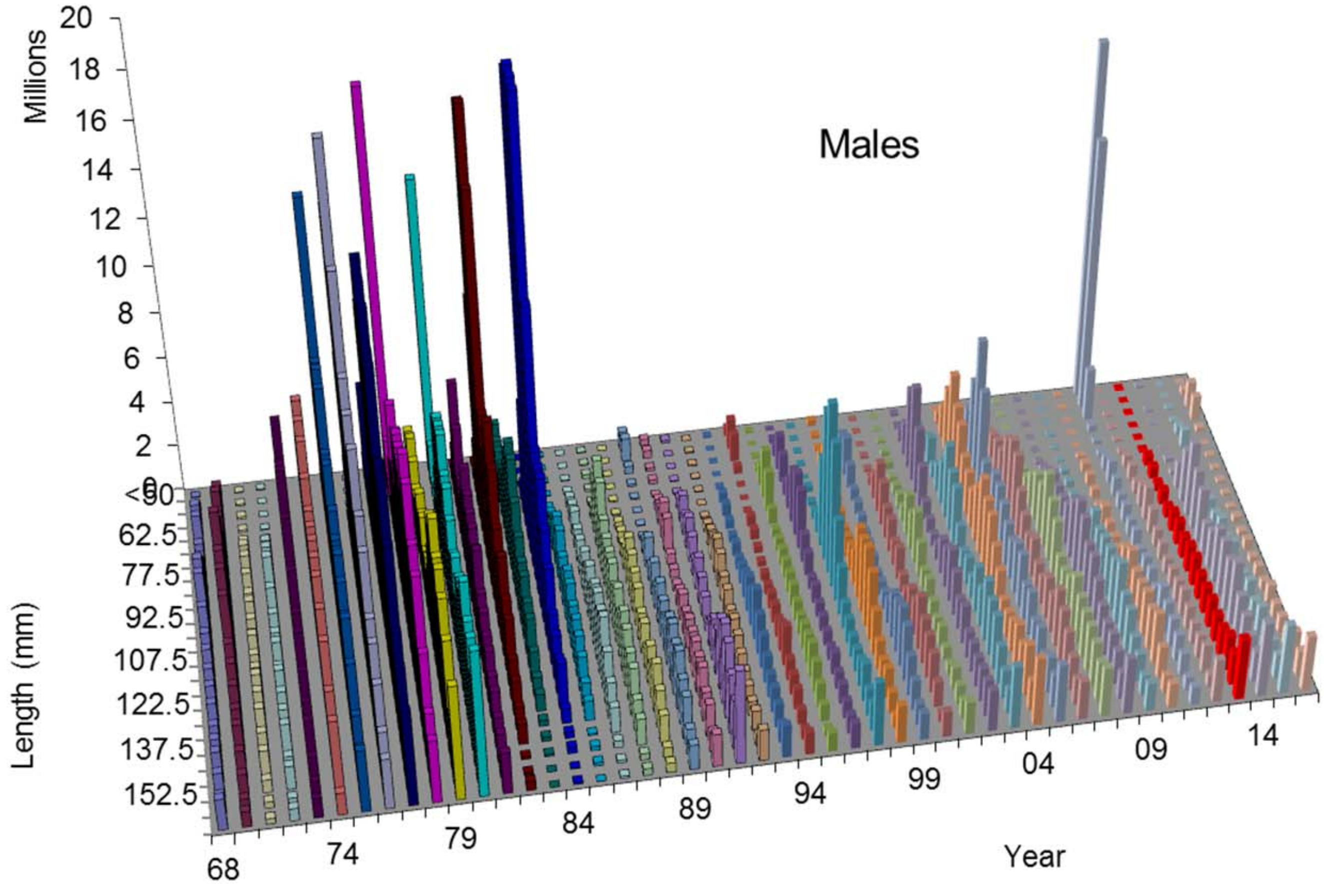

Figure 5a. Survey abundances by 5-mm carapace length bin for male Bristol Bay red king crab from 1968 to 2016.

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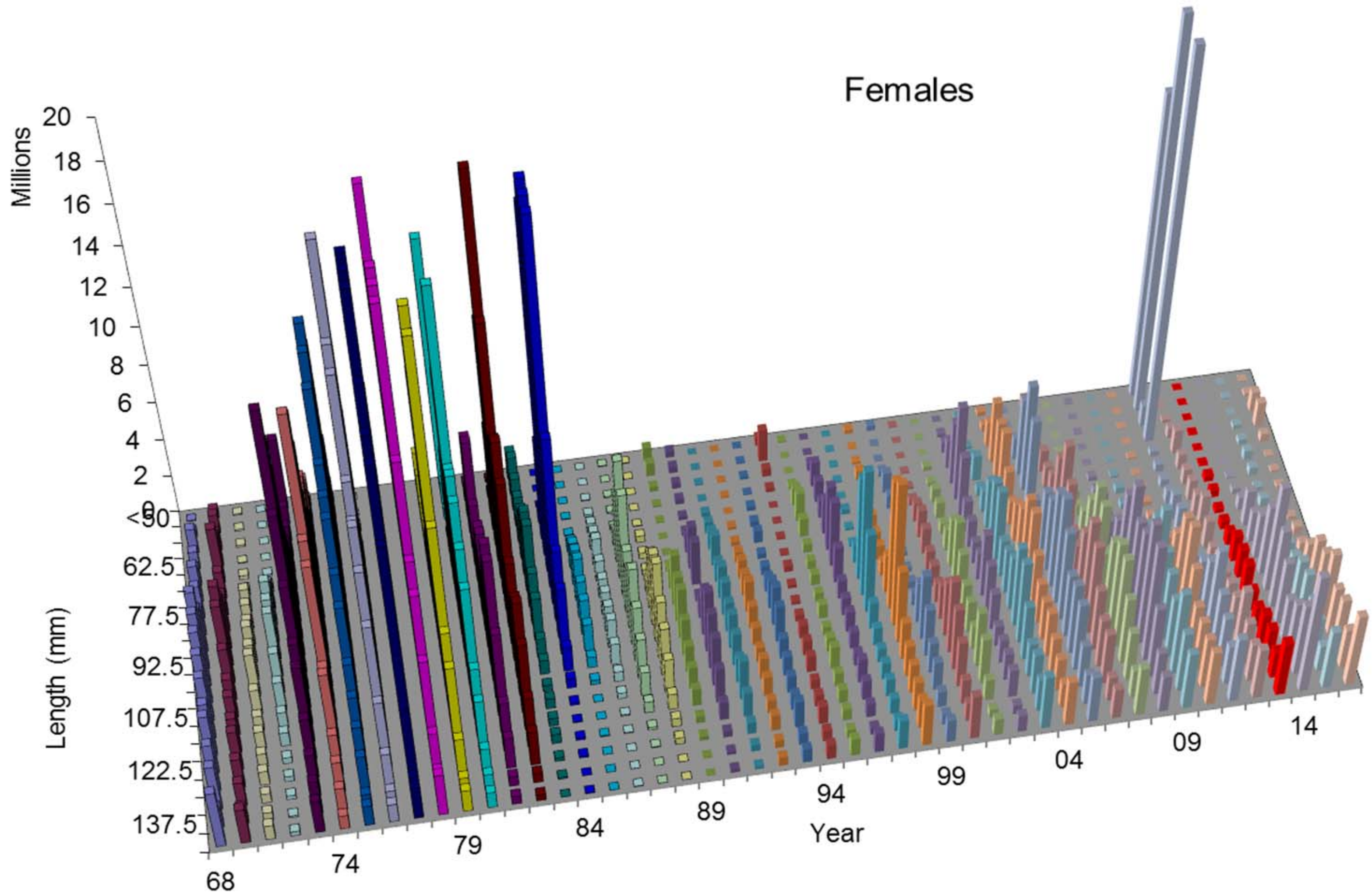

Figure 5b. Survey abundances by 5 mm carapace length bin for female Bristol Bay red king crab from 1968 to 2016.

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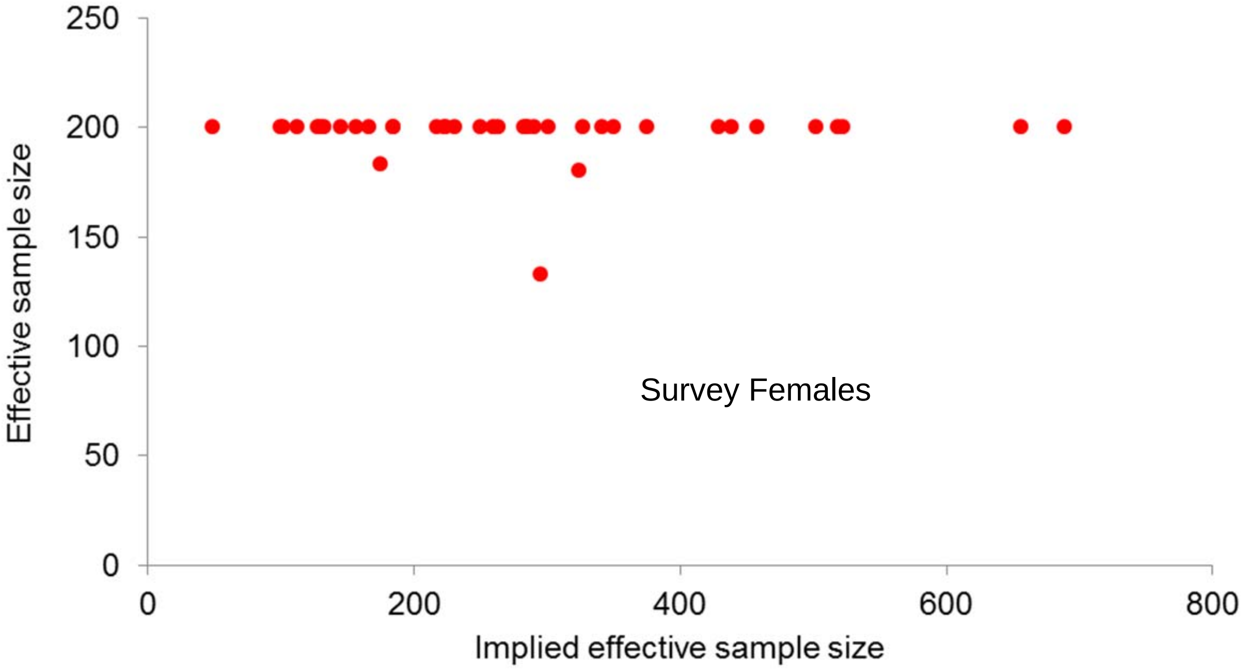

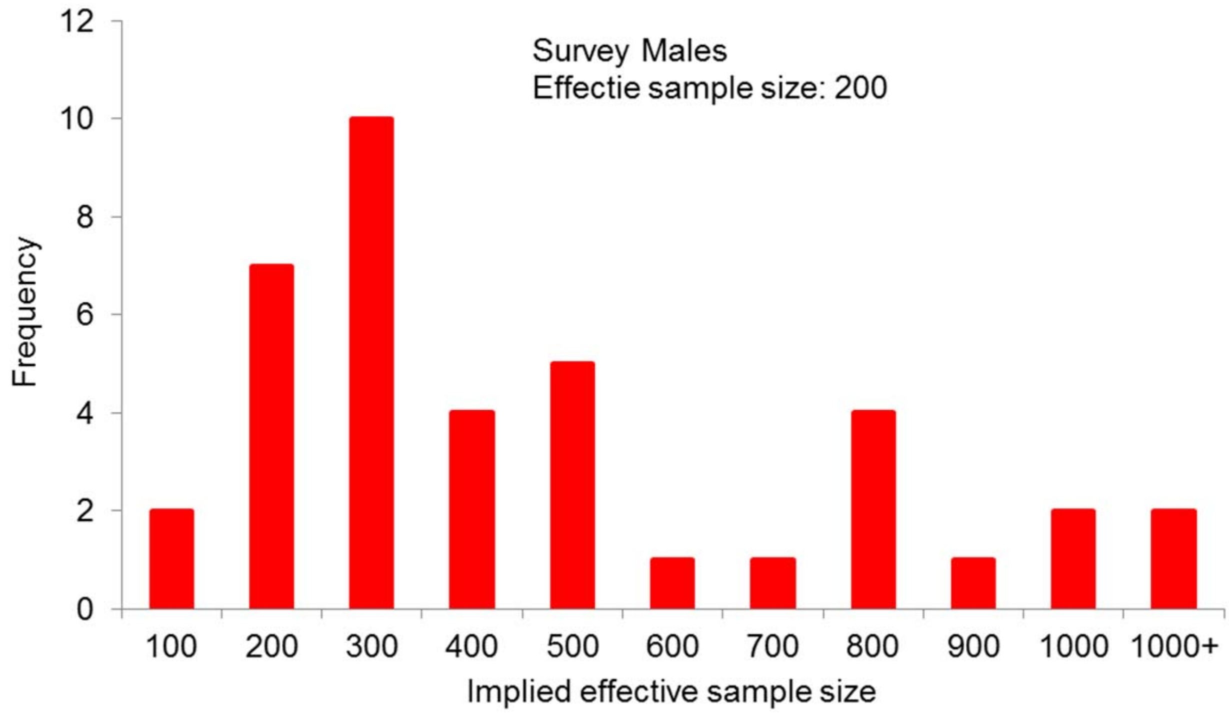

Figure 6. Relationship between implied effective sample sizes (section 3(a)(5)(i)) and effective sample sizes (see effective sample sizes for scenario 1) for length/sex composition data with scenario 1: trawl survey data.

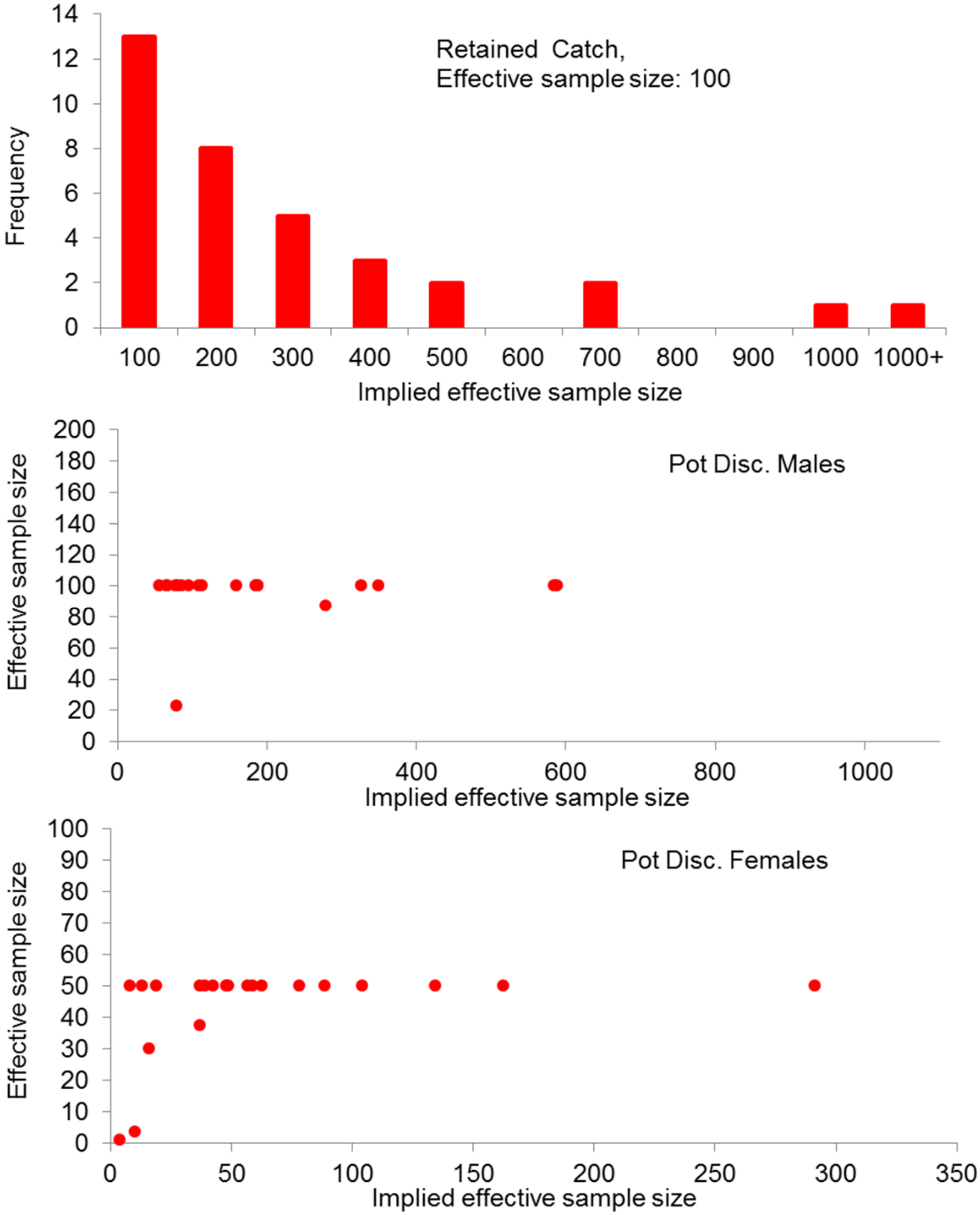

Figure 7. Relationship between implied effective sample sizes (section 3(a)(5)(i)) and effective sample sizes (see effective sample sizes for scenario 1) for length/sex composition data with scenario 1: directed pot fishery data.

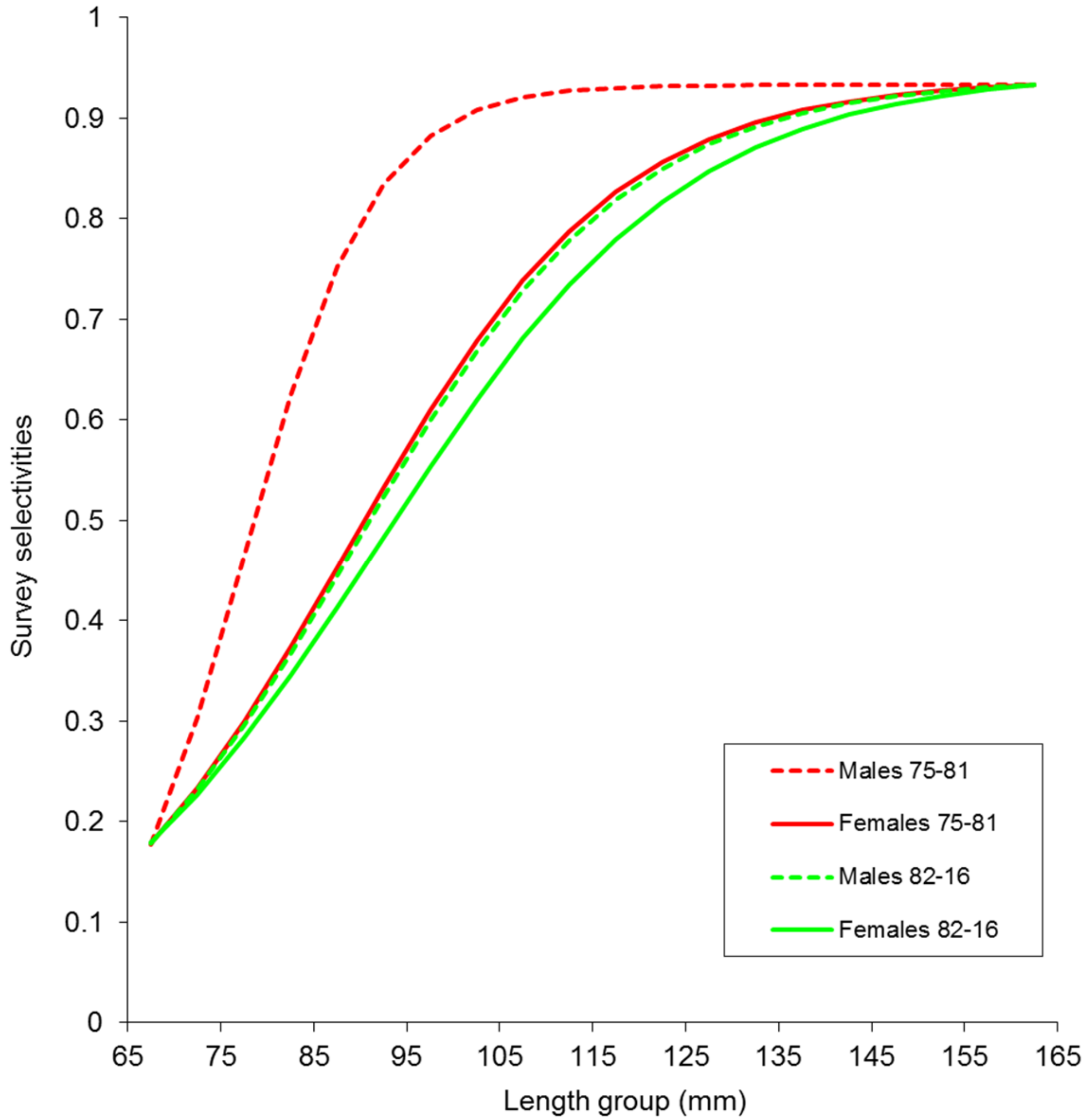

Figure 8a(1). Estimated trawl survey selectivities under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

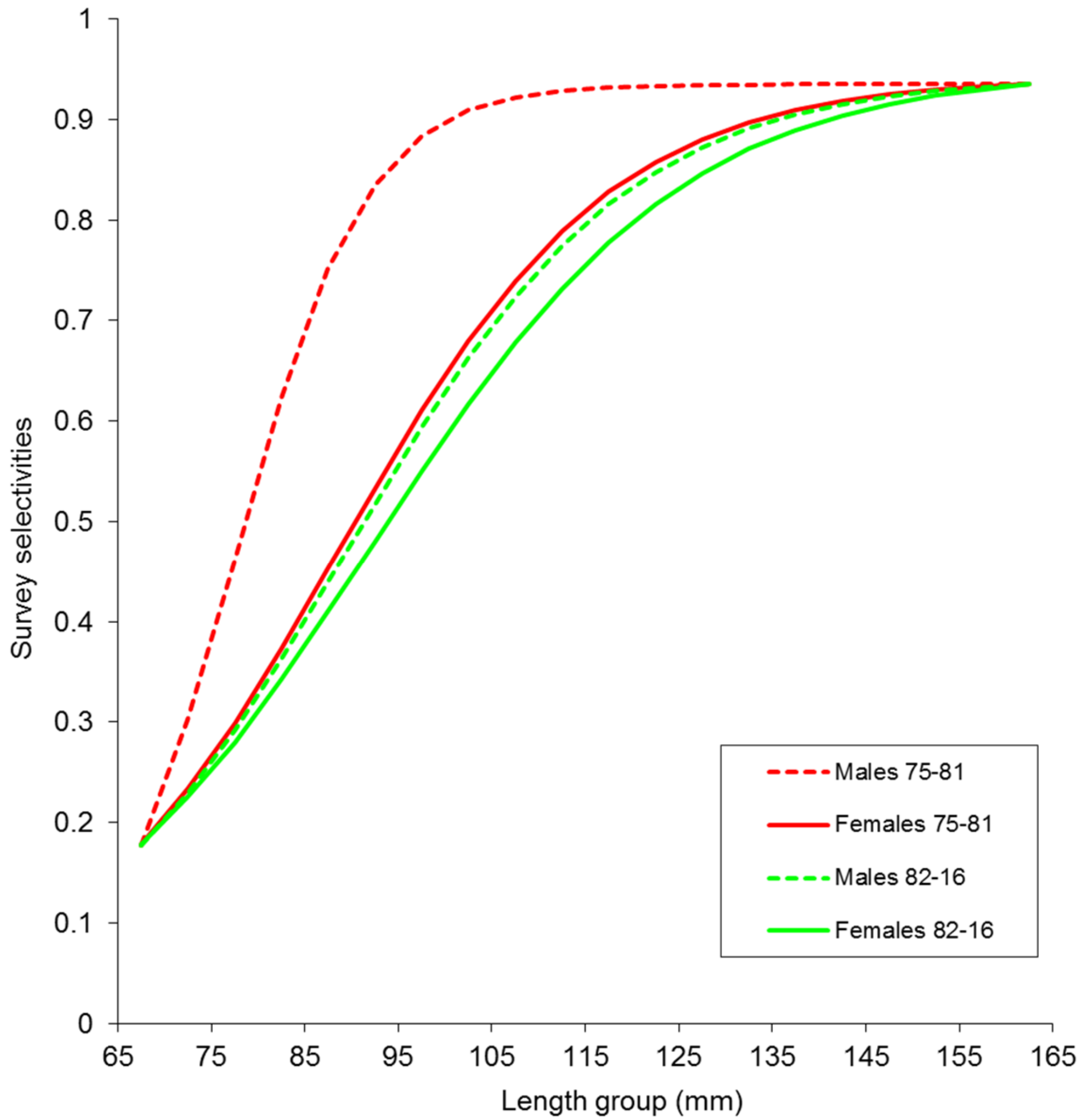

Figure 8a(1n). Estimated trawl survey selectivities under scenario 1n. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

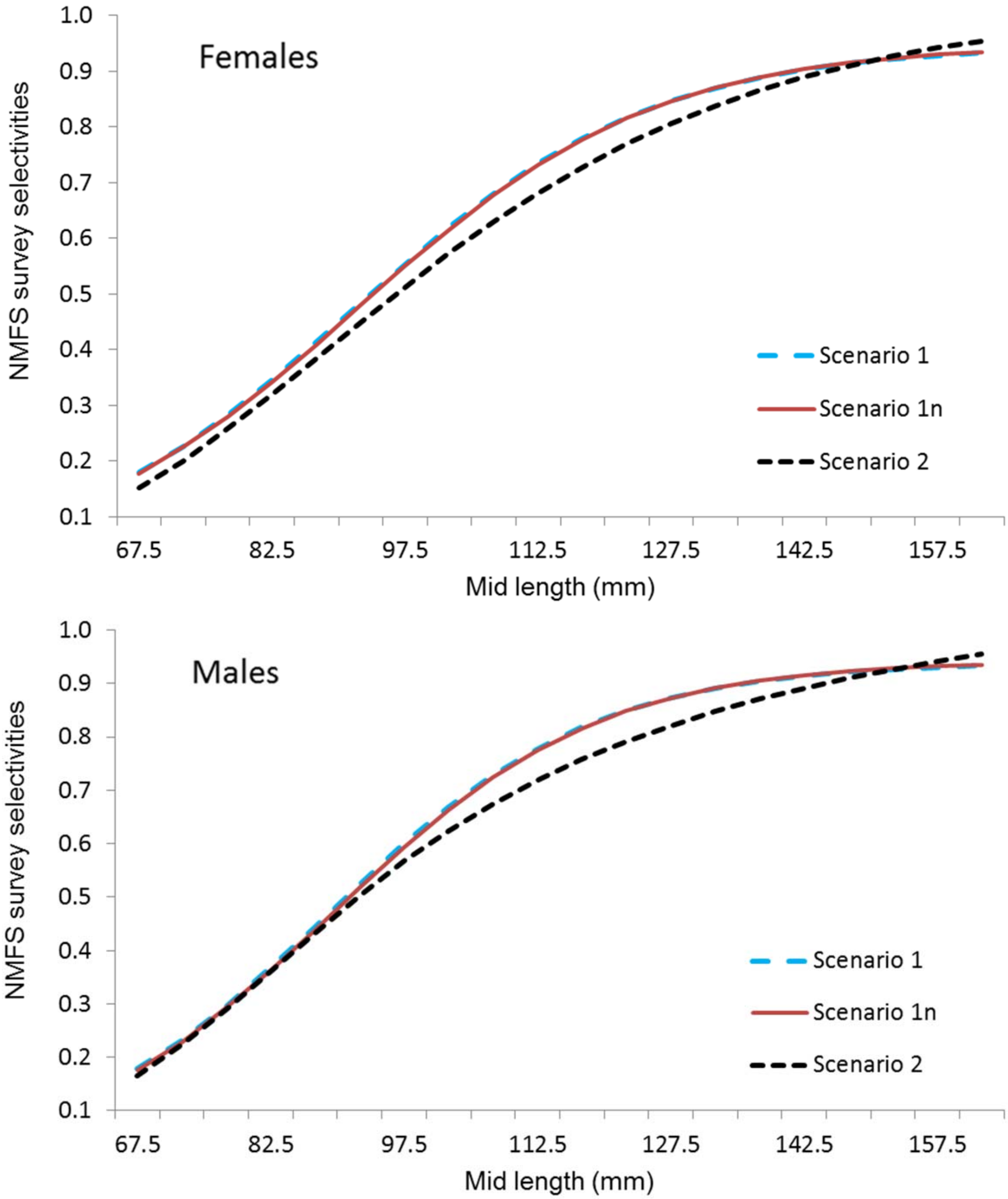

Figure 8b. Comparisons of estimated NMFS trawl survey selectivities for period 1982-2016 under scenarios 1, 1n and 2. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

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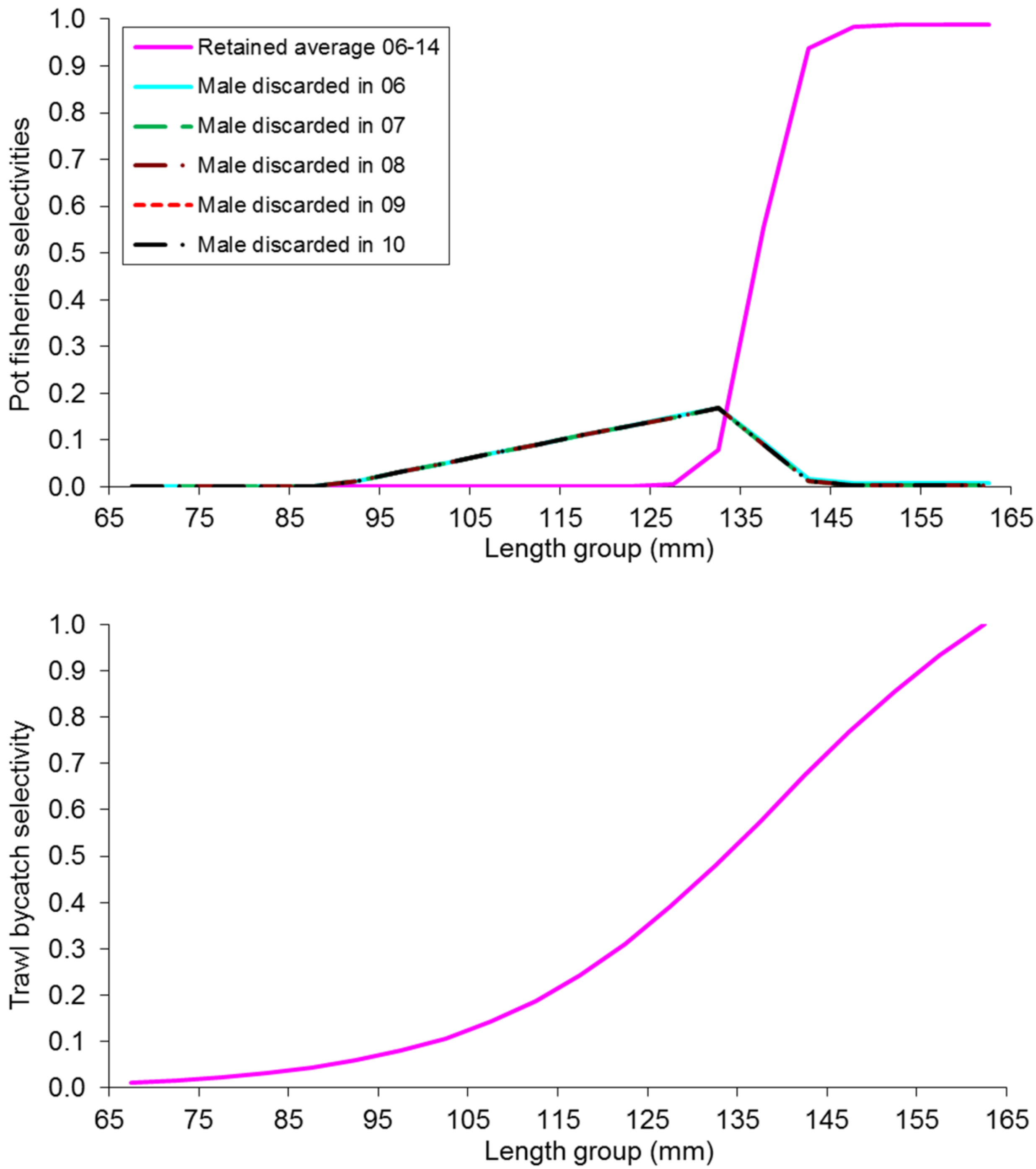


Figure 8c. Estimated pot fishery selectivities and groundfish trawl bycatch selectivities under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

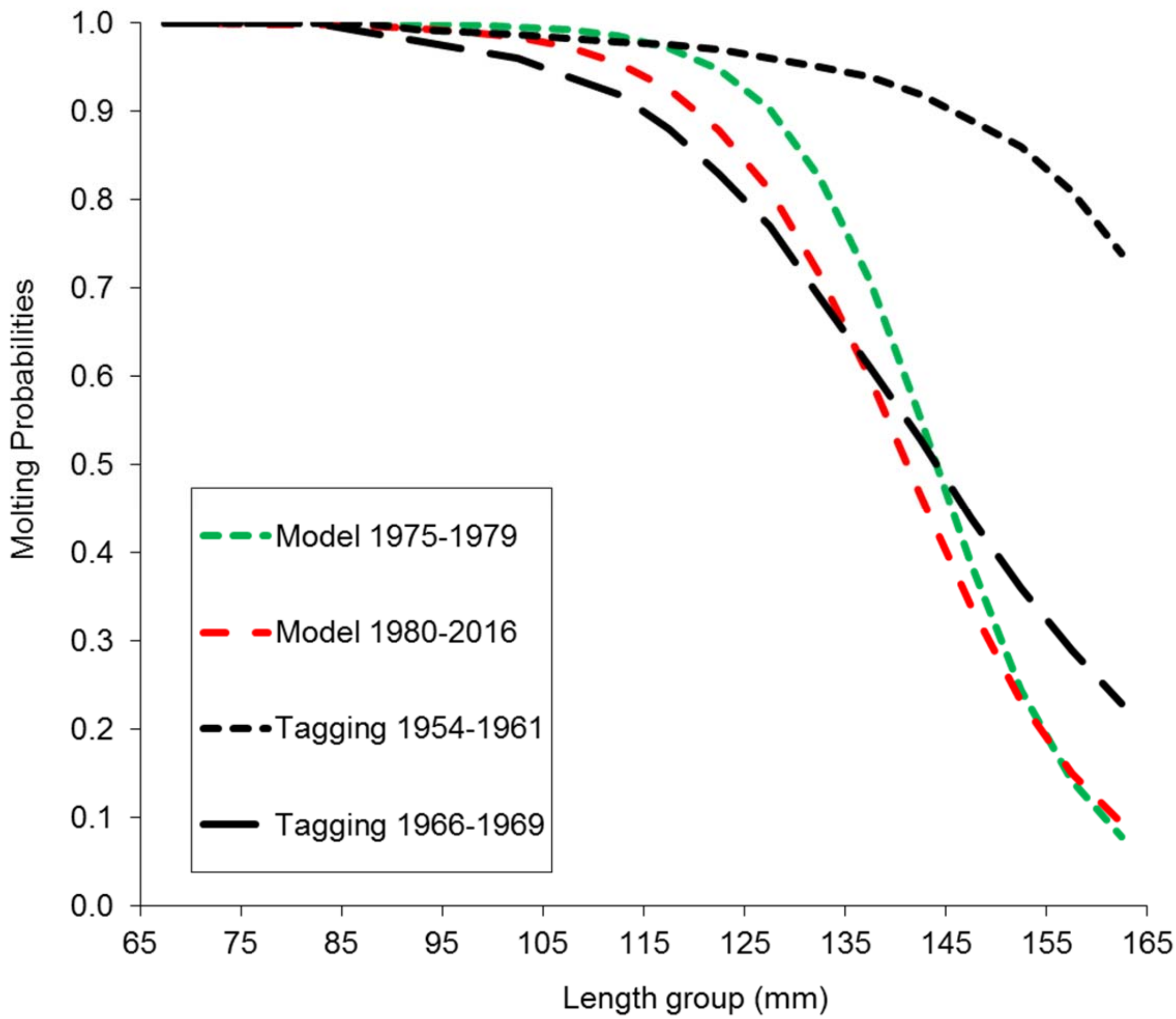


Figure 9(1). Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-2016 were estimated with a length-based model with a pot handling mortality rate of 0.2 under scenario 1.

65

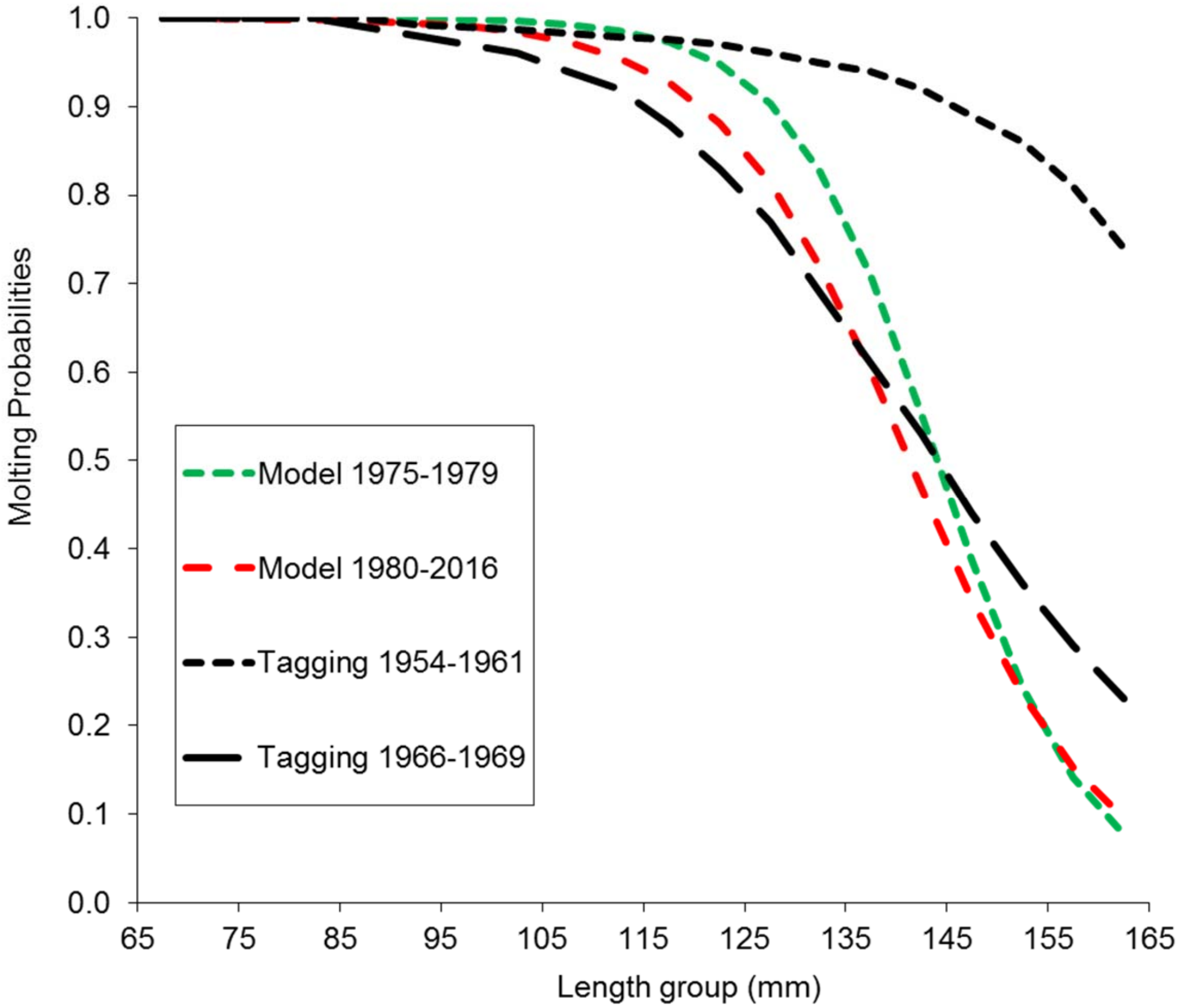


Figure 9(1n). Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-2016 were estimated with a length-based model with pot handling mortality rate of 0.2 under scenario 1n.

66

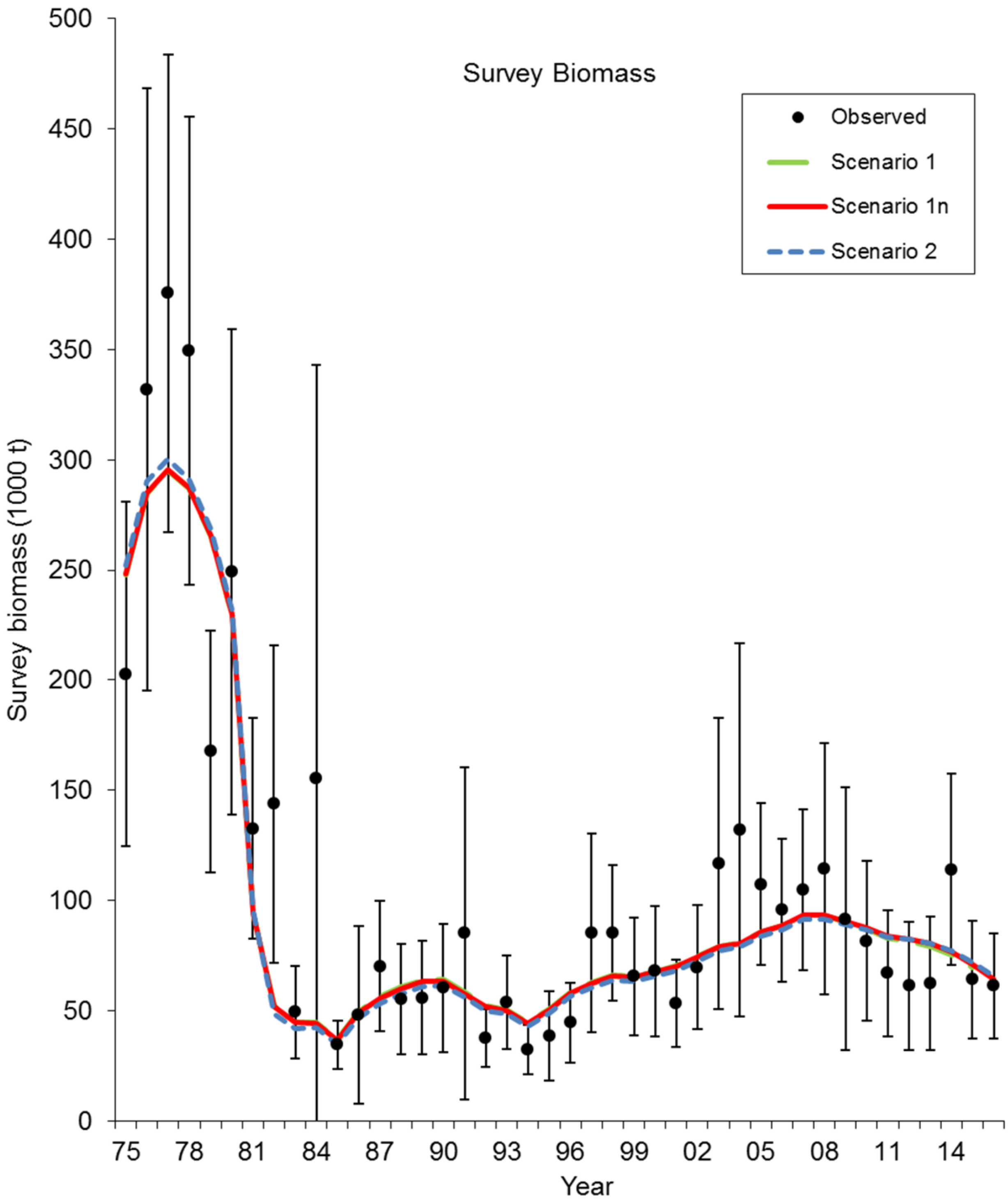


Figure 10a(1, 1n & 2). Comparisons of area-swept estimates of total survey biomass and model prediction for model estimates in 2016 under scenarios 1, 1n and 2. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively. The error bars are plus and minus 2 standard deviations.

67

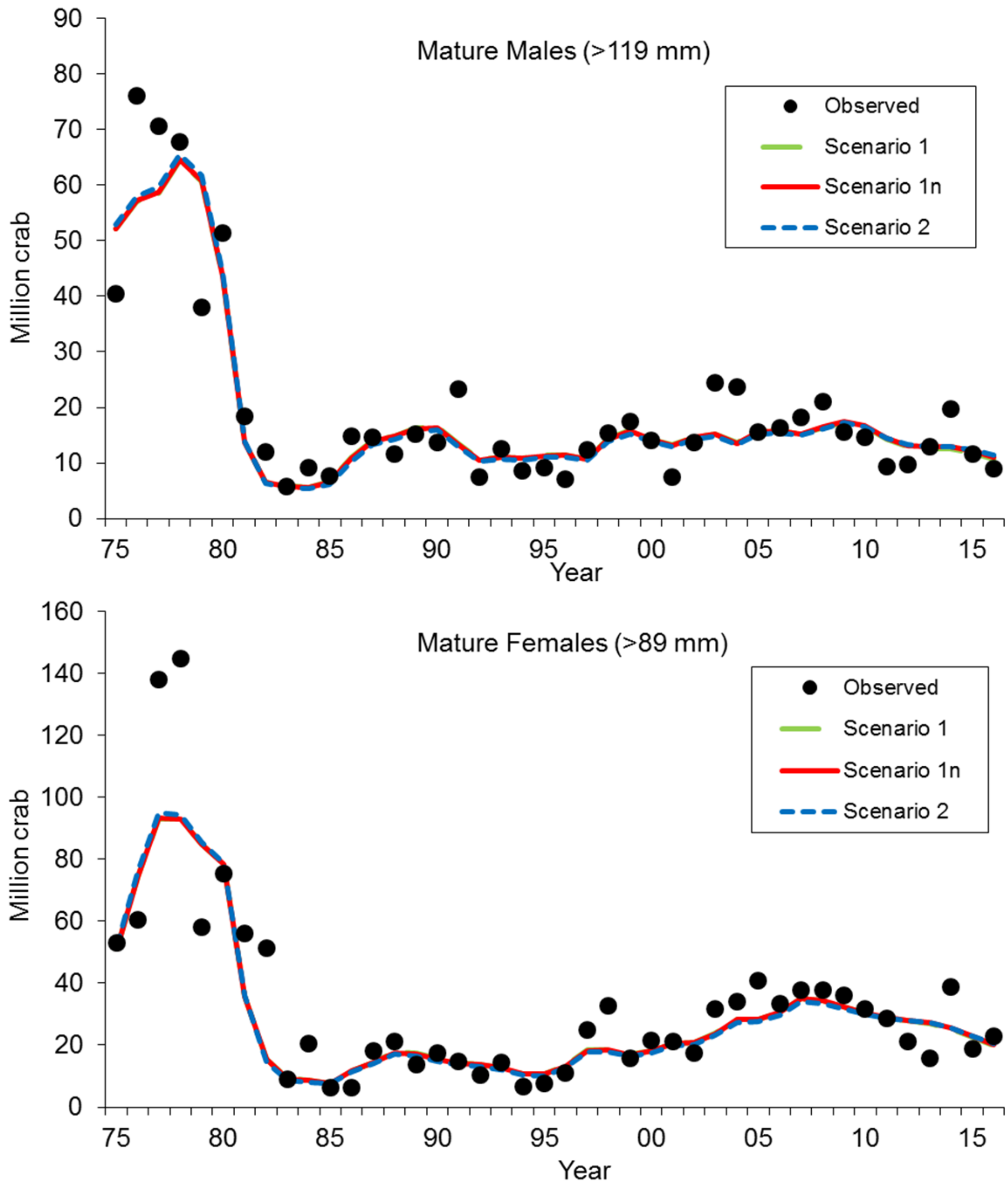


Figure 10b(1, 1n & 2). Comparisons of area-swept estimates of male (>119 mm) and female (>89 mm) abundance and model prediction for model estimates in 2014 under scenarios 1, 1n and 2. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

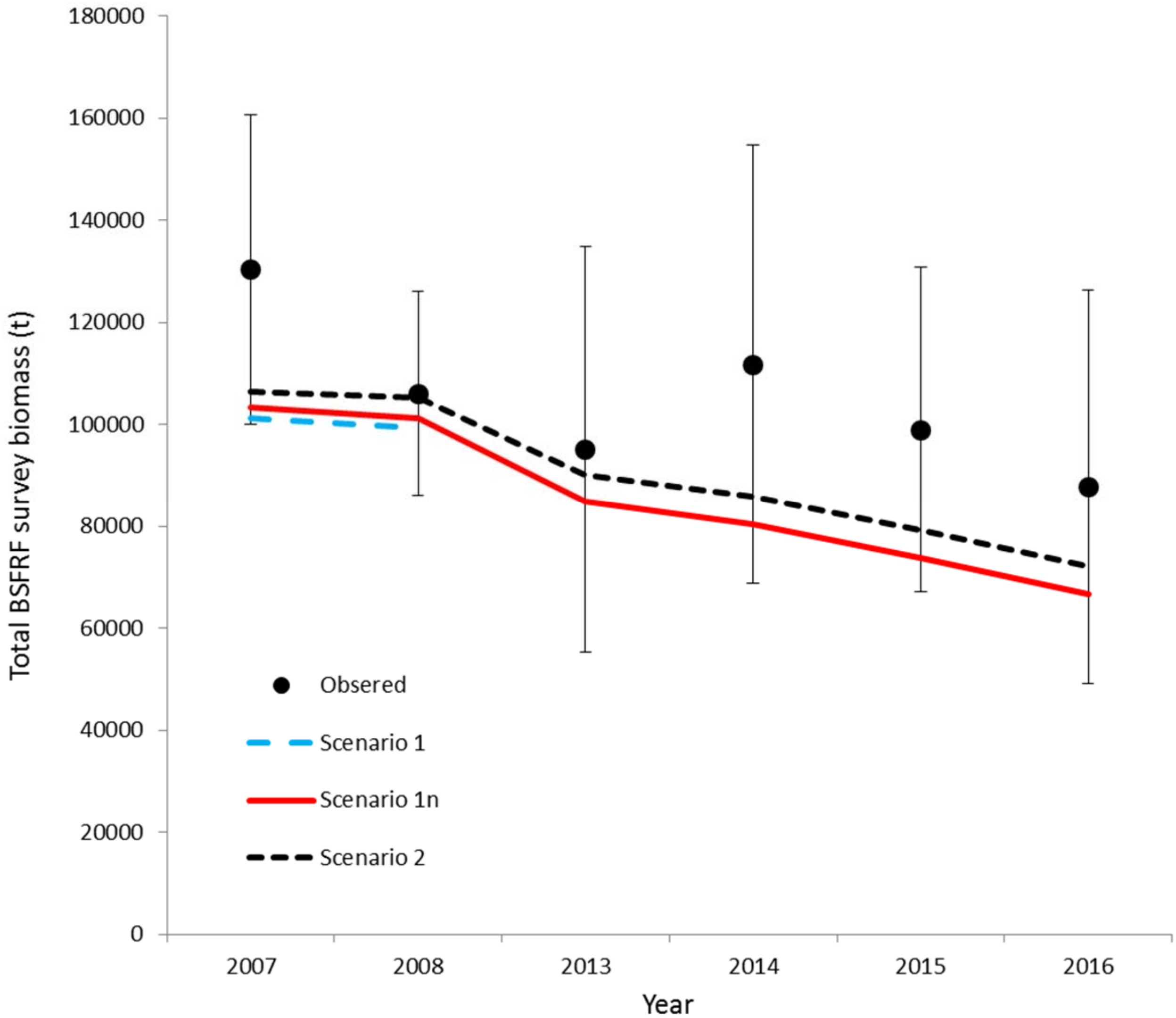


Figure 10c. Comparisons of total survey biomass estimates by the BSFRF survey and the model for model estimates in 2016 (scenarios 1, 1n & 2). The error bars are plus and minus 2 standard deviations of scenario 1n.

69

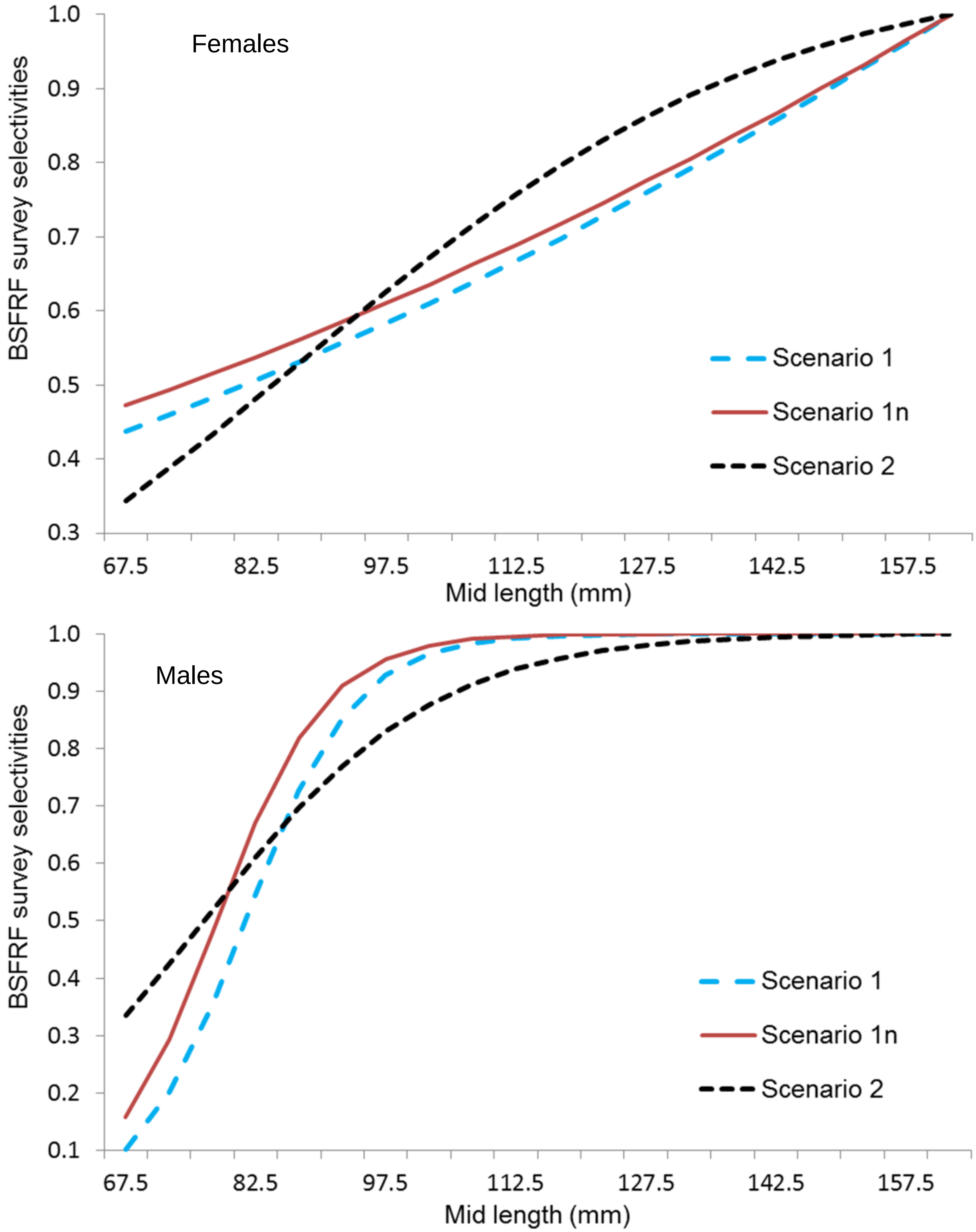


Figure 10d(1, 1n & 2). Comparisons of estimated BSFRF survey selectivities with scenarios 1, 1n and 2. The catchability is assumed to be 1.0.

70

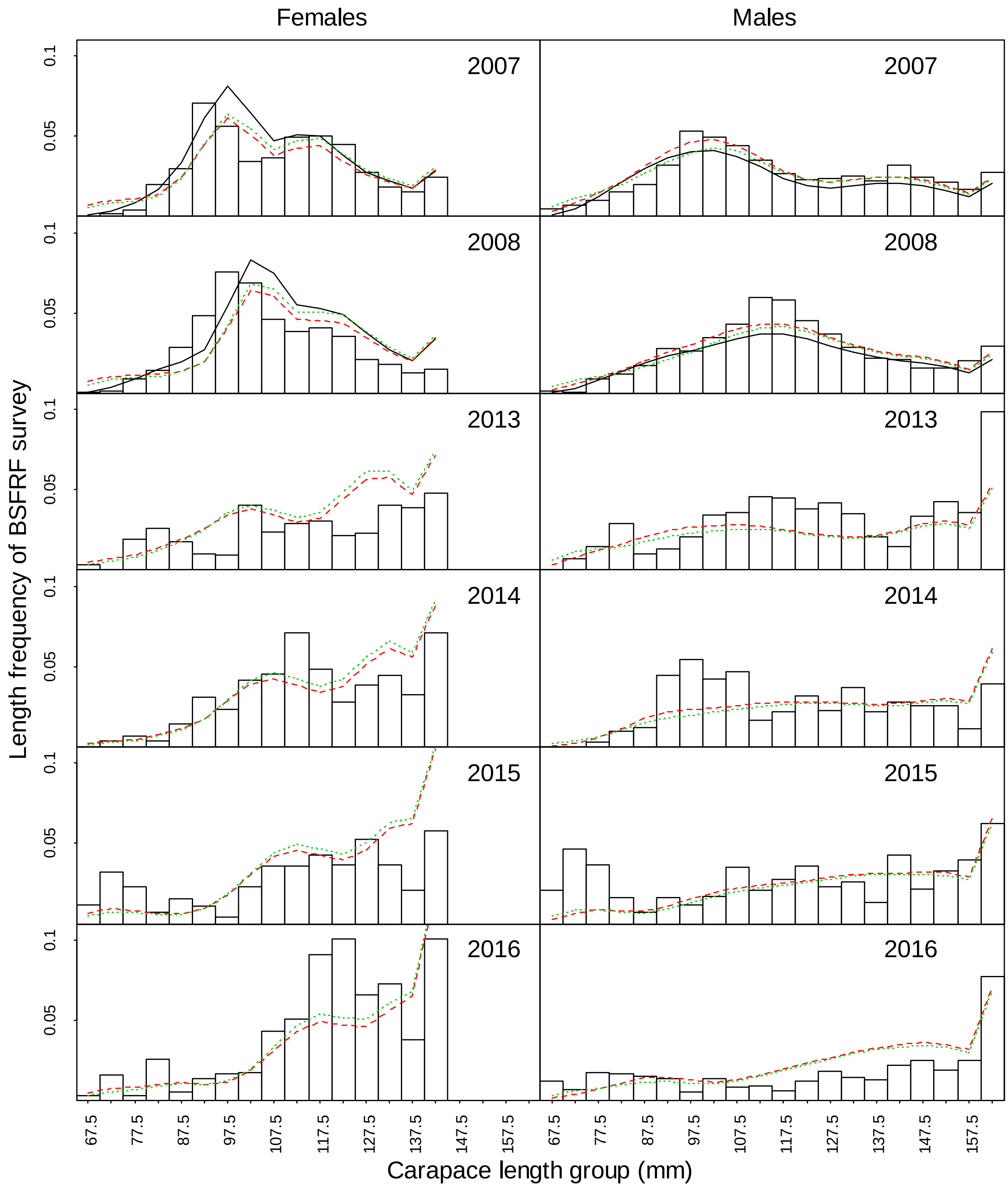


Figure 10e(1, 1n & 2). Comparisons of length compositions by the BSFRF survey and the model estimates during 2007-2008 and 2013-2016 with scenarios 1 (solid black), 1n (dashed red), and 2 (green lines).

71

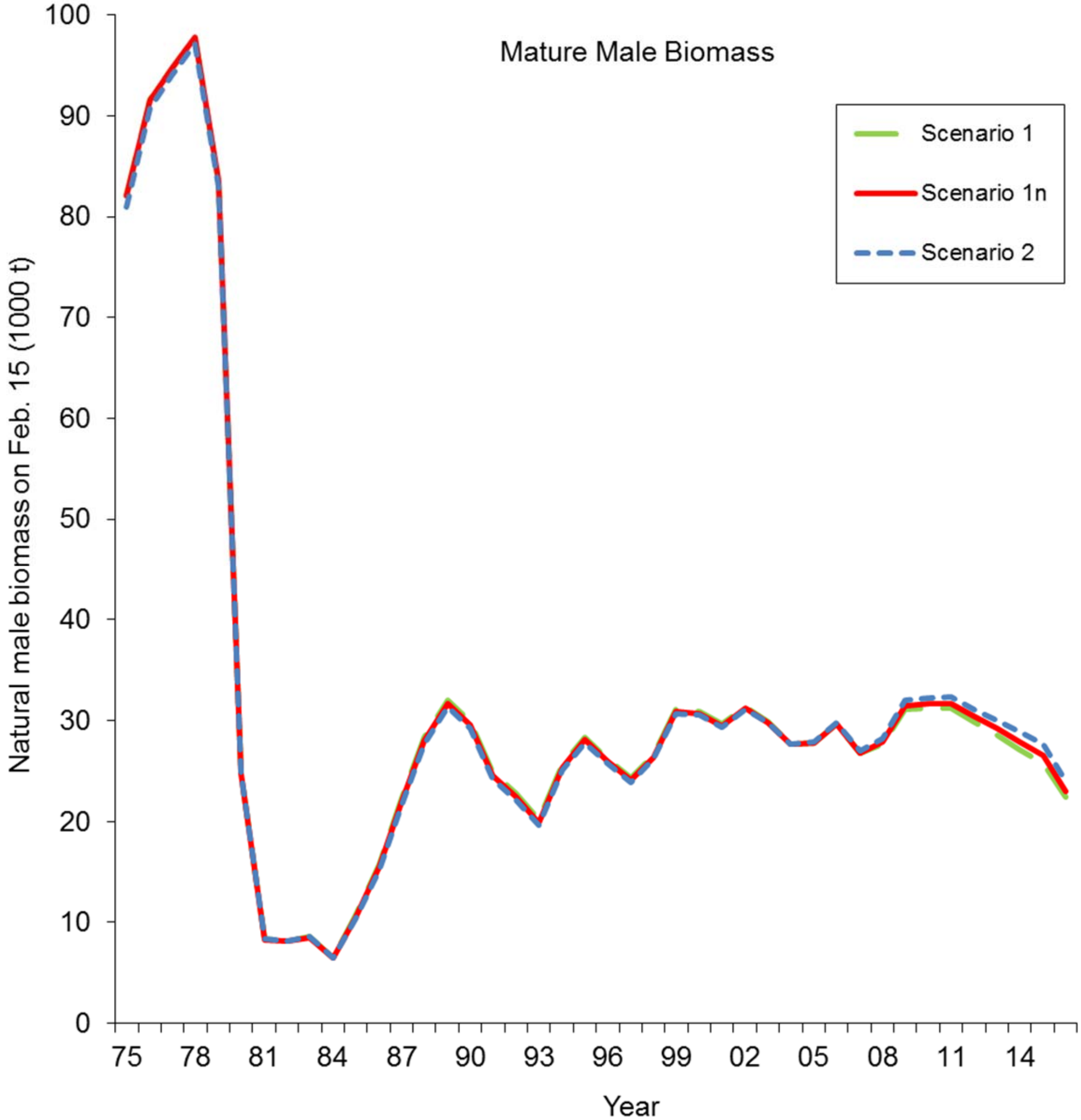


Figure 11. Estimated absolute mature male biomasses during 1975-2016 for scenarios 1, 1n and 2.

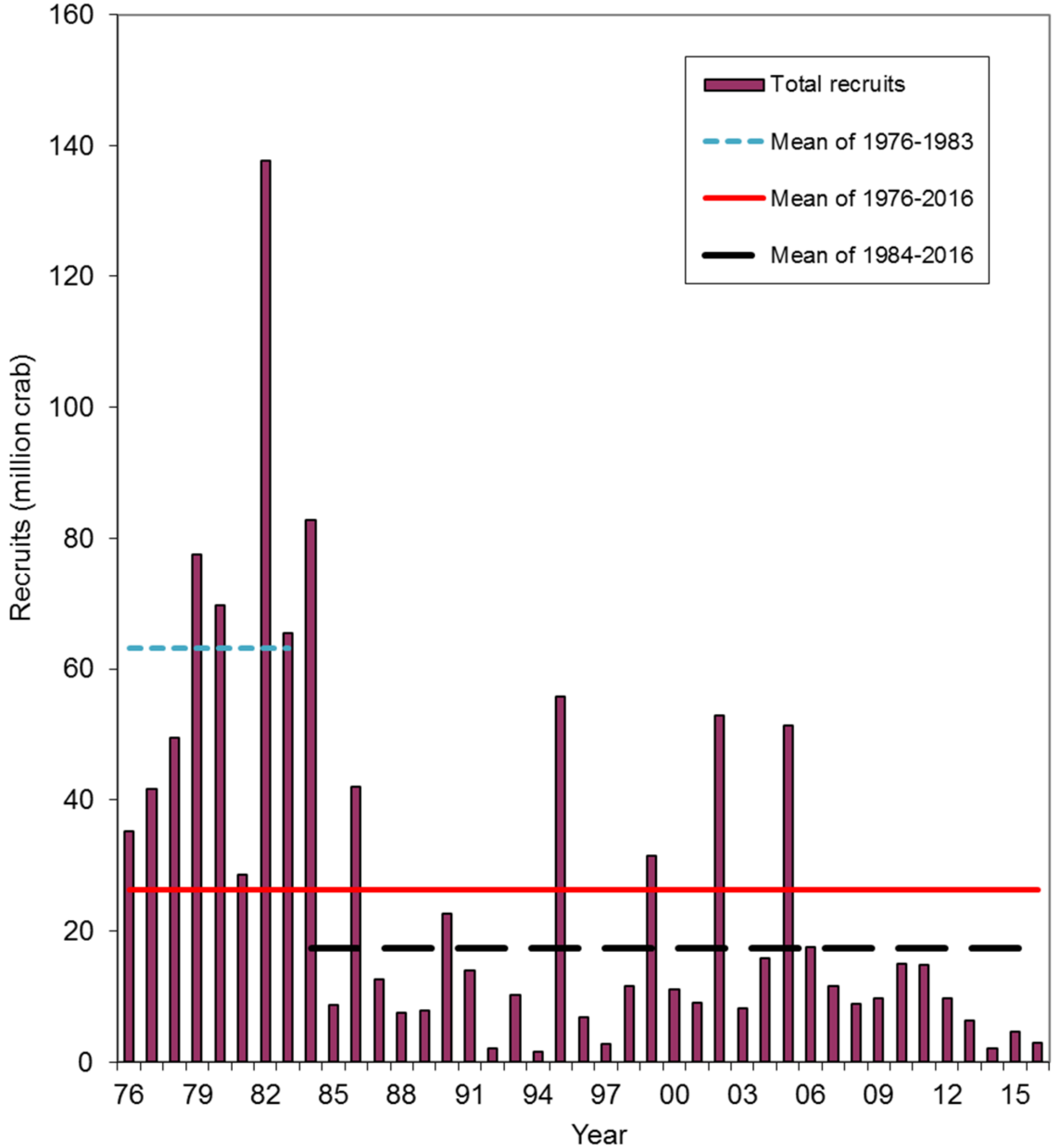


Figure 12(1). Estimated recruitment time series during 1976-2016 with scenario 1. Mean male recruits during 1984-2016 was used to estimate $B_{35\%}$.

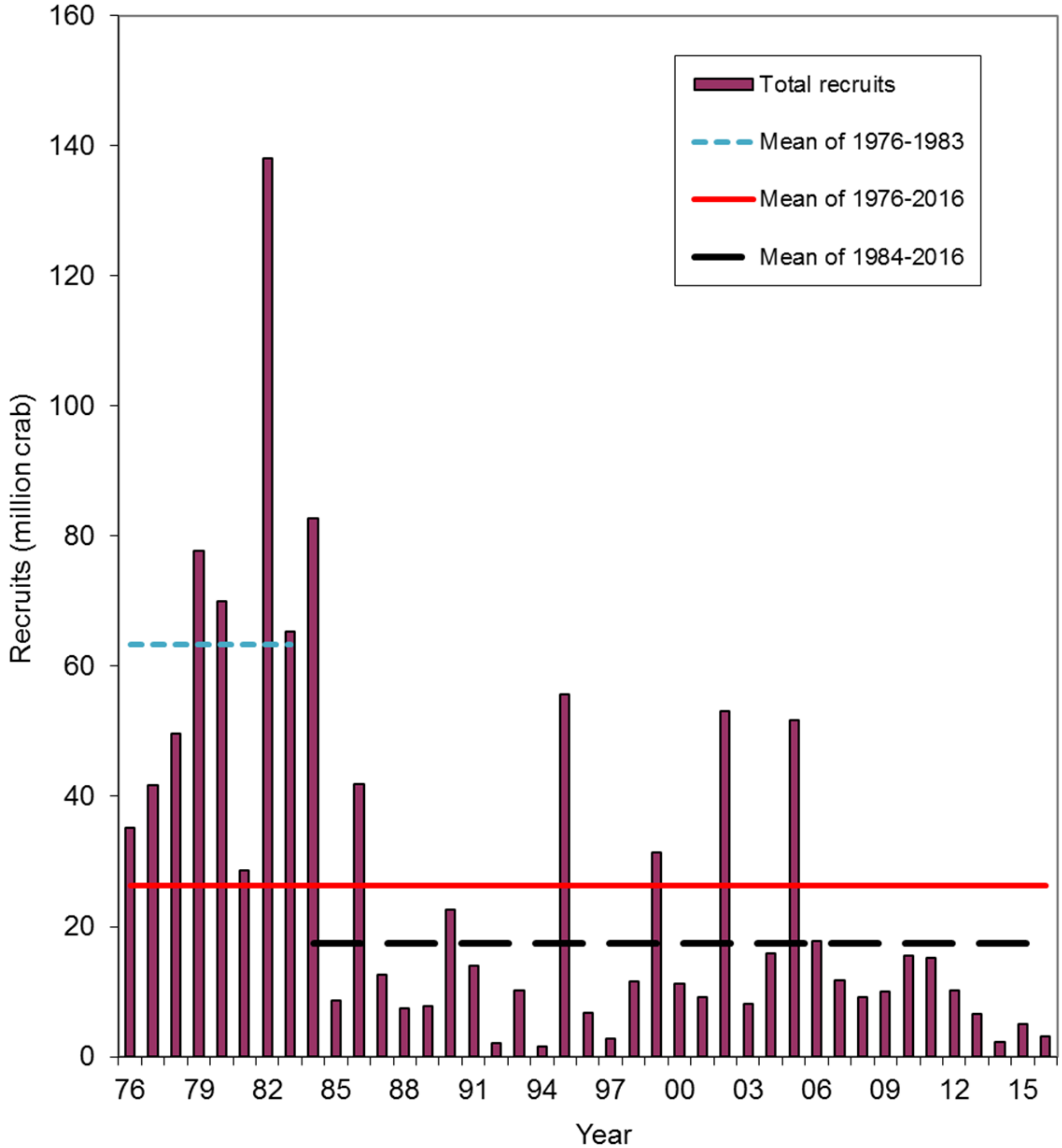


Figure 12(1n). Estimated recruitment time series during 1976-2016 with scenario 1n. Mean male recruits during 1984-2016 was used to estimate $B_{35\%}$.

74

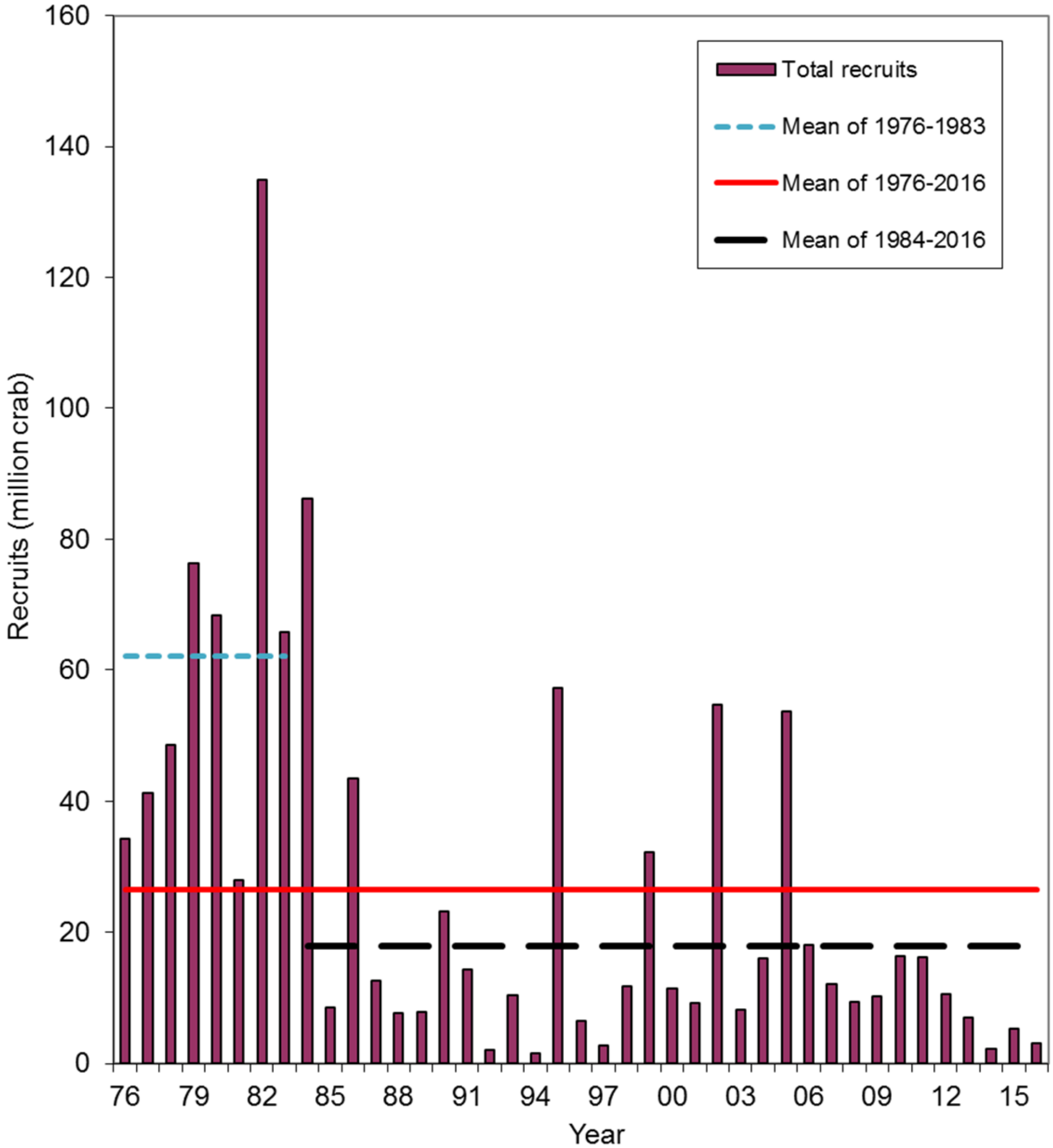


Figure 12(2). Estimated recruitment time series during 1976-2016 with scenario 2. Mean male recruits during 1984-2016 was used to estimate B35%.

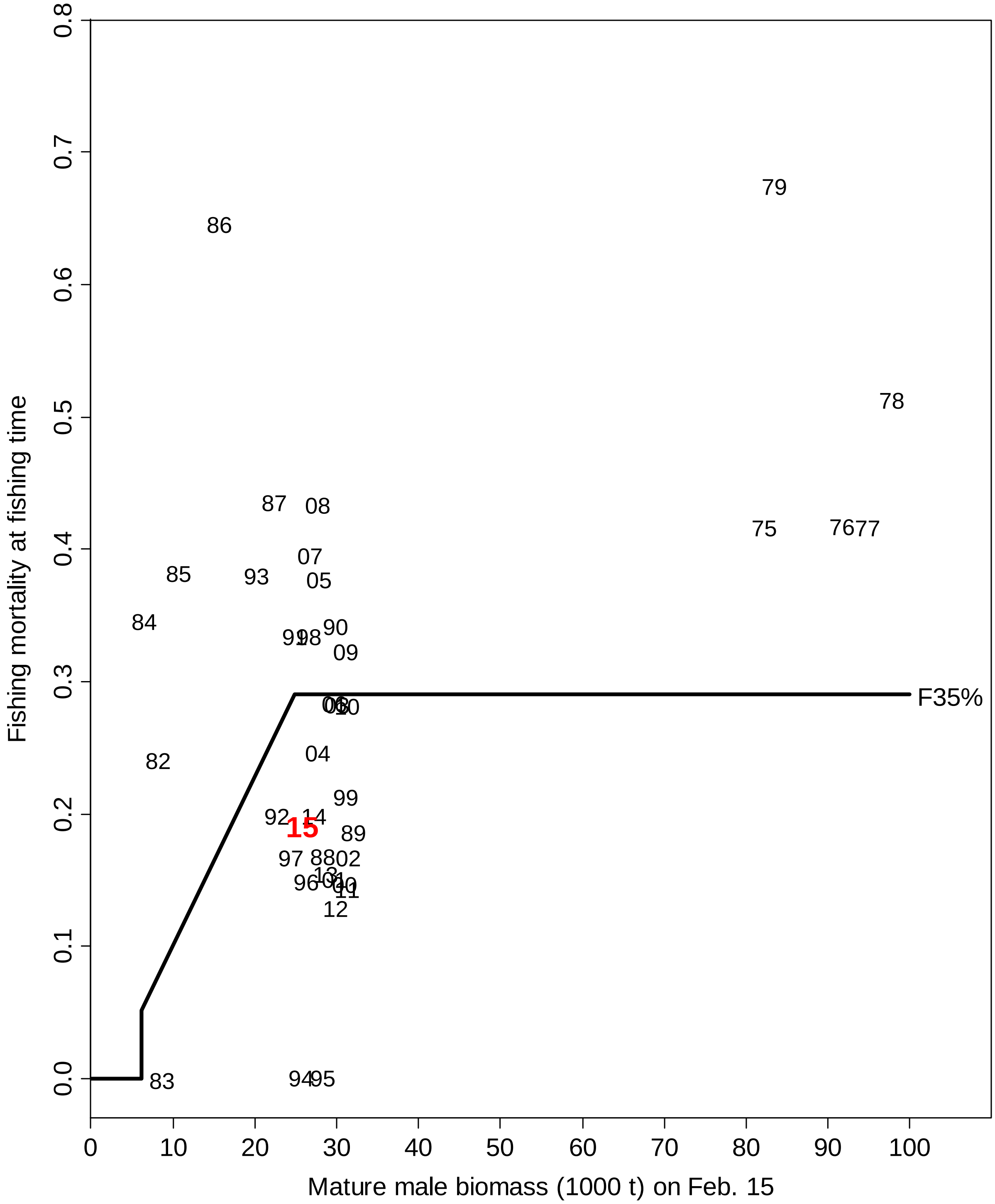


Figure 13(1). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2015 under scenario 1. Average of recruitment from 1984 to 2016 was used to estimate B_{MSY}. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

76

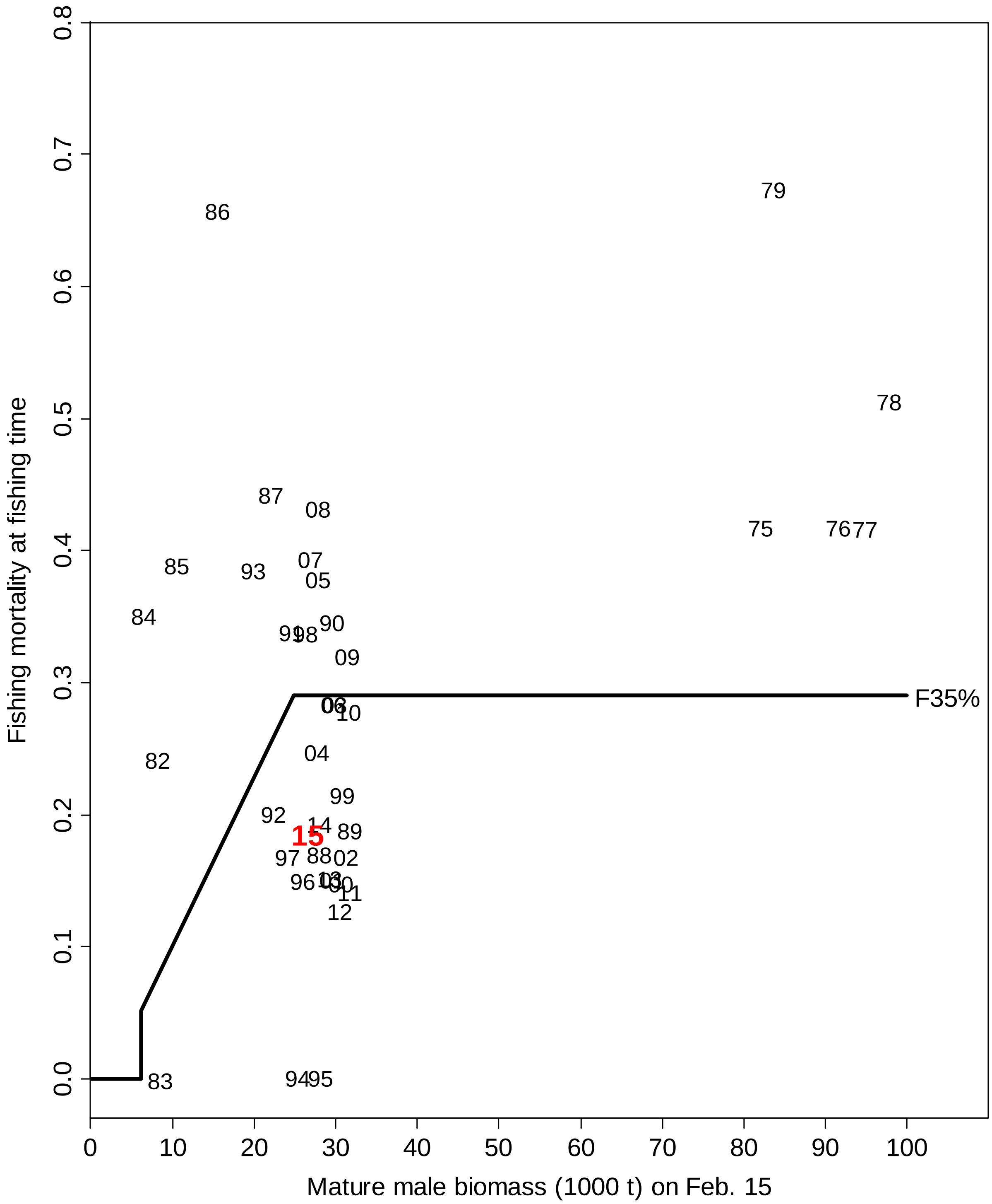


Figure 13(1n). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2015 under scenario 1n. Average of recruitment from 1984 to 2016 was used to estimate B_{MSY}. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

77

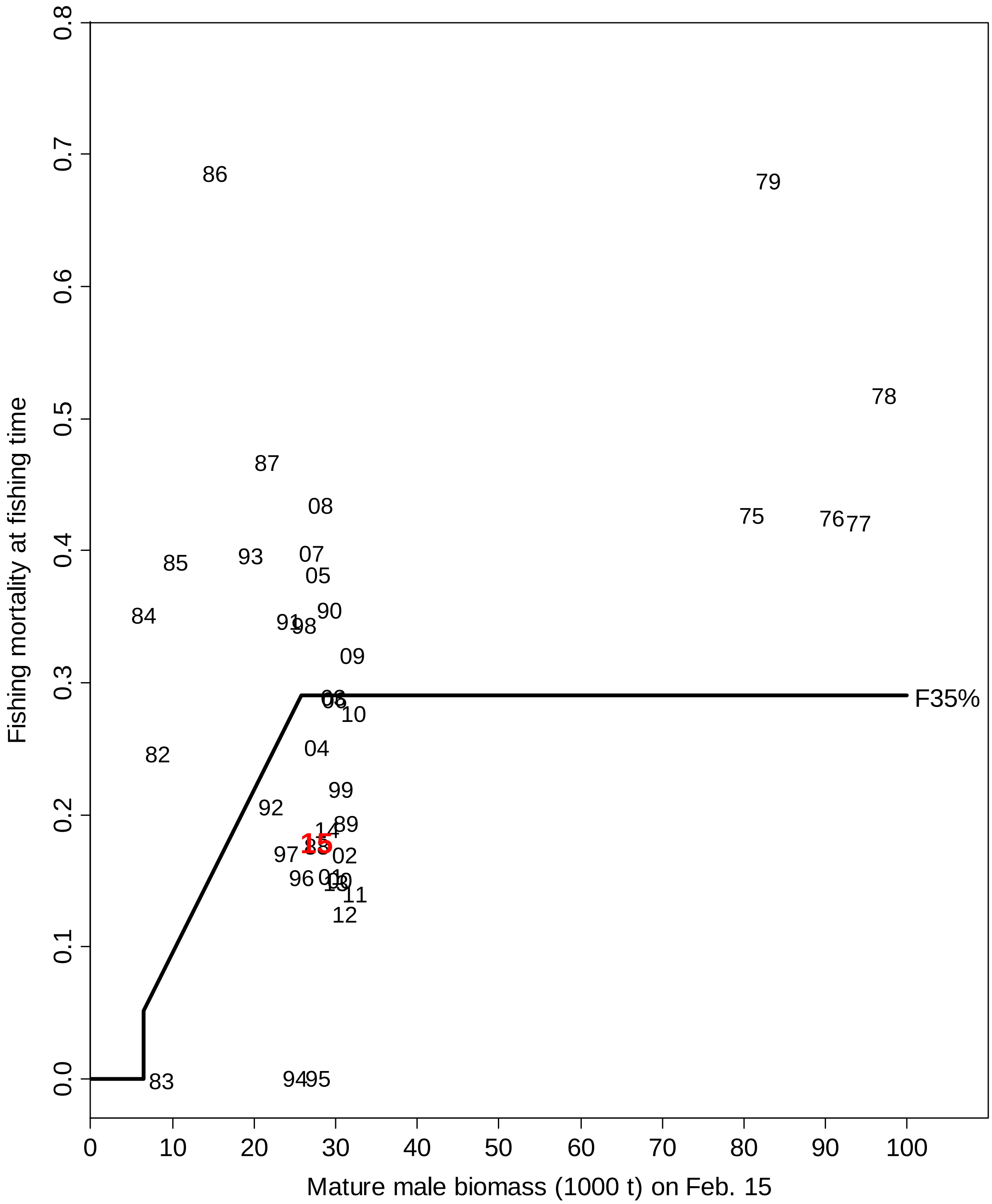


Figure 13(2). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2015 under scenario 2. Average of recruitment from 1984 to 2016 was used to estimate BMSY. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

78

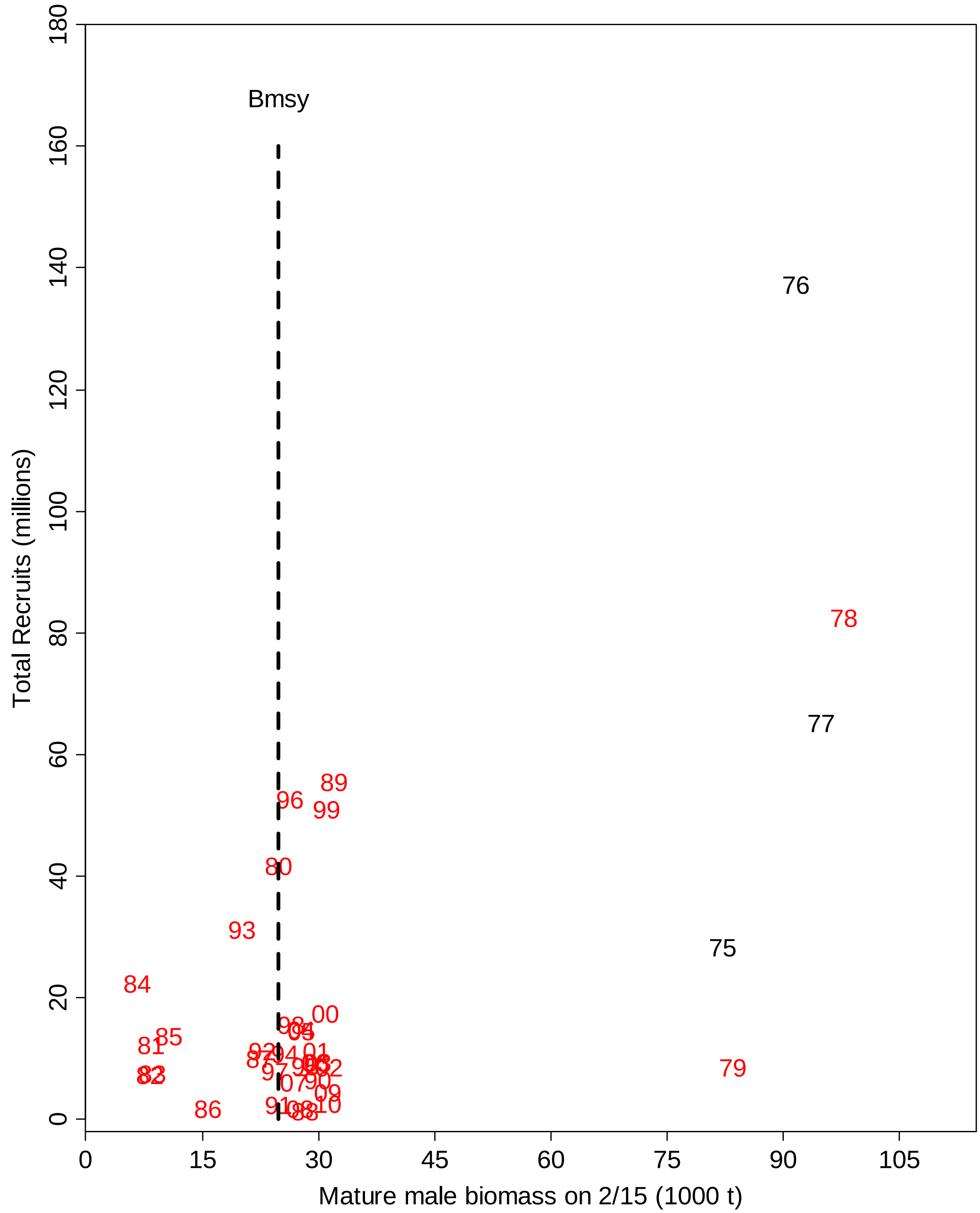


Figure 14a. Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6-year time lag) for Bristol Bay red king crab with pot handling mortality rate of 0.2 under scenario 1. Numerical labels are years of mating, and the vertical dotted line is the estimated $B_{35\%}$ based on the mean recruitment level during 1984 to 2016.

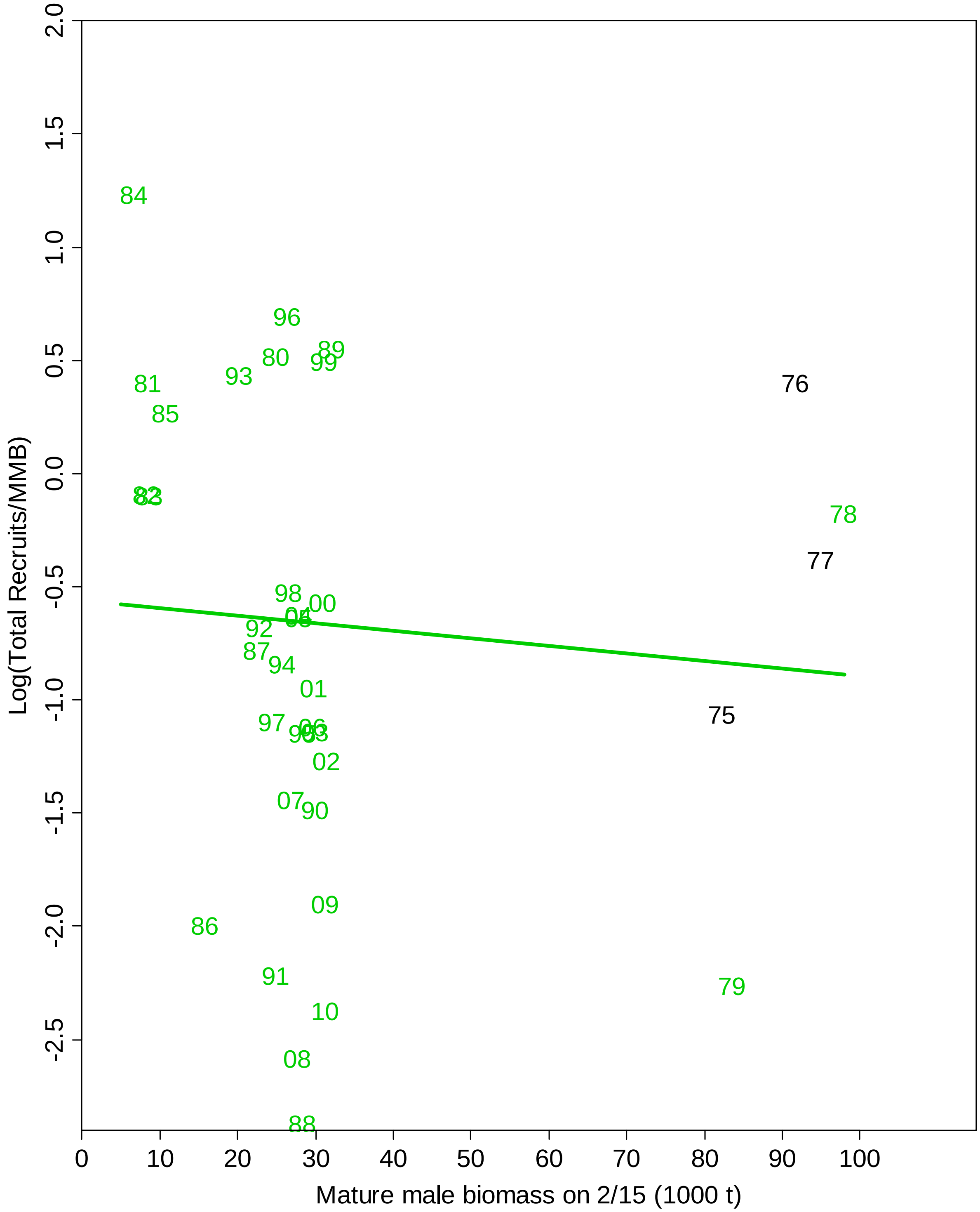


Figure 14b. Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate of 0.2 under scenario 1. Numerical labels are years of mating, and the line is the regression line for data of 1978-2010.

80

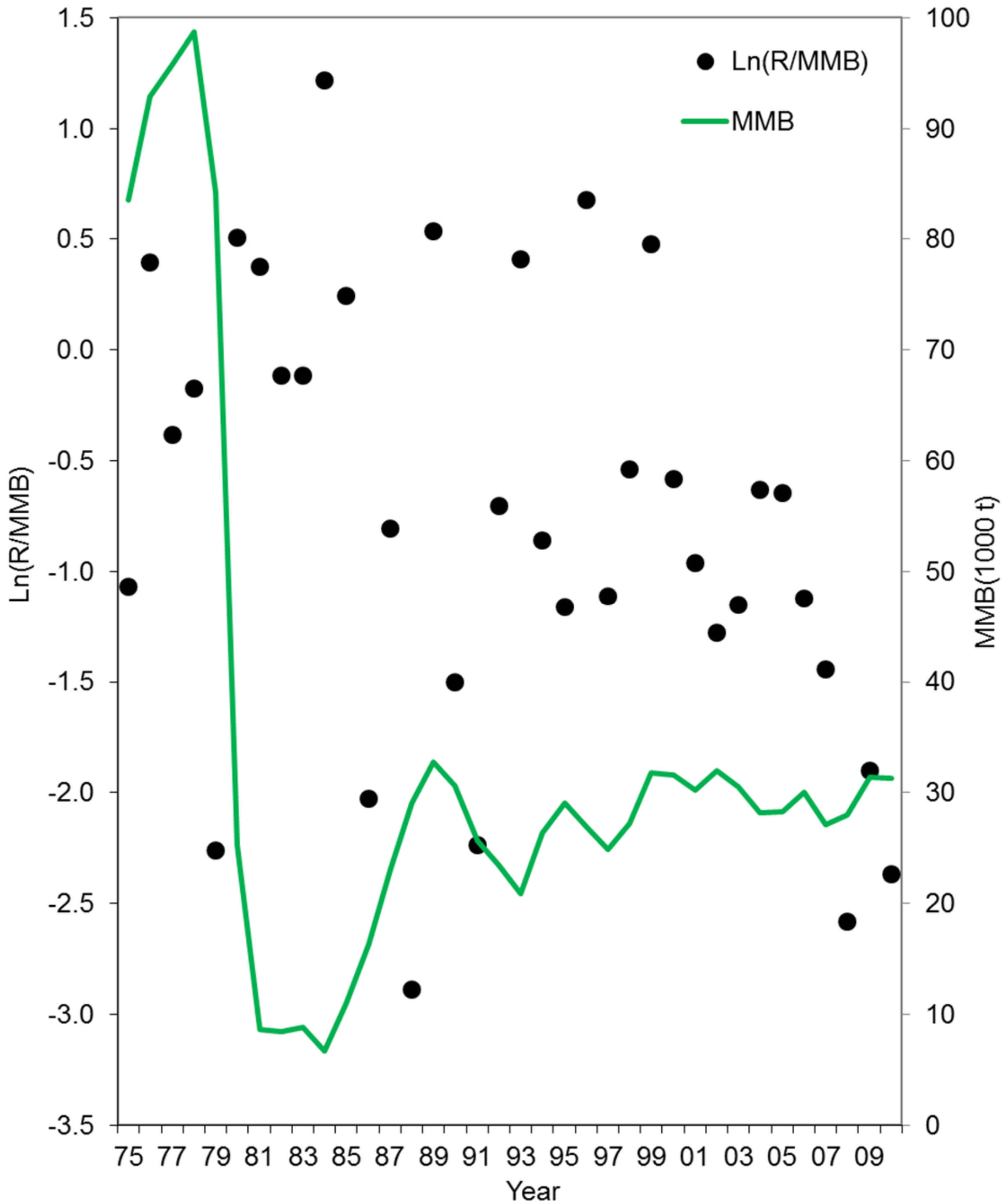


Figure 14c. Time series of log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate of 0.2 under scenario 1.

81

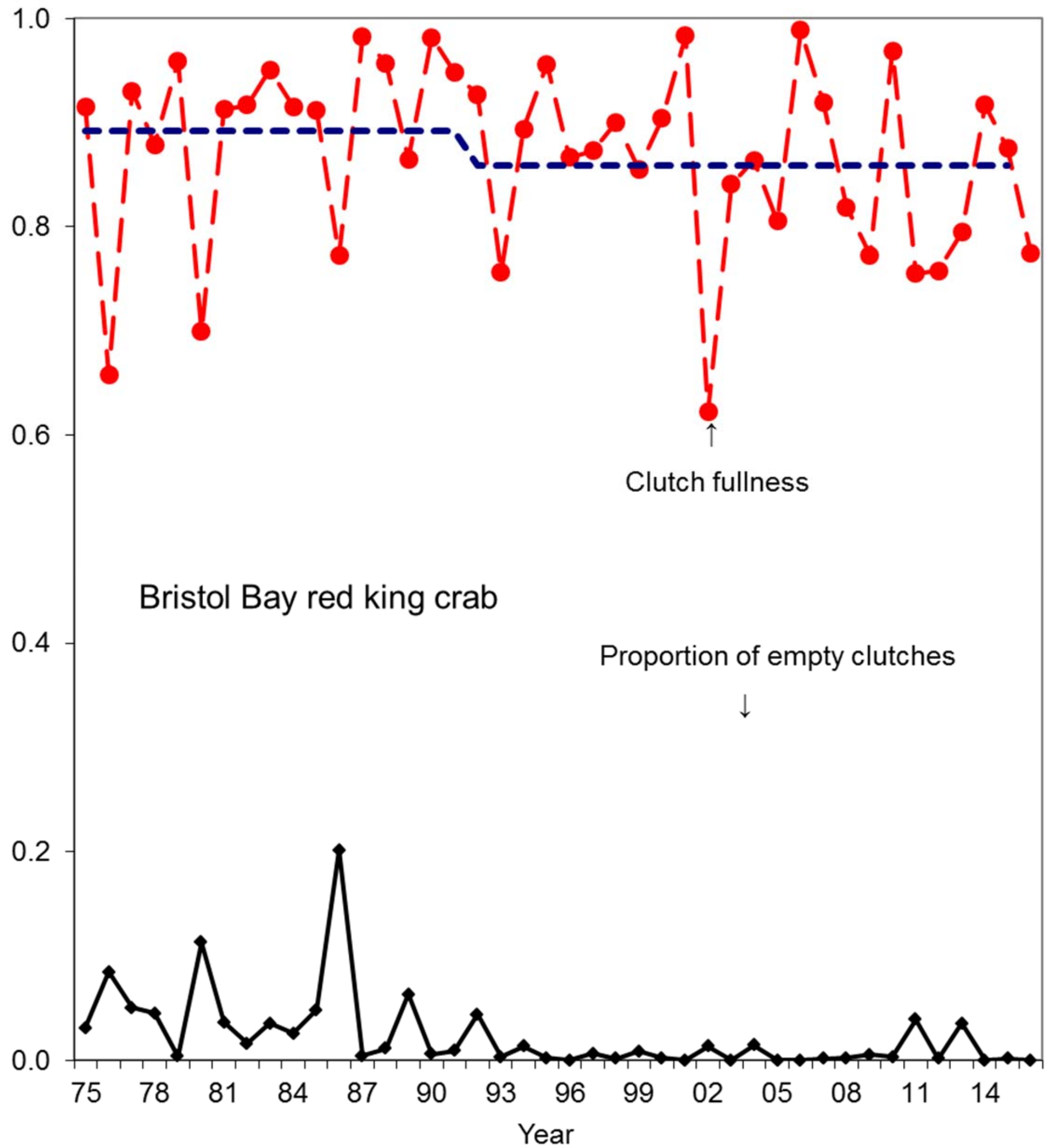


Figure 15. Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crab >89 mm CL from 1975 to 2016 from survey data. Oldshell females were excluded.

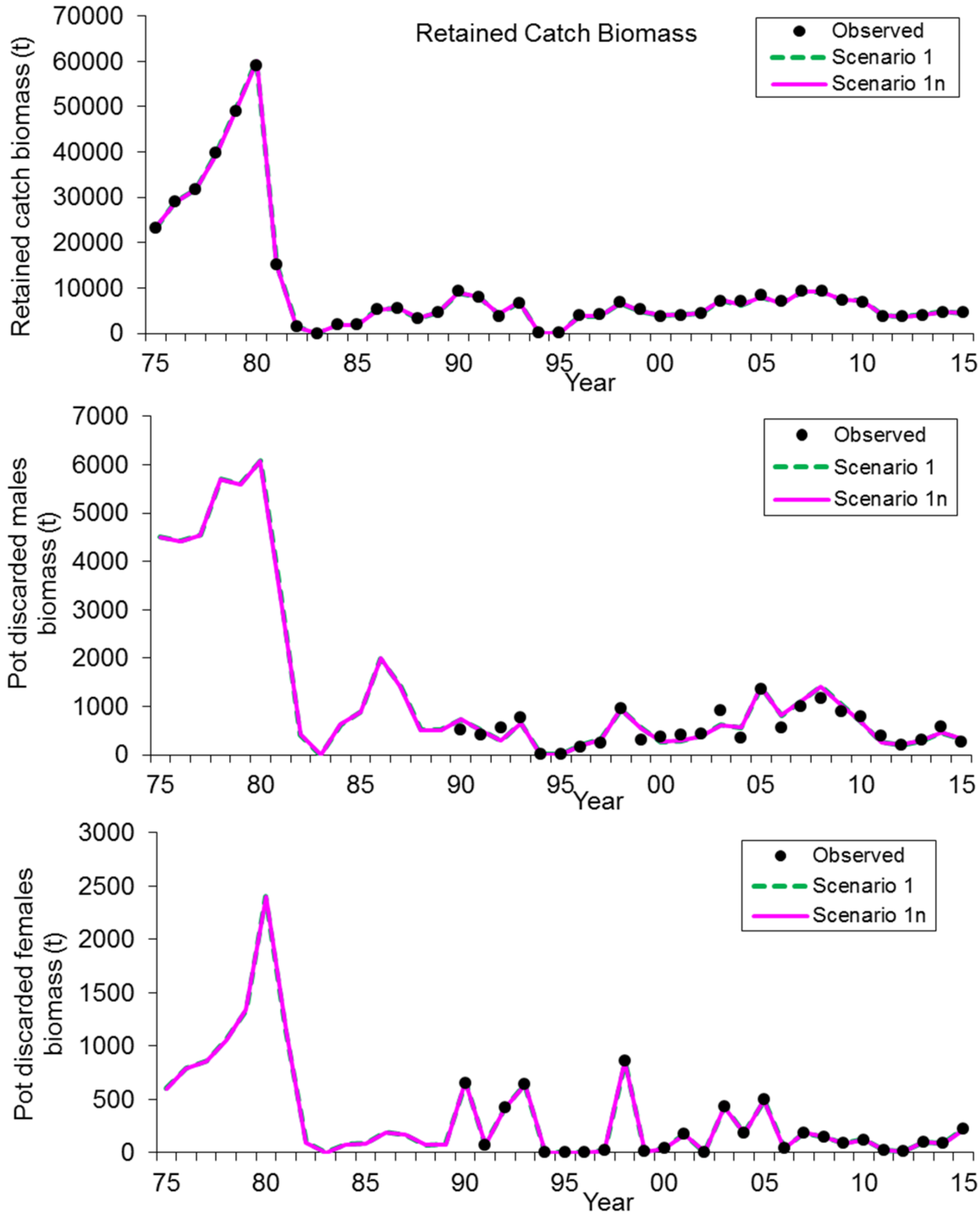


Figure 16a. Observed and predicted catch mortality biomass under scenarios 1 and 1n. Mortality biomass is equal to caught biomass times a handling mortality rate. Pot handling mortality rate is 0.2.

83

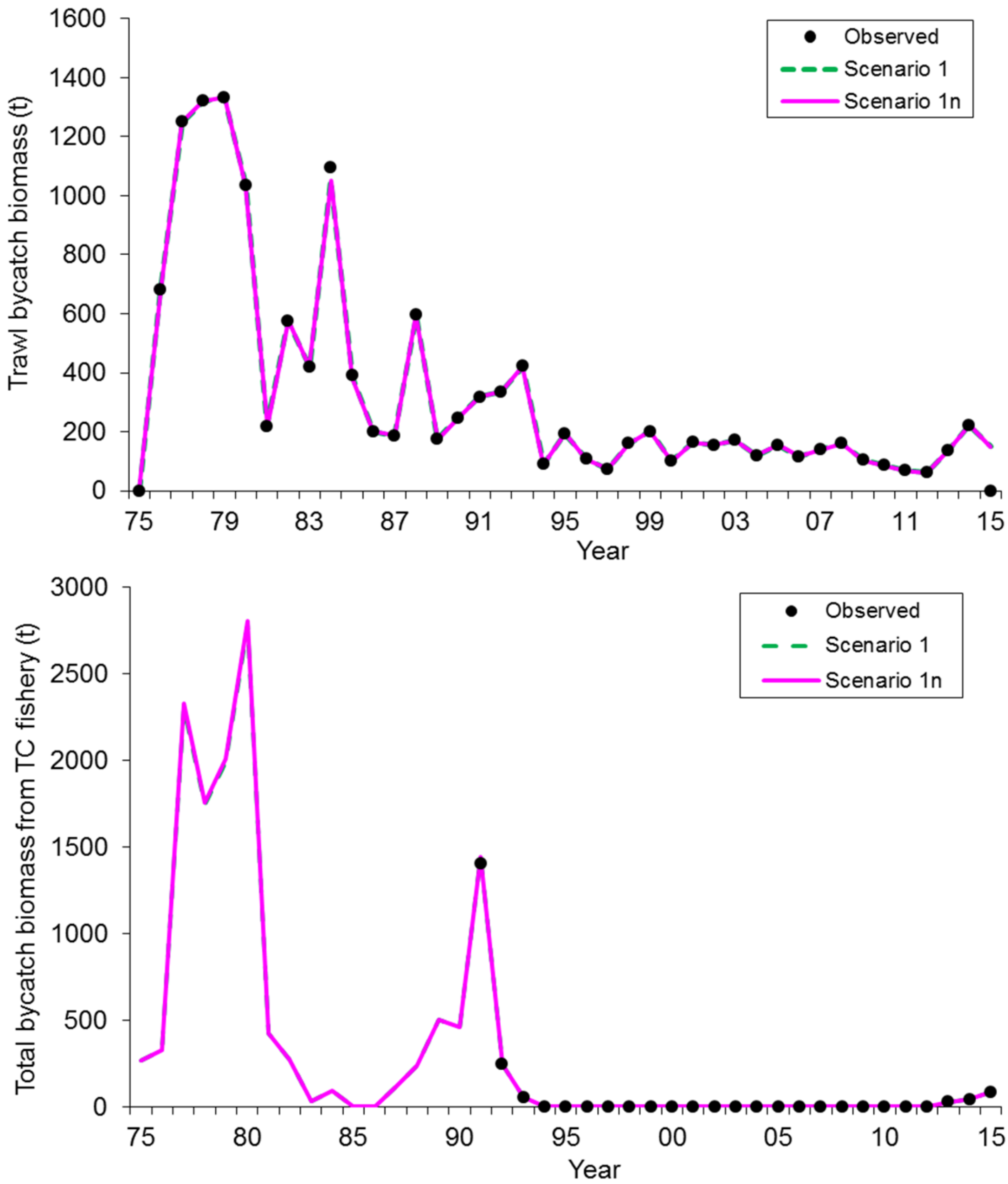


Figure 16b. Observed and predicted bycatch mortality biomass from trawl fisheries and the Tanner crab fishery under scenarios 1 and 1n. Mortality biomass is equal to caught biomass times a handling mortality rate. Trawl handling mortality rate is 0.8, and Tanner crab pot handling mortality is 0.25. Trawl bycatch biomass was 0 before 1976.

84

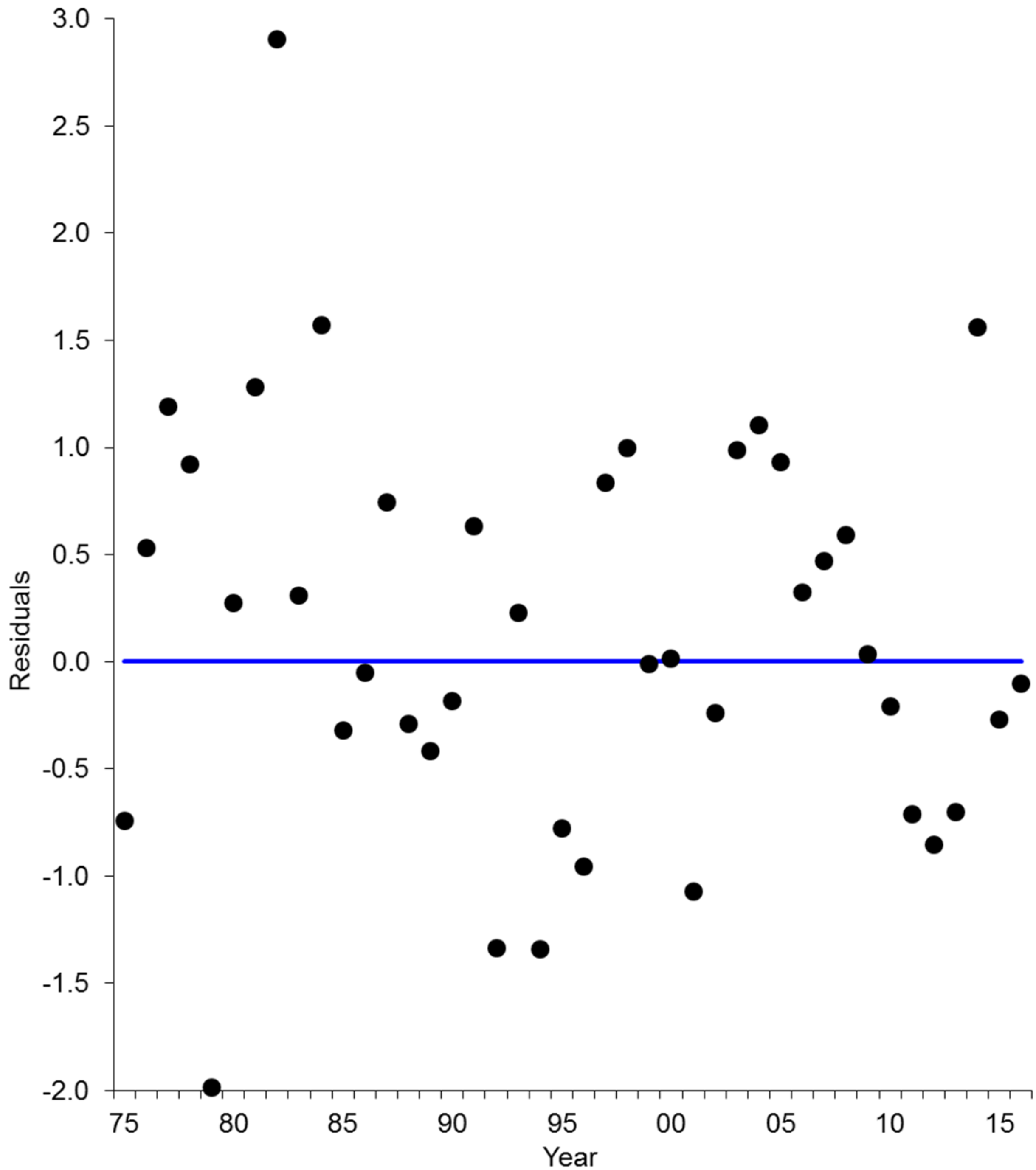


Figure 17(1). Standardized residuals of total survey biomass under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

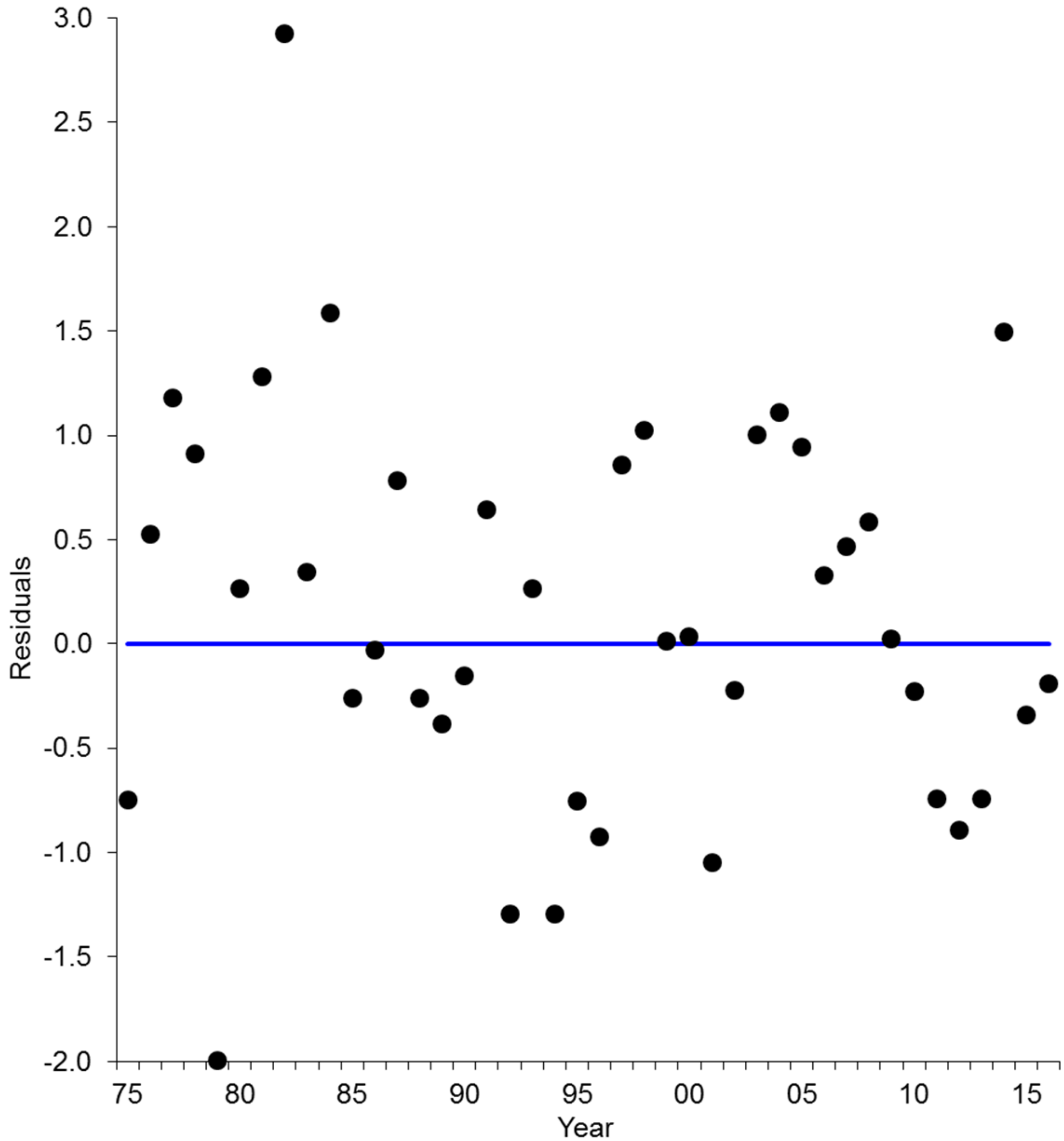


Figure 17(1n). Standardized residuals of total survey biomass under scenario 1n. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

86

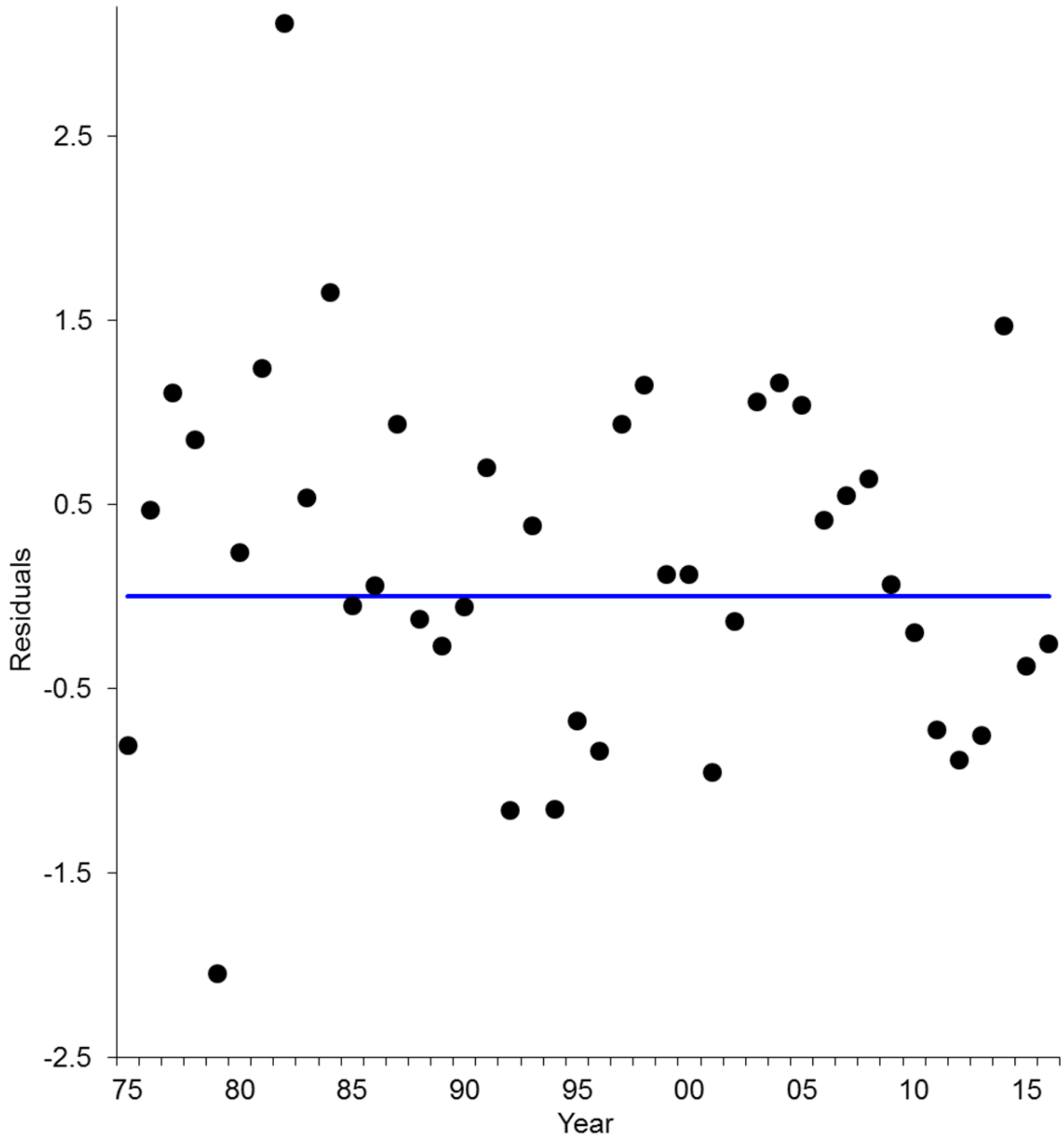


Figure 17(2). Standardized residuals of total survey biomass under scenario 2. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

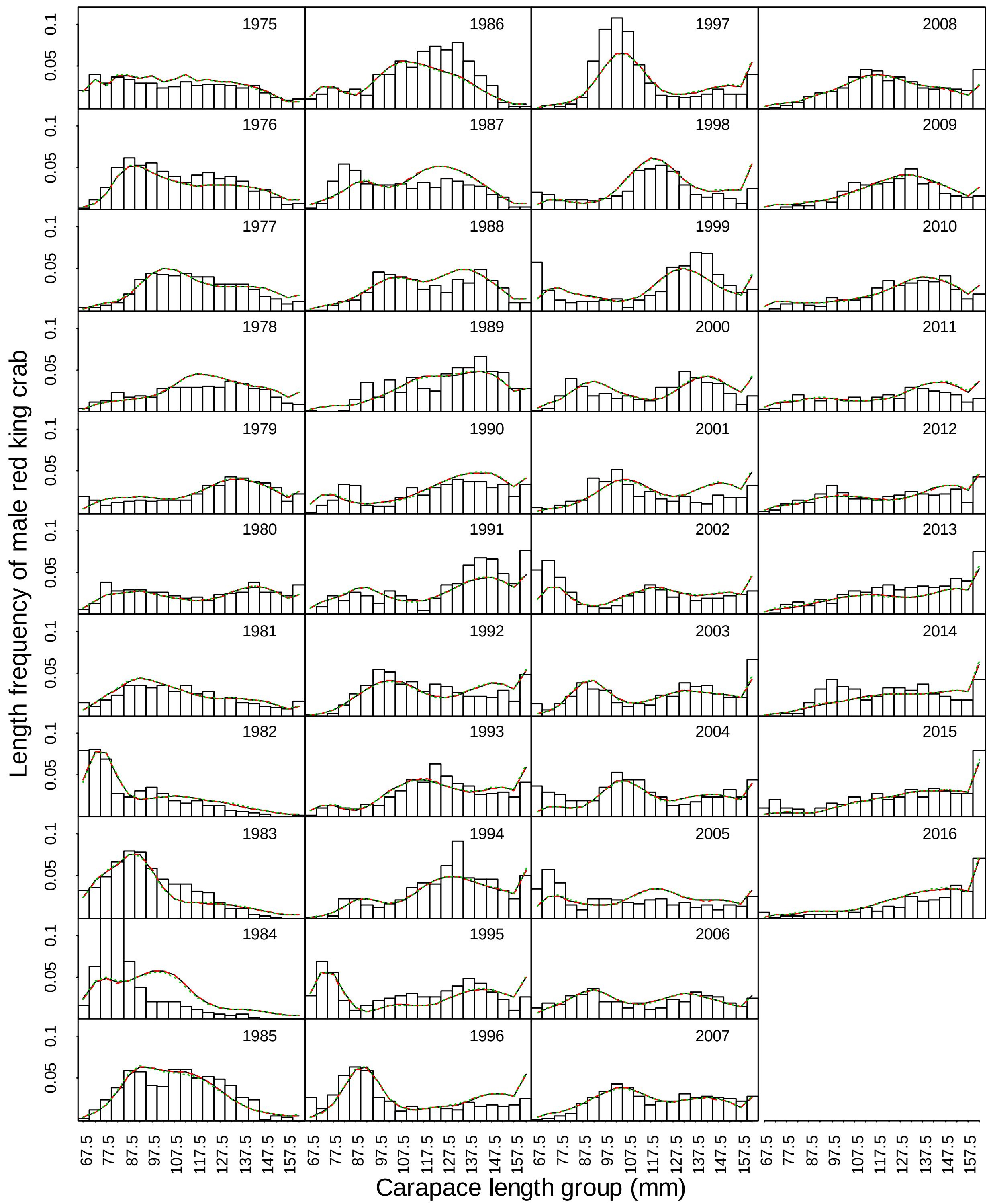


Figure 18(1,1n & 2). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay male red king crab by year under scenarios 1(solid black), 1n (dashed red), and 2 (green lines). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8.

88

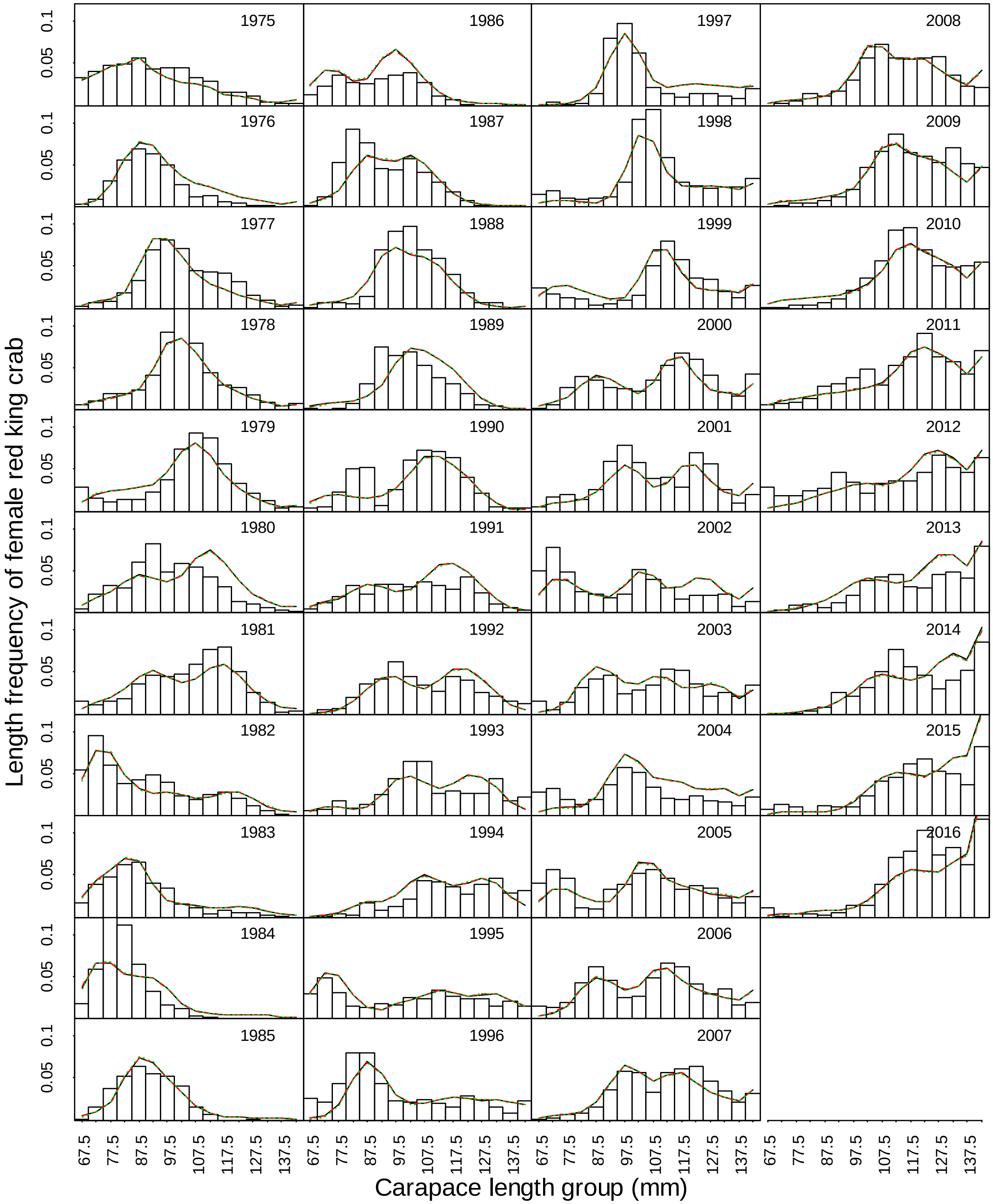


Figure 19(1,1n & 2). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay female red king crab by year under scenarios 1(solid black), 1n (dashed red), and 2 (green lines). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8.

89

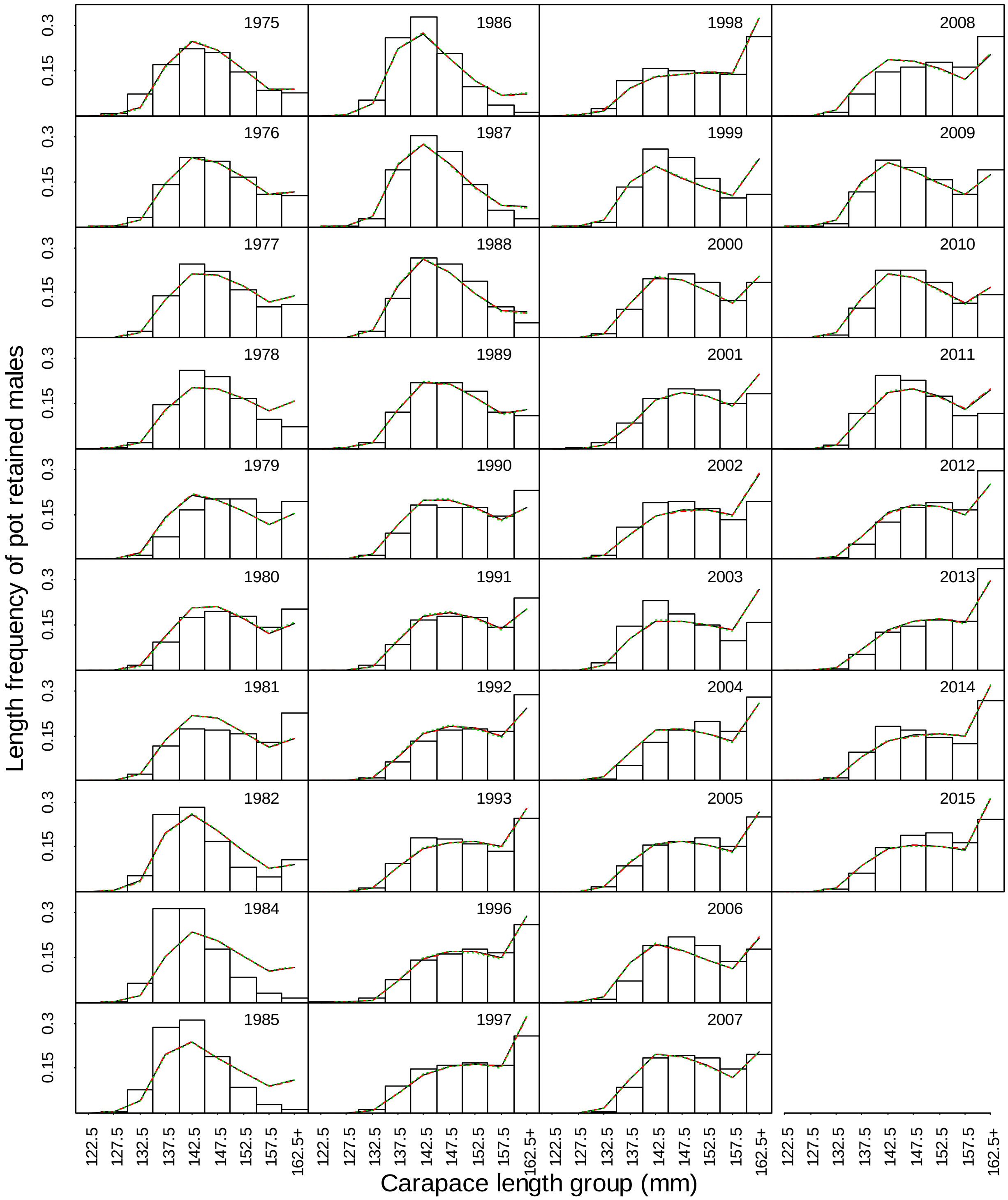


Figure 20(1,1n & 2). Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under scenarios 1 (solid black), 1n (dashed red), and 2 (green lines). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

90

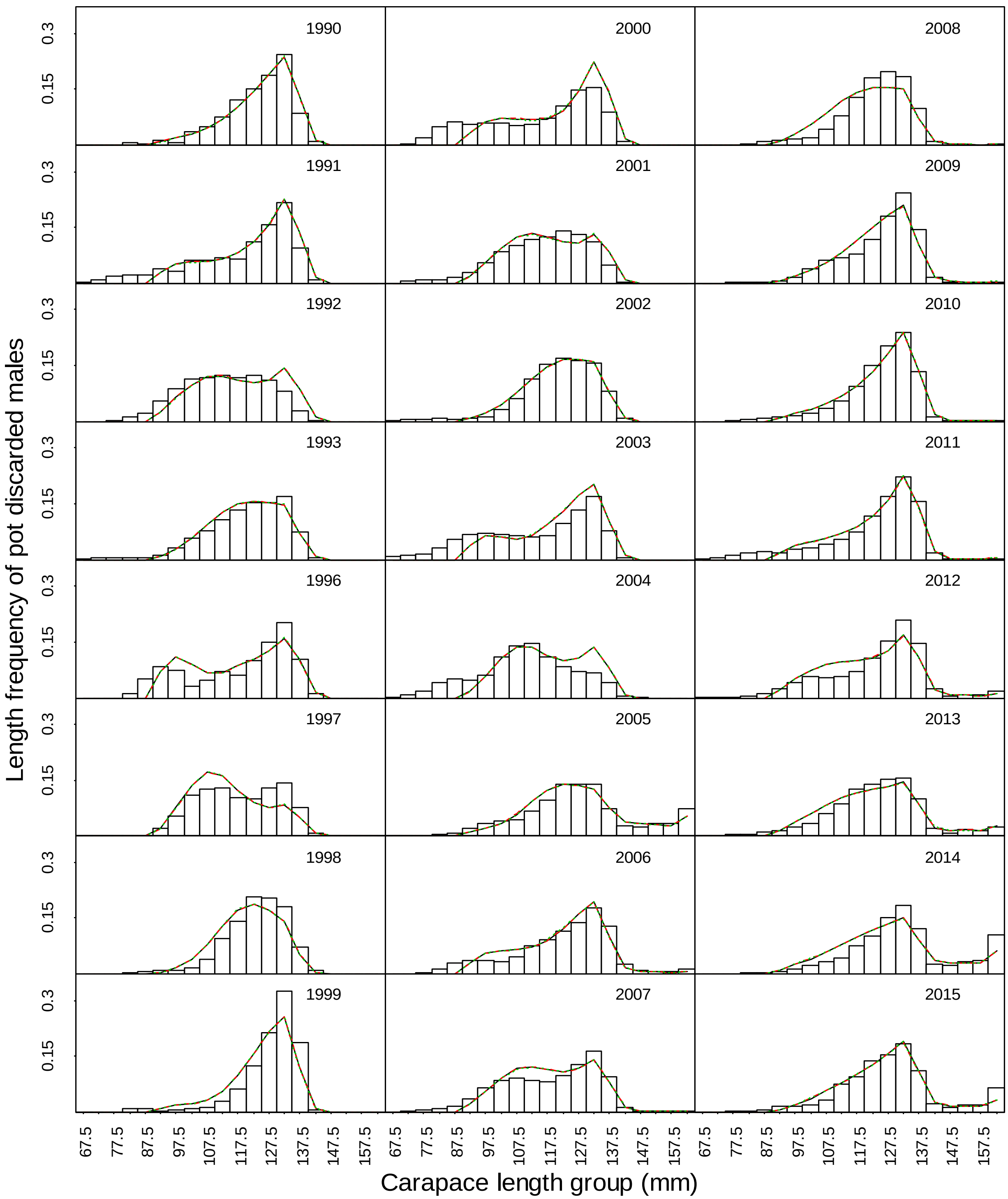


Figure 21(1,1n & 2). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under scenarios 1 (solid black), 1n (dashed red), and 2 (green lines). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

91

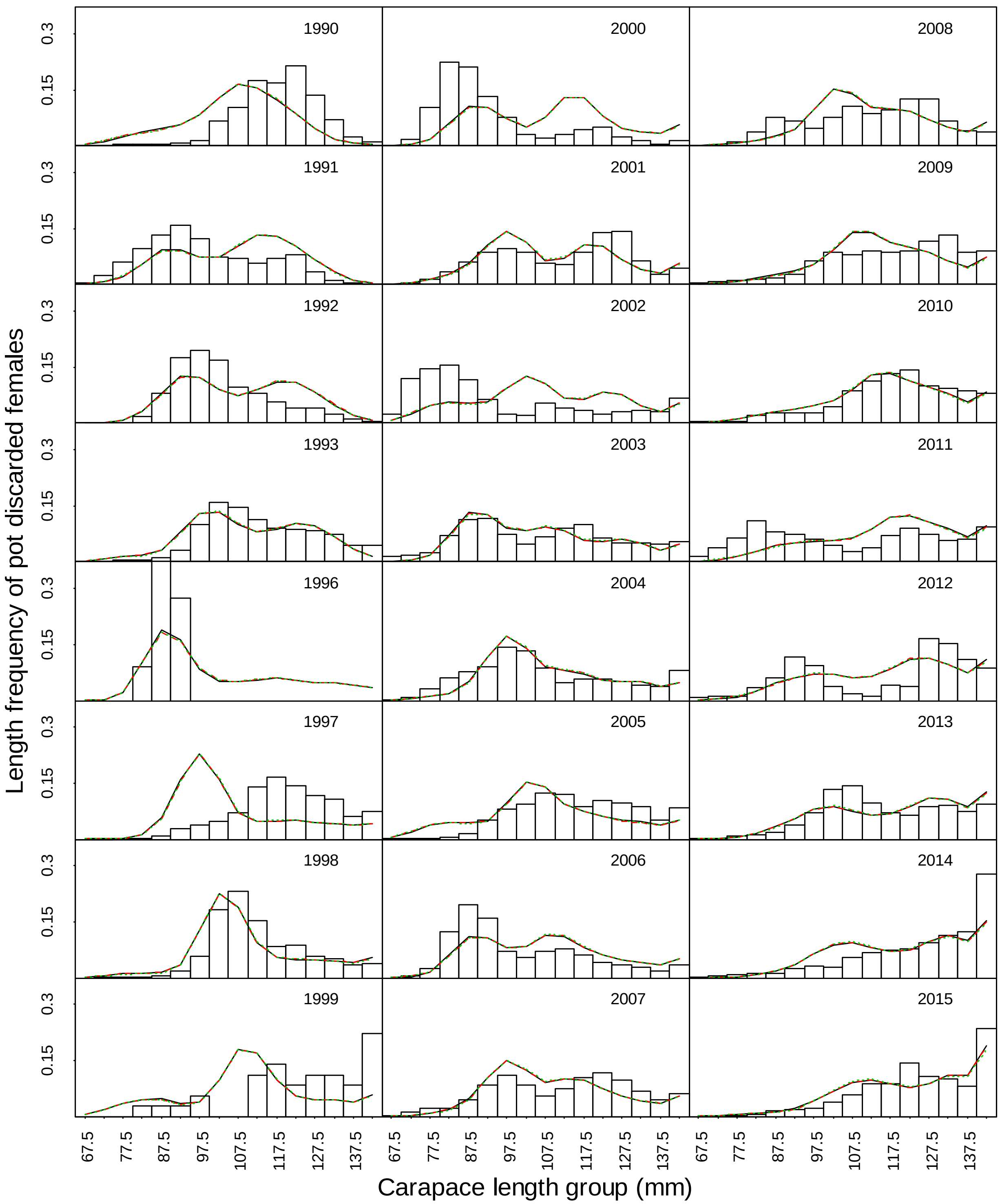


Figure 22(1,1n & 2). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the directed pot fishery under scenarios 1 (solid black), 1n (dashed red), and 2 (green lines). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

92

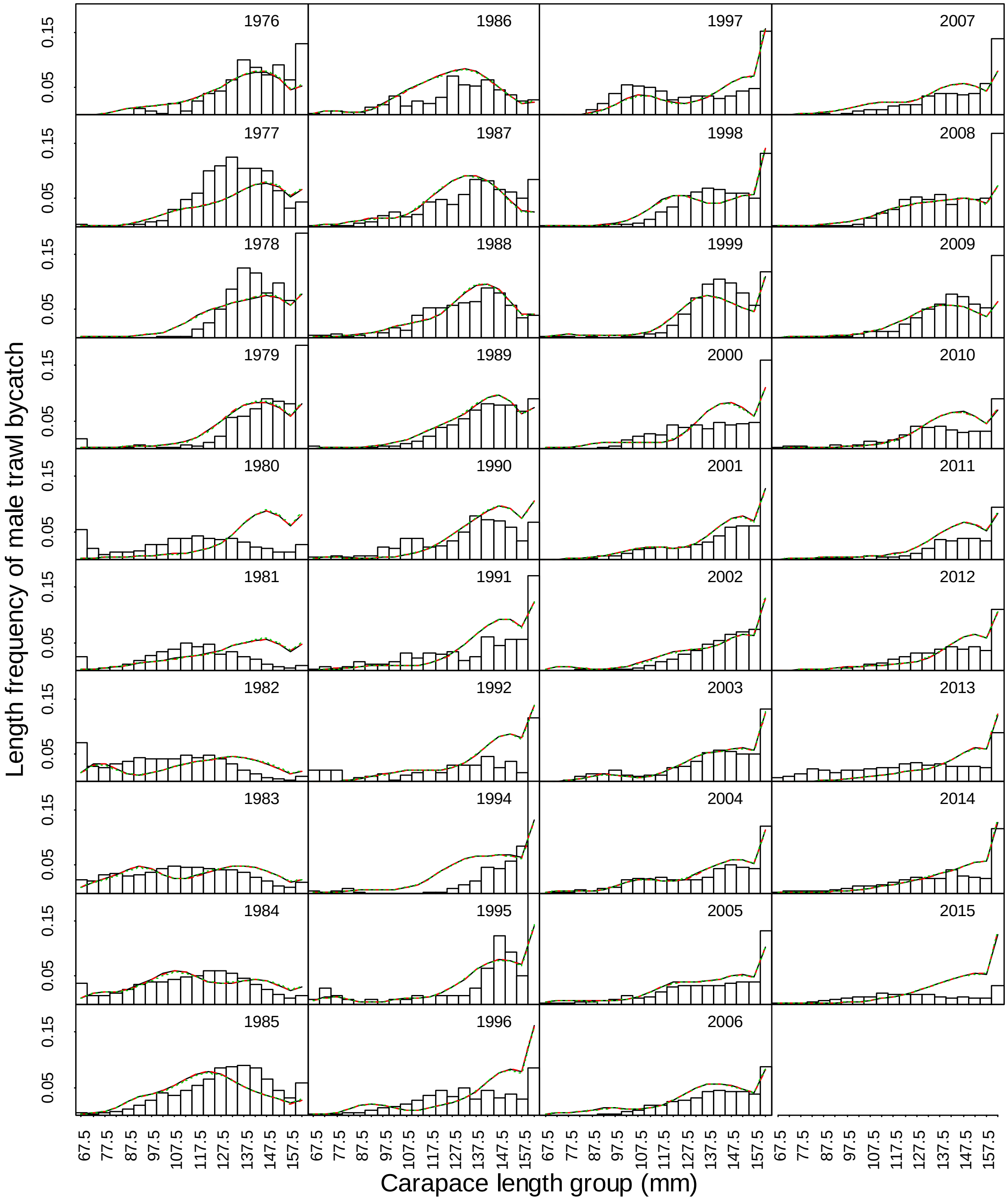


Figure 23(1,1n & 2). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish trawl fisheries under scenarios 1 (solid black), 1n (dashed red), and 2 (green lines). Pot handling mortality rate is 0.2, and trawl bycatch mortality rate is 0.8.

93

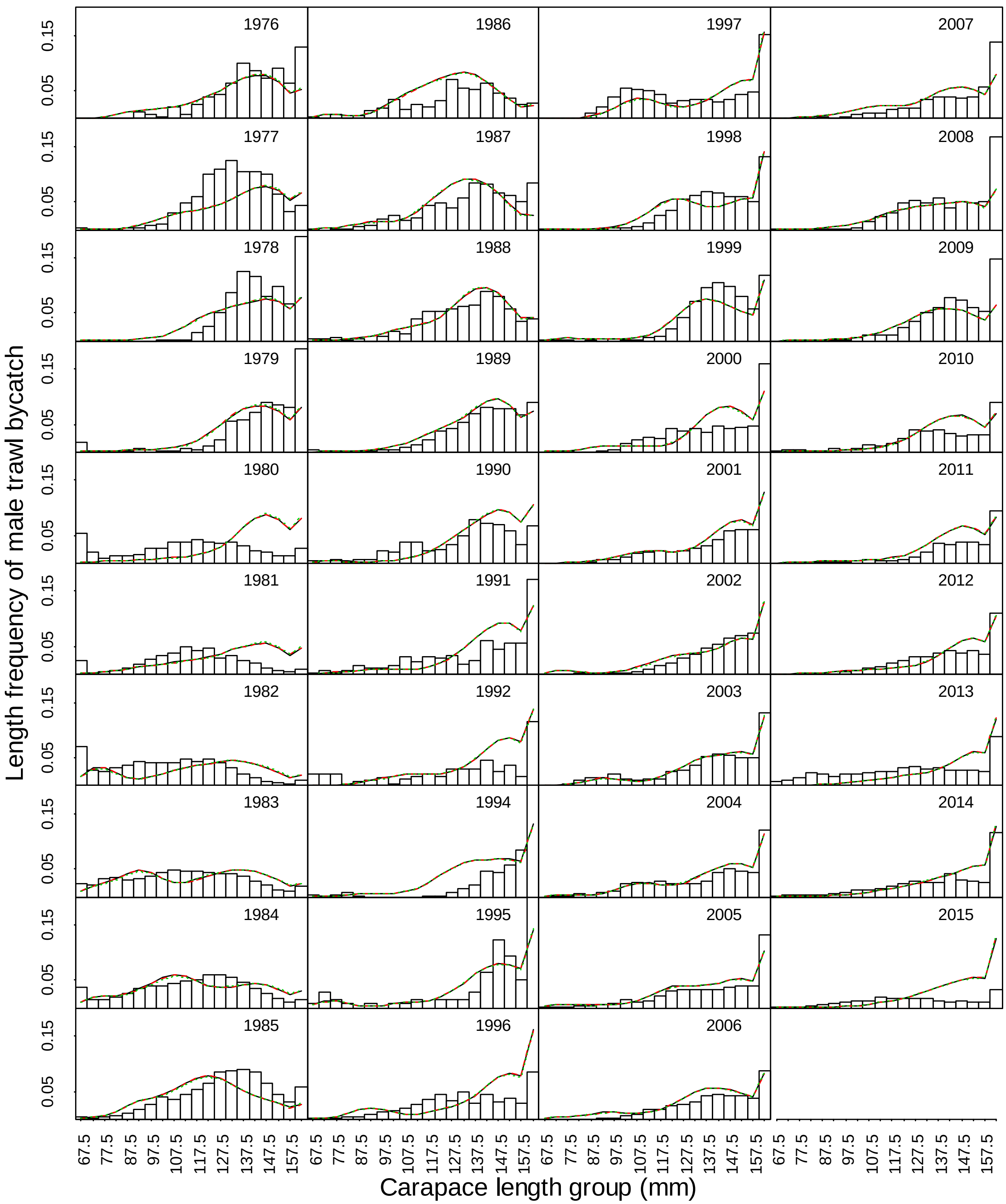


Figure 24(1,1n & 2). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish trawl fisheries under scenarios 1 (solid black), 1n (dashed red), and 2 (green lines). Pot handling mortality rate is 0.2, and trawl bycatch mortality rate is 0.8.

94

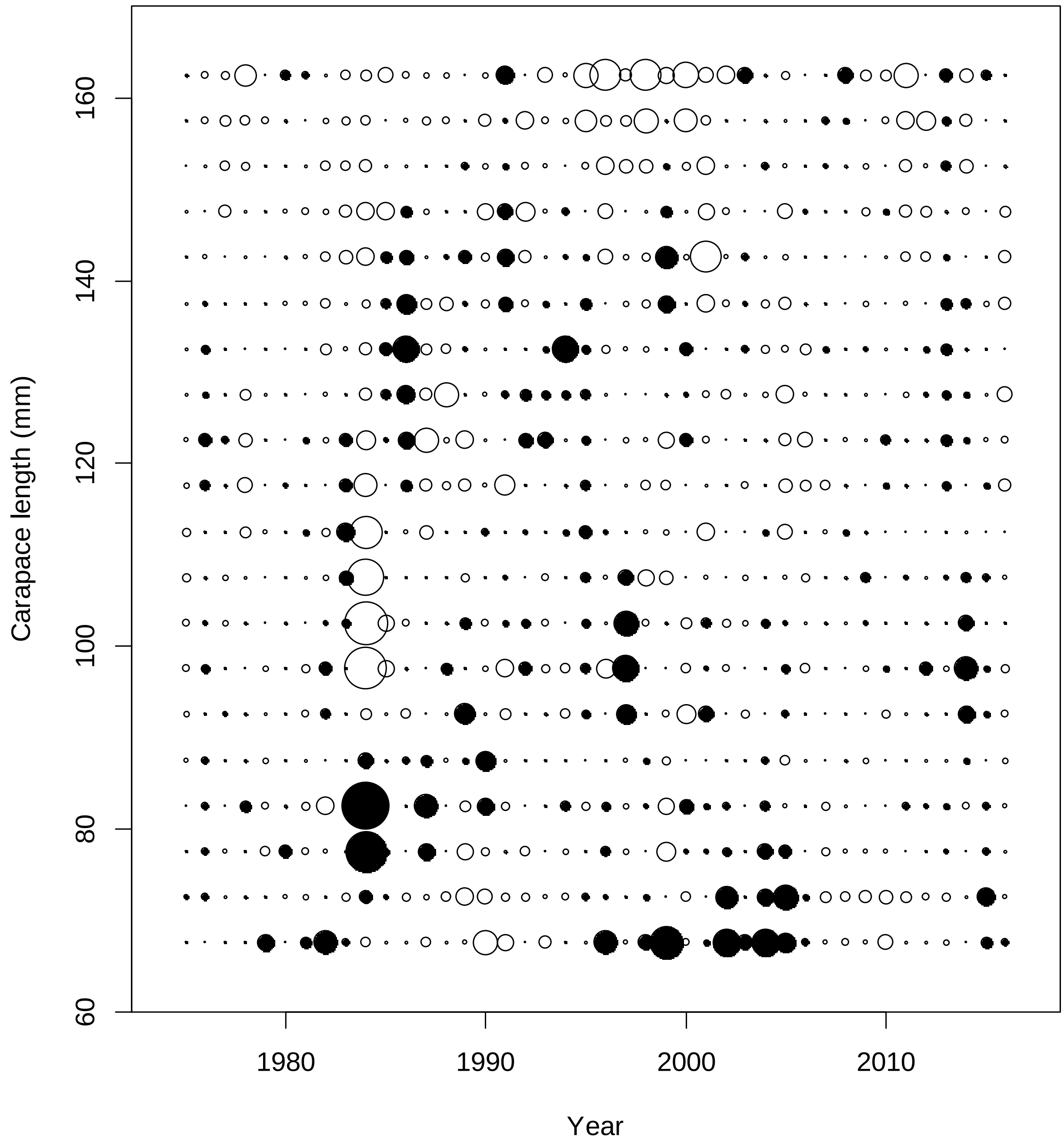


Figure 25(1). Standardized residuals of proportions of survey male red king crab under scenario 1. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

95

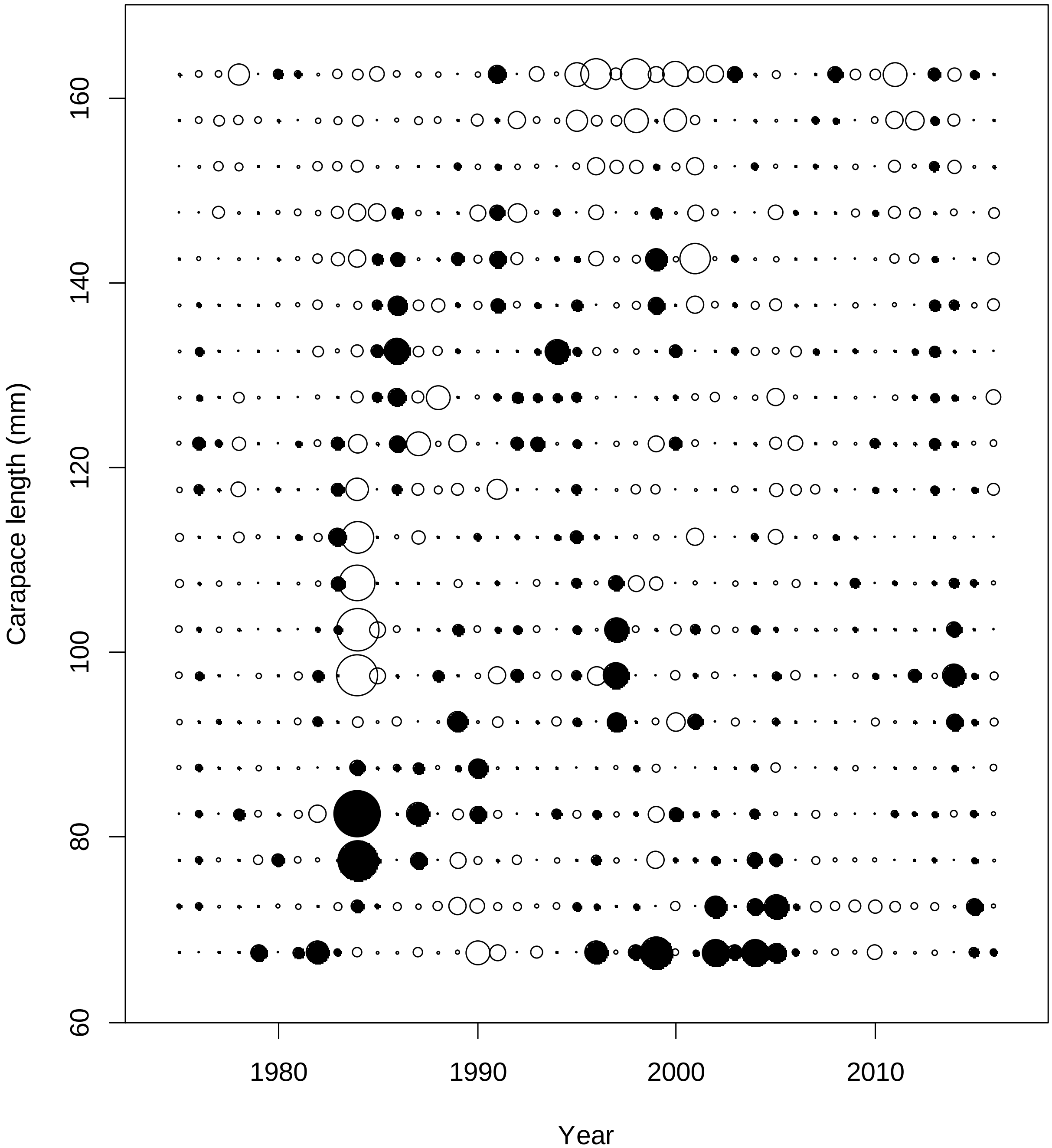


Figure 25(1n). Standardized residuals of proportions of survey male red king crab under scenario 1n. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

96

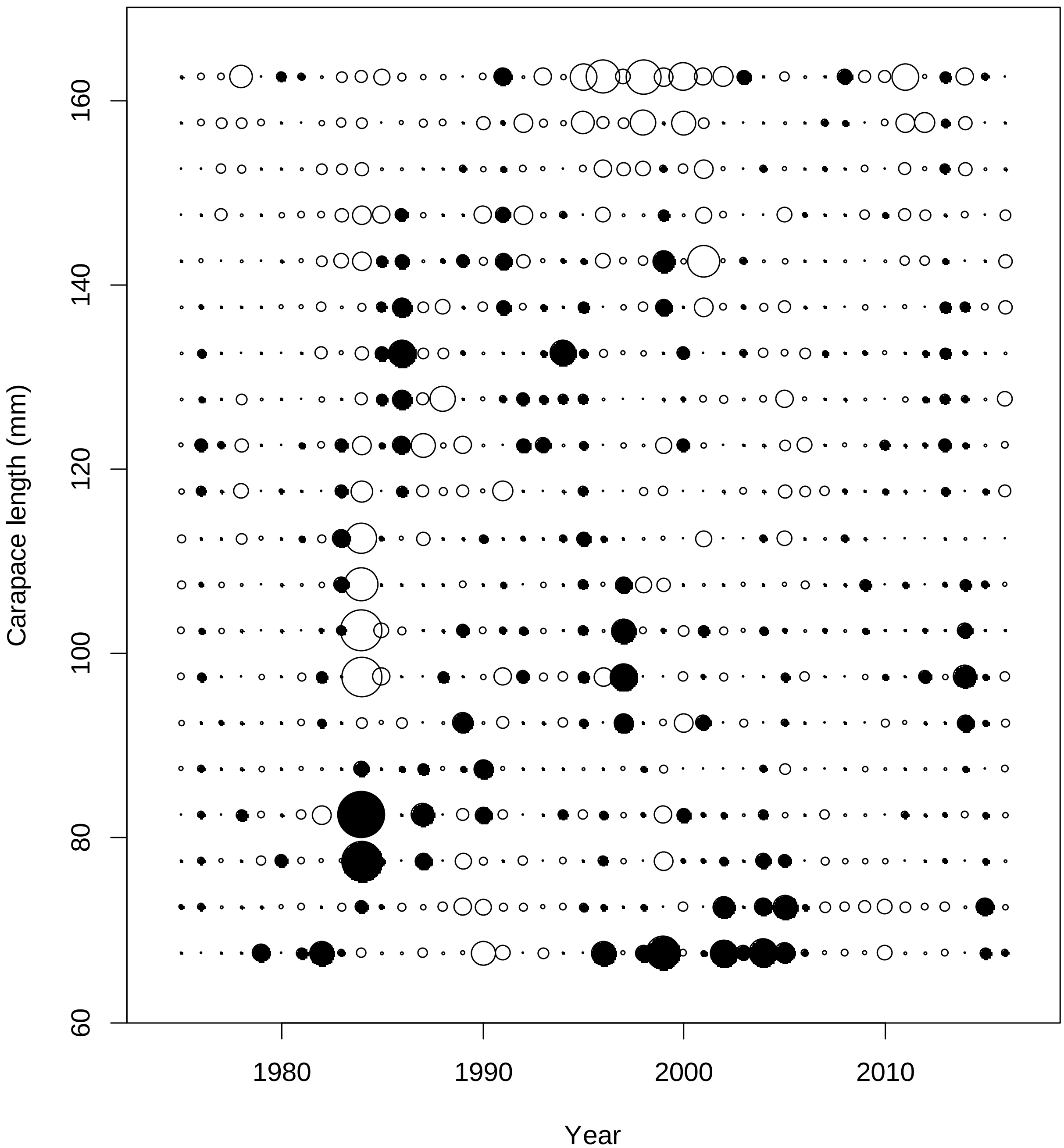


Figure 25(2). Standardized residuals of proportions of survey male red king crab under scenario 2. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

97

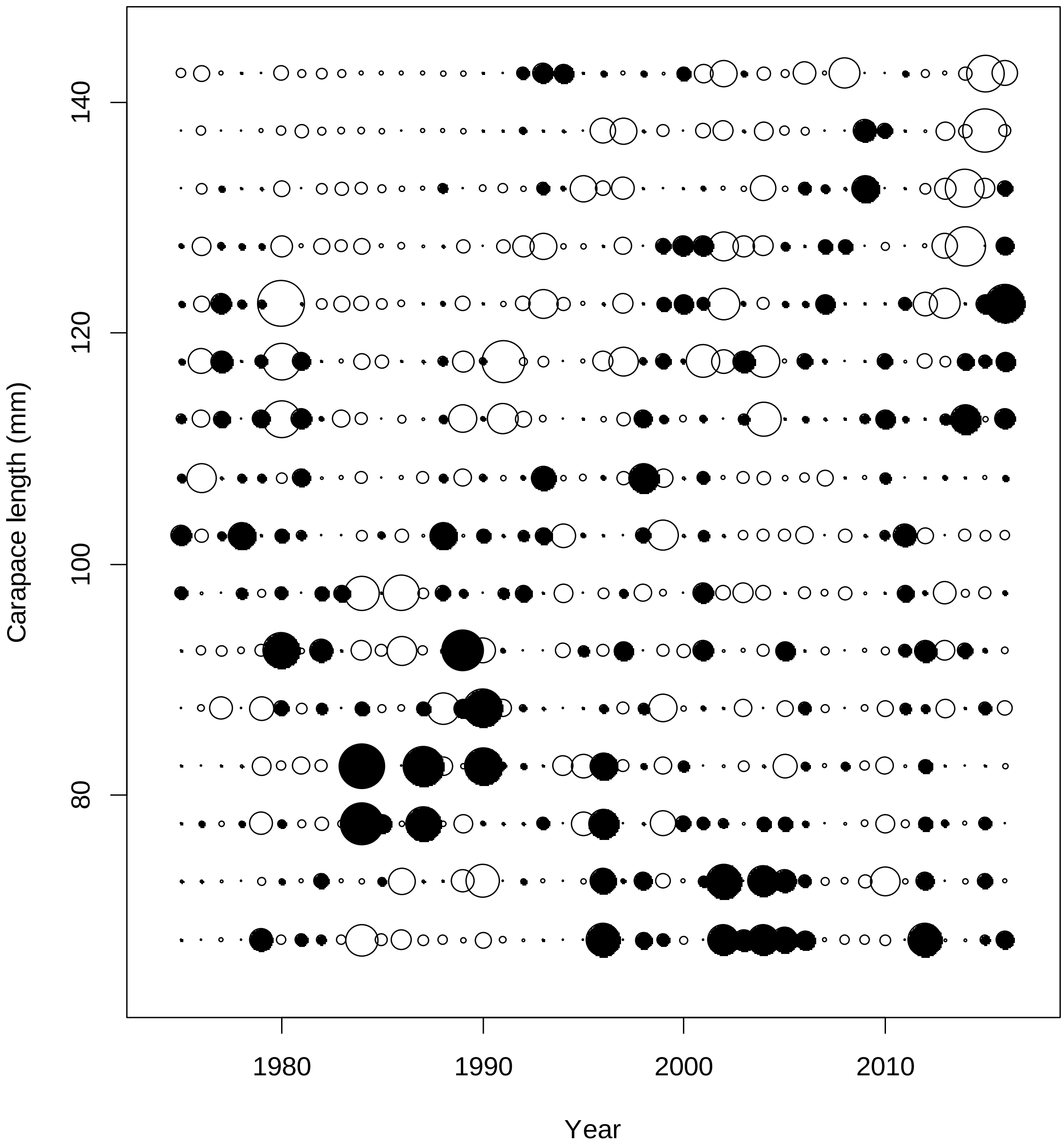


Figure 26(1). Standardized residuals of proportions of survey female red king crab under scenario 1. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

98

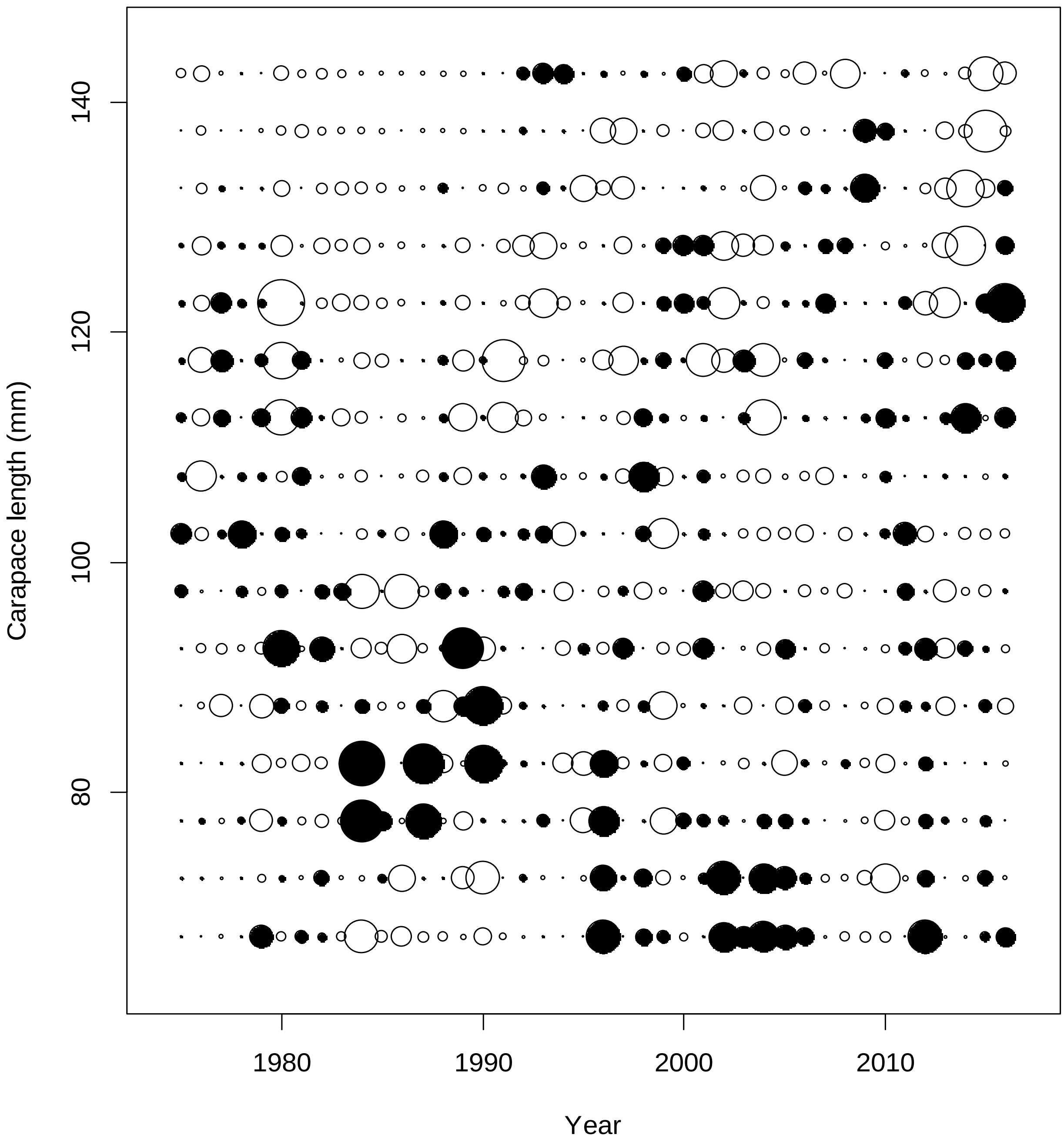


Figure 26(1n). Standardized residuals of proportions of survey female red king crab under scenario 1n. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

99

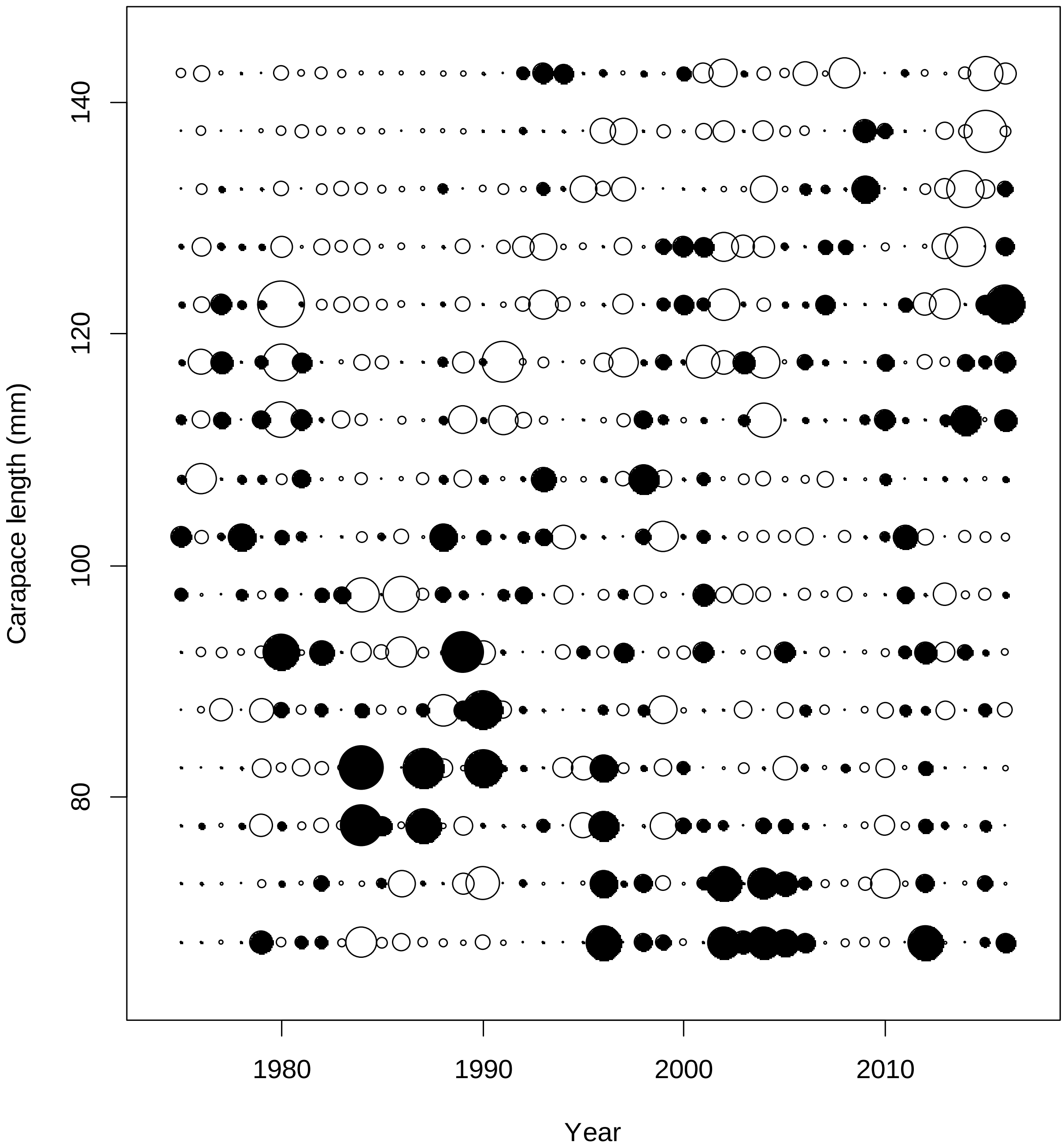
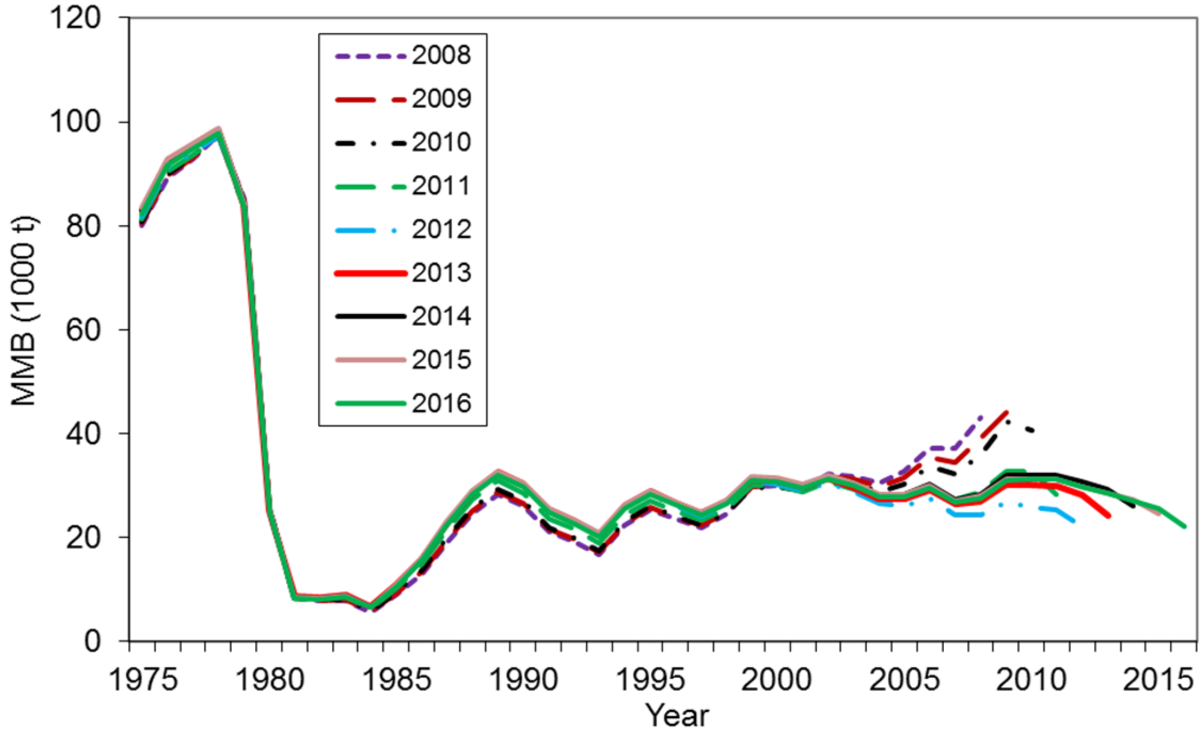


Figure 26(2). Standardized residuals of proportions of survey female red king crab under scenario 2. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.



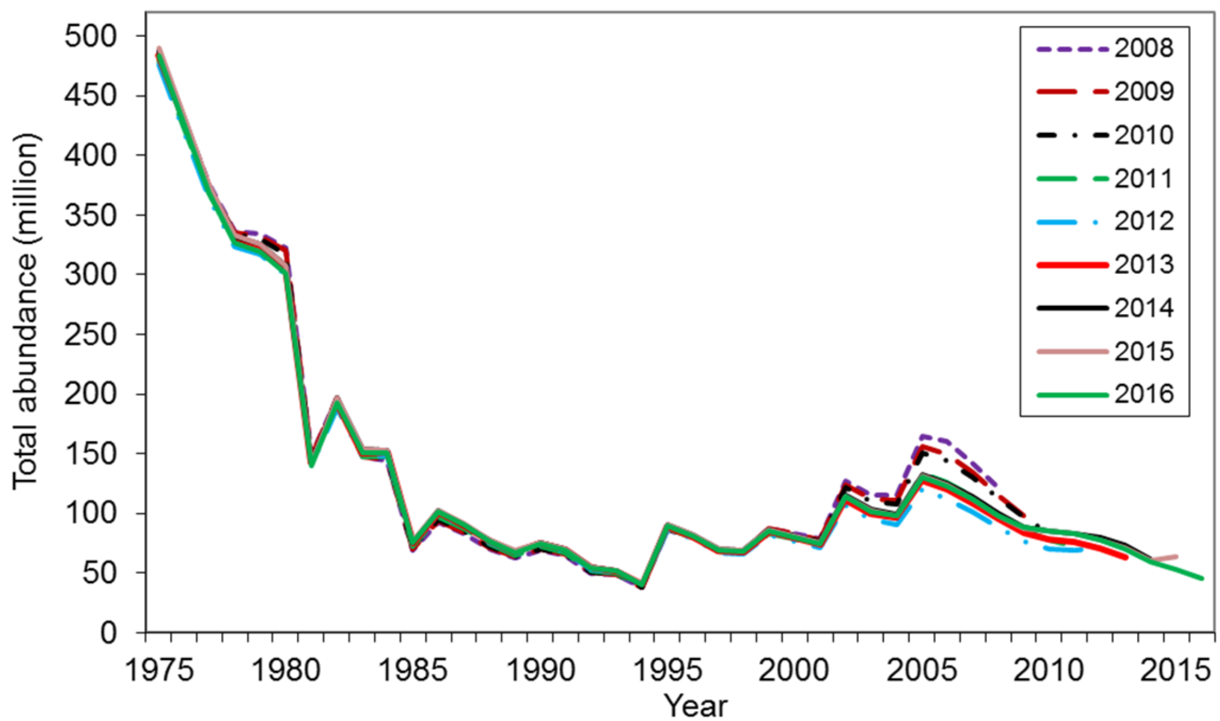


Figure 27. Comparison of hindcast estimates of mature male biomass on Feb. 15 (top) and total abundance (bottom) of Bristol Bay red king crab from 1975 to 2016 made with terminal years 2008-2016 with scenario 1. These are results of the 2016 model. Legend shows the terminal year. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

101

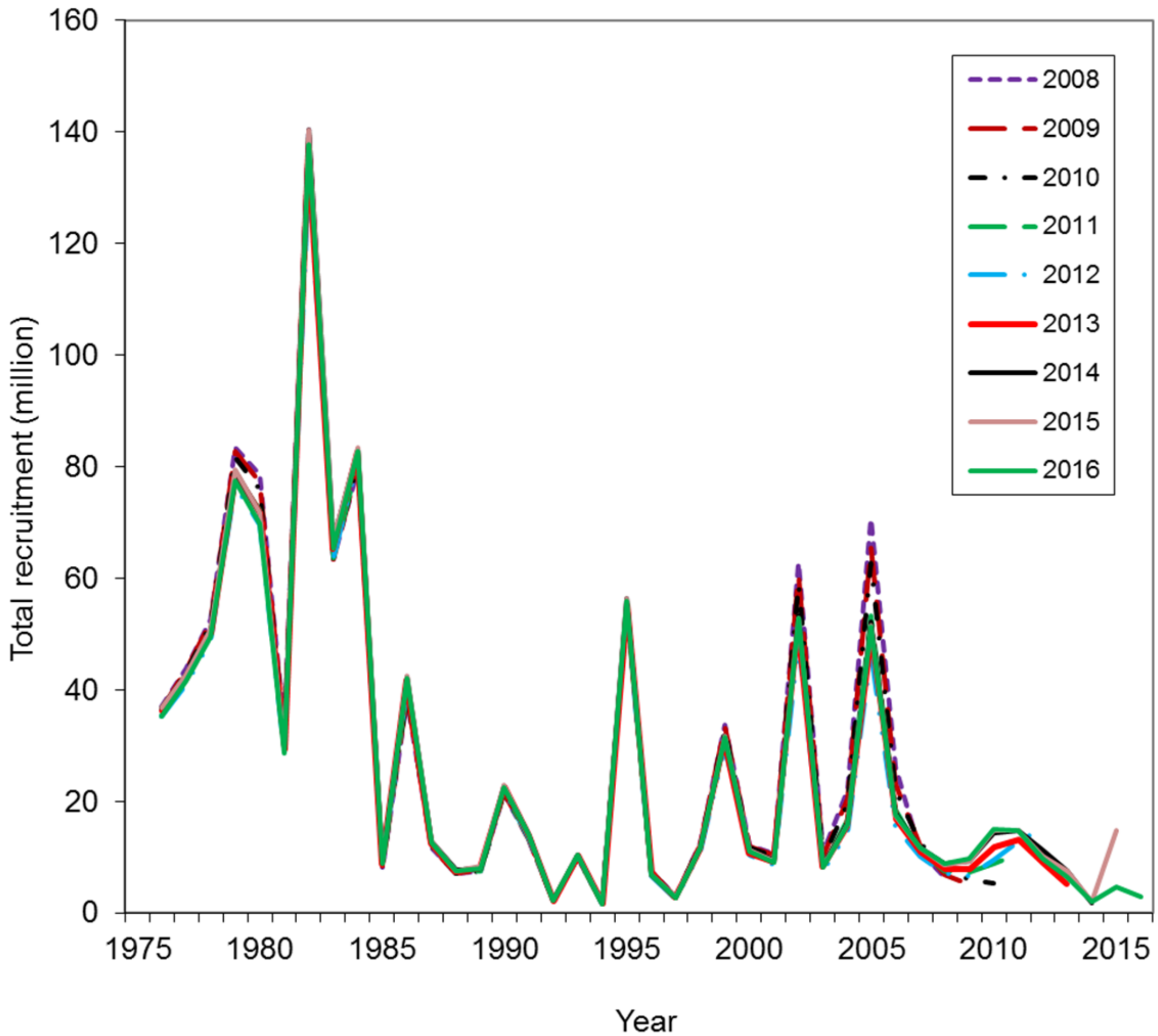
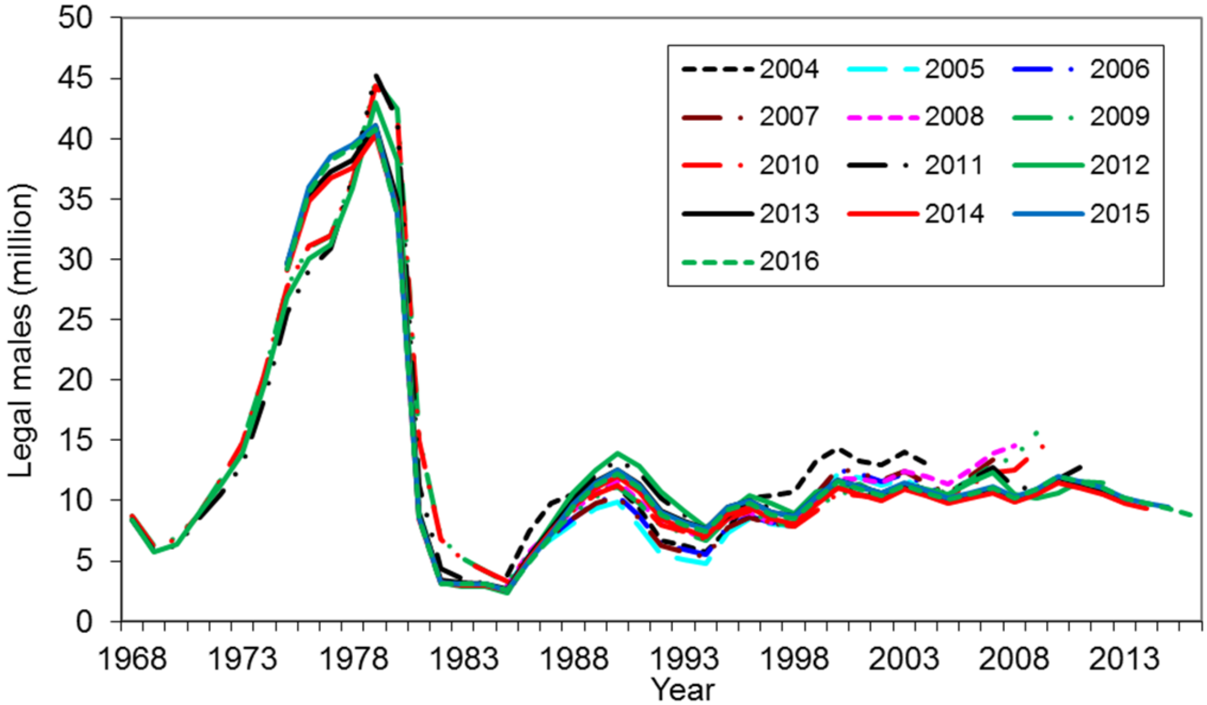


Figure 28. Comparison of hindcast estimates of total recruitment for scenario 1 of Bristol Bay red king crab from 1976 to 2016 made with terminal years 2008-2016. These are results of the 2016 model. Legend shows the terminal year. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.



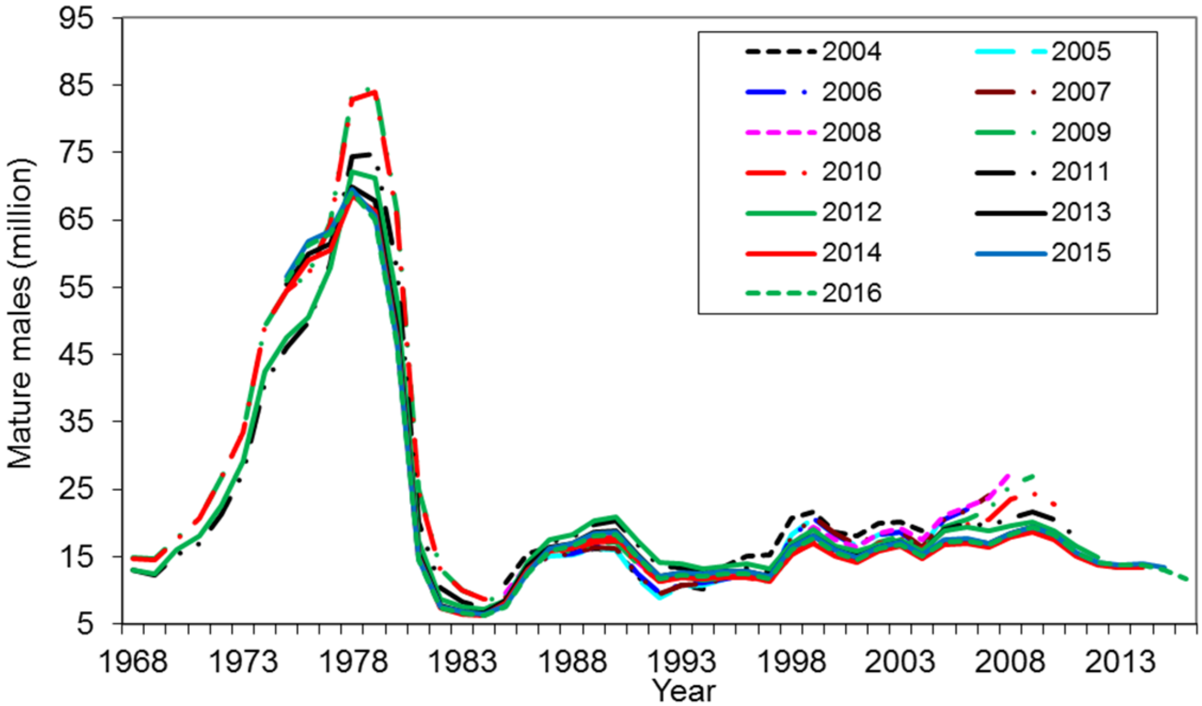


Figure 29. Comparison of estimates of legal male abundance (top) and mature males (bottom) of Bristol Bay red king crab from 1968 to 2016 made with terminal years 2004-2016 with the base scenarios. Scenario 1 is used for 2014-2016. These are results of historical assessments. Legend shows the year in which the assessment was conducted. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

103

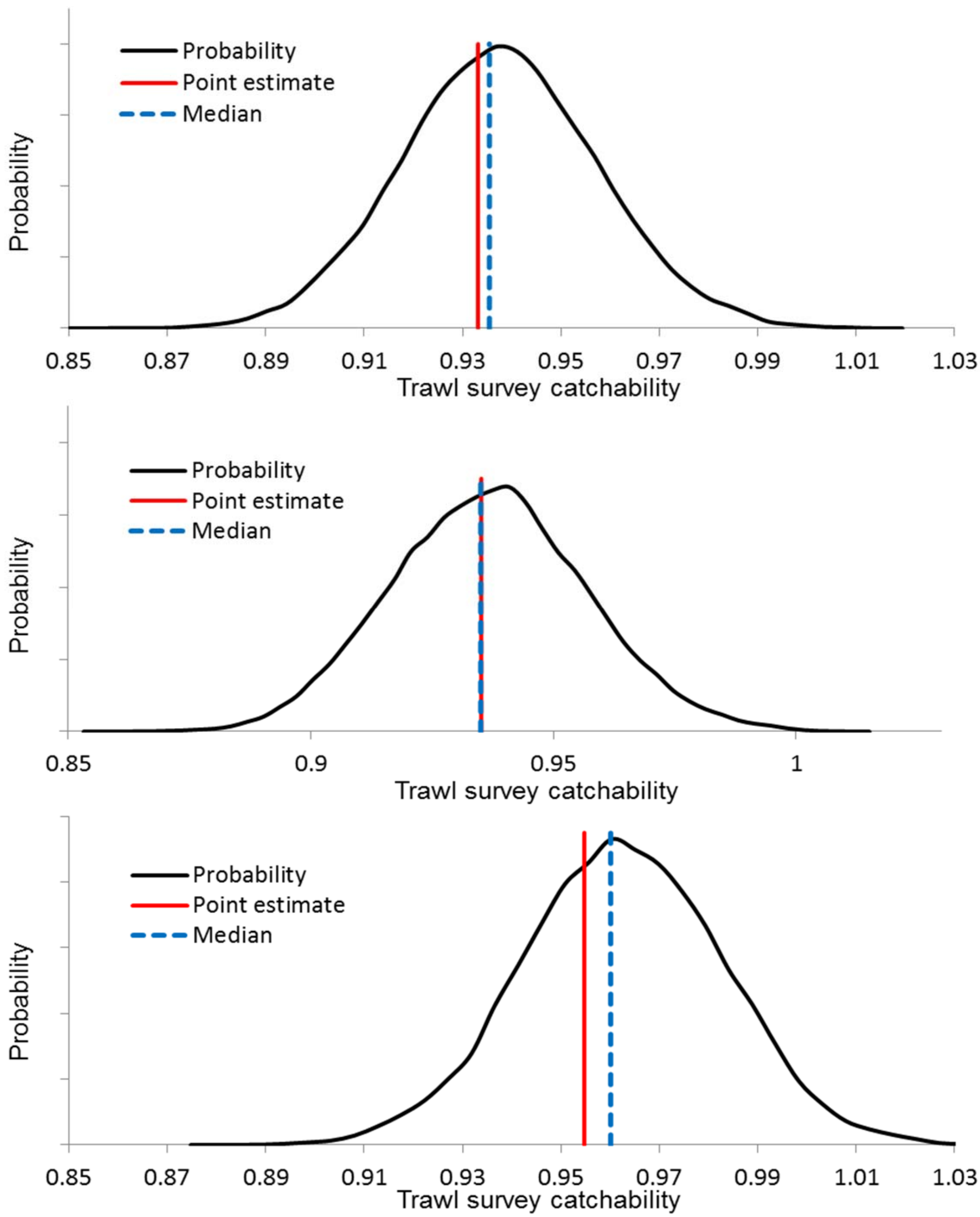


Figure 30(1, 1n & 2). Probability distributions of estimated trawl survey catchability (*Q*) under scenarios 1 (upper panel), 1n (middle panel) and 2 (lower panel) with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

104

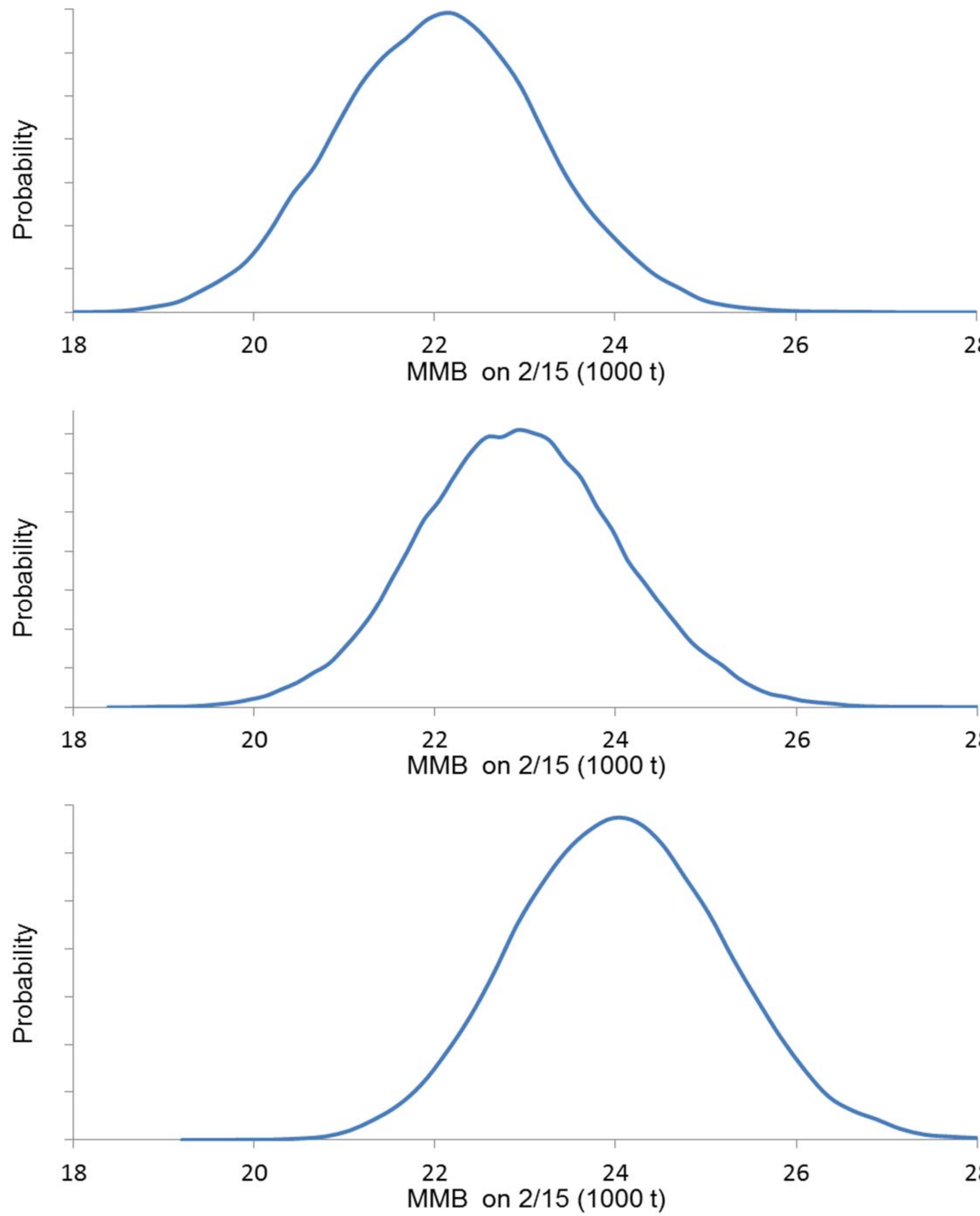


Figure 31a(1, 1n & 2). Probability distributions of estimated mature male biomass on Feb. 15, 2016 with $F_{35\%}$ under scenarios 1 (upper panel), 1n (middle panel) and 2 (lower panel) with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

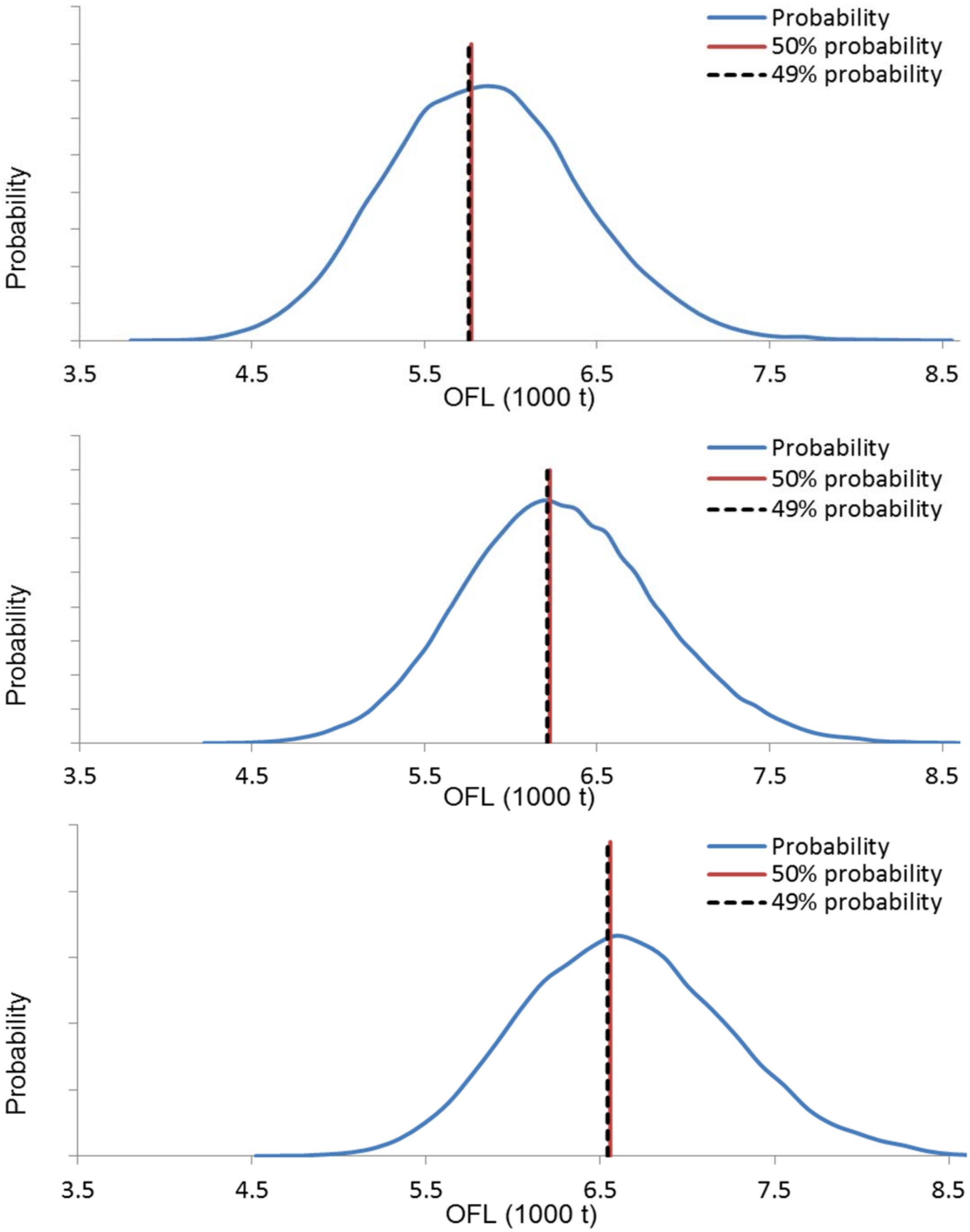


Figure 31b(1, 1n & 2). Probability distributions of the 2016 estimated OFL with scenarios 1 (upper panel), 1n (middle panel) and 2 (lower panel) with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

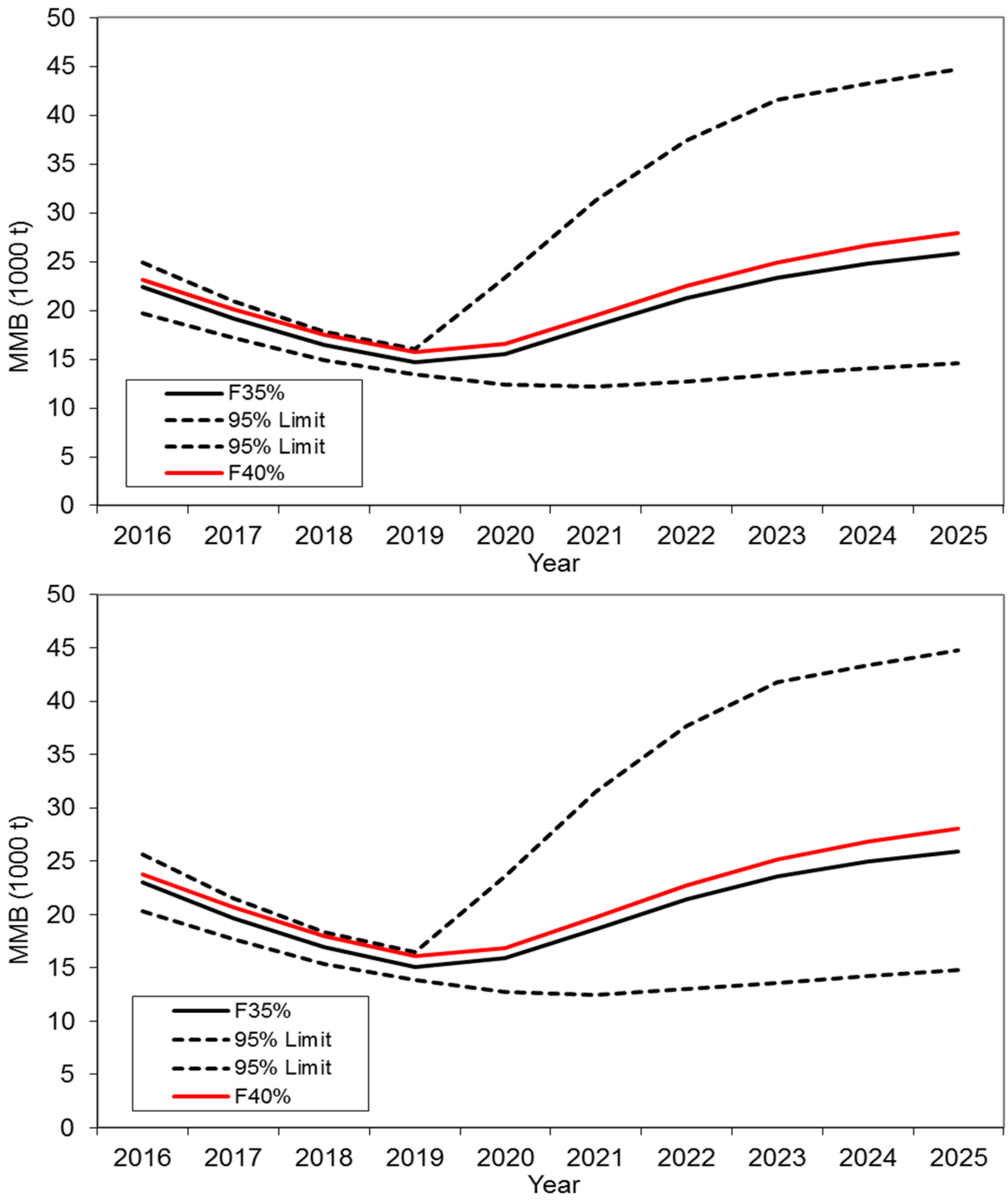
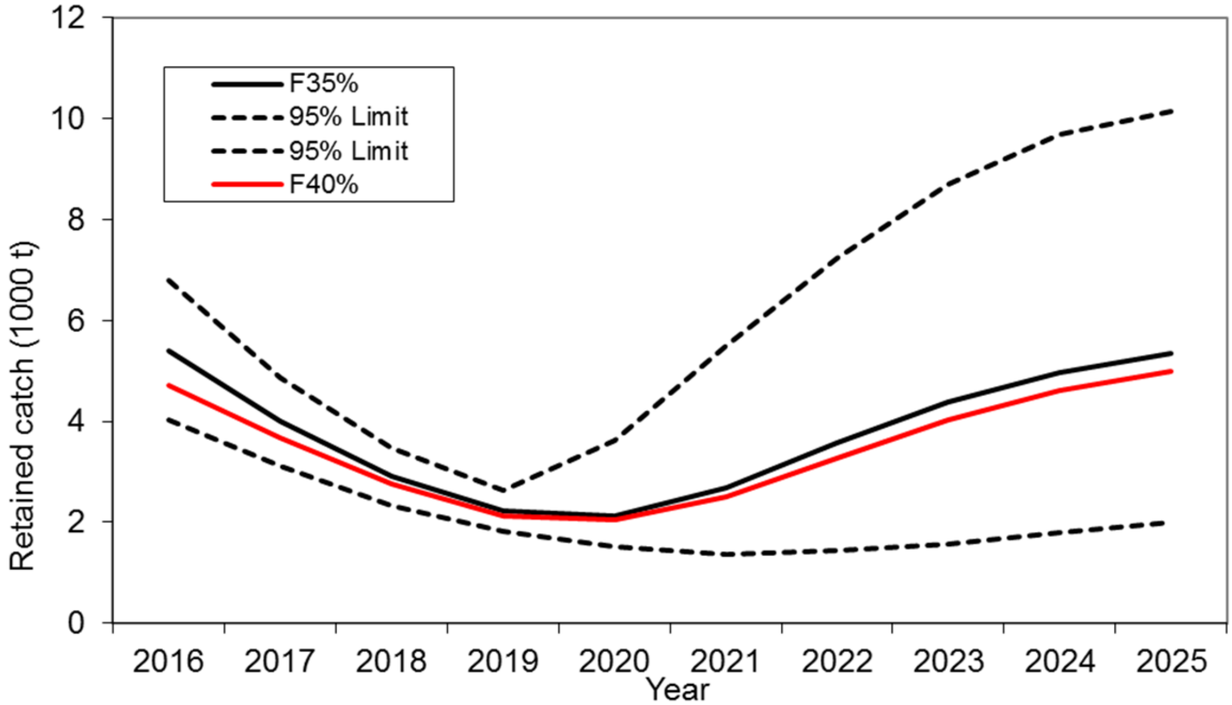


Figure 32(1&1n). Projected mature male biomass on Feb. 15 with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2016-2025. Input parameter estimates are based on scenarios 1 (upper panel) and 1n (lower panel). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.



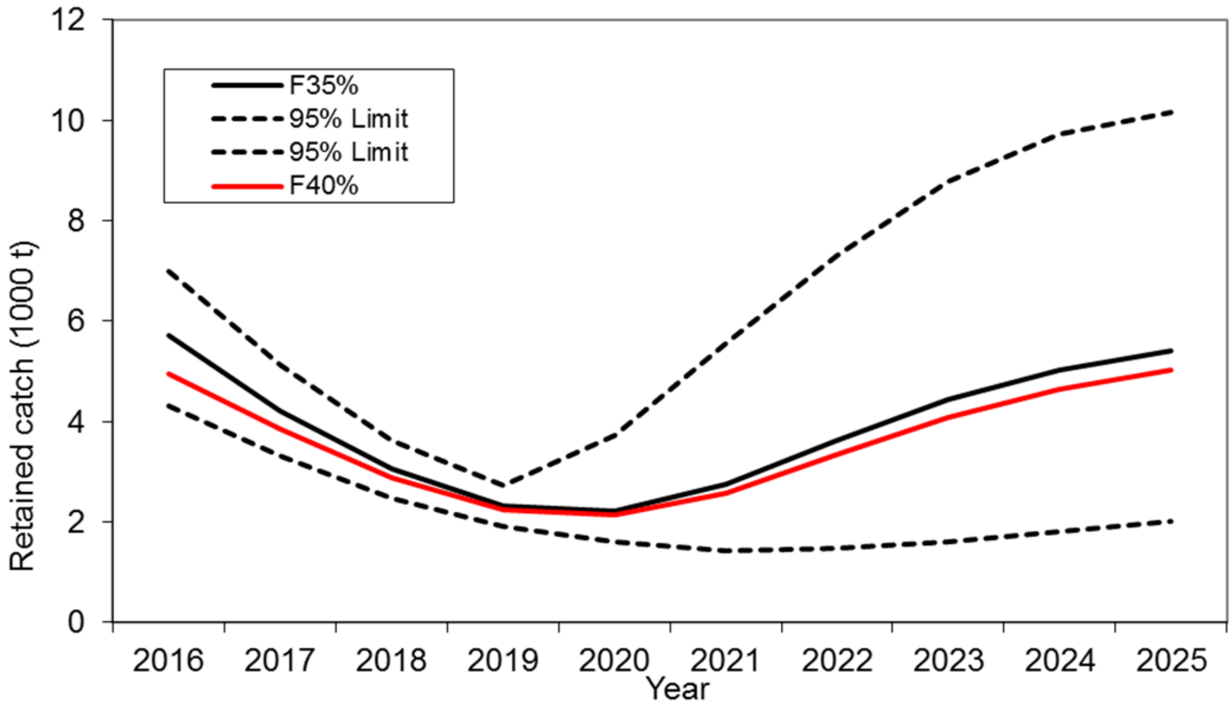


Figure 33(1&1n). Projected retained catch biomass with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2015-2124. Input parameter estimates are based on scenarios 1 (upper panel) and 1n (lower panel). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

108

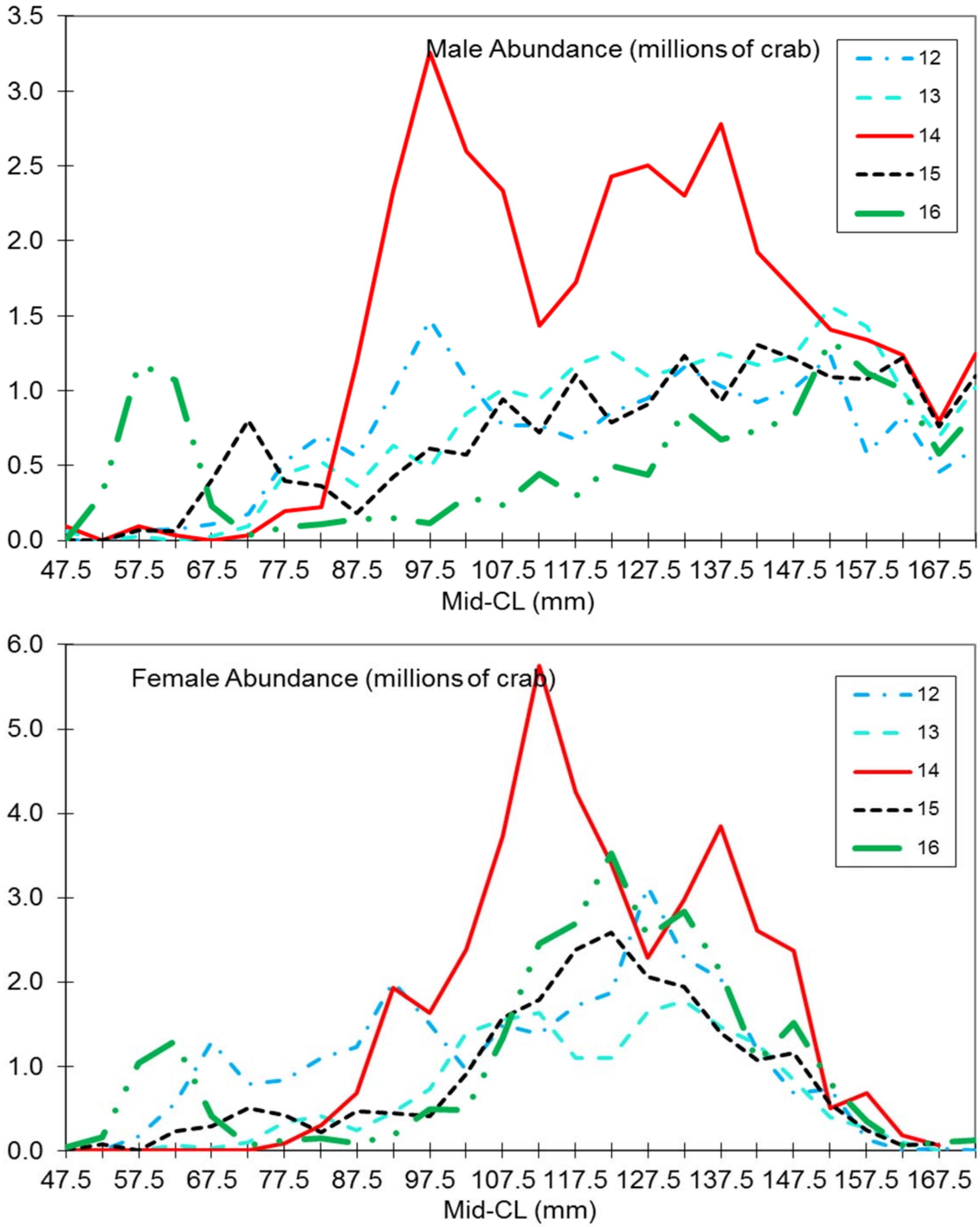


Figure 34. Length frequency distributions of male (top panel) and female (bottom panel) red king crab in Bristol Bay from NMFS trawl surveys during 2012-2016. For purposes of these graphs, abundance estimates are based on area-swept methods.

Appendix A. Description of the Bristol Bay Red King Crab Model

a. Model Description

i. Population model

The original LBA model was described in detail by Zheng et al. (1995a, 1995b) and Zheng and Kruse (2002). Crab abundances by carapace length and shell condition in any one year are modeled to result from abundances in the previous year minus catch and handling and natural mortalities, plus recruitment, and additions to or losses from each length class due to growth:

$$N^s_{l,t+1} = \sum_{l'=1}^{l} \{P^s_{l',l,t}[(N^s_{l',t}+O^s_{l',t})e^{-M^s_t} - (C^s_{l',t}+D^s_{l',t})e^{(y_t-1)M^s_t} - T^s_{l',t}\, e^{(j_t-1)M^s_t}]m^s_{l',t}\} + R^s_{t+1}U^s_l$$
$$O^s_{l,t+1} = [(N^s_{l,t}+O^s_{l,t})e^{-M^s_t} - (C^s_{l,t}+D^s_{l,t})e^{(y_t-1)M^s_t} - T^s_{l,t}\, e^{(j_t-1)M^s_t}](1-m^s_{l,t}) \qquad \text{(A1)}$$

where $N^s_{l,t}$ is the number of new shell crab of sex *s* in length-class *l* at the start of year *t*, $O^s_{l,t}$ the number of old shell crab of sex *s* in length-class *l* at the start of year *t*, $P^s_{l',l,s}$ the proportion during year *t* of an animals of sex *s* in length-class *l'* which grow into length-class *l* given that they moulted, M^s_t the rate of natural mortality on animals of sex *s* during year *t*, $m^s_{l,t}$ the probability that an animal of sex *s* in length-class *l* will moult during year *t*, R^s_{t+1} the recruitment [to the model] of animals of sex *s* during year *t*, U^s_l the proportion of recruits of sex *s* which recruit to length-class *l*, $C^s_{l,t}$ the retained catch (in numbers) of animals of sex *s* in length-class *l* during year *t*, $D^s_{l,t}$ the discarded catch of animals of sex *s* in length-class *l* during year *t* in the directed fishery and the trawl fishery, $T^s_{l,t}$ the discarded catch of animals of sex *s* in length-class *l* during year *t* in the Tanner crab fishery, y_t the time in years between survey and the directed pot and groundfish trawl fisheries during year *t*, and j_t the time in years between survey and the Tanner fishery during year *t*.

The minimum carapace length for both males and females is set at 65 mm, and crab abundance is modeled with a length-class interval of 5 mm. The last length class includes all crab ≥160-mm CL for males and ≥140-mm CL for females. Thus, length classes/groups are 20 for males and 16 for females. Since females moult annually (Powell 1967), females have only the first part of the equation (A1).

The growth increment is assumed to be gamma distributed with mean which depends linearly on pre-moult length, i.e.:

$$P^s_{l,l',t} = \int_{L_l-\Delta L/2}^{L_l+\Delta L/2} \frac{x^{\alpha^s_{L_{l'},t}}\, e^{x/\beta^s}}{(\beta^s)^{\alpha^s_{L_{l'},t}}\,\Gamma(\alpha^s_{L_{l'},t})}\,dx \qquad \alpha^s_{L_l,t}\beta^s = a^s_t + b^s_t L_l \qquad \text{(A2)}$$

where L_l is the mid-point of length-class *l*, ΔL the width of each size-class (5 mm carapace length), a_t^s, b_t^s the parameters of the length–growth increment relationship for sex *s* and year *t*, and β^s the parameter determining the variance of the growth increment. Growth is time-invariant for males, and specified for three time-blocks for females (1968-82; 1983-93; 1994-2016) based on changes to the size at maturity for females. The probability of moulting as a function of length for males is given by an inverse logistic function, i.e.:

$$m_l = \frac{1}{1+e^{\tilde{\beta}(L_l - L_{50})}} \tag{A3}$$

where $\tilde{\beta}, L_{50}$ are the parameters which determine the relationship between length and the probability of moulting.

Recruitment is defined as recruitment to the model and survey gear rather than recruitment to the fishery. Recruitment is separated into a time-dependent variable, R_{t+1}^s, and size-dependent variables, U_l^s, representing the proportion of recruits belonging to each length class. R_{t+1}^s is assumed to consist of crab at the recruiting age with different lengths and thus represents year class strength for year *t*. The proportion of recruits by length-class, U_l^s, is described using a gamma distribution with parameters α_l^s and β_l^s. Because of different growth rates, recruitment is estimated separately for males and females under a constraint of approximately equal sex ratios of recruitment over time.

ii. Catches and Fisheries Selectivities

Before 1990, no observed bycatch data were available in the directed pot fishery; the crab that were discarded and died in those years were estimated as the product of handling mortality rate, legal harvest rates, and mean length-specific selectivities. It is difficult to estimate bycatch from the Tanner crab fishery before 1991. A reasonable index to estimate bycatch fishing mortalities is potlifts of the Tanner crab fishery within the distribution area of Bristol Bay red king crab. Thus, bycatch fishing mortalities from the Tanner crab fishery before 1991 were estimated to be proportional to the smoothing average of potlifts east of 163^{o} W. The smoothing average is equal to $(P_{t-2}+2P_{t-1}+3P_t)/6$ for the potlifts in year t. The smoothing process not only smoothes the annual number of potlifts, it also indexes the effects of lost pots during the previous years.

The catch (by sex) in numbers by the directed fishery and the groundfish trawl fishery is:

$$G_{l,t}^s = (N_{l,t}^s + O_{l,t}^s)e^{-y_t M_t^s}(1-e^{-F_{l,t}^s}) \tag{A4}$$

where $F_{l,t}^s$ is the fishing mortality rate during year *t* on animals of sex *s* in length-class *l* due to the directed fishery and the groundfish trawl fishery:

$$F_{l,t}^s = \begin{cases} S_l^{\text{dir,land}} F_t^{\text{dir}} + (S_l^{\text{dir,disc,mal}} + h_t \phi S_{l,t}^{\text{dir,land}}) F_t^{\text{disc,mal}} + S_l^{\text{trawl}} F_t^{\text{trawl}} & \text{if } s = \text{mal} \\ S_l^{\text{dir,disc,fem}} F_t^{\text{disc,fem}} + S_l^{\text{trawl}} F_t^{\text{trawl}} & \text{if } s = \text{fem} \end{cases} \tag{A5}$$

where $S_l^{\text{dir,land}}$ is the selectivity pattern for the landings by the directed fishery, $S_l^{\text{dir,disc},s}$ the selectivity pattern for the discards in the directed fishery by sex, S_l^{trawl} the selectivity pattern for the bycatch in the groundfish trawl fishery, F_t^{dir} the fully-selected fishing mortality during year t (on males), $F_t^{\text{disc},s}$ the fully-selected fishing mortality on animals of sex s during year t related to discards in the directed fishery, F_t^{trawl} the fully-selected fishing mortality due to the groundfish trawl fishery, ϕ the handling mortality (the proportion of animals which die due to being returned to the water following capture), and h_t the rate of high-grading during year t , i.e. discards of animals which can be legally-retained by the directed pot fishery (non-zero only for 2005-2014).

There are no landings of females in a male-only fishery, while the landings C of males in the directed fishery and discards D of males in the directed and groundfish fisheries are:

$$\begin{aligned} C_{l,t}^{\text{mal}} &= (N_{l,t}^{\text{mal}} + O_{l,t}^{\text{mal}}) e^{-y_t M_t^{\text{mal}}} (1 - e^{-S_l^{\text{dir,land}} F_t^{\text{dir}}}) \\ D_{l,t}^{\text{mal}} &= G_{l,t}^{\text{mal}} - C_{l,t}^{\text{mal}} \end{aligned} \tag{A6}$$

The catch (by sex) in numbers by the Tanner crab fishery in length-class l during year t is given by:

$$T_{l,t}^{s} = (N_{l,t}^{s} + O_{l,t}^{s}) e^{-j_t M_t^{s}} e^{-F_{l,t}^{s}} (1 - e^{-\tilde{F}_{l,t}^{s}}) \tag{A7}$$

where $\tilde{F}_{l,t}^{s}$ is the fishing mortality rate during year t on animals of sex s in length-class l due to the Tanner crab fishery:

$$\tilde{F}_{l,t}^{s} = S_l^{\text{Tanner},s} F_t^{\text{Tanner},s} \tag{A8}$$

where $S_l^{\text{Tanner},s}$ is the selectivity pattern for the discards in the Tanner crab fishery by sex, and, $F_t^{\text{Tanner},s}$ the fully-selected fishing mortality during year t on animals of sex s during year t due to this fishery.

For scenario 2, discarded female bycatch in numbers is separated into immature and mature bycatches. The female bycatches in the directed and trawl fisheries in length-class l and during year $t, D_{l,t}^{i}$ and $D_{l,t}^{m}$, and $T_{l,t}^{i}$ and $T_{l,t}^{m}$, are:

$$\begin{aligned} D_{l,t}^{i} &= N_{l,t}^{i}\, e^{-y_t M_t^{fem}} (1 - e^{-F_{l,t}^{fem}}) \\ D_{l,t}^{m} &= N_{l,t}^{m}\, e^{-y_t M_t^{fem}} (1 - e^{-F_{l,t}^{fem}}) \end{aligned} \tag{A9}$$

The bycatches (by maturity) in numbers by the Tanner crab fishery in length-class l during year t for scenario 2 are given by:

$$\begin{aligned} T_{l,t}^{i} &= N_{l,t}^{i}\, e^{-j_t M_t^{fem}} e^{-F_{l,t}^{fem}} (1 - e^{-\tilde{F}_{l,t}^{fem}}) \\ T_{l,t}^{m} &= N_{l,t}^{m}\, e^{-j_t M_t^{fem}} e^{-F_{l,t}^{fem}} (1 - e^{-\tilde{F}_{l,t}^{fem}}) \end{aligned} \tag{A10}$$

Retained selectivity, $S^{\text{dir,land}}$, selectivity for females in the directed fishery, $S^{\text{dir,disc,fem}}$, selectivity for males and females in the groundfish trawl trawl, S^{trawl} , and selectivity for males and females in the Tanner crab fishery, $S^{\text{Tanner},s}$, are all assumed to be logistic functions of length:

$$S_l^{type} = \frac{1}{1+e^{-\beta^{type}\ (\iota - L_{50}^{type})}} \tag{A11}$$

Different sets of parameters (β, L_{50}) are estimated for retained males, female pot bycatch, male and female trawl bycatch, and discarded males and females from the Tanner crab fishery.

Male pot bycatch selectivity in the directed fishery is modeled by two linear functions:

$$\begin{aligned} s_l &= \varphi + \kappa\,\iota, \quad if\ \iota < 135\,\text{mm CL}, \\ s_l &= s_{l-1} + 5\gamma, \quad if\ \iota > 134\,\text{mm CL} \end{aligned} \tag{A12}$$

where φ, κ, γ are parameters.

iii. Trawl Survey Selectivities

Trawl survey selectivities are estimated as

$$S_{l,t}^{s} = \frac{Q}{1+e^{-\beta_t^{s}\ (\iota - L_{50,t}^{s})}} \tag{A13}$$

with different sets of parameters (β, L_{50}) estimated for males and females as well as two different periods (1975-81 and 1982-15). Survey selectivity for the first length group (67.5 mm) was assumed to be the same for both males and females, so only three parameters (β, L_{50} for females and L_{50} for males) were estimated in the model for each of the four periods. Parameter Q was called the survey catchability that was estimated based on a trawl experiment by Weinberg et al. (2004; Figure A1). Q was assumed to be constant over time.

Assuming that the BSFRF survey caught all crab within the area-swept, the ratio between NMFS abundance and BSFRF abundance is a capture probability for the NMFS survey net. The Delta method was used to estimate the variance for the capture probability. A maximum likelihood method was used to estimate parameters for a logistic function as an estimated capture probability curve (Figure A1). For a given size, the estimated capture probability is smaller based on the BSFRF survey than from the trawl experiment, but the Q value is similar between the trawl experiment and the BSFRF surveys (Figure A1). Because many small-sized crab are likely in the shallow water areas that are not accessible for the trawl survey, NMFS trawl survey selectivity consists of capture probability and crab availability.

b. Software Used: AD Model Builder (Fournier et al. 2012).

c. Likelihood Components

A maximum likelihood approach was used to estimate parameters. For length compositions ($p_{l,t,s,sh}$), the likelihood functions are :

$$Rf = \prod_{l=1}^{L}\prod_{t=1}^{T}\prod_{s=1}^{2}\prod_{sh=1}^{2}\frac{\left\{\exp\left[-\frac{(p_{l,t,s,sh}-\hat{p}_{l,t,s,sh})^2}{2\sigma^2}\right]+0.01\right\}}{\sqrt{2\pi\sigma^2}} \qquad \text{(A14)}$$

$$\sigma^2 = \left[\hat{p}_{l,t,s,sh}(1-\hat{p}_{l,t,s,sh})+0.1/L\right]/n$$

where L is the number of length groups, T the number of years, and n the effective sample size, which was estimated for trawl survey and pot retained catch and bycatch length composition data from the directed pot fishery, and was assumed to be 50 for groundfish trawl and Tanner crab fisheries bycatch length composition data.

The weighted negative log likelihood functions are:

$$\begin{aligned}
&\textit{Length compositions}: \quad -\sum \ln(Rf_i)\\
&\textit{Biomasses other than survey}: \quad \lambda_j \sum \left[\ln(C_t/\hat{C}_t)^2\right]\\
&\textit{NMFS survey biomass}: \quad \sum \left[\ln(B_t/\hat{B}_t)^2/(2\ln(CV_t^2+1))\right]\\
&\textit{BSFRF mature males}: \quad \sum [\ln(\ln(CV_t^2+1))^{0.5}+\ln(B_t/\hat{B}_t)^2/(2\ln(CV_t^2+1))]\\
&\textit{R variation}: \quad \lambda_R \sum [\ln(R_t/\overline{R})^2]\\
&\textit{R sex ratio}: \quad \lambda_s [\ln(\overline{R}_M/\overline{R}_F)^2]\\
&\textit{Trawl bycatch fishing mortalities}: \lambda_t [\ln(F_{t,t}/\overline{F}_t)^2]\\
&\textit{Pot female bycatch fishing mortalities}: \lambda_p [\ln(F_{t,f}/\overline{F}_f)^2]\\
&\textit{Trawl survey catchability}: (Q-\hat{Q})^2/(2\sigma^2)
\end{aligned} \qquad \text{(A15)}$$

where R_t is the recruitment in year t, $\overline{R}$ the mean recruitment, $\overline{R}_M$ the mean male recruitment, $\overline{R}_F$ the mean female recruitment, $\overline{F}_t$ the mean trawl bycatch fishing mortality, $\overline{F}_f$ the mean pot female bycatch fishing mortality, Q summer trawl survey catchability, and σ the estimated standard deviation of Q (all scenarios) or each of six growth increment parameters for scenario 2.

For BSFRF total survey biomass, *CV* is the survey *CV* plus *AV*, where *AV* is additional *CV* and estimated in the model.

Weights λ_j are assumed to be 500 for retained catch biomass, and 100 for all bycatch biomasses, 2 for recruitment variation, 10 for recruitment sex ratio, 0.2 for pot female bycatch fishing mortality, and 0.1 for trawl bycatch fishing mortality. These λ_j values represent prior assumptions about the accuracy of the observed catch biomass data.

d. Population State in Year 1.

The total abundance and proportions for the first year are estimated in the model.

e. Parameter estimation framework:

i. Parameters estimated independently

Basic natural mortality, length-weight relationships, and mean growth increments per molt were estimated independently outside of the model. Mean length of recruits to the model depends on growth and was assumed to be 72.5 for both males and females. High grading parameters h_t were estimated to be 0.2785 in 2005, 0.0440 in 2006, 0.0197 in 2007, 0.0198 in 2008, 0.0337 in 2009, 0.0153 in 2010, 0.0113 in 2011, 0.0240 in 2012, 0.0632 in 2013, 0.1605 in 2014, and 0.07 in 2015, based on the proportions of discarded legal males to total caught legal males. Handling mortality rates were set to 0.2 for the directed pot fishery, 0.25 for the Tanner crab fishery, and 0.8 for the trawl fisheries.

(1). Natural Mortality

Based on an assumed maximum age of 25 years and the 1% rule (Zheng 2005), basic M was estimated to be 0.18 for both males and females. Natural mortality in a given year, M_t, equals to $M + Mm_t$ (for males) or $M + Mf_t$ (females). One value of Mm_t during 1980-1985 was estimated and two values of Mf_t during 1980-1984 and 1976-79, 1985-93 were estimated in the model for scenarios 1, 1n and 2.

(2). Length-weight Relationship

Length-weight relationships for males and females were as follows:

Immature Females: $W = 0.000408\, L^{3.127956}$

Ovigerous Females: $W = 0.003593\, L^{2.666076}$ (A16)

Males: $W = 0.0004031\, L^{3.141334}$

where W is weight in grams, and L CL in mm.

(3). Growth Increment per Molt

A variety of data are available to estimate male mean growth increment per molt for Bristol Bay RKC. Tagging studies were conducted during the 1950s, 1960s and 1990s, and mean growth increment per molt data from these tagging studies in the 1950s and 1960s were analyzed by Weber and Miyahara (1962) and Balsiger (1974). Modal analyses were conducted for the data during 1957-1961 and the 1990s (Weber 1967; Loher et al. 2001). Mean growth increment per molt may be a function of body size and shell condition and vary over time (Balsiger 1974; McCaughran and Powell 1977); however, for simplicity, mean growth increment per molt was assumed to be only a function of body size in the models. Tagging data were used to estimate mean growth increment per molt as a function of pre-molt length for males (Figure A2). The results from modal analyses of 1957-1961 and the 1990s were used to estimate mean growth increment per molt for immature females during 1975-1993 and 1994-2016, respectively, and the data presented in Gray (1963) were used to estimate those for mature females for scenarios 1, 1n and 2 (Figure A2). To make a smooth transition of growth increment per molt from immature to mature females, weighted growth increment averages of 70% and 30% at 92.5 mm CL pre-molt length and 90% and 10% at 97.5 mm CL were used, respectively, for mature and immature females during 1983-1993. These percentages are roughly close to the composition of maturity. During 1975-1982, females matured at a smaller size, so the growth increment per molt as a function of length was shifted to smaller increments. Likewise, during 1994-2016, females matured at a slightly higher size, so the growth increment per molt was shifted to high increments for immature crab (Figure A2). Once mature, the growth increment per molt for male crab decreases slightly and annual molting probability decreases, whereas the growth increment for female crab decreases dramatically but annual molting probability remains constant at 1.0 (Powell 1967).

(4). Sizes at Maturity for Females

The NMFS collected female reproductive condition data during the summer trawl surveys. Mature females are separated from immature females by a presence of egg clutches or egg cases. Proportions of mature females at 5-mm length intervals were summarized and a logistic curve was fitted to the data each year to estimate sizes at 50% maturity. Sizes at 50% maturity are illustrated in Figure A3 with mean values for three different periods (1975-82, 1983-93, and 1994-2015).

(5). Sizes at Maturity for Males

Although size at sexual maturity for Bristol Bay red king crab males has been estimated (Paul et al. 1991), there are no data for estimating size of functional maturity collected in the natural environment. Sizes at functional maturity for Bristol Bay male RKC have been assumed to be 120 mm CL (Schmidt and Pengilly 1990). This is based on mating pair data collected off Kodiak Island (Figure A4). Sizes at maturity for Bristol Bay female RKC are about 90 mm CL, about 15 mm CL less than Kodiak female RKC (Pengilly et al. 2002). The size ratio of mature males to females is 1.3333 at sizes at maturity for Bristol Bay RKC, and since mature males grow at much larger increments than mature females, the mean size ratio of mature males to females is most likely larger than this ratio. Size ratios of the large majority of Kodiak mating pairs were less than 1.3333, and in some bays, only a small proportion of mating pairs had size ratios above 1.3333 (Figure A4).

In the laboratory, male RKC as small as 80 mm CL from Kodiak and Southeast Alaska can successfully mate with females (Paul and Paul 1990). But few males less than 100 mm CL were observed to mate with females in the wild. Based on the size ratios of males to females in the Kodiak mating pair data, setting 120 mm CL as a minimum size of functional maturity for Bristol Bay male RKC is proper in terms of managing the fishery.

(6). Potential Reasons for High Mortality during the Early 1980s

Bristol Bay red king crab abundance had declined sharply during the early 1980s. Many factors have been speculated for this decline: (i) completely wiped out by fishing: the directed pot fishery, the other directed pot fishery (Tanner crab fishery), and bottom trawling; and (ii) high fishing and natural mortality. With the survey abundance, harvest rates in 1980 and 1981 were among the highest, thus the directed fishing definitely had a big impact on the stock decline, especially legal and mature males. However, for the sharp decline during 1980-1884 for males, 3 out of 5 years had low mature harvest rates. During the 1981-1984 decline for females, 3 out of 4 years had low mature harvest rates. Also pot catchability for females and immature males are generally much lower than for legal males, so the directed pot fishing alone cannot explain the sharp decline for all segments of the stock during the early 1980s.

Red king crab bycatch in the eastern Bering Sea Tanner crab fishery is another potential factor (Griffin et al. 1983). The main overlap between Tanner crab and Bristol Bay red king crab is east of 163^{o} W. No absolute red king crab bycatch estimates are available until 1991. So there are insufficient data to fully evaluate the impact. Retained catch and potlifts from the eastern Bering Sea Tanner crab fishery are illustrated in Figure A5. The observed red king crab bycatch in the Tanner crab fishery during 1991-1993 and total potlifts east of 163^{o} W during 1968 to 2005 were used to estimate the bycatch mortality in the current model. Because winter sea surface temperatures and air temperatures were warmer (which means a lower handling mortality rate) and there were fewer potlifts during the early 1980s than during the early 1990s, bycatch in the Tanner crab fishery is unlikely to have been a main factor for the sharp decline of Bristol Bay red king crab.

Several factors may have caused increases in natural mortality. Crab diseases in the early 1980s were documented by Sparks and Morado (1985), but inadequate data were collected to examine their effects on the stock. Stevens (1990) speculated that senescence may be a factor because many crab in the early 1980s were very old due to low temperatures in the 1960s and early 1970s. The biomass of the main crab predator, Pacific cod, increased about 10 times during the late 1970s and early 1980s. Yellowfin sole biomass also increased substantially during this period. Predation is primarily on juvenile and molting/softshell crab. But we lack stomach samples in shallow waters (juvenile habitat) and during the period when red king crab molt. Also cannibalism occurs during molting periods for red king crab. High crab abundance in the late 1970s and early 1980s may have increased the occurrence of cannibalism.

Overall, the likely causes for the sharp decline in the early 1980s are combinations of the above factors, such as pot fisheries on legal males, bycatch, and predation on females and juvenile and sublegal males, senescence for older crab, and disease for all crab. In our model, we estimated one mortality parameter for males and another for females during 1980-1984. We also estimated a mortality parameter for females during 1976-1979 and 1985-1993. These three mortality parameters are additional to the basic natural mortality of 0.18yr^{-1}, all directed fishing mortality, and non-directed fishing mortality. These three mortality parameters could be attributed to natural mortality as well as undocumented non-directed fishing mortality. The model fit the data much better with these three parameters than without them.

ii. Parameters estimated conditionally

The following model parameters were estimated for male and female crab: total recruits for each year (year class strength R_t for t = 1976 to 2016), total abundance in the first year (1975), growth parameter β, and recruitment parameter β_r for males and females separately. Molting probability parameters β and L_{50} were also estimated for male crab. Estimated parameters also include β and L_{50} for retained selectivity, β and L_{50} for pot-discarded female selectivity, β and L_{50} for pot-discarded male and female selectivities from the eastern Bering Sea Tanner crab fishery, β and L_{50} for groundfish trawl discarded selectivity, φ, κ and γ for pot-discarded male selectivity, and β for trawl survey selectivity and L_{50} for trawl survey male and females separately. The NMFS survey catchabilities Q for some scenarios were also estimated. Three selectivity parameters were estimated for the survey data from the Bering Fisheries Research Foundation. Annual fishing mortalities were also estimated for the directed pot fishery for males (1975-2015), pot-discarded females from the directed fishery (1990-2015), pot-discarded males and females from the eastern Bering Sea Tanner crab fishery (1991-93, 2013-15), and groundfish trawl discarded males and females (1976-2015). Three additional mortality parameters for Mm_t and Mf_t were also estimated. Some estimated parameters were constrained in the model. For example, male and female recruitment estimates were forced to be close to each other for a given year.

f. Definition of model outputs.

i. Biomass: two population biomass measurements are used in this report: total survey biomass (crab >64 mm CL) and mature male biomass (males >119 mm CL). Mating time is assumed to Feb. 15.

ii. Recruitment: new entry of number of males in the 1st seven length classes (65- 99 mm CL) and new entry of number of females in the 1st five length classes (65-89 mm CL).

iii. Fishing mortality: full-selected instantaneous annual fishing mortality rate at the time of fishery.

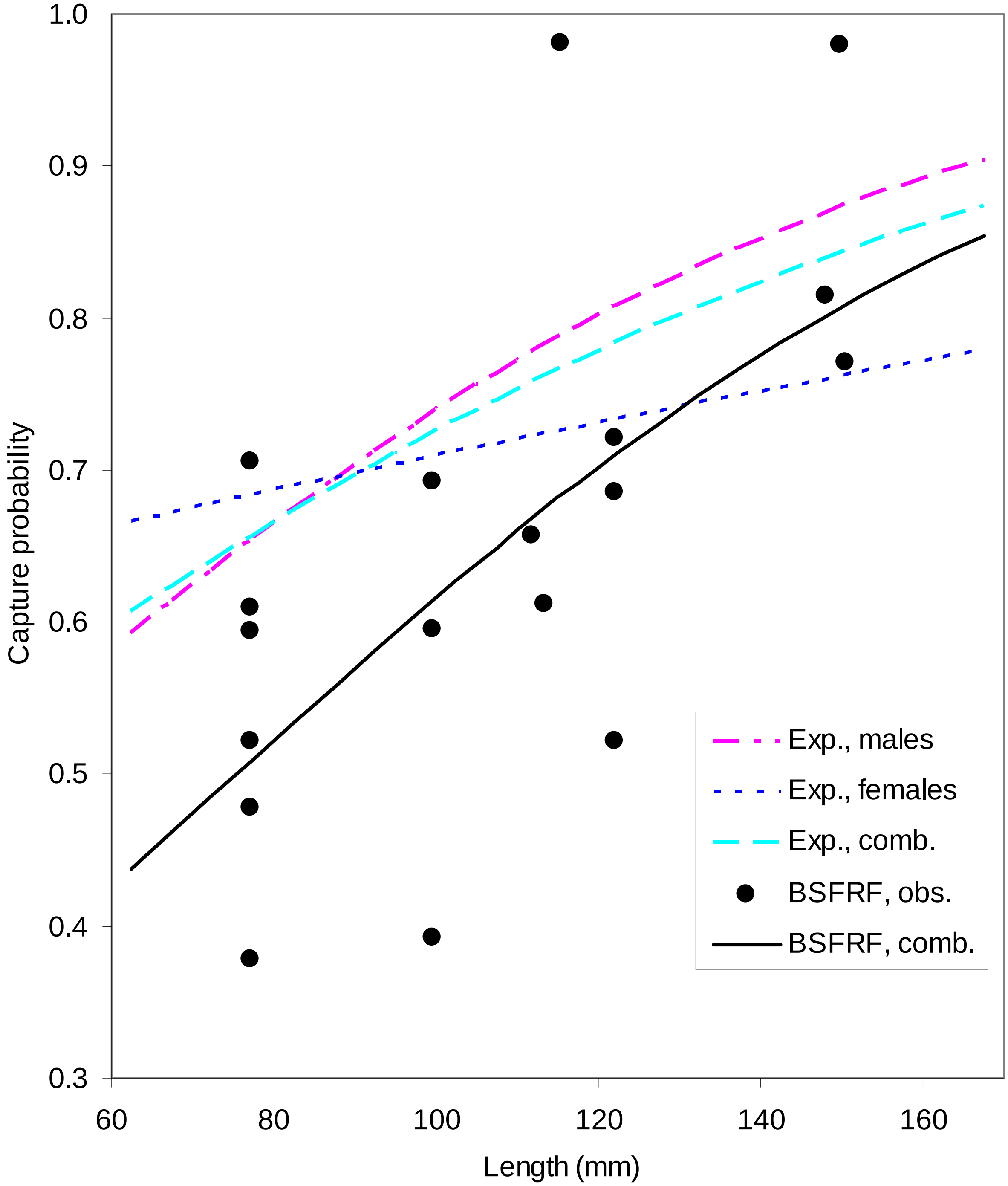
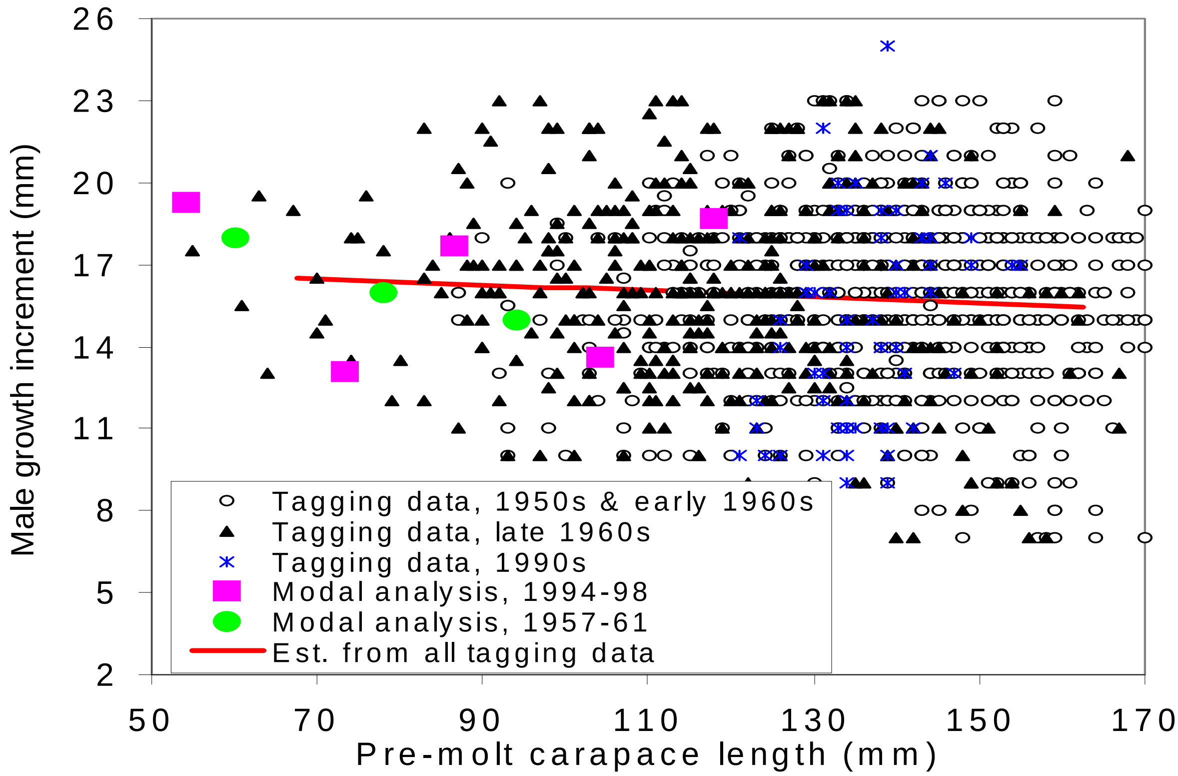


Figure A1. Estimated capture probabilities for NMFS Bristol Bay red king crab trawl surveys by Weinberg et al. (2004) and the Bering Sea Fisheries Research Foundation surveys.



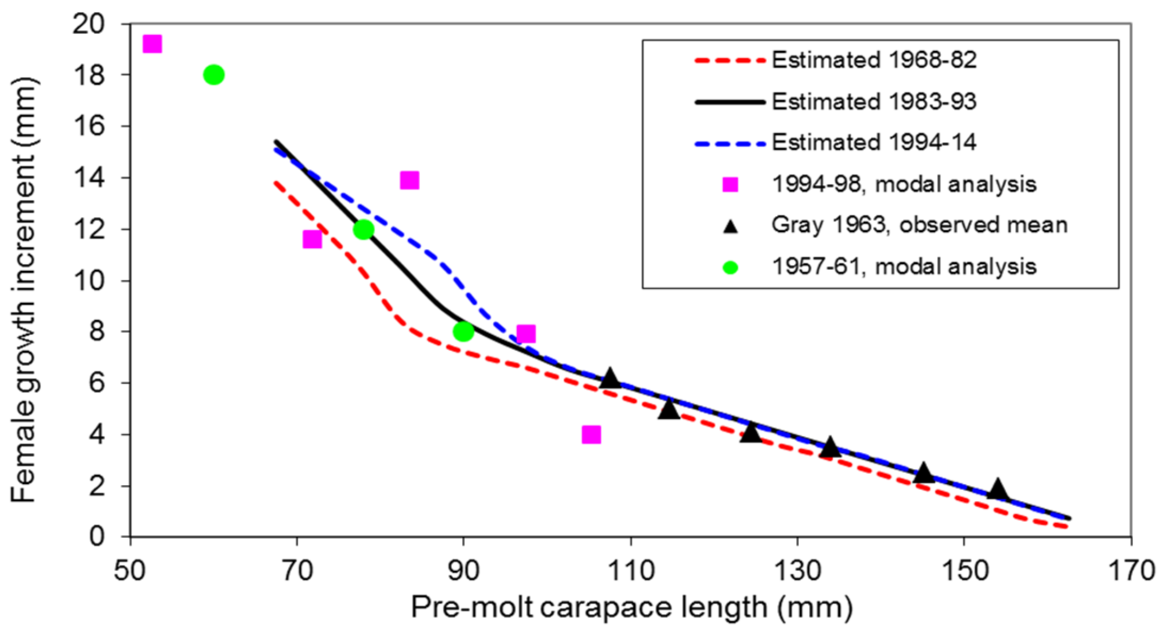


Figure A2. Mean growth increments per molt for Bristol Bay red king crab. Note: "tagging"---based on tagging data; "mode"---based on modal analysis. The female growth increments per molt are for scenarios 1, 1n and 2.

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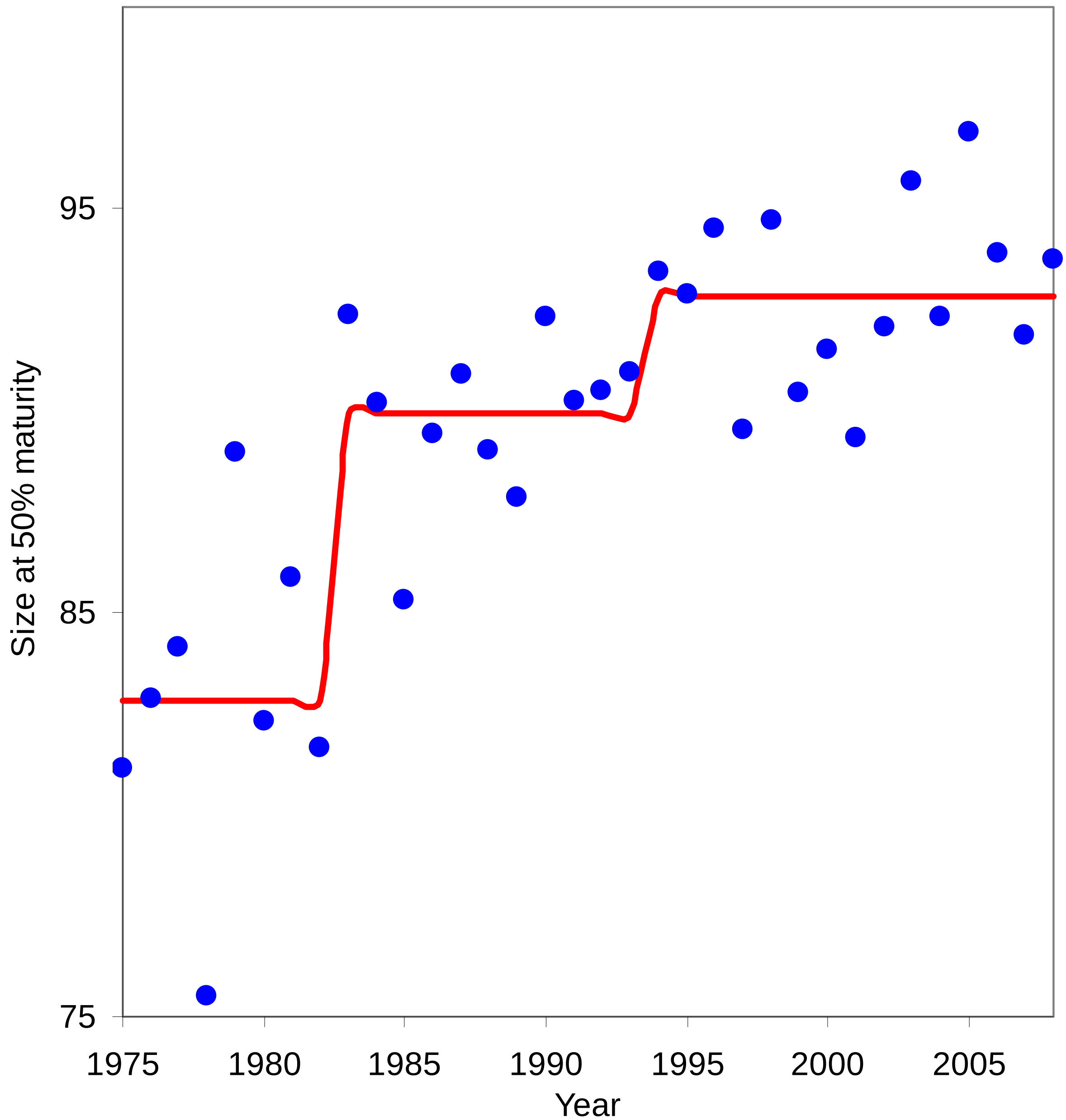

Figure A3. Estimated sizes at 50% maturity for Bristol Bay female red king crab from 1975 to 2008. Averages for three periods (1975-82, 1983-93, and 1994-08) are plotted with a line.

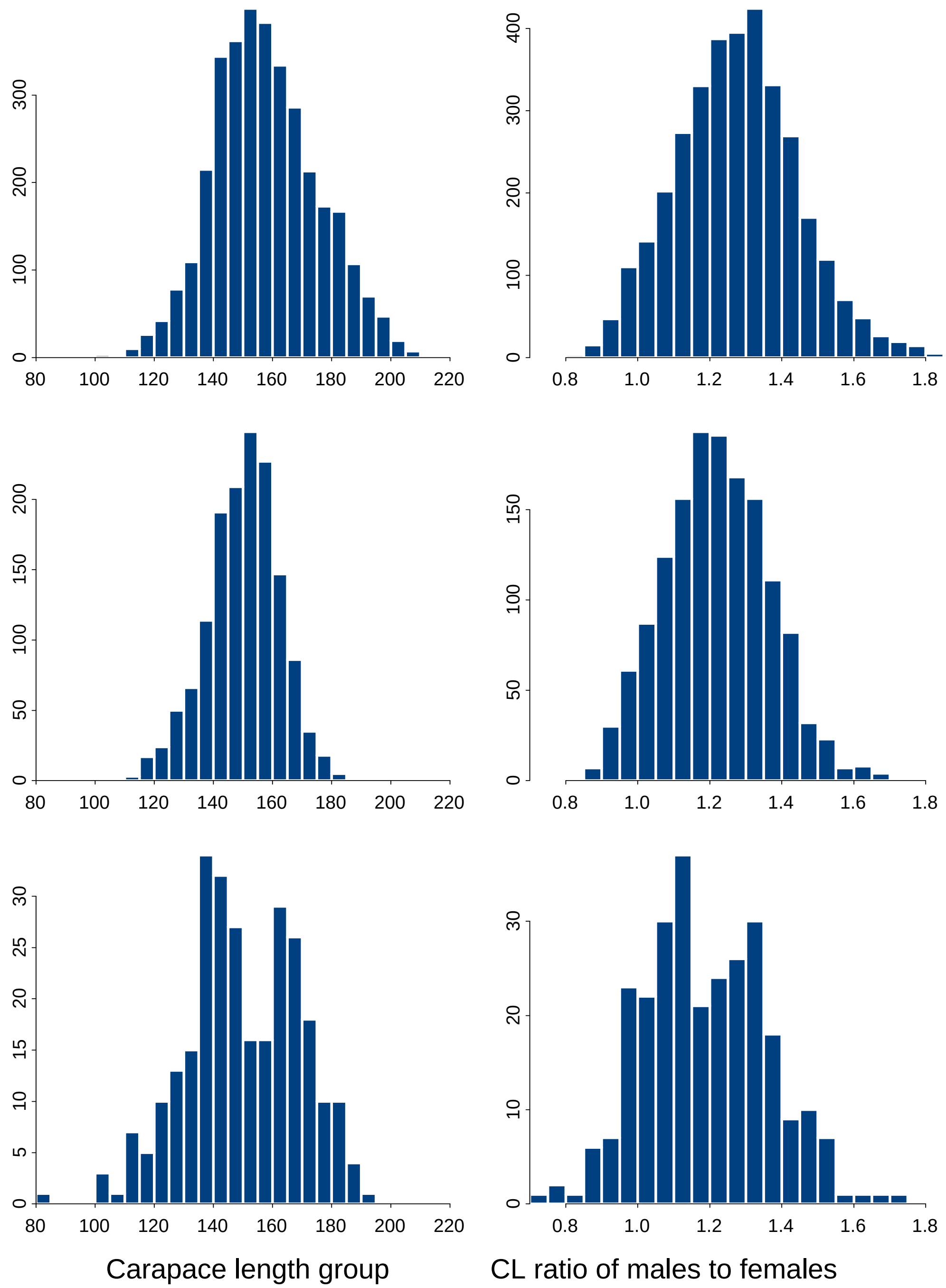

Figure A4. Histograms of carapace lengths (CL) and CL ratios of males to females for male shell ages ≤13 months of red king crab males in grasping pairs; Powell's Kodiak data. Upper plot: all locations and years pooled; middle plot: location 11; lower plot: locations 4 and 13. Sizes at maturity for Kodiak red king crab are about 15 mm larger than those for Bristol Bay red king crab. (Doug Pengilly, ADF&G, pers. comm.).

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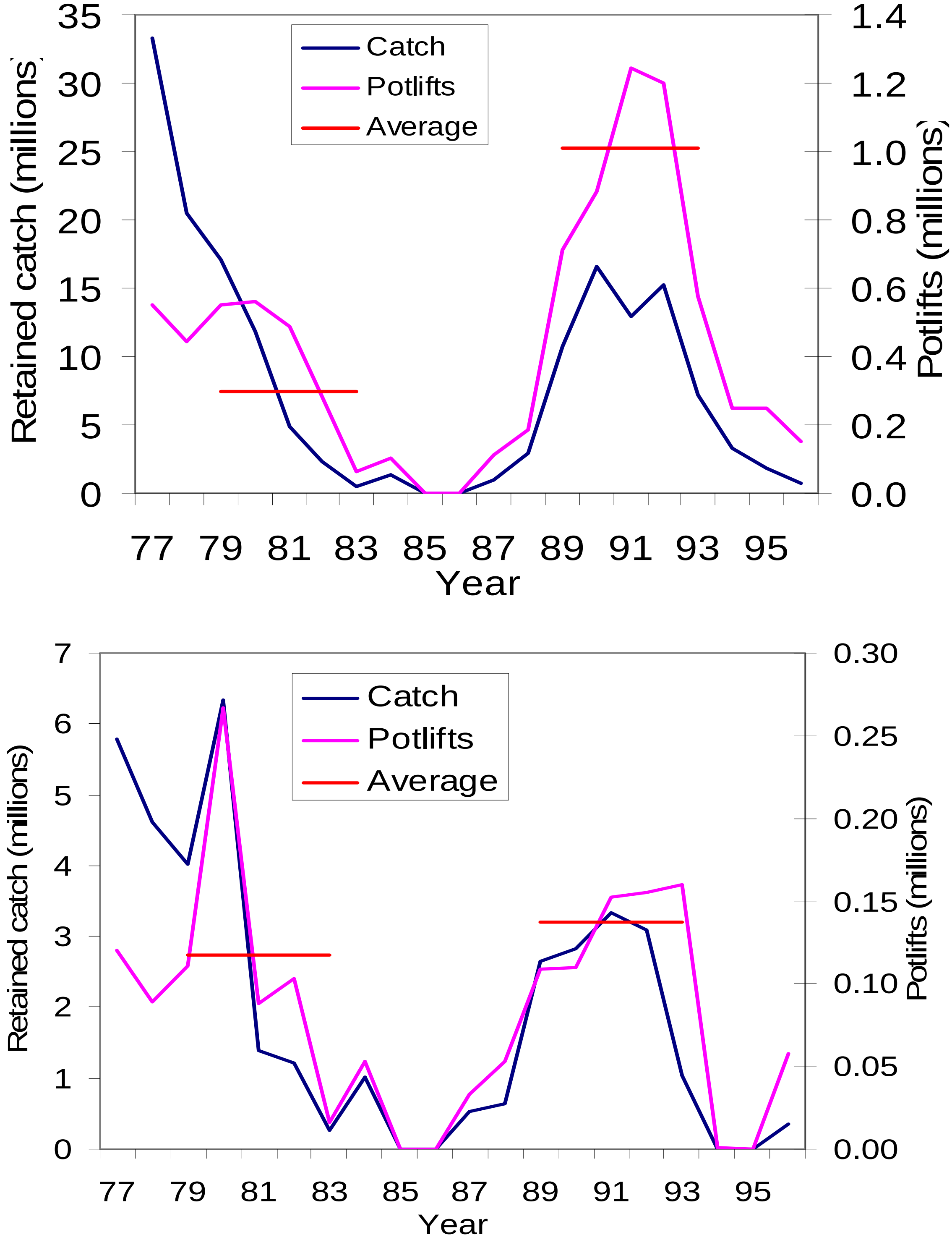

Figure A5. Retained catch and potlifts for total eastern Bering Sea Tanner crab fishery (upper plot) and the Tanner crab fishery east of 163° W (bottom).

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A stock assessment for eastern Bering Sea snow crab

Cody Szuwalski and Jack Turnock

Sept 21, 2016

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Executive summary

1. Stock: Eastern Bering Sea snow crab, *Chionoecetes opilio.*
2. Catches: trends and current levels

Retained catches increased from relatively low levels in the early 1980s (e.g. retained catch of 13.32 kt during 1981) to historical highs in the early and mid-nineties (retained catch during 1991, 1992, and 1998 were 143.02, 104.68, and 88.09 kt, respectively). The stock was declared overfished in 1999 at which time retained catches dropped to levels similar to the early 1980s (e.g. retained catch during 2000 was 11.46 kt). Retained catches have slowly increased since 1999 as the stock rebuilt, although retained catch during 2015 was low (18.42 kt).

Discard mortality is the next largest source of mortality after retained catch and approximately tracks the retained catch. The highest estimated discard mortality occurred during 1993 at 17.06 kt which was 16% of the retained catch. The most recent estimated mortality was 3.52 kt which was 11% of the retained catch.

3. Stock Biomass:

Observed mature male biomass (MMB) at the time of the survey has increased from an average of 160.81 kt in the early to mid-1980s to historical highs in the early and mid-nineties (observed MMB during 1990, 1991, and 1997 were 443.79, 466.61, and 326.75 kt, respectively). The stock was declared overfished in 1999 in response to the total mature biomass dropping below the minimum stock size threshold. MMB in that year decreased to 95.85 kt. Observed MMB slowly increased after 1999, and the stock was declared rebuilt in 2011 when estimated MMB at mating was above $B_{35\%}$. However, since 2011, the stock has declined again and the observed MMB at the time of survey dropped to an all time low in 2016 of 63.21 kt during 2016.

4. Recruitment

Estimated recruitment shifts from a period of high recruitment to a period of low recruitment in the mid 1990s (late 1980s when lagged to fertilization). Recent estimated recruitments have been above the average of the 'low' period , but are still beneath the average of the 'high' recruitment period. Recent survey length frequency data reflect what may be the largest recruitment event seen since the early 1990s, but data informing the estimates of numbers in the smaller size classes are still uncertain.

5. Management

Table 1: Historical status and catch specifications for snow crab (1,000t).

Year	MSST	Biomass (MMB)	TAC	Retained catch	Total catch	OFL	ABC
2011/2012	77.3	165.2	40.3	40.5	42	73.5	66.2
2012/2013	77.1	170.1	30.1	30.1	32.4	67.8	61
2013/2014	71.5	126.5	24.5	24.5	27.7	78.1	69.3
2014/2015	73.2	129.3	30.8	30.8	34.3	69	62.1
2015/2016	73.2	123.5	18.4	18.4	21.4	61.5	55.4
2016/2017	75.8	91.6				23.7	21.3

Table 2: Historical status and catch specifications for snow crab (millions of lbs).

Year	MSST	Biomass (MMB)	TAC	Retained catch	Total catch	OFL	ABC
2011/2012	170.4	364.2	88.85	89.29	92.59	162	145.9
2012/2013	170	375	66.36	66.36	71.43	149.5	134.5
2013/2014	157.6	278.9	54.01	54.01	61.07	172.2	152.8
2014/2015	161.4	285.1	67.9	67.9	75.62	152.1	136.9
2015/2016	161.4	272.3	40.57	40.57	47.18	135.6	122.1
2016/2017	167.1	201.9				52.25	46.96

6. Basis for the OFL

The OFL for 2016 from the chosen model was 23.71 kt fishing at $F_{OFL} = 1.14$ (59 % of the calculated $F_{35\%}$, 1.91). The calculated OFL was a -61% change from the 2015 OFL of 61.5 kt. The projected ratio of MMB at the time of mating to $B_{35\%}$ is 0.6.

7. Probability Density Function of the OFL

The probabillity density function of the OFL was characterized by using a Markov Chain Monte Carlo algorithm to sample from the a posterior distribution of the OFL. This allows all uncertainty in the data to which the model was fitted to be propagated forward into the OFL calculation.

8. Basis for ABC

The ABC calculated for the chosen model for 2016/2017 was specified as 21.34 kt by subtracting a 10% buffer from the OFL as recommended by the SSC. The alternate 'P_{star}' approach of calculating the 49th quantile of the distribution of the OFL produced an ABC of 23.69 kt.

A. Summary of Major Changes

1. Management: None

2. Input data:

Data added to the assessment included: 2016 Bering Sea survey biomass and length frequency data, 2015 directed fishery retained and discard catch and length frequencies for retained and discard catch, and groundfish discard length frequency and discard from 2015. Five additional data points for growth increment were included and weight at length parameters for both sexes were revised, with the largest impact being on female biomass.

3. Assessment methodology:

Six models are presented in this assessment with several incremental steps, each of which are illustrated. Model 0 represents the 2015 model with minor structural changes suggested by the CPT implemented and serves as a basis for comparison to the previous year's assessment. Model 1 addresses the way in which fishing mortality in the trawl fleet is estimated. Model 2 removes the priors on maturity. Model 3 changes the way maturity and female discards are estimated. Scenarios in which the weighting of survey size composition (Model 3a) and female growth data and natural mortality priors (Model 3b) are varied are also presented.

The OFL was calculated using Bayesian methodologies, which is different than the previous projection framework. Management quantities are identified as the medians of posterior distributions resulting from application of a Markov Chain Monte Carlo algorithm. This is preferable to the previous projection framework because it explicitly incorporates uncertainty in all parameters, rather than only numbers at length.

4. Assessment results

Based on last year's assessment results, MMB was 84% of $B_{35\%}$. The projected MMB (February 15, 2017) will be 60% of $B_{35\%}$. Estimated MMB on February 15, 2016 from this assessment was 91.57 kt, which placed the stock at 60 % of $B_{35\%}$. Fits to all data sources were relatively good for the chosen model and estimated population processes were credible.

B. CPT May 2016 comments, SSC comments, and author response:

CPT and SSC comments

CPT comments are divided into two categories below. There were no comments from the SSC that required changes to the analyses.

Changes to model structure and presentation of results

- Show fits to the pot CPUE data
- Provide a retrospective analysis
- Implement Francis weighting method and report weights
- Provide plots of the observed and model-predicted mean lengths
- Ensure catchability for all surveys is bounded at one
- Document the jittering approach

Model scenarios to explored

- Model 0:
  - Only small structural changes from above were implemented to provide a comparison to last year's model (described below)
- Model 1:
  - All changes in model 0
  - Estimate average F for the groundfish trawl, rather than specifying it
  - Remove penalties on F from 1992 to present
  - Estimate a separate vector of F_devs for 1978-90 and 1991-present
  - Estimate a constant of proportionality between fishing effort in the pot fishery and F for the females in the pot fishery
- Model 2:
  - All changes in model 1
  - Remove priors on probabillity of maturing for males and females
- Model 3:
  - Increase the weight on the smoothness penalty for the probability of maturity
  - Estimate the 50% selectivity parameter for female discard
- Model 3a:
  - All changes in model 3
  - Decrease the effective sample sizes for survey size composition data by applying Francis' weighting methodology
- Model 3b:
  - All changes in model 3
  - Increase weighting on female growth likelihood
  - Decrease the variance for the prior on natural mortality

Several other small changes were made to the code, beginning with model 0, including: rearranging the code to improve readability and functionality (e.g. deleting legacy code and adding space in arrays to allow for calculation of reference points, alllowing the weight at length parameters to be input, rather than included in the .DAT file as a prespecified vector), migrating constants to control file, correcting the conversion for tonnes to million pounds (i.e. changing the conversion factor from 2200 to 2204.6), and adding a recruitment deviation for the end year.

All changes were undertaken in a stepwise fashion and the resulting changes in the estimated MMB and management quantities were recorded (Table 4). Only scenarios for which large changes in estimated parameters and MMB resulted from a given change in the model are presented in the figures and text. Model 3b is the author preferred model based on the its fit to the data and fewer assumptions placed on the data. Model 3b was added to the CPT recommended scenarios of models 1-3a because all of the changes made through 3b were rational and improved fits to the data in most instances, but fit the female growth data poorly and pinned the estimate of the prior for natural mortality on immature crab to its bound. Making these two modifications decreased the severity of these problems.

Authors response

Nearly all requests by the CPT were fulfilled and described below. Model scenarios include all CPT recommended models, save one. Estimating a constant of proportionality between fishing effort in the pot fishery and fishing mortality in the trawl fishery was not performed because this is a stepbackwards from estimating a vector of deviations. 'Jittering' was not performed because the management advice produced from this assessment is Bayesian in nature–i.e. the estimated management quantities (e.g. MMB, $B_{35\%}$, OFL) are the medians of posterior distributions of these quantities. Consequently, 'jittering' would not influence the outcome of this assessment. Finally, although functions to calculate Francis weights were included in the assessment, the presented scenarios (except two included for illustrative purposes) use the previous weightings of 200 on the survey size composition data. The illustrative example also only specified weights at 20% of their previous values (i.e. 40) because the Francis weighting algorithm lowered the weights to a point at which a positive-definite Hessian was not produced. Given the need for an invertible Hessian to perform MCMC, using weights at only 20% of the previously used values was a necessary compromise and served to illustrate some of the problems with downweighting the survey size composition data (discussed below).

C. Introduction

Distribution

Snow crab (*Chionoecetes opilio*) are distributed on the continental shelf of the Bering Sea, Chukchi Sea, and in the western Atlantic Ocean as far south as Maine. In the Bering Sea, snow crab are distributed widely over the shelf and are common at depths less than about 200 meters (Figure 1 & Figure 2). Smaller crabs tend to occupy more inshore northern regions (Figure 3) and mature crabs deeper areas to the south of the juveniles (Figure 4 & Figure 5; Zheng et al. 2001). The eastern Bering Sea population within U.S. waters is managed as a single stock; however, the distribution of the population may extend into Russian waters to an unknown degree.

Life history characteristics

Studies relevant to key population and fishery processes are discussed below to provide background for the model description in appendix A.

Natural Mortality

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

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

The mean for the prior for natural mortality used in this assessment is based on the assumption (informed by the studies above) that longevity would be at least 20 years in a virgin population of snow crab. Under negative exponential depletion, the 99th percentile corresponding to age 20 of an unexploited population corresponds to a natural mortality rate of 0.23. Using Hoenig's (1983) method a natural mortality equal to 0.23 corresponds to a maximum age of 18 years. Consequently, natural mortality for mature females was set to 0.23 yr^{-1}. Mature male natural mortality was estimated in the model with a prior constraint of mean of 0.23 yr^{-1} with a standard error equal to 0.054 (estimated from using the 95% CI of +-1.7 years on maximum age estimates from dactal wear and tag return analysis in Fonseca, et al. (2008)). Natural mortality for immature males and females was estimated in the model with a mean of 0.23 yr^{-1} and a standard error of 1.

Weight at length

Weight at length is calculated by a power function, the parameters for which were recalculated by the Kodiak lab in August 2016 and resulted in very small changes in weight at length for males, but rather large changes for females (Figure 6). New weight at length parameters were applied to all years of data, rather than just the most recent observations. To provide context for the change, a juvenile female crab of carapace width 52.5 mm was previously estimated to weigh 65 g and now 48 g; a mature female crab of carapce width 57.5 mm was estimated to previously weigh 102 g and now 67.7 g; and a male of carapace width 92.5 mm was previously estimated to weigh 450 g and now weighs 451 g.

Maturity

Maturity of females collected during the NMFS summer survey was determined by the shape of the abdomen, by the presence of brooded eggs, or egg remnants. Morphometric maturity for males was determined by chela height measurements, which were available starting from the 1989 survey (Otto 1998). Mature male biomass referenced throughout this document refers to a morphometrically mature male. A maturity curve for males was estimated using the average fraction mature based on chela height data and applied to all years of survey data to estimate mature survey numbers. The separation of mature and immature males by chela height may not be adequately refined given the current measurement to the nearest millimeter. Chela height measured to the nearest tenth of a millimeter (by Canadian researchers on North Atlantic snow crab) shows a clear break in chela height at small and large widths and shows fewer mature animals at small widths than the Bering Sea data measured to the nearest millimeter. Measurements taken in 2004-2005 on Bering Sea snow crab chela to the nearest tenth of a millimeter show a similar break in chela height to the Canadian data (Rugolo et al. 2005). The probabillity of maturing (which is different from the fraction mature at length) is estimated within the model for both sexes as a freely estimated (but smoothed) function of length.

Molting probability

Bering Sea male snow crab appear to have a terminal molt to maturity based on hormone level data and findings from molt stage analysis via setagenesis (Tamone et al. 2005). The models presented here assume a terminal molt for both males and females, which is supported by research on populations in the Bering Sea and the Atlantic Ocean (e.g., Dawe, et al. 1991).

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

Crabs in their first few years of life may molt more than once per year, however, the smallest crabs included in the model are approximately 3 to 4 years old and would be expected to molt annually. The growth transition matrix was applied to animals that molt, resulting in new shell animals. Crab that do not molt become old shell animals. Further research on the relationship between shell condition and time from last molt is needed.

Mating ratio and reproductive success

Bering Sea snow crab are managed using mature male biomass as a proxy for reproductive potential. MMB is used as the currency for management because the fishery only keeps males. Male snow crab are sperm conservers, using less than 4% of their sperm at each mating and females also will mate with more than one male. The amount of stored sperm and clutch fullness varies with sex ratio (Sainte-Marie 2002). If mating with only one male is inadequate to fertilize a full clutch, then females will need to mate with more than one male, necessitating a sex ratio closer to 1:1 in the mature population, than if one male is assumed to be able to adequately fertilize multiple females. Although mature male biomass is currently the currency of management, female biomass may also be an important indicator of reproductive potential of the stock.

Quantifying the reproductive potential of the female population from survey data can be less than straightforward. For example, full clutches of unfertilized eggs may be extruded and appear normal to visual examination, and may be retained for several weeks or months by snow crab. Resorption of eggs may occur if not all eggs are extruded resulting in less than a full clutch. Female snow crab at the time of the survey may have a full clutch of eggs that are unfertilized, resulting in overestimation of reproductive potential. Barren females are a more obvious indication of low reproductive potential and increased in the early 1990s then decreased in the mid- 1990s then increased again in the late 1990s. The highest levels of barren females coincides with the peaks in catch and exploitation rates that occurred in 1992 and 1993 fishery seasons and the 1998 and 1999 fishery seasons. While the biomass of mature females was high in the early 1990s, it is possible the production may have been impacted by the spatial distribution of the catch and the resulting sex ratio in areas of highest reproductive potential. Biennial spawning is another confounding factor in determining the reproductive potential of snow crab. Laboratory analysis showed that female snow crab collected in waters colder than 1.5 degrees C from the Bering Sea spawn only every two years.

Further complicating the process of quantifying reproductive capacity, clutch fullness and fraction of unmated females may not account for the fraction of females that may have unfertilized eggs, since these cannot be detected by the naked eye at the time of the survey. The fraction of barren females observed in the survey may not be an accurate measure of fertilization success because females may retain unfertilized eggs for months after extrusion. To examine this hypothesis, RACE personnel sampled mature females from the Bering Sea in winter and held them in tanks until their eggs hatched in March of the same year (Rugolo et al. 2005). All females then extruded a new clutch of eggs in the absence of males. All eggs were retained until the crabs were sacrificed near the end of August. Approximately 20% of the females had full clutches of unfertilized eggs. The unfertilized eggs could not be distinguished from fertilized eggs by visual inspection at the time they were sacrificed. Indices of fertilized females based on the visual inspection method of assessing clutch fullness and percent unmated females may overestimate fertilized females and not an accurate index of reproductive success.

Growth

Little information exists on growth for Bering Sea snow crab. Tagging experiments were conducted on snow crab in 1980 with recoveries occurring in the Tanner crab (Chionoecetes bairdi) fishery in 1980 to 1982 (Mcbride 1982). However, data from this study are not used due to uncertainty about the effect of tagging on growth. Currently, 40 data points from 5 studies are used to estimate the post-molt length from pre-molt length for females and males (Table 5). The studies include:

1. Transit study (Rugolo unpublished data, 2003); 14 crab
2. Cooperative seasonality study (Rugolo); 6 crab
3. Dutch harbor holding study; 9 crab
4. NMFS Kodiak holding study held less than 30 days; 6 crab
5. NMFS Kodiak holding study 2016; 5 crab

Data from the NMFS Kodiak holding study 2016 are new for this year's study. In the "Transit study", pre- and post-molt measurements of 14 male crabs that molted soon after being captured were collected. The crabs were measured when shells were still soft because all died after molting, so measurements may be underestimates of postmolt width (Rugolo, pers. com.). The holding studies include only data for crab held less than 30 days because growth of crabs held until the next spring's molting was much lower. Females molting to maturity were excluded from all data sets, since the molt increment is usually smaller. Crab missing more than two limbs were excluded due to other studies showing lower growth. Crab from Rugolo's seasonal study were excluded that were measured less than 3 days after molting due to difficulty in measuring soft crab accurately. In general, growth of snow crab in the Bering Sea appears to be greater than growth of some North Atlantic snow crab stocks (Sainte-Marie 1995).

Management history

ADFG harvest strategy

Before the year 2000, the Guideline Harvest Level (GHL) for retained crab only was a harvest rate 58% of the number of male crab over 101 mm CW estimated from the survey. The minimum legal size limit for snow crab is 78 mm, however, the snow crab market generally accepts animals greater than 101 mm. In 2000, due to the decline in abundance and the declaration of the stock as overfished, the harvest rate for calculation of the GHL was reduced to 20% of male crab over 101 mm. After 2000, a rebuilding strategy was developed based on simulations by Zheng (2002) based on survey biomass estimates. The realized retained catch typically exceeded the GHL historically, resulting in exploitation rates for the retained catch on males >101mm ranging from about 10% to 80%. The estimated exploitation rate for total catch divided by mature male biomass ranged from 6% to 46% for the models considered in this assessment (Figure 7).

The harvest strategy since 2000 sets harvest rate based on estimated mature biomass. The harvest rate scales with the status of the population relative to B_{MSY}, which is calculated as the average total mature biomass at the time of the survey from 1983 to 1997 and MSST was one half B_{MSY}. The harvest rate begins at 0.10 when total mature biomass exceeded 50% MSST (230 million lbs) and increases linearly to 0.225 when biomass is equal to or greater than B_{MSY} (Zheng et al. 2002).

$$u = \begin{cases} Bycatch & if \frac{TMB}{TMB_{MSY}} \leq 0.25 \\ \frac{0.225(\frac{TMB}{TMB_{MSY}} - \alpha)}{1-\alpha} & if 0.25 < \frac{TMB}{TMB_{MSY}} < 1 \\ 0.225 & if TMB > TMB_{MSY} \end{cases} \tag{1}$$

The maximum retained catch is set as the product of the exploitation rate, u, calculated from the above control rule and survey mature male biomass. If the retained catch in numbers is greater than 58% of the estimated number of new shell crabs greater than 101 mm plus 25% of the old shell crab greater than 101 mm, the catch is capped at 58%.

History of BMSY

Prior to adoption of Amendment 24, B_{MSY} was defined as the average total mature biomass (males and females) estimated from the survey for the years 1983 to 1997 (921.6 million lbs; NPFMC 1998) and MSST was defined as 50% of B_{MSY}. Definitions of biological reference points based on the biomass over a range of years make a host of assumptions that may or may not be fulfilled. Currently, the biological reference point for biomass is calculated using a spawning biomass per recruit proxy, $B_{35\%}$ (Clark, 1993). $B_{35\%}$ is the biomass at which spawning biomass per recruit is 35% of virgin levels and has been shown to provide close to maximum sustainable yield for a range of steepnesses (Clark, 1993). Consequently, it is an often used target when a stock recruit relationship is unknown or unreliable.

Fishery history

Snow crab were harvested in the Bering Sea by the Japanese from the 1960s until 1980 when the Magnuson Act prohibited foreign fishing. After the closure to foreign fleets, retained catches increased from relatively low levels in the early 1980s (e.g. retained catch of 13.32 kt during 1981) to historical highs in the early and mid-nineties (retained catch during 1991, 1992, and 1998 were 143.02, 104.68, and 88.09 kt, respectively). The stock was declared overfished in 1999 at which time retained catches dropped to levels similar to the early 1980s (e.g. retained catch during 2000 was 11.46 kt). Retained catches have slowly increased since 1999 as the stock rebuilt, although retained catch during 2015 was low (18.42 kt).

Discard mortality is the next largest source of mortality after retained catch and approximately tracks the retained catch. The highest estimated discard mortality occurred during 1993 at 17.06 kt which was 16% of the retained catch. The most recent estimated mortality was 3.52 kt which was 11% of the retained catch.

Discard from the directed pot fishery was estimated from observer data since 1992 and ranged from 11% to 64% (average 33%) of the retained catch of male crab biomass (Table 6). Female discard catch is very low compared to male discard catch and not a significant source of mortality. Discard of snow crab in groundfish fisheries from highest to lowest is the yellowfin sole trawl fishery, flathead sole trawl fishery, Pacific cod bottom trawl fishery, rock sole trawl fishery, and the Pacific cod hook-and-line and pot fisheries. Bycatch in fisheries other than the groundfish trawl fishery has historically been relatively low, but this year bycatch from sources other than the groundfish trawl fishery reached almost ~25% of the reported bycatch. Size frequency data and catch per pot have been collected by observers on snow crab fishery vessels since 1992. Observer coverage has been 10% on catcher vessels larger than 125 ft (since 2001), and 100% coverage on catcher processors (since 1992).

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

D. Data

New time series of survey indices and size compositions were calculated from data downloaded from the AKFIN database. Bycatch data (biomass and size composition) were updated for the most recent year from the AKFIN database. Retained, total, and discarded catch (in numbers and biomass) and size composition data for each of these data sources were updated for the most recent year based on files provided by the State of Alaska.

Catch data

Catch data and size frequencies of retained crab from the directed snow crab pot fishery from survey year 1978 to the 2015 were used in this analysis (Table 6). Size frequency data on the total catch (retained plus discarded) in the directed crab fishery were available from survey year 1992 to 2015. Total discarded catch was estimated from observer data from 1992 to 2015 (Table 1). The discarded male catch was estimated for survey year 1978 to 1991 in the model using the estimated fishery selectivities based on the observer data for the period of survey year 1992 to 2015. The discard catch estimate was multiplied by the assumed mortality of discards from the pot fishery. The mortality of discarded crab was 30% for all model scenarios. This estimate differs from the currently used strategy (since 2001) to the present by ADFG to set the TAC, which assumes a discard mortality of 25% (Zheng, et al. 2002). The discards prior to 1992 may be underestimated due to the lack of escape mechanisms for undersized crab in the pots before 1997.

The following table contains the various data components used in the model and the time periods for which they are available:

Table 3: Data included in the assessment. Dates indicate survey year.

Data component	Years
Retained male crab pot fishery size frequency by shell condition	1978 - 2015
Discarded Males and female crab pot fishery size frequencey	1992 - 2015
Trawl fishery bycatch size frequencies by sex	1991 - 2015
Survey size frequencies by sex and shell condition	1978 - 2016
Retained catch estimates	1978 - 2015
Discard catch estimates from crab pot fishery	1992 - 2015
Trawl bycatch estimates	1973 - 2015
Total survey biomass estimates and coefficients of variation	1978 - 2016
2009 study area biomass estimates, CVs, and size frequencey for BSFRF and NMFS tows	2009
2010 study area biomass estimates, CVs, and size frequencey for BSFRF and NMFS tows	2010

Survey biomass and size composition data

Abundance was estimated from the annual eastern Bering Sea (EBS) bottom trawl survey conducted by NMFS (see Rugolo et al. 2003 for design and methods). Since 1989, the survey has sampled stations farther north than previous years (it only reached to 61.2 N previous to 1989). In 1982 the survey net was changed resulting in a potential change in catchability. Consequently, survey selectivity was modeled in three 'eras' in the assessment (1978-1981, 1982-1988, 1989-present). All survey data in this assessment used measured net widths instead of the fixed 50 ft net width based on Chilton et al.'s (2009) survey estimates. Carapace width and shell conditions were measured and reported for snow crab caught in the survey.

Mature biomass for males and females at the time of the survey were the primary indices of population size fit to in this assessment. Total survey numbers (Figure 8 & Figure 9) were input to the model via the .DAT file, after which MMB and FMB at the time of the survey were calculated based on the size composition data, which were delineated by shell condition, maturity state, and sex. Distinguishing between mature and immature crab for the size composition was accomplished by demarcating any female that had eggs reported in the survey as 'mature'. Mature male size composition data were calculated by multiplying the total numbers at length for new shell male crab by a vector of observed proportion of mature males at length. The observed proportion of mature males at length was calculated by chelae height and therefore refers only to 'morphometrically' mature males. All old shell crab of both sexes were assumed to be mature. New shell crab were demarcated as any crab with shell condition index $<= 2$. The biomass of new and old shell mature individuals was calculated by multiplying the vector of numbers at length by weight at length. These vectors were then summed by sex to provide the index to which the model was fit (Table 7). The size composition data were also fit within the assessment.

Spatial distribution of survey abundance and catch

Spatial gradients exist in the survey data by maturity and size for both sexes. For example, larger males were more prevalent on the south west portion of the shelf (Figure 4) while smaller males were more prevalent on the north west portion of the shelf (Figure 1). Females exhibited a similar pattern (compare Figure 2 to Figure 5). In addition to changing spatially over the size and shelf, distributions of crab by size and maturity also changed temporally. The centroids of abundance in the summer survey moved over time (Figure 10 & Figure 11). Centroids of mature female abundance early in the history of the survey were the farther south, but moved north during the 1990s. Since the late 1990s and early 2000s, the centroids moved back south again, but not to the extent seen in the early 1980s. This phenomenon was mirrored in centroids of abundance for large males (Figure 11).

Centroids of the catch were generally south of 58.5 N, even when ice cover did not restrict the fishery moving farther north. This is possibly due to proximity to port and practical constraints of meeting delivery schedules. The majority of catch was taken west and north of the Pribilof Islands, but this rule had exceptions.

A difference between the summer survey distribution of large males and the fishery catch distribution existed. The origin of this difference is unknown. It is possible that crab moved between the fishery and the survey, but it is also possible that fishers did not target the centroids of abundance. The underlying explanation of this phenomenon could hold implications for relative exploitation rates spatially and it has been suggested that high exploitation rates in the southern portion of the snow crab range may have resulted in a northward shift in snow crab distribution (Orensanz, 2004). Snow crab larvae likely drift north and east after hatching in spring. Snow crab appeared to move south and west as they age, however, no tagging studies have been conducted to fully characterize the ontogenetic or annual migration patterns of this stock (Murphy et al. 2010).

Experimental study of survey selectivity

Bering Sea Fisheries Research Foundation (BSFRF) conducted a survey of 108 tows in 27 survey stations (hereafter referred to as the “study area”) in the Bering Sea in summer 2009 (Figure 12). The BSFRF performed a similar study during 2010 in which the study area covered a larger portion of the distribution of snow crab than the 2009 study area. The mature biomass and size composition data gleaned from each of these experiments (and their complimentary NMFS survey observations; Figure 13 & Figure 14) are incorporated into the model by fitting them as an extra survey that is linked to the NMFS survey through a shared selectivity (see appendix A for a description of the way in which the surveys are related in the assessment model). Abundances estimated by the industry surveys were generally higher than the NMFS estimates, which provides evidence that the catchability of the NMFS survey gear is less than 1. Larger females are an exceptions to this observation, but this difference may be due to different towing locations for the two nets within the study area, or to variable catchability of females due to aggregation behavior.

E. Analytic approach

History of modeling approaches for the stock

Historically, survey estimates of large males (>101 mm) were the basis for calculating the Guideline Harvest Level (GHL) for retained catch. A harvest strategy was developed using a simulation model that pre-dated the current stock assessment model (Zheng et al. 2002). This model has been used to set the GHL (renamed ‘TAC’ since 2009) by Alaska Department of Fish and Game (ADFG) since the 2000/2001 fishery. Currently, NMFS uses an integrated size-structured assessment to calculate the overfishing level (OFL), which constrains the ADFG harvest strategy.

Model description

The integrated size-structured model used by NMFS (and presented here) was developed following Fournier and Archibald’s (1982) methods, with many similarities to Methot (1990). The model was implemented using automatic differentiation software developed as a set of libraries under C++ (ADModel Builder). ADModel

Builder can estimate a large number of parameters in a non-linear model using automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries.

The snow crab population dynamics model tracked the number of crab of sex s, shell condition v, maturity state m, during year y at length l, $N_{s,v,m,y,l}$. A terminal molt was modeled in which crab move from an immature to a mature state, after which no further molting occurred. The mid-points of the size bins tracked in the model spanned from 27.5 to 132.5mm carapace width, with 5 mm size classes. For the base assessment (model 0), 331 parameters were estimated. Parameters estimated witin the assessment included those associated with the population processes recruitment, growth, natural mortality (subject to a fairly informative prior), fishing mortality, selectivity (fishery and survey), catchabillity, and maturity (also sometimes subject to a prior; see Table 8 & Table 9). Molting probability, weight at length, discard mortality, bycatch mortality, and parameters associated with the variance in growth and proportion of recruitment allocated to size bin were estimated outside of the model or specified. See appendix A for a complete description of the population dynamics.

Samples were drawn from the posterior distributions of estimated parameters and derived quantities used in management (e.g. MMB and OFL) via MCMC. This involved conducting 2,000,000 cycles of the MCMC algorithm, implementing a 5% burn-in period, and saving every 500th draw. Chains were then thinned until diagnostic statistics (e.g. Geweke statistics) demonstrated a lack of evidence of non-convergence.

Model selection and evaluation

Models were evaluated based on their fit to the data (Table 10), the credibility of the estimated population processes, and the strength of the influence of the assumptions of the model on the outcomes of the assessment. A high-level overview of the changes in management quantities arising by step-wise changes in the assessment model are presented first, followed by a more in depth look at results for six selected models. Estimated parameters for the six selected models can be seen in Table 9 and their posterior distributions can be seen in Figure 15, Figure 16, Figure 17, and Figure 18.

Results

Relatively small changes in all management quantities appeared when making the small structural changes suggested by the CPT (e.g. estimate CPUE q, fix survey catchability to 1 for females; Table 4). Changing weight parameters influenced management quantities very little because parameters for males changed very little. However, downweighting the survey composition data (beginning with model 0) resulted in large changes to management quantities, which were manifested most strongly through changes in estimated natural mortality, survey catchability, and probability of maturing (when the priors were removed in model 3). The changes of the management quantities for steps within a 'scenario' (i.e. model 1a within model 1) were relatively small compared to these changes. Below, the results for six models are described (only one of which (model 3a) has the downweighted survey size composition data). The traces of the objective functions for each model were stationary, though several were slightly autocorrelated (Figure 19).

Fits to data

Survey mature biomass

Fits to the survey mature male biomass were similar for all models for the majority of years in the the time series (Figure 20). Model 0 deviated from the other models during the 2000s and model 3a deviated from the other models during the early 1990s. Each of these deviations improved the fit to the data (Table 10). Estimates of survey MMB in the final year ranged from 67.5 to 105.7 kt. Model 3a fit the final data point most closely.

Fits to the survey mature female biomass were also similar for all models for the majority of years in the time series (Figure 20). Model 0 deviated from the other models during the 1990s and model 3, 3a, and 3b deviated from the other models during the early 1980s. Model 0's deviations improved the fit to the data, but deviations for the model 3 variants did not (Table 10). Estimates of survey MFB in the final year ranged from 68.1 to 90.5 kt. Model 3a again fits the final data point most closely.

Growth data

Three models provided adequate (but less than ideal) fits to the female growth data: model 0, 3a, and 3b (Figure 22). All models except for model 3a provide adequate fits to the male growth data. In sum, only models 0 and 3b fit both the male and female growth data acceptably (Table 10).

Catch data

Retained catch data were fit by all models well, with no discernable differences among models (Figure 23). Female discard data were fit adequately given the specified uncertainty and very little difference in fits existed among models (Figure 23 & (Table 10)). Male discard data during the period for which data exist (early 1990s to the present) were well fit by every model with little discernable difference (Figure 23 & (Table 10)). Fits to the trawl data were adequate for all models given the uncertainty in the data (Figure 23). In general, models 1-3b fit the trawl data during the 2000s better than model 0, but this trend was reversed during the 2010s.

CPUE data

Fits to the fishery CPUE data were poor for all models, but vaguely reflected the trends in observed cpue (Figure 24).

Size composition data

Fits to the size composition data for the BSFRF data were similar for all models (Figure 25 & (Table 10)). The number of males was underestimated by the industry survey in 2009 and overestimated by the NMFS survey, while the opposite pattern was seen for females. Fits to the 2010 survey size composition data were better than the 2009 fits. Fits to female survey composition data were similar for all models in most years, but fits for models 0 and model 3a departed from the other models in some years (Figure 26). Similar patterns in fits among models can be seen for the male survey composition data (Figure 27); the fits of models 0 and 3a departed from the fits of the other models.

The distribution of residuals for male and female survey composition data for the chosen model varied by maturity state and sex. Immature females tended to be underestimated (Figure 28), whereas mature females tended to be overestimated (Figure 29). No clear skew towards overestimation or underestimation existed for immature males (Figure 30), and size composition data for mature males exhibited the best residual patterns of the fitted survey composition data (Figure 31).

Predicted average size by shell condition and maturity state in the survey were generally similar among models and fit the observed average size reasonably well, with the exception of the old shell mature males and new shell immature females (Figure 32). Model 3a performed more poorly than the other models for predicting old shell mature males; model 0 performed slightly better than the other models for the latter portion of the time series.

Retained catch size composition data were fit well by all models (Figure 33); trawl size composition data were generally well fit, with several notable exceptions. All models performed similarly in fitting the trawl size composition data (Figure 34 & (Table 10)).

Estimated population processes and derived quantities

Estimates of mature male biomass at the time of mating varied by 6-44% among models over the history of the fishery. Projected MMB for 2016 ranged from 97.0 to 170.9 kt. Estimated mature female biomass at the time of mating varied by 6-35% over the length of the time series among models. Projected FMB for 2016 ranged from 125.7 to 189.9 kt (Figure 35). In general, estimated fishing mortality in the recent past has been well below $F_{35\%}$, but estimated MMB has been less than $B_{35\%}$ since 2011 (Figure 36).

Estimated fishing mortality in the directed fishery was similar for all models except model 0 and model 3a (Figure 37). Estimated fishing mortality in model 0 was lower than the other models, while model 3a's was higher. This result was related to the relative differences in the estimates of male biomass (model 0 was highest; model 3a was lowest). The same catch taken from populations of different sizes results in different estimated fishing mortalities, provided directed selectivity remains similar. Total and retained fishery selectivity was very similar for all models because of the weight put on the retained catch and its associated size composition data (Figure 37). Size at 50% selection in the trawl fishery increased for all models after model 0 because the parameter was fixed in the model 0, but estimated in all subsequent models (Figure 37). Size at 50% selection for discarded females increased for model 3, 3a a, and 3b because it was fixed in all models previous to these (Figure 37). Changes in selectivity for these fisheries was reflected in the estimated fishing mortalities. See Figure 15 and Figure 16 for posterior densities for all parameters related to mortality in the different fisheries.

Estimated survey selectivity was similar for all models during survey era 1 (Figure 38). Catchability for males was close to 1 and ranged from 0.7-1 for females with very narrow posteriors (Figure 16). Size at 50% selection in the survey gear ranged from ~36 mm to ~44 mm for both females and males (Figure 16 & Figure 17). Estimated survey selectivity for females during survey era 2 was similar for all models, with estimated catchability ranging from 0.32 to 0.35. Estimated catchability for males ranged from 0.48 to 0.61. Size at 50% selection in the survey gear ranged from ~41 mm to ~45 mm for both females and males (Figure 16 & Figure 17). Estimated catchability for males during survey era 3 ranged from 0.52 to 0.7; estimated female catchability ranged from 0.48 to 0.6. Size at 50% selection in the survey gear ranged from 33 mm to 34 mm for females and 34 mm to 40 mm for males (Figure 16 & Figure 17). BSFRF 'availability' curves varied from 2009 to 2010, with the availability of crab to the experimental survey increasing in 2010 (Figure 39).

The probability of maturing by size was fairly consistent among scenarios for both males and females. The probability of maturing by size for female crab was about 50% at about 48 mm and increased to 100% at 60mm (Figure 40). The probability of maturing for male crab was about 15% to 20% at 60 mm to 90mm and increased sharply to 50% at about 98mm, and 100% at 108 mm. Model 3a predicted higher probability of molting to maturity for both males and females, which increased $F_{35\%}$ substantially.

Patterns in recruitment were similar for all models–a period of high recruitment in which 3 large cohorts pass through the population occured during the 1980s and into the early 1990s. A period of low recruitment followed that period which persisted from the early 1990s to present. All models indicated a potentially large recruitment event occuring in the last few years (Figure 41). Recruitment entering the model was placed primarily in the first three size bins (Figure 41). Distinct stock recruitment relationships were not apparent between the estimates of MMB and recruitment for any model (Figure 41). Relationships were not apparent between mature female biomass and recruitment either. Estimated multipliers for natural mortality ranged from 1.3 to 2 for immature crab and 1.11 to 1.14 for mature crab (Table 9).

F. Calculation of the OFL

Methodology for OFL

The OFL was calculated using proxies for biomass and fishing mortality reference points and a sloped control rule. Proxies for biomass and fishing mortality reference points were calculated using spawner-per-recruit methods (e.g. Clark, 1991). After fitting the assessment model to the data and estimating population parameters, the model was projected forward 100 years using the estimated parameters under no exploitation to determine 'virgin' mature male biomass-per-recruit. Projections were repeated in which the bisection method was used to identify a fishing mortality that reduced the mature male biomass-per-recruit to 35% of the virgin level (i.e. $F_{35\%}$ and $B_{35\%}$). Calculations of $F_{35\%}$ were made under the assumption that bycatch fishing mortality was equal to the estimated average value.

Calculated values of $F_{35\%}$ and $B_{35\%}$ were used in conjunction with a control rule to adjust the proportion of $F_{35\%}$ that is applied based on the status of the population relative to $B_{35\%}$ (Amendment 24, NMFS).

$$F_{OFL} = \begin{cases} Bycatch & if \frac{MMB}{MMB_{35}} \leq 0.25 \\ \frac{F_{35}(\frac{MMB}{MMB_{35}} - \alpha)}{1-\alpha} & if 0.25 < \frac{MMB}{MMB_{35}} < 1 \\ F_{35} & if MMB > MMB_{35} \end{cases} \tag{2}$$

Where MMB is the projected mature male biomass in the current survey year after fishing at the F_{OFL}, $MMB_{35\%}$ is the mature male biomass at the time of mating resulting from fishing at $F_{35\%}$, $F_{35\%}$ is the fishing mortality that reduces the mature male biomass per recruit to 35% of unfished levels, and α determines the slope of the descending limb of the harvest control rule (set to 0.1 here).

Previously, reference points and the OFL were calculated by fitting the model to the data, then transferring the estimated parameters to a script with a projection model in which all parameters were assumed known. The projection script began in the final year of the assessment period and was initiated by pasting the numbers at length from the report file of the assessment into a data file read in by the projection script. Reference points were calculated by projecting the population into the future under no fishing mortalty (to find virgin biomass) and a fishing mortality was solved for that reduced the mature male biomass-per-recruit to 35% of virgin levels. The process was repeated to find the OFL, but, to allow for some uncertainty in the calculation, lognormal error was added to the initial numbers at length (i.e. those in the final year of assessment) and the F_{OFL} was calculated based on the harvest control rule outlined above. Many simulations with different lognormal errors were carried out to develop a distribution of the OFL which was then used to determine an ABC.

The previously used projection method does not propagate the uncertainty in all parameters forward, so a Bayesian methodology was adopted for this iteration of the assessment to more fully represent the uncertainty associated with model estimates of quantities used in management. In the Bayesian implementation of this assessment model, none of the equations changed (other than in the ways requested by the CPT), but distributions for the OFL, MMB, $B_{35\%}$, and $F_{35\%}$ were developed by sampling from the posterior distributions of these quantities via a Markov Chain Monte Carlo algorithm built into ADMB. Accomplishing this required building in functions to calculate reference points and extra storage space (see functions 'get_fut_mortality', 'find_OFL', 'find_F35' in the .TPL on github).

Calculated OFLs and interpretation

Medians of the posterior densities of the OFLs calculated for the suite of six presented models ranged from 9.36 to 32.43 (Table 12). Differences in OFLs were a result of differences in estimated MMB (see above), calculated $B_{35\%}$ (which ranged from 137.7 to 155t), Figure 43), $F_{35\%}$ (which ranged from 0.95 to 2.48 yr^{-1}, Figure 43), and F_{OFL} (which ranged from 0.67 to 1.23 yr^{-1}, Figure 43). Model 3a had the lowest calculated OFL, due in large part to the lowest estimated MMB among the six models.

G. Calculation of the ABC

The acceptable biological catch (ABC) was set in two different ways. First, the ABC was set below the OFL by a proportion based on a predeterminied probability that the ABC would exceed the OFL (P_{star}).

Currently, P_{star} is set to 0.49 and the ABC was calculated as the 49th quantile of the posterior distribution of the overfishing level (OFL). The second method, which was recommended by the SSC, set the ABC by subtracting a 10% buffer from the OFL.

Author recommendations

The process of selecting a preferred model began with excluding models that did not fit the data. Model 3a was eliminated first because, although it fit the survey biomass data the best, it did so without fitting the male growth data and produced poorer fits to survey composition data. Model 3a also tracked observed average size for new shell immature males poorly and estimated era 3 survey catchability much higher than the implied catchability from the observed ratios between the NMFS and BSFRF tows in 2009 and 2010. Downweighting the survey size composition data (as in model 3a) should be done, but it should be done in concert with other changes in the weighting of the model (and perhaps while directly fitting the estimates of selectivity from the selectivity experiments) to ensure fits to other data components and credible estimates of population processes.

Models 1, 2, and 3 fit female growth data poorly, but this didn't have a large influence on the calculated OFL. Aside from poor fits to the female growth data, there were no other serious problems in the fits to the data that would warrant the exclusion of a model. However, the consistent estimation of a higher size at 50% selection in the trawl selectivity by models in which that parameter was free suggests that model 0 should be eliminated. A similar reasoning could be applied to female discard mortality and model 1 and 2, which leaves model 3 and 3b as candidates for the author selected model. Model 3 fits the female growth data poorly and the multiplier for natural mortality hits its bound of 2, so, model 3b was chosen as the preferred model for the 2016 snow crab assessment.

Consequently, the recommended OFL for 2016 was 23.71 kt fishing at $F_{OFL} = 1.14$ (59 % of the calculated $F_{35\%}$, 1.91). The projected ratio of MMB at the time of mating to $B_{35\%}$ is 0.6. The associated ABC was 21.34 (calculated via the 10% buffer suggested by the SSC).

H. Data gaps and research priorities

Data sources

With the shift to a Bayesian paradigm, as many raw data sources as possible should be included in the assessment. Estimating parameters outside of the model and inputing them as 'known' artificially decreases the uncertainty represented in the posteriors of management quantities. Weight at length data, data used to develop priors for natural mortality and maturity, and the selectivities calculated from the BSFRF data should be considered for inclusion in the model to comprehensively represent the uncertainty in management quantities. In addition to pulling as much data into the model as possible, standardizing and automating the creation of data files from the survey and catch databases would be very useful given the short time frame of the assessment cycle.

Modeling

The model in its current state appeared to be internally consistent, but there are several model features that could be tested for their impact on management quantities and estimation. For example, bycatch was assumed to come entirely from the groundfish trawl fisheries. However, almost a quarter of it came from the pot fisheries in 2016, so it may be useful to model more fisheries for bycatch. Testing other forms of the relationship between pre- and post-molt length may also be useful. Visually, the need for a piece-wise model was not immediately clear. Often times piece-wise fits are used when growth changes after maturity as more energy is directed towards reproduction. However, given a terminal molt for both sexes, this should not impact the growth relationship. When incorporating weight at length data into the assessment, it may be useful to consider a split in parameters for mature and immature males as is done for females. Revisiting the use of BSFRF data to more directly determine selectivity in the most recent survey era may provide stability needed to allow for the downweighting of the survey composition data.

Linking the catchability coefficients for the different survey eras may provide for more intuitive interpretation of the relationships between the parameters. The relationship between catchability in different eras can greatly influence the perceived status and impacts of fishing on the population. The survey data were originally split because of an increase in the area surveyed (era 1 to era 2) and a change in gear type (era 2 to era 3). Presumably, this means that catchability in era 2 should always be higher than era 1 (fewer stations were sampled in era 1). When splitting the mature males in the first year, it is assumed that they are all new shell, but the females are split out between new and old shell condition. Finally, considering the impact of basing natural mortality off of longevity and then splitting it into immmature and mature M on the calculation of reference points may improve the interpretability of estimates of natural mortality.

Weighting

Different weighting of likelihood components can have drastic impacts on the management advice provided from an assessment (as seen here in model 3a). A close look at the way CVs, sample sizes, and other weighting factors are calculated and their influence on assessment results could provide better understanding of how well the model is balanced. Standardization of the weighting schemes would also improve readability of the code (for example, some size composition data have both 'weights' and 'sample sizes').

Scientific uncertainty

Natural mortality exerts a large influence over estimated management quantities, but is poorly known. Tagging studies targeted at estimating natural mortality could be very useful and could also shed light on the migration patterns, which could help us understand the impact of the fishery (e.g. centroids of large male abundance in the survey and catch do not match–is this because the crab are moving or because the fishery operates in a specific place? The answer to this question could influence priors on catchability.) Similarly, establishing measures of reproductive capacity that include females, the spatial overlap of mature individuals, the role water temperature plays in biennial spawning, and the effectiveness of mating by size for males may allow for relationships between recruitment and mature biomass to be found. In general, exploring the spatial dynamics of the population may allow for patterns and influences of the fishery and environment on the producitivity of the stock to be more easily identified. Preliminary analyses suggest that retrospective biases may be a problem for the snow crab assessment (Figure 42; also compare the trajectory of MMB in last year's assessment to this year). Retrospective biases can result from unaccounted for time-varying processes in the population dynamics of the model (Hurtado et al., 2015). Focused research on the potential for retrospective biases in the snow crab assessment should be pursued.

Style

Although the code was trimmed considerably, legacy code and unused variables still exist within the assessment. Streamlining the code makes it more readable and reduces the probability of bugs. Most constants were migrated from the .TPL to the .CTL file, but parameter bounds have not yet been moved. Adjusting the manner in which output files are opened when evaluating MCMC output should also be implemented to avoid overwriting .REP files.

I. Ecosystem Considerations

Recruitment for snow crab can be divided into two periods via regime shift algorithms (e.g. Rodionov, 2004). The shift in recruitment corresponds with a change in the Pacific Decadal Oscillation (Szuwalski and Punt, 2013), but also with a period of intense fishing mortality. Regime-based management strategies have been evaluated for snow crab, but found that only small improvements in long-term yield are derived from changing the target reference points based on a change point algorithm and those changes come at a higher risk of overfishing (Szuwalski and Punt, 2012). Given the uncertainty around whether or not the environment or the fishery precipitated changes in recruitment, the precautionary principle guides managers to assume it is the fishery. Spatial analyses of recruitment, mature biomass, environmental drivers, and the impact of the fishery may provide insight to the population dynamics of snow crab, but modeling techniques capable of fully-spatial stock assessment are only recently feasible.

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Appendix A: Model structure

Population dynamics

Numbers of sex s of shell condition v and maturity state m at length l in the initial year of the assessment, $N_{s,v,m,y=1,l}$, were calculated from an estimated vector of numbers at length l by sex s and maturity state m for males, $\lambda_{s,m,l}$ and numbers at length l by sex s and shell condition v for females (i.e. 2 vectors for each sex were estimated). Estimated vectors of initial numbers at length by maturity for females were calculated by splitting the estimated vectors at length by the observed proportion mature in the first year of the survey.

$$N_{s,v,m,y=1,l} = \begin{cases} \Omega^{obs}_{s,l}\lambda_{s,1,l} & \text{if v = new; m = mat, s = fem} \\ 1-\Omega^{obs}_{s,l}\lambda_{s,1,l} & \text{if v = new; m = imat, s = fem} \\ \lambda_{s,2,l} & \text{if v = old; m = mat, s = fem} \\ 0 & \text{if v = old; m = imat} \end{cases} \tag{3}$$

Initial numbers at length for males were all assumed to be new shell.

$$N_{s,v,m,y=1,l} = \begin{cases} \lambda_{s,1,l} & \text{if v = new; m = mat, s = male} \\ \lambda_{s,2,l} & \text{if v = new; m = imat, s = male} \\ 0 & \text{if v = old; m = mat, s = male} \\ 0 & \text{if v = old; m = imat, s = male} \end{cases} \tag{4}$$

The dynamics after the initial year were described by:

$$N_{s,v,m,y+1,l} = \begin{cases} \Omega_{s,l}\kappa_{s,l'}Q_{s,imat,y,l'}X_{s,l',l} & \text{if v = new; m = mat} \\ 1-\Omega_{s,l}\kappa_{s,l'}Q_{s,imat,y,l'}X_{s,l',l} + Rec^{\epsilon}_{y}Pr_l & \text{if v = new; m = imat} \\ Q_{s,mat,y,l'} & \text{if v = old; m = mat} \\ (1-\kappa_{s,l'})Q_{s,imat,y,l'} & \text{if v = old; m = imat} \end{cases} \tag{5}$$

Where $\Omega_{s,l}$ was the probability of maturing at length l for sex s (a freely estimated vector for both males and females constrained by penalties on smoothness and a prior in some scenarios), $\kappa_{s,l'}$ was the probability of molting for an immature crab of sex s at length l' (set to 1 for all immature crab), and $X_{s,l,l'}$ was the size transition matrix describing the probability of transitioning from size l' to size l for sex s. $Q_{s,m,y,l'}$ was the number of crab of sex s, maturity state m, and length l' surviving natural and fishing mortality during year y:

$$Q_{s,m,y,l} = \sum_{v} N_{s,v,m,y,l}e^{Z_{s,v,m,y,l}} \tag{6}$$

Where $N_{s,v,m,y,l}$ represented the numbers, N, of sex s during year y of shell condition v and maturity state m at length l. $Z_{x,v,m,y,l}$ represented the total mortality experienced by the population and consisted of the sum of instantaneous rates of natural mortality by sex and maturity state, $M_{s,m}$, and fishing mortality, $F_{s,f,y,l}$ from each fishery. Each fishing mortality was subject to seletivity by length l, which varied between sexes s and fisheries f (and by year y if specified) . $M_{s,m}$ was specified in the model and a multiplier $\gamma_{natM,m}$

was estimated subject to constraints (see Table 8; this formulation effectively specified a mean and standard deviation for a prior distribution for M).

$$Z_{s,v,m,y,l} = \gamma_{natM,m} M_{s,m} + \sum_{f} S_{s,f,y,l} F_{s,f,y,l} \tag{7}$$

Selectivities in the directed and bycatch fisheries were estimated logistic functions of size. Different selectivity parameters were estimated for females and males in the directed fisheries ($S_{fem,dir,l}$ and $S_{male,dir,l}$, respectively), a single selectivity for both sexes was estimated for bycatch in the groundfish trawl fishery ($S_{trawl,l}$), and a retention selectivity was estimated for the directed fishery for males ($R_{dir,l}$; all females were discarded).

$$S_{male,dir,l} = \frac{1}{1+e^{-S_{slope,m,d}(L_l - S_{50,m,d}}}) \tag{8}$$

$$S_{fem,dir,l} = \frac{1}{1+e^{-S_{slope,f,d}(L_l - S_{50,f,d}}}) \tag{9}$$

$$S_{trawl,l} = \frac{1}{1+e^{-S_{slope,t}(L_l - S_{50,t}}}) \tag{10}$$

$$R_{dir,l} = \frac{1}{1+e^{-S_{slope,m,d}(L_l - S_{50,m,d}}}) \tag{11}$$

Where $S_{slope,s,f}$ was the slope of the logistic curve for sex s in fishery f and $S_{50,s,f}$ was the length at 50% selection for sex s in fishery f. Catches for all fisheries were modeled as pulse fisheries in which all catch was removed instantaneously (i.e. no natural mortality occured during the fishery). Catch in fishery f during year y was calculated as the fraction of the total fishing mortality, $F_{s,f,y,l}$, applied to a given sex s in a fishery f times the biomass removed by all fisheries for that sex.

$$C_{male,dir,y} = \sum_l \sum_v \sum_m w_{male,l} \frac{R_l F_{male,dir,y,l}}{F_{male,dir,y,l+F_{trawl,y,l}}} N_{male,v,m,y,l} e^{-\delta_y M_{s,m}} (1 - e^{-(F_{male,dir,y,l}+F_{trawl,y,l})}) \tag{12}$$

$$C_{male,tot,y} = \sum_l \sum_v \sum_m w_{male,l} \frac{F_{male,dir,y,l}}{F_{male,dir,y,l+F_{trawl,y,l}}} N_{male,v,m,y,l} e^{-\delta_y M_{s,m}} (1 - e^{-(F_{male,dir,y,l}+F_{trawl,y,l})}) \tag{13}$$

$$C_{fem,dir,y} = \sum_l \sum_v \sum_m w_{fem,l} \frac{F_{fem,dir,y,l}}{F_{fem,dir,y,l+F_{trawl,y,l}}} N_{fem,v,m,y,l} e^{-\delta_y M_{s,m}} (1 - e^{-(F_{fem,dir,y,l}+F_{trawl,y,l})}) \tag{14}$$

$$C_{m+f,trawl,y} = \sum_s \sum_l \sum_v \sum_m w_{s,l} N_{s,v,m,y,l} e^{-\delta_y M_{s,m}} (1 - e^{-(F_{trawl,y,l})}) \tag{15}$$

Where δ_y was the mid point of the fishery (all fisheries were assumed to occur concurrently and the midpoint was based on the directed fishery, which accounts for the vast majority of the fishing mortality) and $w_{s,l}$ was the weight at length l for sex s. Trawl data and discard data were entered into the model with an assumed mortality of 80% and 30%, respectively. Fully-selected fishing mortality parameters for fishery f were estimated as a logged average over a given time period (F^{log}_{avg}) with yearly deviations around that mean ($F^{log}_{dev,y}$).

$$F_{f,y} = e^{(F^{log}_{avg,f} + F^{log}_{dev,f,y})} \tag{16}$$

Selectivity for the survey was estimated for 3 eras: 1978-1981, 1982-1988, and 1989-present. Selectivity was assumed to be logistic and separate parameters representing the length at which selection probability equal 50% and 95% ($s_{50,s,e}$ and $s_{95,s,e}$, respectively) were estimated for males and females in the third era (1989-present). Separate catchability coefficients ($q_{s,e}$) were estimated for males and females in all eras.

$$S_{surv,s,l,e} = \frac{q_{s,e}}{1 + e^{-log(19)\frac{L_l - s_{50,s,e}}{s_{95,s,e} - s_{50,s,e}}}}) \tag{17}$$

Survey selectivity was informed by experimental surveys during the years 2009 and 2010. A portion of the NMFS summer survey tows were accompanied by an industry vessel using nephrops trawls with an assumed selectivity of 1 for all size classes. To represent the proportion of the population covered by the experiment, a vector was freely estimated for males, S_y^{free} (subject to a scaling parameter), and a logistic curve was estimated for females.

$$S_{ind,s,l,y} = \begin{cases} \frac{q_{ind,s,y}}{1+e^{-log(19)\frac{L_l - s_{50,s,y}}{s_{95,s,y} - s_{50,s,y}}}}) & \text{if s = female} \\ q_{ind,s,y}S_y^{free} & \text{if s = male} \end{cases} \tag{18}$$

Based on this logic, after identifying the fraction of the crab at length covered by the experimental surveys, the length frequencies of the NMFS data collected simultaneously with the experimental trawls can be calculated by multiplying the numbers at length 'available' to the experimental trawls by the overall survey selectivity, $S_{surv,s,l,y}$. The predicted numbers at length for the NMFS and industry data from the selectivity experiment were calculated by multiplying the respective selectivities by the survey numbers at length.

$$S_{nmfs,s,l,y} = S_{ind,s,l,y}S_{surv,s,l,y} \tag{19}$$

Mature male and female biomass (MMB and FMB, respectively) were fitted in the objective function and were the product of mature numbers at length during year y and the weight at length, $w_{s,l}$:

$$MMB_y = \sum_{l,v} w_{male,l}N_{male,v,mat,y,l} \tag{20}$$

$$FMB_y = \sum_{l,v} w_{fem,l}N_{fem,v,mat,y,l} \tag{21}$$

$$w_{s,l} = \alpha_{wt,s}L_l^{\beta_{wt,s}} \tag{22}$$

Mature biomass can be calculated for different time through out the year, in which case the numbers at length are decremented by the estimated natural mortality. Parameters $\alpha_{wt,s}$ and $\beta_{wt,s}$ were estimated outside of the assessment model and specified in the control file.

Molting and growth occur before the survey. Immmature crab were assumed to molt every year with an estimated probabillity of molting to maturity based on length l (in all the scenarios presented here, the probability of molting was 1 for all immature animals). For crab that do molt, the growth increment within the size-transition matrix, $X_{s,l,l'}$, was based on a piece-wise linear relationship between predicted pre- and post-molt length, ($\hat{L}_{s,l}^{pred}$ and $\hat{L}_{s,l}^{post}$, respectively) and the variabillity around that relationship was characterized by a discretized and renormalized gamma function, $Y_{s,l,l'}$.

$$X_{s,l,l'} = \frac{Y_{s,l,l'}}{\sum_{l'} Y_{s,l,l'}} \tag{23}$$

$$Y_{s,l,l'} = (\Delta_{l,l'})^{\frac{\hat{L_{s,l}} - (\bar{L}_l - 2.5)}{\beta_s}} \tag{24}$$

$$\hat{L}_{s,l}^{post,1} = \alpha_s + \beta_{s,1}L_l \tag{25}$$

$$\hat{L}_{s,l}^{post,2} = \alpha_s + \delta_s(\beta_{s,1} - \beta_{s,2}) + \beta_{s,2} L_l \tag{26}$$

$$\hat{L}_{s,l}^{post} = 1 - \Phi(\frac{\hat{L}_{s,l}^{post,1} - \delta_{a,x}}{stgr}) + \Phi(\frac{\hat{L}_{s,l}^{post,2} - \delta_{a,x}}{stgr}) \tag{27}$$

$$\Delta_{l,l'} = \bar{L}_{l'} + 2.5 - L_l \tag{28}$$

$\hat{L}_{s,l}^{post,1}$ and $\hat{L}_{s,l}^{post,2}$ were predicted post-molt lengths from each piece of the piece-wise relationship, and $\Phi()$ was a cumulative normal distribution in which $\delta_{a,x}$ was an estimated change point.

An average recruitment for the assessment period (1978-present) and yearly deviations around this average were estimated within the assessment. The sex ratio of recruitment was assumed to be 50/50 male to female. Each year's estimated recruitment was allocated to length bins based on a discretized and renormalized gamma function with parameters specified in the control file.

$$Rec_y = e^{(Rec_{avg} + Rec_{dev,y})} \tag{29}$$

$$Pr_l = \frac{(\Delta_{1,l})^{\alpha_{rec}/\beta_{rec}} e^{-\Delta_{1,l'}/\beta_{rec}}}{\sum_{l'} (\Delta_{1,l'})^{\alpha_{rec}/\beta_{rec}} e^{(-\Delta_{1,l'}/\beta_{rec})}} \tag{30}$$

Likelihood components

Three general types of likelihood components were used to fit to the available data (Table 11). Multinomial likelihoods were used for size composition data, log-normal likelihoods were used for indices of abundance data, and normal likelihoods were used for catch data, growth data, priors, and penalties. Multinomial likelihoods were implemented in the form:

$$L_x = \lambda_x \sum_y N_{x,y}^{eff} \sum_l p_{x,y,l}^{obs} ln(\hat{p}_{x,y,l}/p_{x,y,l}^{obs}) \tag{31}$$

L_x was the likelihood associated with data component x, where λ_x represented an optional additional weighting factor for the likelihood, $N_{x,y}^{eff}$ was the effective sample sizes for the likelihood, $p_{x,y,l}^{obs}$ was the observed proportion in size bin l during year y for data component x, and $\hat{p}_{x,y,l}$ was the predicted proportion in size bin l during year y for data component x. 10 multinomial likelihood components were included in the assessment (see Table 11 for descriptions, weighting factors, and effective sample sizes).

Iterative methods for determining appropriate effective samples sizes for composition data are suggested to avoid overweighting the size composition data and washing out the signal from the indices of abundance. The method of implementation used here is discussed below.

Lognormal likelihoods were implemented in the form:

$$L_x = \lambda_x \sum_y \frac{(ln(\hat{I}_{x,y}) - ln(I_{x,y}))^2}{2(ln(CV_{x,y}^2 + 1))} \tag{32}$$

L_x was the contritbution to the objective function of data component x, λ_x was any additional weighting applied to the component, $\hat{I}_{x,y}$ was the predicted value of quantity I from data component x during year y, $I_{x,y}$ was the observed value of quantity I from data component x during year y and $CV_{x,y}$ was the coefficient of variation for data component x during year y. 5 lognormal likelihood components were included in this assessment (see Table 11 for descriptions, weighting factors, and CVs).

Normal likelihoods were implemented in the form:

$$L_x = \lambda_x \sum_y (\hat{I}_{x,y} - I_{x,y})^2 \tag{33}$$

L_x was the contritbution to the objective function of data component x, λ_x was represents the weight applied to the data component (and can be translated to a standard deviation), $\hat{I}_{x,y}$ was the predicted value of quantity I from data component x during year y, $I_{x,y}$ was the observed value of quantity I from data component x during year y. 12 normal likelihood components were included in this assessment (see Table 11 for descriptions, weighting factors, and translated standard deviations).

Smoothing penalties were also placed on some estimated vectors of parameters in the form of normal likelihoods on the second differences of the vector. Code for this assessment can be found on github.com/szuwalski/SnowCrab.

Francis weighting

Downweighting size compositon data associated with indices of abundance is a suggested practice. Using the raw effective samples sizes can lead to overfitting the size composition data at the expense of poor fits to the index, which is one of the most important pieces of information to be fit in an assessment. Here, Francis' method (2011) of iterative reweighting of the size composition data was implemented by calculating a weighting factor by which to multiply the input sample sizes for the size composition of the survey data.

$$Francis = \frac{1}{var_y(\frac{\bar{L}_y - \hat{L}_y}{SE(\hat{L}_y)})} \tag{34}$$

$$\bar{L}_y = \sum_l \bar{L}_L p_{y,L} \tag{35}$$

$$\hat{L}_y = \sum_l \bar{L}_L \hat{p}_{y,L} \tag{36}$$

$$SE(\hat{L}_y) = \sqrt{\frac{\sum_L \hat{p}_{y,L}(\bar{L}_y - \hat{L}_y)^2}{N_y}} \tag{37}$$

Where $\bar{L}_y$ was the observed mean length of the catch in year y, $\hat{L}_y$ was the predicted mean length of the catch in year y, and $SE(\hat{L}_y)$ was the predicted standard error of the mean length of the catch in year y. $\bar{L}_L$ was the mide-point of a size bin and $p_{y,L}$ was the proportion of catch in sizebin L inyear y. N_y is the number of observation in year y. The weights were iteratively calculated and applied to the effective sample sizes for survey size composition data by sex (i.e. combining shell condition and maturity state) until the output Francis weights converged on a value <1.05 and > 0.95.

Tables and figures

Table 4: Changes in management quantities for stepwise changes in assessment model. Models progress stepwise through the list reported in section B of this report. Reported quantites are the MLEs because running MCMC for every model was prohibitively time-consuming. The MLEs for scenarios in which MCMCs were performed are very close to the medians of the posterior distributions and can be seen in the table of projected management quantities

Model	MMB	B35	F35	FOFL	OFL
Base	140.3	163.8	1.49	1.07	44.15
Base 2 CPUEq	137.4	163.2	1.48	1.06	42.81
Base 3 SurvFq	139.1	163.4	1.48	1.06	43.47
Base 4 AddRetroFrancis	139.1	163.4	1.48	1.06	43.47
Base 5 ChangeWtPars	139.3	164.7	1.43	1.03	43.17
Model 0_200	139.3	164.7	1.43	1.03	43.17
Model 0	116.7	146.6	0.96	0.7	34.25
Model 1a TrawlF_estAvg	95.54	140.2	1.12	0.74	26.4
Model 1b TrawlF_NoPen	96.3	141.2	1.27	0.83	26.73
Model 1c TrawlF_2vec	86.83	137.7	1.25	0.79	23.09
Model 2a MatPrior	55.3	134.1	2.05	0.95	7.81
Model 3a SmoothMat_Weight	58.47	136.1	2.4	1.17	9.24
Model 3b SmoothMat_Disc50	59.02	135.9	2.44	1.2	9.53
Model 1c TrawlF_2vec_200	101.8	150.9	2.02	1.25	28.35
Model 2a MatPrior_200	96.99	148.9	1.72	1.04	26.54
Model 3a SmoothMat_Weight_200	101.1	151.4	2.03	1.24	28.57
Model 3b SmoothMat_Disc50_200	99.73	150.5	2.02	1.23	28.14

Table 5: Observed growth increment data by sex

Female premolt length (mm)	Female postmolt length (mm)	Male premolt length (mm)	Male postmolt length (mm)
19.37	24.24	21.23	26.41
20.7	27.4	22.2	28.1
21.25	28.73	23.48	28.27
21.94	28.71	29.9	39.9
23.09	29.26	30.3	40.3
32.8	44.9	30.7	40.5
35.3	47.6	44.2	58.7
38.3	50.9	44.7	57.3
38.9	53	64.7	82.7
41	55.8	67.6	86
42.1	54.6	67.9	85.3
44.2	59.5	74.5	93.9
44.3	59.3	79.9	97.8
44.8	59.7	89.8	110
45.2	59.6	89.9	112.1
46.9	60.4	89.9	112.3
47	61.4	93.8	117.6
47.9	61.4	20	26.3
20.6	25.1		
20.8	27.6		
22	28.2		
22.9	28.6		

Table 6: Observed retained catches, discarded catch, and bycatch

Survey year	Retained catch (10000s)	Retained catch (10000 lbs)	Discarded females (10000s)	Discarded males (10000s)	Trawl bycatch (10000s)
1978	4021	5227	26.94	1407	1318
1979	5002	7503	33.51	1751	1053
1980	4462	6693	29.9	1562	766
1981	2409	2936	16.9	615.1	319.6
1982	2385	2613	23	554.9	130
1983	2401	2681	16.1	313.1	167.5
1984	5290	6600	15.94	893.8	178
1985	7650	9798	16.05	1464	152.8
1986	8131	10190	35.36	1410	656.3
1987	10572	13535	51.13	1851	1.92
1988	11262	14946	54.35	1527	235.4
1989	12898	16182	70.66	1904	273.3
1990	26512	32865	75.28	13782	209
1991	22738	31530	86.21	4808	805.5
1992	16956	23079	177.2	15967	1132
1993	11478	14978	118.3	5190	1301
1994	6061	7525	85.41	4788	835.9
1995	5291	6571	23.15	5634	448.8
1996	9998	11954	102.2	7398	330.1
1997	19352	25219	7.98	5159	530.3
1998	15104	19420	9.65	4157	290.2
1999	2508	3329	0.59	474.3	157.3
2000	1943	2526	0.62	520.4	152.5
2001	2515	3263	0.62	1574	104.9
2002	2325	2832	6.28	1401	66.59
2003	1867	2394	0.92	487.8	214.5
2004	1799	2489	0.92	550.6	348.9
2005	2455	3697	3.47	1125	133.1
2006	2968	3636	1.1	1630	234.8
2007	5253	6303	15.73	2237	159.2
2008	4595	5855	12.12	1771	109.5
2009	3529	4801	10.74	1066	234.4
2010	3768	5426	8.95	488.4	71.71
2011	6056	8883	260.9	1339	66.16
2012	4746	6625	40.83	1907	89.64
2013	4193	5398	96.3	3309	41.05
2014	5503	6794	249.5	3343	51.59
2015	2961	4061	101.5	2577	51.77
2016	NA	NA	NA	NA	NA

Table 7: Observed mature male and female biomass (1000 t) at the time of the survey and coefficients of variation

Survey year	Female mature biomass	Female CV	Mature male biomass	Male CV	Males >101mm (10000s)	Males >101mm (kt)
1978	101.7	0.2	193.5	0.12	16.34	98.95
1979	216.8	0.2	241.3	0.12	16.91	105
1980	281.3	0.32	187.5	0.17	11.64	69.98
1981	123.3	0.17	113.5	0.11	4.04	23.01
1982	144.4	0.15	176.8	0.14	6.09	33.34
1983	90.13	0.2	161.6	0.13	7.01	38.09
1984	42.32	0.19	177.7	0.12	15.18	88.73
1985	6.12	0.2	71.84	0.11	7.28	43.39
1986	15.74	0.18	89.81	0.11	7.79	46.7
1987	122.6	0.16	194.6	0.11	12.86	74.44
1988	169.9	0.17	259.4	0.15	17.31	104.7
1989	264.2	0.25	299.2	0.11	15.89	92.31
1990	182.9	0.19	443.8	0.14	38.64	224.7
1991	214.9	0.19	466.6	0.15	45.29	292.2
1992	131.4	0.18	235.5	0.09	22.73	143.9
1993	132.1	0.16	183.9	0.1	12.67	78.11
1994	126.2	0.15	171.3	0.08	7.26	44.78
1995	168.7	0.14	220.5	0.13	6.52	37.75
1996	107.3	0.14	288.4	0.12	15.53	87.57
1997	103.8	0.2	326.8	0.1	28.06	168.7
1998	72.73	0.25	206.4	0.09	20.97	126.7
1999	30.89	0.21	95.85	0.09	8.52	52.53
2000	96.46	0.52	96.39	0.14	6.98	41.88
2001	77.24	0.28	136.5	0.12	7.07	41.51
2002	30.22	0.28	93.17	0.23	6.42	36.56
2003	41.71	0.31	79.07	0.12	5.56	32.57
2004	50.16	0.26	79.57	0.14	5.74	35.99
2005	64.85	0.17	123.5	0.11	6.33	40.67
2006	51.93	0.18	139.3	0.26	12.09	71.13
2007	55.89	0.22	153.1	0.15	12.75	73.62
2008	57.15	0.19	142	0.1	11.36	66.56
2009	52.16	0.21	148.2	0.13	12.99	78.92
2010	98.01	0.18	162.8	0.12	13.83	88.35
2011	175.8	0.18	167.1	0.11	14.76	94.67
2012	149.4	0.2	122.2	0.12	8.54	53.17
2013	131.4	0.18	97.46	0.12	7.18	42.93
2014	119.7	0.19	163.5	0.16	13.88	81.39
2015	85.13	0.17	80.04	0.12	5.61	35.77
2016	55.39	0.21	63.21	0.11	3.65	21.96

Table 8: Parameter bounds and symbols

Parameter	Lower	Upper	Estimated?	Symbol
af	-100	0	1	α_f
am	-50	0	1	α_m
bf	1	10	1	$\beta_{f,1}$
bm	1	5	1	$\beta_{m,1}$
b1	1	1.5	1	$\beta_{f,2}$
bf1	1	2	1	$\beta_{m,2}$
deltam	10	50	1	δ_m
deltaf	5	50	1	δ_f
st__gr	0.5	0.5	0	stgr
growth__beta	0.749	0.751	0	β_g
mateste	-6	-1e-10	1	$\Omega_{m,l}$
matestfe	-6	-1e-10	1	$\Omega_{f,l}$
mean__log__rec	-Inf	Inf	1	Rec_{avg}
rec__devf	-15	15	1	$Rec_{f,dev,y}$
alpha1__rec	11.49	11.51	0	α_{rec}
beta__rec	3.99	4.01	0	β_{rec}
mnatlen__styr	-3	15	1	$\lambda_{male,v,l}$
fnatlen__styr	-10	15	1	$\lambda_{fem,v,l}$
log__avg__fmort	-Inf	Inf	1	$F^{log}_{avg,dir}$
fmort__dev	-5	5	1	$F^{log}_{dev,dir,y}$
log__avg__fmortdf	-8	-1e-04	1	$F^{log}_{avg,disc}$
fmortdf__dev	-15	15	1	$F^{log}_{dev,disc,y}$
log__avg__fmortt	-8	-1e-04	1	$F^{log}_{avg,trawl}$
fmortt__dev__era1	-15	15	1	$F^{log}_{dev,trawl,era1}$
fmortt__dev__era2	-15	15	1	$F^{log}_{dev,trawl,era2}$
log__avg__sel50__mn	4	5	1	$S_{50,new,dir}$
log__avg__sel50__mo	4	5	1	$S_{50,old,dir}$
fish__slope__mn	0.1	0.5	1	$S_{slope,m,d}$
fish__fit__slope__mn	0.05	0.5	1	$S_{slope,m,d}$
fish__fit__sel50__mn	85	120	1	$S_{50,old,dir}$
fish__slope__mo2	1.9	2	1	$S_{slope,m,d}$
fish__sel50__mo2	159	160	1	$S_{50,old,dir}$
fish__slope__mn2	0.01	2	1	$S_{slope,m,d}$
fish__sel50__mn2	100	160	1	$S_{50,old,dir}$
fish__disc__slope__f	0.1	0.7	1	$S_{slope,m,d}$
fish__disc__sel50__f	1	5	1	$S_{50,old,dir}$
fish__disc__slope__tf	0.01	0.3	1	$S_{slope,trawl}$
fish__disc__sel50__tf	30	120	1	$S_{50,trawl}$
srv1__q	0.2	1	1	$q_{m,era1,surv}$
srv1__q__f	0.2	1	1	$q_{f,era1,surv}$
srv1__sel95	30	150	1	$S_{95,era1,surv}$
srv1__sel50	0	150	1	$S_{50,era1,surv}$
srv2__q	0.2	1	1	$q_{m,era2,surv}$
srv2__q__f	0.2	1	1	$q_{f,era2,surv}$
srv2__sel95	50	160	1	$S_{95,era2,surv}$
srv2__sel50	0	80	1	$S_{50,era2,surv}$
srv3__q	0.2	1	1	$q_{m,era3,surv}$
srv3__sel95	40	200	1	$S_{95,m,era2,surv}$
srv3__sel50	25	90	1	$S_{50,m,era2,surv}$

Parameter	Lower	Upper	Estimated?	Symbol
srv3_q_f	0.2	1	1	$q_{f,era3,surv}$
srv3_sel95_f	40	150	1	$S_{95,f,era2,surv}$
srv3_sel50_f	0	90	1	$S_{50,f,era2,surv}$
srvind_q	0.1	1	1	$q_{m,09,ind}$
srvind_q_f	0.01	1	1	$q_{f,09,ind}$
srvind_sel95_f	55	120	1	$S_{95,f,09,ind}$
srvind_sel50_f	-50	55	1	$S_{50,f,09,ind}$
srv10in_q	0.1	1	1	$q_{m,10,ind}$
srv10ind_q_f	0.01	1	1	$q_{f,10,ind}$
selsmo10ind	-4	-0.001	1	SelVecMaleInd09
selsmo09ind	-4	-0.001	1	SelVecMaleInd10
Mmult_imat	0.2	2	1	$\gamma_{natM,imm}$
Mmult	0.2	2	1	$\gamma_{natM,mat,m}$
cpueq	8.77e-05	0.00877	1	q_{cpue}

Table 9: Estimated parameter values by scenario (these are maximum likelihood estimates)

Parameter	Model 0	Model 1	Model 2	Model 3	Model 3a	Model 3b
af	-4.09	-3.24	-3.67	-3.56	-4.82	-5.08
am	-10.61	-11.9	-10.45	-5.58	-11.15	-5.74
bf	1.48	1.44	1.46	1.45	1.51	1.53
bm	1.76	1.82	1.73	1.53	1.76	1.54
b1	1.17	1.16	1.12	1.15	1.11	1.15
bf1	1.03	1.04	1	1	1.04	1.02
deltam	27.56	27.43	34.16	32.18	34.42	32.2
deltaf	33.84	32.59	32.98	32.44	33.94	34.37
st_gr	0.5	0.5	0.5	0.5	0.5	0.5
growth_beta	vector	vector	vector	vector	vector	vector
mateste	vector	vector	vector	vector	vector	vector
matestfe	vector	vector	vector	vector	vector	vector
rec_devf	vector	vector	vector	vector	vector	vector
alpha1_rec	11.5	11.5	11.5	11.5	11.5	11.5
beta_rec	4	4	4	4	4	4
mnatlen_styr	vector	vector	vector	vector	vector	vector
fnatlen_styr	vector	vector	vector	vector	vector	vector
log_avg_fmort	-0.55	-0.05	0.04	-0.1	0.15	-0.15
fmort_dev	vector	vector	vector	vector	vector	vector
log_avg_fmortdf	-6.84	-6.72	-6.6	-5.5	-5.63	-6.42
fmortdf_dev	vector	vector	vector	vector	vector	vector
log_avg_fmortt	-5.4	-4.14	-4.04	-4.23	-3.97	-4.21
fmortt_dev_era1	NA	vector	vector	vector	vector	vector
fmortt_dev_era2	NA	vector	vector	vector	vector	vector
log_avg_sel50_mn	4.66	4.68	4.67	4.67	4.67	4.67
log_avg_sel50_mo	4.5	4.5	4.5	4.5	4.5	4.5
fish_slope_mn	0.18	0.18	0.19	0.19	0.2	0.19
fish_fit_slope_mn	0.42	0.42	0.43	0.42	0.41	0.42
fish_fit_sel50_mn	96.11	95.68	95.33	95.72	95.39	95.78
fish_slope_mo2	1.95	1.95	1.95	1.95	1.95	1.95
fish_sel50_mo2	159.5	159.5	159.5	159.5	159.5	159.5
fish_slope_mn2	1	1	1	1	1	1
fish_sel50_mn2	130	130	130	130	130	130
fish_disc_slope_f	0.3	0.3	0.29	0.23	0.24	0.24
fish_disc_sel50_f	4.2	4.2	4.2	4.33	4.3	4.26
fish_disc_slope_tf	0.1	0.09	0.09	0.09	0.09	0.08
fish_disc_sel50_tf	96.86	114.99	114.3	112.69	114.39	114.18
srv1_q	1	1	1	1	1	1
srv1_q_f	1	1	1	1	0.77	1
srv1_sel95	62.48	62.84	57.71	63.01	54.95	59.89
srv1_sel50	43.7	44.08	41.69	44.21	39.05	42.66
srv2_q	0.47	0.51	0.56	0.51	0.63	0.49
srv2_q_f	0.32	0.35	0.38	0.35	0.36	0.32
srv2_sel95	64.51	67.94	61.35	67.69	71.51	61.3
srv2_sel50	42.74	44.49	41.62	44.61	45.73	41.32
srv3_q	0.56	0.64	0.72	0.63	0.67	0.62
srv3_sel95	60.44	61.02	53.51	60.52	52.25	57.24
srv3_sel50	39.78	39.89	37.71	39.92	37.38	38.42
srv3_q_f	0.44	0.49	0.6	0.49	0.53	0.49

Parameter	Model 0	Model 1	Model 2	Model 3	Model 3a	Model 3b
srv3_sel95_f	43.94	44.16	44.1	44.58	44.58	43.09
srv3_sel50_f	33.86	33.87	33.93	34.04	34.48	33.27
srvind_q	0.36	0.35	0.38	0.36	0.36	0.36
srvind_q_f	0.11	0.11	0.12	0.11	0.11	0.11
srvind_sel95_f	55.92	56.96	56.88	56.06	55.45	55
srvind_sel50_f	49.72	50.22	50.08	49.82	49.6	49.21
srv10ind_q_f	1	1	1	1	1	1
selsmo10ind	vector	vector	vector	vector	vector	vector
selsmo09ind	vector	vector	vector	vector	vector	vector
Mmult_imat	1.93	1.99	2	2	2	1.8
Mmult	1.13	1.11	1.16	1.12	1.12	1.13
cpueq	0	0	0	0	0	0

Table 10: Contribution to the objective function by individual likelihood component by modeling scenario. Values in columns after Model 0 are the likelihood contribution of Model 0 minus the likelihood contribution of the model in the column. Positive values represent improvements in fit. Note that some of the model scenarios involve changing the weightings of data sources which invalidate the comparison of likelihoods for a data source among models.

Likelihood component	Model 0	Model 1	Model 2	Model 3	Model 3a	Model 3b
Recruitment deviations	38.44	-1.05	-2.16	-1.73	-5.56	-1.89
Initial numbers old shell males small length bins	2.21	0.01	0.04	0.02	0.84	0.03
ret fishery length	389.5	5.32	-1	5.54	44.49	6.88
total fish length (ret + disc)	829.7	8.37	12.29	8.56	23.15	7.99
female fish length	231.4	-4.68	-5.62	1.59	6.67	9.48
survey length	4563	64.6	39.37	77.97	3564	-76.22
trawl length	291	4.21	-19.12	6.51	-23.16	0.57
2009 BSFRF length	-81.27	0.26	2.21	0.43	3.91	1.67
2009 NMFS study area length	-68.12	-0.43	-0.07	0.56	1.66	-0.32
M multiplier prior	5.9	1.26	-3.01	0.32	0.86	-13.91
maturity smooth	58.62	1.71	53.08	18.97	35.98	17.85
growth males	54.93	17.3	14.73	18.43	4.52	16.53
growth females	97.99	3.4	4.3	-18.05	68.49	-35.4
2009 BSFRF biomass	0.16	-0.07	-0.17	-0.06	-0.1	-0.05
2009 NMFS study area biomass	0.05	-0.06	-0.17	-0.06	-0.11	-0.04
cpue q	0.16	-0.04	-0.07	-0.05	-0.08	-0.04
retained catch	3.8	-0.31	0.26	-0.31	2.08	-0.26
discard catch	170.9	27.03	85.28	26.57	128.8	18.47
trawl catch	6.65	-1.23	0.87	-1.1	0.2	-1.98
female discard catch	5.93	-0.4	-0.62	-0.59	-1.09	-0.19
survey biomass	368.5	7.03	26.69	8.6	38.71	2.68
F penalty	83.84	45.03	45.08	45.89	41.54	46.45
2010 BSFRF Biomass	1.63	-1.23	-4.39	-1.13	-3.02	-1.25
2010 NMFS Biomass	0.49	-0.52	-1.2	-0.53	-0.74	-0.38
Extra weight survey lengths first year	562.6	51.78	55.46	50.63	462.2	52.19
2010 BSFRF length	-56.99	0.04	-1.93	0.45	-1.35	-2.41
2010 NMFS length	-62.95	0.85	-4.48	1.64	-2.73	-3.74
smooth selectivity	3.51	0.24	0.04	0.31	0.23	0.21
smooth female selectivity	0	0	0	0	0	0
init nos smooth constraint	36.41	-3.91	-3.55	-4.94	1.22	-4.03

Table 11: Likelihoods form, weighting, and priors for the base model

Likelihood component	Form	Weighting	Prior
Recruitment deviations	normal	sd = 0.71	0
Initial numbers old shell males small length bins	normal	sd = 707.11	NA
ret fishery length	multinomial	EffN = 200	NA
total fish length (ret + disc)	multinomial	EffN = 200	NA
female fish length	multinomial	EffN = 200	NA
survey length	multinomial	EffN = 200	NA
trawl length	multinomial	EffN = 200	NA
2009 BSFRF length	multinomial	EffN = 200	NA
2009 NMFS study area length	multinomial	EffN = 200	NA
M multiplier prior	normal	sd = 0.23	1
maturity smooth	normal	sd = 3.16	NA
growth males	normal	sd = 0.5	NA
growth females	normal	sd = 0.5	NA
2009 BSFRF biomass	lognormal	cv = 1.64,1.79 (f,m)	NA
2009 NMFS study area biomass	lognormal	cv = 0.46,0.32 (f,m)	NA
cpue q	normal	sd = 0.32	NA
retained catch	normal	sd = 0.22	NA
discard catch	normal	sd = 3	NA
trawl catch	normal	sd = 0.22	NA
female discard catch	normal	sd = 17	NA
survey biomass	lognormal	cv = 0.14-0.57; 0.084-0.227 (f,m)	NA
F penalty	normal	sd = 0.5	1.15
2010 BSFRF Biomass	lognormal	cv = 0.19,0.29 (f,m)	NA
2010 NMFS Biomass	lognormal	cv = 0.13,0.21 (f,m)	NA
Extra weight survey lengths first year	multinomial	EffN = 200	NA
2010 BSFRF length	multinomial	EffN = 200	NA
2010 NMFS length	multinomial	EffN = 200	NA
smooth selectivity	norm2(firstdiff(firstDiff))	wt = 2	NA
smooth female selectivity	norm2(firstdiff(firstDiff))	wt = 3	NA
init nos smooth constraint	norm2(firstdifference)	wt = 1	NA

Table 12: Projected status and catch specifications for snow crab (1,000t). '(ml)' indicates the maximum likelihood estimate of the quantity. ABCs are calculated based on a 10% buffer subtracted from the OFL.

Model	OFL	OFL (ml)	B35	MMB	Status	F35	FOFL	ABC	ABC (ml)
Model 0	32.74	35.8	158.5	115.1	0.73	1.41	0.95	29.47	32.22
Model 1	19.74	19.71	146.6	81.77	0.56	1.98	1.11	17.77	17.74
Model 2	11.87	12.1	134.9	59.46	0.44	1.89	0.92	10.69	10.89
Model 3	19.84	19.63	146.2	81	0.55	2.06	1.13	17.86	17.66
Model 3a	13.62	13.02	139.7	68.59	0.49	2.64	1.37	12.26	11.72
Model 3b	23.71	24.59	151.6	91.57	0.6	1.91	1.14	21.34	22.13

Table 13: Predicted mature male, mature female, and males >101mm biomass (1000 t) and numbers (in 10000s) at the time of the survey from the chosen model

Survey year	Female mature biomass	Mature male biomass	Males >101mm biomass	Female numbers	Male numbers	Males >101mm numbers
1978	94.19	183.3	71.6	264.2	163	11.47
1979	130	167.7	64.12	382.2	252.8	9.62
1980	202.6	128.2	30.21	432.4	304.8	4.8
1981	225.7	125.2	12.28	410.5	293.2	2.25
1982	68.89	90.21	40.14	116.9	122.1	7.35
1983	60.54	135.8	109.7	109	113.5	18.84
1984	56.2	154.6	146.1	117.4	130.6	24.32
1985	60.15	142.5	133	136.1	162.8	22.03
1986	69.76	121.3	95.23	196.2	255.7	15.94
1987	99.32	118.2	69.33	211.4	277	12.03
1988	110.2	133.6	63.43	244.8	323.3	11.28
1989	220.4	213.7	83.06	449.5	396.7	14.84
1990	213.6	277.4	143	374.9	315.3	25.07
1991	185.1	261.2	127.2	320.1	235.1	22.05
1992	157.9	221.4	102.6	453.1	329	18.13
1993	189.6	191	89.8	494.4	387.4	15.28
1994	217.9	167.5	53.22	433	354.9	9.01
1995	207	188.9	52.55	354.8	280.6	9.38
1996	176.7	257.9	127	286.5	207.9	22.49
1997	144.8	299.5	200.3	234.1	153	34
1998	118.2	232.7	148.8	212.4	126.5	24.99
1999	103	153.8	78.96	209	126.7	13.39
2000	97.67	124.5	60.43	183.8	118.9	10.21
2001	88.82	106.2	46.49	156.7	102.8	7.94
2002	77.08	98.9	43.36	145.6	95.6	7.57
2003	69.61	101.4	54.59	162.7	114.5	9.41
2004	72.72	100.6	60.19	205.9	160.5	10.14
2005	87.72	96.69	53.39	205.6	172.5	8.96
2006	93.49	100.2	47.64	201.6	171.6	8.17
2007	93.24	119.8	60.98	171.6	143.6	10.6
2008	83.78	139.3	83	143.3	112.4	14.33
2009	71.23	147.2	99.03	149.9	112.6	16.73
2010	68.94	139.5	98.7	156.2	121	16.54
2011	70.99	120.5	81.77	142.6	113.6	13.62
2012	67.6	91.33	46.46	144.2	112.6	7.95
2013	66.47	83.07	36.97	150.1	117.4	6.56
2014	68.22	85.87	43.06	144.7	114.6	7.48
2015	67.3	80.25	37.08	215.7	174.5	6.39
2016	88.38	87.25	81.26	439.1	377.9	14.05

Table 14: Predicted mature male biomass at mating, mature female biomass at mating, and recruitment (10000s)

Survey year	Female mature biomass	Mature male biomass	Recruit
1978	183.8	110	202.9
1979	169.2	155.5	143.3
1980	130.6	236.2	85.06
1981	128	259.1	30.07
1982	188.2	246	123.9
1983	281.4	215.4	214.6
1984	319.7	200.3	264.8
1985	295.3	215	648.1
1986	252.5	249.3	121.9
1987	248.1	356.4	567.8
1988	280.3	391.4	28.25
1989	349.4	448.9	68.66
1990	451.9	434.7	64.44
1991	425.3	376.7	652.6
1992	360.3	321.3	303.1
1993	312	386.2	82.44
1994	274.8	443.6	30.95
1995	309	421.4	13.82
1996	419.6	359.6	20.21
1997	486.1	294.7	84.5
1998	377.7	240.5	116
1999	250	209.6	35.41
2000	202.8	198.8	31.1
2001	173	180.8	65.52
2002	161	156.9	143.6
2003	165	141.7	225.4
2004	163.7	148.1	93.24
2005	157.8	178.6	113.8
2006	163.5	190.3	16.84
2007	195.2	189.8	23.15
2008	226.4	170.5	116.9
2009	238.9	145	98.35
2010	226.5	140.3	42.47
2011	195.8	144.5	97.15
2012	148.7	137.6	98.83
2013	135.4	135.3	65.58
2014	139.9	138.9	325.2
2015	130.8	137	823.7
2016	142.6	180	NA

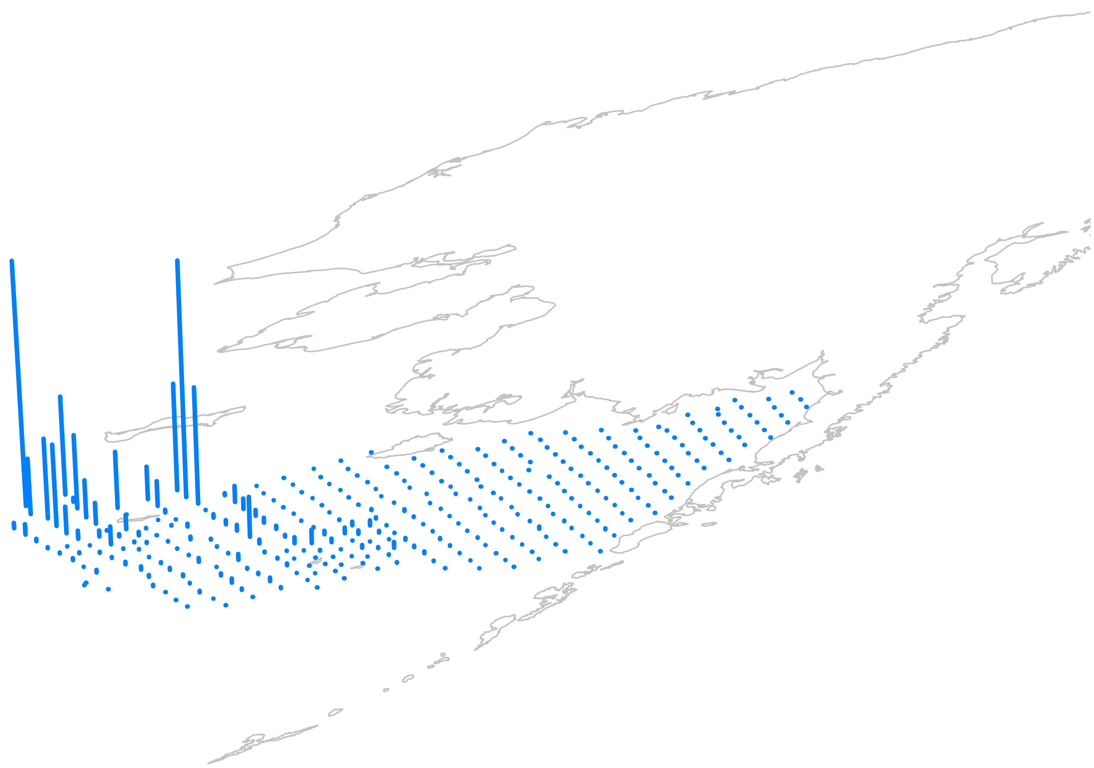


Figure 1: Observed relative density of all males at the time of the 2016 NMFS summer survey

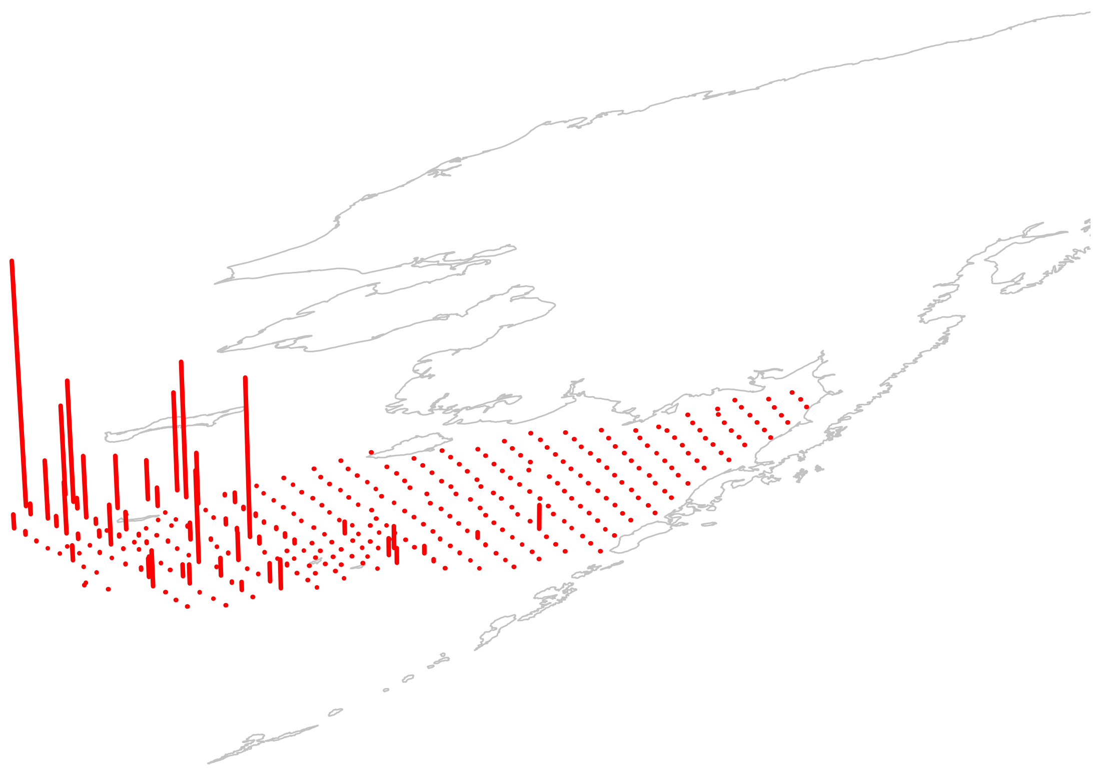


Figure 2: Observed relative density of all females at the time of the 2016 NMFS summer survey

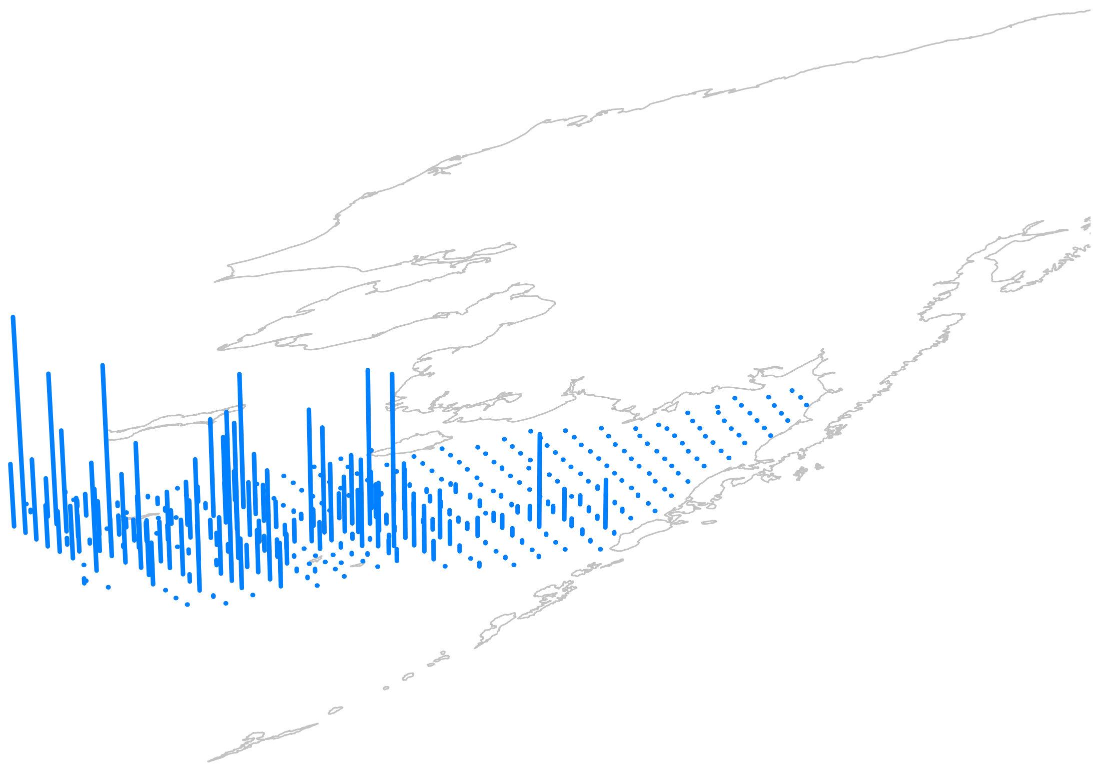


Figure 3: Observed relative density of males >77mm carapace width at the time of the 2016 NMFS summer survey

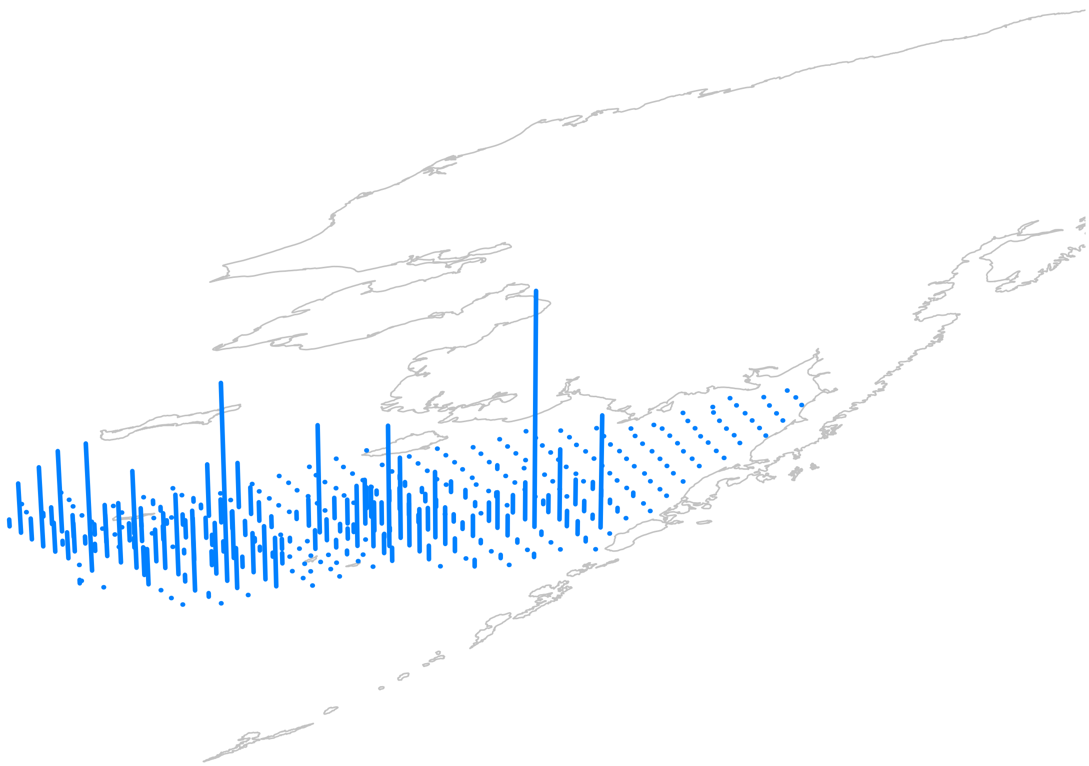


Figure 4: Observed relative density of males >101mm carapace width at the time of the 2016 NMFS summer survey

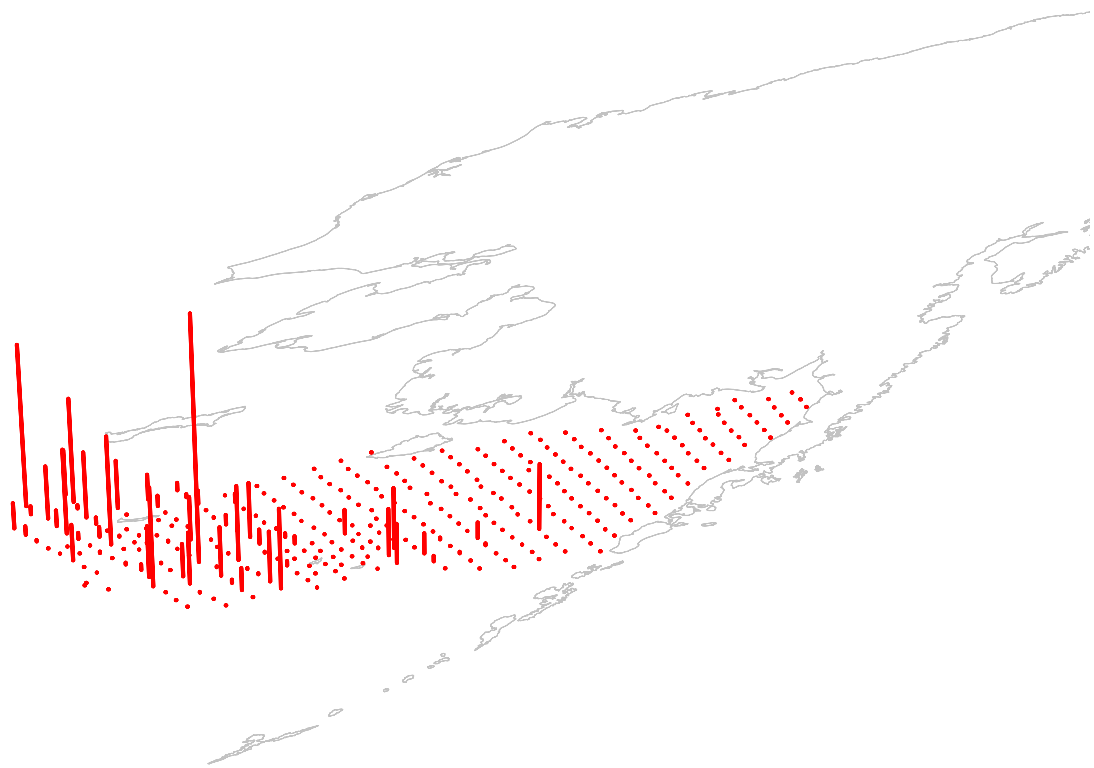


Figure 5: Observed relative density of mature females at the time of the 2016 NMFS summer survey

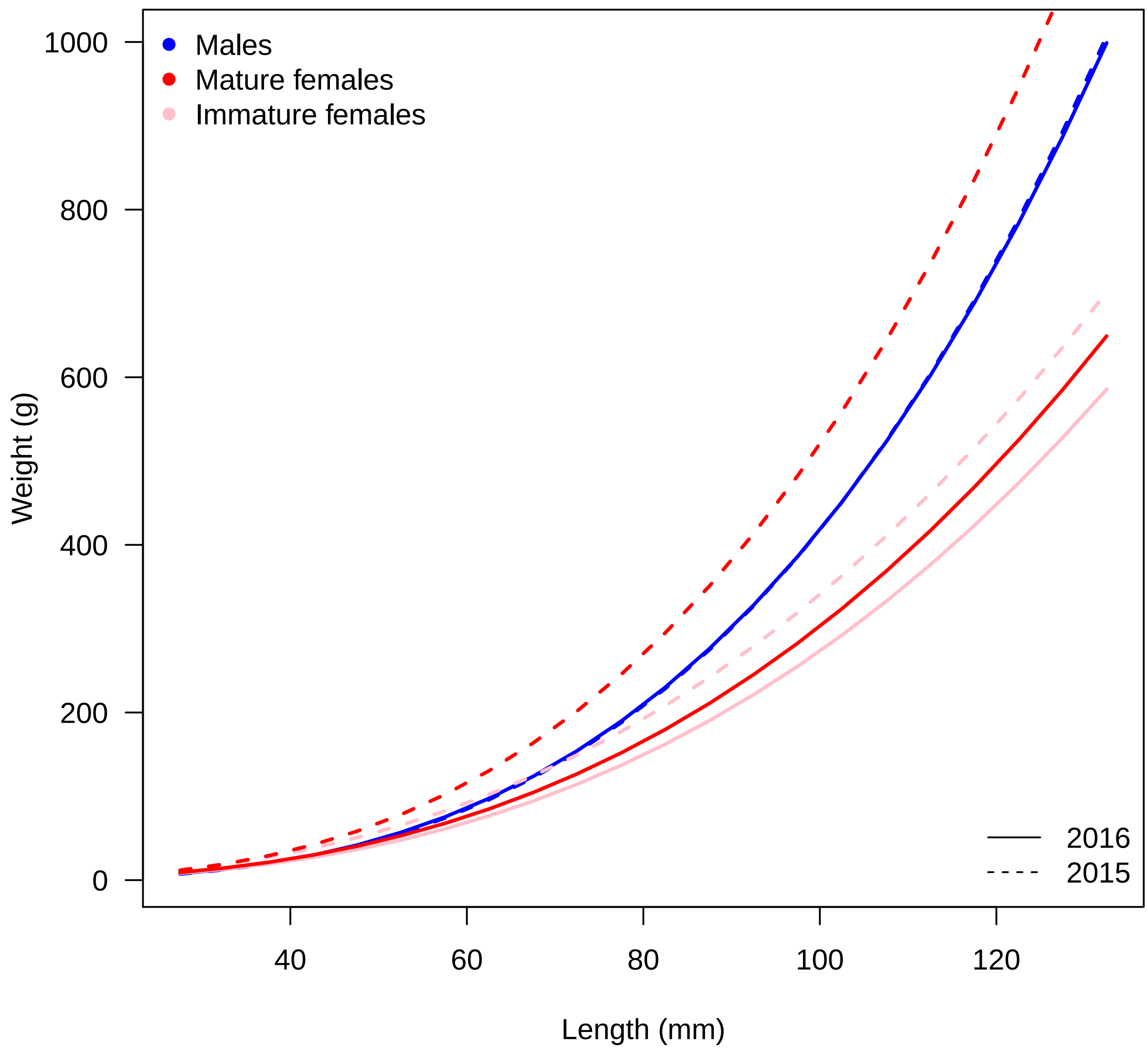


Figure 6: Changes in weight at length from 2015 to 2016 assessment

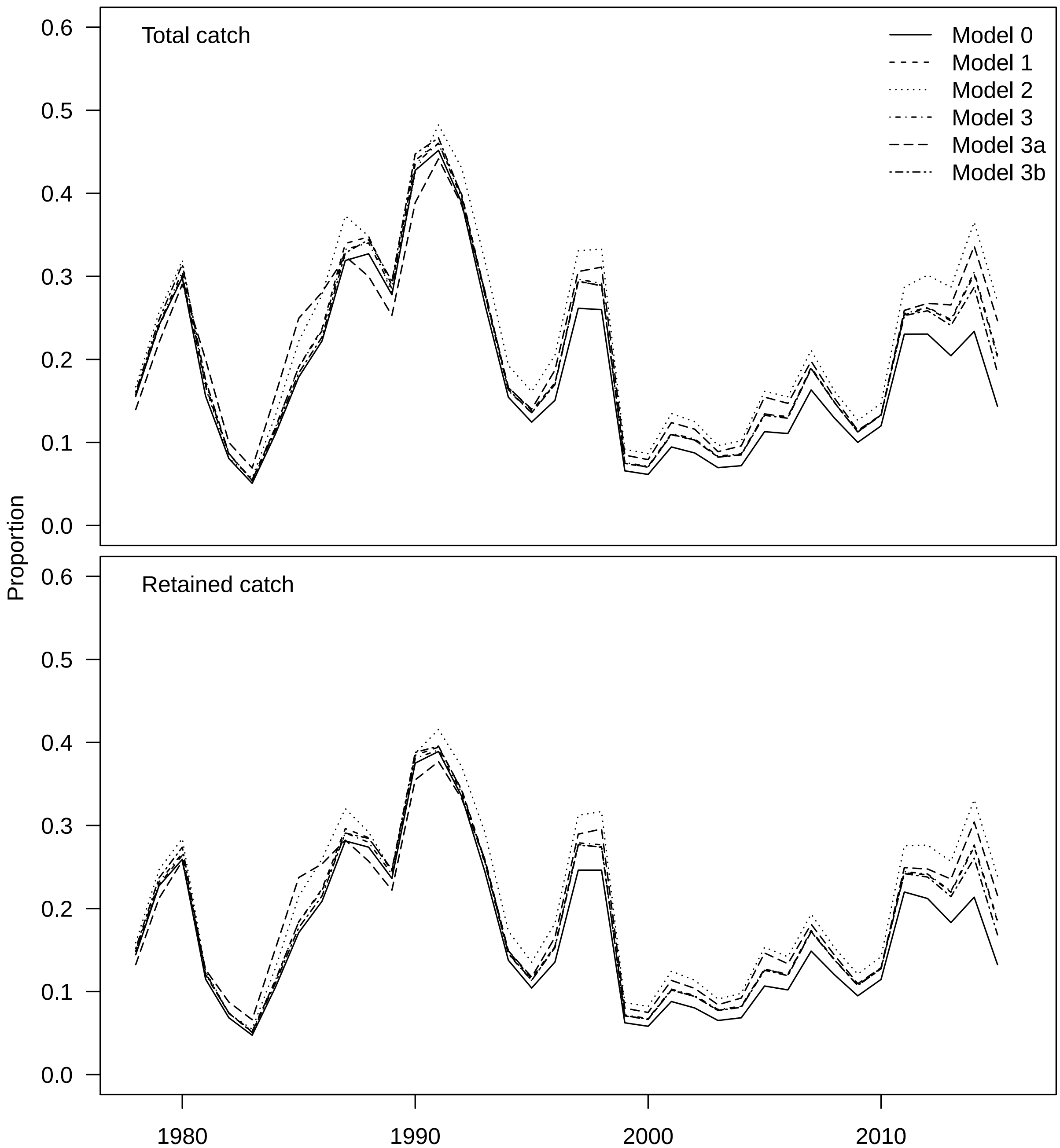


Figure 7: Model predicted ratio of catch to mature male biomass

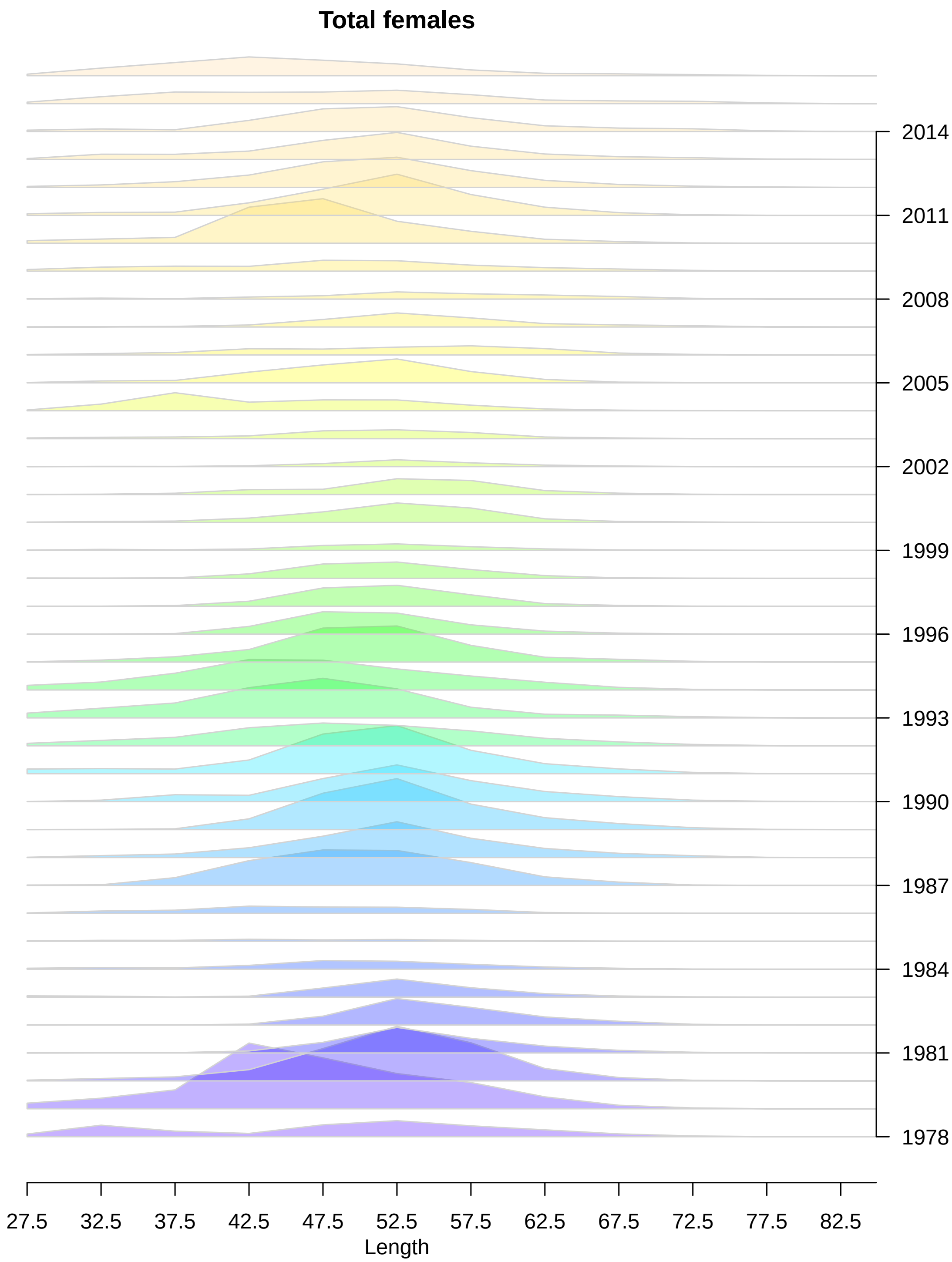


Figure 8: Observed relative numbers at length at the time of the survey

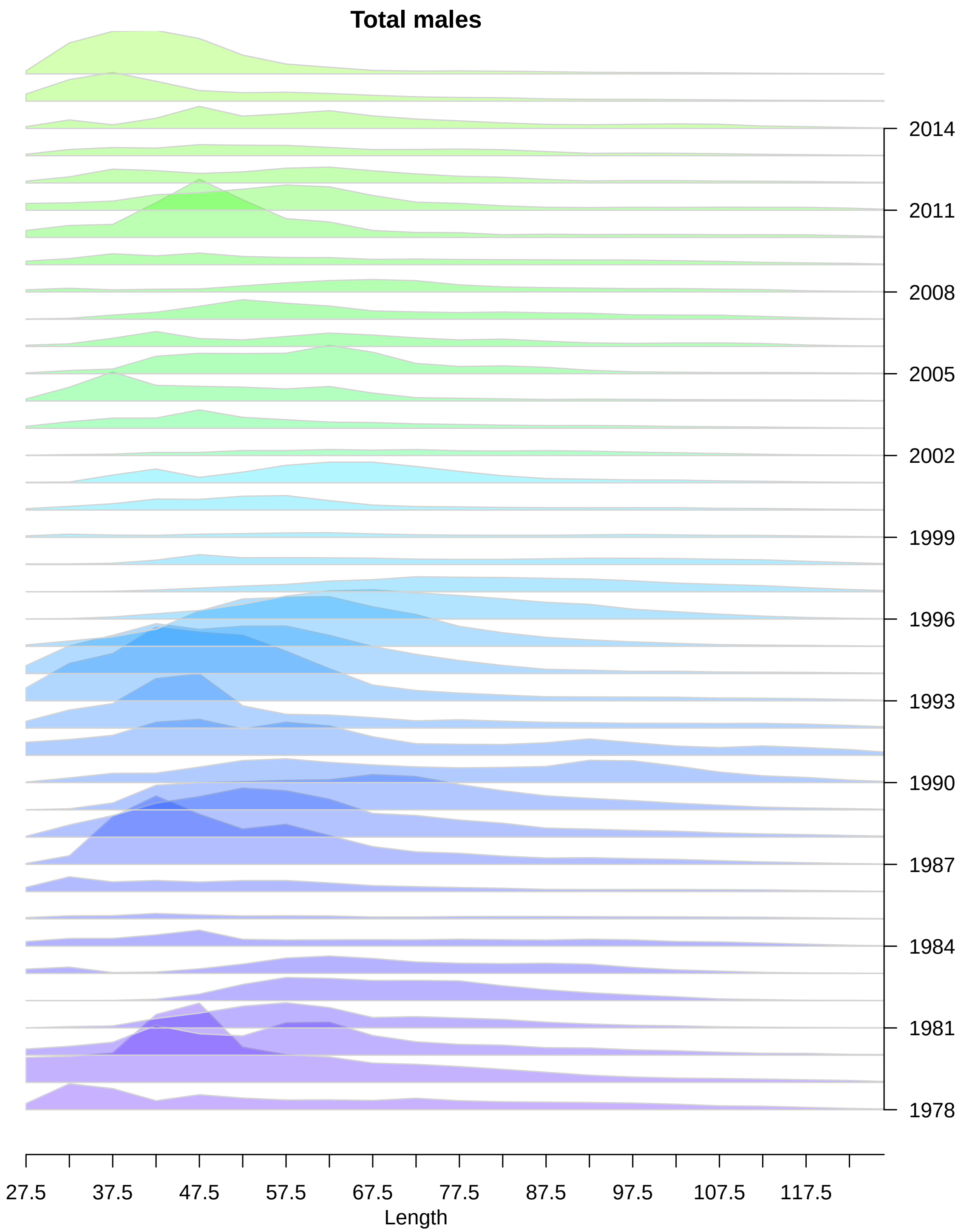


Figure 9: Observed relative numbers at length at the time of the survey

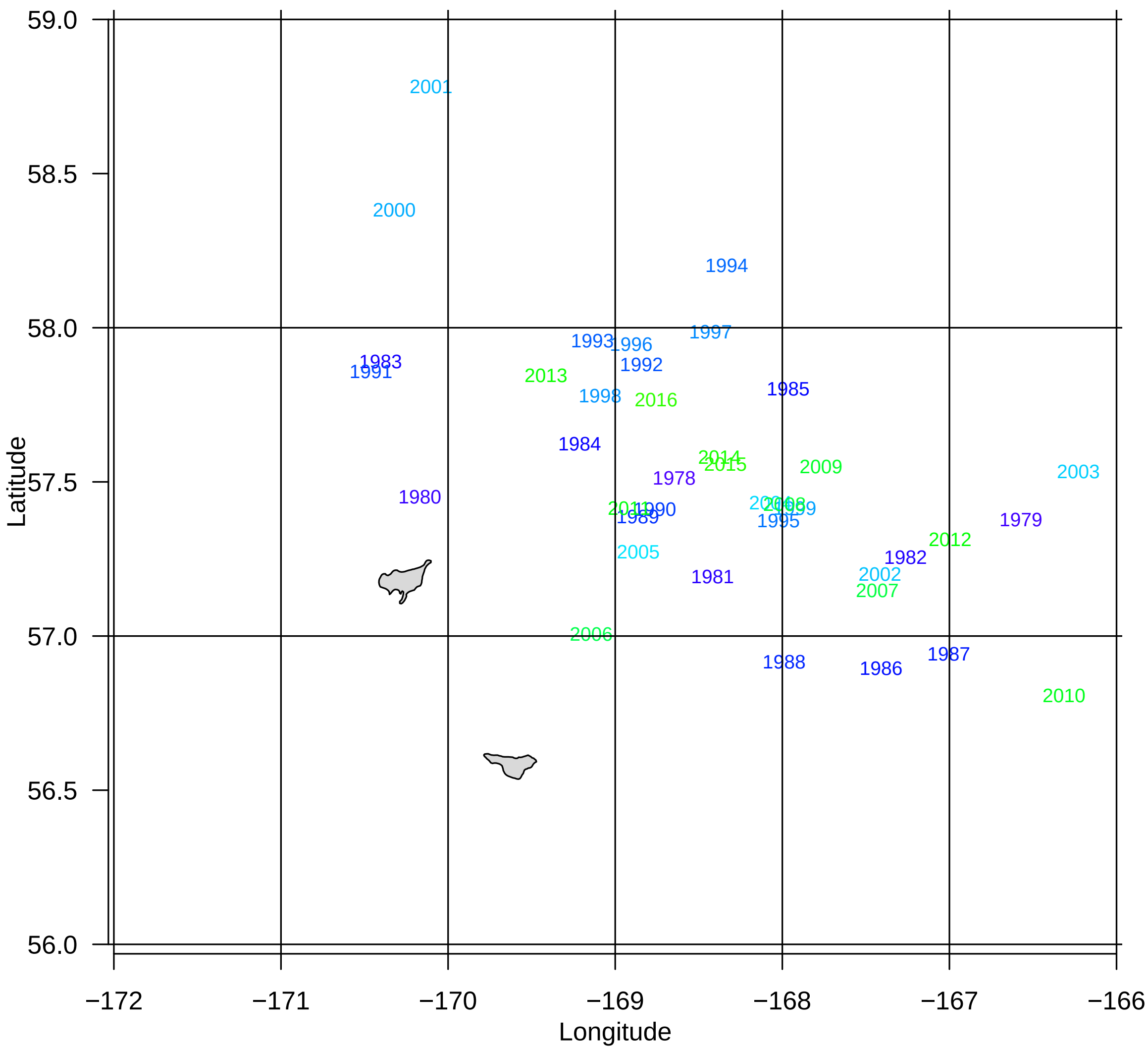


Figure 10: Centroid of mature females observed in the survey over time. Dark blue indicates years early in the time series; green are the most recent years in the time series.

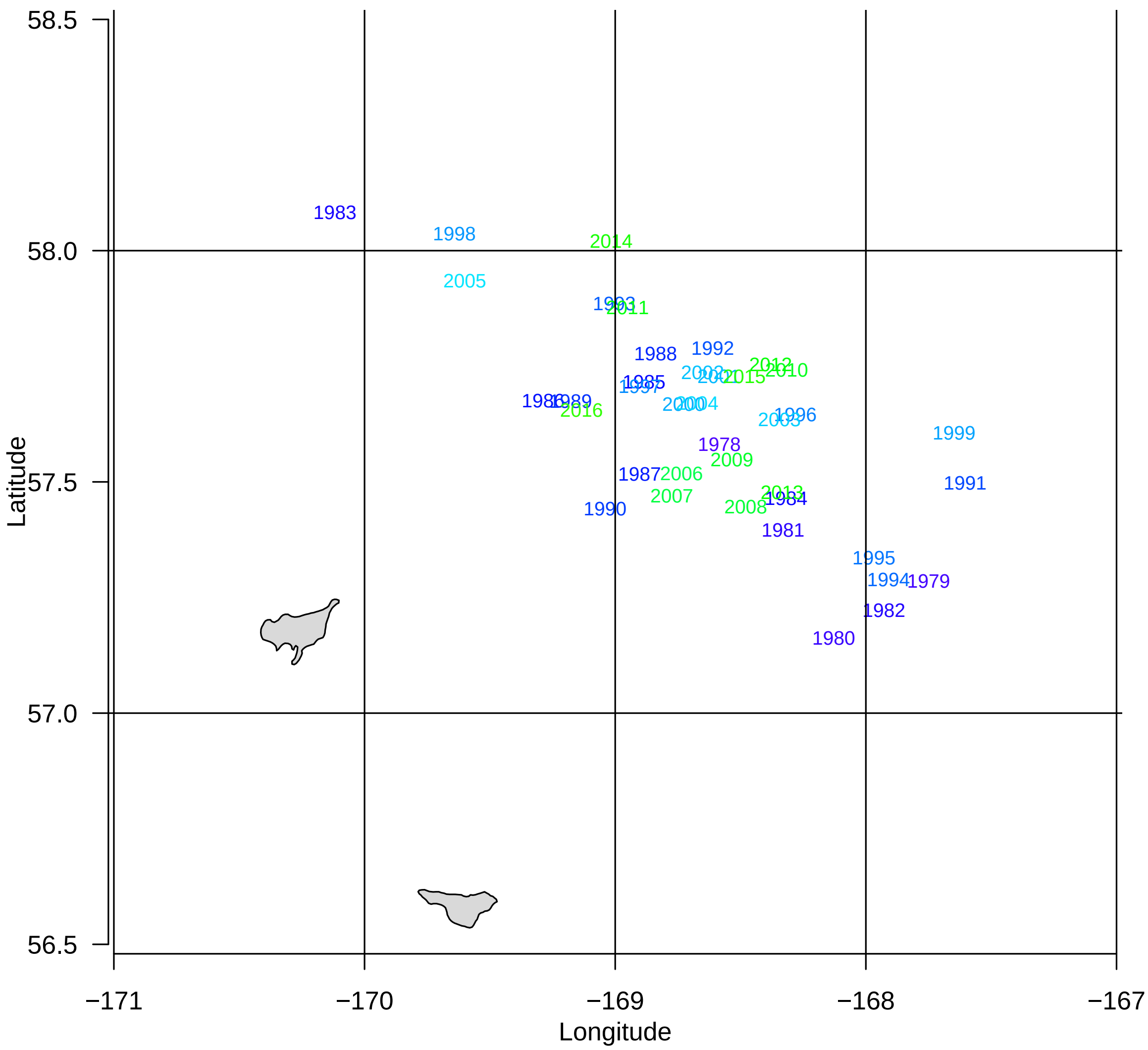


Figure 11: Centroid of large males observed in the survey over time. Dark blue indicates years early in the time series; green are the most recent years in the time series.

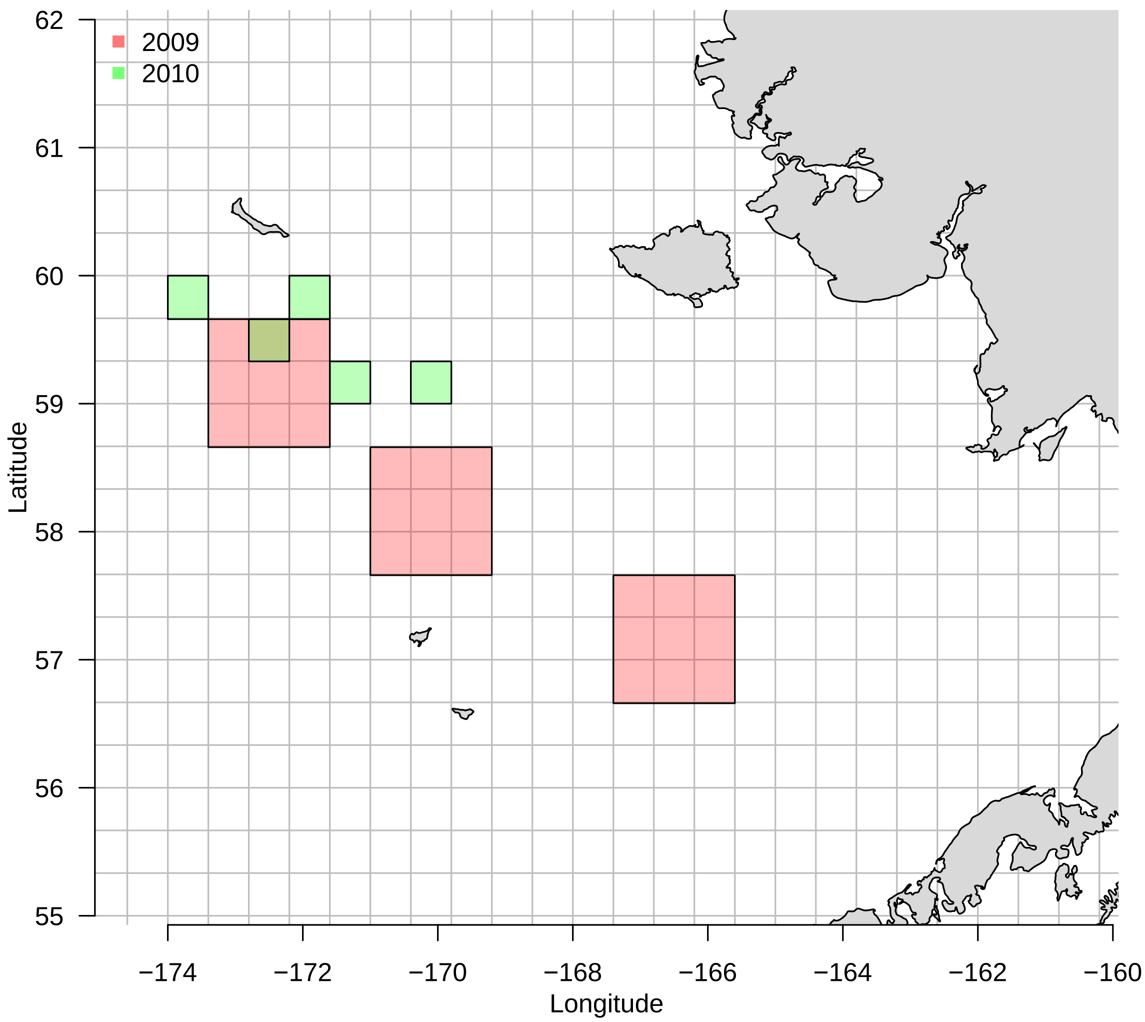


Figure 12: Location of survey selectivity experiments (2009 & 2010; revise this figure with BSFRF data)

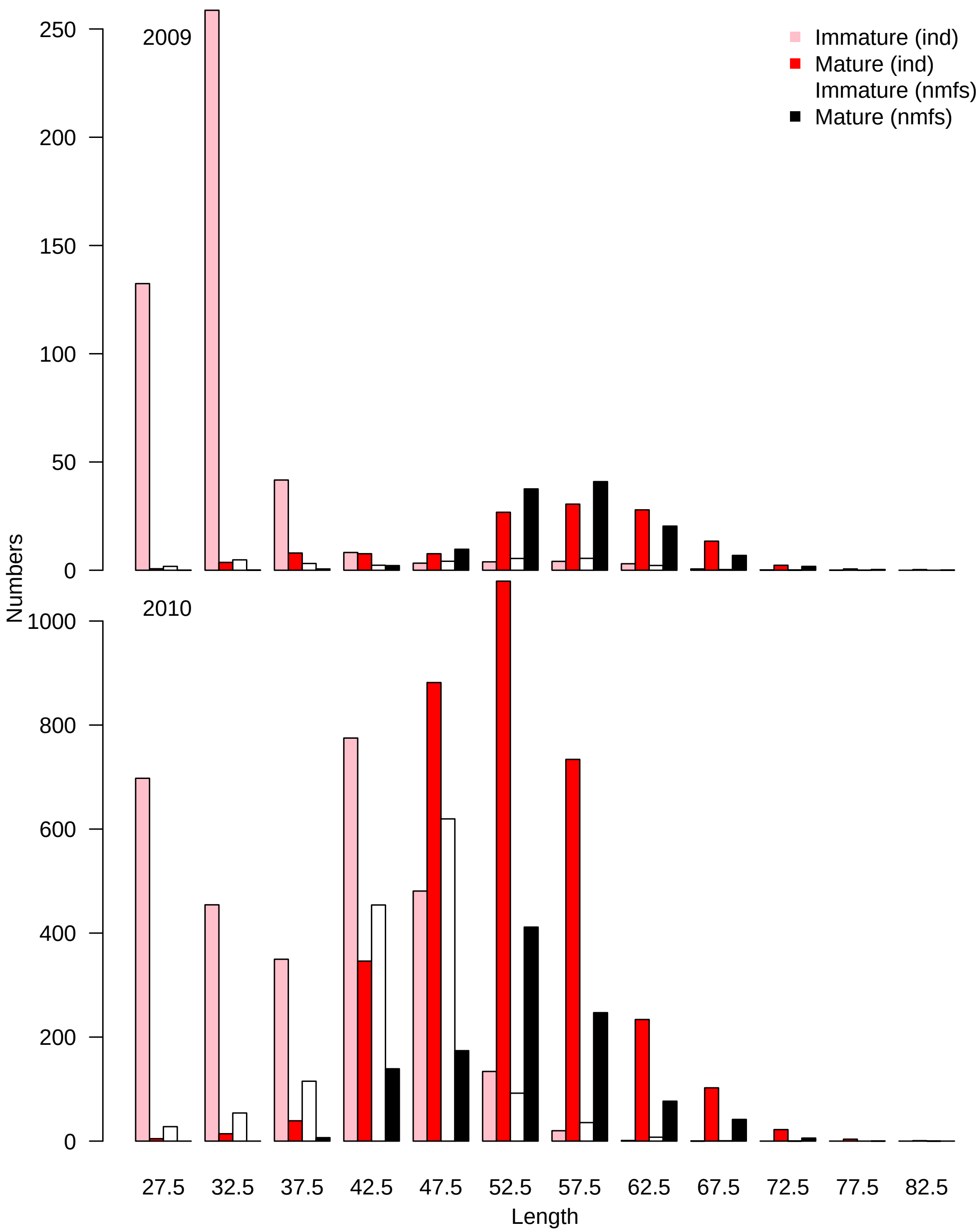


Figure 13: Raw female numbers from BSFRF survey selectivity experiments (2009 & 2010)

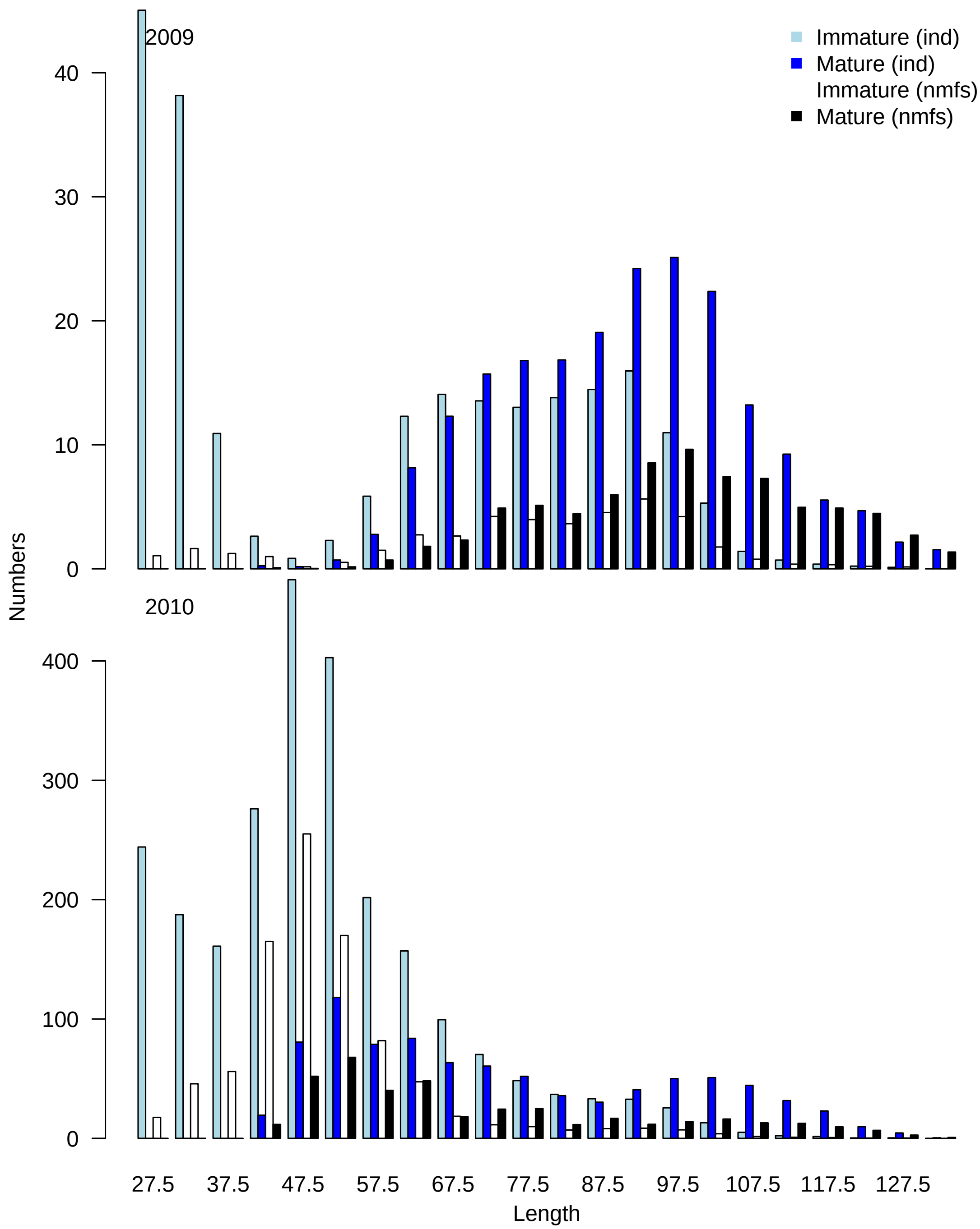


Figure 14: Raw male numbers from BSFRF survey selectivity experiments (2009 & 2010)

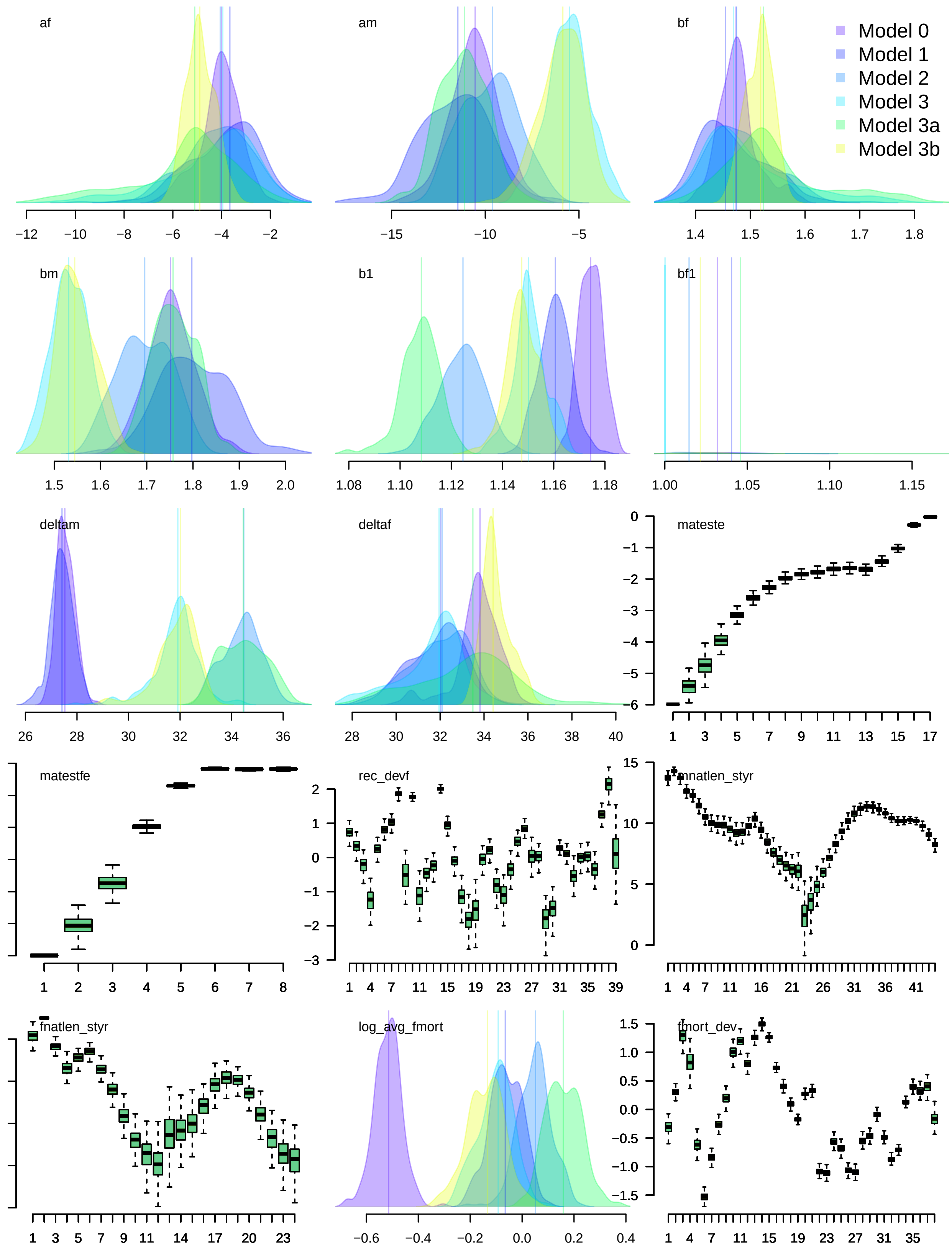


Figure 15: Posterior densities for estimated parameters by scenario

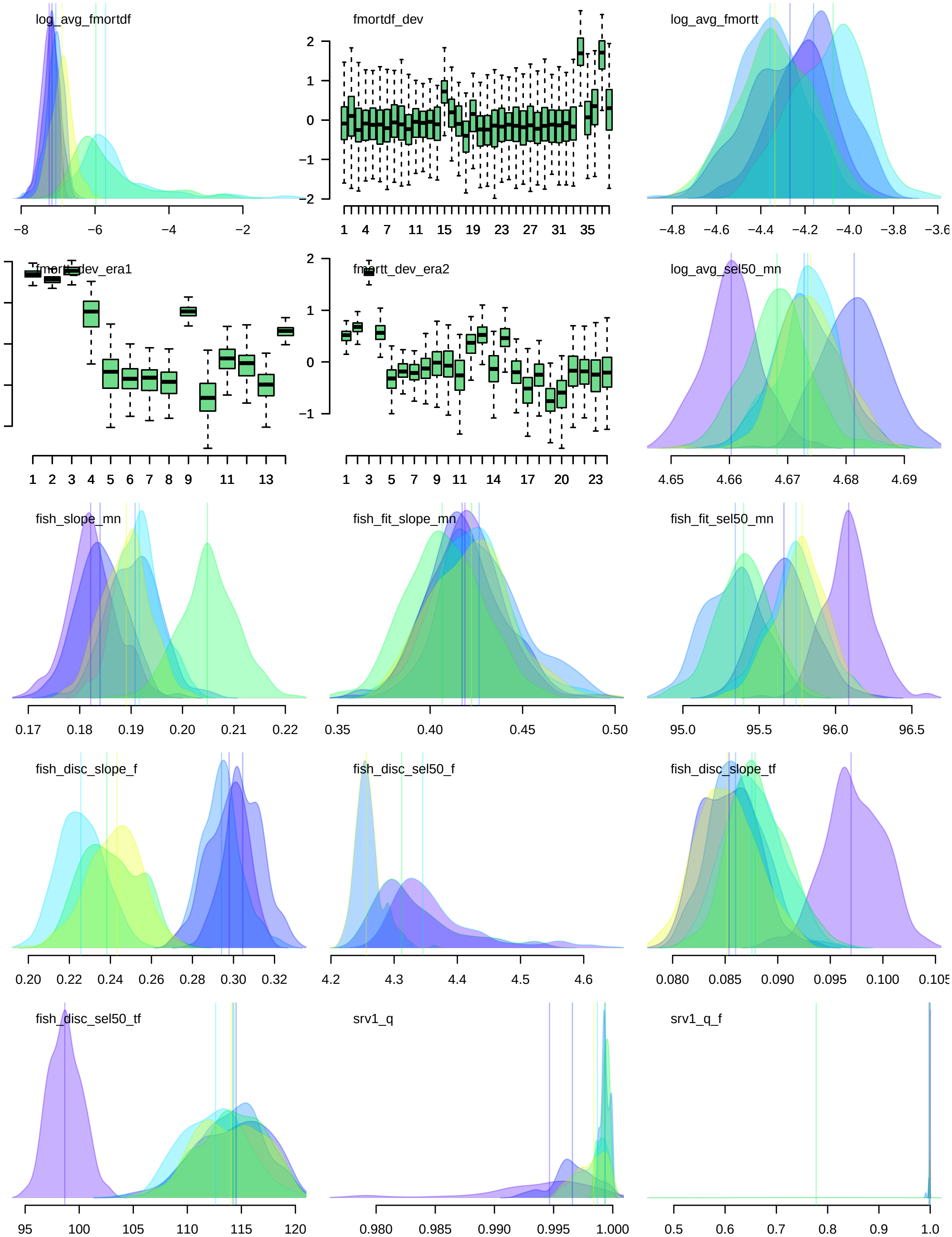


Figure 16: Posterior densities for estimated parameters by scenario

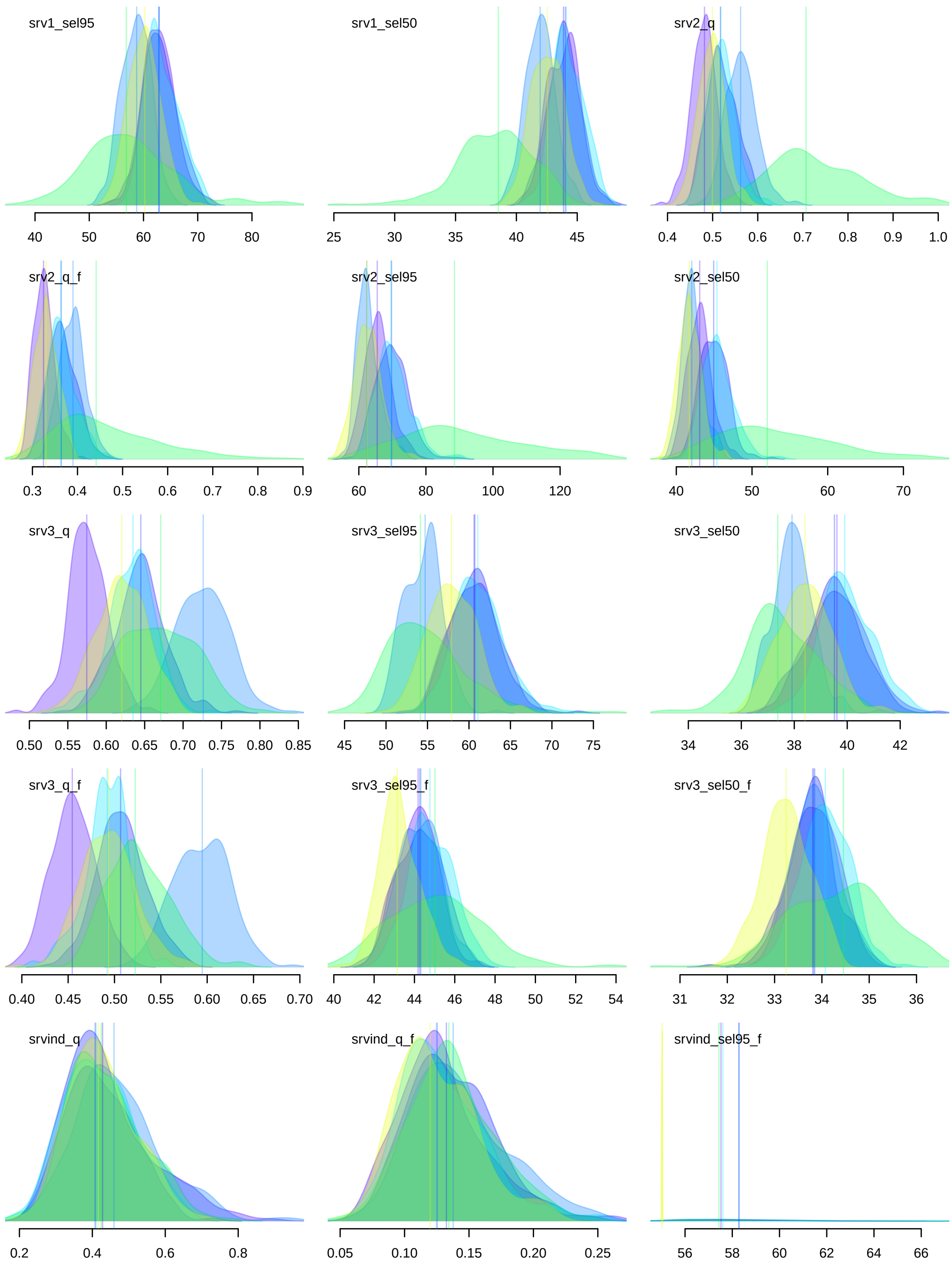


Figure 17: Posterior densities for estimated parameters by scenario

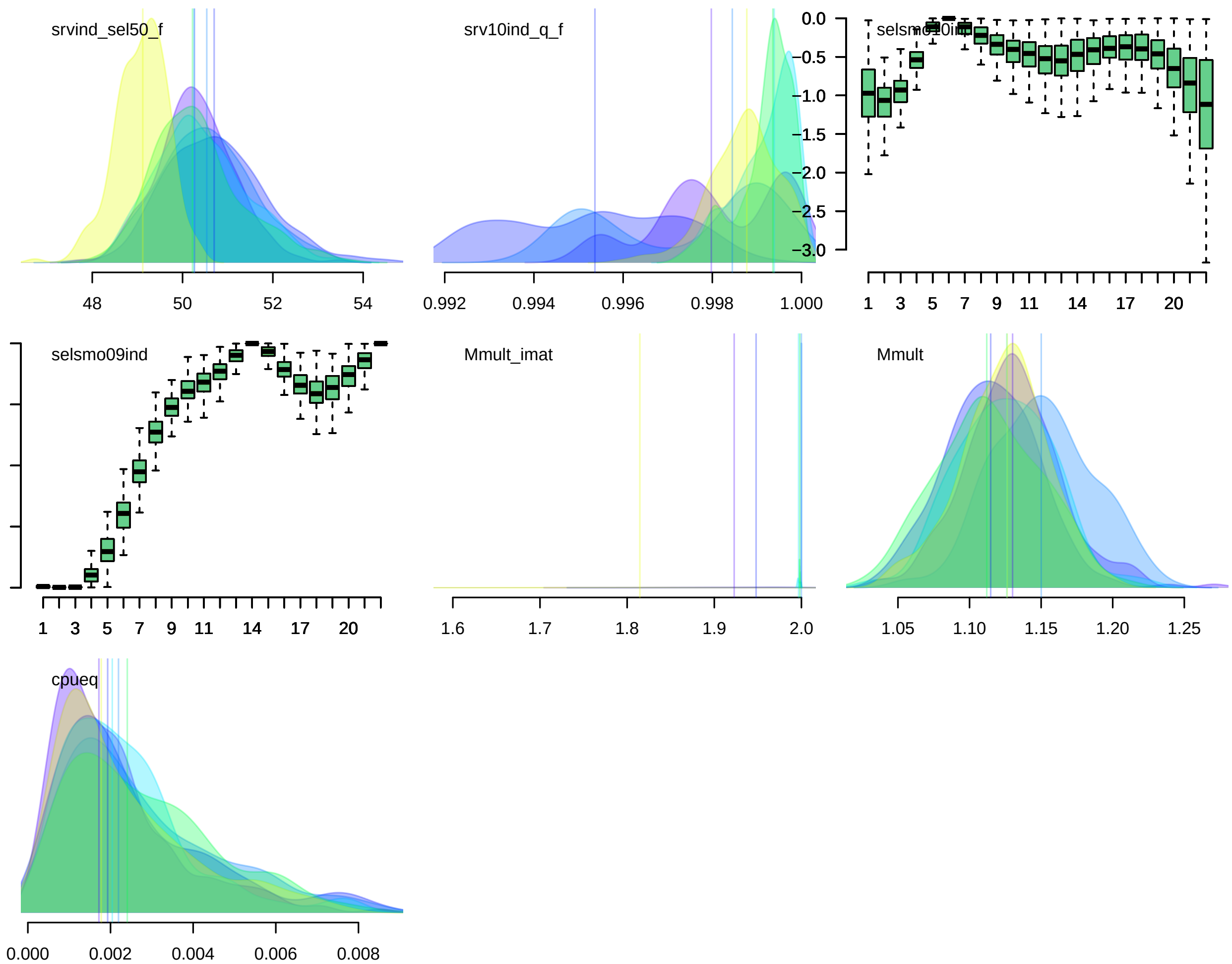


Figure 18: Posterior densities for estimated parameters by scenario

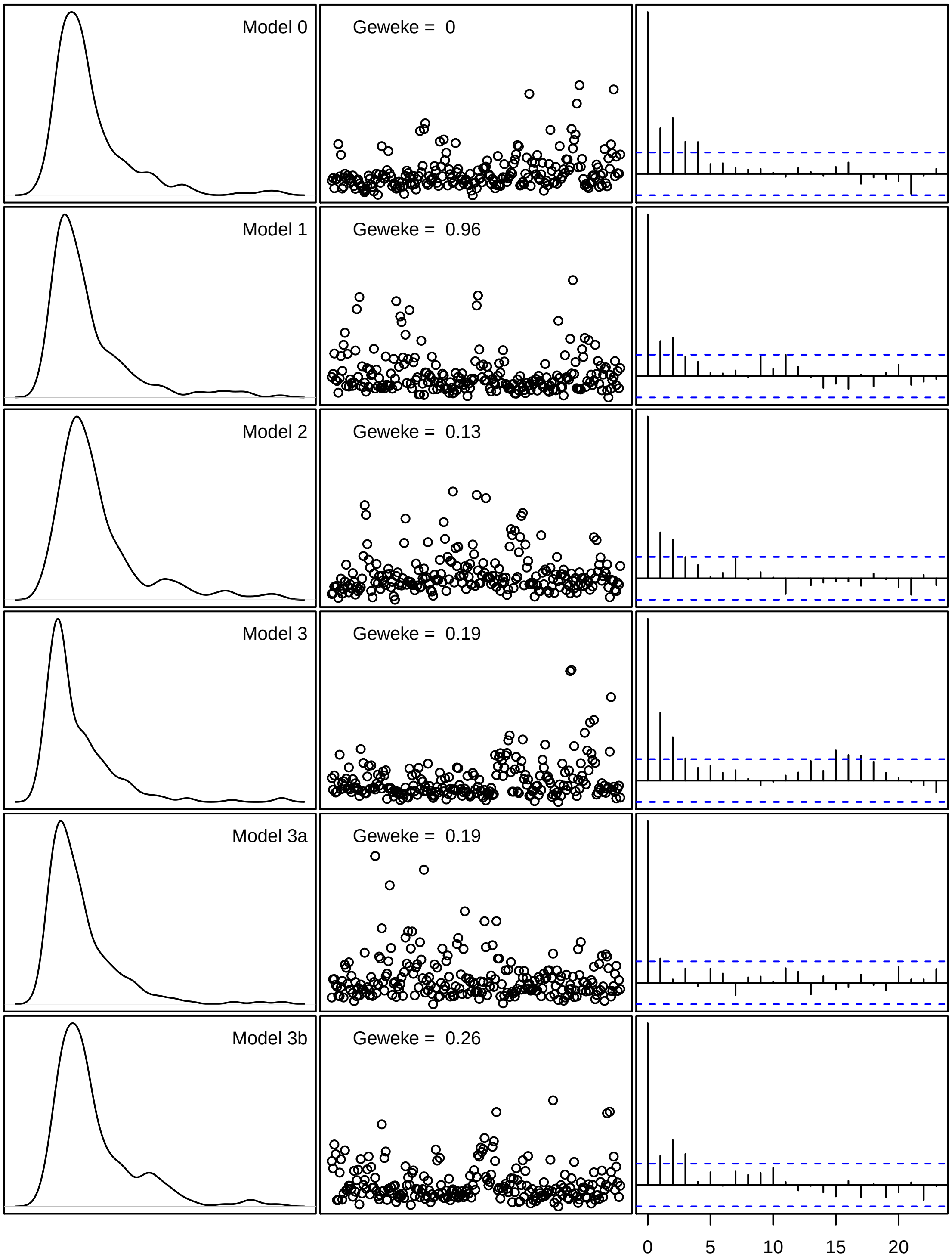


Figure 19: MCMC diagnostics. Density of the objective function value (left), traces of the objective function value (middle) with Geweke diagnostic statistic (i.e. the p value of a two sample t test where the first sample is the first 10% of the trace and the second sample is the last 50% of the trace)Traces of the objective function value from MCMC by model, autocorrelation of the trace of the objective function (right)

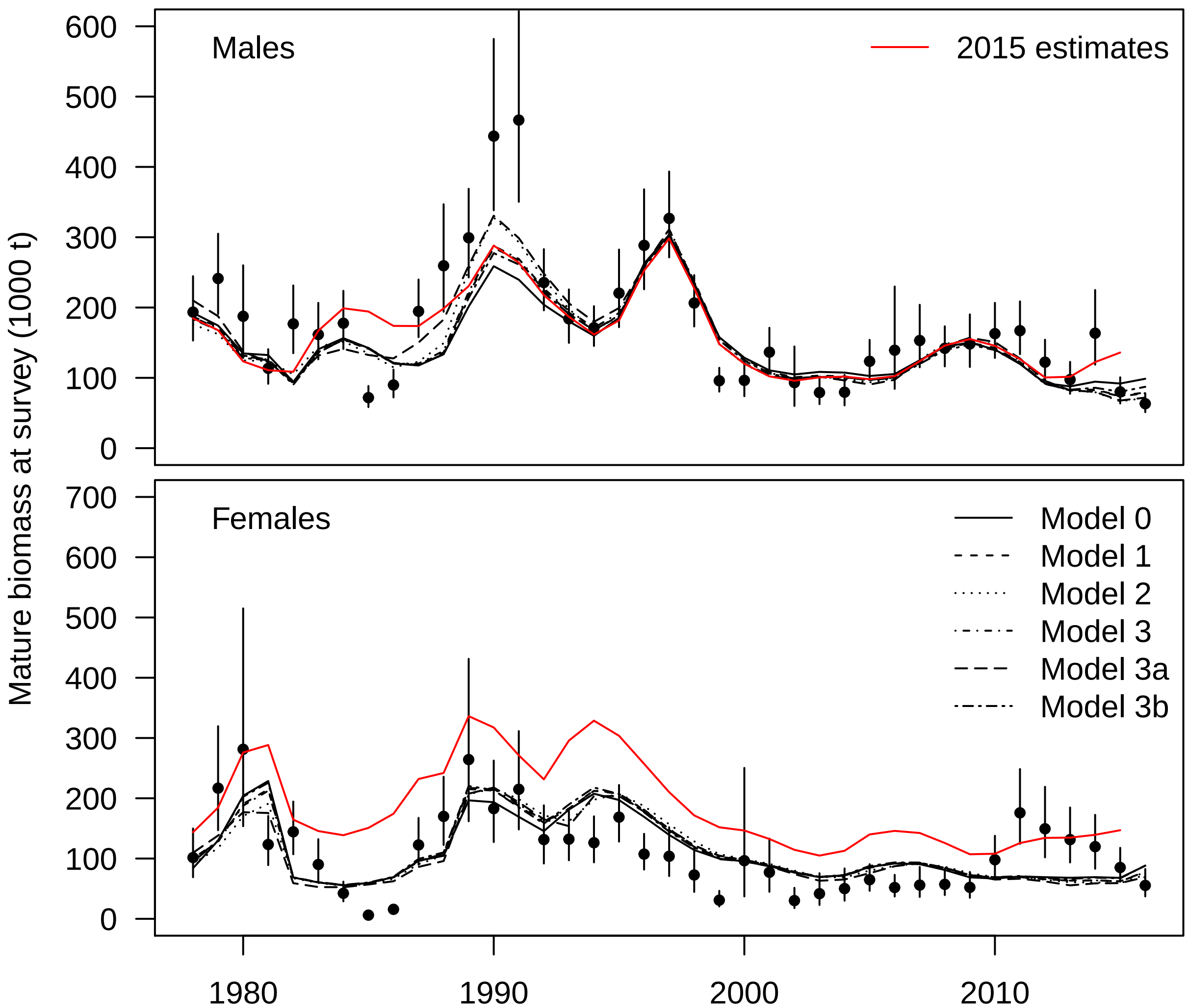


Figure 20: Model fits to the observed mature biomass at survey

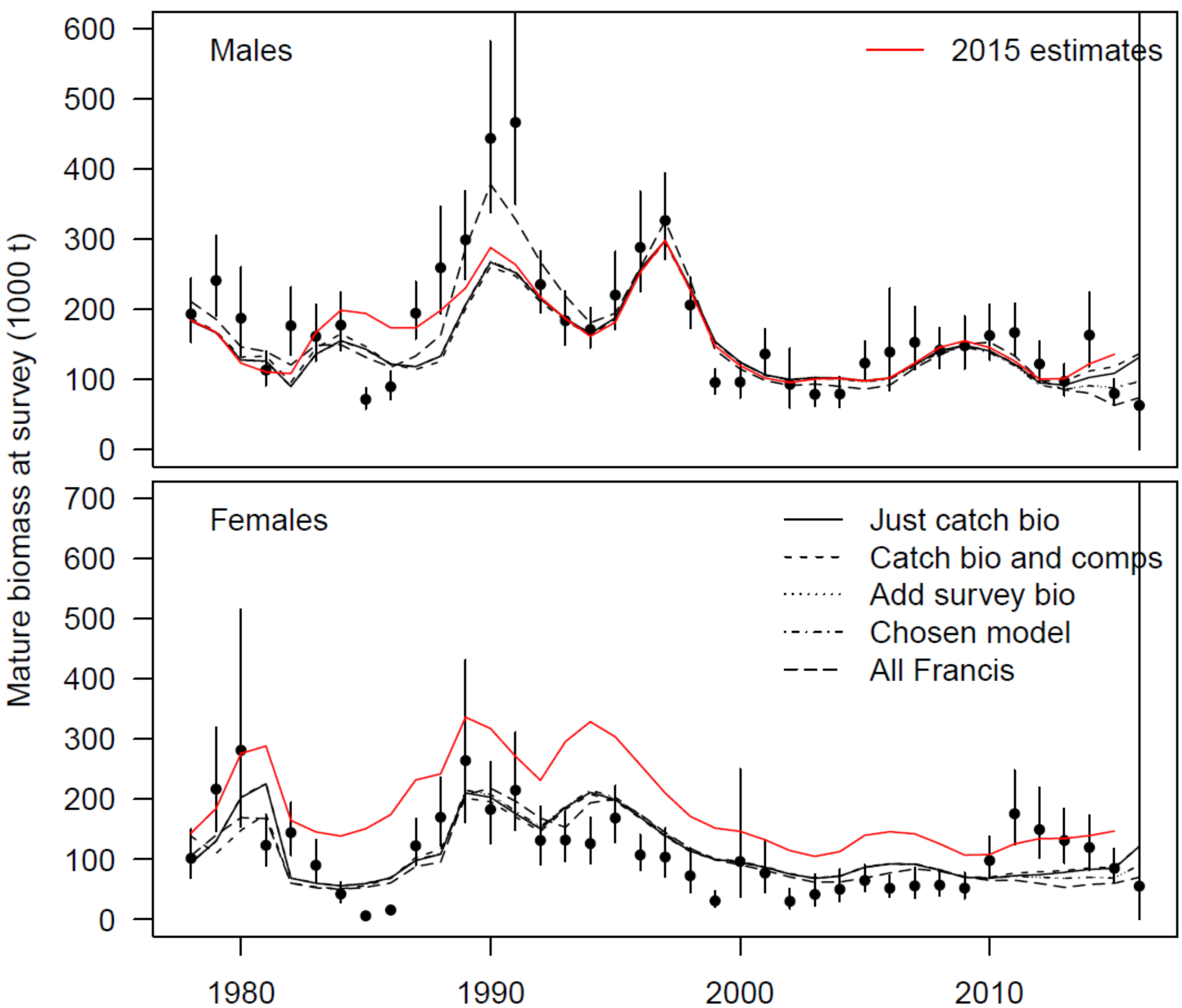


Figure 21: Stepwise addition of the data components for the chosen model and a model run in which all size composition data are down-weighted.

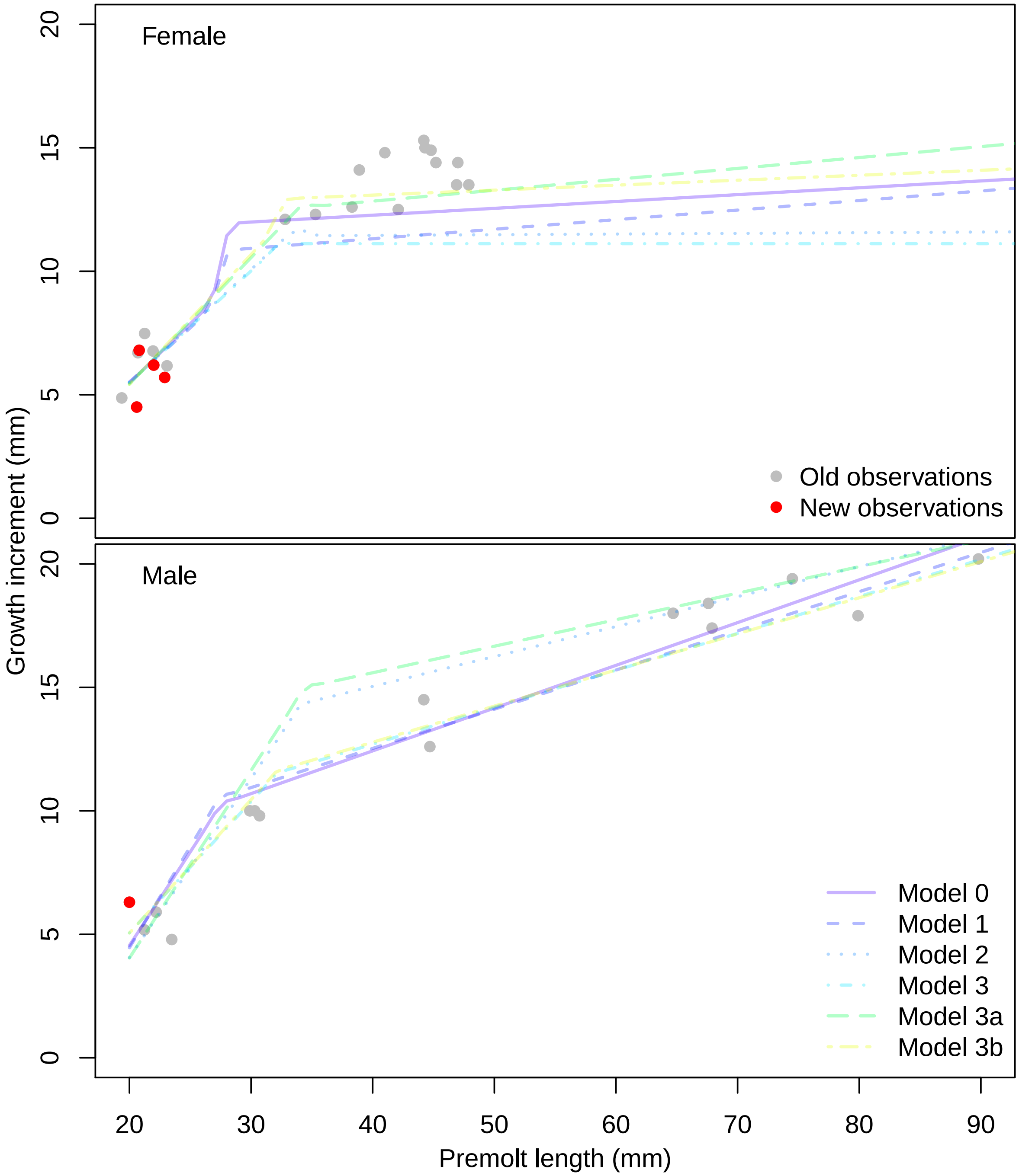


Figure 22: Model fits to the growth data

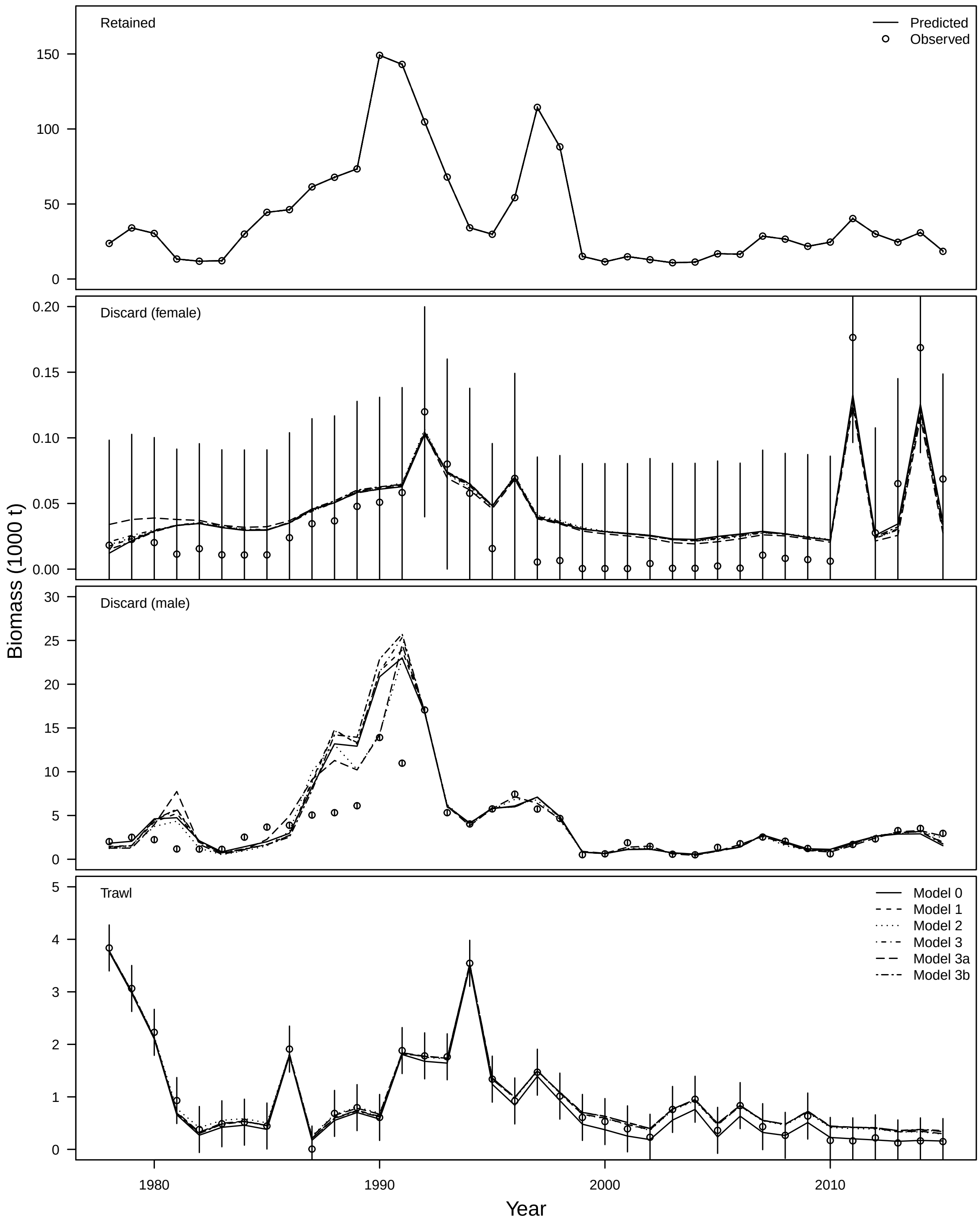


Figure 23: Model fits to catch data

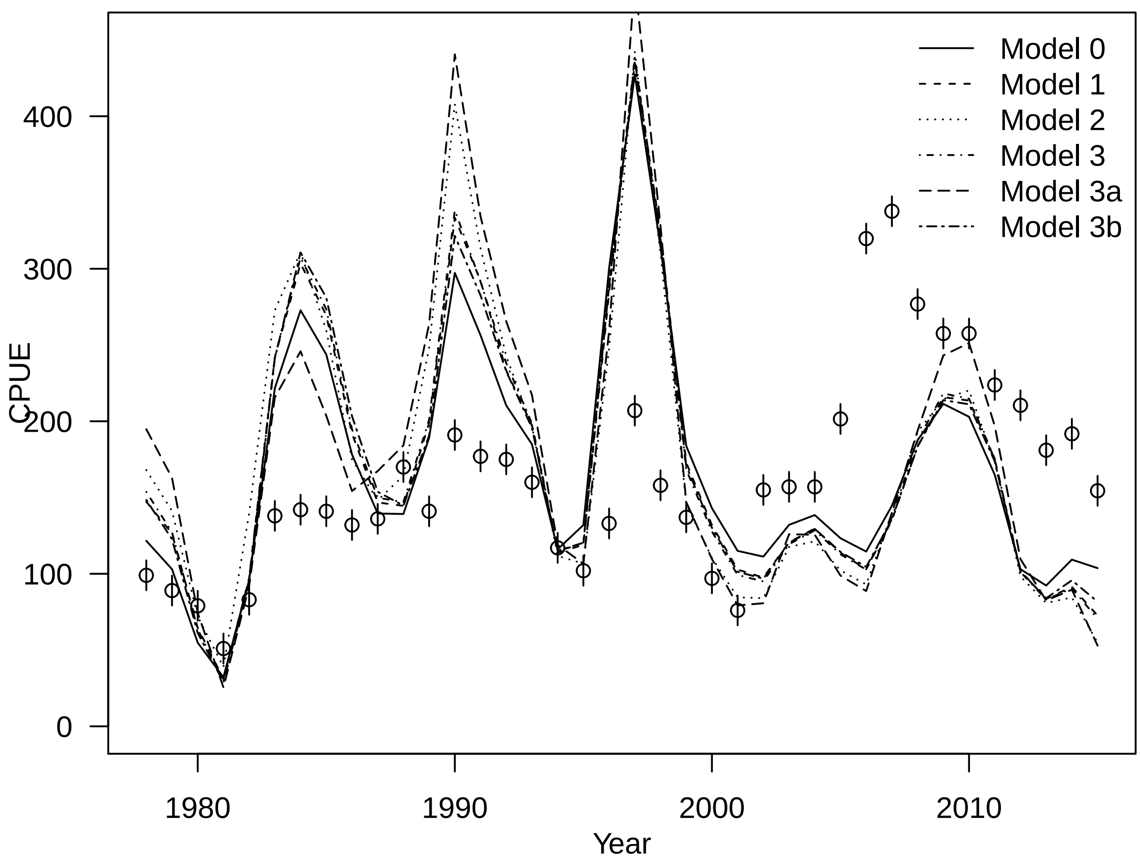


Figure 24: Model fits to pot CPUE data

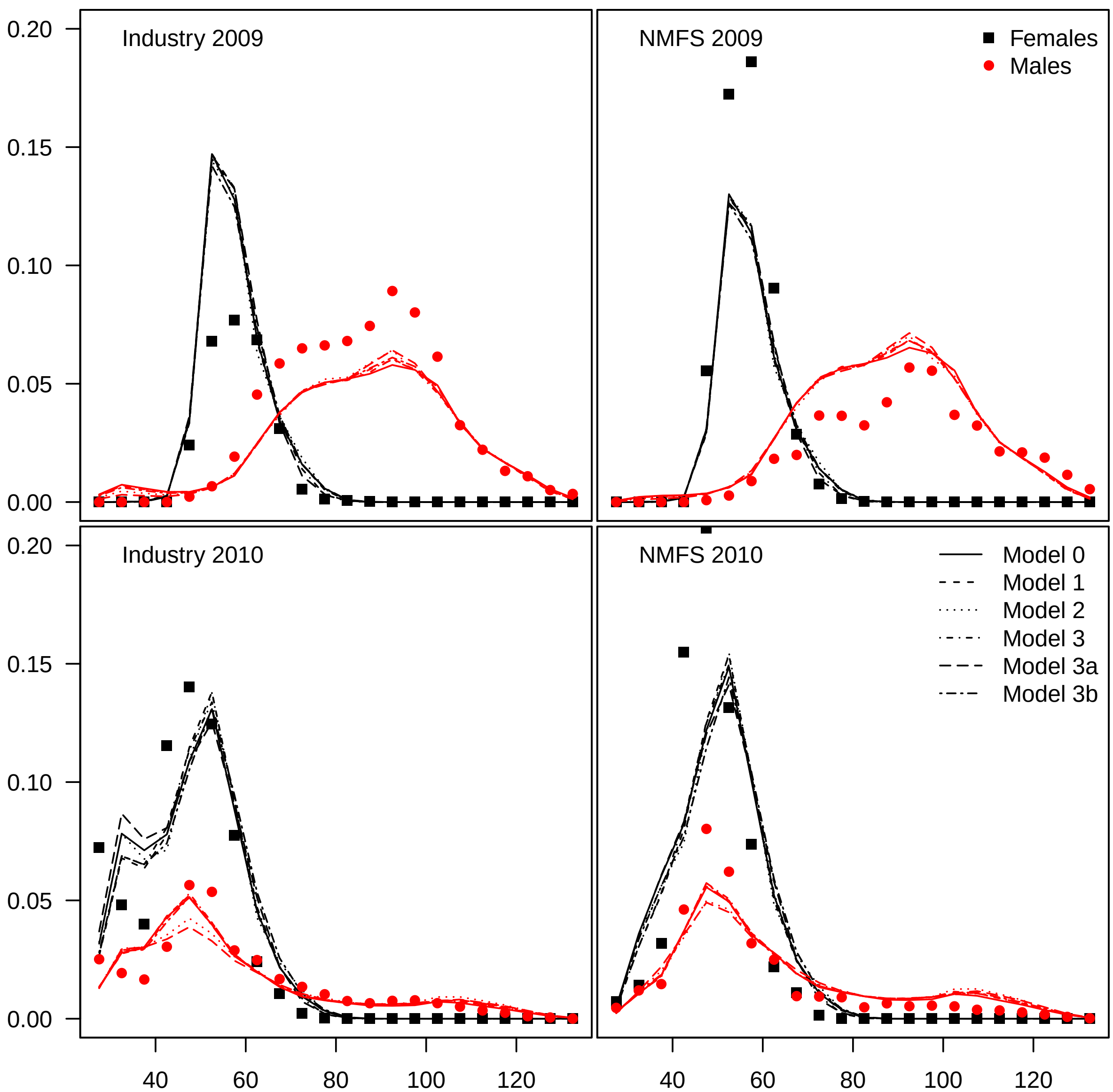


Figure 25: Model fits to size composition data from summer survey experiments (2009 & 2010)

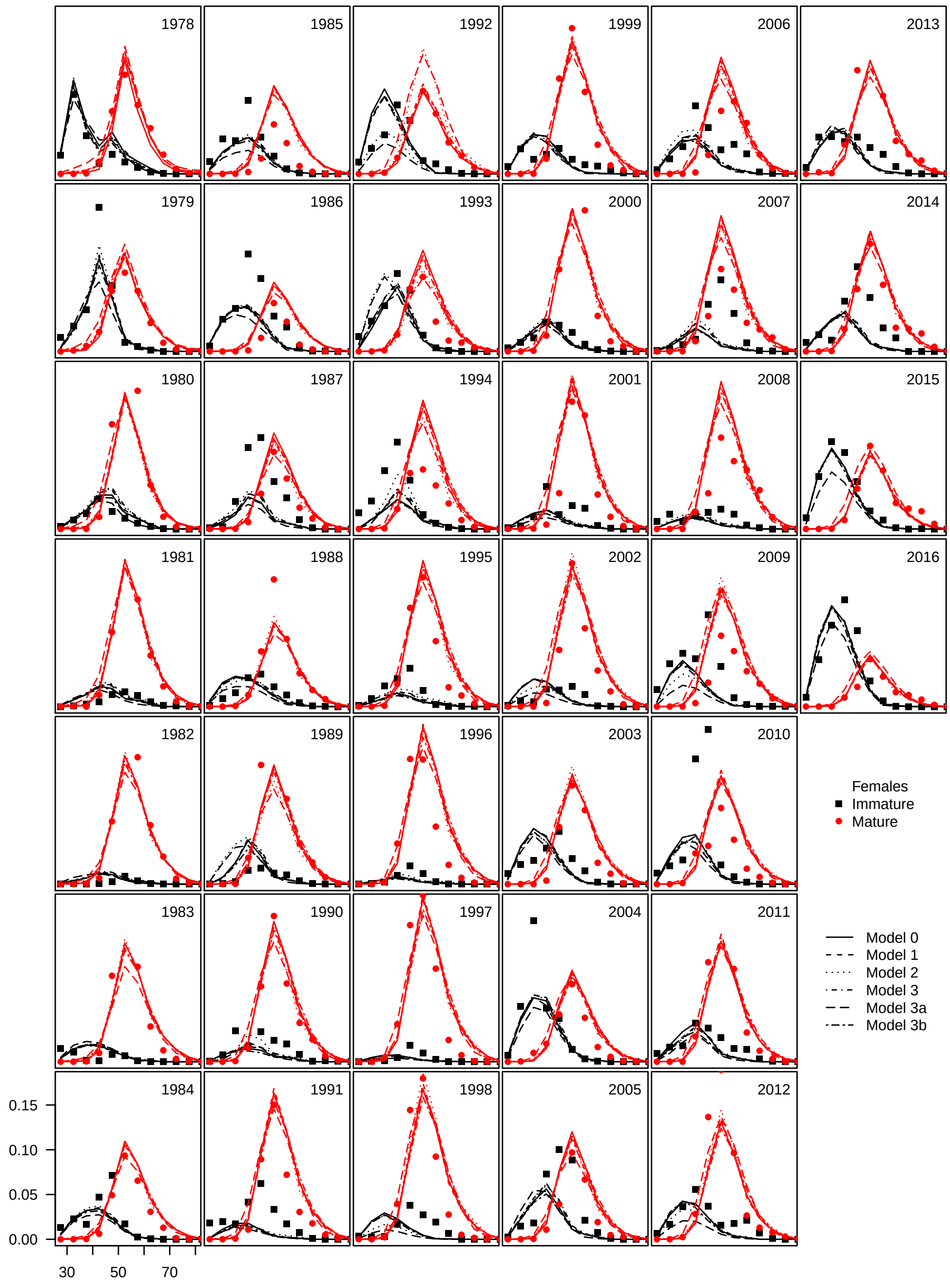


Figure 26: Model fits to female survey size composition data

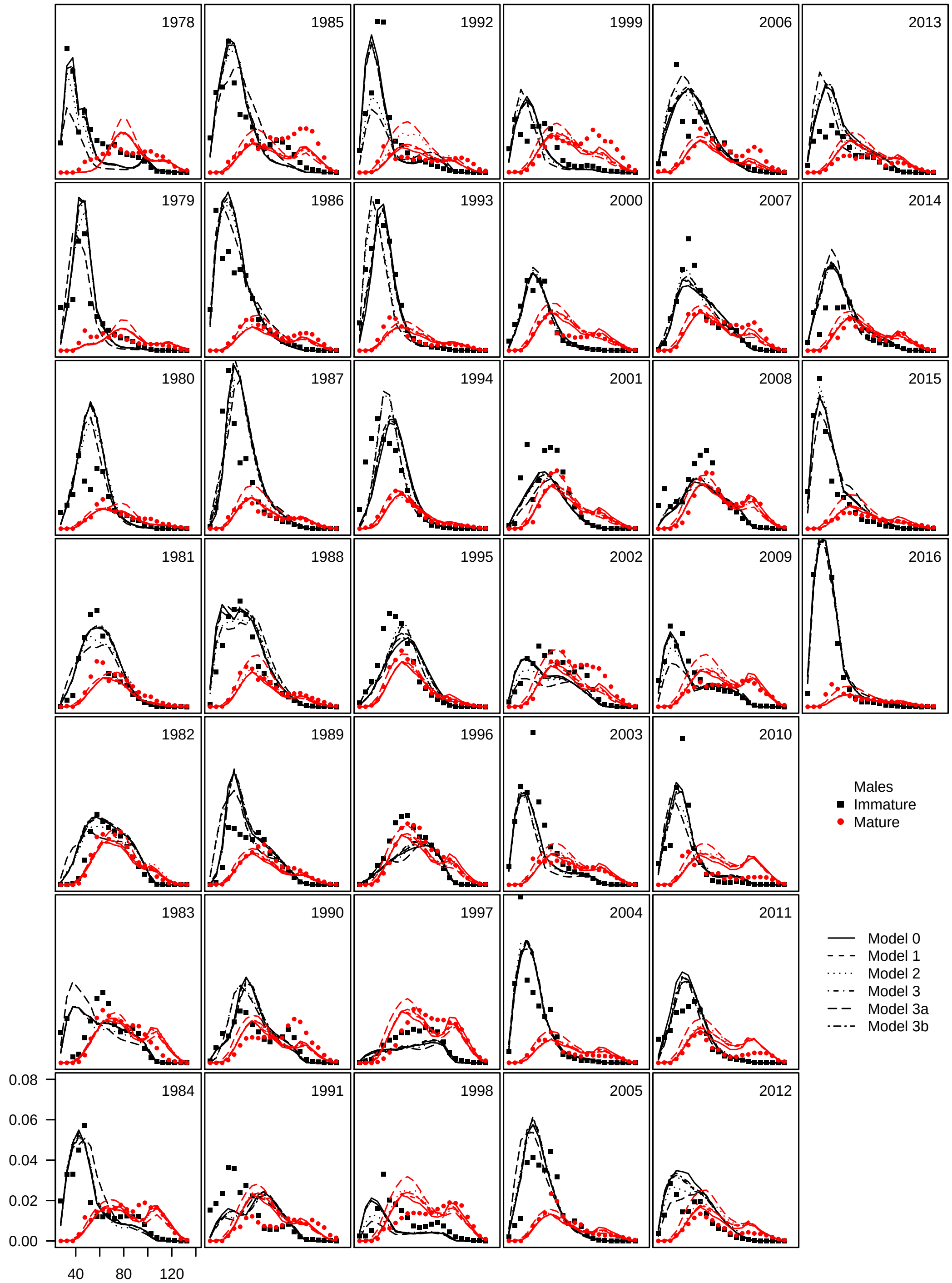


Figure 27: Model fits to male survey size composition data

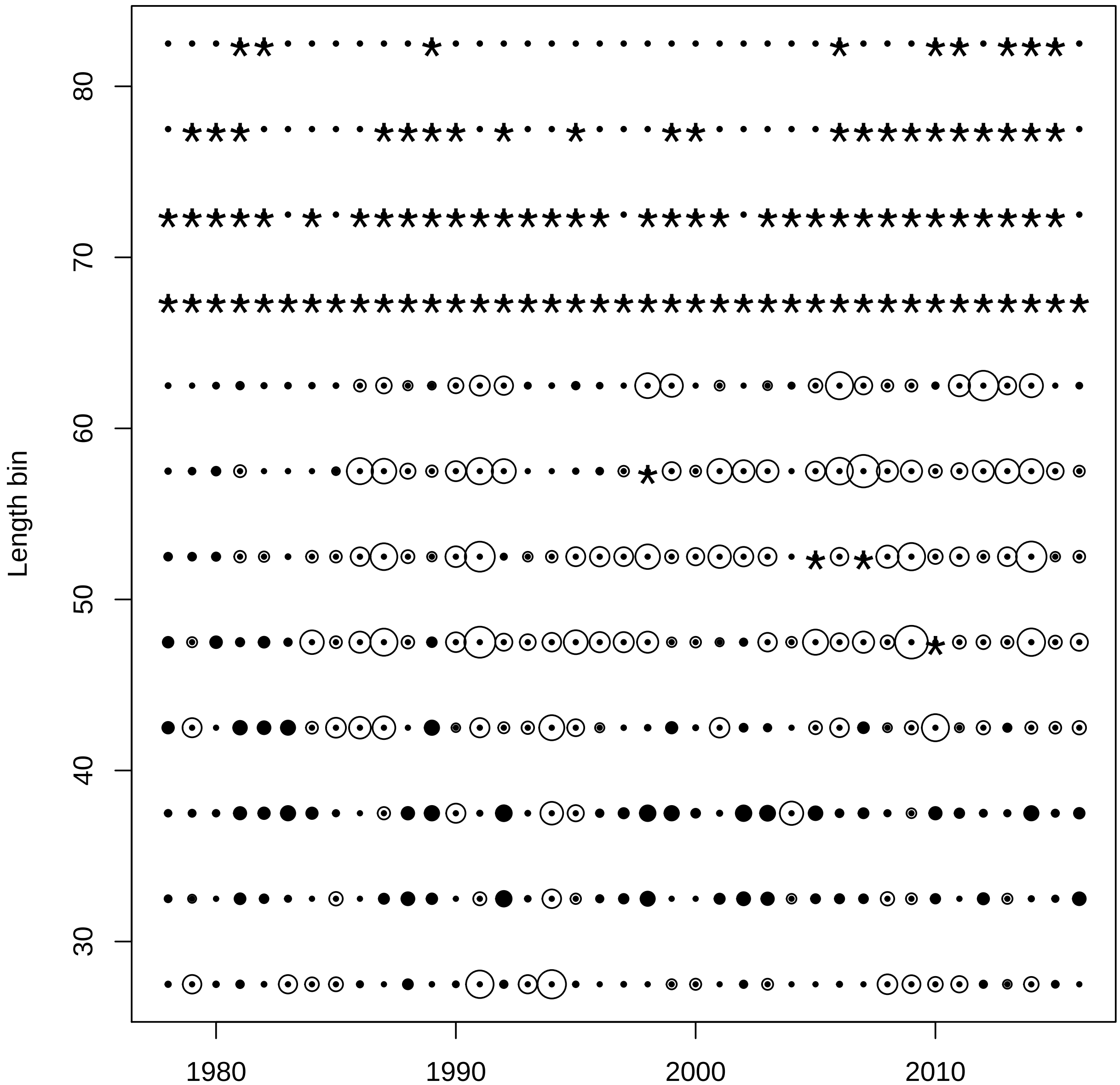


Figure 28: Residuals for immature female survey length proportion data for the author's preferred model (3b). Open circles are positive residuals, filled are negative, and the size of the circle is proportional to the magnitude of the residual. Stars are residuals > 5.

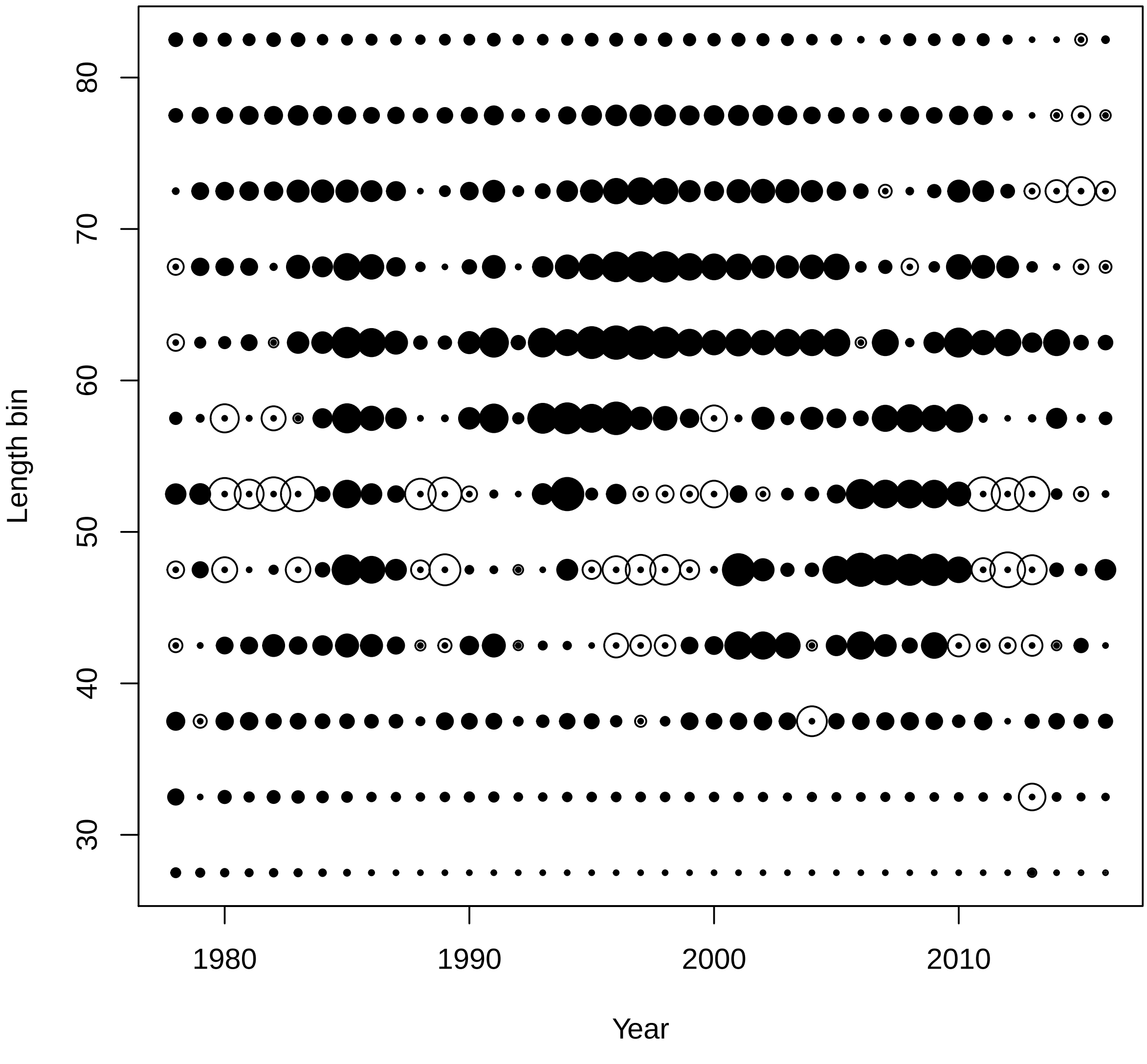


Figure 29: Residuals for mature female survey length proportion data for the author's preferred model (3b). Open circles are positive residuals, filled are negative, and the size of the circle is proportional to the magnitude of the residual. Stars are residuals > 5.

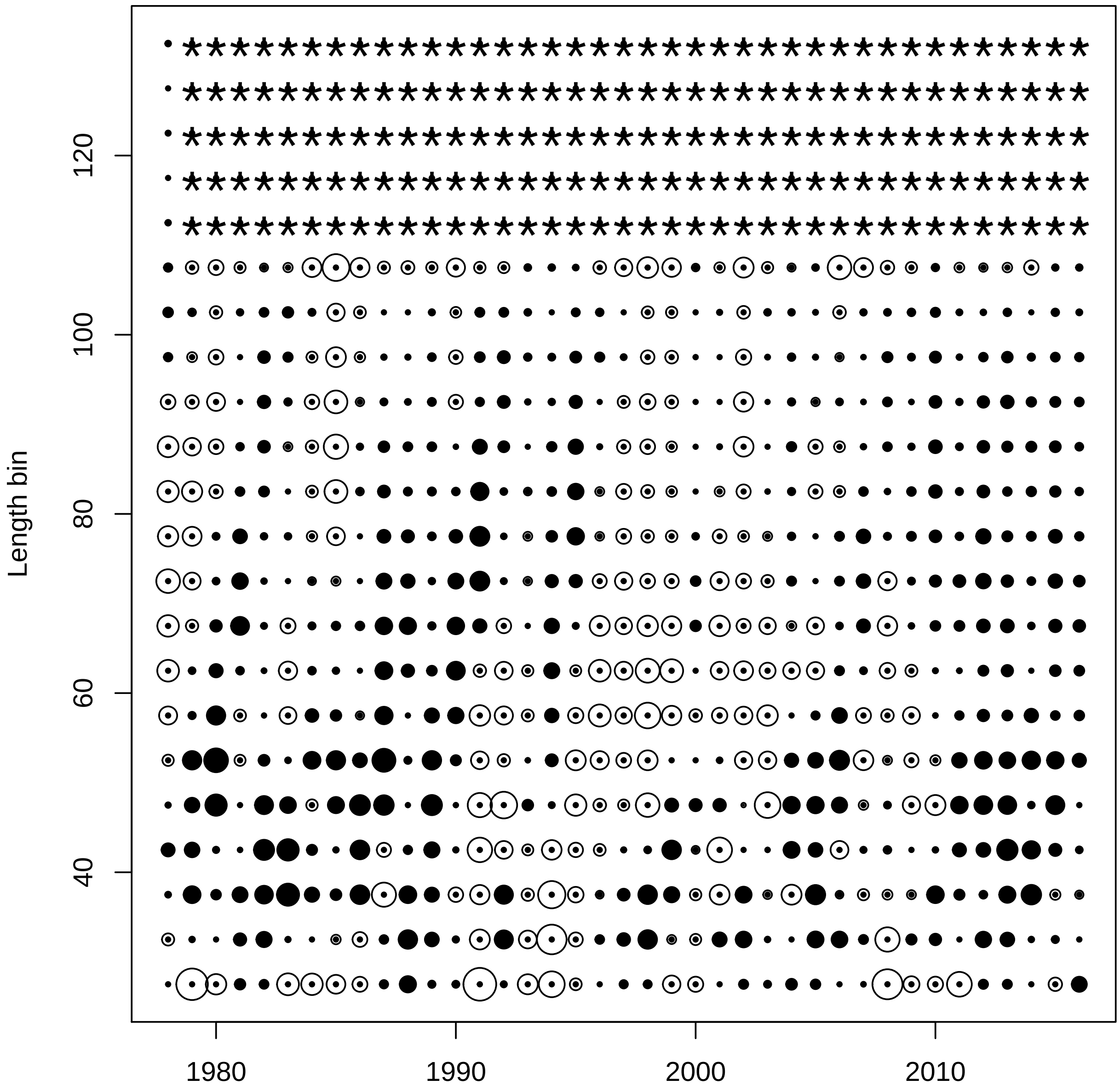


Figure 30: Residuals for fits to immature male survey proportion at length data for the author's preferred model (3b). Open circles are positive residuals, filled are negative, and the size of the circle is proportional to the magnitude of the residual. Stars are residuals > 5.

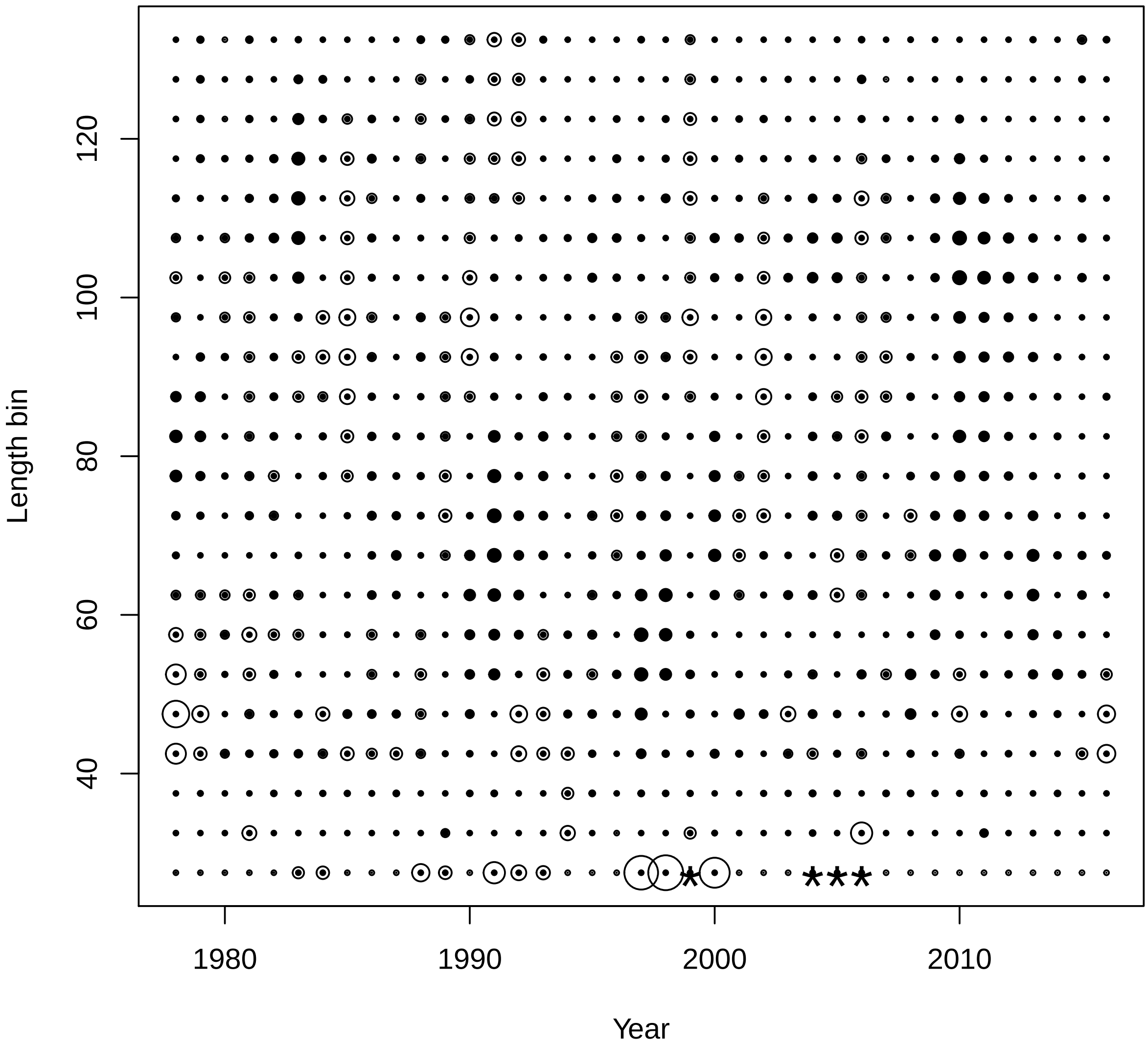


Figure 31: Residuals for fits to mature male survey proportion at length data for the author's preferred model (3b). Open circles are positive residuals, filled are negative, and the size of the circle is proportional to the magnitude of the residual. Stars are residuals > 5.

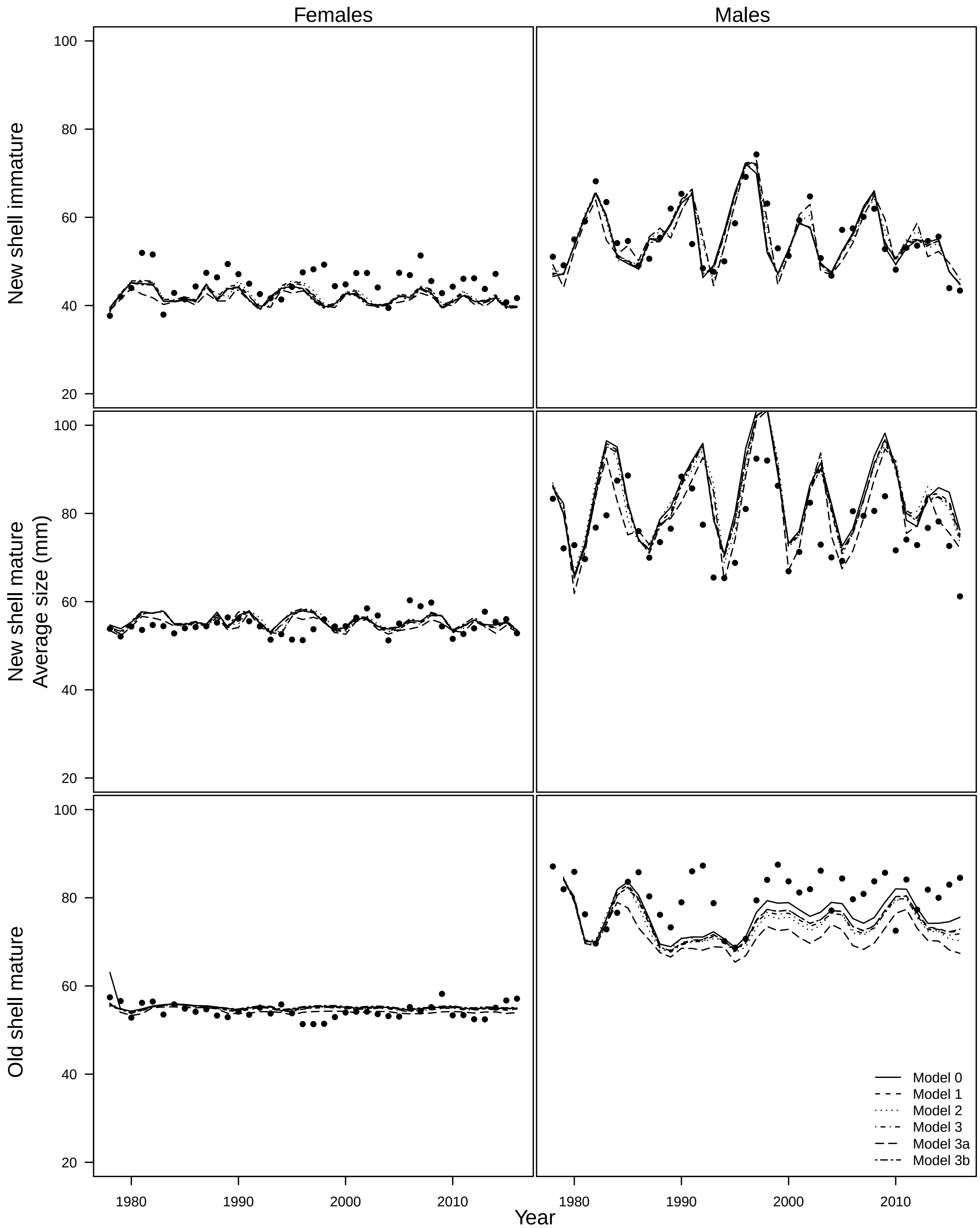


Figure 32: Observed and predicted average size in the survey composition data.

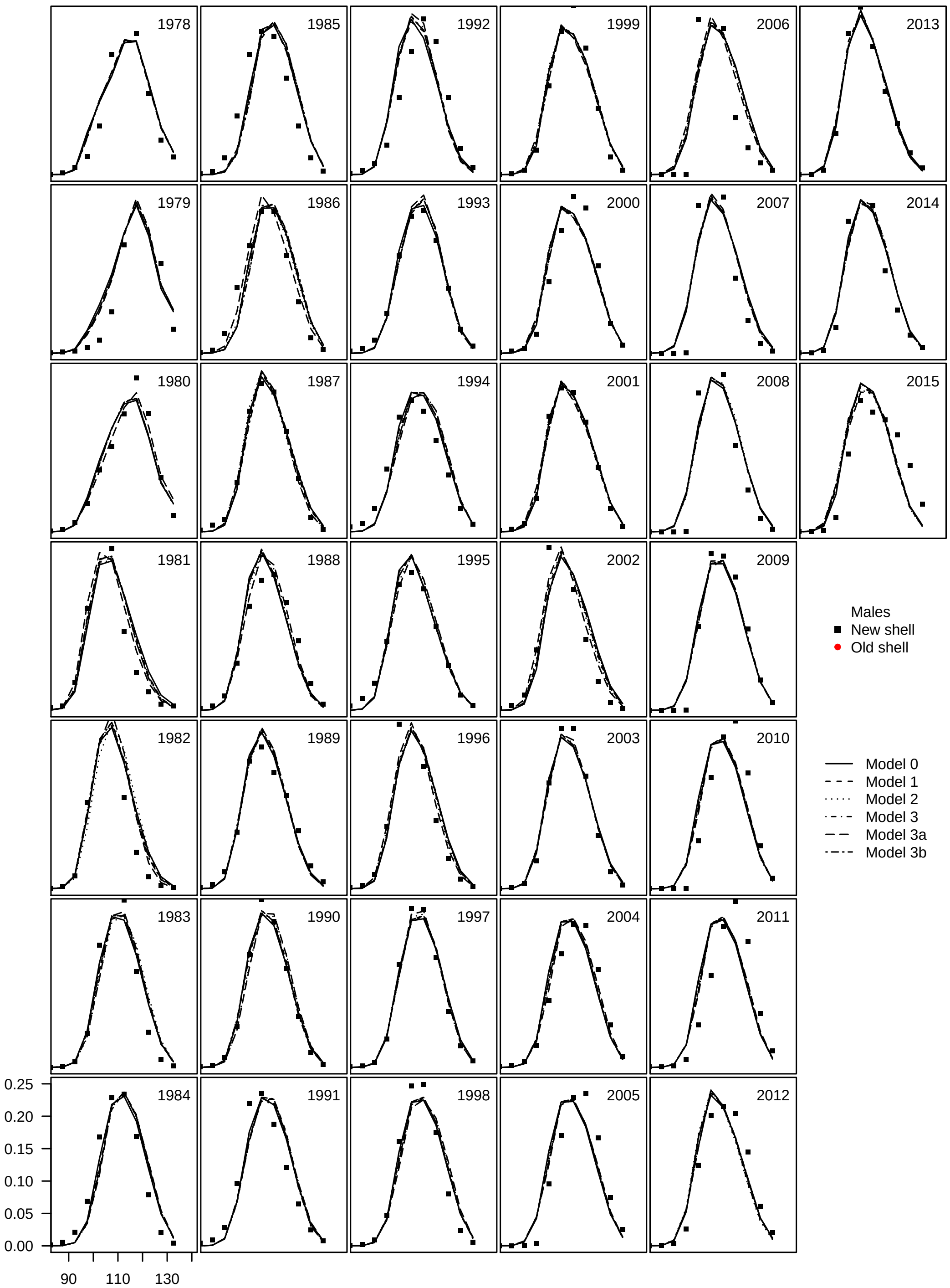


Figure 33: Model fits to retained catch size composition data

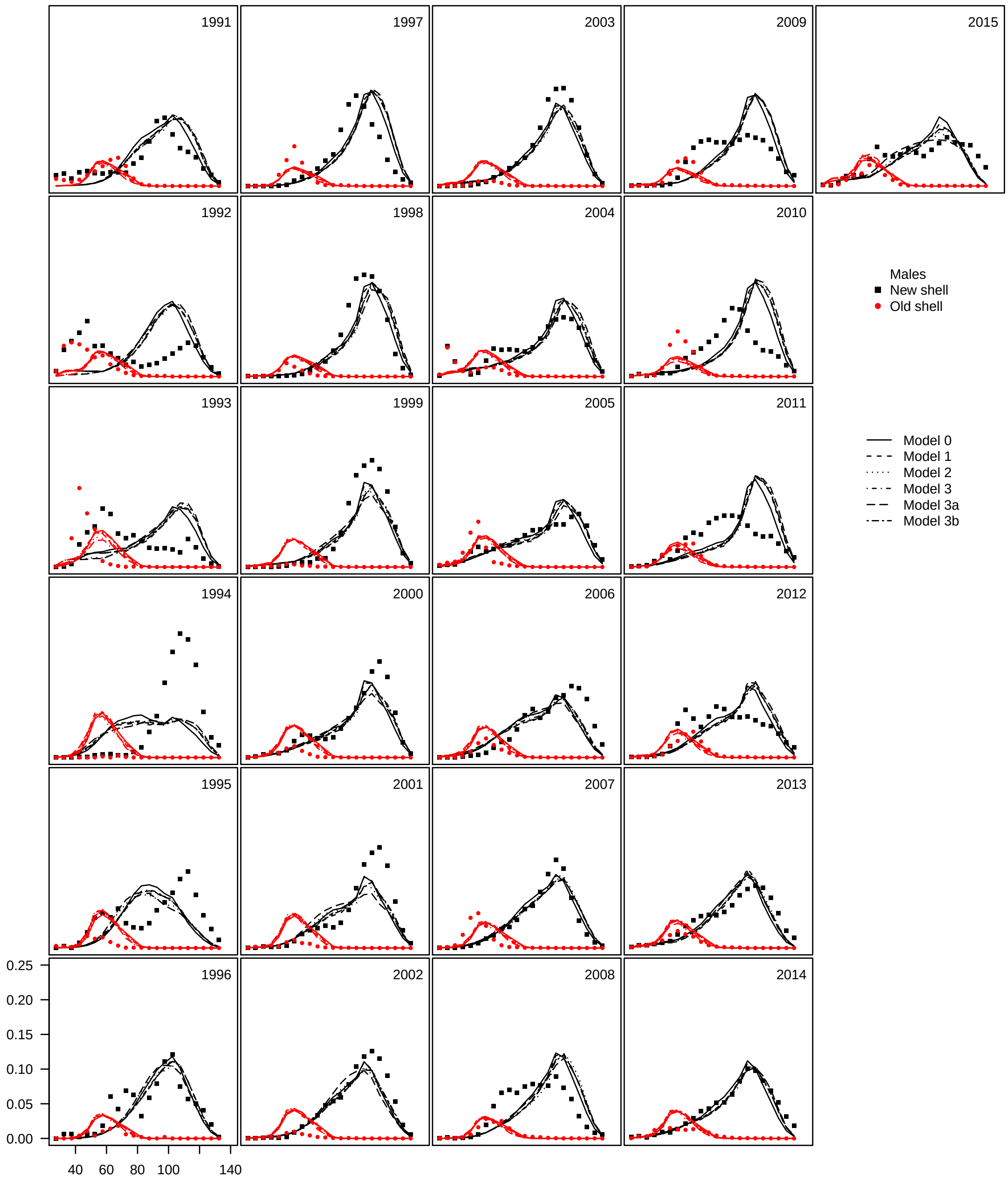


Figure 34: Model fits to trawl catch size composition data

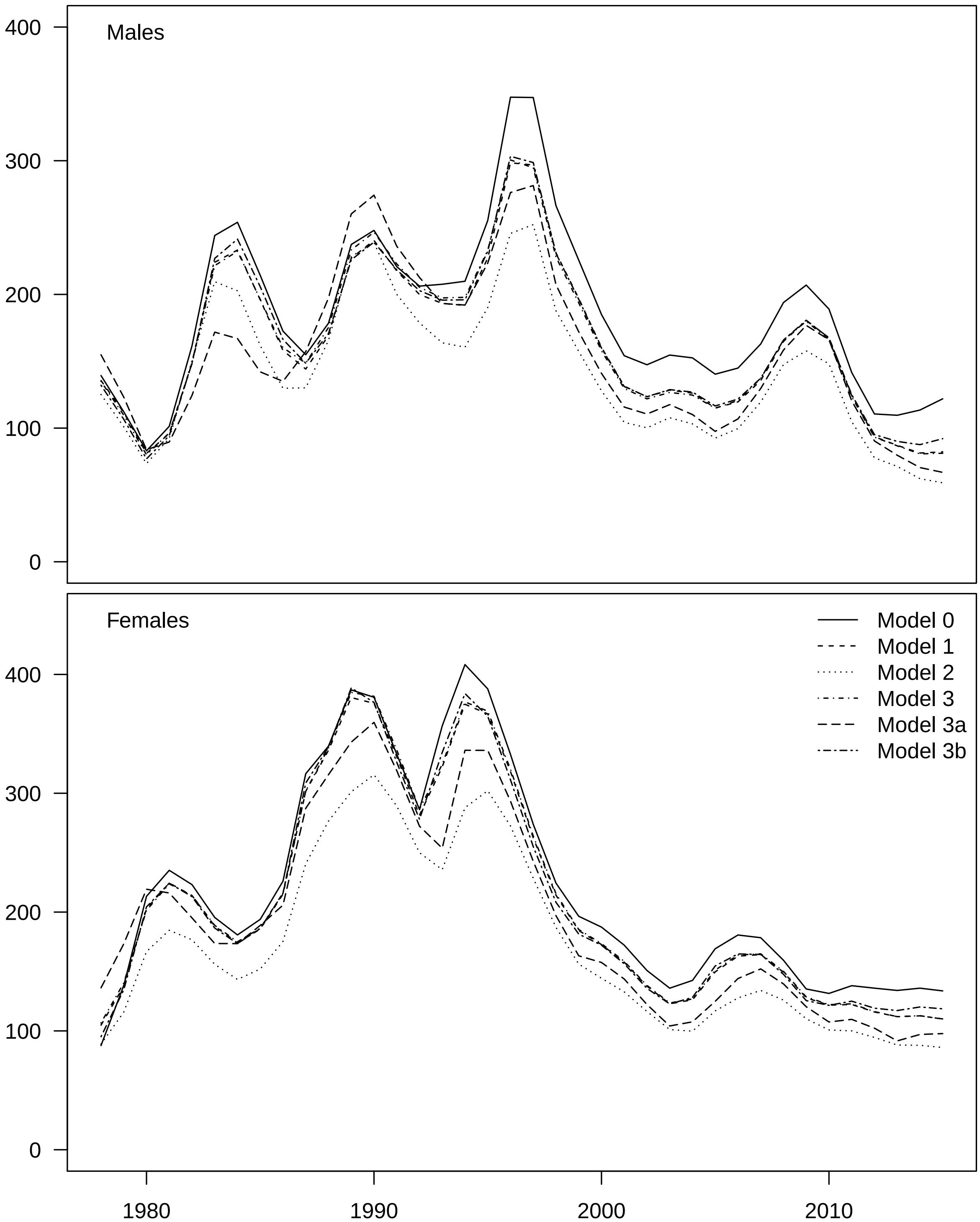


Figure 35: Model predicted mature male biomass at mating time

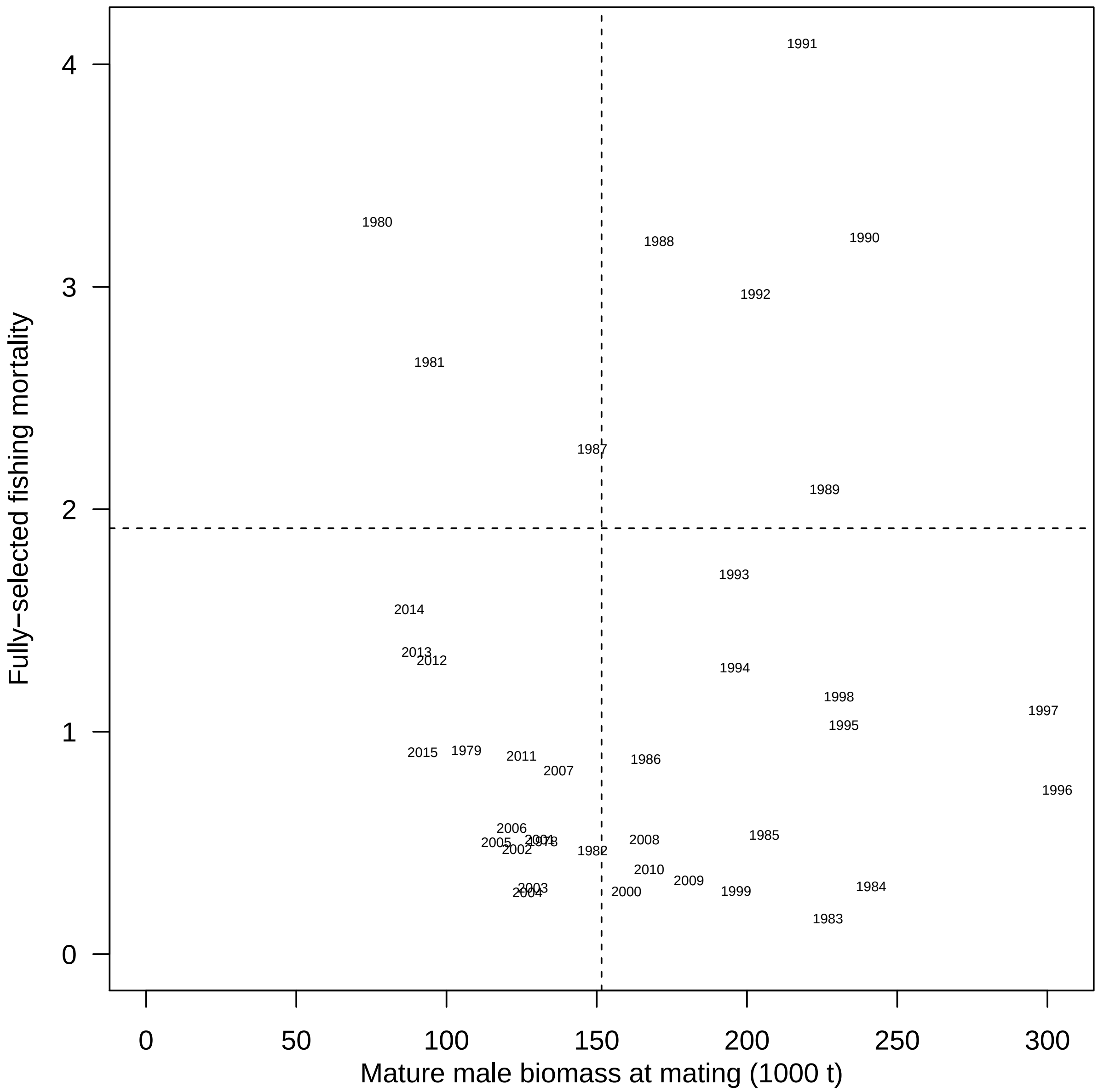


Figure 36: Kobe plot for the chosen model. Vertical line represents the median posterior value for B35; horizontal lines presents F35

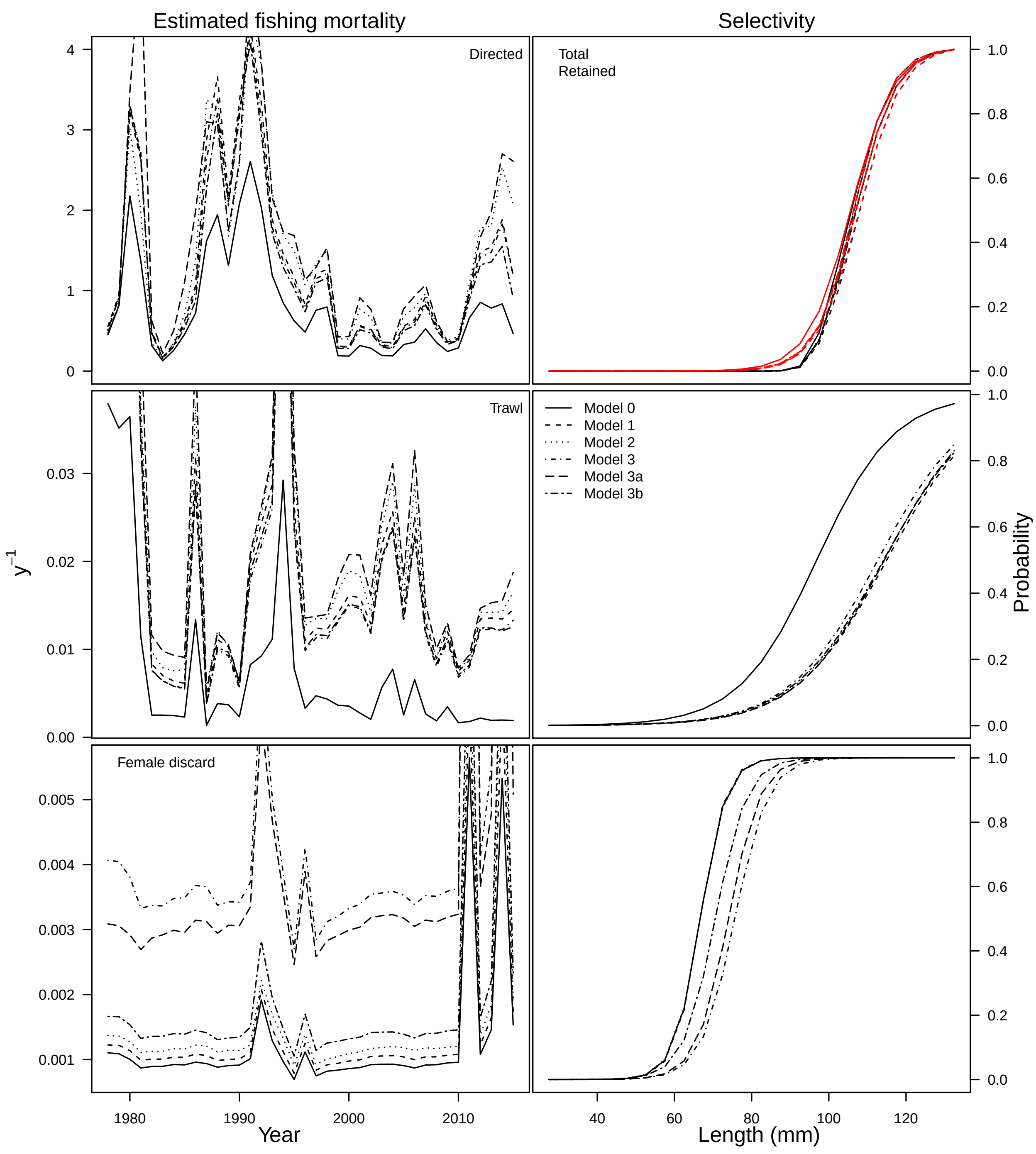


Figure 37: Model predicted fishing mortalities and selectivities for all sources of mortality

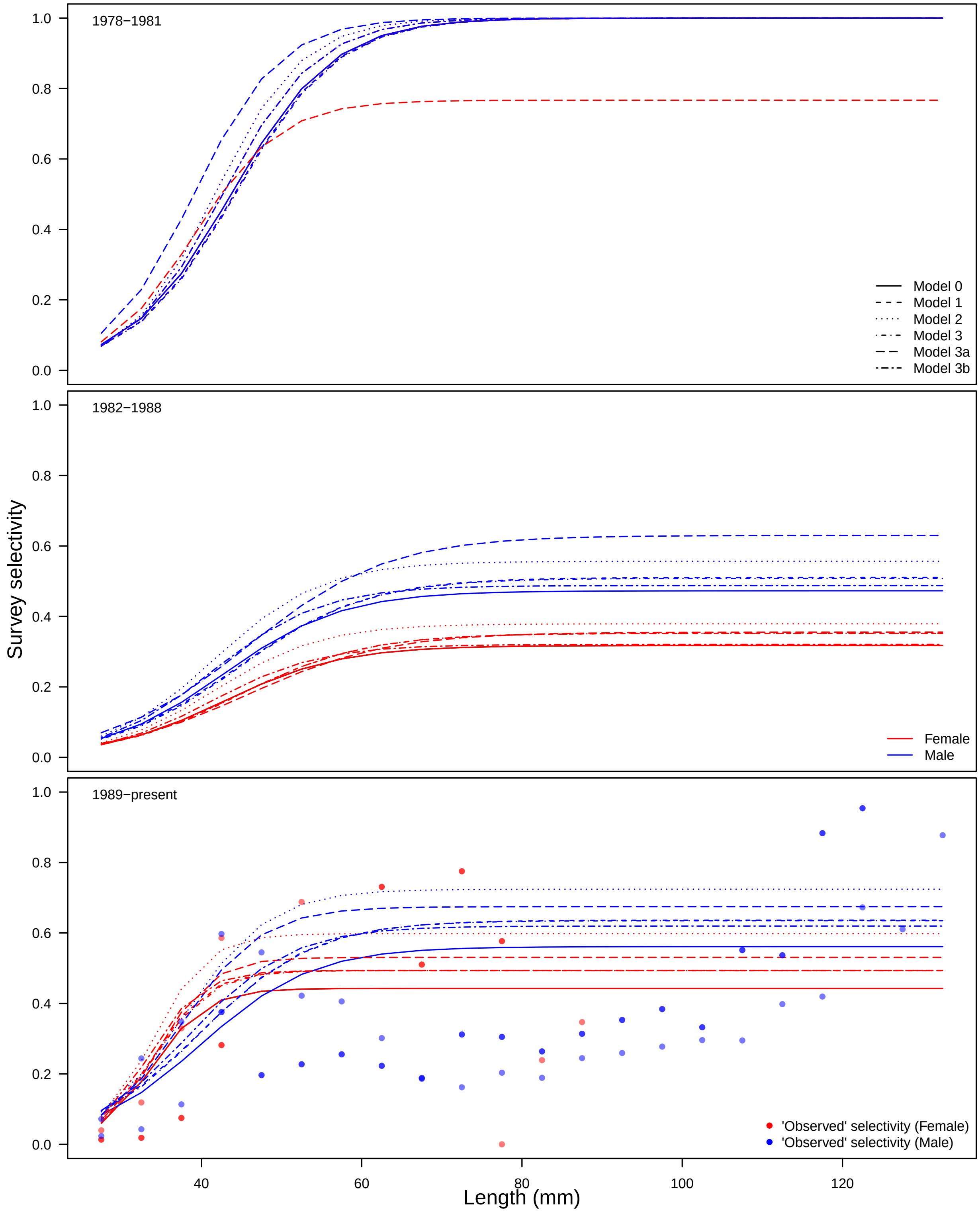


Figure 38: Estimated survey selectivity

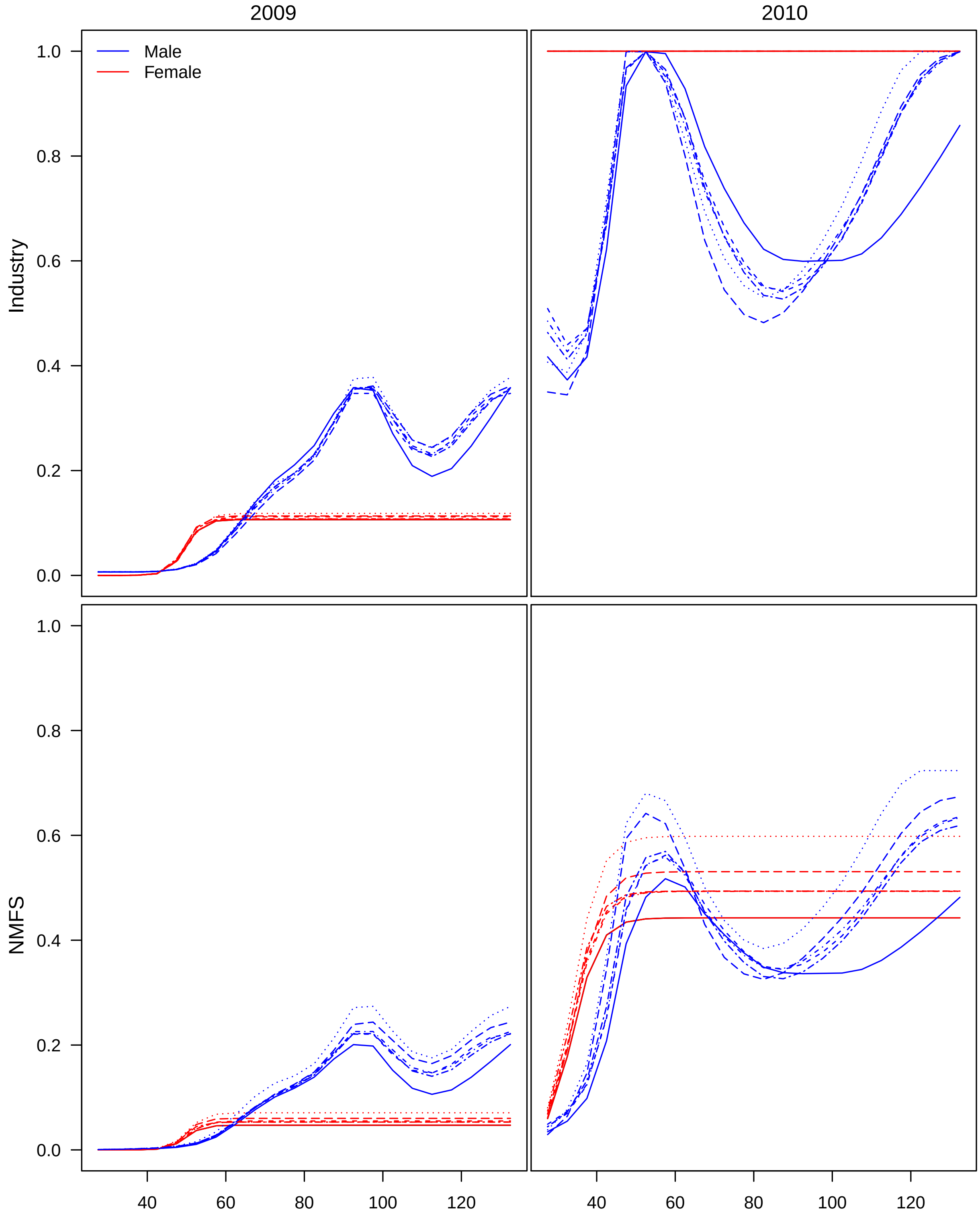


Figure 39: Estimated experimental survey selectivity (availability * survey selectivity)

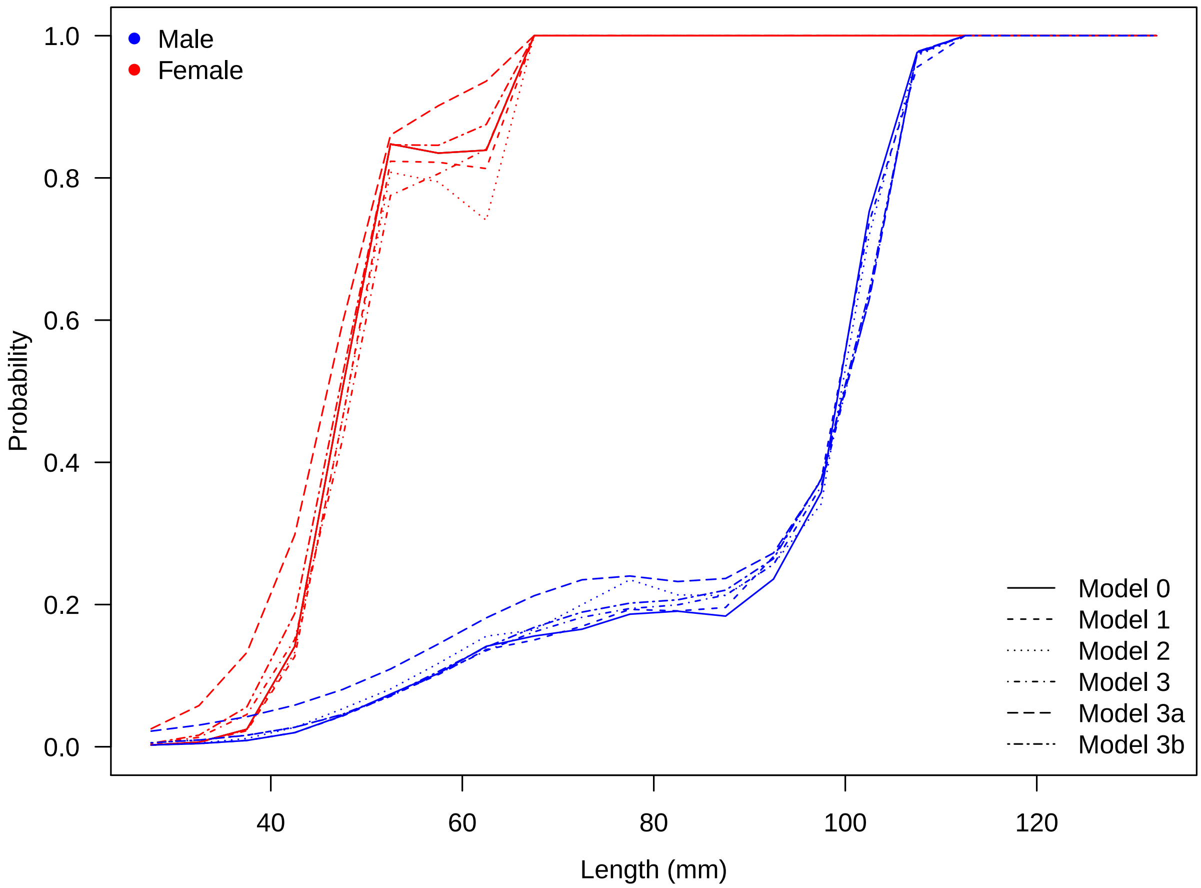


Figure 40: Estimated probability of maturing

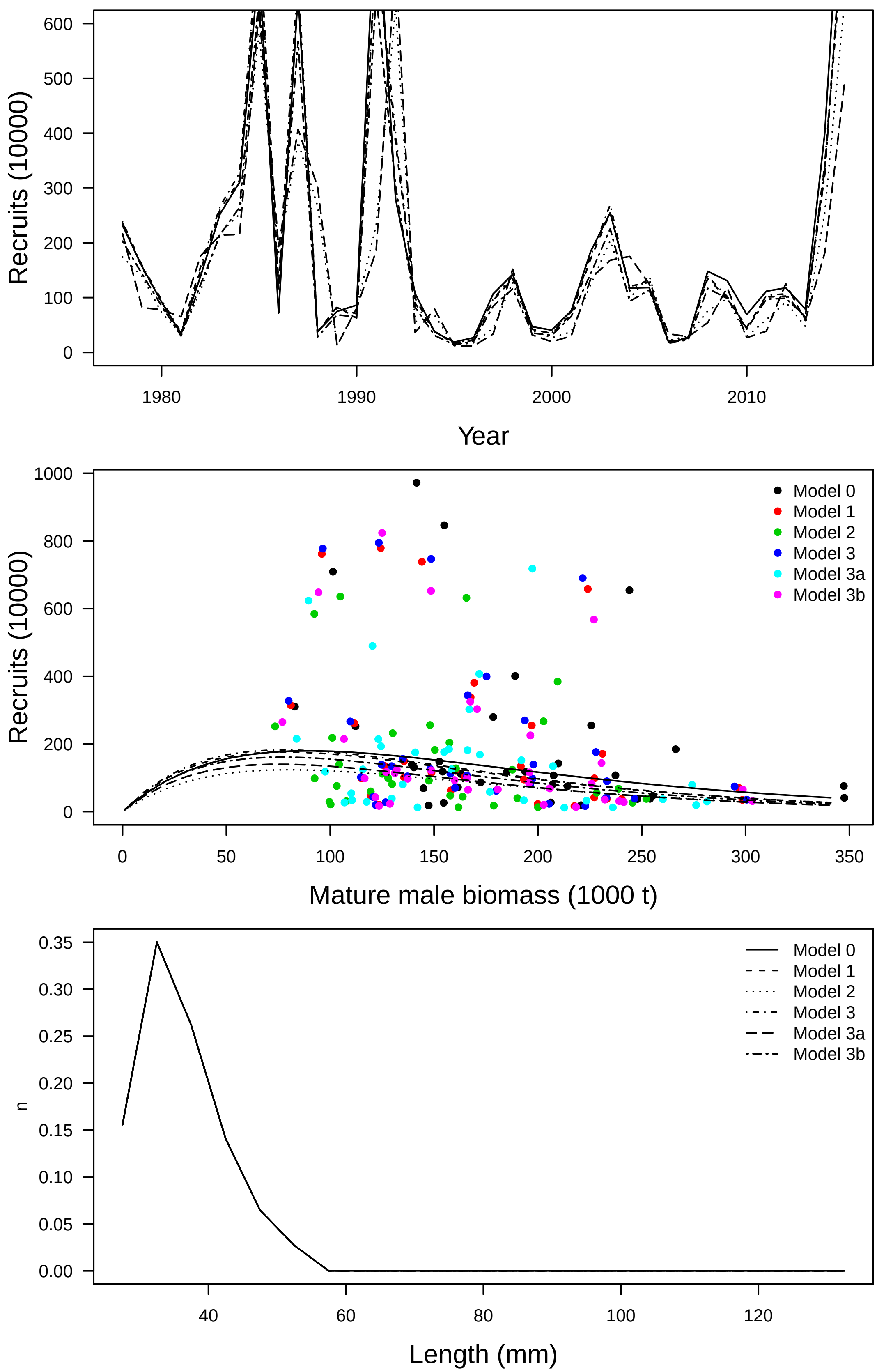


Figure 41: Estimated recruitment, fits to stock recruit curve (MMB lagged 5 years), and proportions recruiting to length bin

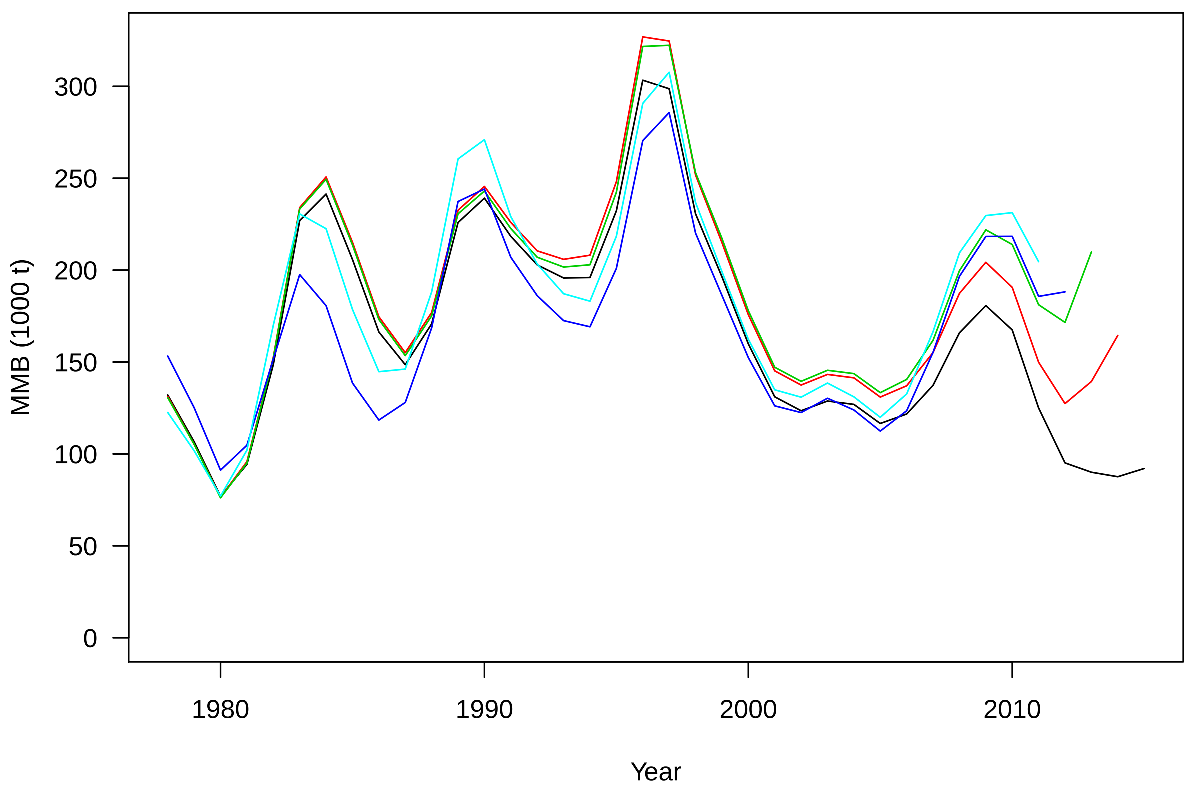


Figure 42: Retrospective pattern in MMB for chosen model

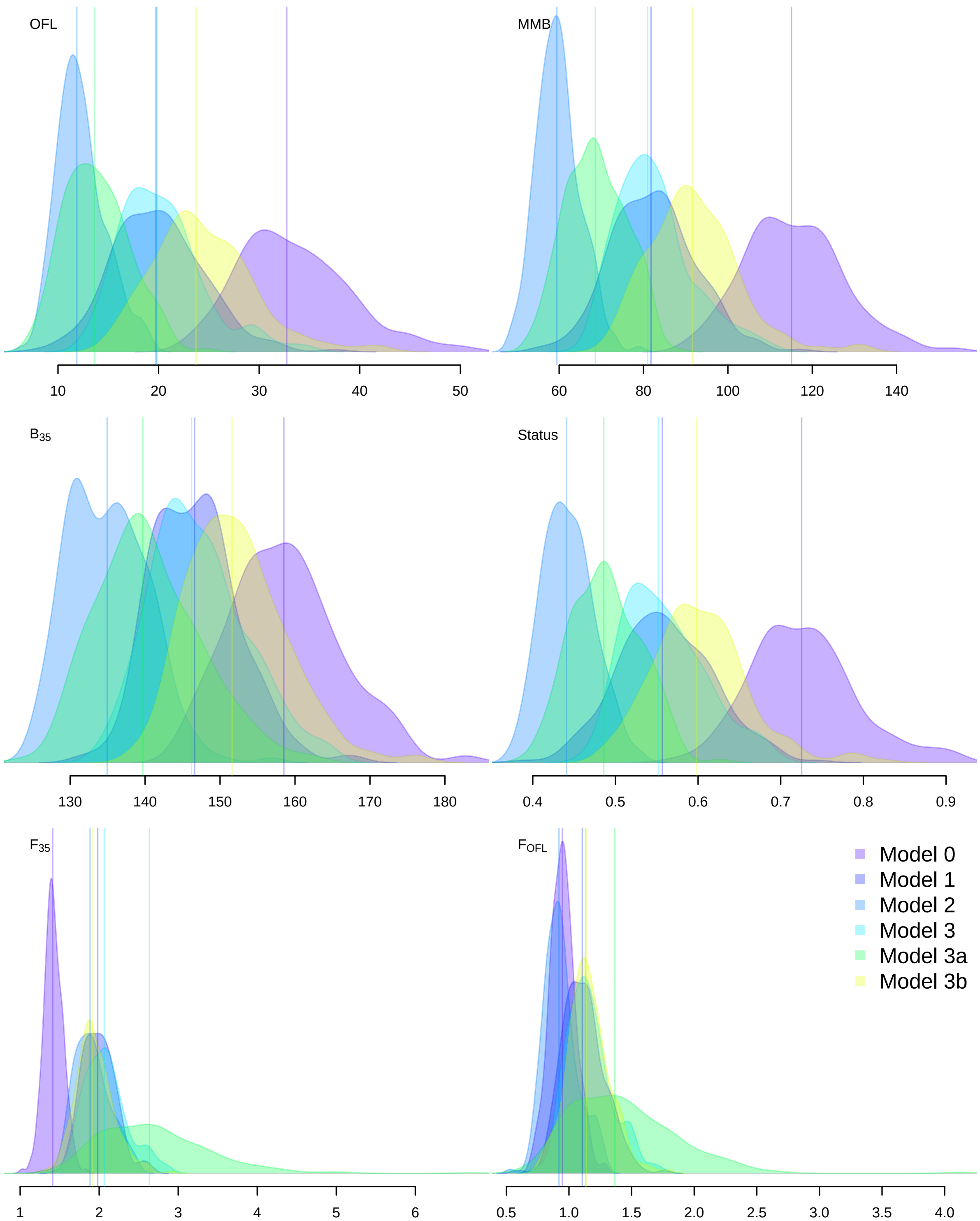


Figure 43: Posterior densities for management quantities by scenario

2016 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

William T. Stockhausen
Alaska Fisheries Science Center
23 September 2016

Executive Summary

1. Stock: species/area.
Southern Tanner crab (*Chionoecetes bairdi*) in the eastern Bering Sea (EBS).

2. Catches: trends and current levels.
Legal-sized male Tanner crab are caught and retained in the directed (male-only) Tanner crab fishery in the EBS. The directed fishery was opened in 2013/14 for the first time since 2009/10 because the stock was not overfished in 2012/13 (Stockhausen et al., 2013) and stock metrics met the State of Alaska (SOA) criteria for opening the fishery in 2013/14. TAC was set at 1,645,000 lbs (746 t) for the area west of 166° W and at 1,463,000 lbs (664 t) for the area east of 166° W in the SOA's Eastern Subdistrict of the Bering Sea District Tanner crab Registration Area J. The fisheries opened on October 15 and closed on March 31. On closing, 79.6% (594 t) of the TAC was taken in the western area while 98.6% (654 t) was taken in the eastern area. Prior to the closures, the retained catch averaged 770 t per year between 2005/06-2009/10.

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

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

Non-retained females and sub-legal males are caught in the directed fishery as bycatch and discarded. Total bycatch (not discounted for assumed handling mortality) in the directed fishery was 3,104 t. Tanner crab are also caught as bycatch in the snow crab and Bristol Bay red king crab fisheries, in the groundfish fisheries and, to a minor extent, in the scallop fishery. Over the last five years, the snow crab fishery has been the major source of Tanner crab bycatch among these fisheries, averaging 1,414 t for the 5-year period 2011/12-2015/16. Bycatch in the snow crab fishery in 2015/16 was 3,536 t. The groundfish fisheries have been the next major source of Tanner crab bycatch over the same five year time period, averaging 296 t. Bycatch in the groundfish fisheries in 2015/16 was 352 t. The Bristol Bay red king crab fishery has typically been the smallest source of Tanner crab bycatch among these fisheries, averaging 61 t over the 5-year time period, although 297 t caught and discarded in 2014/15. In 2015/16, this fishery accounted for 180 t of Tanner crab bycatch.

In order to account for mortality of discarded crab, handling mortality rates are assumed to be 32.1% for Tanner crab discarded in the crab fisheries and 80% for Tanner crab discarded in the groundfish fisheries to account for differences in gear and handling procedures used in the various fisheries.

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

For EBS Tanner crab, spawning stock biomass is expressed as mature male biomass (MMB) at the time of mating (mid-February). From the author's preferred model (Model C), estimated MMB for 2015/16 was 73.9 thousand t (Table 30, Fig. 48). This was slightly smaller than that for 2014/15 (75.4 thousand t), but larger than that for 2013/14 (61.2 thousand t). MMB has generally been rising since 2011/12. It remains above the very low levels seen in the mid-1990s to early 2000s (1990 to 2005 average: 29 thousand t) and the 2014/15 estimate is the largest since 1978/79. However, it is considerably below model-estimated historic levels in the early 1970s when MMB peaked at ~241 thousand t (1971).

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

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

5. Management performance

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

(a) in 1000's t.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2012/13	16.77	59.35[A]	0.00	0.00	0.71	19.02	8.17
2013/14	16.98	72.70[A]	1.41	1.26	2.78	25.35	17.82
2014/15	13.40	71.57[A]	6.85	6.16	9.16	31.48	25.18
2015/16	12.82[C]	73.93[A]	8.92	8.91	11.38	27.19	21.75
2016/17		45.34[B]				25.61[C]	20.49[C]

(b) in millions lbs.

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

A—Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate, based on the subsequent assessment, from the projection the previous year.
B—Projected biomass from the current stock assessment. This value will be updated next year.
C—Based on the author's preferred model (Model C).

6. Basis for the OFL

a) in 1000's t.

Year	Tier^A	B_{MSY}^A	Current MMB^A	B/B_{MSY}^A	F_{OFL}^A (yr^{-1})	Years to define B_{MSY}^A	Natural Mortality^A,B (yr^{-1})
2012/13	3a	33.45	58.59	1.75	0.61	1982-2012	0.23
2013/14	3a	33.54	59.35	1.77	0.73	1982-2013	0.23
2014/15	3a	29.82	63.80	2.14	0.61	1982-2014	0.23
2015/16	3a	26.79	53.70	2.00	0.58	1982-2015	0.23
2016/17	3a	25.65	45.34	1.77	0.79	1982-2016	0.23

b) in millions lbs.

Year	Tier^A	B_{MSY}^A	Current MMB^A	B/B_{MSY}^A	F_{OFL}^A (yr^{-1})	Years to define B_{MSY}^A	Natural Mortality^A,B (yr^{-1})
2012/13	3a	73.74	129.17	1.75	0.61	1982-2012	0.23
2013/14	3a	73.94	130.84	1.77	0.73	1982-2013	0.23
2014/15	3a	65.74	140.66	2.14	0.61	1982-2014	0.23
2015/16	3a	59.06	118.38	2.00	0.58	1982-2015	0.23
2016/17	3a	56.54	99.95	1.77	0.79	1982-2016	0.23

A—Calculated from the assessment reviewed by the Crab Plan Team in 20XX of 20XX/(XX+1) or based on the author's preferred model for 2016/17.
B—Nominal rate of natural mortality. Actual rates used in the assessment are estimated and may be different.

Current male spawning stock biomass (MMB), as projected for 2016/17, is estimated at 45.34 thousand t. B_{MSY} for this stock is calculated to be 25.65 thousand t, so MSST is 12.82 thousand t. Because current MMB > MSST, **the stock is not overfished**. Total catch mortality (retained + discard mortality in all fisheries, using a discard mortality rate of 0.321 for pot gear and 0.8 for trawl gear) in 2015/16 was 11.38 thousand t, which was less than the OFL for 2015/16 (27.19 thousand t); consequently **overfishing did not occur**. The OFL for 2016/17 based on the author's preferred model (Model C) is 25.61 thousand t. The ABC_{max} for 2016/17, based on the p^* ABC, is 25.57 thousand t. In 2014, the SSC adopted a 20% buffer to calculate ABC for Tanner crab to incorporate concerns regarding model uncertainty for this stock. Based on this buffer, the ABC would be 20.49 thousand t.

7. Rebuilding analyses summary.
The EBS Tanner crab stock was found to be above MSST (and B_{MSY}) in the 2012 assessment (Rugolo and Turnock, 2012b) and was subsequently declared rebuilt. The stock remains not overfished. Consequently no rebuilding analyses were conducted.

A. Summary of Major Changes

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

At the March, 2015 SOA Board of Fish meeting, the Board adopted a revised harvest strategy for Tanner crab in the Bering Sea District[1], wherein the TAC for the area east of 166° W longitude would be based on a minimum preferred harvest size of 127 mm CW (5.0 inches), including the lateral spines. Formerly, this calculation was based on a minimum preferred size of 140 mm CW (5.5 inches). The TAC in the area west of 166° W longitude continues to be based on a minimum preferred harvest size of 127 mm CW (including lateral spines).

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

2. Changes to the input data

The following table summarizes data sources that have been updated for this assessment:

Updated data sources.

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

3. Changes to the assessment methodology.

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

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

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

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

B. Responses to SSC and CPT Comments

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

June 2016 SSC Meeting
No general comments.

May2016 Crab Plan Team Meeting
No general comments.

October 2015 SSC Meeting
No general comments.

September 2015 Crab Plan Team Meeting
No general comments.

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

June 2016 SSC Meeting
The SSC endorsed the CPT suggestions from its May meeting.

May2016 Crab Plan Team Meeting
The CPT outlined the base model to be used for this assessment, based on results presented by the author for a suite of models.
Response: The base model recommended by the CPT is the base model used here (Model B).

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

October 2015 SSC Meeting
Comment: "The SSC endorses all of the CPT recommendations with respect to the poor fits to some of the retained catch time series, poor fits to the size composition data for retained catch and survey data, and issues with the total directed fishery selectivity curve for males (in particular the 1996 'outlier')."
Response: See responses to CPT comments below.

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

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

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

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

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

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

September 2015 CPT Meeting

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

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

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

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

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

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

June 2015 SSC Meeting
No specific comments.

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

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

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

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

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

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

Comment: "Evaluate the feasibility of estimating F_{MSY} (and B_{MSY}) for the stock using the estimates of recruitment and MMB during the post-1982 period, and compare to the $F_{35\%}$ MSY proxy."
Response: Not yet addressed.

Comment: "If time permits, apply the groundfish plan team's stock structure template to Tanner crab to synthesize the available information on stock structure."
Response: Not yet addressed.

Comment: The CPT "recommends that all assessment authors document assumptions and simulate data under those assumptions to test the ability of the model to estimate key parameters in an unbiased manner."
Response: Not yet addressed.

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

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

Comment: "Consider fitting to total biomass (by sex?) and to the compositional data rather than to mature biomass (include the fit to mature biomass by sex as a diagnostic)."
Response: Not yet addressed.

Comment: "Do not fit to male compositional data by maturity state for the years for which chela height-maturity relationships are not available."
Response: Not yet addressed.

Comment: "There is still a residual pattern in the fit to the size-composition data for the survey. This could be due to time-varying growth, which should be examined as an alternative model."
Response: Not yet addressed.

C. Introduction

1. Scientific name.
*Chionocoetes bairdi.*Tanner crab is one of five species in the genus *Chionoecetes* (Rathbun, 1924). The common name "Tanner crab" for *C. bairdi* (Williams et al. 1989) was recently modified to "southern Tanner crab" (McLaughlin et al. 2005). Prior to this change, the term "Tanner crab" had also been used to refer to other members of the genus, or the genus as a whole. Hereafter, the common name "Tanner crab" will be used in reference to "southern Tanner crab".

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

In the eastern Bering Sea (EBS), the Tanner crab distribution may be limited by water temperature (Somerton 1981a). The unit stock is that defined across the geographic range of the EBS continental shelf, and managed as a single unit (Fig. 1). *C. bairdi* is common in the southern half of Bristol Bay, around the Pribilof Islands, and along the shelf break, although males less than the industry-preferred size (>125 mm CW) and ovigerous and immature females of all sizes are distributed broadly from southern Bristol Bay northwest to St. Matthew Island (Rugolo and Turnock, 2011a). The southern range of the cold water congener the snow crab, *C. opilio*, in the EBS is near the Pribilof Islands (Turnock and Rugolo, 2011). The distributions of snow and Tanner crab overlap on the shelf from approximately 56° to 60°N, and in this area, the two species hybridize (Karinen and Hoopes 1971).

3. Evidence of stock structure
Tanner crabs in the EBS are considered to be a separate stock distinct from Tanner crabs in the eastern and western Aleutian Islands (NPFMC 1998). Somerton (1981b) suggests that clinal differences in some biological characteristics may exist across the range of the unit stock. These conclusions may be limited since terminal molt at maturity in this species was not recognized at the time of that analysis, nor was stock movement with ontogeny considered. Biological characteristics estimated based on comparisons of length frequency distributions across the range of the stock, or on modal length analysis over time may be confounded as a result.

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

4. Life history characteristics

a. Molting and Shell Condition
Tanner crabs, like all crustaceans, normally exhibit a hard exoskeleton of chitin and calcium carbonate. This hard exoskeleton requires individuals to grow through a process referred to as molting, in which the individual sheds its current hard shell, revealing a new, larger exoskeleton that is initially soft but which rapidly hardens over several days. Newly-molted crab in this "soft shell" phase can be vulnerable to predators because they are generally torpid and have few defenses if discovered. Subsequent to hardening, an individual's shell provides a settlement substrate for a variety of epifaunal "fouling" organisms such as barnacles and bryozoans. The degree of hard-shell fouling was once thought to correspond closely to post-molt age and led to a classification of Tanner crab by shell condition (SC) in survey and fishery data similar to that described in the following table (NMFS/AFSC/RACE, unpublished):

Shell Condition Class	Description
0	pre-molt and molting crab
1	carapace soft and pliable
2	carapace firm to hard, clean
3	carapace hard; topside usually yellowish brown; thoracic sternum and underside of legs yellow with numerous scratches; pterygostomial and bronchial spines worn and polished; dactyli on meri and metabranchial region rounded; epifauna (barnacles and leech cases) usually present but not always.
4	carapace hard, topside yellowish-brown to dark brown; thoracic sternum and undersides of legs data yellow with many scratches and dark stains; pterygostomial and branchial spines rounded with tips sometimes worn off; dactyli very worn, sometimes flattened on tips; spines on meri and metabranchial region worn smooth, sometimes completely gone; epifauna most always present (large barnacles and bryozoans).
5	conditions described in Shell Condition 4 above much advanced; large epifauna almost completely covers crab; carapace is worn through in metabranchial regions, pterygostomial branchial spines, or on meri; dactyli flattened, sometimes worn through, mouth parts and eyes sometimes nearly immobilized by barnacles.

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

b. Growth

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

Growth in immature Tanner crab larger than 25 mm CW proceeds by a series of annual molts, up to a final (terminal) molt to maturity (Tamone et al., 2007). Relationships between pre-molt and post-molt size specific to Tanner crab in the EBS have not been evaluated, although data on individual molt increments from 125 crab collected in the EBS in 2015 and 2016 (Fig. 2).

Rugolo and Turnock (2012a) derived growth relationships for male and female Tanner crab used as priors for estimated growth parameters in this (and previous) assessments from data on observed growth in males to approximately 140 mm carapace width (CW) and in females to approximately 115 mm CW that were collected near Kodiak Island in the Gulf of Alaska (Munk, unpublished.; Donaldson et al. 1981; Fig. 2).

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

c. Weight at Size

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

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

d. Maturity and Reproduction

It is now generally accepted that both Tanner crab males (Tamone et al. 2007) and females (Donaldson and Adams 1989) undergo a terminal molt to maturity, as in most majid crabs. Females usually undergo their terminal molt from their last juvenile, or pubescent, instar while being grasped by a male (Donaldson and Adams 1989). Subsequent mating takes place annually in a hard shell state (Hilsinger 1976) and after extruding the female's clutch of eggs. While mating involving old-shell adult females has been documented (Donaldson and Hicks 1977), fertile egg clutches can be produced in the absence of males by using sperm stored in the spermathacae (Adams and Paul 1983, Paul and Paul 1992). Two or more consecutive egg fertilization events can follow a single copulation using stored sperm to self-fertilize the new clutch (Paul 1982, Adams and Paul 1983), although egg viability decreases with time and age of the stored sperm (Paul 1984).

Maturity in males can be classified either physiologically or morphometrically. Physiological maturity refers to the presence or absence of spermataphores in the gonads whereas morphometric maturity refers to the presence or absence of a large claw (Brown and Powell 1972). During the molt to morphometric maturity, there is a disproportionate increase in the size of the chelae in relation to the carapace (Somerton 1981a). While many earlier studies on Tanner crabs assumed that morphometrically mature male crabs continued to molt and grow, there is now substantial evidence supporting a terminal molt for males (Otto 1998, Tamone et al. 2007). A consequence of the terminal molt in male Tanner crab is that a substantial portion of the population may never achieve legal size (NPFMC 2007).

Although observations are lacking in the EBS, seasonal differences have been observed between mating periods for pubescent and multiparous females in the Gulf of Alaska and Prince William Sound. There, pubescent molting and mating takes place over a protracted period from winter through early summer, whereas multiparous mating occurs over a relatively short period during mid April to early June (Hilsinger 1976, Munk et al. 1996, and Stevens 2000). In the EBS, egg condition for multiparous Tanner crabs assessed between April and July 1976 also suggested that hatching and extrusion of new clutches for this maturity state began in April and ended sometime in mid-June (Somerton 1981a).

e. Fecundity

A variety of factors affect female fecundity, including somatic size, maturity status (primiparous vs. multiparous), age post terminal molt, and egg loss (NMFS 2004). Of these factors, somatic size is the most important, with estimates of 89 to 424 thousand eggs for females 75 to 124 mm CW, respectively (Haynes et al. 1976). Maturity status is another important factor affecting fecundity, with primiparous females being only ~70% as fecund as equal size multiparous females (Somerton and Meyers 1983). The number of years post maturity molt, and whether or not, a female has had to use stored sperm from that first mating can also affect egg counts (Paul 1984, Paul and Paul 1992). Additionally, older senescent females often carry small clutches or no eggs (i.e., are barren) suggesting that female crab reproductive output is a concave function of age (NMFS 2004).

f. Size at Maturity

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

g. Mortality

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

Rugolo and Turnock (2011a) examined empirical evidence for reliable estimates of oldest observed age for male Tanner crab. Unlike its congener the snow crab, information on longevity of the Tanner crab is lacking. They reasoned that longevity in a virgin population of Tanner crab would be analogous to that of the snow crab, where longevity would be at least 20 years, given the close analogues in population dynamic and life-history characteristics (Turnock and Rugolo 2011a). Employing 20 years as a proxy for longevity and assuming that this age represented the upper 98.5th percentile of the distribution of ages in an unexploited population, M was estimated to be 0.23 based on Hoenig's (1983) method. If 20 years was assumed to represent the 95% percentile of the distribution of ages in the unexploited stock, the estimate for M was 0.15. Rugolo and Turnock (2011a) adopted M=0.23 for both male and female Tanner because the value corresponded with the range estimated by Somerton (1981a), as well as the value used in the analysis to estimate new overfishing definitions underlying Amendment 24 to the Crab Fishery Management Plan (NPFMC 2007).

5. Brief summary of management history.

A complete summary of the management history is provided in the ADF&G Area Management Report appended to the annual SAFE. Fisheries have historically taken place for Tanner crab throughout their range in Alaska, but currently only the fishery in the EBS is managed under a federal Fishery Management Plan (FMP; NPFMC 2011). The plan defers certain management controls for Tanner crab to the State of Alaska, with federal oversight (Bowers et al. 2008). The State of Alaska manages Tanner crab based on registration areas divided into districts. Under the FMP, the state can adjust districts as needed to avoid overharvest in a particular area, change size limits from other stocks in the registration area, change fishing seasons, or encourage exploration (NPFMC 2011).

The Bering Sea District of Tanner crab Registration Area J (Fig. 1) includes all waters of the Bering Sea north of Cape Sarichef at 54° 36'N and east of the U.S.-Russia Maritime Boundary Line of 1991. This district is divided into the Eastern and Western Subdistricts at 173°W. The Eastern Subdistrict is further divided at the Norton Sound Section north of the latitude of Cape Romanzof and east of 168°W and the General Section to the south and west of the Norton Sound Section (Bowers et al. 2008). In this report, I use the terms “east region” and “west region” as shorthand to refer to the regions demarcated by 166ºW.

In March 2011, the Alaska Board of Fisheries BOF) approved a new minimum size limit harvest strategy for Tanner crab effective for the 2011/12 fishery. Prior to this change, the minimum legal size limit was 5.5” (138 mm CW) throughout the Bering Sea District. The new regulations established different minimum size limits east and west of 166º W. The minimum size limit for the fishery to the east of 166ºW is now 4.8” (122 mm CW) and that to the west is 4.4” (112 mm CW), where the size measurement includes the lateral spines. For economic reasons, fishers may adopt larger minimum sizes for retention of crab in both areas, and the SOA’s harvest strategy and total allowable catch (TAC) calculations are based on assumed minimum preferred sizes that are larger than the legal minimums. In 2011, these minimum preferred sizes were set at 5.5” (140 mm CW) in the east and 5” (127 mm CW) in the west, including the lateral spines. In 2015, following a petition by the crab industry, the BOF revised the minimum preferred size for TAC calculations in the area east of 166º W longitude to 5” (127 mm CW), the same as that in the western area. These new “preferred” sizes were used to set the TAC for the 2015/16 fishery season.

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

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

The domestic Tanner crab pot fishery developed rapidly in the mid-1970s (Tables 1 and 2; Fig.3). Domestic US landings were first reported for Tanner crab in 1968 at 0.46 thousand t taken incidentally to the EBS red king crab fishery. Tanner crab was targeted thereafter by the domestic fleet and landings rose sharply in the early 1970s, reaching a high of 30.21 thousand t in 1977/78. Landings fell sharply after the peak in 1977/78 through the early 1980s, and domestic fishing was closed in 1985/86 and 1986/87 due to depressed stock status. In 1987/88, the fishery reopened and landings rose again in the late-1980s to a second peak in 1990/91 at 18.19 thousand t, and then fell sharply through the mid-1990s. The domestic Tanner crab fishery was closed between 1996/97 and 2004/05 as a result of conservation concerns regarding depressed stock status. It re-opened in 2005/06 and averaged 0.77 thousand t retained catch between 2005/06-2009/10 (Tables 1 and 2). For the 2010/11-2012/13 seasons, the State of Alaska closed directed commercial fishing for Tanner crab due to estimated female stock metrics being below thresholds adopted in the state harvest strategy. However, these thresholds were met in fall 2013 and the directed fishery was opened in 2013/14. TAC was set at 1,645,000 lbs (746 t) for the area west of 166º W and at 1,463,000 lbs (664 t) for the area east of 166º W in the State of Alaska’s Eastern Subdistrict of Tanner crab Registration Area J. The fisheries opened on October 15 and closed on March 31. On closing, 79.6% (594 t) of the TAC had been taken in the western area while 98.6% (654 t) had been taken in the eastern area. Prior to the closures, the retained catch averaged 770 t per year between 2005/06-2009/10. In 2014, TAC was set at 6,625,000 lbs (3,005 t) for the area west of 166º W and at 8,480,000 lbs (3,846 t) for the area east of 166º W. On closing, 77.5% (2,329 t) of the TAC was taken in the western area while 99.6% (3,829 t) were taken in the eastern area. In 2015, TAC was set at 8,396,000 lbs (3,808 t) in the western area and 11,272,000 lbs (5,113 t) in the eastern area. On closing, essentially 100% of the TAC was taken in each area (3,798 t in the west, 5,111 t in the east). The total retained catch in 2015/16 (8,910 t) was the largest taken in the fishery since 1992/93 (Tables 1, 2; Fig. 3).

Bycatch and discard losses of Tanner crab originate from the directed pot fishery, non-directed snow crab and Bristol Bay red king crab pot fisheries, and the groundfish fisheries (Tables 4 and 5, Fig.s 5-7). Bycatch estimates are converted to discard mortality using assumed handling mortality rates of 32.1% for bycatch in the crab fisheries and 80% for bycatch in the groundfish fisheries. Bycatch was persistently high during the early-1970s; a subsequent peak mode of discard losses occurred in the early-1990s. In the early-1970s, the groundfish fisheries contributed significantly to total bycatch losses (although bycatch in the crab fisheries was undocumented at the time). From 1992/93 (when reliable crab fishery bycatch estimates are first available) to 2004/05, the groundfish fisheries accounted for the largest proportion of discard mortality. Since 2005/06, however, the crab fisheries have accounted for the largest proportion.

D. Data

1. Summary of new information

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

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

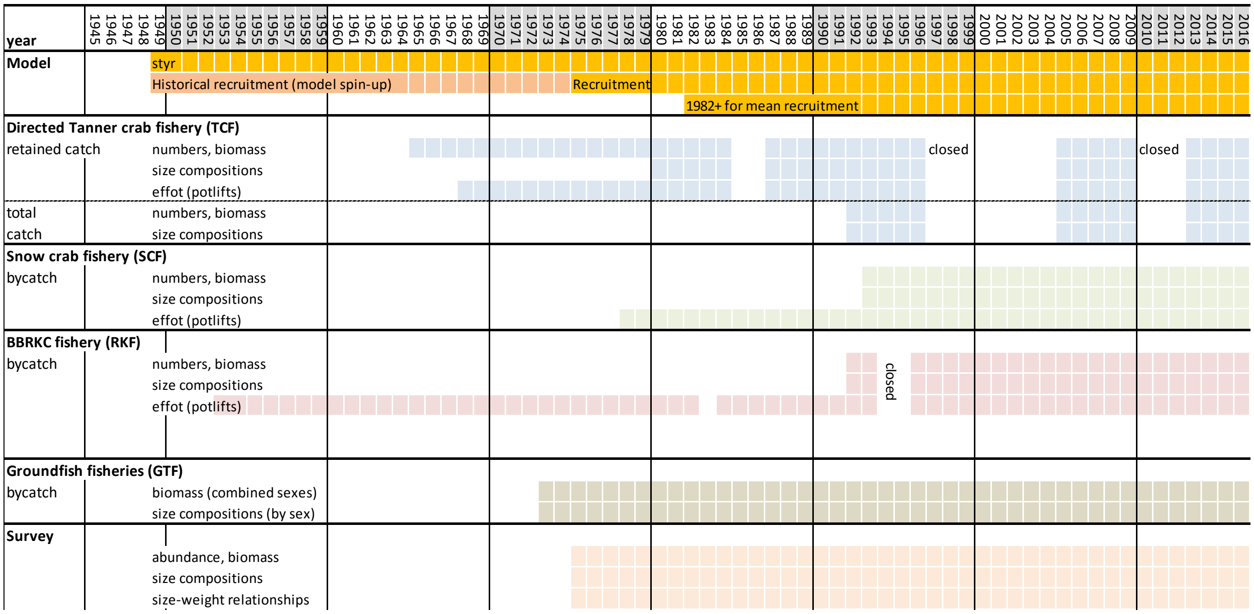
Tanner crab bycatch data in the groundfish fisheries (biomass, size compositions) were extracted for 2015/16 from the groundfish observer and AKFIN databases.

The following table summarizes data sources that have been updated for this assessment:

Updated data sources.

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

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



2. Data presented as time series

For the stock biomass and fishery data presented in this document, the convention is that 'year' refers to the year in which the NMFS bottom trawl survey was conducted (nominally July 1, yyyy), and fishery data are those subsequent to the survey (July 1, yyyy to June 30, yyyy+1)--e.g., 2015/16 indicates the 2015 bottom trawl survey and the winter 2015/16 fishery.

a. Total catch

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

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

b. Information on bycatch and discards

Annual bycatch (discards) of Tanner crab are provided by sex in Tables 3 and 4 (and Fig.s 4-6) from ADFG crab observer sampling, starting in 1992/93 for the directed Tanner crab fishery, the snow crab fishery, and the BBRKC fishery. Annual discards for the groundfish fisheries, based on NMFS groundfish observer programs, are also provided starting in 1973/74, but sex is undifferentiated. A value of 0.321 is used for "handling mortality" in the crab fisheries to convert observed bycatch to (unobserved) mortality (Stockhausen, 2014). For the groundfish fisheries, a value of 0.8 for handling mortality is used to reflect differences in gear and on-deck operations with those of the crab fleets.

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

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

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

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

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

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

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

d. Survey biomass estimates

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

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

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

e. Survey catch-at-length

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

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

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

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

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

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

3. Data which may be aggregated over time:

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

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

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

4. Information on any data sources that were available, but were excluded from the assessment.
The 1974 NMFS trawl survey was dropped entirely from the standardized survey dataset in 2015 due to inconsistencies in spatial coverage with the standardized dataset.

E. Analytic Approach

1. History of modeling approaches for this stock

Prior to the 2012 stock assessment, Tanner crab was managed as a Tier-4 stock using a survey-based assessment approach (Rugolo and Turnock 2011b). The Tier 3 Tanner Crab Stock Assessment Model (TCSAM) was developed by Rugolo and Turnock and presented for review in February 2011 to the Crab Modeling Workshop (Martel and Stram 2011), to the SSC in March 2011, to the CPT in May 2011, and to the CPT and SSC in September 2011. The model was revised after May 2011 and the report to the CPT in September 2011 (Rugolo and Turnock 2011a) described the developments in the model per recommendations of the CPT, SSC and Crab Modeling Workshop through September 2011. In January 2012, the TCSAM was reviewed at a second Crab Modeling Workshop. Model revisions were made during the Workshop based on consensus recommendations. The model resulting from the Workshop was presented to the SSC in January 2012. Recommendations from the January 2012 Workshop and the SSC, as well as Rugolo's and Turnock's research plans, guided changes to the model. A model incorporating all revisions recommended by the CPT, the SSC and both Crab Modeling Workshops was presented to the SSC in March 2012.

In May 2012 and June 2012, respectively, the TCSAM was presented to the CPT and SSC to determine its suitability for stock assessment and the rebuilding analysis (Rugolo and Turnock 2012b). The CPT agreed that the model could be accepted for management of the stock in the 2011/12 cycle, and that the stock should be promoted to Tier-3 status. The CPT also agreed that the TCSAM could be used as the basis for rebuilding analyses to underlie a rebuilding plan developed in 2012. In June 2012, the SSC reviewed the model and accepted the recommendations of the CPT. The Council subsequently approved the SSC recommendations in June 2012. For 2011/12, the Tanner crab was assessed as a Tier-3 stock and the model was used for the first time to estimate status determination criteria and overfishing levels.

In December 2012, a new analyst (Stockhausen) was assigned as principal author for the Tanner crab assessment. Modifications have been made to the TCSAM computer code to improve code readability, computational speed, model output, and user friendliness without altering its underlying dynamics and overall framework. A detailed description of the 2013 model (TCSAM2013) is presented in Appendix 3 of the 2014 SAFE chapter (Stockhausen, 2014). Following the 2014 assessment, the model code was put under version control using "git" software and is publicly available for download from the GitHub website[2].

2. Model Description

a. Overall modeling approach

TCSAM is a stage/size-based population dynamics model that incorporates sex (male, female), shell condition (new shell, old shell), and maturity (immature, mature) as different categories into which the overall stock is divided on a size-specific basis. For details of the model, the reader is referred to Appendix 3 of the 2014 assessment (Stockhausen, 2014).

In brief, crab enter the modeled population as recruits following the size distribution in Fig. 30. An equal (50:50) sex ratio is assumed at recruitment, and all recruits begin as immature, new shell crab. Within a model year, new shell, immature recruits are added to the population numbers-at-sex/shell condition/maturity state/size remaining on July 1 from the previous year. These are then projected forward to Feb. 15 ($\delta t = 0.625$ yr) and reduced for the interim effects of natural mortality. Subsequently, the various fisheries that either target Tanner crab or catch them as bycatch are prosecuted as pulse fisheries (i.e., instantaneously). Catch by sex/shell condition/maturity state/size in the directed Tanner crab, snow crab, BBRKC, and groundfish fisheries is calculated based on fishery-specific stage/size-

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

based selectivity curves and fully-selected fishing mortalities and removed from the population. The numbers of surviving immature, new shell crab that will molt to maturity are then calculated based on sex/size-specific probabilities of maturing, and growth (via molt) is calculated for all surviving new shell crab. Crab that were new shell, mature crab become old shell, mature crab (i.e., they don't molt) and old shell crab remain old shell. Population numbers are then adjusted for the effects of maturation, growth, and change in shell condition. Finally, population numbers are reduced for the effects of natural mortality operating from Feb. 15 to July 1 ($\delta t = 0.375$ yr) to calculate the population numbers (prior to recruitment) on July 1.

Model parameters are estimated using a maximum likelihood approach, with Bayesian-like priors on some parameters and penalties for smoothness and regularity on others. Data components entering the likelihood include fits to mature survey biomass, survey size compositions, retained catch, retained catch size compositions, bycatch mortality in the bycatch fisheries, and bycatch size compositions in the bycatch fisheries (Stockhausen, 2014).

b. Changes since the previous assessment.

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

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

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

Model changes made subsequent to May 2016 are summarized here:

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

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

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

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

3. Model Selection and Evaluation

a. Description of alternative model configurations

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

d. Convergence status and convergence criteria

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

e. Sample sizes assumed for the compositional data

Input sample sizes used for compositional data are listed in Tables 5-9 for fishery-related size compositions. Input sample sizes for all survey size compositions were set to 200, which was also the maximum allowed for the fishery-related sample sizes. Otherwise, input sample sizes were scaled as described in Stockhausen (2014, Appendix 5):

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

where $\overline{SS}$ was the mean sample size for all males from dockside sampling in the directed fishery.

f. Parameter sensibility

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

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

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

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

h. Residual analysis

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

i. Evaluation of the model(s)

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

4. Results (best model(s))

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

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

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

b. Tables of estimates:

i. All parameters

Parameter estimates and associated standard errors, based on inversion of the converged model's Hessian, are listed in Tables 21-28.

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

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

iii. Recruitment time series

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

iv. Time series of catch divided by biomass.

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

c. Graphs of estimates

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

Estimates of natural mortality by sex and maturity state are shown in Fig. 31. Mortality rates are assumed equal by sex for immature crab, but are allowed to differ by sex for mature crab. Mortality rates for mature crab are estimated by sex across two time periods: 1949-1979+1985-2013 and 1980-1984. The latter period has been identified as a period of high natural mortality in the BBRKC stock (Zheng et al., 2012) and was identified as a separate period for Tanner crab in the 2012 assessment. The following table summarizes the estimated rates by stock component:

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

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

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

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

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

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

Separate curves are estimated for 3 different time periods for each bycatch fishery, corresponding to changes in available data and fishery activity. For the snow crab fishery, separate sex-specific curves are estimated for 1989/90-1996/97, 1997/98-2004/05, and 2005/06-present. The time periods are the same for the BBRKC fishery. The directed Tanner crab fishery was closed during 1997/98-2004/05, which may have encouraged changes in how the snow crab and BBRKC fisheries were prosecuted—with associated changes in bycatch selectivity on Tanner crab. For the groundfish fisheries, the three time periods corresponding to the selectivity curves are 1973-1987, 1988-1996, and 1997-present. These correspond to changes in the groundfish fleets and Tanner crab fishery, with the curtailment of foreign and joint-venture fishing by 1988, the expansion of domestic fisheries from 1988 to 1996, and the closure of the tanner crab fishery in 1996/97. Estimated male selectivity curves in the bycatch fisheries (Fig.s 38-40) from the two models are similar for each time period, whereas the female selectivity curves tend to be left-shifted to smaller sizes in Model A relative to the 2015 assessment model (Fig.s 38-40). Again, this latter phenomenon is due to estimating female-specific offsets to male capture rates in Model A.

iii. Estimated full selection F over time

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

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

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

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

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

iv. Estimated fishing mortality versus estimated spawning stock biomass

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

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

Not available.

e. Evaluation of the fit to the data:

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

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

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

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

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

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

ii. Graphs of model fits to survey numbers

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

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

iii. Graphs of model fits to catch proportions by length

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

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

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

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

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

iv. Graphs of model fits to survey proportions by length

Model fits from the 2015 assessment and Model C to observed proportions-at-size in the annual NMFS trawl survey are shown for males in Fig. 74. The similarity in results between the two models is fairly remarkable. As with the 2015 assessment model, Model C appears to be suitably sensitive to relatively large cohorts recruiting to the model size range (e.g., 1997-2002), but appears to be less able to track strong cohorts through time (the mode in the model proportions at ~100 mm CW in 1982 disappears after two years, but appears to last until at least 1985 in the observed proportions. After 1982, the model tends to under-predict size proportions for males in the 70-120 mm range and over-predict the proportion of large (> 120 mm CW) males after 2000. Model fits to proportions at size in the survey for females are shown in Fig. 75. The model tends to over-predict proportions-at-size in the 65-85 mm CW range. The patterns of residuals for males and females evident in the bubble plots for Model A are almost identical to those obtained from the 2015 assessment (Fig. 76).

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

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

The observed and predicted (Model A) marginal proportions for males taken as bycatch in the snow crab fishery are in good agreement at all sizes for both models (Fig. 79, lower plot), while both models tend to underestimate the proportion of females taken as bycatch near the peak proportions (~80-90 mm CW) and over-estimate the proportions at larger sizes (Fig. 79, upper plot). The opposite pattern is true for both models regarding the proportion-at-size of females taken as bycatch in the BBRKC fishery, where intermediate-size females are over-represented in the model predictions and under-represented at larger sizes (Fig. 80). The patterns of model-predicted marginal proportions-at-size for males taken as bycatch in the BBRKC fishery are similar to that found for the snow crab fishery, but shifted to larger sizes by ~20 mm CW. Unfortunately, these result in poorer fits to the observations, overestimating proportions at larger sizes and underestimating them at smaller sizes, than those for the snow crab fishery. The patterns of marginal predicted proportions at size for males and females taken in the groundfish fishery (Fig. 81) obtained using Model C are much closer to the data than those obtained in the 2015 assessment. The improvement occurs Model C uses an improved approach to combining the male and female size compositions prior to fitting them (documented at the May 2016 CPT meeting).

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

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

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

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

Not available.

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

Not available.

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

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

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

ii. Historic analysis (plot of actual estimates from current and previous assessments).
Many of the plots contained in this assessment feature comparisons between results from the 2015 assessment model and the author's preferred model for this assessment. Most of them indicate little difference between the two models, particularly for more recent periods (e.g., since 1990).

g. Uncertainty and sensitivity analyses
Not available.

F. Calculation of the OFL and ABC

1. Status determination and OFL calculation

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

The (total catch) OFL for 2015/16 was 27.19 thousand t while the total catch mortality for 2014/15 was 11.38 thousand t, based on applying discard mortality rates of 1.000 for retained catch, 0.321 to bycatch in the crab fisheries, and 0.800 to bycatch in the groundfish fisheries to the reported catch by fleet for 2015/16 (Tables 1 and 4). Therefore overfishing did not occur.

Amendment 24 to the NPFMC fishery management plan (NPFMC 2007) revised the definitions for overfishing for EBS crab stocks. The information provided in this assessment is sufficient to estimate overfishing limits for Tanner crab under Tier 3. The OFL control rule for Tier 3 is (Fig. 90):

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

and is based on an estimate of "current" spawning biomass at mating (B above, taken as MMB at mating in the assessment year) and spawning biomass per recruit (SBPR)-based proxies for F_{MSY} and B_{MSY}. In the above equations, α=0.1 and β=0.25. For Tanner crab, the proxy for F_{MSY} is $F_{35\%}$, the fishing mortality that reduces the SBPR to 35% of its value for an unfished stock. Thus, if $\phi(F)$ is the SBPR at fishing mortality F, then $F_{35\%}$ is the value of fishing mortality that yields $\phi(F) = 0.35 \cdot \phi(0)$. The Tier 3 proxy for B_{MSY} is $B_{35\%}$, the equilibrium biomass achieved when fishing at $F_{35\%}$, where $B_{35\%}$ is simply 35% of the unfished stock biomass. Given an estimate of average recruitment, $\bar{R}$, then $B_{35\%} = 0.35 \cdot \bar{R} \cdot \phi(0)$.

Thus Tier 3 status determination and OFL setting for 2015/16 require estimates of B = $MMB_{2016/17}$ (the projected MMB at mating time for the coming year), $F_{35\%}$, spawning biomass per recruit in an unfished stock ($\phi(0)$), and $\bar{R}$. Current stock status is determined by the ratio $B/B_{35\%}$ for Tier 3 stocks. If the ratio is greater than 1, then the stock falls into Tier 3a and $F_{OFL} = F_{35\%}$. If the ratio is less than one but greater than β, then the stock falls into Tier 3b and F_{OFL} is reduced from $F_{35\%}$ following the descending limb of the control rule (Fig. 90). If the ratio is less than β, then the stock falls into Tier 3c and directed fishing must cease. In addition, if B is less than ½ $B_{35\%}$ (the minimum stock size threshold, MSST), the stock must be declared overfished and a rebuilding plan subsequently developed.

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

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

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

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

The determination of B_{MSY}=$B_{35\%}$ for Tanner crab depends on the selection of an appropriate time period over which to calculate average recruitment ($\bar{R}$). After much discussion in 2012 and 2013, the SSC endorsed an averaging period of 1982+. Starting the average recruitment period in 1982 is consistent with a 5-6 year recruitment lag from 1976/77, when a well-known climate regime shift occurred in the EBS (Rodionov and Overland, 2005) that may have affected stock productivity. The value of $\bar{R}$ for this period from the author's preferred model is 182.27 million. The estimates of average recruitment are reasonably similar between the 2015 assessment model and the author's preferred model (Table 33, Fig. 45). The value of B_{MSY}=$B_{35\%}$ for $\bar{R}$ is 25.65 thousand t. Thus, the stock is "not overfished" because B/$B_{35\%}$ > 0.5 (i.e., B > MSST).

Once F_{OFL} is determined using the control rule (Fig. 90), the (total catch) OFL can be calculated based on projecting the population forward one year assuming that $F = F_{OFL}$. In the absence of uncertainty, the OFL would then be the predicted total catch taken when fishing at $F = F_{OFL}$. When uncertainty (e.g. assessment uncertainty, variability in future recruitment) is taken into account, the OFL is taken as the median total catch when fishing at $F = F_{OFL}$.

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

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

where C is total catch (biomass), $F_{f,x,z}$ is the fishing mortality in fishery f on crab in size bin z by sex (x), $F_{.,x,z} = \sum_f F_{f,x,z}$ is the total fishing mortality by sex on crab in size bin z, $w_{x,z}$ is the mean weight of crab in size bin z by sex, M_x is the sex-specific rate of natural mortality, δt is the time from July 1 to the time of the fishery (0.625 yr), and $N_{x,z}$ is the numbers by sex in size bin z on July 1, 2016 as estimated by the assessment model.

Assessment uncertainty was included in the calculation of OFL using the same approach as that used for previous assessments (Stockhausen, 2014, 2015). Basically, initial numbers at size on July 1, 2016 were randomized based on an assumed lognormal assessment error distribution and the cv of estimated MMB for 2015/16 from the assessment model, the control rule was applied to obtain F_{OFL}, and the population projected forward to next year assuming that fishing occurred consistent with F_{OFL}. This was repeated 10,000 times to generate a distribution of total catch OFLs. **The value of OFL for 2016/17 from the author's preferred model (Model C) is 25.61 thousand t** (Table 35, Fig. 93)**.**

Model C is the author's preferred model for calculating the B_{MSY} proxy as $B_{35\%}$, so MSST = 0.5 B_{MSY} = 12.82 thousand t. Because current B = 45.34 thousand t > MSST, **the stock is not overfished**. The population state (directed F vs. MMB) is plotted for each year from 1965-2014 in Fig. 94 against the Tier 3 harvest control rule.

2. ABC calculation

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

Two methods for establishing the ABC control rule are: 1) a constant buffer where the ABC is set by applying a multiplier to the OFL to meet a specified buffer below the OFL; and 2) a variable buffer where the ABC is set based on a specified percentile (P*) of the distribution of the OFL that accounts for uncertainty in the OFL. P* is the probability that ABC would exceed the OFL and overfishing occur. In 2010, the NPFMC prescribed that ABCs for BSAI crab stocks be established at P*=0.49 (following Method 2). Thus, annual ACL=ABC levels should be established such that the risk of ovefishing, P[ABC>OFL], is 49%. In 2014, however, the SSC adopted a buffer of 20% on OFL for the Tanner crab stock for calculating ABC. Here, ABCs are provided based on both methods.

ABCs based on the P*=0.49 approach were calculated from quantiles of the associated OFL distributions such that probability that the selected ABC was greater than the true OFL was 0.49. The resulting ABC for each scenario was almost identical to the associated OFL (Table 35). ABCs were also calculated using the SSC's 20% OFL buffer (Table 35).

For the author's preferred model, Model C, the P* ABC (ABC_{max}) is 25.57 thousand t while the 20% Buffer ABC is 20.49 thousand t. The author remains concerned that the projection model, based on $F_{35\%}$ as a proxy for F_{MSY}, is overly optimistic regarding the actual productivity of the stock. Fishery-related mortality similar to these ABC levels has occurred only in the latter half of the 1970s and in 1992/93, coincident with collapses in stock biomass to low levels. This suggests that $F_{35\%}$ may not be a realistic proxy for F_{MSY} and/or that MMB may not be a good proxy for reproductive success, as are currently assumed for this stock. Given this uncertainty concerning the stock, **the author recommends using the 20% buffer adopted by the SSC last yearfor this stock to calculate ABC. Consequently, the author's recommended ABC is 20.49 thousand t**.

G. Rebuilding Analyses

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

H. Data Gaps and Research Priorities

Information on growth-per-molt has finally been collected in the EBS on Tanner crab (molt increments observed on 100+ individuals collected in 2015 and 2016; R. Foy, AFSC, pers. comm.). More data regarding temperature-dependent effects on molting frequency would be helpful to assess potential impacts of the EBS cold pool on the stock. Information on temperature-dependent changes in crab movement and survey catchability would also e of value. In addition, it would be extremely worthwhile to develop a "better" index of reproductive potential than MMB that can be calculated in the assessment model and to revisit the issue of MSY proxies for this stock.

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

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

I. Ecosystem Considerations

Mature male biomass is currently used as the "currency" of Tanner crab spawning biomass for assessment purposes. However, its relationship to stock-level rates of egg production, perhaps an ideal measure of stock-level reproductive capacity, is unclear. Thus, use of MMB to reflect Tanner crab reproductive potential may be misleading as to stock health. Nor is it likely that mature female biomass has a clear relationship to annual egg production. For Tanner crab, the fraction of barren mature females by shell condition appears to vary on a decadal time scale (Rugolo and Turnock, 2012), suggesting a potential climatic driver.

1. Ecosystem Effects on Stock

Time series trends in prey availability or abundance are generally unknown for Tanner crab because typical survey gear is not quantitative for Tanner crab prey. On the other hand, Pacific cod (*Gadus macrocephalus*) is thought to account for a substantial fraction of annual mortality on Tanner crab (Aydin et al., 2007). Total P. cod biomass is estimated to have been slowly declining from 1990 to 2008, during the time frame of a collapse in the Tanner crab stock, but has been increasing rather rapidly since 2008 (Thompson and Lauth, 2012). This suggests that the rates of "natural mortality" used in the stock assessment for the period post-1980 may be underestimates (and increasingly biased low if the trend in P. cod abundance continues). This trend is definitely one of potential concern.

2. Effects of Tanner crab fishery on ecosystem

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

Effects of Tanner crab fishery on ecosystem

Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	salmon are unlikely to be trapped inside a pot when it is pulled, although halibut can be	unlikely to have substantial effects at the stock level	minimal to none
Forage (including herring, Atka mackerel, cod and pollock)	Forage fish are unlikely to be trapped inside a pot when it is pulled	unlikely to have substantial effects	minimal to none
HAPC biota	crab pots have a very small footprint on the bottom	unlikely to be having substantial effects post-rationalization	minimal to none
Marine mammals and birds	crab pots are unlikely to attract birds given the depths at which they are fished	unlikely to have substantial effects	minimal to none
Sensitive non-target species	Non-targets are unlikely to be trapped in crab pot gear in substantial numbers	unlikely to have substantial effects	minimal to none
Fishery concentration in space and time	substantially reduced in time following rationalization of the fishery	unlikely to be having substantial effects	probably of little concern
Fishery effects on amount of large size target fish	Fishery selectively removes large males	May impact stock reproductive potential as large males can mate with a wider range of females	possible concern
Fishery contribution to discards and offal production	discarded crab suffer some mortality	May impact female spawning biomass and numbers recruiting to the	possible concern

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

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Tables

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

Eastern Bering Sea *Chionoecetes bairdi* Retained Catch (1,000's t)				
Year	US Pot	Japan	Russia	Total
1965/66		1.17	0.75	1.92
1966/67		1.69	0.75	2.44
1967/68		9.75	3.84	13.60
1968/69	0.46	13.59	3.96	18.00
1969/70	0.46	19.95	7.08	27.49
1970/71	0.08	18.93	6.49	25.49
1971/72	0.05	15.90	4.77	20.71
1972/73	0.10	16.80		16.90
1973/74	2.29	10.74		13.03
1974/75	3.30	12.06		15.24
1975/76	10.12	7.54		17.65
1976/77	23.36	6.66		30.02
1977/78	30.21	5.32		35.52
1978/79	19.28	1.81		21.09
1979/80	16.60	2.40		19.01
1980/81	13.47			13.43
1981/82	4.99			4.99
1982/83	2.39			2.39
1983/84	0.55			0.55
1984/85	1.43			1.43
1985/86	0.00			0.00
1986/87	0.00			0.00
1987/88	1.00			1.00
1988/89	3.15			3.18
1989/90	11.11			11.11
1990/91	18.19			18.19
1991/92	14.42			14.42
1992/93	15.92			15.92
1993/94	7.67			7.67
1994/95	3.54			3.54
1995/96	1.92			1.92
1996/97	0.82			0.82
1997/98	0.00			0.00
1998/99	0.00			0.00
1999/00	0.00			0.00
2000/01	0.00			0.00
2001/02	0.00			0.00
2002/03	0.00			0.00
2003/04	0.00			0.00
2004/05	0.00			0.00
2005/06	0.43			0.43
2006/07	0.96			0.96
2007/08	0.96			0.96
2008/09	0.88			0.88
2009/10	0.60			0.60
2010/11	0.00			0.00
2011/12	0.00			0.00
2012/13	0.00			0.00
2013/14	1.25			1.25
2014/15	6.16			6.16
2015/16	8.91			8.91

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

year (ADF&G year)	Total Crab (no.)	Total Harvest (lbs)	GHL/TAC (millions lbs)	Vessels (no.)	Season
1968/69 (1969)	353,300	1,008,900			
1969/70 (1970)	482,300	1,014,700			
1970/71 (1971)	61,300	166,100			
1971/72 (1972)	42,061	107,761			
1972/73 (1973)	93,595	231,668			
1973/74 (1974)	2,531,825	5,044,197			
1974/75	2,773,770	7,028,378		28	
1975/76	8,956,036	22,358,107		66	
1976/77	20,251,508	51,455,221		83	
1977/78	26,350,688	66,648,954		120	
1978/79	16,726,518	42,547,174		144	
1979/80	14,685,611	36,614,315	28-36	152	11/01-05/11
1980/81 (1981)	11,845,958	29,630,492	28-36	165	01/15-04/15
1981/82 (1982)	4,830,980	11,008,779	12-16	125	02/15-06/15
1982/83 (1983)	2,286,756	5,273,881	5.6	108	02/15-06/15
1983/84 (1984)	516,877	1,208,223	7.1	41	02/15-06/15
1984/85 (1985)	1,272,501	3,036,935	3	44	01/15-06/15
1985/86 (1986)	closed	closed	closed	closed	closed
1986/87 (1987)	closed	closed	closed	closed	closed
1987/88 (1988)	957,318	2,294,997	5.6	98	01/15-04/20
1988/89 (1989)	2,894,480	6,982,865	13.5	109	01/15-05/07
1989/90 (1990)	9,800,763	22,417,047	29.5	179	01/15-04/24
2015/16	16,608,625	40,081,555	42.8	255	11/20-03/25
1991/92	12,924,102	31,794,382	32.8	285	11/15-03/31
1992/93	15,265,865	35,130,831	39.2	294	11/15-03/31
1993/94	7,235,898	16,892,320	9.1	296	11/01-11/10, 11/20-01/01
1994/95 (1994)	3,351,639	7,766,886	7.5	183	11/01-11/21
1995/96 (1995)	1,877,303	4,233,061	5.5	196	11/01-11/16
1996/97 (1996)	734,296	1,806,077	6.2	196	11/01-11/05, 11/15-11/27
1997/98-2004/05	closed	closed	closed	closed	closed
2005/06	443,978	952,887	1.7	49	10/15-03/31
2006/07	927,086	2,122,589	3.0	64	10/15-03/31
2007/08	927,164	2,106,655	5.7	50	10/15-03/31
2008/09	830,363	1,939,571	4.3	53	10/15-03/31
2009/10	485,676	1,327,952	1.3	45	10/15-03/31
2010/11	closed	closed	closed	closed	closed
2011/12	closed	closed	closed	closed	closed
2012/13	closed	closed	closed	closed	closed
2013/14	1,426,670	2,751,124	3.108	32	10/15-03/31
2014/15	7,442,931	13,576,105	15.105	100	10/15-03/31
2015/16	10,856,418	19,642,462	19.668	112	10/15-03/31

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

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

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

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

Table 5. Sample sizes for retained catch-at-size in the directed fishery. N = number of individuals. N` = scaled sample size used in assessment.

year	new+old shell	
	N	N'
1980/81	13,310	97.8
1981/82	11,311	83.1
1982/83	13,519	99.3
1983/84	1,675	12.3
1984/85	2,542	18.7
1988/89	12,380	91.0
1989/90	4,123	30.3
1990/91	120,676	200.0
1991/92	126,299	200.0
1992/93	125,193	200.0
1993/94	71,622	200.0
1994/95	27,658	200.0
1995/96	1,525	11.2
1996/97	4,430	32.6
2005/06	705	5.2
2006/07	2,940	21.6
2007/08	6,935	51.0
2008/09	3,490	25.6
2009/10	2,417	17.8
2013/14	4,760	35.0
2014/15	14,055	103.3
2015/16	24,420	200.0

Table 6. Sample sizes for total catch-at-size in the directed fishery, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.

	N		N'	
year	males	females	males	females
1991/92	31,252	5,605	200.0	40.2
1992/93	54,836	8,755	200.0	62.8
1993/94	40,388	10,471	200.0	75.1
1994/95	5,792	2,132	42.6	15.3
1995/96	5,589	3,119	41.1	22.4
1996/97	352	168	2.6	1.2
2005/06	19,715	1,107	144.9	7.9
2006/07	24,226	4,432	178.0	31.8
2007/08	61,546	3,318	200.0	23.8
2008/09	29,166	646	200.0	4.6
2009/10	17,289	147	127.0	1.1
2013/14	17,287	710	127.0	5.2
2014/15	85,114	1,191	200.0	8.8
2015/16	119,846	1,622	200.0	11.9

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

year	N		N'	
	males	females	males	females
1992/93	6,280	859	46.1	6.3
1993/94	6,969	1,542	51.2	11.3
1994/95	2,982	1,523	21.9	11.2
1995/96	1,898	428	13.9	3.1
1996/97	3,265	662	24.0	4.9
1997/98	3,970	657	29.2	4.8
1998/99	1,911	324	14.0	2.4
1999/00	976	82	7.2	0.6
2000/01	1,237	74	9.1	0.5
2001/02	3,113	160	22.9	1.2
2002/03	982	118	7.2	0.9
2003/04	688	152	5.1	1.1
2004/05	848	707	6.2	5.2
2005/06	9,792	368	72.0	2.7
2006/07	10,391	1,256	76.4	9.2
2007/08	13,797	728	101.4	5.3
2008/09	8,455	722	62.1	5.3
2009/10	11,057	474	81.2	3.5
2010/11	12,073	250	88.7	1.8
2011/12	9,453	189	69.5	1.4
2012/13	7,336	190	53.9	1.4
2013/14	12,932	356	95.0	2.6
2014/15	24,877	804	182.8	5.9
2015/16	19,838	230	145.8	1.7

Table 8. Sample sizes for total bycatch-at-size in the BBRKC fishery, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.

year	N		N'	
	males	females	males	females
1992/93	2,056	105	15.1	0.8
1993/94	7,359	1,196	54.1	8.8
1996/97	114	5	0.8	0.0
1997/98	1,030	41	7.6	0.3
1998/99	457	20	3.4	0.1
1999/00	207	14	1.5	0.1
2000/01	845	44	6.2	0.3
2001/02	456	39	3.4	0.3
2002/03	750	50	5.5	0.4
2003/04	555	46	4.1	0.3
2004/05	487	44	3.6	0.3
2005/06	983	70	7.2	0.5
2006/07	798	76	5.9	0.6
2007/08	1,399	91	10.3	0.7
2008/09	3,797	121	27.9	0.9
2009/10	3,395	72	24.9	0.5
2010/11	595	30	4.4	0.2
2011/12	344	4	2.5	0.0
2012/13	618	48	4.5	0.4
2013/14	2,110	60	15.5	0.4
2014/15	3,110	32	22.9	0.2
2015/16	2,176	182	22.9	0.2

Table 9. Sample sizes for total catch-at-size in the groundfish fisheries, from groundfish observer sampling. N = number of individuals. N` = scaled sample size used in the assessment.

year	N		N'	
	males	females	males	females
1973/74	3,155	2,277	23.2	16.7
1974/75	2,492	1,600	18.3	11.8
1975/76	1,251	839	9.2	6.2
1976/77	6,950	6,683	51.1	49.1
1977/78	10,685	8,386	78.5	61.6
1978/79	18,596	13,665	136.6	100.4
1979/80	19,060	11,349	140.1	83.4
1980/81	12,806	5,917	94.1	43.5
1981/82	6,098	4,065	44.8	29.9
1982/83	13,439	8,006	98.8	58.8
1983/84	18,363	8,305	134.9	61.0
1984/85	27,403	13,771	200.0	101.2
1985/86	23,128	12,728	170.0	93.5
1986/87	14,860	7,626	109.2	56.0
1987/88	23,508	15,857	172.7	116.5
1988/89	10,586	7,126	77.8	52.4
1989/90	59,943	41,234	200.0	200.0
1990/91	23,545	11,212	173.0	82.4
1991/92	6,817	3,479	50.1	25.6
1992/93	3,128	1,175	23.0	8.6
1993/94	1,217	358	8.9	2.6
1994/95	3,628	1,820	26.7	13.4
1995/96	3,904	2,669	28.7	19.6
1996/97	8,306	3,400	61.0	25.0
1997/98	9,949	3,900	73.1	28.7
1998/99	12,105	4,440	89.0	32.6
1999/00	11,053	4,522	81.2	33.2
2000/01	12,895	3,087	94.8	22.7
2001/02	15,788	3,083	116.0	22.7
2002/03	15,401	3,249	113.2	23.9
2003/04	9,572	2,733	70.3	20.1
2004/05	13,844	4,460	101.7	32.8
2005/06	17,785	3,709	130.7	27.3
2006/07	15,903	3,047	116.9	22.4
2007/08	16,031	3,788	117.8	27.8
2008/09	25,976	4,164	190.9	30.6
2009/10	18,852	2,650	138.5	19.5
2010/11	15,044	2,247	110.5	16.5
2011/12	16,115	4,237	118.4	31.1
2012/13	12,983	3,080	95.4	22.6
2013/14	28,781	6,064	200.0	44.6
2014/15	39,119	4,212	200.0	31.0
2015/16	26,656	5,705	195.9	41.9

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

year	Size bin 27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5	147.5	152.5	157.5	162.5	167.5	172.5	177.5	182.5
1949	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1950	4.26E+00	1.01E+01	9.88E+00	9.34E+00	6.98E+00	4.37E+00	2.41E+00	1.22E+00	5.73E-01	2.56E-01	1.09E-01	4.50E-02	1.80E-02	7.00E-03	2.66E-03	9.89E-04	3.60E-04	1.28E-04	4.46E-05	1.53E-05	5.20E-06	1.75E-06	5.84E-07	1.93E-07	6.33E-08	2.06E-08	6.61E-09	2.11E-09	6.66E-10	2.09E-10	6.67E-11	2.61E-11
1951	4.29E+00	1.01E+01	9.95E+00	9.69E+00	8.35E+00	7.16E+00	5.93E+00	4.44E+00	3.01E+00	1.86E+00	1.03E+00	5.07E-01	2.15E-01	8.05E-02	2.89E-02	9.91E-03	2.78E-03	6.10E-04	1.24E-04	3.02E-05	8.97E-06	2.92E-06	9.69E-07	3.20E-07	1.05E-07	3.41E-08	1.10E-08	3.50E-09	1.11E-09	3.47E-10	1.11E-10	4.34E-11
1952	4.34E+00	1.03E+01	1.01E+01	9.77E+00	8.42E+00	7.33E+00	6.47E+00	5.72E+00	5.23E+00	4.66E+00	3.56E+00	2.29E+00	1.24E+00	5.71E-01	2.46E-01	9.45E-02	2.67E-02	5.07E-03	6.96E-04	8.79E-05	1.50E-05	3.90E-06	1.24E-06	4.06E-07	1.33E-07	4.32E-08	1.39E-08	4.43E-09	1.40E-09	4.40E-10	1.40E-10	5.50E-11
1953	4.42E+00	1.04E+01	1.02E+01	9.91E+00	8.53E+00	7.40E+00	6.54E+00	5.87E+00	5.83E+00	6.11E+00	5.48E+00	4.18E+00	2.82E+00	1.65E+00	8.98E-01	4.16E-01	1.34E-01	2.79E-02	3.96E-03	4.33E-04	4.45E-05	6.17E-06	1.49E-06	4.67E-07	1.52E-07	4.95E-08	1.59E-08	5.07E-09	1.60E-09	5.04E-10	1.61E-10	6.29E-11
1954	4.54E+00	1.07E+01	1.05E+01	1.01E+01	8.69E+00	7.53E+00	6.64E+00	6.00E+00	6.22E+00	7.03E+00	6.70E+00	5.38E+00	3.98E+00	2.61E+00	1.59E+00	8.24E-01	2.95E-01	6.79E-02	1.07E-02	1.28E-03	1.28E-04	1.25E-05	1.98E-06	5.49E-07	1.76E-07	5.72E-08	1.84E-08	5.87E-09	1.86E-09	5.83E-10	1.86E-10	7.28E-11
1955	4.74E+00	1.12E+01	1.09E+01	1.05E+01	8.95E+00	7.72E+00	6.79E+00	6.16E+00	6.54E+00	7.73E+00	7.60E+00	6.25E+00	4.82E+00	3.31E+00	2.11E+00	1.14E+00	4.22E-01	1.01E-01	1.66E-02	2.11E-03	2.17E-04	1.96E-05	2.49E-06	6.21E-07	1.97E-07	6.37E-08	2.05E-08	6.54E-09	2.07E-09	6.49E-10	2.07E-10	8.11E-11
1956	5.04E+00	1.19E+01	1.15E+01	1.10E+01	9.36E+00	8.03E+00	7.03E+00	6.37E+00	6.86E+00	8.31E+00	8.31E+00	6.91E+00	5.45E+00	3.82E+00	2.49E+00	1.36E+00	5.13E-01	1.24E-01	2.09E-02	2.71E-03	2.82E-04	2.48E-05	2.88E-06	6.78E-07	2.13E-07	6.89E-08	2.22E-08	7.07E-09	2.24E-09	7.02E-10	2.24E-10	8.77E-11
1957	5.53E+00	1.30E+01	1.25E+01	1.18E+01	9.99E+00	8.50E+00	7.39E+00	6.67E+00	7.21E+00	8.85E+00	8.91E+00	7.46E+00	5.95E+00	4.21E+00	2.76E+00	1.52E+00	5.78E-01	1.41E-01	2.39E-02	3.13E-03	3.28E-04	2.85E-05	3.18E-06	7.28E-07	2.28E-07	7.36E-08	2.37E-08	7.55E-09	2.39E-09	7.50E-10	2.39E-10	9.37E-11
1958	6.33E+00	1.49E+01	1.42E+01	1.32E+01	1.10E+01	9.26E+00	7.96E+00	7.13E+00	7.67E+00	9.42E+00	9.51E+00	7.98E+00	6.39E+00	4.55E+00	3.00E+00	1.66E+00	6.33E-01	1.55E-01	2.64E-02	3.47E-03	3.66E-04	3.18E-05	3.49E-06	7.93E-07	2.48E-07	8.01E-08	2.58E-08	8.22E-09	2.60E-09	8.16E-10	2.60E-10	1.02E-10
1959	7.79E+00	1.83E+01	1.72E+01	1.56E+01	1.28E+01	1.05E+01	8.90E+00	7.85E+00	8.32E+00	1.01E+01	1.02E+01	8.53E+00	6.83E+00	4.87E+00	3.21E+00	1.78E+00	6.79E-01	1.67E-01	2.85E-02	3.75E-03	3.96E-04	3.46E-05	3.84E-06	8.76E-07	2.74E-07	8.86E-08	2.85E-08	9.09E-09	2.87E-09	9.03E-10	2.88E-10	1.13E-10
1960	1.08E+01	2.52E+01	2.32E+01	2.03E+01	1.61E+01	1.28E+01	1.06E+01	9.08E+00	9.36E+00	1.11E+01	1.11E+01	9.22E+00	7.35E+00	5.22E+00	3.44E+00	1.90E+00	7.27E-01	1.79E-01	3.05E-02	4.03E-03	4.27E-04	3.78E-05	4.33E-06	1.01E-06	3.16E-07	1.02E-07	3.29E-08	1.05E-08	3.32E-09	1.04E-09	3.33E-10	1.30E-10
1961	1.86E+01	4.31E+01	3.82E+01	3.14E+01	2.35E+01	1.77E+01	1.39E+01	1.14E+01	1.12E+01	1.28E+01	1.24E+01	1.02E+01	8.06E+00	5.68E+00	3.72E+00	2.05E+00	7.82E-01	1.92E-01	3.27E-02	4.33E-03	4.61E-04	4.19E-05	5.14E-06	1.25E-06	3.94E-07	1.28E-07	4.10E-08	1.31E-08	4.13E-09	1.30E-09	4.14E-10	1.62E-10
1962	4.12E+01	9.48E+01	8.11E+01	6.21E+01	4.34E+01	3.03E+01	2.20E+01	1.68E+01	1.51E+01	1.59E+01	1.49E+01	1.19E+01	9.18E+00	6.36E+00	4.10E+00	2.24E+00	8.46E-01	2.07E-01	3.51E-02	4.64E-03	5.01E-04	4.83E-05	6.75E-06	1.76E-06	5.59E-07	1.81E-07	5.83E-08	1.86E-08	5.87E-09	1.85E-09	5.88E-10	2.30E-10
1963	9.02E+01	2.08E+02	1.78E+02	1.36E+02	9.39E+01	6.33E+01	4.34E+01	3.08E+01	2.47E+01	2.31E+01	2.01E+01	1.54E+01	1.13E+01	7.57E+00	4.75E+00	2.54E+00	9.46E-01	2.29E-01	3.87E-02	5.13E-03	5.71E-04	6.27E-05	1.09E-05	3.10E-06	9.97E-07	3.23E-07	1.04E-07	3.31E-08	1.05E-08	3.29E-09	1.05E-09	4.10E-10
1964	1.24E+02	2.89E+02	2.66E+02	2.31E+02	1.75E+02	1.26E+02	8.98E+01	6.40E+01	4.88E+01	4.12E+01	3.29E+01	2.36E+01	1.62E+01	1.02E+01	6.11E+00	3.15E+00	1.15E+00	2.73E-01	4.57E-02	6.07E-03	7.13E-04	9.35E-05	2.00E-05	6.04E-06	1.96E-06	6.36E-07	2.05E-07	6.52E-08	2.06E-08	6.48E-09	2.07E-09	8.08E-10
1965	1.11E+02	2.64E+02	2.66E+02	2.67E+02	2.26E+02	1.85E+02	1.49E+02	1.17E+02	9.42E+01	8.00E+01	6.26E+01	4.35E+01	2.82E+01	1.67E+01	9.48E+00	4.70E+00	1.66E+00	3.84E-01	6.26E-02	8.15E-03	9.65E-04	1.35E-04	3.07E-05	9.44E-06	3.07E-06	9.96E-07	3.20E-07	1.02E-07	3.23E-08	1.01E-08	3.23E-09	1.27E-09
1966	8.58E+01	2.06E+02	2.16E+02	2.30E+02	2.11E+02	1.93E+02	1.75E+02	1.53E+02	1.41E+02	1.34E+02	1.12E+02	8.07E+01	5.29E+01	3.11E+01	1.74E+01	8.48E+00	2.93E+00	6.63E-01	1.05E-01	1.30E-02	1.44E-03	1.80E-04	3.76E-05	1.13E-05	3.68E-06	1.19E-06	3.84E-07	1.22E-07	3.87E-08	1.22E-08	3.87E-09	1.52E-09
1967	7.01E+01	1.68E+02	1.73E+02	1.82E+02	1.70E+02	1.62E+02	1.55E+02	1.48E+02	1.57E+02	1.72E+02	1.59E+02	1.23E+02	8.66E+01	5.38E+01	3.14E+01	1.56E+01	5.47E+00	1.24E+00	1.95E-01	2.36E-02	2.41E-03	2.46E-04	4.10E-05	1.15E-05	3.71E-06	1.20E-06	3.87E-07	1.24E-07	3.90E-08	1.23E-08	3.91E-09	1.53E-09
1968	6.61E+01	1.57E+02	1.56E+02	1.57E+02	1.41E+02	1.31E+02	1.24E+02	1.23E+02	1.44E+02	1.80E+02	1.80E+02	1.49E+02	1.13E+02	7.55E+01	4.65E+01	2.42E+01	8.74E+00	2.03E+00	3.26E-01	4.01E-02	4.00E-03	3.52E-04	4.39E-05	1.09E-05	3.44E-06	1.11E-06	3.58E-07	1.14E-07	3.61E-08	1.13E-08	3.61E-09	1.42E-09
1969	7.25E+01	1.71E+02	1.64E+02	1.56E+02	1.34E+02	1.17E+02	1.07E+02	1.04E+02	1.26E+02	1.70E+02	1.79E+02	1.54E+02	1.24E+02	8.68E+01	5.57E+01	2.99E+01	1.11E+01	2.67E+00	4.41E-01	5.58E-02	5.63E-03	4.65E-04	4.71E-05	1.01E-05	3.14E-06	1.01E-06	3.26E-07	1.04E-07	3.29E-08	1.03E-08	3.29E-09	1.29E-09
1970	8.01E+01	1.88E+02	1.81E+02	1.71E+02	1.43E+02	1.21E+02	1.05E+02	9.80E+01	1.17E+02	1.60E+02	1.71E+02	1.48E+02	1.22E+02	8.80E+01	5.75E+01	3.14E+01	1.19E+01	2.91E+00	4.92E-01	6.39E-02	6.57E-03	5.37E-04	5.00E-05	9.95E-06	3.04E-06	9.81E-07	3.15E-07	1.01E-07	3.18E-08	9.99E-09	3.18E-09	1.25E-09
1971	6.80E+01	1.62E+02	1.66E+02	1.70E+02	1.50E+02	1.30E+02	1.13E+02	1.03E+02	1.18E+02	1.56E+02	1.65E+02	1.42E+02	1.18E+02	8.49E+01	5.56E+01	3.04E+01	1.16E+01	2.85E+00	4.88E-01	6.44E-02	6.72E-03	5.54E-04	5.14E-05	1.02E-05	3.10E-06	1.00E-06	3.22E-07	1.03E-07	3.24E-08	1.02E-08	3.25E-09	1.27E-09
1972	5.01E+01	1.21E+02	1.28E+02	1.39E+02	1.30E+02	1.21E+02	1.13E+02	1.07E+02	1.22E+02	1.59E+02	1.66E+02	1.41E+02	1.15E+02	8.25E+01	5.37E+01	2.93E+01	1.11E+01	2.74E+00	4.70E-01	6.23E-02	6.53E-03	5.41E-04	5.03E-05	9.97E-06	3.04E-06	9.81E-07	3.15E-07	1.01E-07	3.18E-08	9.99E-09	3.18E-09	1.25E-09
1973	3.08E+01	7.52E+01	8.42E+01	9.75E+01	9.60E+01	9.51E+01	9.37E+01	9.48E+01	1.17E+02	1.58E+02	1.67E+02	1.43E+02	1.16E+02	8.18E+01	5.25E+01	2.82E+01	1.06E+01	2.59E+00	4.42E-01	5.82E-02	6.06E-03	4.97E-04	4.49E-05	8.67E-06	2.63E-06	8.48E-07	2.73E-07	8.70E-08	2.75E-08	8.64E-09	2.76E-09	1.08E-09
1974	2.32E+01	5.58E+01	5.90E+01	6.44E+01	6.34E+01	6.50E+01	6.70E+01	7.22E+01	9.81E+01	1.44E+02	1.57E+02	1.37E+02	1.13E+02	8.09E+01	5.20E+01	2.79E+01	1.05E+01	2.55E+00	4.33E-01	5.66E-02	5.84E-03	4.68E-04	3.94E-05	7.06E-06	2.11E-06	6.79E-07	2.19E-07	6.97E-08	2.20E-08	6.92E-09	2.21E-09	8.65E-10
1975	4.65E+01	1.07E+02	9.30E+01	7.41E+01	5.75E+01	4.93E+01	4.65E+01	5.04E+01	7.52E+01	1.20E+02	1.37E+02	1.23E+02	1.04E+02	7.56E+01	4.91E+01	2.65E+01	1.00E+01	2.45E+00	4.18E-01	5.48E-02	5.64E-03	4.43E-04	3.46E-05	5.63E-06	1.64E-06	5.29E-07	1.70E-07	5.42E-08	1.71E-08	5.39E-09	1.72E-09	6.73E-10
1976	8.38E+01	1.94E+02	1.70E+02	1.37E+02	9.91E+01	7.02E+01	5.22E+01	4.57E+01	6.16E+01	9.94E+01	1.15E+02	1.04E+02	9.06E+01	6.70E+01	4.40E+01	2.40E+01	9.12E+00	2.25E+00	3.88E-01	5.15E-02	5.35E-03	4.26E-04	3.42E-05	5.78E-06	1.70E-06	5.48E-07	1.76E-07	5.62E-08	1.78E-08	5.58E-09	1.78E-09	6.96E-10
1977	6.62E+01	1.59E+02	1.65E+02	1.71E+02	1.45E+02	1.14E+02	8.80E+01	6.97E+01	7.15E+01	9.47E+01	1.02E+02	8.96E+01	7.66E+01	5.60E+01	3.62E+01	1.94E+01	7.36E+00	1.82E+00	3.17E-01	4.25E-02	4.49E-03	3.73E-04	3.48E-05	6.87E-06	2.09E-06	6.75E-07	2.17E-07	6.92E-08	2.19E-08	6.87E-09	2.19E-09	8.58E-10
1978	3.38E+01	8.38E+01	9.97E+01	1.22E+02	1.22E+02	1.19E+02	1.11E+02	9.90E+01	9.91E+01	1.14E+02	1.11E+02	9.03E+01	7.10E+01	4.83E+01	2.91E+01	1.49E+01	5.45E+00	1.33E+00	2.29E-01	3.06E-02	3.25E-03	2.78E-04	2.83E-05	6.05E-06	1.87E-06	6.03E-07	1.94E-07	6.18E-08	1.95E-08	6.14E-09	1.96E-09	7.67E-10
1979	1.34E+01	3.41E+01	4.46E+01	6.07E+01	6.84E+01	7.72E+01	8.33E+01	8.80E+01	1.05E+02	1.31E+02	1.30E+02	1.05E+02	7.84E+01	5.00E+01	2.85E+01	1.38E+01	4.84E+00	1.13E+00	1.88E-01	2.41E-02	2.48E-03	2.07E-04	2.07E-05	4.37E-06	1.34E-06	4.34E-07	1.40E-07	4.45E-08	1.41E-08	4.42E-09	1.41E-09	5.53E-10
1980	7.14E+00	1.76E+01	2.08E+01	2.63E+01	3.04E+01	3.69E+01	4.38E+01	5.36E+01	7.95E+01	1.18E+02	1.28E+02	1.09E+02	8.45E+01	5.44E+01	3.12E+01	1.52E+01	5.28E+00	1.21E+00	1.92E-01	2.33E-02	2.25E-03	1.73E-04	1.42E-05	2.53E-06	7.53E-07	2.43E-07	7.81E-08	2.49E-08	7.87E-09	2.47E-09	7.88E-10	3.09E-10
1981	1.03E+01	2.40E+01	2.19E+01	1.95E+01	1.74E+01	1.78E+01	2.00E+01	2.65E+01	4.80E+01	8.40E+01	9.83E+01	8.83E+01	7.23E+01	4.88E+01	2.92E+01	1.49E+01	5.39E+00	1.27E+00	2.06E-01	2.52E-02	2.41E-03	1.75E-04	1.13E-05	1.39E-06	3.76E-07	1.20E-07	3.86E-08	1.23E-08	3.89E-09	1.22E-09	3.89E-10	1.52E-10
1982	6.95E+00	1.68E+01	1.83E+01	2.01E+01	1.78E+01	1.51E+01	1.35E+01	1.55E+01	2.93E+01	5.62E+01	6.88E+01	6.37E+01	5.49E+01	3.89E+01	2.44E+01	1.29E+01	4.87E+00	1.20E+00	2.03E-01	2.62E-02	2.63E-03	1.94E-04	1.18E-05	1.21E-06	3.03E-07	9.60E-08	3.08E-08	9.83E-09	3.11E-09	9.76E-10	3.11E-10	1.22E-10
1983	2.65E+01	6.03E+01	4.89E+01	3.36E+01	2.28E+01	1.75E+01	1.49E+01	1.47E+01	2.26E+01	4.04E+01	4.87E+01	4.50E+01	3.97E+01	2.91E+01	1.90E+01	1.05E+01	4.07E+00	1.03E+00	1.82E-01	2.46E-02	2.57E-03	1.95E-04	1.18E-05	1.17E-06	2.87E-07	9.09E-08	2.92E-08	9.30E-09	2.94E-09	9.23E-10	2.94E-10	1.15E-10
1984	2.47E+01	5.85E+01	5.83E+01	5.69E+01	4.49E+01	3.18E+01	2.21E+01	1.74E+01	2.11E+01	3.28E+01	3.76E+01	3.39E+01	2.95E+01	2.17E+01	1.44E+01	8.05E+00	3.18E+00	8.18E-01	1.47E-01	2.04E-02	2.19E-03	1.76E-04	1.35E-05	2.10E-06	6.06E-07	1.95E-07	6.27E-08	2.00E-08	6.32E-09	1.98E-09	6.33E-10	2.48E-10
1985	3.88E+01	9.00E+01	8.10E+01	6.88E+01	5.47E+01	4.53E+01	3.78E+01	3.08E+01	2.86E+01	3.29E+01	3.32E+01	2.83E+01	2.36E+01	1.71E+01	1.13E+01	6.28E+00	2.47E+00	6.30E-01	1.13E-01	1.56E-02	1.70E-03	1.43E-04	1.32E-05	2.55E-06	7.75E-07	2.50E-07	8.04E-08	2.56E-08	8.10E-09	2.55E-09	8.11E-10	3.18E-10
1986	3.57E+01	8.48E+01	8.49E+01	8.41E+01	7.03E+01	5.63E+01	4.56E+01	3.86E+01	3.84E+01	4.30E+01	4.09E+01	3.26E+01	2.49E+01	1.70E+01	1.08E+01	5.89E+00	2.28E+00	5.74E-01	1.01E-01	1.39E-02	1.53E-03	1.38E-04	1.59E-05	3.71E-06	1.16E-06	3.77E-07	1.21E-07	3.86E-08	1.22E-08	3.84E-09	1.22E-09	4.79E-10
1987	3.46E+01	8.19E+01	8.11E+01	8.02E+01	7.06E+01	6.27E+01	5.55E+01	4.84E+01	4.72E+01	5.16E+01	4.89E+01	3.93E+01	2.97E+01	1.98E+01	1.22E+01	6.39E+00	2.36E+00	5.71E-01	9.69E-02	1.28E-02	1.37E-03	1.27E-04	1.62E-05	4.01E-06	1.27E-06	4.11E-07	1.32E-07	4.22E-08	1.33E-08	4.19E-09	1.34E-09	5.23E-10
1988	3.37E+01	7.98E+01	7.89E+01	7.77E+01	6.79E+01	6.00E+01	5.41E+01	5.01E+01	5.34E+01	6.16E+01	5.91E+01	4.74E+01	3.55E+01	2.35E+01	1.44E+01	7.55E+00	2.77E+00	6.63E-01	1.10E-01	1.42E-02	1.48E-03	1.34E-04	1.66E-05	4.06E-06	1.28E-06	4.15E-07	1.34E-07	4.26E-08	1.35E-08	4.23E-09	1.35E-09	5.28E-10
1989	1.46E+01	3.68E+01	4.63E+01	5.93E+01	5.85E+01	5.51E+01	5.11E+01	4.82E+01	5.34E+01	6.53E+01	6.53E+01	5.41E+01	4.18E+01	2.83E+01	1.76E+01	9.24E+00	3.39E+00	8.09E-01	1.34E-01	1.72E-02	1.77E-03	1.55E-04	1.79E-05	4.21E-06	1.32E-06	4.28E-07	1.38E-07	4.39E-08	1.39E-08	4.36E-09	1.39E-09	5.45E-10
1990	5.65E+00	1.44E+01	1.91E+01	2.65E+01	3.11E+01	3.67E+01	4.01E+01	4.21E+01	5.08E+01	6.59E+01	6.76E+01	5.68E+01	4.49E+01	3.10E+01	1.96E+01	1.04E+01	3.86E+00	9.26E-01	1.54E-01	1.97E-02	2.00E-03	1.64E-04	1.59E-05	3.28E-06	1.01E-06	3.26E-07	1.05E-07	3.35E-08	1.06E-08	3.32E-09	1.06E-09	4.15E-10
1991	3.29E+00	8.05E+00	9.22E+00	1.13E+01	1.31E+01	1.61E+01	1.96E+01	2.51E+01	3.88E+01	5.89E+01	6.43E+01	5.57E+01	4.50E+01	3.13E+01	1.97E+01	1.05E+01	3.88E+00	9.35E-01	1.56E-01	2.01E-02	2.03E-03	1.59E-04	1.28E-05	2.18E-06	6.44E-07	2.07E-07	6.67E-08	2.13E-08	6.72E-09	2.11E-09	6.73E-10	2.64E-10
1992	2.50E+00	6.00E+00	6.33E+00	6.92E+00	6.91E+00	7.41E+00	8.54E+00	1.19E+01	2.36E+01	4.34E+01	5.16E+01	4.73E+01	4.05E+01	2.92E+01	1.88E+01	1.01E+01	3.77E+00	9.15E-01	1.54E-01	1.99E-02	2.01E-03	1.53E-04	1.07E-05	1.48E-06	4.15E-07	1.33E-07	4.28E-08	1.36E-08	4.31E-09	1.35E-09	4.32E-10	1.69E-10
1993	2.32E+00	5.51E+00	5.51E+00	5.56E+00	5.09E+00	4.88E+00	5.02E+00	6.76E+00	1.50E+01	3.05E+01	3.77E+01	3.53E+01	3.15E+01	2.37E+01	1.57E+01	8.68E+00	3.33E+00	8.29E-01	1.43E-01	1.89E-02	1.94E-03	1.47E-04	9.44E-06	1.09E-06	2.87E-07	9.13E-08	2.94E-08	9.36E-09	2.96E-09	9.30E-10	2.96E-10	1.16E-10
1994	2.91E+00	6.81E+00	6.38E+00	5.81E+00	4.85E+00	4.23E+00	3.98E+00	4.96E+00	1.09E+01	2.23E+01	2.77E+01	2.59E+01	2.35E+01	1.79E+01	1.20E+01	6.70E+00	2.61E+00	6.61E-01	1.17E-01	1.59E-02	1.67E-03	1.27E-04	7.97E-06	8.47E-07	2.15E-07	6.84E-08	2.20E-08	7.01E-09	2.22E-09	6.96E-10	2.22E-10	8.70E-11
1995	3.87E+00	9.04E+00	8.37E+00	7.42E+00	5.91E+00	4.74E+00	4.04E+00	4.39E+00	8.55E+00	1.69E+01	2.07E+01	1.92E+01	1.74E+01	1.32E+01	8.79E+00	4.87E+00	1.90E+00	4.83E-01	8.60E-02	1.18E-02	1.26E-03	9.72E-05	6.22E-06	6.91E-07	1.79E-07	5.69E-08	1.83E-08	5.83E-09	1.84E-09	5.79E-10	1.85E-10	7.24E-11
1996	3.96E+00	9.35E+00	9.14E+00	8.78E+00	7.31E+00	5.95E+00	4.95E+00	4.76E+00	7.52E+00	1.35E+01	1.60E+01	1.47E+01	1.31E+01	9.86E+00	6.51E+00	3.58E+00	1.39E+00	3.52E-01	6.28E-02	8.65E-03	9.26E-04	7.26E-05	4.96E-06	6.36E-07	1.74E-07	5.55E-08	1.78E-08	5.69E-09	1.80E-09	5.65E-10	1.80E-10	7.06E-11
1997	9.78E+00	2.24E+01	1.90E+01	1.42E+01	1.01E+01	7.66E+00	6.20E+00	5.62E+00	7.43E+00	1.17E+01	1.33E+01	1.19E+01	1.03E+01	7.64E+00	4.98E+00	2.71E+00	1.04E+00	2.63E-01	4.67E-02	6.41E-03	6.87E-04	5.48E-05	4.08E-06	6.09E-07	1.74E-07	5.58E-08	1.79E-08	5.72E-09	1.81E-09	5.68E-10	1.81E-10	7.09E-11
1998	4.01E+00	1.02E+01	1.30E+01	1.65E+01	1.49E+01	1.18E+01	8.96E+00	7.30E+00	8.14E+00	1.13E+01	1.21E+01	1.05E+01	8.80E+00	6.34E+00	4.05E+00	2.17E+00	8.26E-01	2.06E-01	3.63E-02	4.95E-03	5.34E-04	4.51E-05	4.26E-06	8.49E-07	2.59E-07	8.36E-08	2.69E-08	8.57E-09	2.71E-09	8.51E-10	2.71E-10	1.06E-10
1999	1.17E+01	2.68E+01	2.23E+01	1.65E+01	1.29E+01	1.20E+01	1.15E+01	1.04E+01	1.07E+01	1.25E+01	1.24E+01	1.02E+01	8.22E+00	5.76E+00	3.63E+00	1.93E+00	7.23E-01	1.78E-01	3.09E-02	4.15E-03	4.43E-04	3.75E-05	3.68E-06	7.62E-07	2.34E-07	7.55E-08	2.43E-08	7.74E-09	2.45E-09	7.69E-10	2.45E-10	9.59E-11
2000	6.96E+00	1.70E+01	1.92E+01	2.17E+01	1.86E+01	1.41E+01	1.09E+01	9.62E+00	1.11E+01	1.42E+01	1.42E+01	1.16E+01	8.91E+00	6.00E+00	3.70E+00	1.93E+00	7.15E-01	1.74E-01	2.96E-02	3.93E-03	4.19E-04	3.77E-05	4.48E-06	1.06E-06	3.35E-07	1.08E-07	3.49E-08	1.11E-08	3.51E-09	1.10E-09	3.52E-10	1.38E-10
2001	2.12E+01	4.84E+01	4.01E+01	2.90E+01	2.11E+01	1.74E+01	1.52E+01	1.30E+01	1.27E+01	1.47E+01	1.46E+01	1.22E+01	9.71E+00	6.72E+00	4.22E+00	2.22E+00	8.16E-01	1.95E-01	3.26E-02	4.21E-03	4.39E-04	3.88E-05	4.52E-06	1.06E-06	3.34E-07	1.08E-07	3.48E-08	1.11E-08	3.50E-09	1.10E-09	3.51E-10	1.37E-10
2002	8.04E+00	2.06E+01	2.71E+01	3.51E+01	3.16E+01	2.44E+01	1.84E+01	1.50E+01	1.52E+01	1.77E+01	1.71E+01	1.38E+01	1.06E+01	7.20E+00	4.55E+00	2.43E+00	9.12E-01	2.22E-01	3.76E-02	4.92E-03	5.24E-04	4.94E-05	6.68E-06	1.71E-06	5.44E-07	1.76E-07	5.67E-08	1.81E-08	5.71E-09	1.79E-09	5.72E-10	2.24E-10
2003	1.60E+01	3.70E+01	3.22E+01	2.64E+01	2.33E+01	2.38E+01	2.36E+01	2.14E+01	2.03E+01	2.14E+01	1.99E+01	1.60E+01	1.23E+01	8.38E+00	5.27E+00	2.79E+00	1.03E+00	2.48E-01	4.16E-02	5.40E-03	5.70E-04	5.16E-05	6.39E-06	1.56E-06	4.93E-07	1.60E-07	5.13E-08	1.64E-08	5.17E-09	1.62E-09	5.18E-10	2.03E-10
2004	2.47E+01	5.73E+01	5.17E+01	4.36E+01	3.26E+01	2.39E+01	1.90E+01	1.79E+01	2.10E+01	2.60E+01	2.54E+01	2.03E+01	1.51E+01	1.00E+01	6.21E+00	3.29E+00	1.22E+00	2.94E-01	4.92E-02	6.38E-03	6.68E-04	6.04E-05	7.51E-06	1.84E-06	5.81E-07	1.88E-07	6.05E-08	1.93E-08	6.10E-09	1.92E-09	6.11E-10	2.39E-10
2005	7.20E+00	1.91E+01	2.80E+01	3.96E+01	3.84E+01	3.31E+01	2.73E+01	2.22E+01	2.16E+01	2.55E+01	2.58E+01	2.20E+01	1.76E+01	1.22E+01	7.78E+00	4.14E+00	1.52E+00	3.63E-01	6.01E-02	7.70E-03	8.05E-04	7.41E-05	9.65E-06	2.43E-06	7.70E-07	2.50E-07	8.03E-08	2.56E-08	8.09E-09	2.54E-09	8.11E-10	3.18E-10
2006	5.55E+00	1.33E+01	1.41E+01	1.61E+01	1.90E+01	2.38E+01	2.65E+01	2.64E+01	2.79E+01	3.15E+01	3.00E+01	2.41E+01	1.88E+01	1.32E+01	8.59E+00	4.73E+00	1.80E+00	4.38E-01	7.38E-02	9.56E-03	9.91E-04	8.47E-05	9.12E-06	2.04E-06	6.34E-07	2.05E-07	6.59E-08	2.10E-08	6.64E-09	2.09E-09	6.65E-10	2.61E-10
2007	3.72E+00	9.01E+00	9.84E+00	1.11E+01	1.07E+01	1.09E+01	1.21E+01	1.54E+01	2.29E+01	3.26E+01	3.41E+01	2.85E+01	2.22E+01	1.53E+01	9.76E+00	5.27E+00	1.97E+00	4.76E-01	7.97E-02	1.03E-02	1.07E-03	8.87E-05	8.40E-06	1.69E-06	5.16E-07	1.66E-07	5.34E-08	1.70E-08	5.38E-09	1.69E-09	5.39E-10	2.11E-10
2008	4.64E+00	1.09E+01	1.02E+01	9.41E+00	8.28E+00	7.87E+00	7.83E+00	8.79E+00	1.42E+01	2.44E+01	2.88E+01	2.65E+01	2.27E+01	1.68E+01	1.12E+01	6.15E+00	2.32E+00	5.57E-01	9.25E-02	1.18E-02	1.20E-03	9.46E-05	7.82E-06	1.37E-06	4.07E-07	1.31E-07	4.21E-08	1.34E-08	4.24E-09	1.33E-09	4.24E-10	1.66E-10
2009	3.03E+01	6.86E+01	5.38E+01	3.36E+01	1.95E+01	1.18E+01	8.26E+00	7.48E+00	1.13E+01	1.95E+01	2.30E+01	2.13E+01	1.92E+01	1.50E+01	1.05E+01	6.06E+00	2.37E+00	5.87E-01	1.00E-01	1.31E-02	1.35E-03	1.06E-04	7.96E-06	1.23E-06	3.53E-07	1.13E-07	3.63E-08	1.15E-08	3.65E-09	1.15E-09	3.65E-10	1.43E-10
2010	3.77E+01	8.83E+01	8.27E+01	7.35E+01	5.43E+01	3.56E+01	2.21E+01	1.44E+01	1.32E+01	1.78E+01	1.97E+01	1.78E+01	1.59E+01	1.25E+01	8.85E+00	5.14E+00	2.03E+00	5.09E-01	8.86E-02	1.20E-02	1.28E-03	1.10E-04	1.10E-05	2.30E-06	7.04E-07	2.27E-07	7.27E-08	2.31E-08	7.31E-09	2.30E-09	7.32E-10	2.86E-10
2011	2.20E+01	5.38E+01	6.12E+01	7.08E+01	6.51E+01	5.61E+01	4.62E+01	3.56E+01	2.85E+01	2.63E+01	2.31E+01	1.81E+01	1.46E+01	1.09E+01	7.51E+00	4.32E+00	1.69E+00	4.23E-01	7.36E-02	1.00E-02	1.10E-03	1.04E-04	1.36E-05	3.36E-06	1.06E-06	3.41E-07	1.09E-07	3.48E-08	1.10E-08	3.45E-09	1.10E-09	4.31E-10
2012	3.80E+00	1.11E+01	2.07E+01	3.46E+01	4.06E+01	4.52E+01	4.64E+01	4.43E+01	4.36E+01	4.40E+01	3.80E+01	2.80E+01	1.95E+01	1.26E+01	7.80E+00	4.19E+00	1.57E+00	3.80E-01	6.43E-02	8.55E-03	9.36E-04	9.16E-05	1.29E-05	3.33E-06	1.05E-06	3.40E-07	1.09E-07	3.47E-08	1.10E-08	3.44E-09	1.10E-09	4.30E-10
2013	9.51E+00	2.18E+01	1.85E+01	1.51E+01	1.57E+01	2.05E+01	2.56E+01	3.05E+01	3.94E+01	4.98E+01	4.91E+01	3.97E+01	2.91E+01	1.88E+01	1.14E+01	5.87E+00	2.10E+00	4.83E-01	7.69E-02	9.53E-03	9.68E-04	8.56E-05	1.03E-05	2.49E-06	7.78E-07	2.51E-07	8.04E-08	2.56E-08	8.09E-09	2.54E-09	8.10E-10	3.17E-10
2014	7.62E+00	1.82E+01	1.89E+01	1.95E+01	1.61E+01	1.27E+01	1.13E+01	1.39E+01	2.41E+01	4.00E+01	4.56E+01	4.08E+01	3.35E+01	2.38E+01	1.54E+01	8.29E+00	3.05E+00	7.17E-01	1.16E-01	1.43E-02	1.41E-03	1.14E-04	1.08E-05	2.22E-06	6.76E-07	2.17E-07	6.97E-08	2.22E-08	7.01E-09	2.20E-09	7.02E-10	2.75E-10
2015	5.34E+00	1.29E+01	1.39E+01	1.54E+01	1.46E+01	1.38E+01	1.27E+01	1.22E+01	1.73E+01	2.96E+01	3.53E+01	3.31E+01	2.97E+01	2.29E+01	1.59E+01	9.03E+00	3.48E+00	8.49E-01	1.43E-01	1.84E-02	1.86E-03	1.46E-04	1.16E-05	1.95E-06	5.71E-07	1.83E-07	5.87E-08	1.87E-08	5.90E-09	1.85E-09	5.91E-10	2.32E-10
2016	9.20E+00	2.13E+01	1.89E+01	1.58E+01	1.28E+01	1.15E+01	1.09E+01	1.15E+01	1.66E+01	2.65E+01	3.03E+01	2.73E+01	2.43E+01	1.90E+01	1.35E+01	7.87E+00	3.11E+00	7.79E-01	1.35E-01	1.81E-02	1.89E-03	1.49E-04	1.10E-05	1.65E-06	4.67E-07	1.49E-07	4.78E-08	1.52E-08	4.81E-09	1.51E-09	4.81E-10	1.89E-10

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

year	Size bin																														
	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5	147.5	152.5	157.5	162.5	167.5	172.5	177.5	182.5
1949	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1950	4.26E+00	9.97E+00	9.56E+00	8.60E+00	6.54E+00	4.53E+00	2.79E+00	1.58E+00	8.52E-01	4.43E-01	2.22E-01	1.09E-01	5.20E-02	2.45E-02	1.13E-02	5.19E-03	2.34E-03	1.05E-03	4.65E-04	2.04E-04	8.92E-05	3.87E-05	1.67E-05	7.13E-06	3.03E-06	1.28E-06	5.32E-07	2.18E-07	8.81E-08	3.49E-08	1.41E-08	7.04E-09
1951	4.29E+00	1.00E+01	9.62E+00	8.80E+00	7.31E+00	6.15E+00	5.34E+00	4.35E+00	3.38E+00	2.52E+00	1.77E+00	1.19E+00	7.65E-01	4.81E-01	2.95E-01	1.76E-01	1.03E-01	5.90E-02	3.31E-02	1.81E-02	9.66E-03	5.03E-03	2.59E-03	1.32E-03	6.61E-04	3.12E-04	1.36E-04	5.24E-05	1.70E-05	4.22E-06	6.70E-07	6.60E-08
1952	4.34E+00	1.01E+01	9.71E+00	8.88E+00	7.37E+00	6.21E+00	5.49E+00	4.73E+00	4.08E+00	3.59E+00	3.21E+00	2.78E+00	2.34E+00	1.93E+00	1.54E+00	1.18E+00	8.75E-01	6.32E-01	4.43E-01	3.00E-01	1.96E-01	1.24E-01	7.78E-02	4.82E-02	2.88E-02	1.61E-02	8.22E-03	3.70E-03	1.39E-03	3.97E-04	7.21E-05	7.26E-06
1953	4.42E+00	1.03E+01	9.87E+00	9.01E+00	7.46E+00	6.29E+00	5.55E+00	4.79E+00	4.14E+00	3.70E+00	3.38E+00	3.07E+00	2.79E+00	2.57E+00	2.38E+00	2.16E+00	1.90E+00	1.66E+00	1.42E+00	1.17E+00	9.18E-01	6.94E-01	5.15E-01	3.76E-01	2.62E-01	1.70E-01	9.96E-02	5.12E-02	2.19E-02	7.15E-03	1.52E-03	1.87E-04
1954	4.54E+00	1.06E+01	1.01E+01	9.21E+00	7.61E+00	6.40E+00	5.65E+00	4.87E+00	4.21E+00	3.77E+00	3.48E+00	3.20E+00	2.96E+00	2.82E+00	2.73E+00	2.59E+00	2.36E+00	2.24E+00	2.10E+00	1.91E+00	1.65E+00	1.36E+00	1.11E+00	8.84E-01	6.81E-01	4.88E-01	3.16E-01	1.80E-01	8.49E-02	3.07E-02	7.40E-03	1.09E-03
1955	4.74E+00	1.11E+01	1.05E+01	9.53E+00	7.85E+00	6.58E+00	5.79E+00	4.99E+00	4.31E+00	3.87E+00	3.59E+00	3.32E+00	3.10E+00	3.01E+00	2.99E+00	2.90E+00	2.70E+00	2.64E+00	2.57E+00	2.44E+00	2.20E+00	1.87E+00	1.56E+00	1.27E+00	1.01E+00	7.45E-01	4.99E-01	2.93E-01	1.43E-01	5.38E-02	1.36E-02	2.19E-03
1956	5.04E+00	1.18E+01	1.11E+01	1.00E+01	8.22E+00	6.85E+00	6.01E+00	5.16E+00	4.45E+00	4.00E+00	3.71E+00	3.45E+00	3.24E+00	3.19E+00	3.22E+00	3.16E+00	2.96E+00	2.95E+00	2.94E+00	2.85E+00	2.62E+00	2.26E+00	1.90E+00	1.56E+00	1.25E+00	9.33E-01	6.32E-01	3.75E-01	1.85E-01	7.07E-02	1.82E-02	3.01E-03
1957	5.53E+00	1.29E+01	1.21E+01	1.08E+01	8.79E+00	7.28E+00	6.34E+00	5.42E+00	4.66E+00	4.17E+00	3.87E+00	3.60E+00	3.39E+00	3.36E+00	3.42E+00	3.39E+00	3.19E+00	3.21E+00	3.24E+00	3.17E+00	2.95E+00	2.56E+00	2.16E+00	1.78E+00	1.43E+00	1.07E+00	7.31E-01	4.36E-01	2.17E-01	8.30E-02	2.15E-02	3.60E-03
1958	6.33E+00	1.47E+01	1.38E+01	1.21E+01	9.72E+00	7.97E+00	6.87E+00	5.83E+00	4.98E+00	4.44E+00	4.10E+00	3.81E+00	3.58E+00	3.56E+00	3.64E+00	3.61E+00	3.41E+00	3.45E+00	3.50E+00	3.45E+00	3.22E+00	2.81E+00	2.37E+00	1.95E+00	1.57E+00	1.18E+00	8.08E-01	4.83E-01	2.41E-01	9.25E-02	2.41E-02	4.05E-03
1959	7.79E+00	1.81E+01	1.67E+01	1.43E+01	1.13E+01	9.13E+00	7.75E+00	6.50E+00	5.50E+00	4.85E+00	4.45E+00	4.10E+00	3.85E+00	3.81E+00	3.89E+00	3.86E+00	3.64E+00	3.69E+00	3.75E+00	3.71E+00	3.47E+00	3.03E+00	2.56E+00	2.10E+00	1.70E+00	1.28E+00	8.72E-01	5.22E-01	2.60E-01	1.00E-01	2.62E-02	4.41E-03
1960	1.08E+01	2.50E+01	2.26E+01	1.87E+01	1.44E+01	1.13E+01	9.31E+00	7.65E+00	6.37E+00	5.54E+00	5.02E+00	4.57E+00	4.25E+00	4.17E+00	4.23E+00	4.18E+00	3.93E+00	3.98E+00	4.03E+00	3.99E+00	3.73E+00	3.25E+00	2.74E+00	2.25E+00	1.81E+00	1.36E+00	9.33E-01	5.59E-01	2.79E-01	1.07E-01	2.80E-02	4.74E-03
1961	1.86E+01	4.28E+01	3.74E+01	2.92E+01	2.12E+01	1.59E+01	1.25E+01	9.92E+00	8.03E+00	6.81E+00	6.02E+00	5.39E+00	4.92E+00	4.76E+00	4.76E+00	4.65E+00	4.34E+00	4.36E+00	4.40E+00	4.33E+00	4.04E+00	3.52E+00	2.96E+00	2.42E+00	1.95E+00	1.46E+00	1.00E+00	5.99E-01	2.98E-01	1.15E-01	3.00E-02	5.06E-03
1962	4.12E+01	9.43E+01	7.97E+01	5.84E+01	3.99E+01	2.79E+01	2.05E+01	1.53E+01	1.18E+01	9.54E+00	8.09E+00	6.99E+00	6.19E+00	5.81E+00	5.67E+00	5.44E+00	5.01E+00	4.96E+00	4.94E+00	4.82E+00	4.46E+00	3.87E+00	3.24E+00	2.64E+00	2.12E+00	1.59E+00	1.08E+00	6.48E-01	3.23E-01	1.24E-01	3.23E-02	5.44E-03
1963	9.02E+01	2.07E+02	1.75E+02	1.28E+02	8.70E+01	5.95E+01	4.18E+01	2.97E+01	2.17E+01	1.66E+01	1.32E+01	1.08E+01	9.11E+00	8.12E+00	7.56E+00	7.00E+00	6.29E+00	6.06E+00	5.90E+00	5.65E+00	5.16E+00	4.44E+00	3.69E+00	2.99E+00	2.39E+00	1.78E+00	1.21E+00	7.21E-01	3.58E-01	1.37E-01	3.56E-02	5.97E-03
1964	1.24E+02	2.86E+02	2.59E+02	2.14E+02	1.60E+02	1.18E+02	8.67E+01	6.29E+01	4.61E+01	3.47E+01	2.68E+01	2.10E+01	1.68E+01	1.41E+01	1.23E+01	1.08E+01	9.28E+00	8.52E+00	7.95E+00	7.35E+00	6.55E+00	5.53E+00	4.54E+00	3.64E+00	2.88E+00	2.13E+00	1.43E+00	8.47E-01	4.18E-01	1.59E-01	4.11E-02	6.83E-03
1965	1.11E+02	2.61E+02	2.56E+02	2.42E+02	2.01E+02	1.64E+02	1.35E+02	1.08E+02	8.52E+01	6.78E+01	5.43E+01	4.33E+01	3.48E+01	2.87E+01	2.42E+01	2.04E+01	1.70E+01	1.48E+01	1.31E+01	1.15E+01	9.84E+00	8.06E+00	6.47E+00	5.10E+00	3.96E+00	2.88E+00	1.91E+00	1.11E+00	5.42E-01	2.04E-01	5.20E-02	8.50E-03
1966	8.58E+01	2.03E+02	2.07E+02	2.06E+02	1.82E+02	1.61E+02	1.48E+02	1.29E+02	1.11E+02	9.56E+01	8.33E+01	7.16E+01	6.11E+01	5.28E+01	4.60E+01	3.96E+01	3.32E+01	2.87E+01	2.49E+01	2.13E+01	1.77E+01	1.41E+01	1.10E+01	8.43E+00	6.37E+00	4.53E+00	2.94E+00	1.68E+00	8.02E-01	2.96E-01	7.37E-02	1.16E-02
1967	7.01E+01	1.65E+02	1.66E+02	1.63E+02	1.45E+02	1.32E+02	1.26E+02	1.15E+02	1.04E+02	9.65E+01	9.10E+01	8.42E+01	7.72E+01	7.17E+01	6.70E+01	6.11E+01	5.39E+01	4.89E+01	4.40E+01	3.86E+01	3.26E+01	2.64E+01	2.08E+01	1.60E+01	1.21E+01	8.58E+00	5.55E+00	3.15E+00	1.50E+00	5.47E-01	1.35E-01	2.08E-02
1968	6.61E+01	1.55E+02	1.51E+02	1.41E+02	1.21E+02	1.07E+02	1.01E+02	9.24E+01	8.47E+01	8.07E+01	7.91E+01	7.66E+01	7.39E+01	7.33E+01	7.35E+01	7.13E+01	6.61E+01	6.34E+01	6.01E+01	5.53E+01	4.84E+01	4.01E+01	3.17E+01	2.40E+01	1.84E+01	1.33E+01	8.71E+00	5.01E+00	2.40E+00	8.87E-01	2.19E-01	3.37E-02
1969	7.25E+01	1.69E+02	1.59E+02	1.42E+02	1.17E+02	9.88E+01	8.90E+01	7.91E+01	7.10E+01	6.69E+01	6.57E+01	6.43E+01	6.35E+01	6.57E+01	6.91E+01	6.98E+01	6.66E+01	6.71E+01	6.68E+01	6.42E+01	5.84E+01	4.98E+01	4.00E+01	3.02E+01	2.38E+01	1.75E+01	1.18E+01	6.92E+00	3.38E+00	1.27E+00	3.23E-01	5.12E-02
1970	8.01E+01	1.87E+02	1.75E+02	1.56E+02	1.26E+02	1.04E+02	9.05E+01	7.77E+01	6.74E+01	6.17E+01	5.92E+01	5.71E+01	5.62E+01	5.88E+01	6.30E+01	6.46E+01	6.22E+01	6.41E+01	6.56E+01	6.47E+01	6.01E+01	5.20E+01	4.14E+01	3.03E+01	2.40E+01	1.79E+01	1.22E+01	7.28E+00	3.61E+00	1.38E+00	3.58E-01	5.84E-02
1971	6.80E+01	1.60E+02	1.59E+02	1.54E+02	1.31E+02	1.11E+02	9.78E+01	8.38E+01	7.19E+01	6.44E+01	6.02E+01	5.68E+01	5.48E+01	5.65E+01	6.01E+01	6.13E+01	5.88E+01	6.08E+01	6.26E+01	6.23E+01	5.82E+01	5.05E+01	3.97E+01	2.82E+01	2.23E+01	1.68E+01	1.15E+01	6.91E+00	3.45E+00	1.33E+00	3.49E-01	5.80E-02
1972	5.01E+01	1.19E+02	1.23E+02	1.24E+02	1.11E+02	1.00E+02	9.42E+01	8.46E+01	7.48E+01	6.83E+01	6.43E+01	6.04E+01	5.77E+01	5.85E+01	6.12E+01	6.16E+01	5.84E+01	5.98E+01	6.12E+01	6.06E+01	5.64E+01	4.88E+01	3.80E+01	2.65E+01	2.10E+01	1.57E+01	1.08E+01	6.46E+00	3.23E+00	1.25E+00	3.28E-01	5.49E-02
1973	3.08E+01	7.39E+01	8.02E+01	8.65E+01	8.11E+01	7.65E+01	7.54E+01	7.07E+01	6.53E+01	6.25E+01	6.16E+01	6.00E+01	5.86E+01	6.02E+01	6.32E+01	6.36E+01	6.02E+01	6.13E+01	6.21E+01	6.10E+01	5.65E+01	4.87E+01	3.77E+01	2.64E+01	2.07E+01	1.55E+01	1.05E+01	6.29E+00	3.13E+00	1.21E+00	3.16E-01	5.28E-02
1974	2.32E+01	5.50E+01	5.65E+01	5.74E+01	5.31E+01	5.10E+01	5.23E+01	5.09E+01	4.87E+01	4.84E+01	4.97E+01	5.02E+01	5.09E+01	5.43E+01	5.89E+01	6.07E+01	5.85E+01	6.03E+01	6.18E+01	6.10E+01	5.66E+01	4.89E+01	3.83E+01	2.73E+01	2.15E+01	1.60E+01	1.09E+01	6.48E+00	3.22E+00	1.24E+00	3.22E-01	5.36E-02
1975	4.65E+01	1.07E+02	9.11E+01	6.91E+01	5.07E+01	4.08E+01	3.72E+01	3.46E+01	3.29E+01	3.34E+01	3.55E+01	3.72E+01	3.92E+01	4.37E+01	4.92E+01	5.21E+01	5.11E+01	5.40E+01	5.64E+01	5.67E+01	5.32E+01	4.63E+01	3.65E+01	2.62E+01	2.08E+01	1.56E+01	1.06E+01	6.35E+00	3.16E+00	1.22E+00	3.17E-01	5.29E-02
1976	8.38E+01	1.93E+02	1.67E+02	1.28E+02	9.10E+01	6.51E+01	4.84E+01	3.71E+01	3.02E+01	2.73E+01	2.73E+01	2.80E+01	2.97E+01	3.41E+01	3.98E+01	4.32E+01	4.30E+01	4.65E+01	4.97E+01	5.07E+01	4.82E+01	4.23E+01	3.32E+01	2.35E+01	1.87E+01	1.41E+01	9.66E+00	5.82E+00	2.91E+00	1.13E+00	2.96E-01	4.98E-02
1977	6.62E+01	1.56E+02	1.58E+02	1.55E+02	1.30E+02	1.04E+02	8.28E+01	6.41E+01	4.96E+01	4.02E+01	3.43E+01	3.05E+01	2.89E+01	3.06E+01	3.42E+01	3.63E+01	3.55E+01	3.83E+01	4.09E+01	4.17E+01	3.96E+01	3.45E+01	2.58E+01	1.64E+01	1.29E+01	9.69E+00	6.66E+00	4.02E+00	2.02E+00	7.84E-01	2.07E-01	3.48E-02
1978	3.38E+01	8.21E+01	9.43E+01	1.08E+02	1.03E+02	9.71E+01	9.33E+01	8.34E+01	7.18E+01	6.20E+01	5.41E+01	4.71E+01	4.18E+01	3.96E+01	3.92E+01	3.78E+01	3.45E+01	3.43E+01	3.41E+01	3.28E+01	2.96E+01	2.47E+01	1.61E+01	8.22E+00	6.17E+00	4.55E+00	3.08E+00	1.83E+00	9.12E-01	3.52E-01	9.20E-02	1.50E-02
1979	1.34E+01	3.32E+01	4.18E+01	5.26E+01	5.54E+01	5.83E+01	6.35E+01	6.34E+01	6.10E+01	5.97E+01	5.90E+01	5.67E+01	5.35E+01	5.18E+01	5.04E+01	4.72E+01	4.16E+01	3.85E+01	3.51E+01	3.08E+01	2.57E+01	2.01E+01	1.20E+01	6.41E+00	4.63E+00	3.21E+00	2.04E+00	1.14E+00	5.38E-01	1.96E-01	4.79E-02	6.99E-03
1980	7.14E+00	1.73E+01	1.96E+01	2.28E+01	2.41E+01	2.67E+01	3.12E+01	3.37E+01	3.51E+01	3.78E+01	4.13E+01	4.32E+01	4.43E+01	4.62E+01	4.78E+01	4.66E+01	4.21E+01	3.87E+01	3.42E+01	2.87E+01	2.28E+01	1.72E+01	1.09E+01	7.40E+00	5.36E+00	3.58E+00	2.15E+00	1.13E+00	4.92E-01	1.64E-01	3.55E-02	4.11E-03
1981	1.03E+01	2.38E+01	2.13E+01	1.78E+01	1.47E+01	1.36E+01	1.43E+01	1.50E+01	1.59E+01	1.79E+01	2.06E+01	2.27E+01	2.45E+01	2.69E+01	2.93E+01	3.00E+01	2.85E+01	2.75E+01	2.55E+01	2.26E+01	1.92E+01	1.57E+01	1.16E+01	8.78E+00	6.86E+00	4.93E+00	3.19E+00	1.79E+00	8.30E-01	2.94E-01	6.83E-02	8.78E-03
1982	6.95E+00	1.66E+01	1.75E+01	1.81E+01	1.57E+01	1.32E+01	1.14E+01	9.92E+00	9.05E+00	9.13E+00	9.92E+00	1.08E+01	1.19E+01	1.36E+01	1.56E+01	1.69E+01	1.69E+01	1.76E+01	1.78E+01	1.73E+01	1.61E+01	1.42E+01	1.17E+01	9.59E+00	7.95E+00	6.09E+00	4.20E+00	2.52E+00	1.25E+00	4.80E-01	1.24E-01	1.98E-02
1983	2.65E+01	6.01E+01	4.83E+01	3.21E+01	2.06E+01	1.48E+01	1.24E+01	1.06E+01	9.18E+00	8.26E+00	7.74E+00	7.39E+00	7.30E+00	7.80E+00	8.71E+00	9.35E+00	9.41E+00	1.01E+01	1.08E+01	1.11E+01	1.09E+01	1.00E+01	8.71E+00	7.42E+00	6.34E+00	5.00E+00	3.55E+00	2.20E+00	1.13E+00	4.46E-01	1.20E-01	2.09E-02
1984	2.47E+01	5.78E+01	5.63E+01	5.21E+01	4.12E+01	3.06E+01	2.18E+01	1.53E+01	1.13E+01	9.07E+00	8.01E+00	7.33E+00	6.86E+00	6.74E+00	6.86E+00	6.86E+00	6.55E+00	6.75E+00	7.02E+00	7.18E+00	7.03E+00	6.49E+00	5.71E+00	4.94E+00	4.25E+00	3.38E+00	2.43E+00	1.52E+00	7.92E-01	3.18E-01	8.75E-02	1.59E-02
1985	3.88E+01	8.93E+01	7.90E+01	6.36E+01	4.84E+01	3.87E+01	3.32E+01	2.74E+01	2.20E+01	1.75E+01	1.38E+01	1.09E+01	8.73E+00	7.46E+00	6.79E+00	6.33E+00	5.83E+00	5.70E+00	5.62E+00	5.48E+00	5.15E+00	4.61E+00	3.95E+00	3.31E+00	2.78E+00	2.16E+00	1.53E+00	9.45E-01	4.87E-01	1.94E-01	5.30E-02	9.56E-03
1986	3.57E+01	8.38E+01	8.19E+01	7.65E+01	6.27E+01	5.03E+01	4.08E+01	3.28E+01	2.69E+01	2.31E+01	2.05E+01	1.81E+01	1.58E+01	1.39E+01	1.23E+01	1.08E+01	9.20E+00	8.24E+00	7.54E+00	6.93E+00	6.24E+00	5.40E+00	4.59E+00	3.91E+00	3.25E+00	2.50E+00	1.74E+00	1.07E+00	5.42E-01	2.14E-01	5.75E-02	1.02E-02
1987	3.46E+01	8.09E+01	7.83E+01	7.27E+01	6.13E+01	5.27E+01	4.74E+01	4.09E+01	3.46E+01	2.96E+01	2.58E+01	2.24E+01	1.96E+01	1.78E+01	1.67E+01	1.55E+01	1.39E+01	1.29E+01	1.19E+01	1.08E+01	9.38E+00	7.85E+00	6.50E+00	5.42E+00	4.35E+00	3.22E+00	2.17E+00	1.29E+00	6.36E-01	2.44E-01	6.39E-02	1.10E-02
1988	3.37E+01	7.89E+01	7.61E+01	7.05E+01	5.91E+01	5.05E+01	4.54E+01	3.98E+01	3.50E+01	3.18E+01	2.97E+01	2.74E+01	2.49E+01	2.31E+01	2.18E+01	2.02E+01	1.80E+01	1.68E+01	1.56E+01	1.43E+01	1.26E+01	1.06E+01	8.88E+00	7.47E+00	6.02E+00	4.45E+00	2.99E+00	1.75E+00	8.59E-01	3.25E-01	8.33E-02	1.38E-02
1989	1.46E+01	3.59E+01	4.36E+01	5.22E+01	5.01E+01	4.60E+01	4.29E+01	3.81E+01	3.37E+01	3.08E+01	2.90E+01	2.72E+01	2.56E+01	2.48E+01	2.45E+01	2.37E+01	2.20E+01	2.12E+01	2.01E+01	1.86E+01	1.65E+01	1.39E+01	1.15E+01	9.46E+00	7.55E+00	5.55E+00	3.70E+00	2.16E+00	1.05E+00	3.98E-01	1.02E-01	1.68E-02
1990	5.65E+00	1.40E+01	1.78E+01	2.28E+01	2.48E+01	2.71E+01	3.05E+01	3.07E+01	2.94E+01	2.83E+01	2.76E+01	2.64E+01	2.51E+01	2.47E+01	2.48E+01	2.44E+01	2.28E+01	2.23E+01	2.15E+01	2.02E+01	1.80E+01	1.53E+01	1.23E+01	9.45E+00	7.49E+00	5.51E+00	3.67E+00	2.14E+00	1.04E+00	3.92E-01	9.95E-02	1.60E-02
1991	3.29E+00	7.90E+00	8.73E+00	9.87E+00	1.03E+01	1.15E+01	1.36E+01	1.50E+01	1.62E+01	1.79E+01	2.00E+01	2.12E+01	2.16E+01	2.22E+01	2.31E+01	2.31E+01	2.18E+01	2.13E+01	2.03E+01	1.88E+01	1.65E+01	1.38E+01	1.04E+01	7.10E+00	5.52E+00	4.03E+00	2.67E+00	1.55E+00	7.50E-01	2.81E-01	7.09E-02	1.11E-02
1992	2.50E+00	5.91E+00	6.06E+00	6.15E+00	5.76E+00	5.70E+00	6.23E+00	6.72E+00	7.27E+00	8.47E+00	1.02E+01	1.18E+01	1.30E+01	1.47E+01	1.69E+01	1.83E+01	1.82E+01	1.88E+01	1.88E+01	1.78E+01	1.56E+01	1.25E+01	9.33E+00	6.93E+00	5.33E+00	3.83E+00	2.51E+00	1.44E+00	6.92E-01	2.55E-01	6.25E-02	9.29E-03
1993	2.32E+00	5.44E+00	5.31E+00	5.01E+00	4.37E+00	3.99E+00	4.03E+00	4.05E+00	4.11E+00	4.66E+00	5.64E+00	6.59E+00	7.31E+00	8.49E+00	1.03E+01	1.16E+01	1.19E+01	1.30E+01	1.36E+01	1.33E+01	1.18E+01	9.11E+00	6.63E+00	5.12E+00	3.96E+00	2.88E+00	1.91E+00	1.12E+00	5.42E-01	2.02E-01	4.97E-02	7.29E-03
1994	2.91E+00	6.75E+00	6.19E+00	5.32E+00	4.27E+00	3.60E+00	3.37E+00	3.20E+00	3.08E+00	3.36E+00	3.98E+00	4.57E+00	4.91E+00	5.58E+00	6.81E+00	7.74E+00	7.92E+00	8.84E+00	9.51E+00	9.51E+00	8.48E+00	6.46E+00	4.67E+00	3.71E+00	2.91E+00	2.13E+00	1.44E+00	8.59E-01	4.27E-01	1.63E-01	4.21E-02	6.72E-03
1995	3.87E+00	8.97E+00	8.14E+00	6.82E+00	5.28E+00	4.20E+00	3.59E+00	3.14E+00	2.83E+00	2.89E+00	3.25E+00	3.61E+00	3.75E+00	4.14E+00	4.98E+00	5.62E+00	5.72E+00	6.40E+00	6.93E+00	6.99E+00	6.26E+00	4.75E+00	3.41E+00	2.70E+00	2.06E+00	1.45E+00	9.50E-01	5.52E-01	2.71E-01	1.03E-01	2.70E-02	4.52E-03
1996	3.96E+00	9.25E+00	8.83E+00	7.99E+00	6.49E+00	5.27E+00	4.46E+00	3.76E+00	3.22E+00	3.03E+00	3.13E+00	3.24E+00	3.19E+00	3.33E+00	3.84E+00	4.22E+00	4.21E+00	4.63E+00	4.96E+00	4.97E+00	4.41E+00	3.31E+00	2.39E+00	1.95E+00	1.52E+00	1.10E+00	7.28E-01	4.28E-01	2.12E-01	8.15E-02	2.14E-02	3.64E-03
1997	9.78E+00	2.23E+01	1.86E+01	1.34E+01	9.14E+00	6.68E+00	5.43E+00	4.52E+00	3.83E+00	3.49E+00	3.39E+00	3.30E+00	3.12E+00	3.10E+00	3.38E+00	3.57E+00	3.48E+00	3.74E+00	3.95E+00	3.92E+00	3.48E+00	2.64E+00	1.94E+00	1.60E+00	1.26E+00	9.17E-01	6.12E-01	3.62E-01	1.79E-01	6.91E-02	1.82E-02	3.09E-03
1998	4.01E+00	9.90E+00	1.23E+01	1.47E+01	1.34E+01	1.10E+01	8.58E+00	6.55E+00	5.10E+00	4.30E+00	3.94E+00	3.69E+00	3.41E+00	3.31E+00	3.42E+00	3.46E+00	3.28E+00	3.40E+00	3.49E+00	3.41E+00	3.03E+00	2.36E+00	1.79E+00	1.49E+00	1.18E+00	8.68E-01	5.82E-01	3.44E-01	1.71E-01	6.57E-02	1.72E-02	2.93E-03
1999	1.17E+01	2.67E+01	2.19E+01	1.54E+01	1.11E+01	9.36E+00	9.21E+00	8.56E+00	7.56E+00	6.61E+00	5.79E+00	5.02E+00	4.35E+00	3.95E+00	3.83E+00	3.69E+00	3.41E+00	3.43E+00	3.44E+00	3.32E+00	2.95E+00	2.36E+00	1.85E+00	1.54E+00	1.23E+00	9.05E-01	6.08E-01	3.59E-01	1.77E-01	6.79E-02	1.77E-02	2.98E-03
2000	6.96E+00	1.67E+01	1.83E+01	1.95E+01	1.68E+01	1.33E+01	1.01E+01	7.83E+00	6.48E+00	6.00E+00	6.00E+00	5.90E+00	5.62E+00	5.38E+00	5.21E+00	4.89E+00	4.38E+00	4.19E+00	4.02E+00	3.76E+00	3.31E+00	2.68E+00	2.14E+00	1.77E+00	1.41E+00	1.04E+00	6.98E-01	4.12E-01	2.03E-01	7.74E-02	2.00E-02	3.34E-03
2001	2.12E+01	4.83E+01	3.95E+01	2.74E+01	1.87E+01	1.44E+01	1.28E+01	1.11E+01	9.40E+00	7.97E+00	6.83E+00	5.91E+00	5.28E+00	5.08E+00	5.17E+00	5.17E+00	4.93E+00	4.96E+00	4.91E+00	4.68E+00	4.18E+00	3.46E+00	2.80E+00	2.31E+00	1.82E+00	1.33E+00	8.87E-01	5.19E-01	2.53E-01	9.56E-02	2.44E-02	4.02E-03
2002	8.04E+00	2.00E+01	2.55E+01	3.12E+01	2.84E+01	2.30E+01	1.76E+01	1.32E+01	1.04E+01	8.91E+00	8.24E+00	7.67E+00	7.08E+00	6.70E+00	6.44E+00	6.04E+00	5.44E+00	5.28E+00	5.19E+00	5.01E+00	4.57E+00	3.88E+00	3.25E+00	2.74E+00	2.21E+00	1.66E+00	1.13E+00	6.69E-01	3.31E-01	1.26E-01	3.25E-02	5.36E-03
2003	1.60E+01	3.68E+01	3.15E+01	2.43E+01	1.94E+01	1.81E+01	1.88E+01	1.78E+01	1.57E+01	1.35E+01	1.15E+01	9.65E+00	8.31E+00	7.64E+00	7.39E+00	7.11E+00	6.60E+00	6.51E+00	6.40E+00	6.12E+00	5.54E+00	4.69E+00	3.89E+00	3.24E+00	2.59E+00	1.92E+00	1.30E+00	7.68E-01	3.79E-01	1.45E-01	3.75E-02	6.30E-03
2004	2.47E+01	5.69E+01	5.05E+01	4.05E+01	2.97E+01	2.18E+01	1.67E+01	1.34E+01	1.18E+01	1.15E+01	1.18E+01	1.17E+01	1.13E+01	1.08E+01	1.04E+01	9.63E+00	8.57E+00	8.10E+00	7.75E+00	7.32E+00	6.61E+00	5.62E+00	4.71E+00	3.95E+00	3.18E+00	2.38E+00	1.61E+00	9.59E-01	4.74E-01	1.81E-01	4.67E-02	7.76E-03
2005	7.20E+00	1.84E+01	2.61E+01	3.47E+01	3.36E+01	2.95E+01	2.50E+01	2.02E+01	1.61E+01	1.32E+01	1.13E+01	9.96E+00	9.29E+00	9.42E+00	9.94E+00	1.02E+01	9.83E+00	9.95E+00	9.92E+00	9.53E+00	8.65E+00	7.36E+00	6.13E+00	5.08E+00	4.03E+00	2.98E+00	2.00E+00	1.18E+00	5.78E-01	2.20E-01	5.64E-02	9.38E-03
2006	5.55E+00	1.31E+01	1.34E+01	1.41E+01	1.48E+01	1.69E+01	2.00E+01	2.04E+01	1.91E+01	1.76E+01	1.60E+01	1.42E+01	1.27E+01	1.18E+01	1.14E+01	1.08E+01	9.91E+00	9.88E+00	1.00E+01	9.91E+00	9.28E+00	8.11E+00	6.93E+00	5.90E+00	4.80E+00	3.62E+00	2.48E+00	1.48E+00	7.34E-01	2.81E-01	7.24E-02	1.20E-02
2007	3.72E+00	8.86E+00	9.39E+00	9.86E+00	9.09E+00	8.56E+00	8.73E+00	9.11E+00	9.81E+00	1.11E+01	1.27E+01	1.35E+01	1.37E+01	1.40E+01	1.42E+01	1.38E+01	1.27E+01	1.23E+01	1.20E+01	1.15E+01	1.05E+01	8.95E+00	7.49E+00	6.26E+00	5.04E+00	3.78E+00	2.57E+00	1.54E+00	7.67E-01	2.95E-01	7.71E-02	1.31E-02
2008	4.64E+00	1.08E+01	9.89E+00	8.57E+00	7.11E+00	6.34E+00	6.23E+00	5.99E+00	5.75E+00	5.91E+00	6.45E+00	7.10E+00	7.97E+00	9.46E+00	1.11E+01	1.22E+01	1.22E+01	1.29E+01	1.33E+01	1.32E+01	1.22E+01	1.05E+01	8.85E+00	7.40E+00	5.93E+00	4.42E+00	2.99E+00	1.78E+00	8.77E-01	3.34E-01	8.62E-02	1.43E-02
2009	3.03E+01	6.85E+01	5.34E+01	3.27E+01	1.84E+01	1.09E+01	7.34E+00	5.58E+00	4.71E+00	4.56E+00	4.84E+00	5.19E+00	5.68E+00	6.75E+00	8.09E+00	8.95E+00	9.05E+00	1.01E+01	1.12E+01	1.18E+01	1.15E+01	1.03E+01	8.92E+00	7.69E+00	6.34E+00	4.85E+00	3.35E+00	2.03E+00	1.01E+00	3.92E-01	1.02E-01	1.71E-02
2010	3.77E+01	8.75E+01	8.04E+01	6.81E+01	5.05E+01	3.54E+01	2.34E+01	1.51E+01	9.90E+00	7.07E+00	5.70E+00	5.09E+00	5.03E+00	5.70E+00	6.74E+00	7.41E+00	7.46E+00	8.36E+00	9.34E+00	1.00E+01	9.91E+00	8.96E+00	7.84E+00	6.79E+00	5.61E+00	4.28E+00	2.96E+00	1.80E+00	9.10E-01	3.57E-01	9.50E-02	1.65E-02
2011	2.20E+01	5.28E+01	5.82E+01	6.32E+01	5.69E+01	4.90E+01	4.21E+01	3.41E+01	2.66E+01	2.05E+01	1.56E+01	1.19E+01	9.39E+00	8.19E+00	7.85E+00	7.59E+00	7.07E+00	7.50E+00	8.13E+00	8.59E+00	8.48E+00	7.67E+00	6.73E+00	5.86E+00	4.86E+00	3.73E+00	2.59E+00	1.57E+00	7.99E-01	3.14E-01	8.39E-02	1.47E-02
2012	3.80E+00	1.05E+01	1.89E+01	2.95E+01	3.30E+01	3.48E+01	3.69E+01	3.52E+01	3.20E+01	2.90E+01	2.62E+01	2.30E+01	2.00E+01	1.76E+01	1.56E+01	1.36E+01	1.15E+01	1.04E+01	9.81E+00	9.30E+00	8.53E+00	7.39E+00	6.29E+00	5.36E+00	4.38E+00	3.32E+00	2.29E+00	1.38E+00	6.98E-01	2.73E-01	7.28E-02	1.27E-02
2013	9.51E+00	2.17E+01	1.82E+01	1.37E+01	1.22E+01	1.37E+01	1.74E+01	1.95E+01	2.06E+01	2.18E+01	2.29E+01	2.30E+01	2.24E+01	2.21E+01	2.16E+01	2.04E+01	1.84E+01	1.71E+01	1.59E+01	1.45E+01	1.26E+01	1.05E+01	8.57E+00	6.98E+00	5.46E+00	3.98E+00	2.64E+00	1.54E+00	7.54E-01	2.86E-01	7.37E-02	1.24E-02
2014	7.62E+00	1.80E+01	1.82E+01	1.77E+01	1.46E+01	1.15E+01	9.30E+00	8.31E+00	8.42E+00	9.75E+00	1.18E+01	1.36E+01	1.51E+01	1.71E+01	1.90E+01	1.99E+01	1.94E+01	1.97E+01	1.96E+01	1.89E+01	1.71E+01	1.46E+01	1.21E+01	1.00E+01	7.93E+00	5.82E+00	3.88E+00	2.26E+00	1.10E+00	4.12E-01	1.04E-01	1.67E-02
2015	5.34E+00	1.27E+01	1.33E+01	1.37E+01	1.25E+01	1.14E+01	1.09E+01	9.79E+00	8.49E+00	7.67E+00	7.42E+00	7.58E+00	8.35E+00	1.02E+01	1.26E+01	1.43E+01	1.46E+01	1.60E+01	1.73E+01	1.77E+01	1.69E+01	1.48E+01	1.26E+01	1.07E+01	8.66E+00	6.53E+00	4.46E+00	2.66E+00	1.32E+00	5.02E-01	1.29E-01	2.11E-02
2016	9.20E+00	2.12E+01	1.85E+01	1.46E+01	1.12E+01	9.38E+00	8.83E+00	8.25E+00	7.73E+00	7.65E+00	7.90E+00	8.05E+00	8.31E+00	9.29E+00	1.06E+01	1.13E+01	1.10E+01	1.19E+01	1.31E+01	1.38E+01	1.35E+01	1.18E+01	9.95E+00	8.52E+00	7.06E+00	5.45E+00	3.80E+00	2.32E+00	1.17E+00	4.58E-01	1.21E-01	2.04E-02

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

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

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

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

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

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

Figures

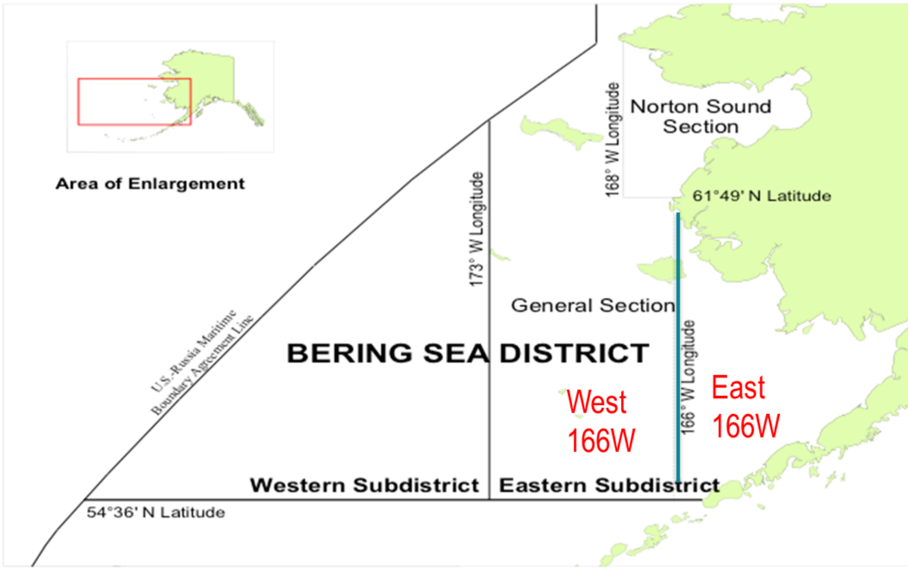


Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008).

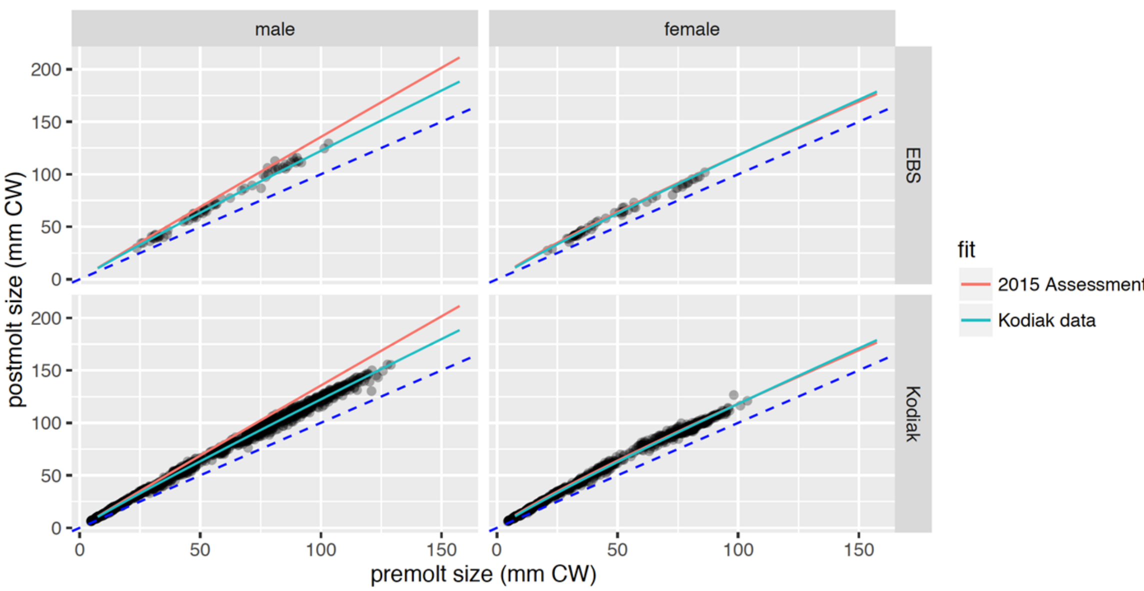


Figure 2. Growth of male (a) and female (b) Tanner crab as a function of premolt size. Grey circles: observations; red lines: post-molt size estimated in the 2015 assessment; green line: post-molt regression based on Kodiak data; dotted blue line: no-growth line.

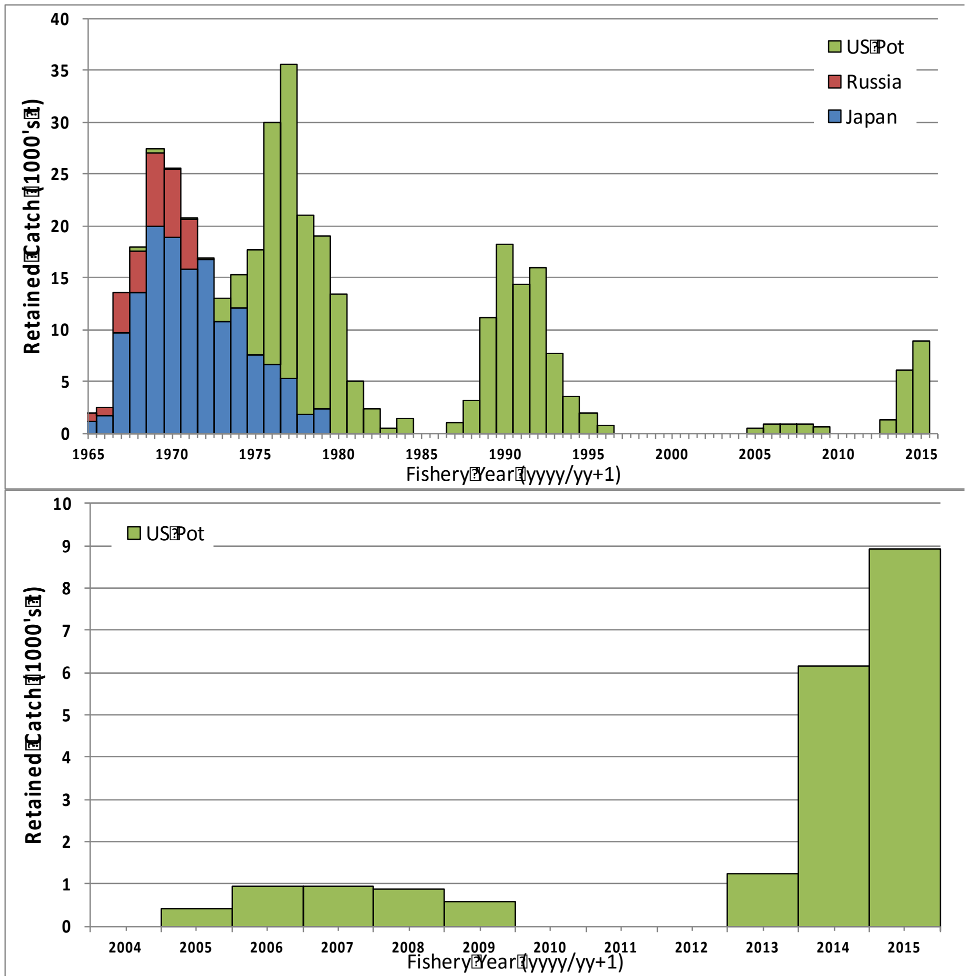


Figure 3. Upper: retained catch (males, 1000's t) in the directed fisheries (US pot fishery [green bars], Russian tangle net fishery [red bars], and Japanese tangle net fisheries [blue bars]) for Tanner crab since 1965/66. Lower: Retained catch (males, 1000's t) in directed fishery since 2001/02. The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

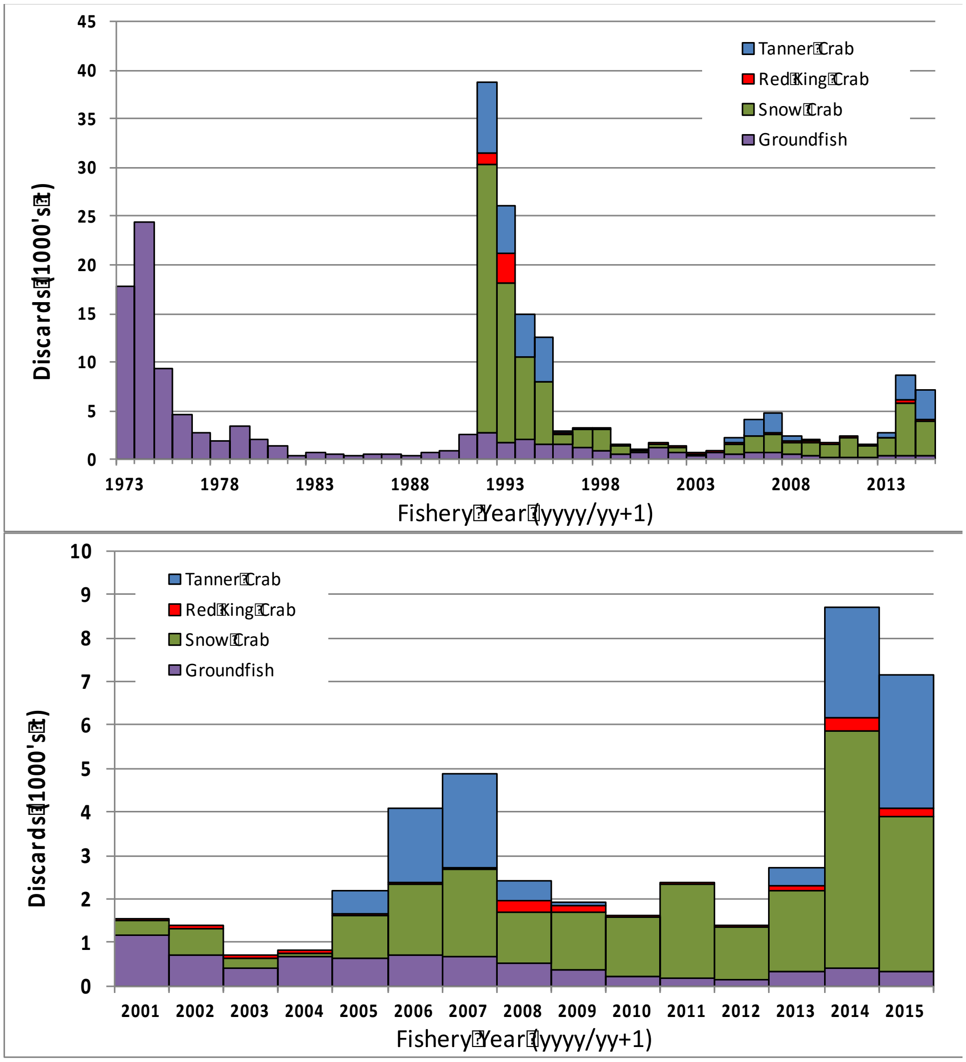


Figure 4. Upper: Tanner crab discards (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Discard reporting began in 1973 for the groundfish fisheries and in 1992 for the crab fisheries. Lower: detail since 2001.

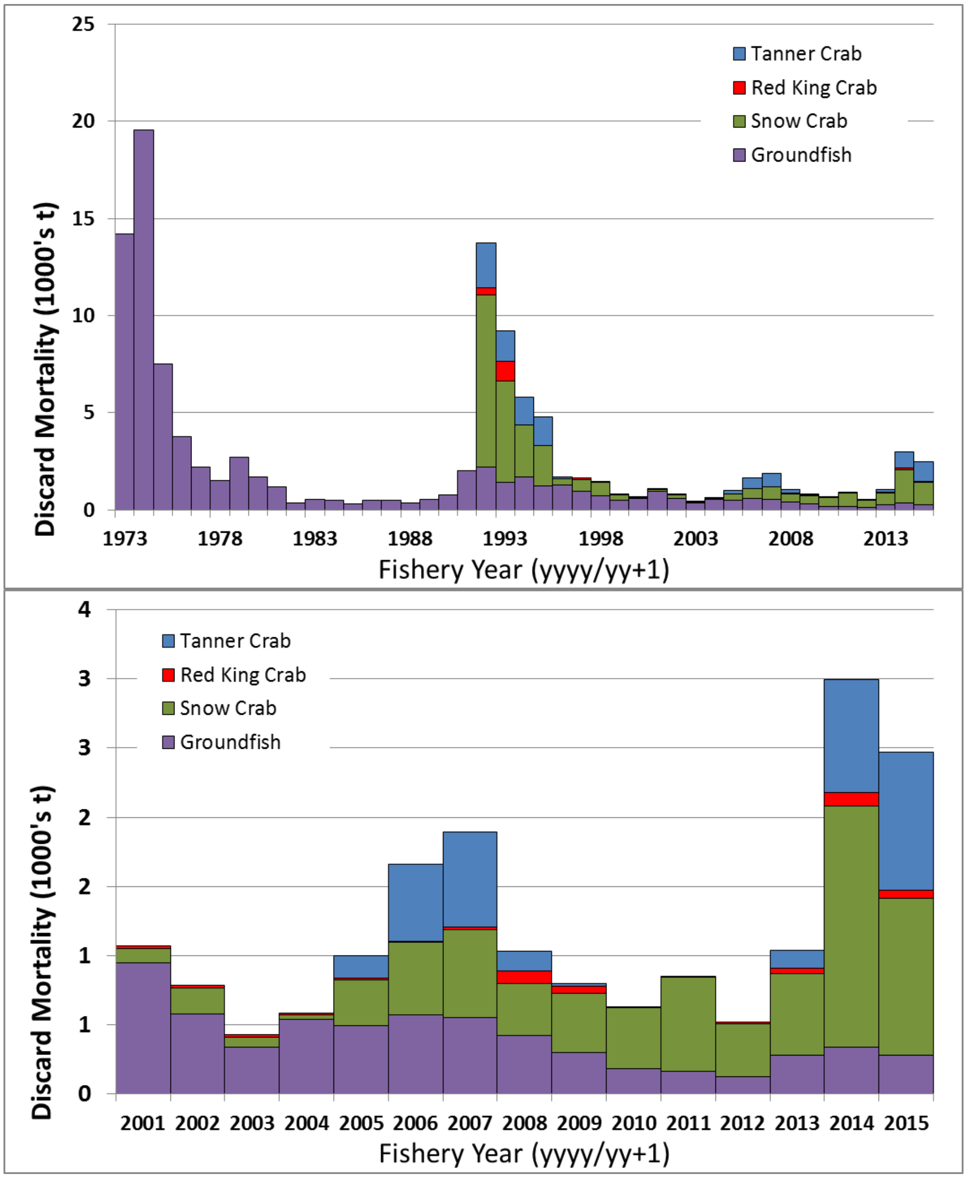


Figure 5. Upper: Tanner crab discard mortality (males and females, 1000’s t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Assumed handling mortality rates of 0.321 for the crab fisheries and 0.80 for the groundfish fisheries were applied to discard biomass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

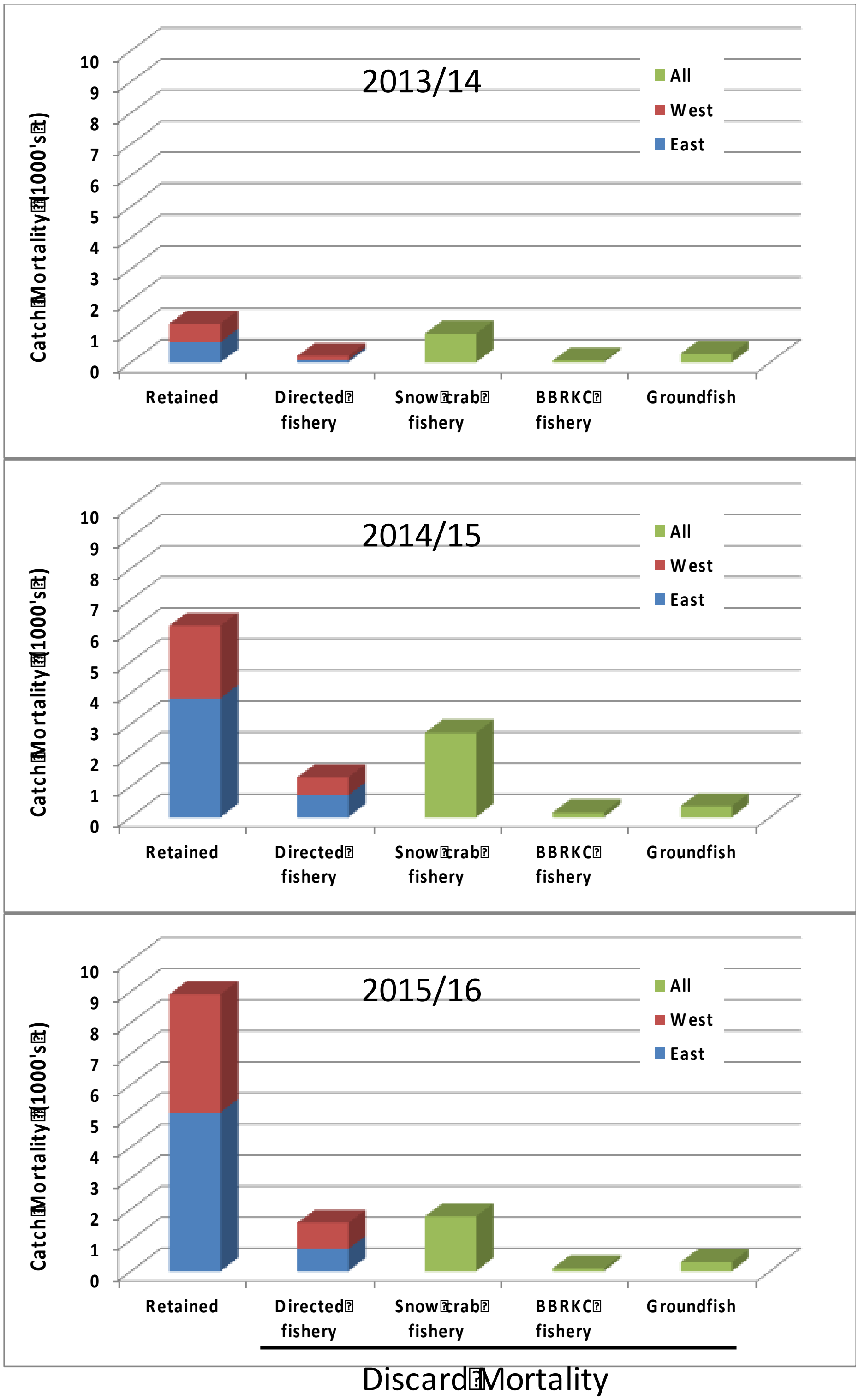


Figure 6. Retained and discard catch mortality (1000's t) in the directed, snow crab, BBRKC and groundfish fisheries. Handling mortality rates of 0.321 for the crab fisheries and 0.8 for the groundfish fisheries were applied to estimated discards.

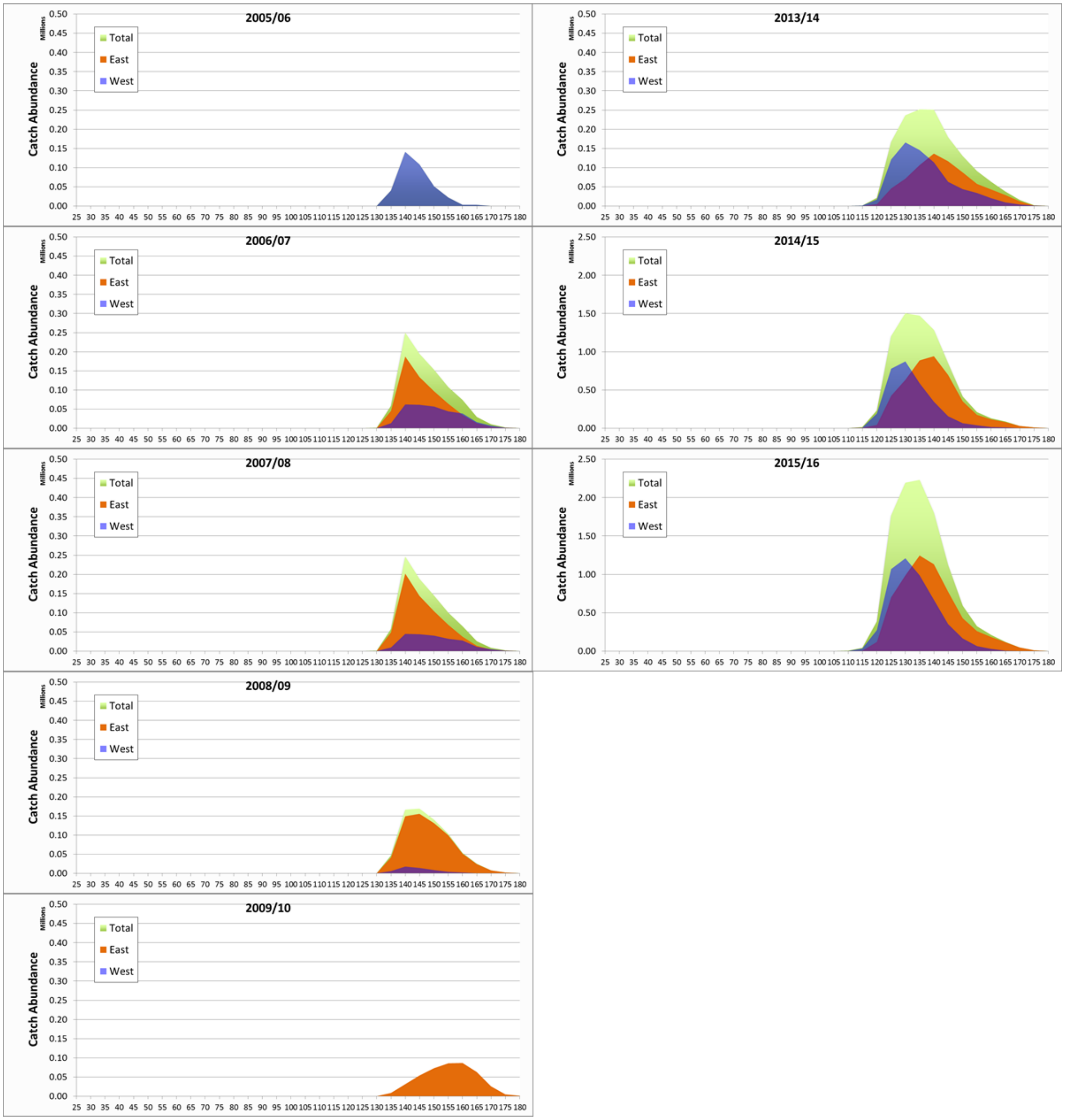


Figure 7. Size compositions, by 5 mm CW bins and expanded to total retained catch, for retained (male) crab in the directed Tanner crab pot fisheries since 2006/07, from dockside crab fishery observer sampling. Fishing occurred only east of 166°W in 2009/10. The entire fishery was closed in 2010/11-2012/13.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

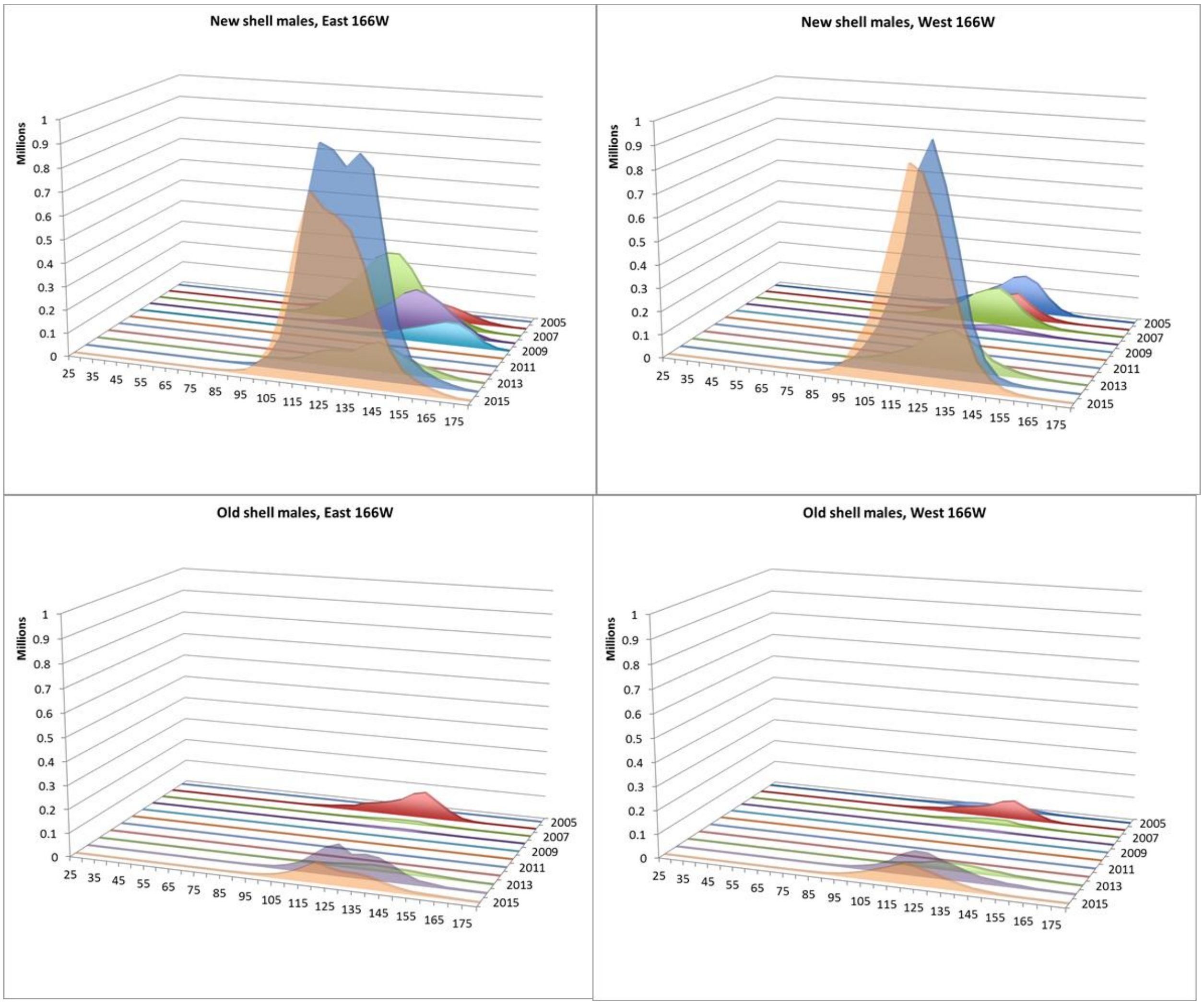


Figure 8. Male Tanner crab catch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling.

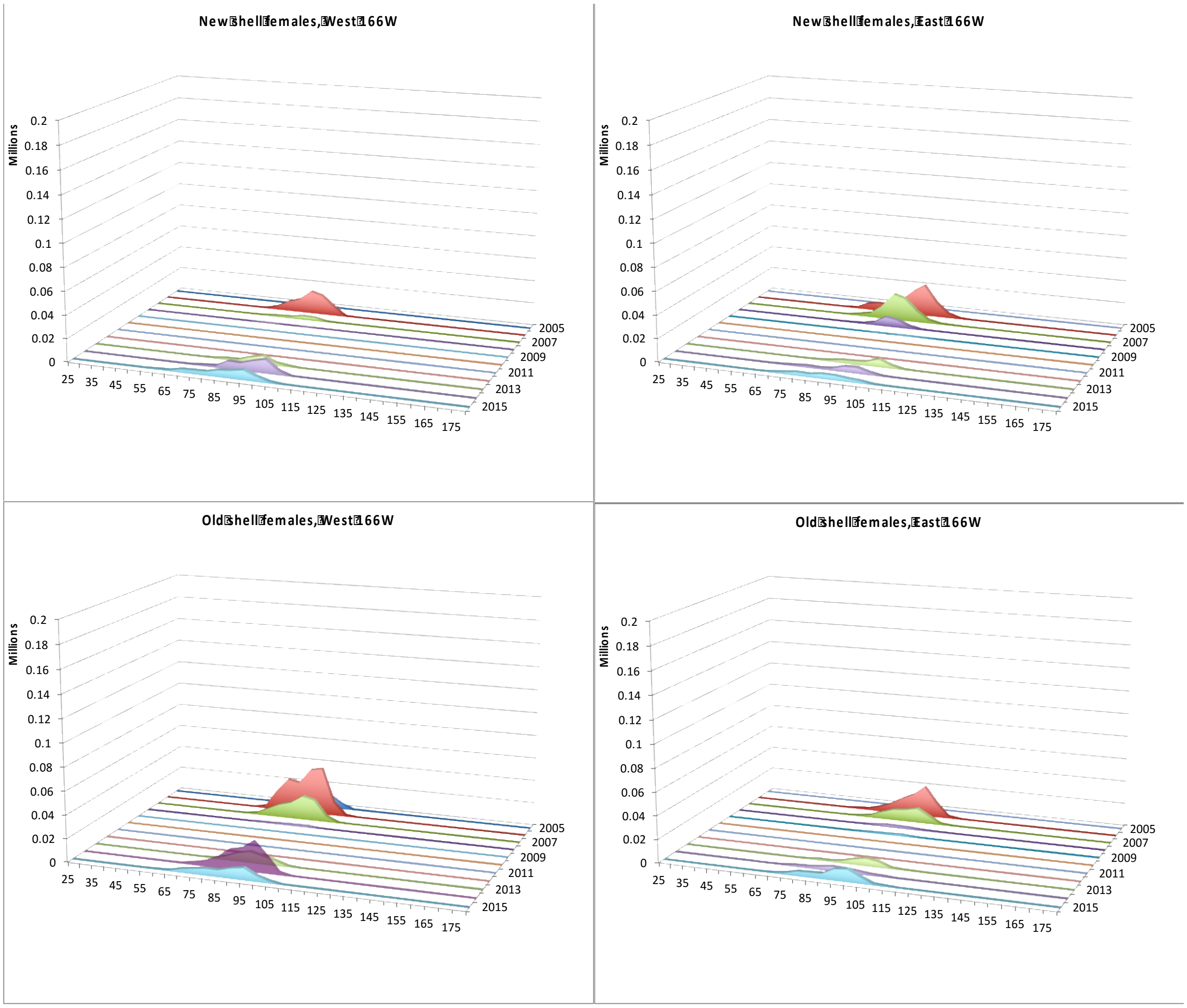


Figure 9. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling.

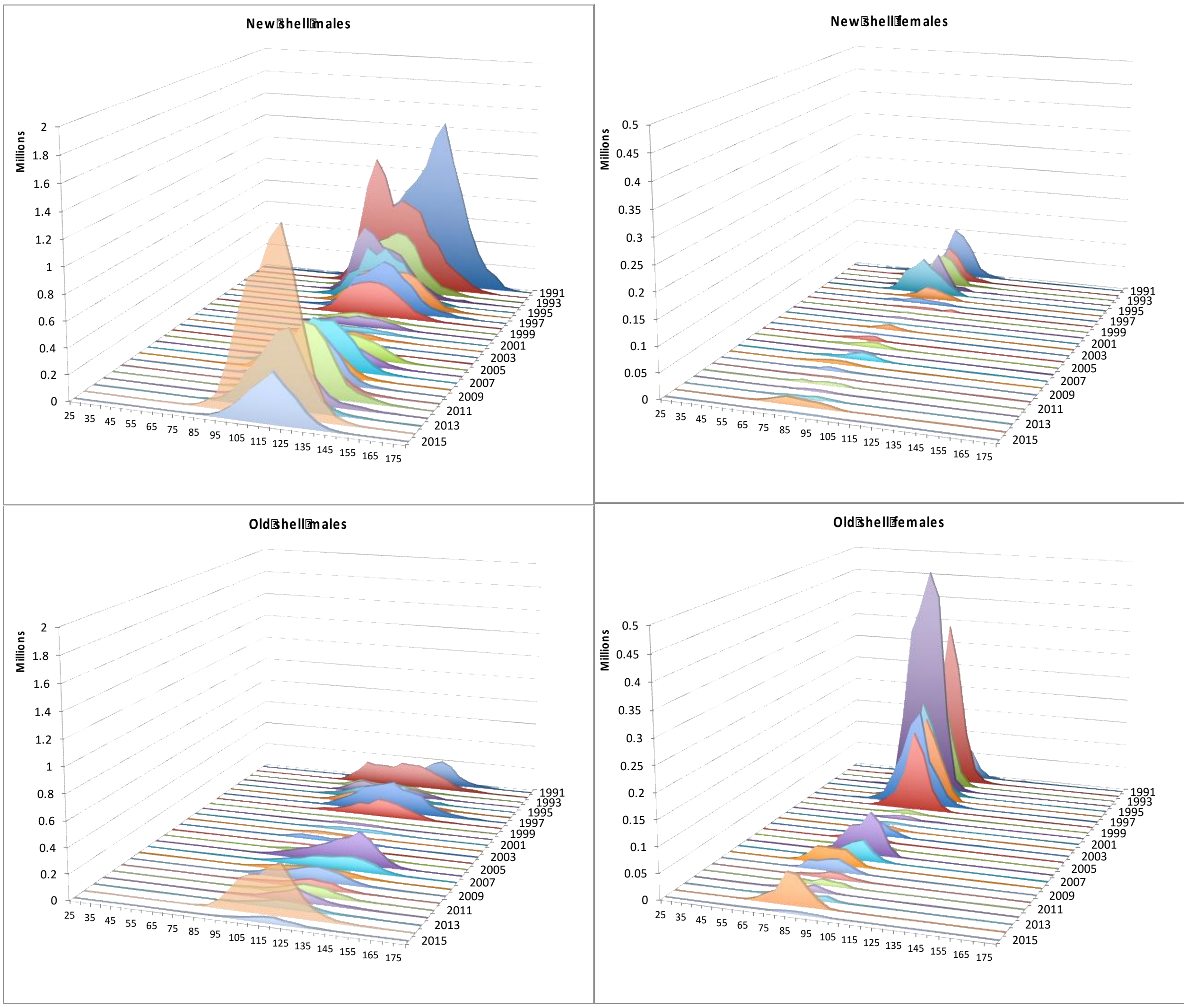


Figure 10. Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the snow crab pot fishery, from at-sea crab fishery observer sampling.

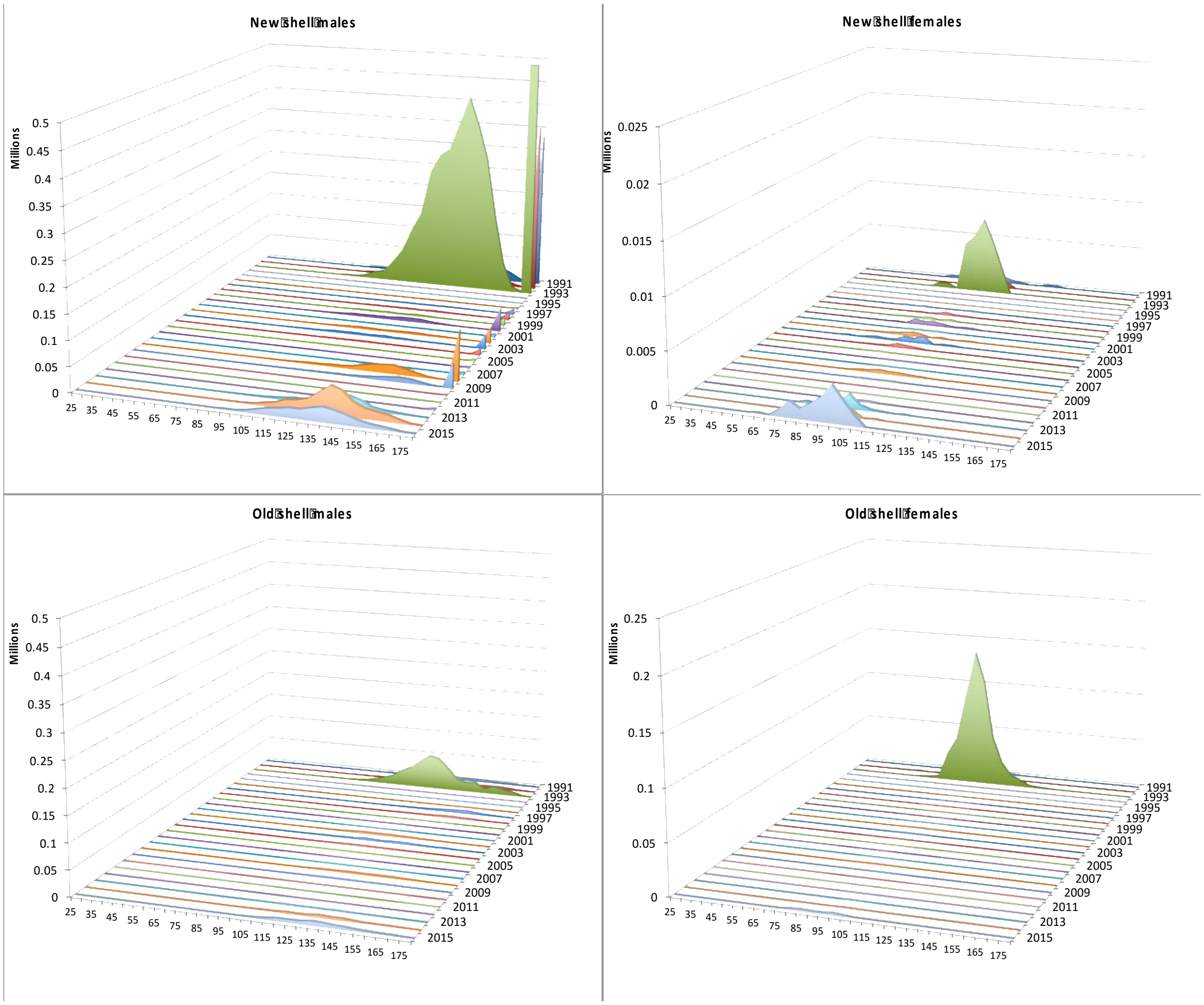


Figure 11. Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the BBRKC pot fishery, from at-sea crab fishery observer sampling.

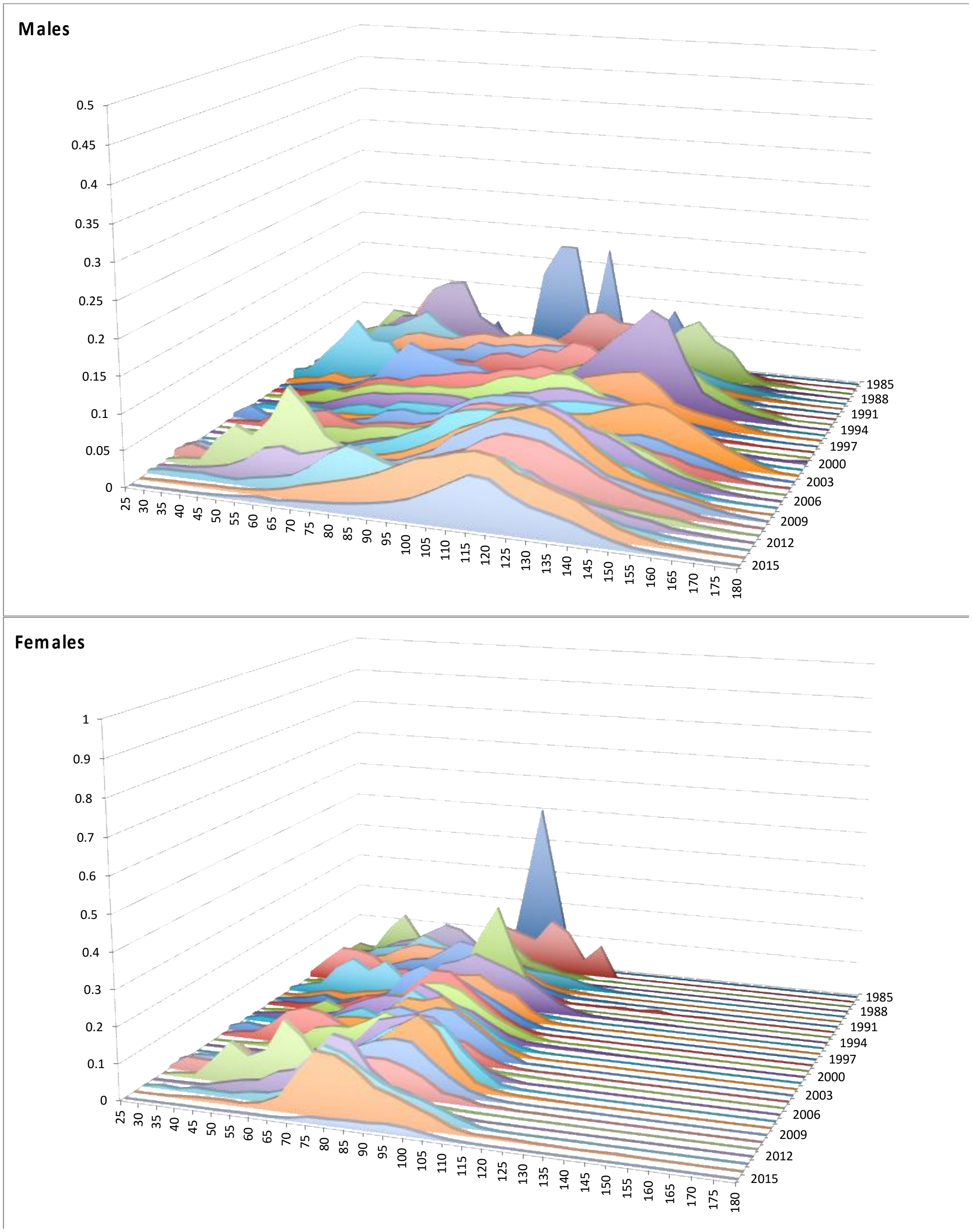


Figure 12. Normalized Tanner crab bycatch size compositions in the groundfish fisheries, from groundfish observer sampling. Size compositions have been normalized to sum to 1 for each year.

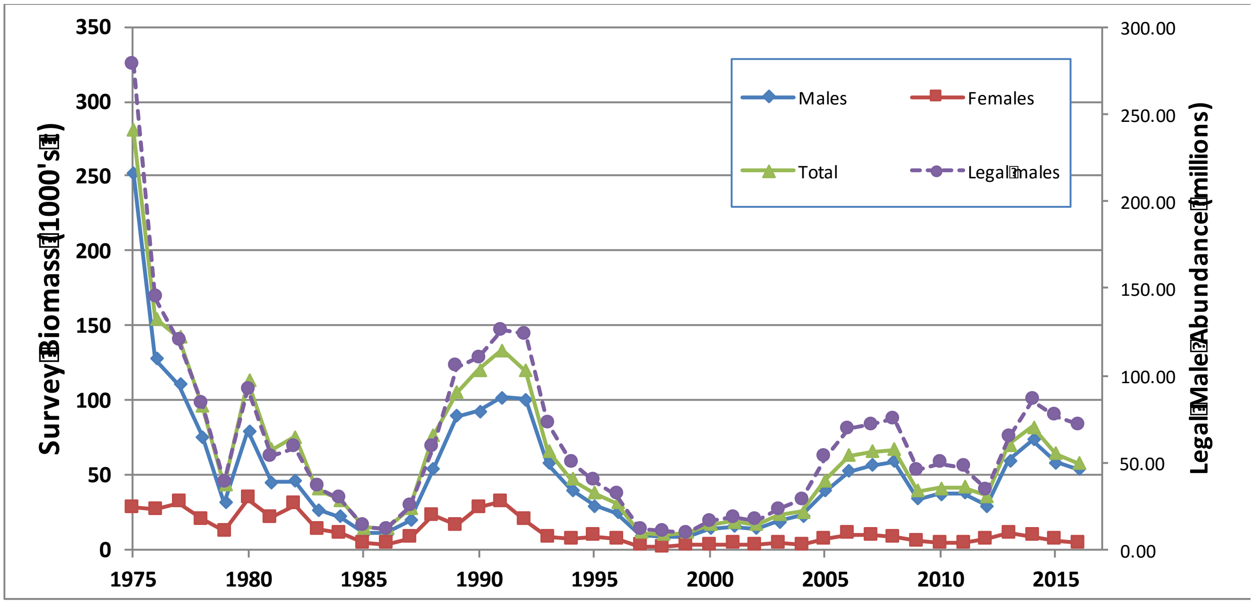


Figure 13. Trends in survey biomass for mature male and female Tanner crab, and in abundance for legal males, based on the NMFS EBS bottom trawl survey.

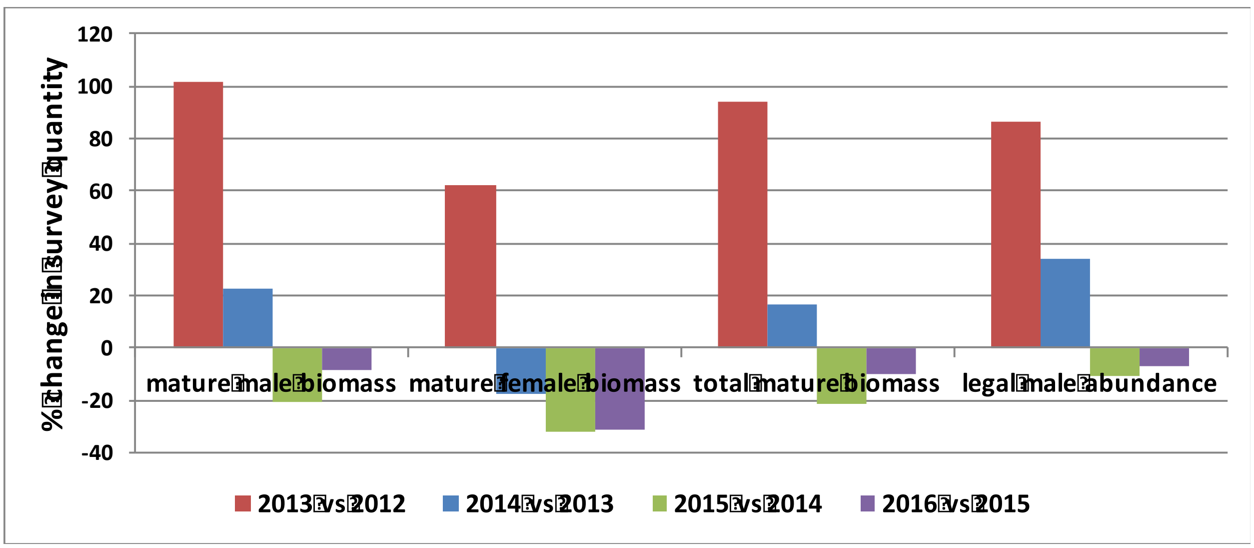


Figure 14. Percent change in mature male biomass, mature female biomass, total mature biomass and abundance of legal crab observed in the NMFS bottom trawl survey during the past 4 surveys.

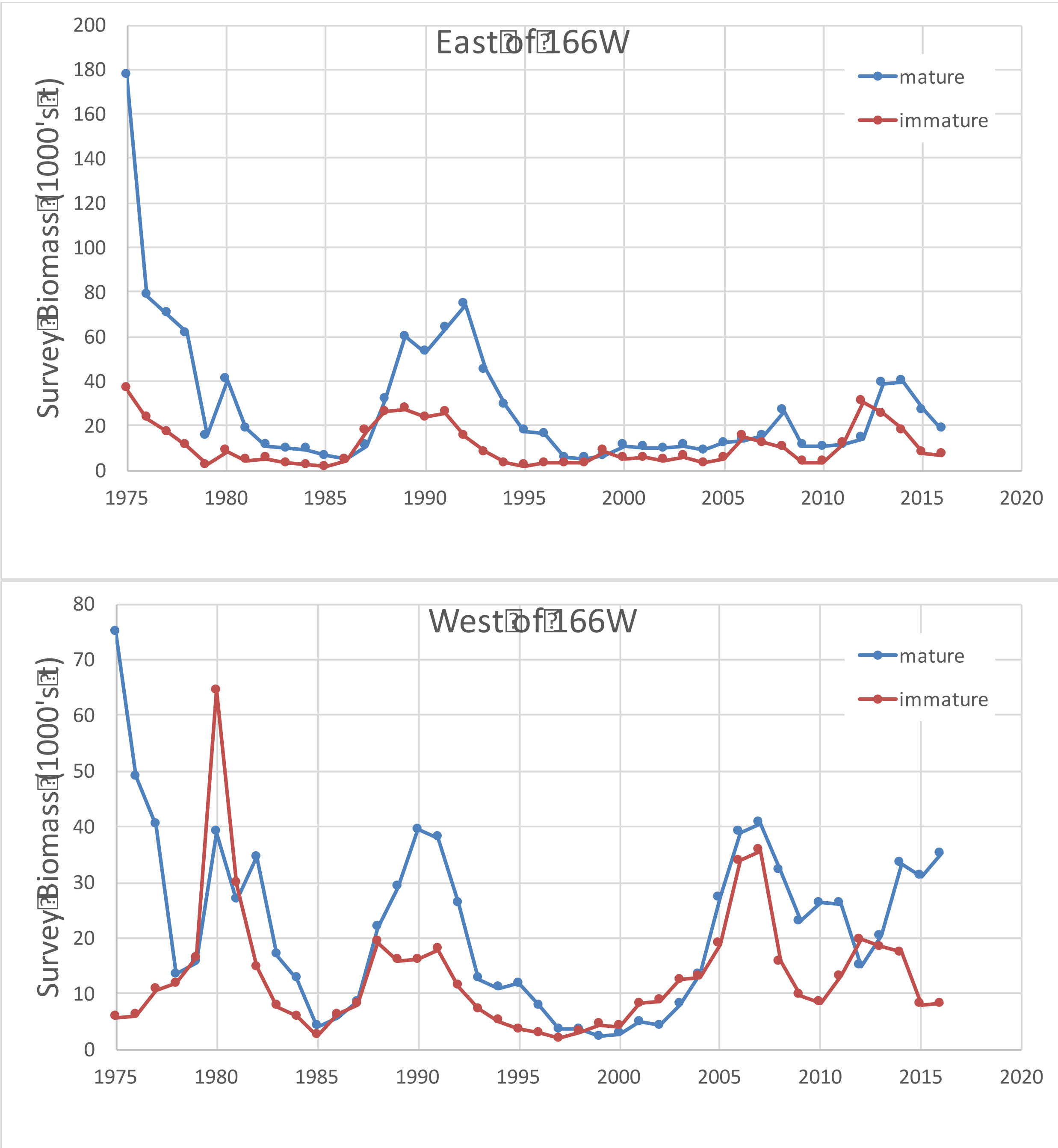


Figure 15. Trends in survey biomass for male Tanner crab in areas east and west of 166°W longitude, based on the NMFS EBS bottom trawl survey.

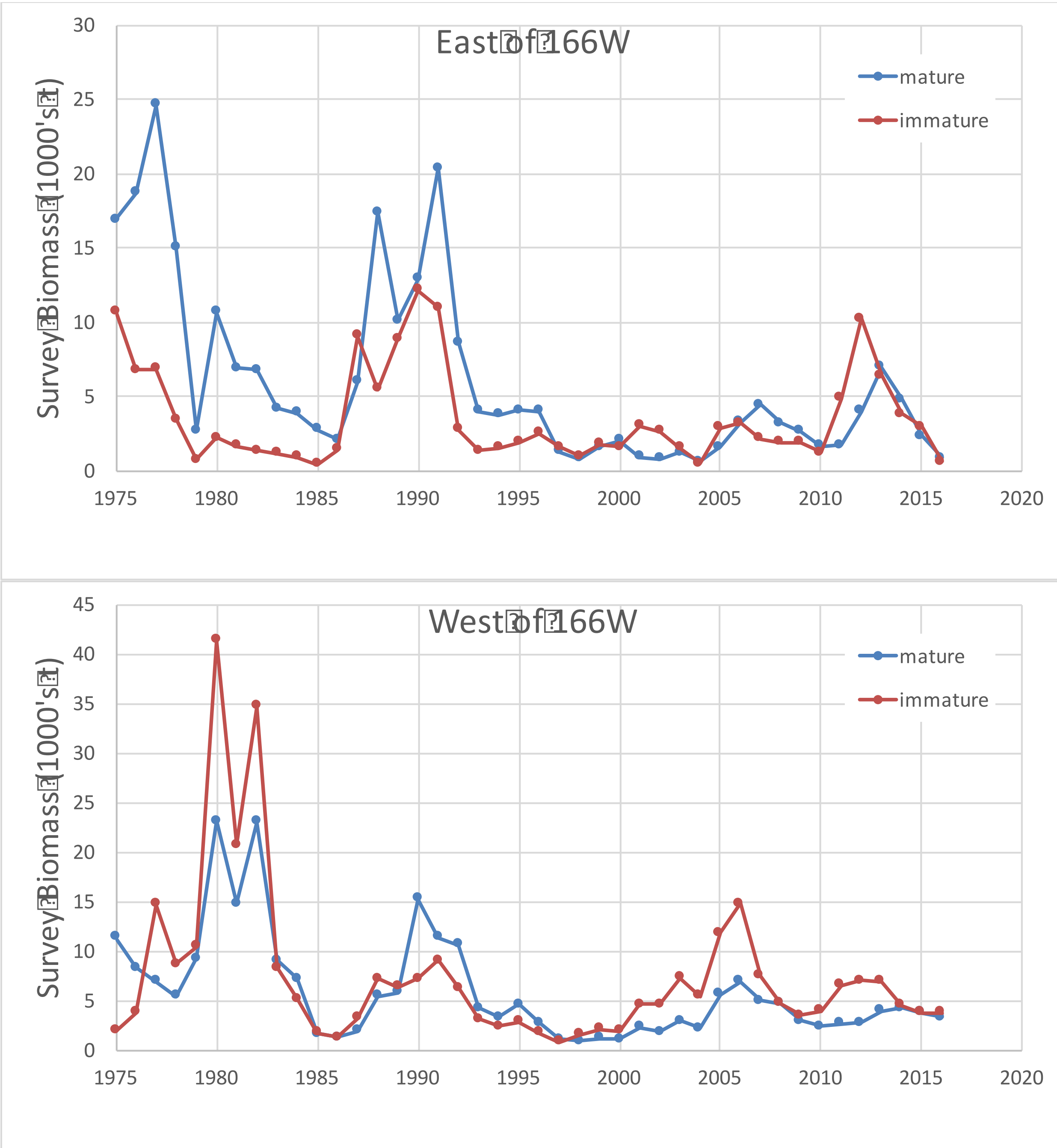


Figure 16. Trends in survey biomass for female Tanner crab in areas east and west of 166ºW longitude, based on the NMFS EBS bottom trawl survey.

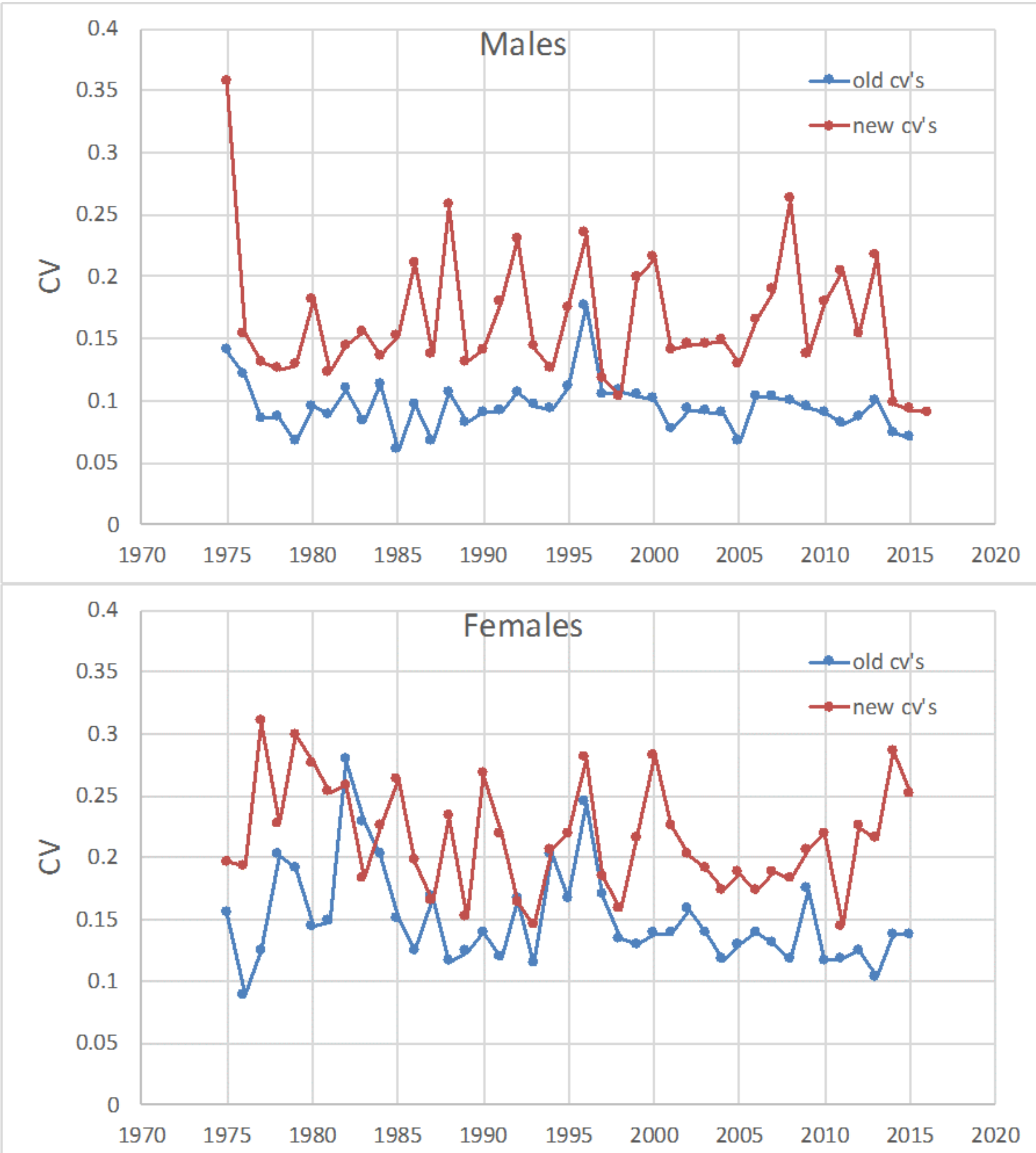


Figure 17. Comparison of cv's for mature survey biomass using the "new" and "old" approaches.

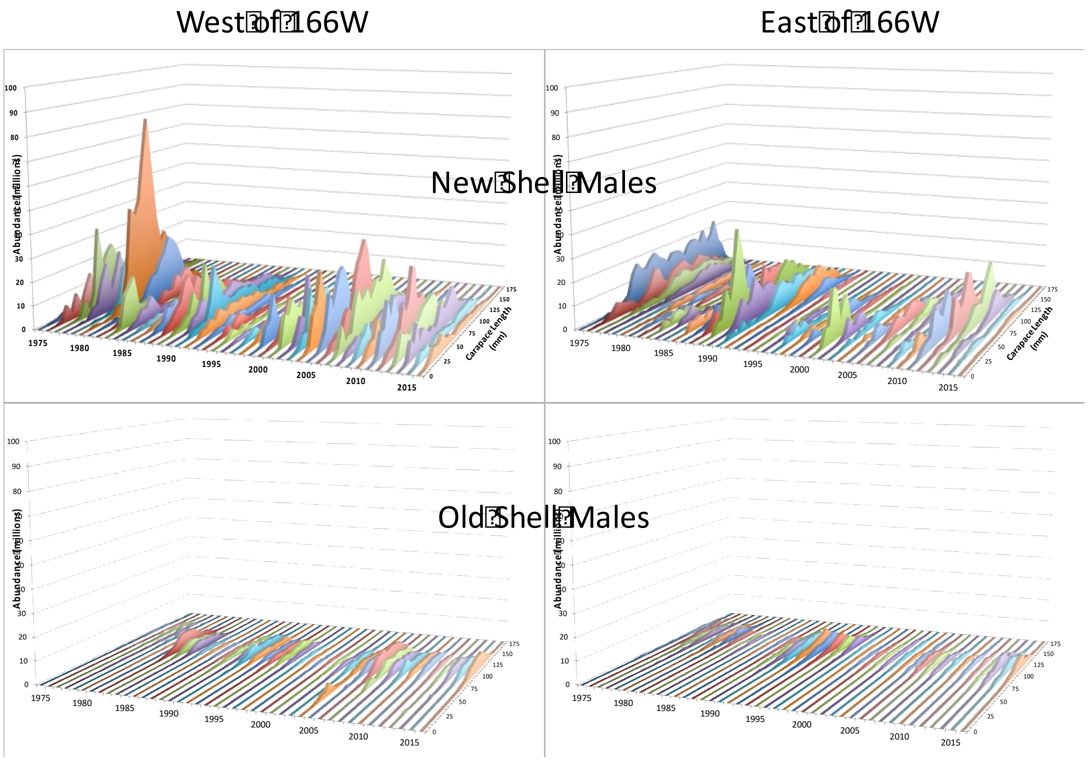


Figure 18. Numbers at size (millions) by area and shell condition for male Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW.

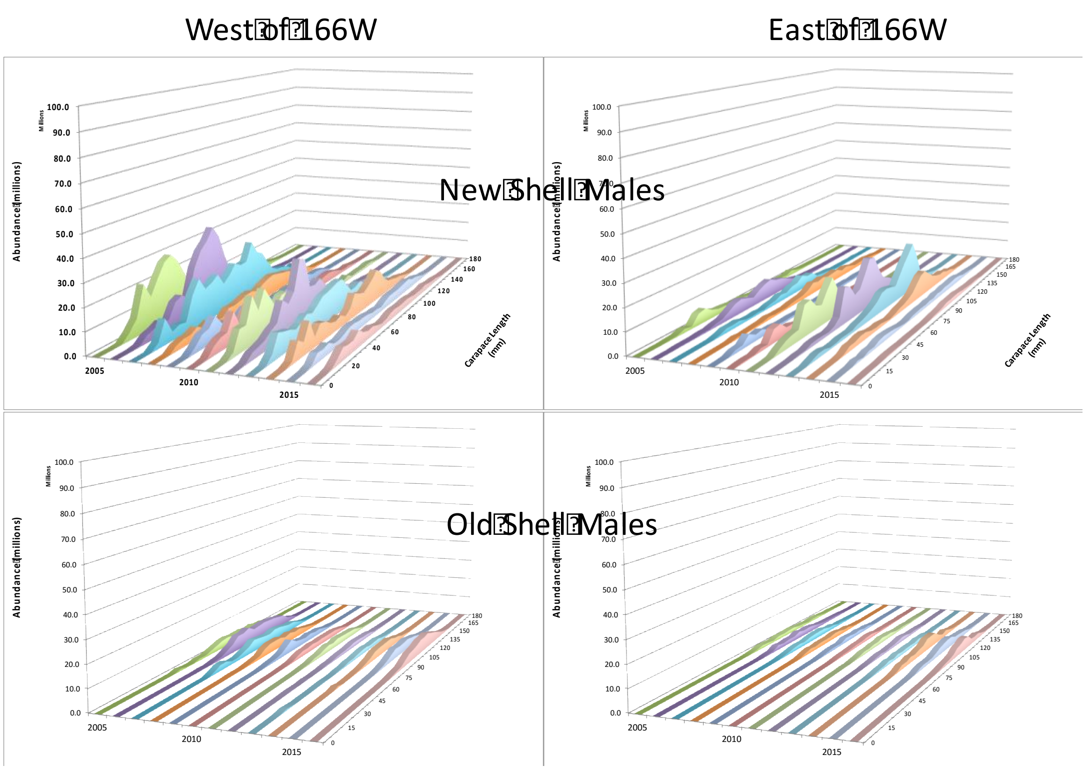


Figure 19. Numbers at size (millions) by area and shell condition for male Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW, since 2005.

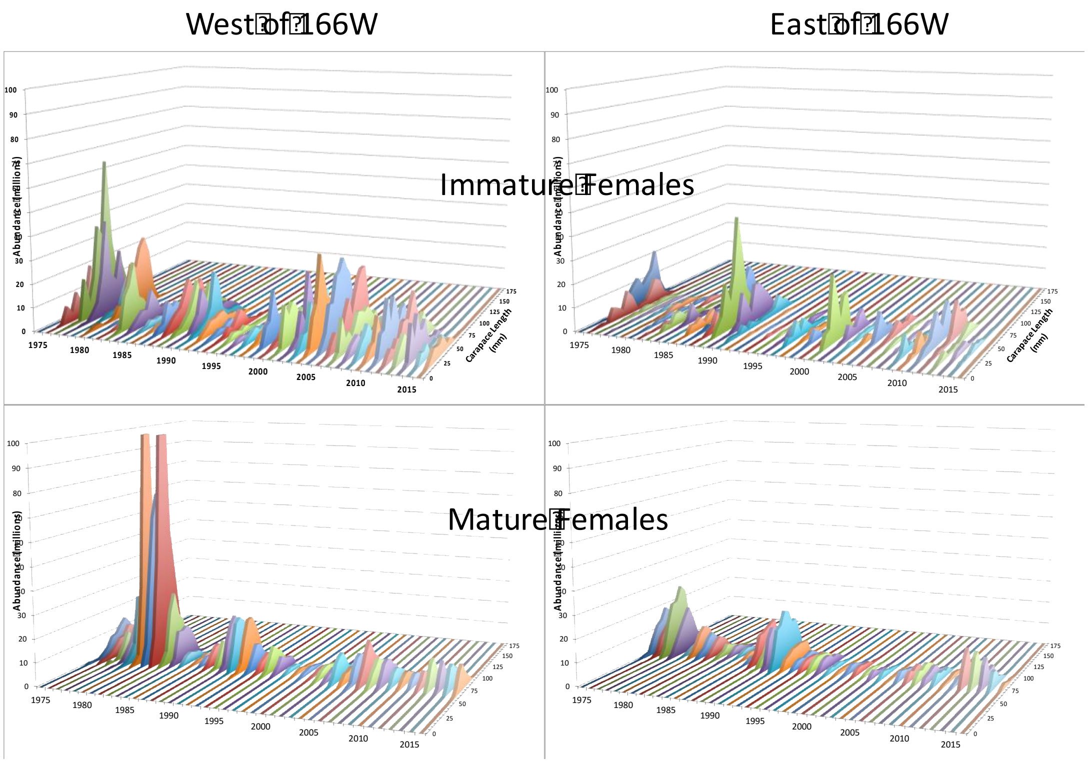


Figure 20. Numbers at size (millions) by area and shell condition for female Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW.

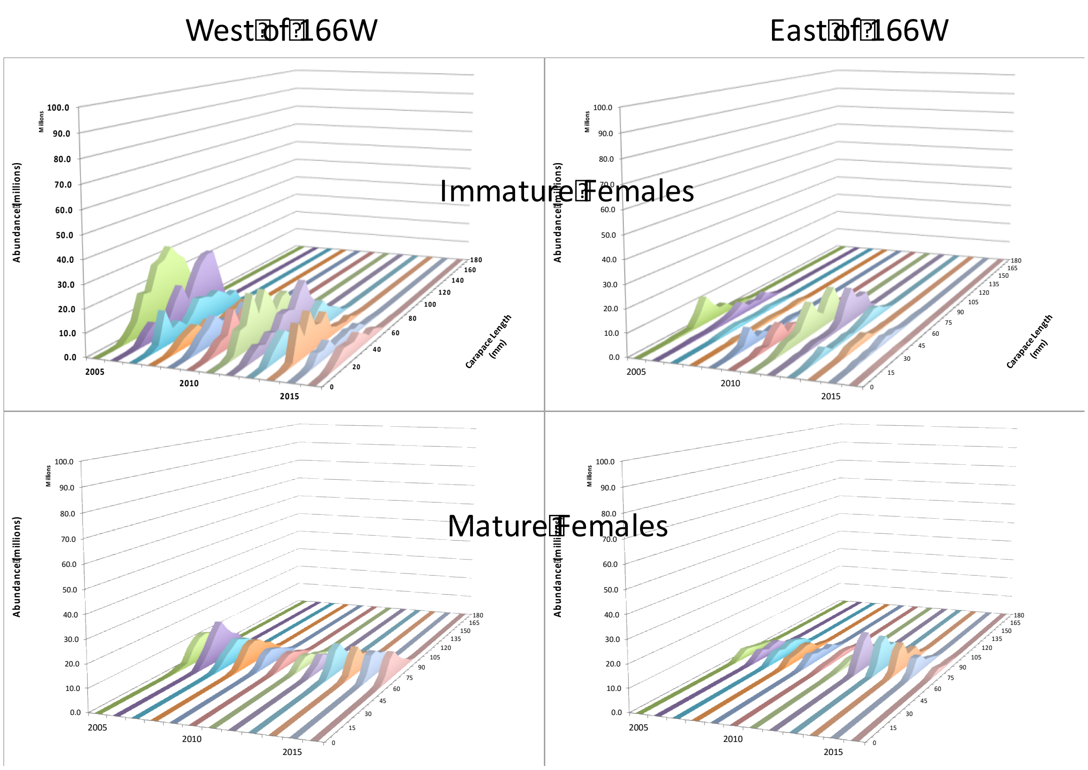


Figure 21. Numbers at size (millions) by area and shell condition for female Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW, since 2005.

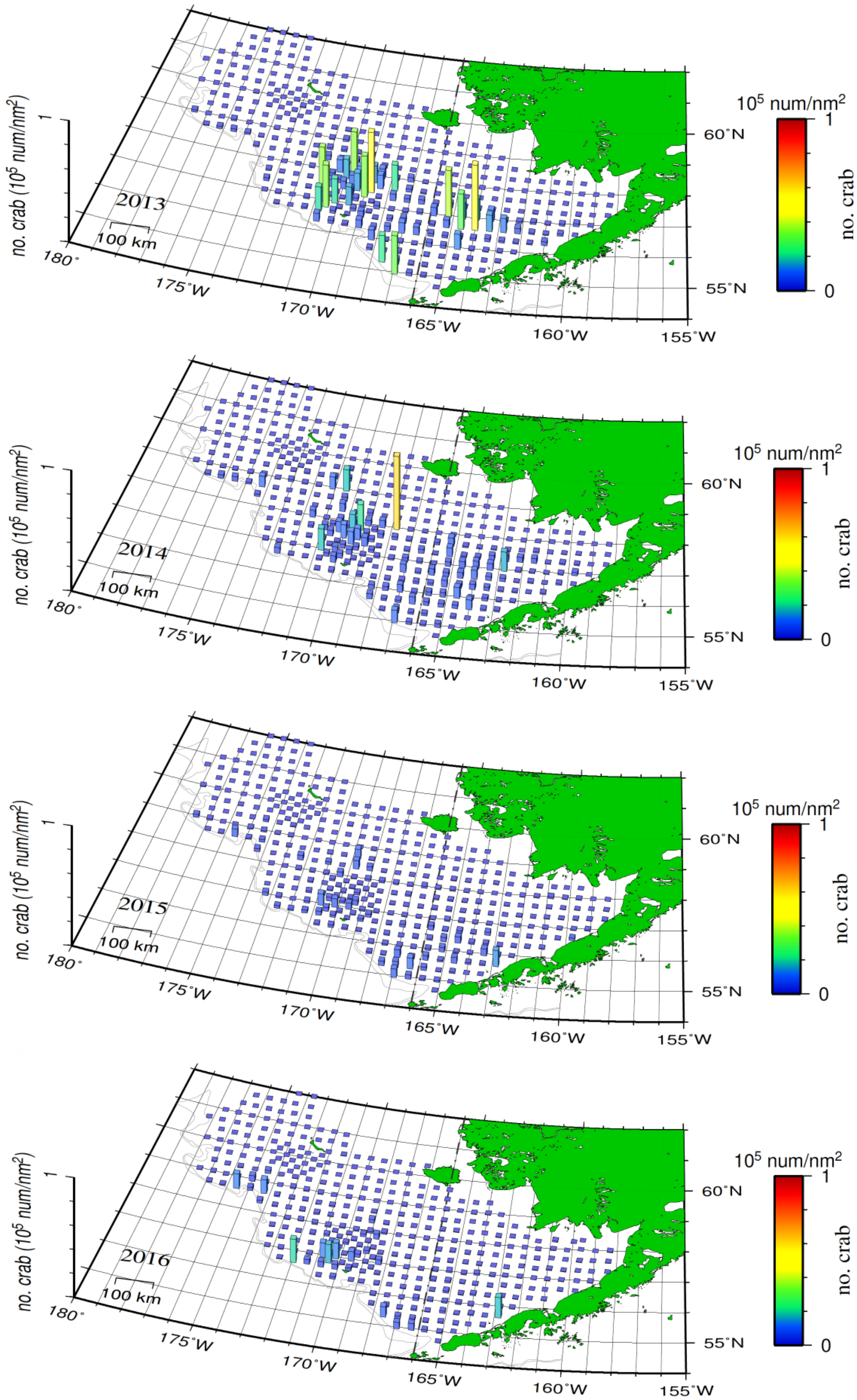


Figure 22. Distribution of immature males (number/ sq. nm) in the summer trawl survey for 2013-16.

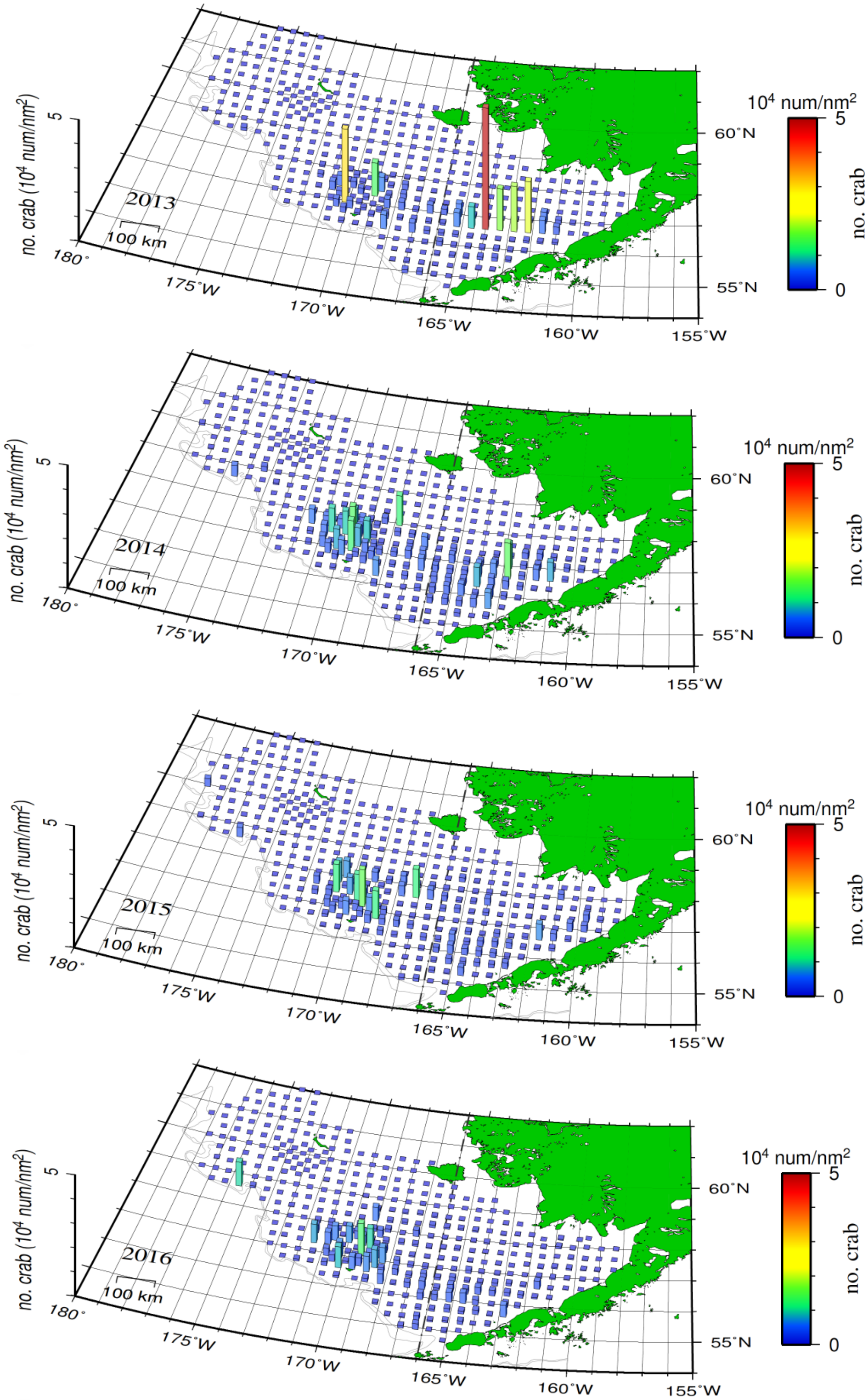


Figure 23. Distribution of mature males (number/ sq. nm) in the summer trawl survey for 2013-16.

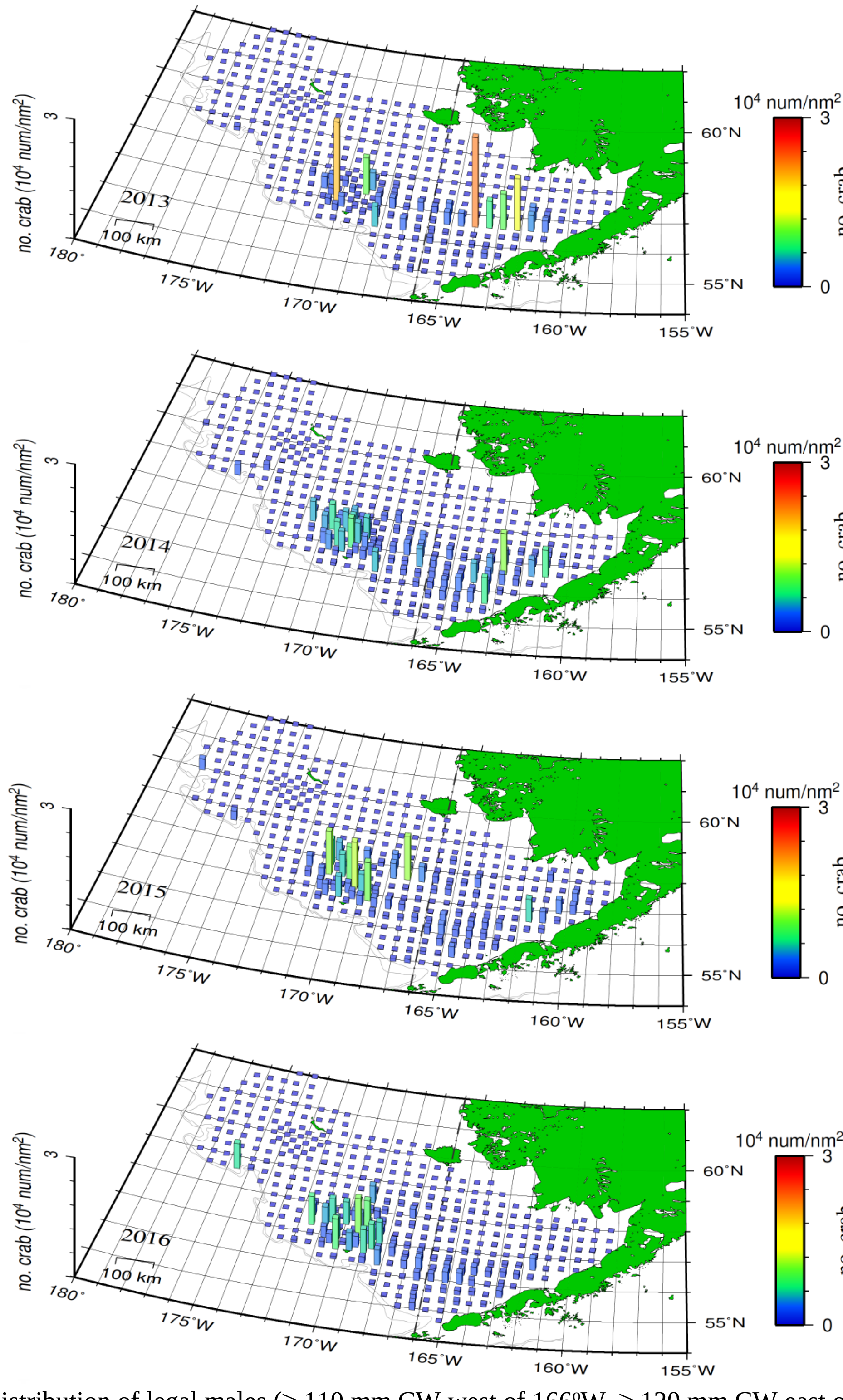


Figure 24. Distribution of legal males (≥ 110 mm CW west of 166°W, ≥ 120 mm CW east of 166°W; number/ sq. nm) in the summer trawl survey for 2013-16.

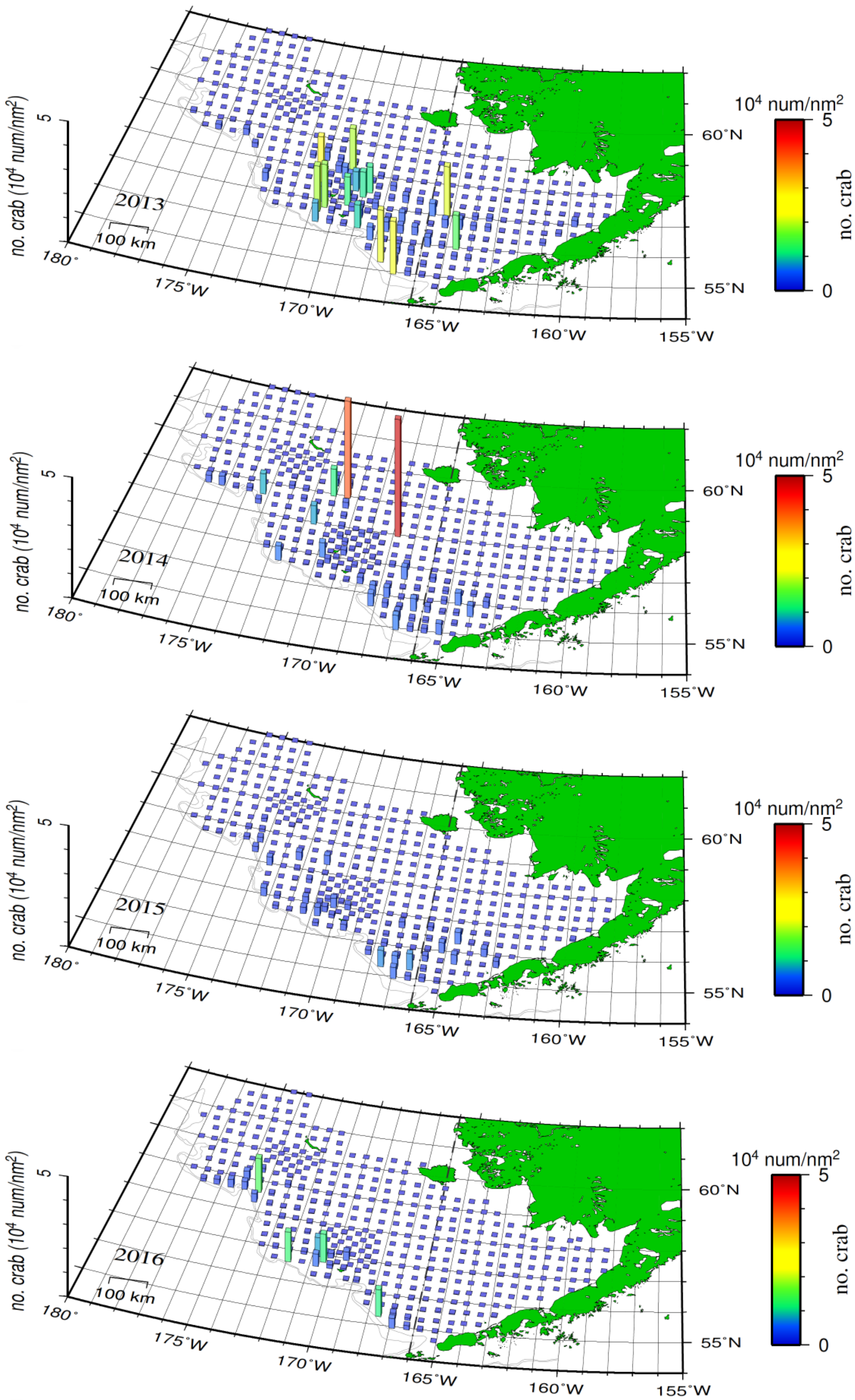


Figure 25. Distribution of immature females (number/ sq. nm) in the summer trawl survey for 2013-16.

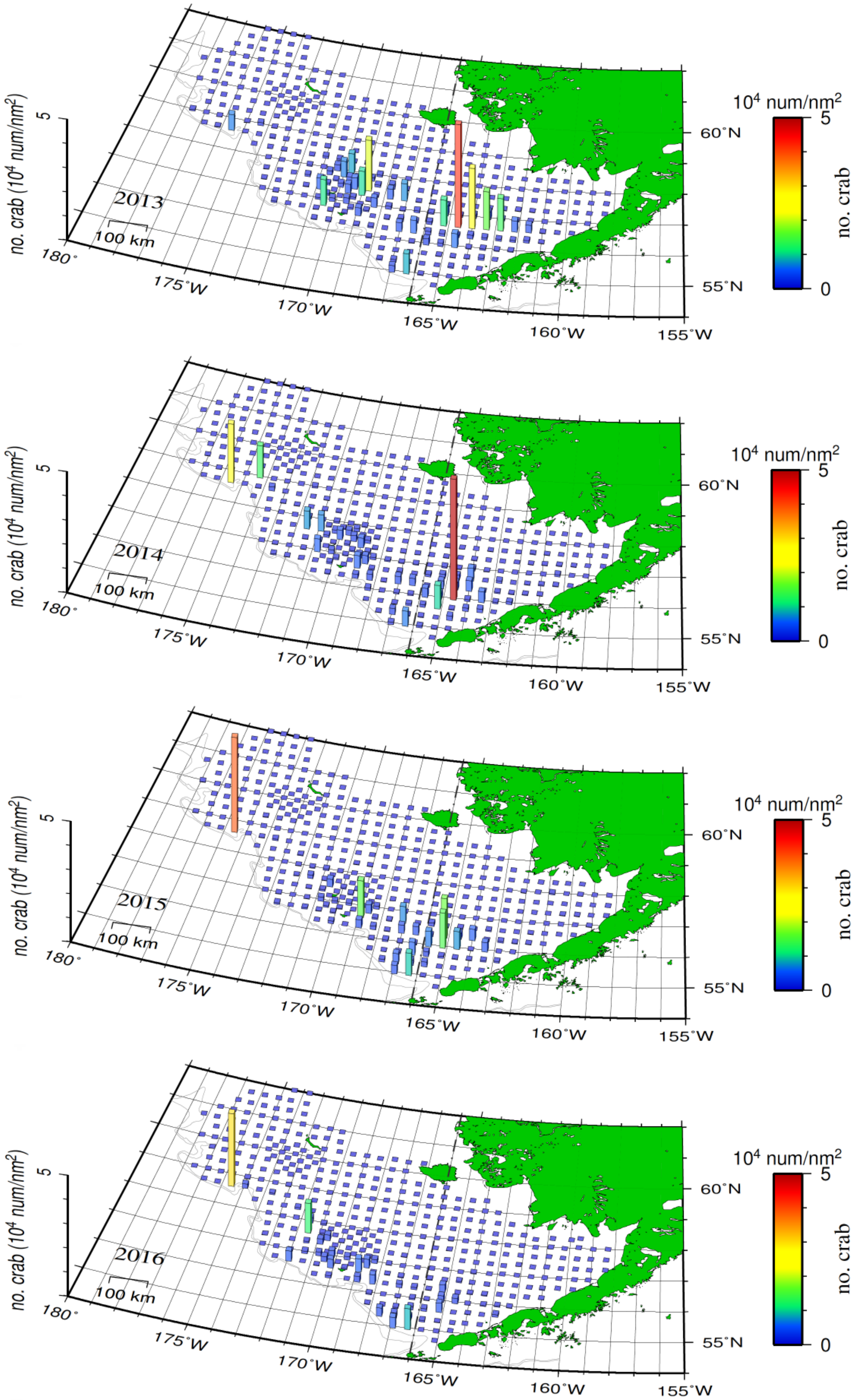


Figure 26. Distribution of mature females (number/ sq. nm) in the summer trawl survey for 2013-16.

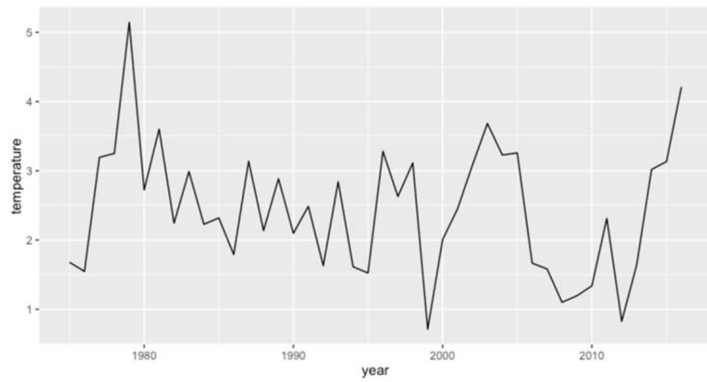


Figure 27. Average bottom temperatures (°C) in the NMFS EBS summer trawl survey for 1975-2016.

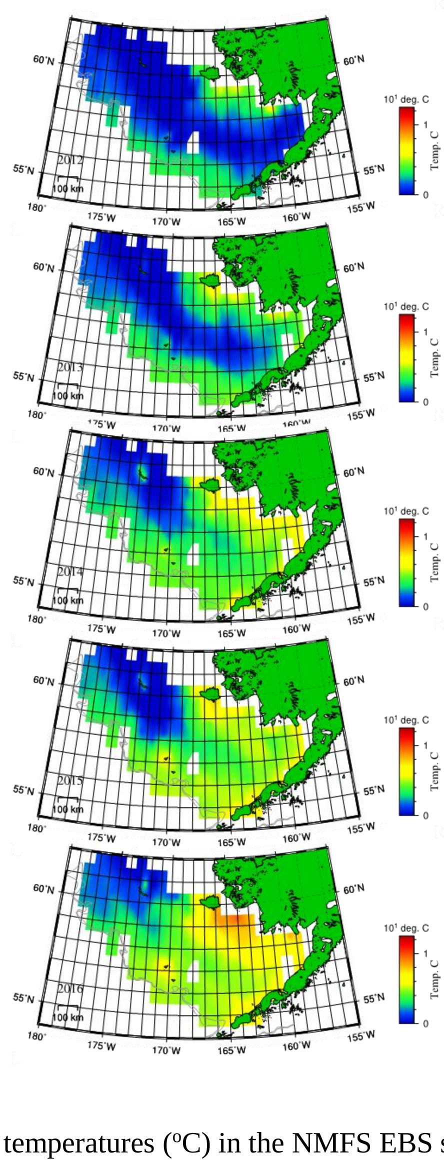


Figure 28. Distribution of bottom temperatures (°C) in the NMFS EBS summer trawl survey for 2012-16.

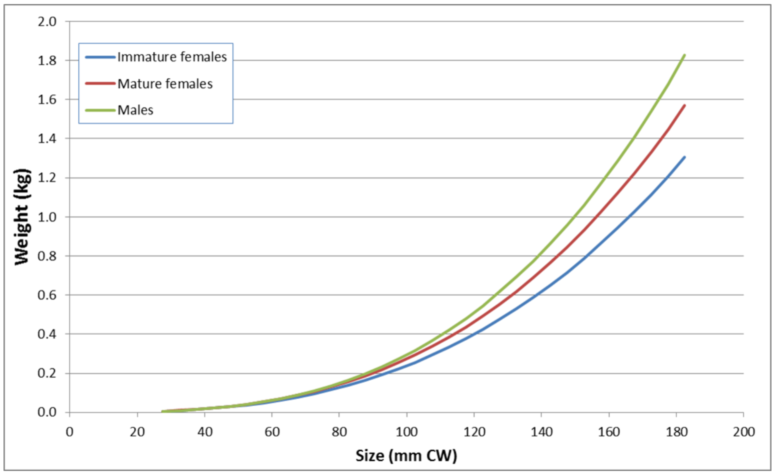


Figure 29. Size-weight relationships developed from NMFS EBS summer trawl survey data.

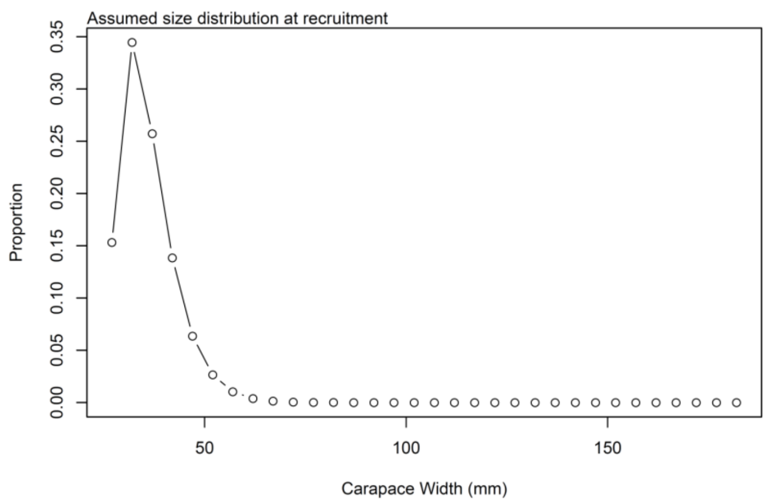


Figure 30. Assumed size distribution for recruits entering the population.

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

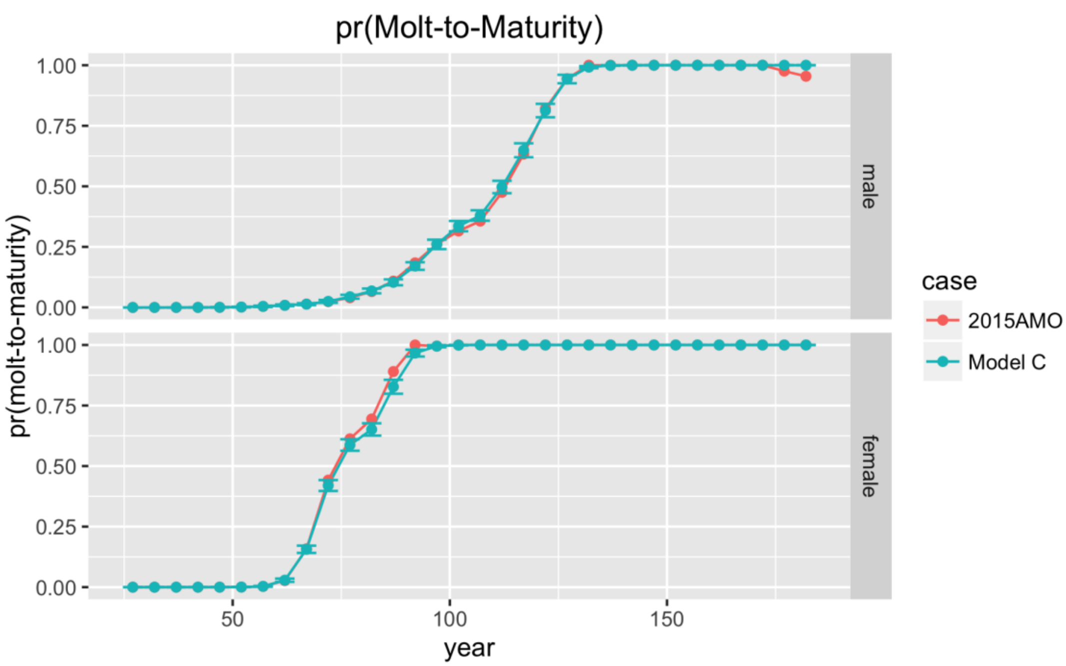


Figure 32. Estimated sex and size-specific probabilities of terminal molt-to-maturity from the 2015 assessment (2015AMO) and the author's preferred model (Model C).

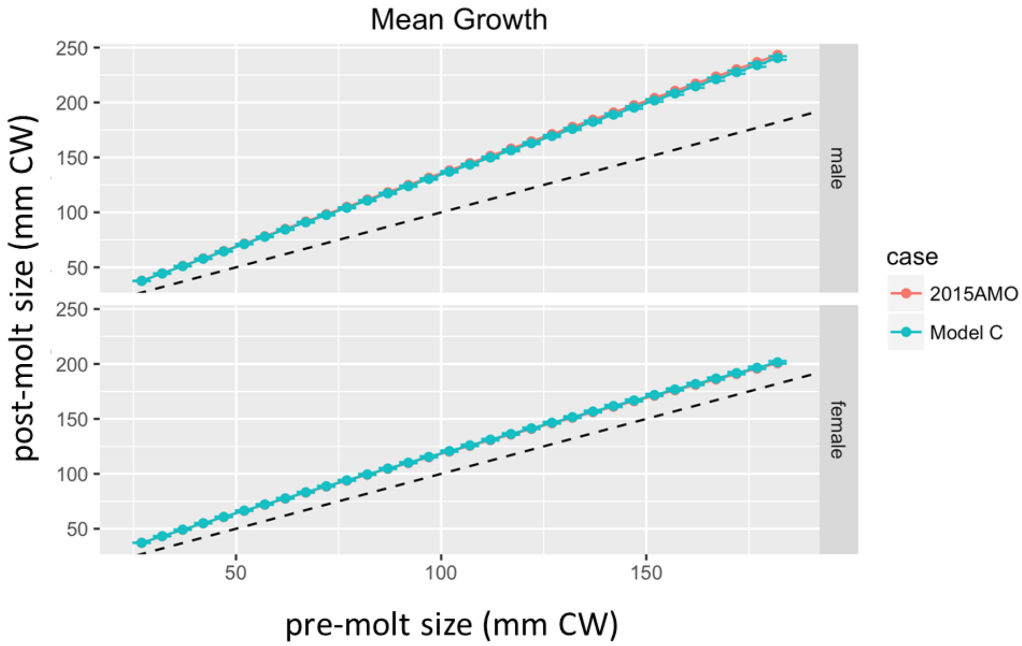


Figure 33. Estimated mean post-molt size, as a function of pre-molt size, from the 2015 assessment (2015AMO) and the author's preferred model (Model C).

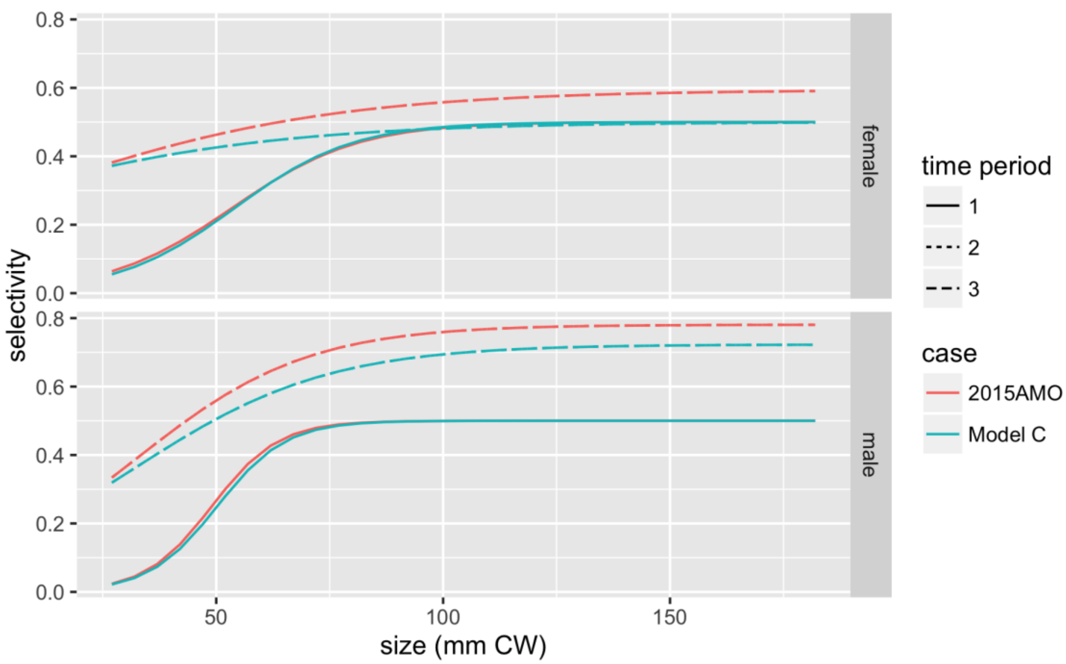


Figure 34. Estimated survey selectivity functions from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Time periods: 1) pre-1982, 2) 1982-1986, 3) 1987-present.

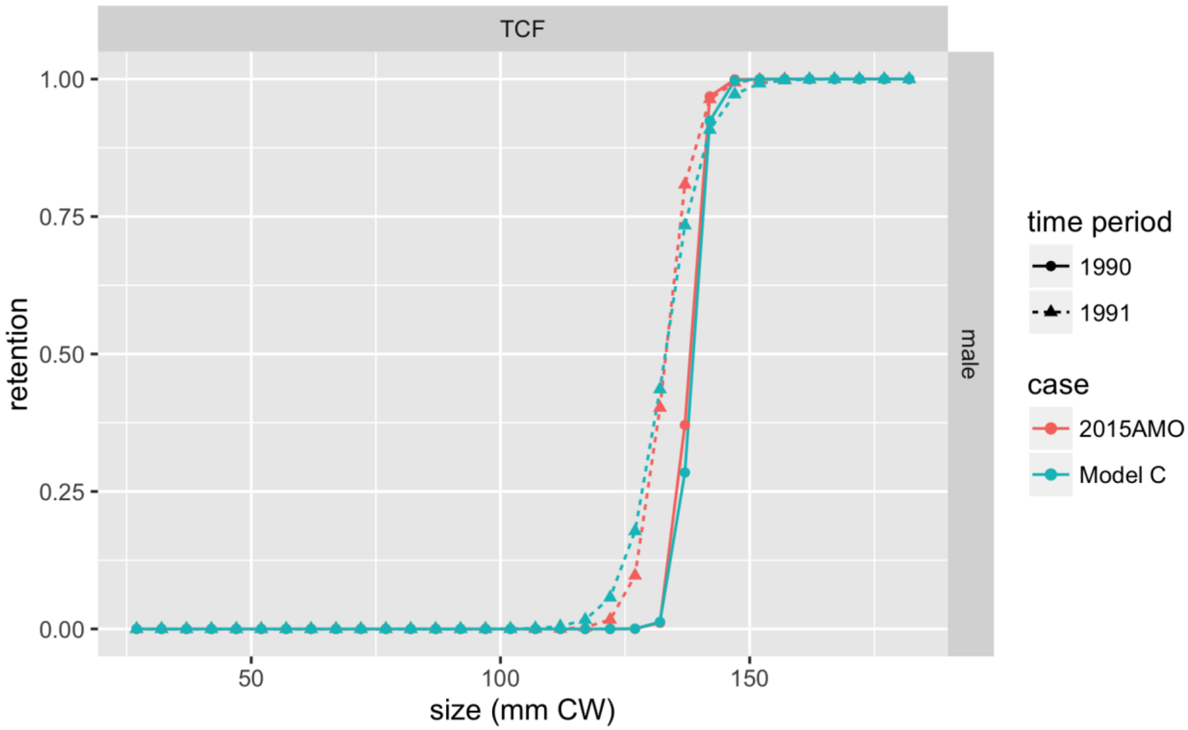


Figure 35. Estimated retention functions from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Time periods: 1) 1974-1981, 2) 1982-1986, 3) 1987-present.

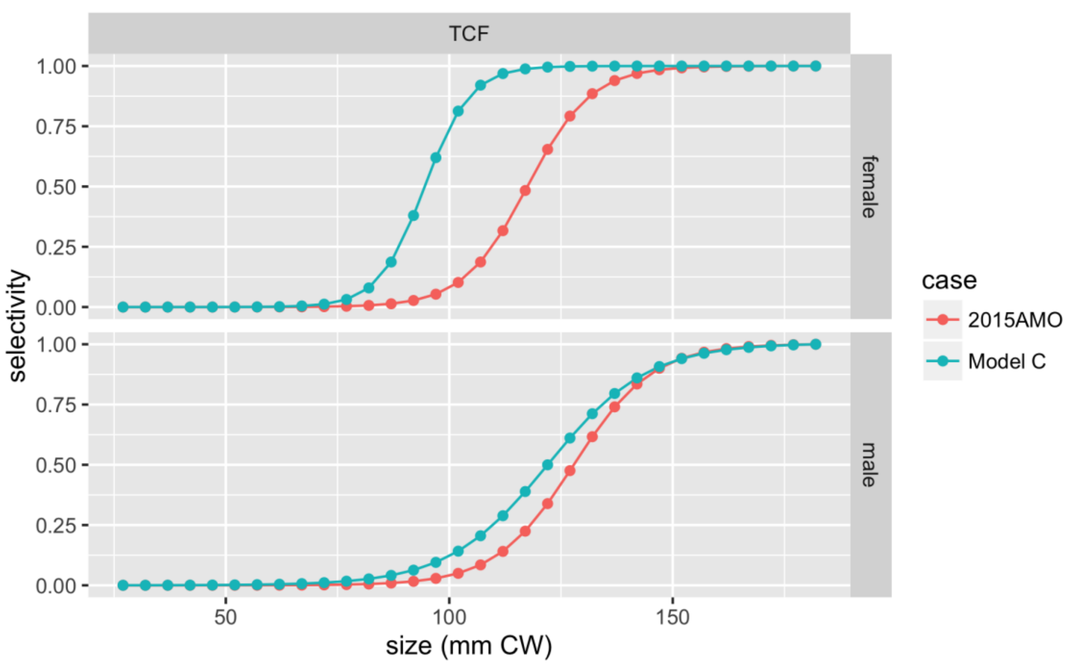


Figure 36. Estimated selectivity functions in the directed fishery from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Time periods: females-entire model period, males-pre-1991.

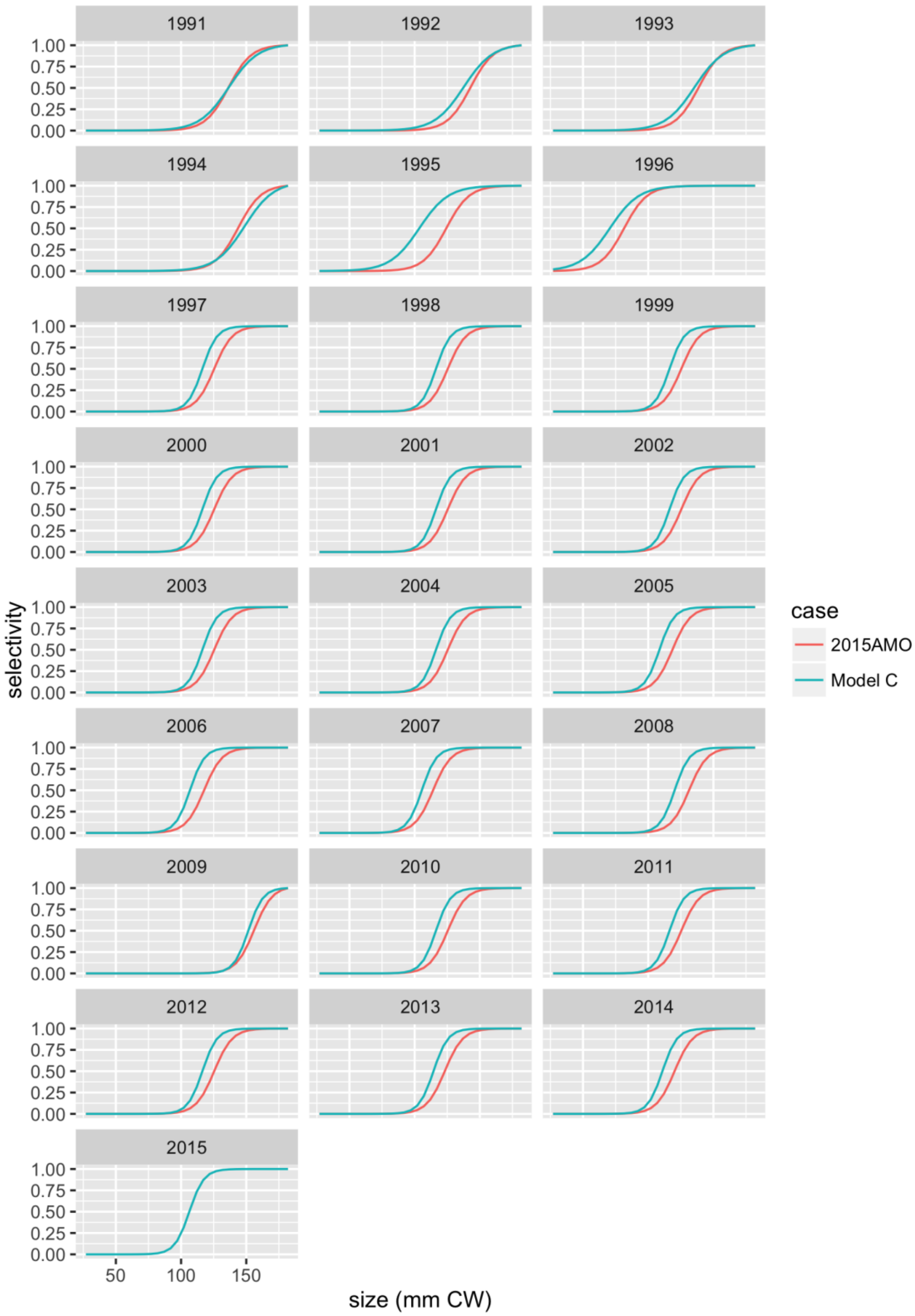


Figure 37. Estimated male selectivity functions in the directed fishery from the 2015 assessment (2015AMO) and the author's preferred model (Model C) during 1991-present.

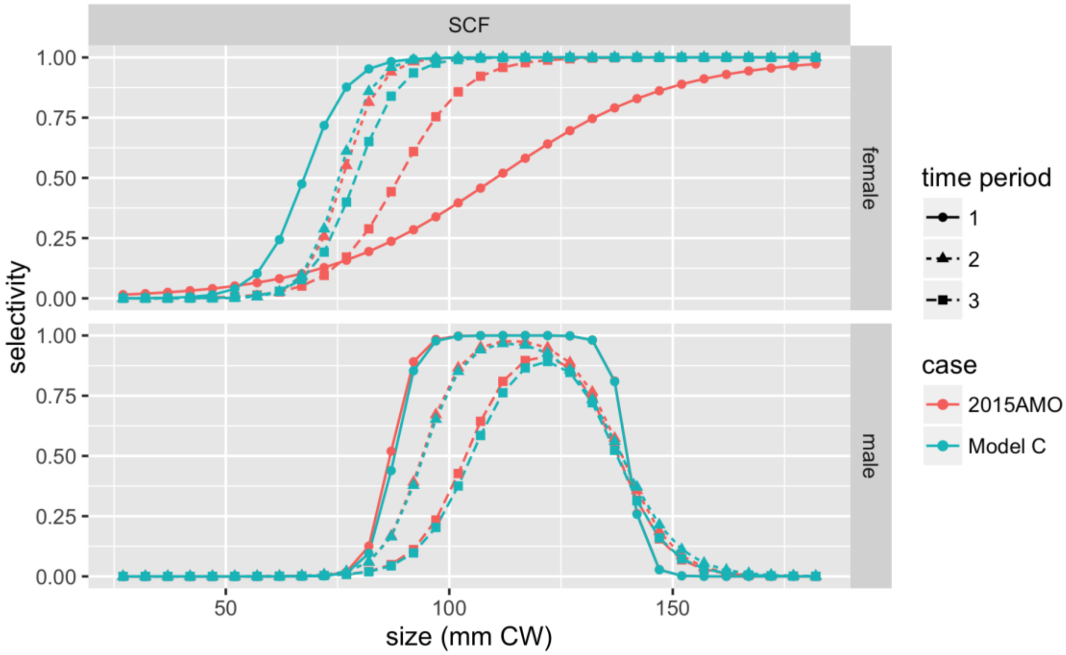


Figure 38. Estimated bycatch selectivity functions in the snow crab fishery (SCF) from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Time periods: 1) pre-1997, 2) 1997-2004, 3) 2005-present.

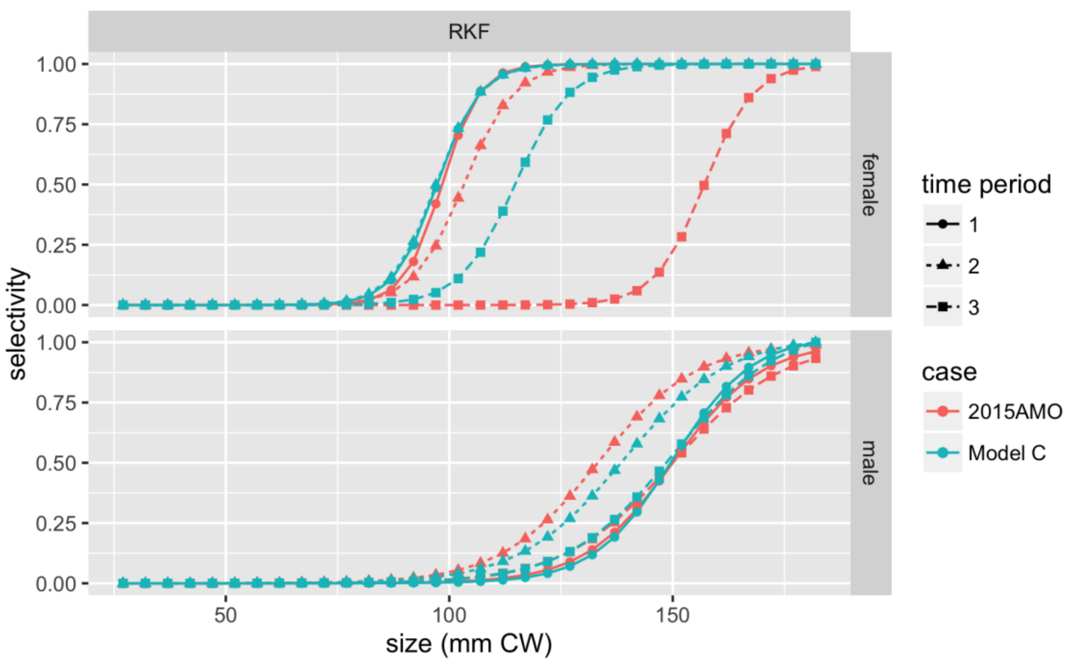


Figure 39. Estimated bycatch selectivity functions in the BBRKC fishery (RKC) from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Time periods: 1) pre-1997, 2) 1997-2004, 3) 2005-present.

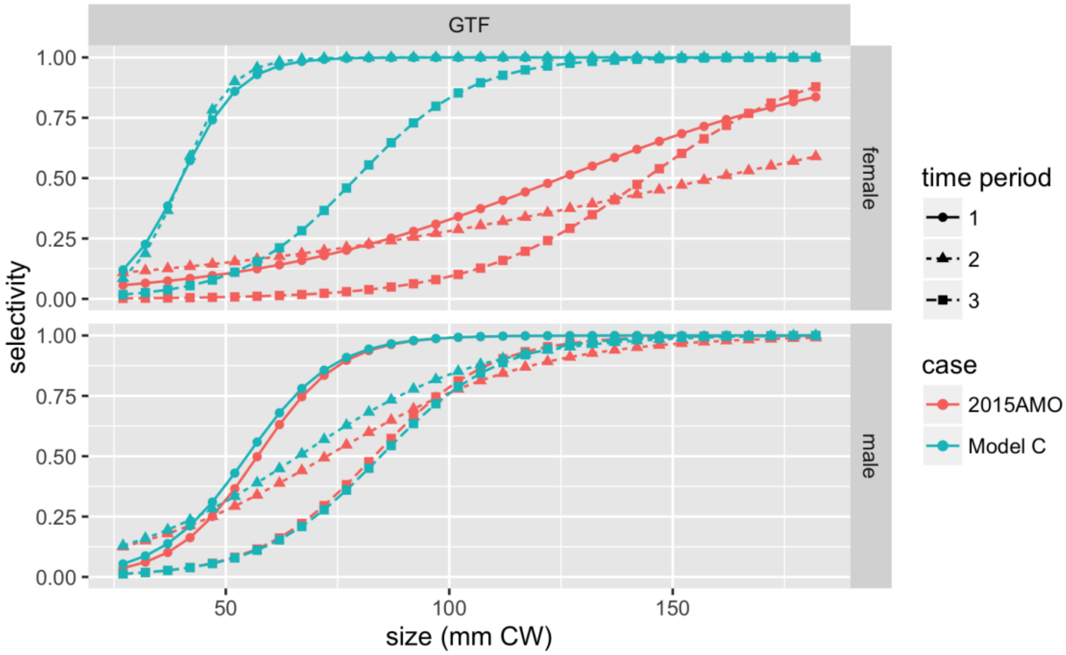


Figure 40. Estimated bycatch selectivity functions in the groundfish fisheries (GTF) from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Time periods: 1) pre-1988, 2) 1988-1996, 3) 1997-present.

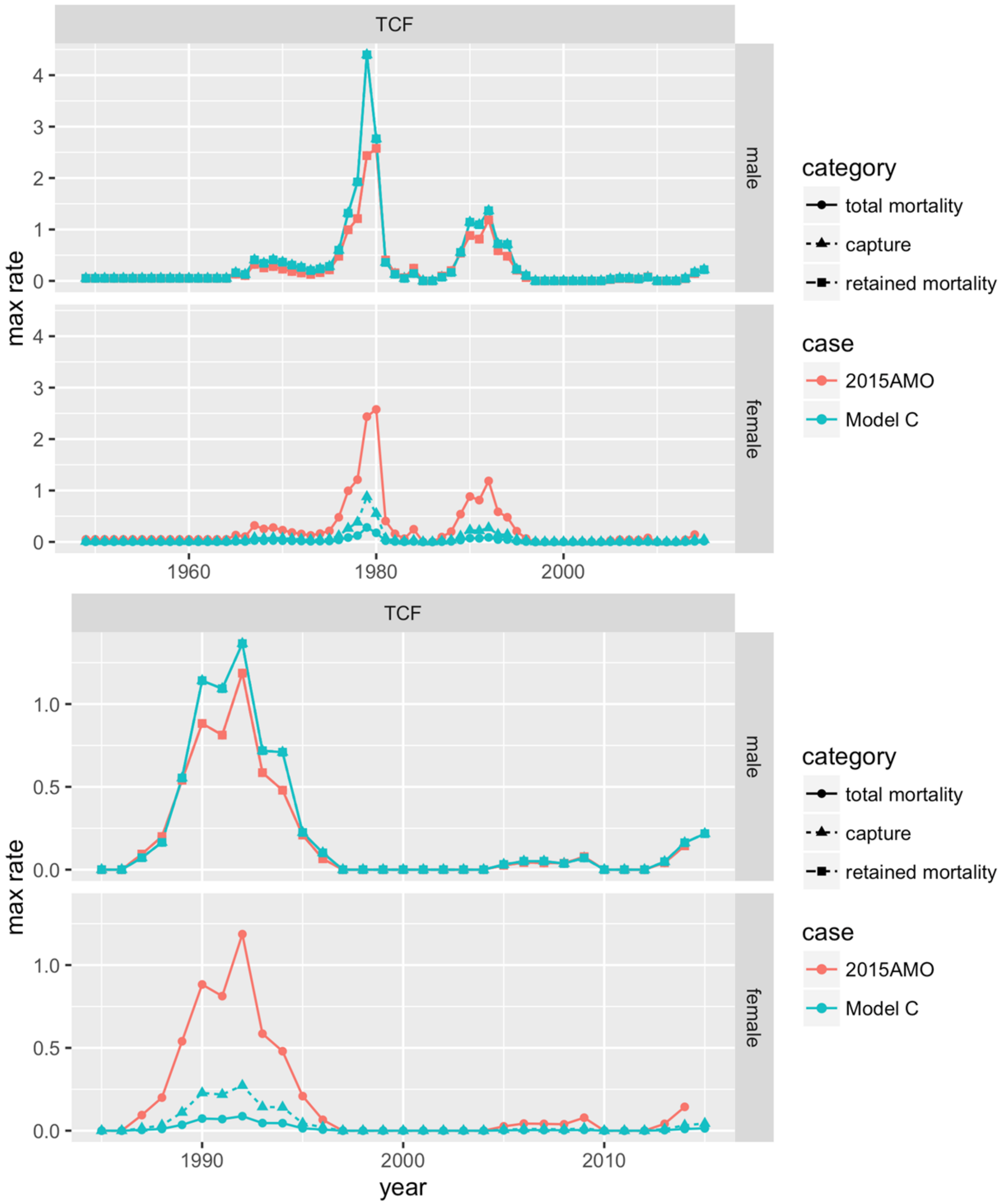


Figure 41. Estimated full selection fishing mortality from the 2015 assessment (2015AMO) and fishery capture rate from the author's preferred model (Model C) for the directed Tanner crab fishery (TCF). Lower plot is zoomed to 1985-2015. For males, fully-selected capture, retained and total mortality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

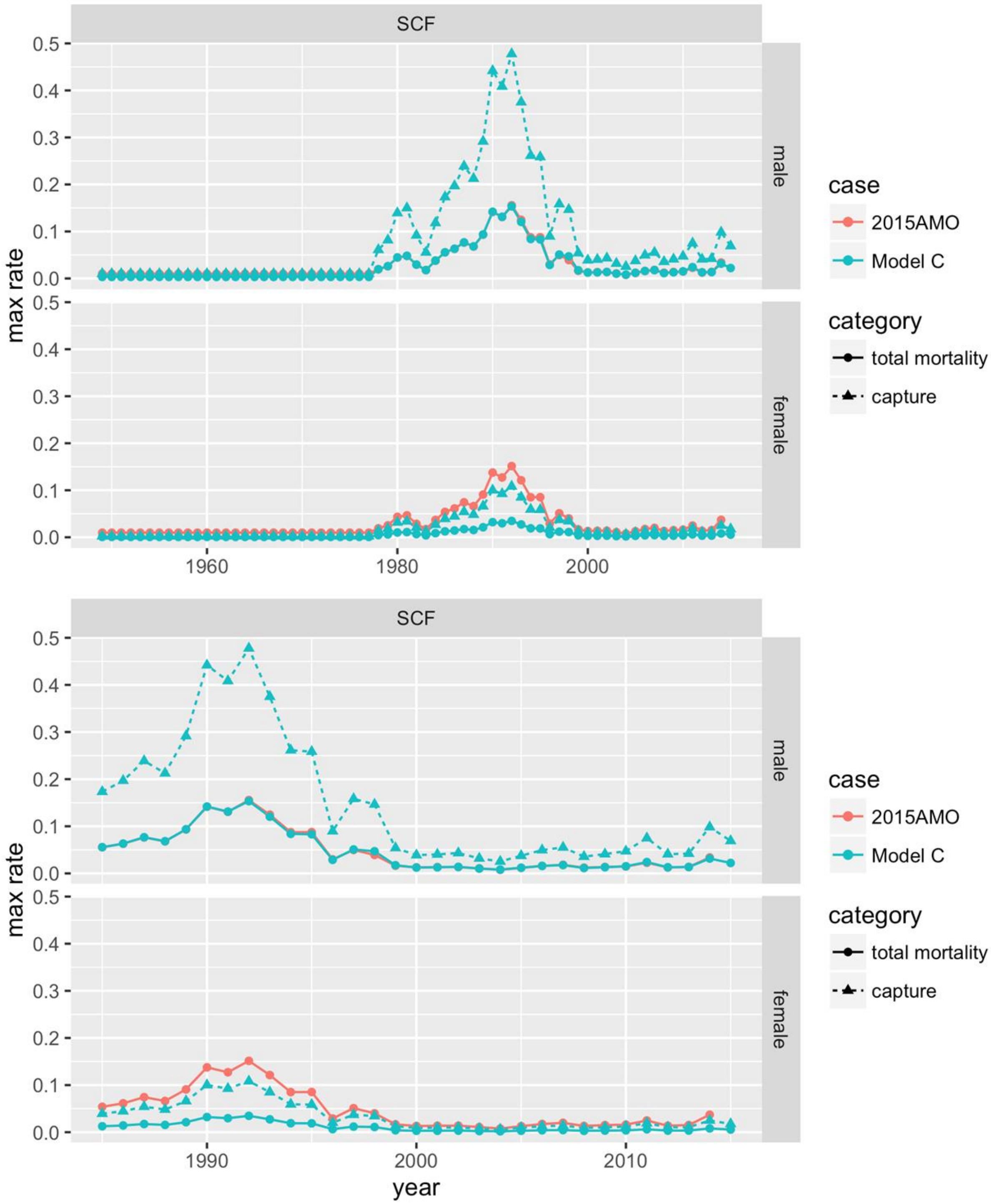
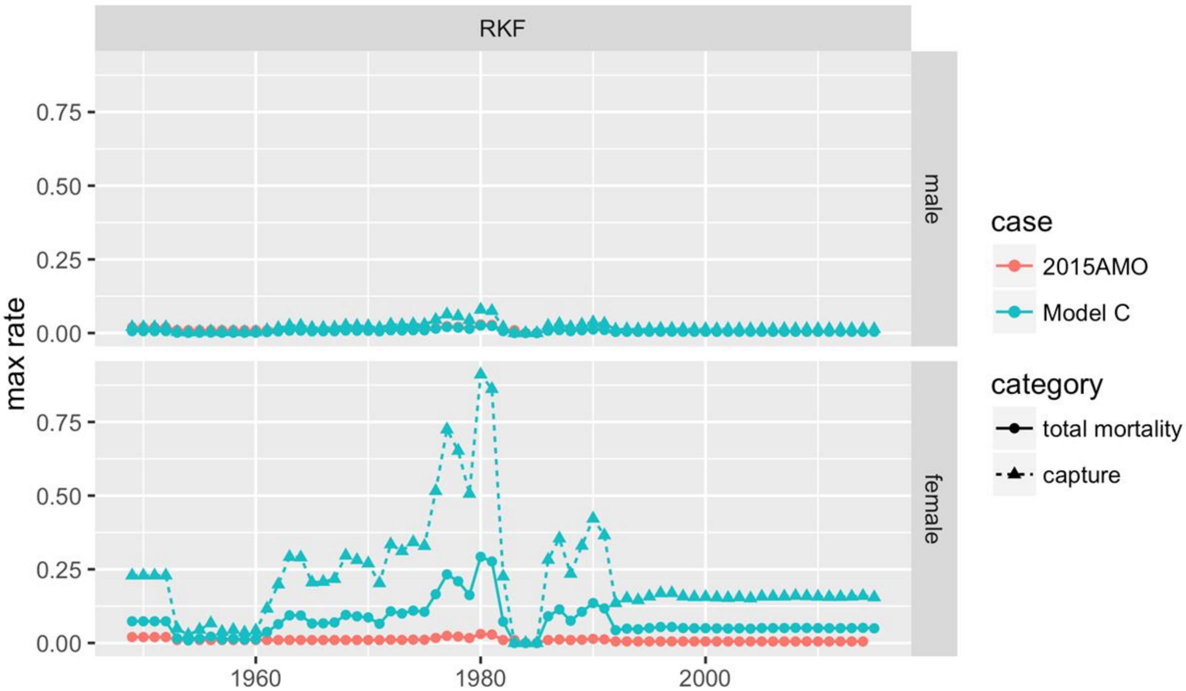


Figure 42. Estimated full selection fishing mortality from the 2015 assessment (2015AMO) and fishery capture rate from the author's preferred model (Model C) for the snow crab fishery (SCF). Lower plot is zoomed to 1985-2015.



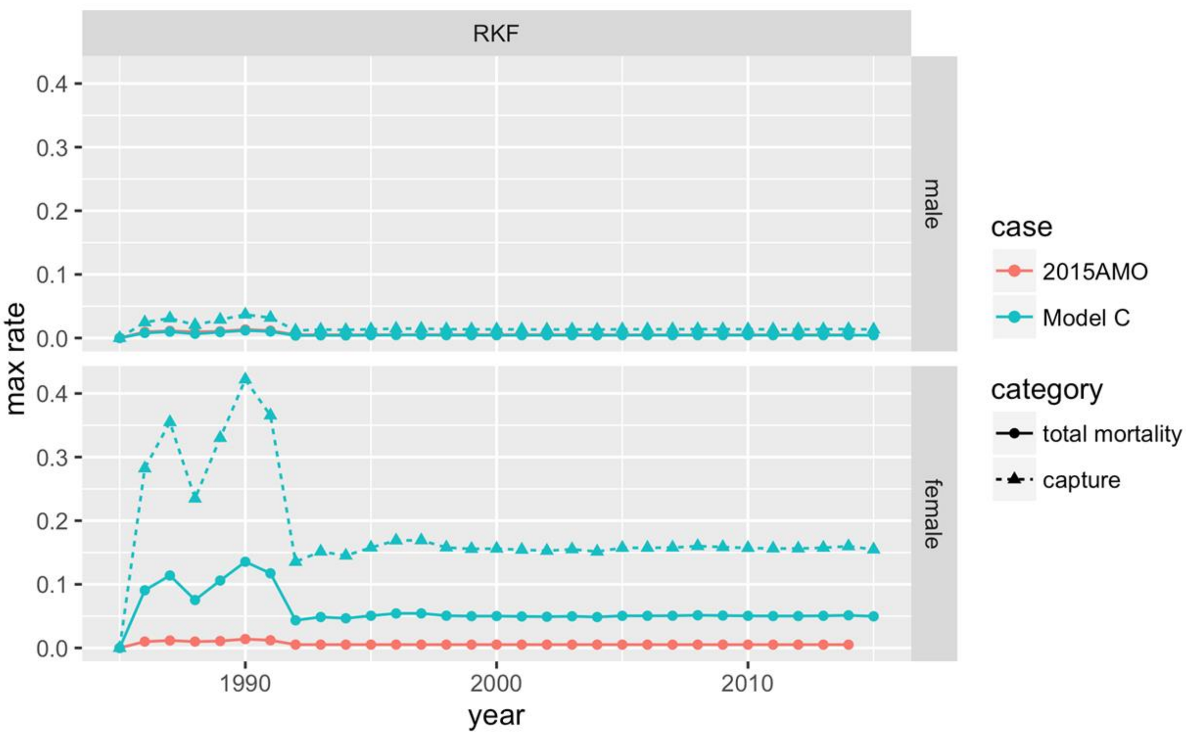
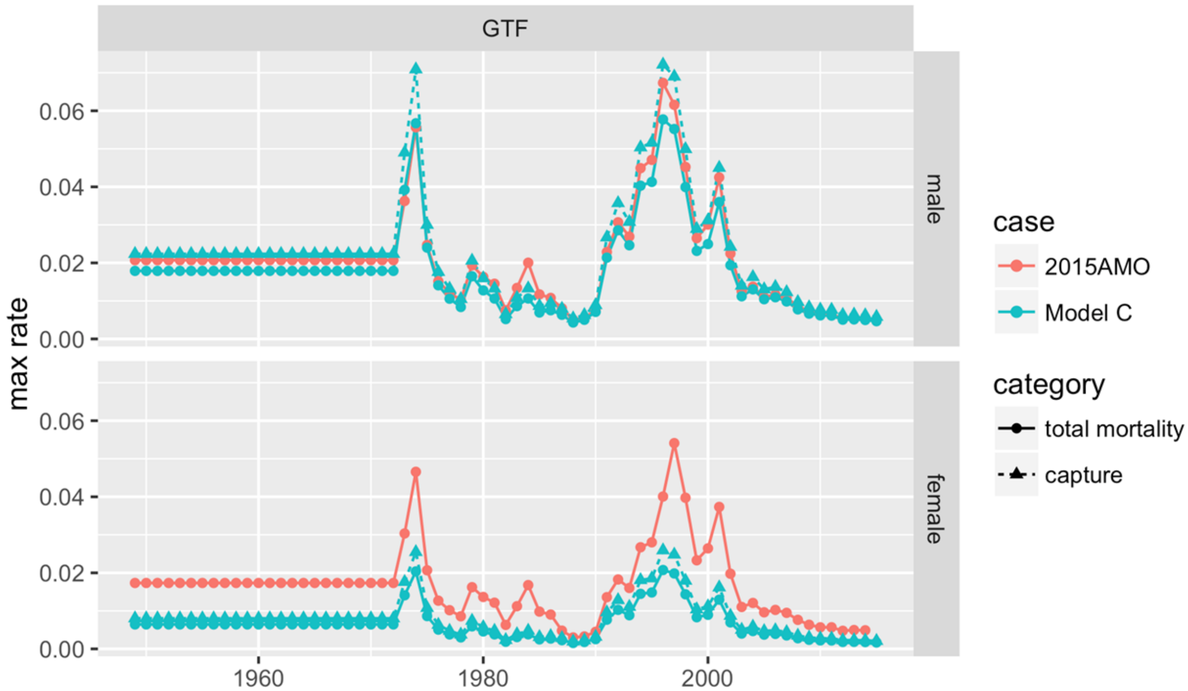


Figure 43. Estimated full selection fishing mortality from the 2015 assessment (2015AMO) and fishery capture rate from the author's preferred model (Model C) for the BBRKC fishery (RKF). Lower plot is zoomed to 1985-2015.



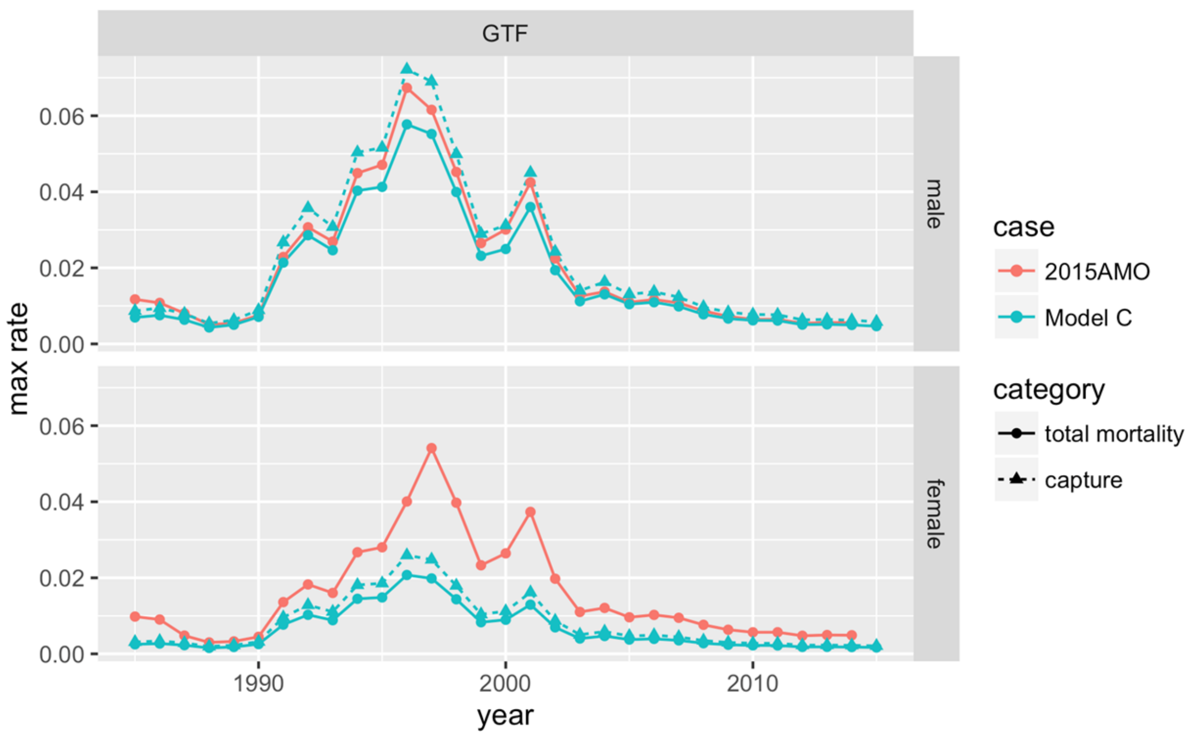


Figure 44. Estimated full selection fishing mortality from the 2015 assessment (2015AMO) and fishery capture rate from the author's preferred model (Model C) for the groundfish fisheries (GTF). Lower plot is zoomed to 1985-2015.

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

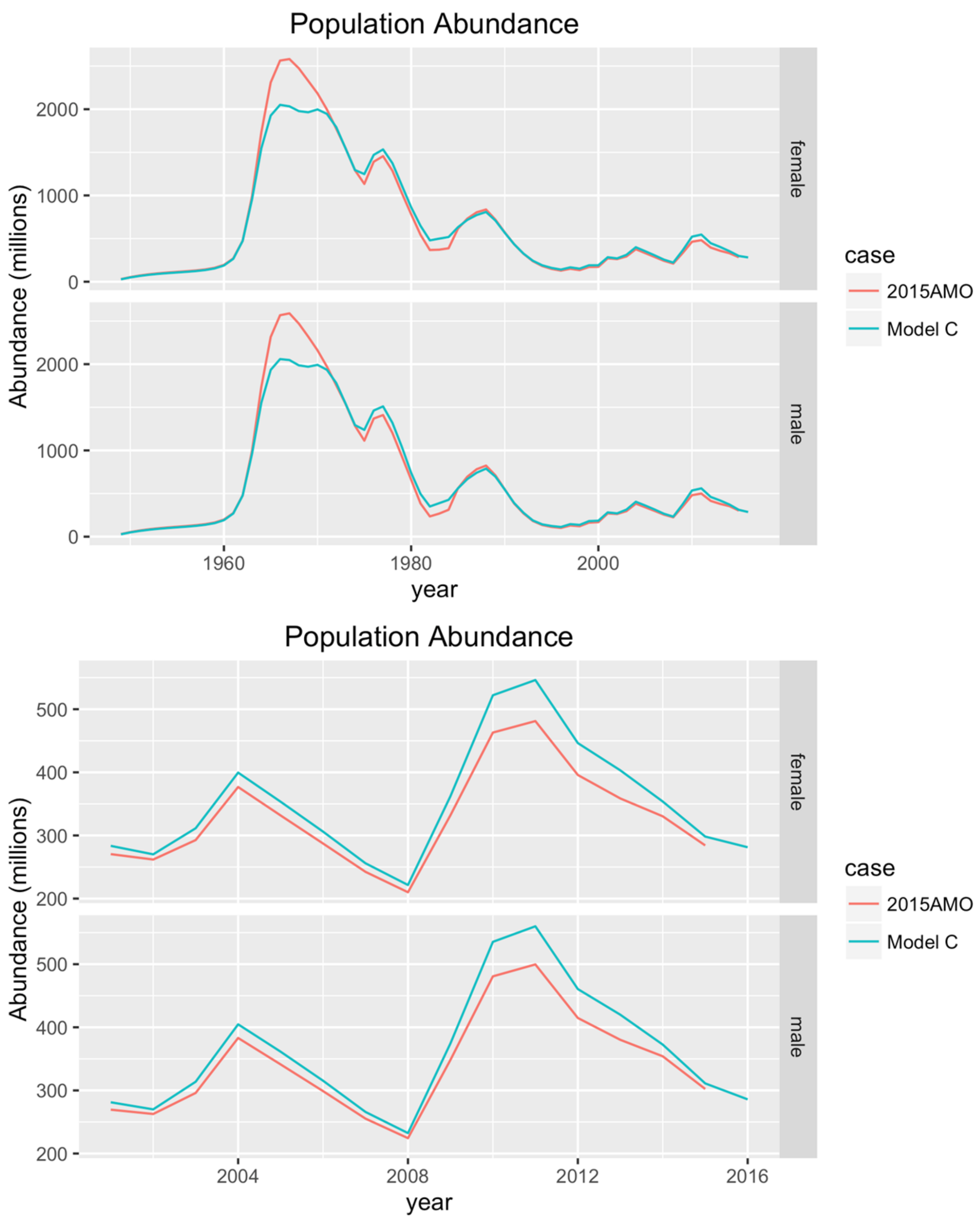
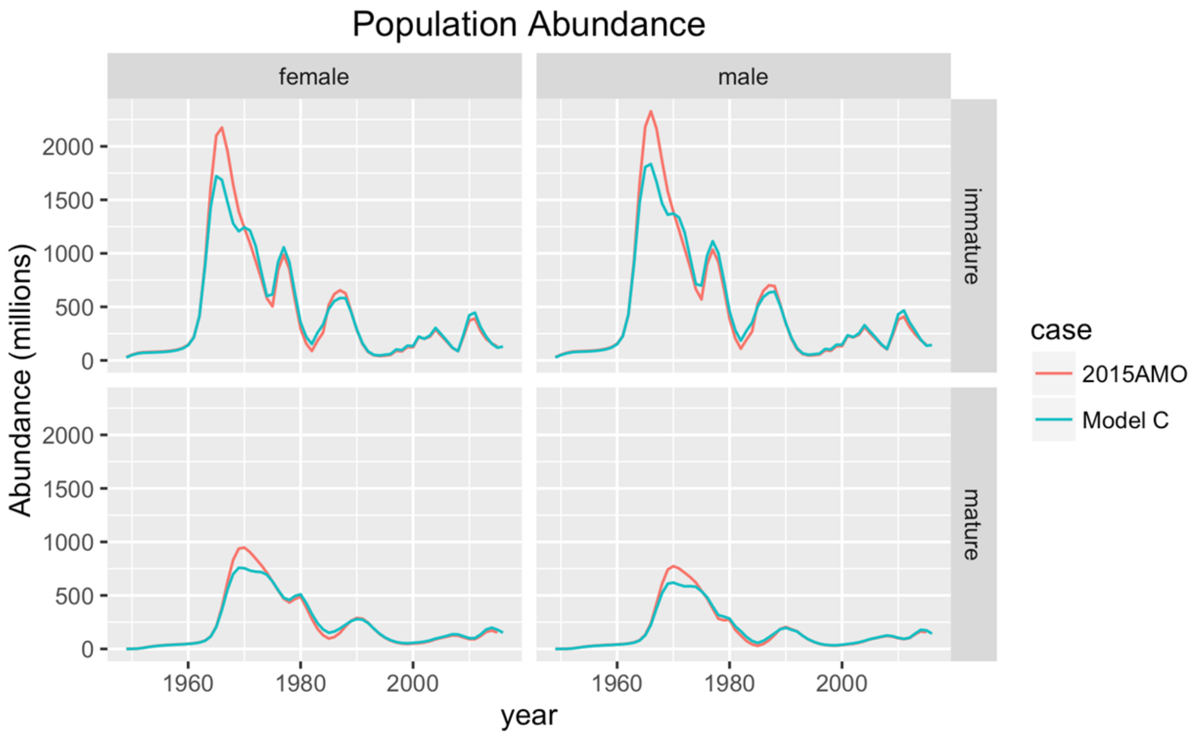


Figure 46. Estimated population abundance by sex from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Lower plot is zoomed to 2000-present.



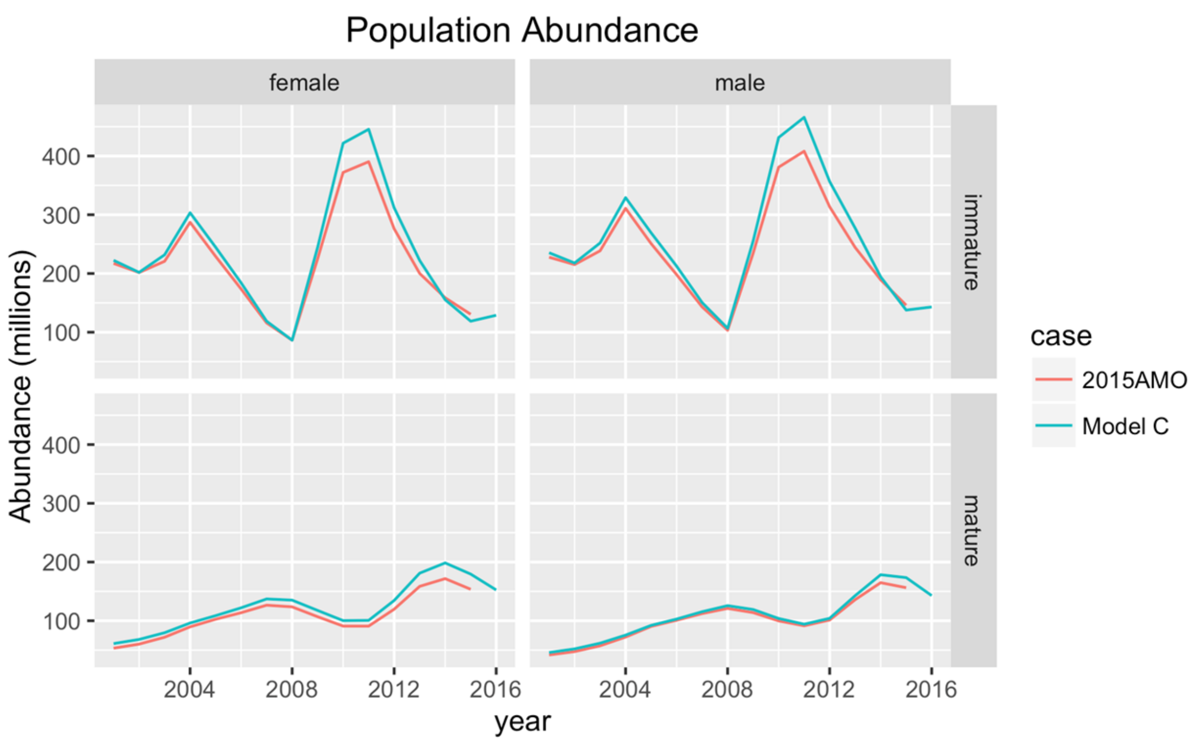
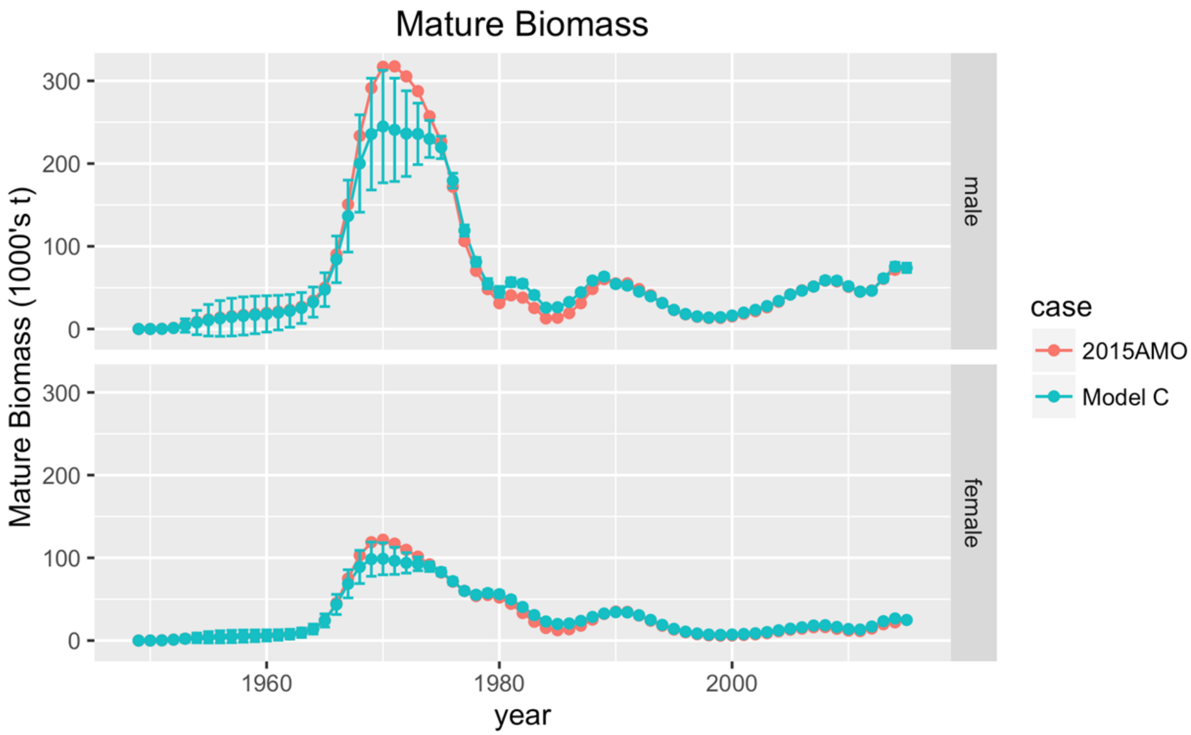


Figure 47. Estimated population abundance by sex and maturity state from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Lower plot is zoomed to 2000-present.



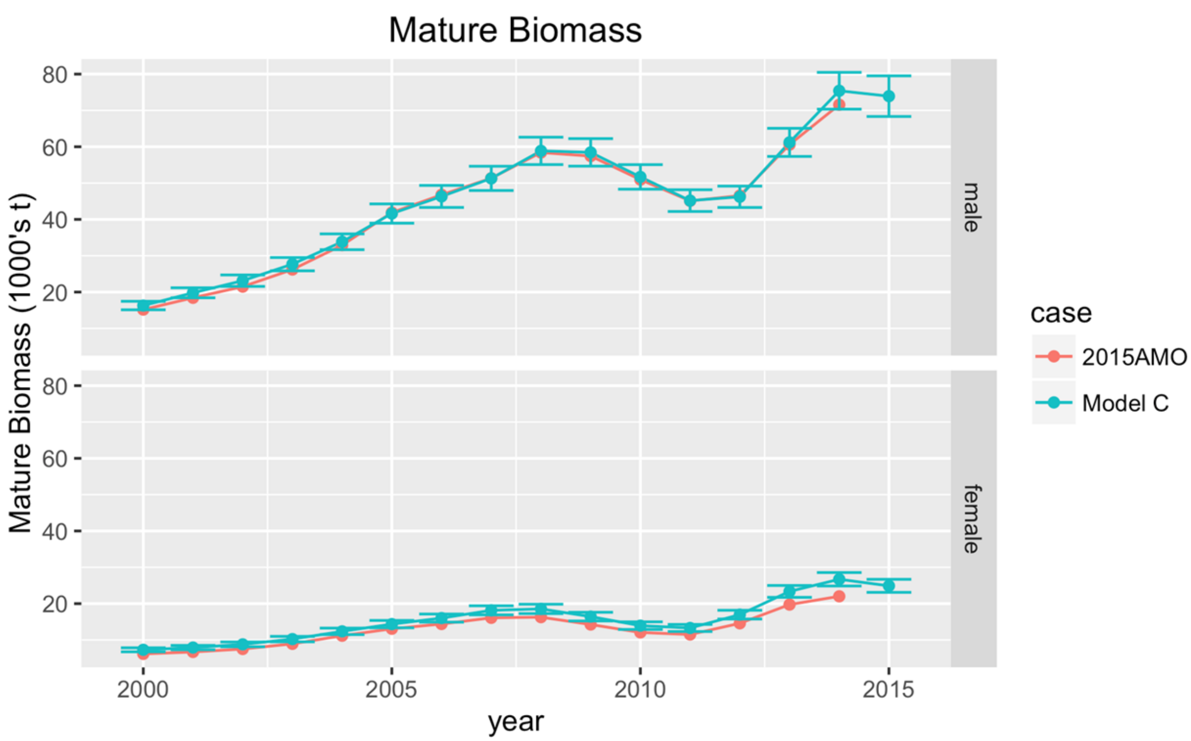


Figure 48. Estimated mature biomass-at-mating from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Lower plot is zoomed to 2000-present.

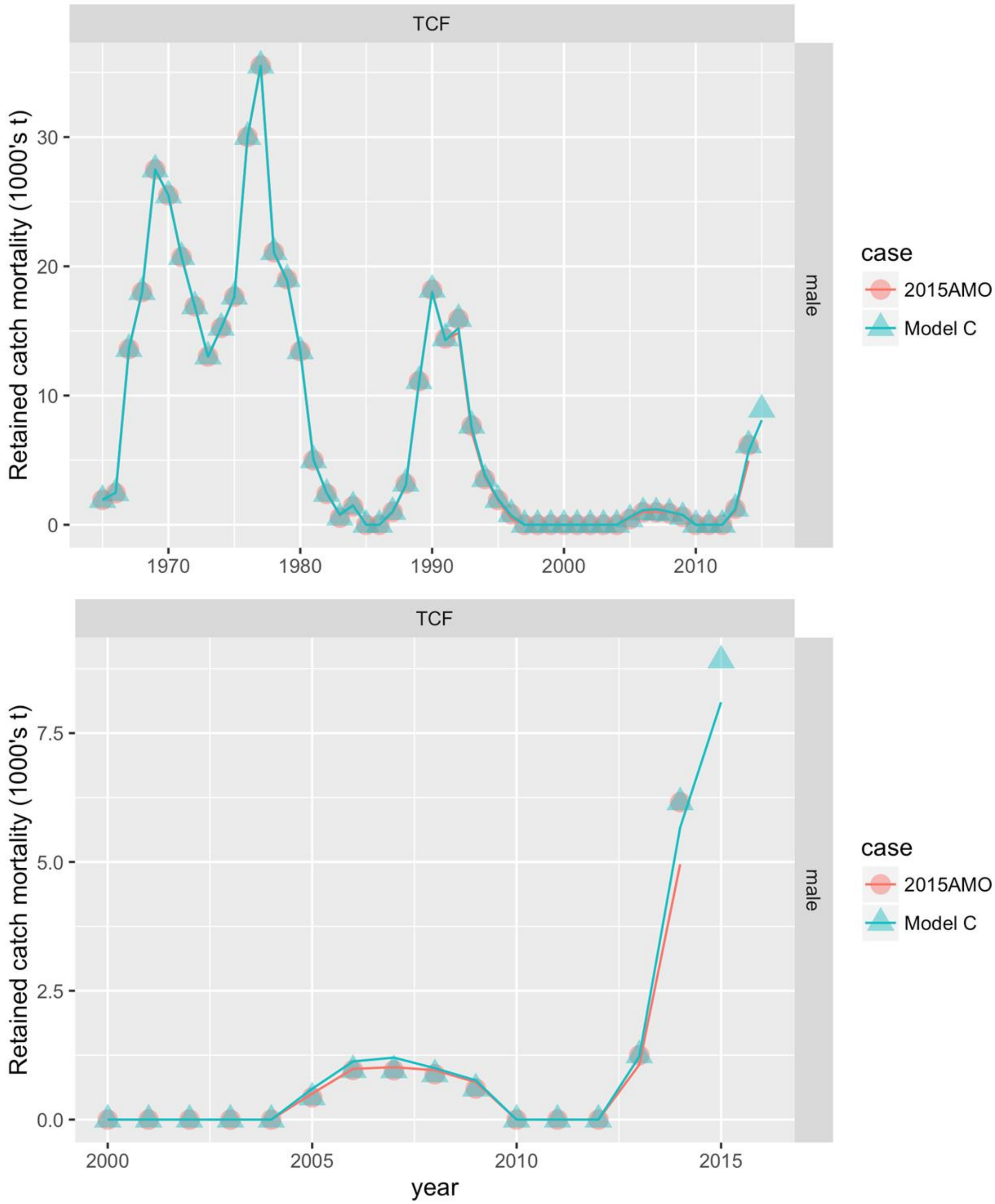


Figure 49. Fits to retained catch biomass from the 2015 assessment (2015AMO) and the author's preferred model (Model C) for the directed Tanner crab fishery (TCF). Lower plot is zoomed to 2000-2015. Predicted: lines. Observed: symbols.

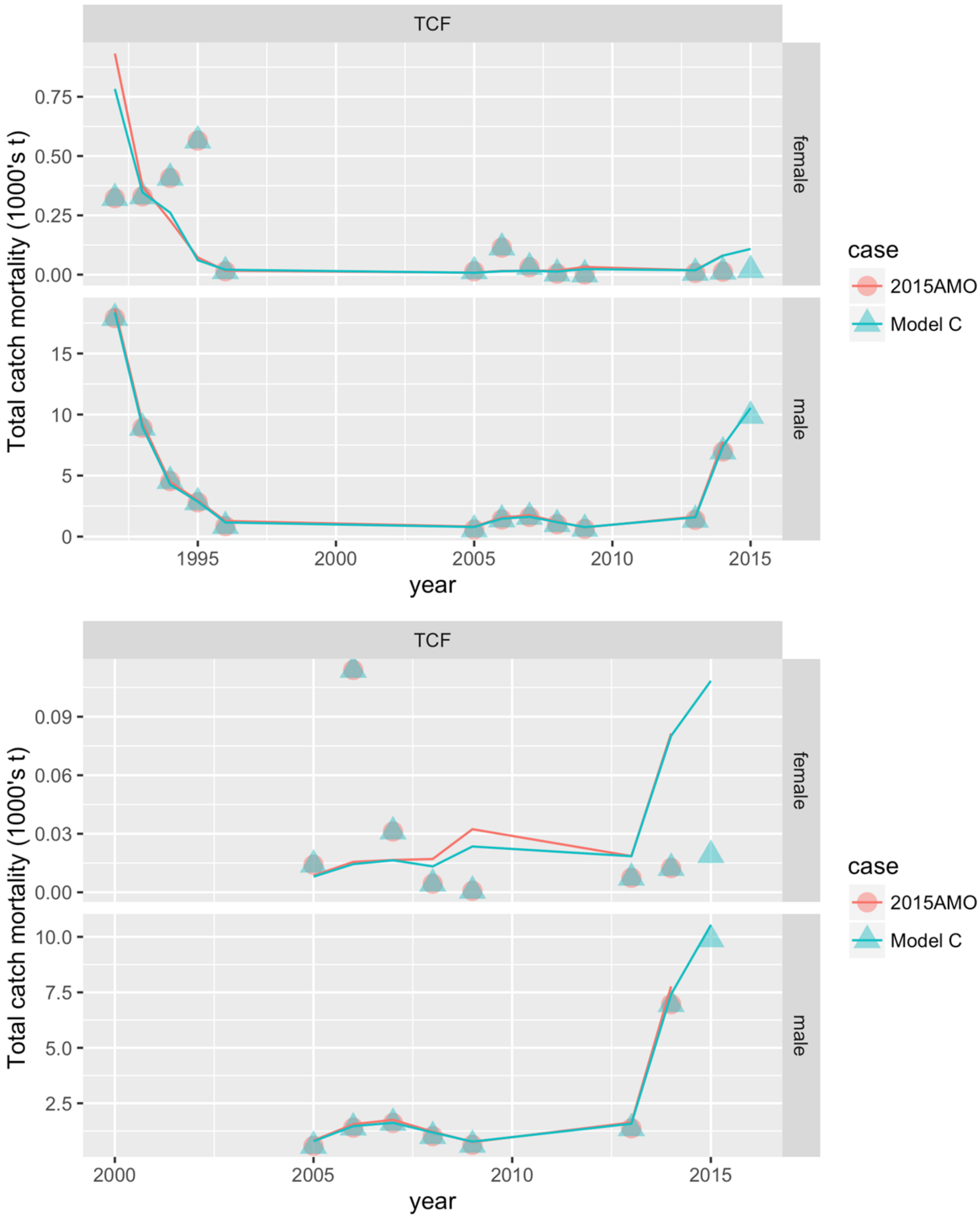


Figure 50. Fits to total catch biomass from the 2015 assessment (2015AMO) and the author's preferred model (Model C) for males in the directed Tanner crab fishery (TCF). Lower plot is zoomed to 2000-2015. Observed: symbols.

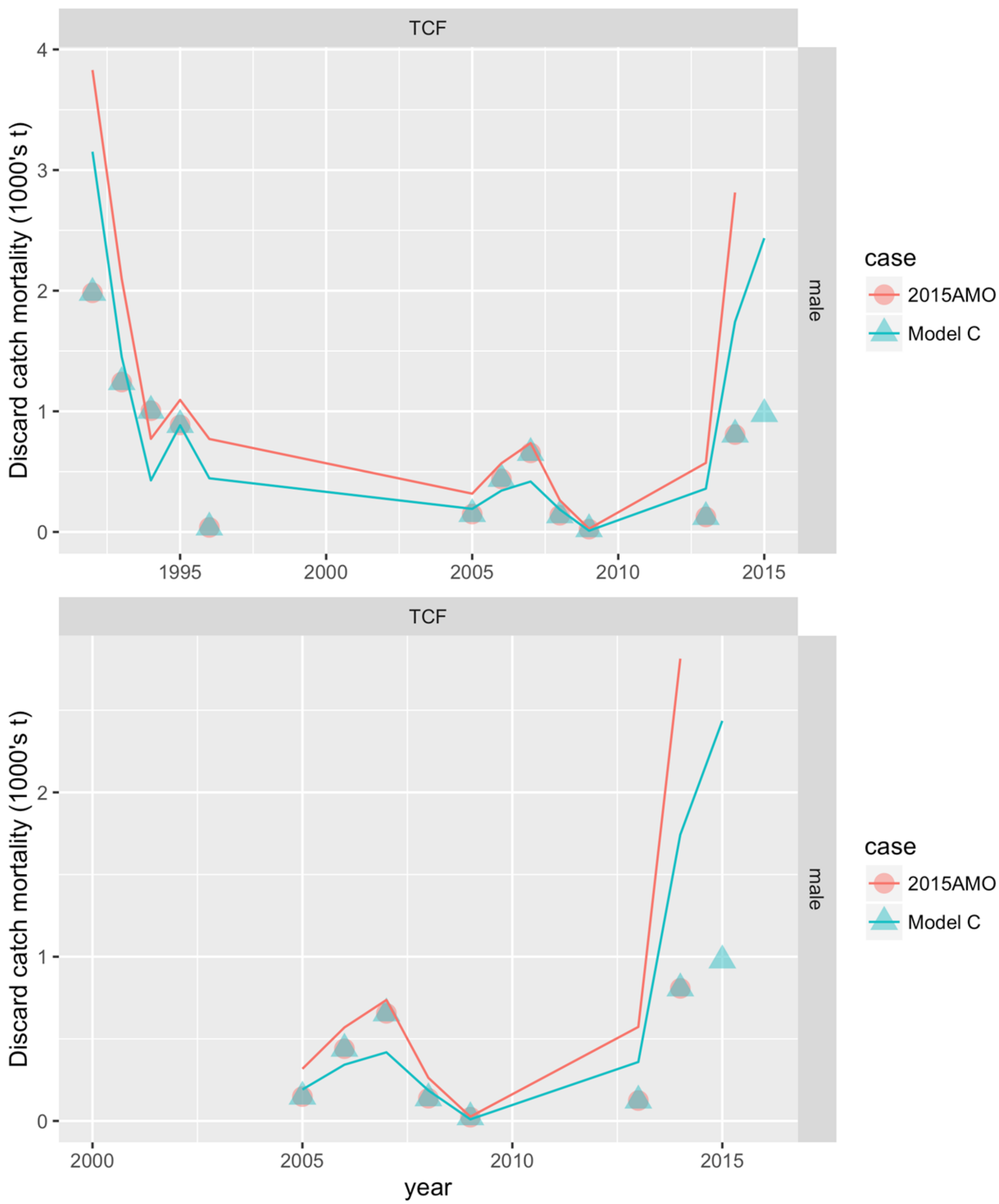


Figure 51. Fits to total catch biomass from the 2015 assessment (2015AMO) and the author's preferred model (Model C) for males in the directed Tanner crab fishery (TCF). Lower plot is zoomed to 2000-2015. Observed: symbols.

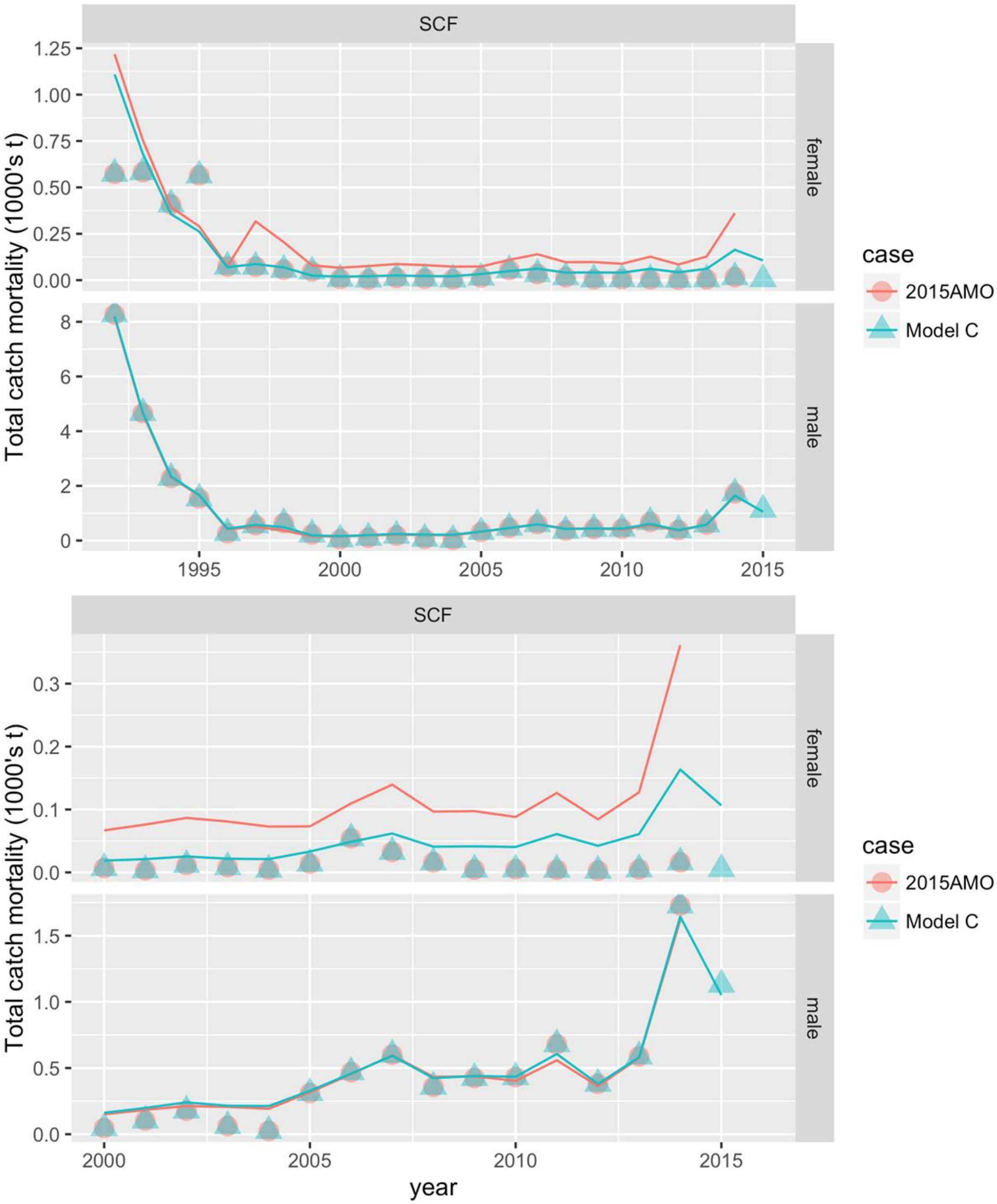


Figure 52. Fits to total catch biomass from the 2015 assessment (2015AMO) and the author's preferred model (Model C) for males in the snow crab bycatch fishery (SCF). Lower plot is zoomed to 2000-2015. Observed: symbols.

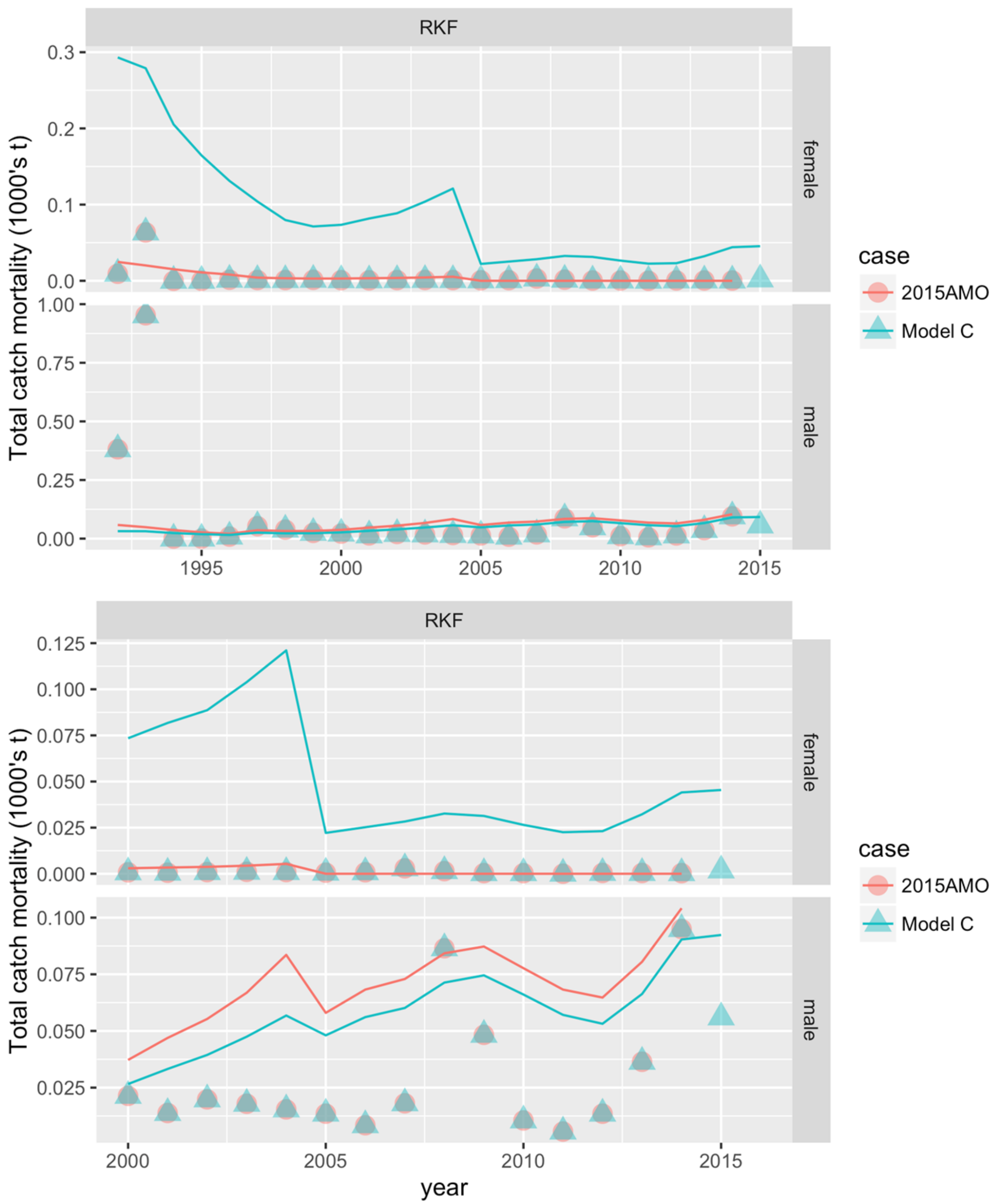


Figure 53. Fits to total catch biomass from the 2015 assessment (2015AMO) and the author's preferred model (Model C) for males in the BBRKC bycatch fishery (RKF). Lower plot is zoomed to 2000-2015. Observed: symbols.

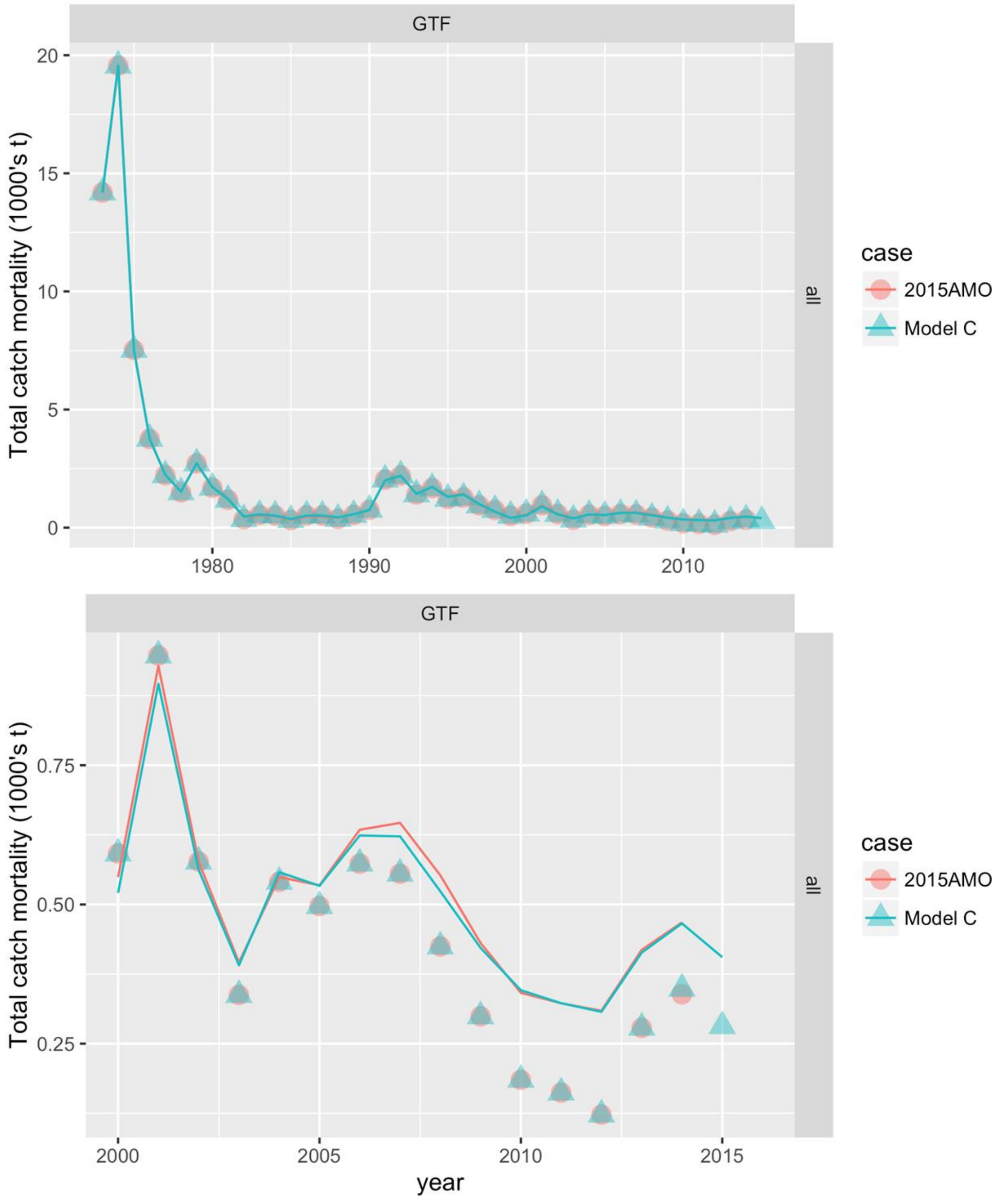


Figure 54. Fits to total catch biomass from the 2015 assessment (2015AMO) and the author's preferred model (Model C) for males in the groundfish fisheries (GTF). Lower plot is zoomed to 2000-2015. Observed: symbols.

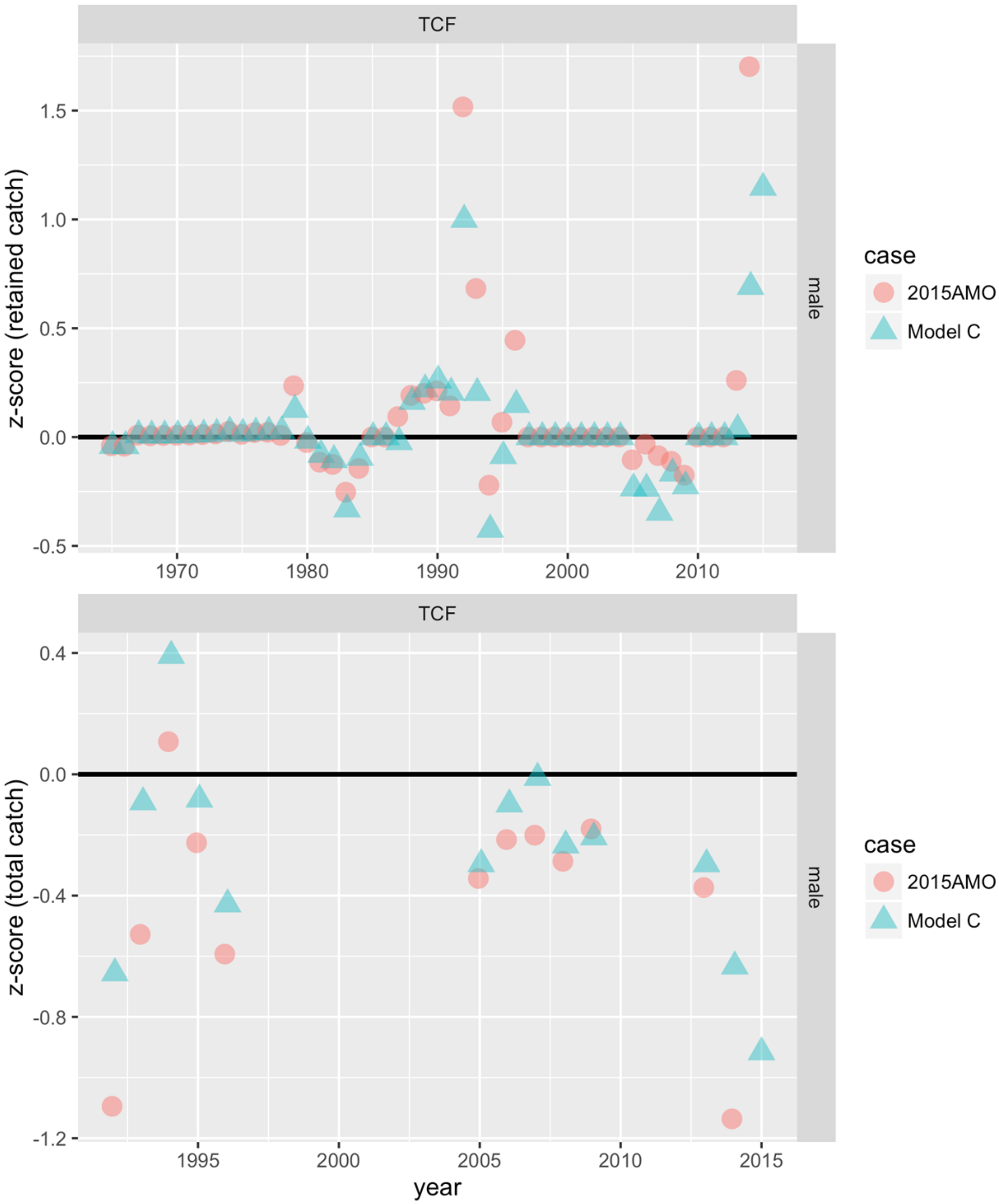


Figure 55. Z-scores for fits to retained and male total catch biomass from the 2015 assessment (2015AMO) and the author's preferred model (Model C) for males in the directed Tanner crab (TCF) fisheries.

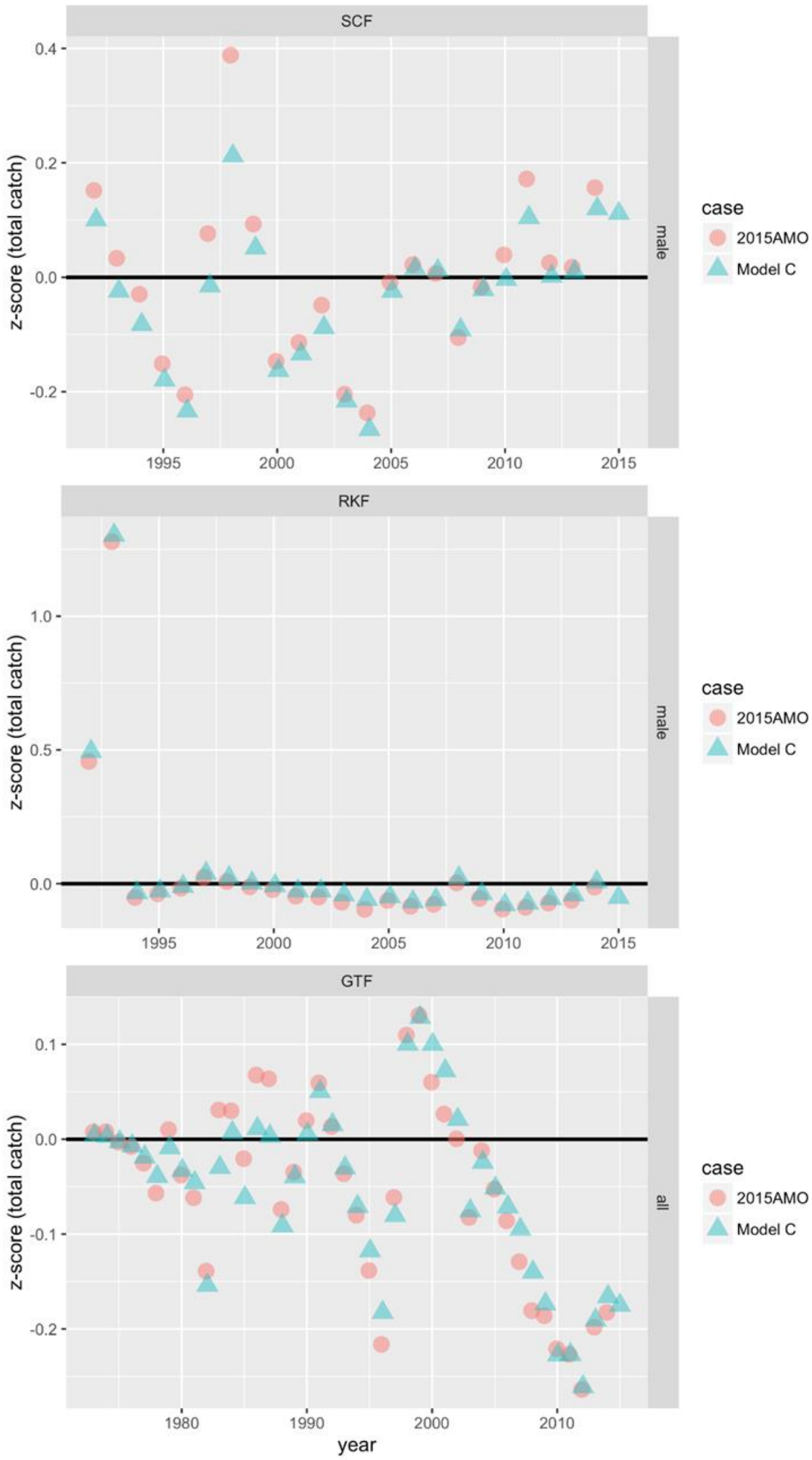


Figure 56. Z-scores for fits to total catch biomass from the 2015 assessment (2015AMO) and the author's preferred model (Model C) for males in the snow crab (SCF) , BBRKC (RKF), and groundfish (GTF) fisheries.

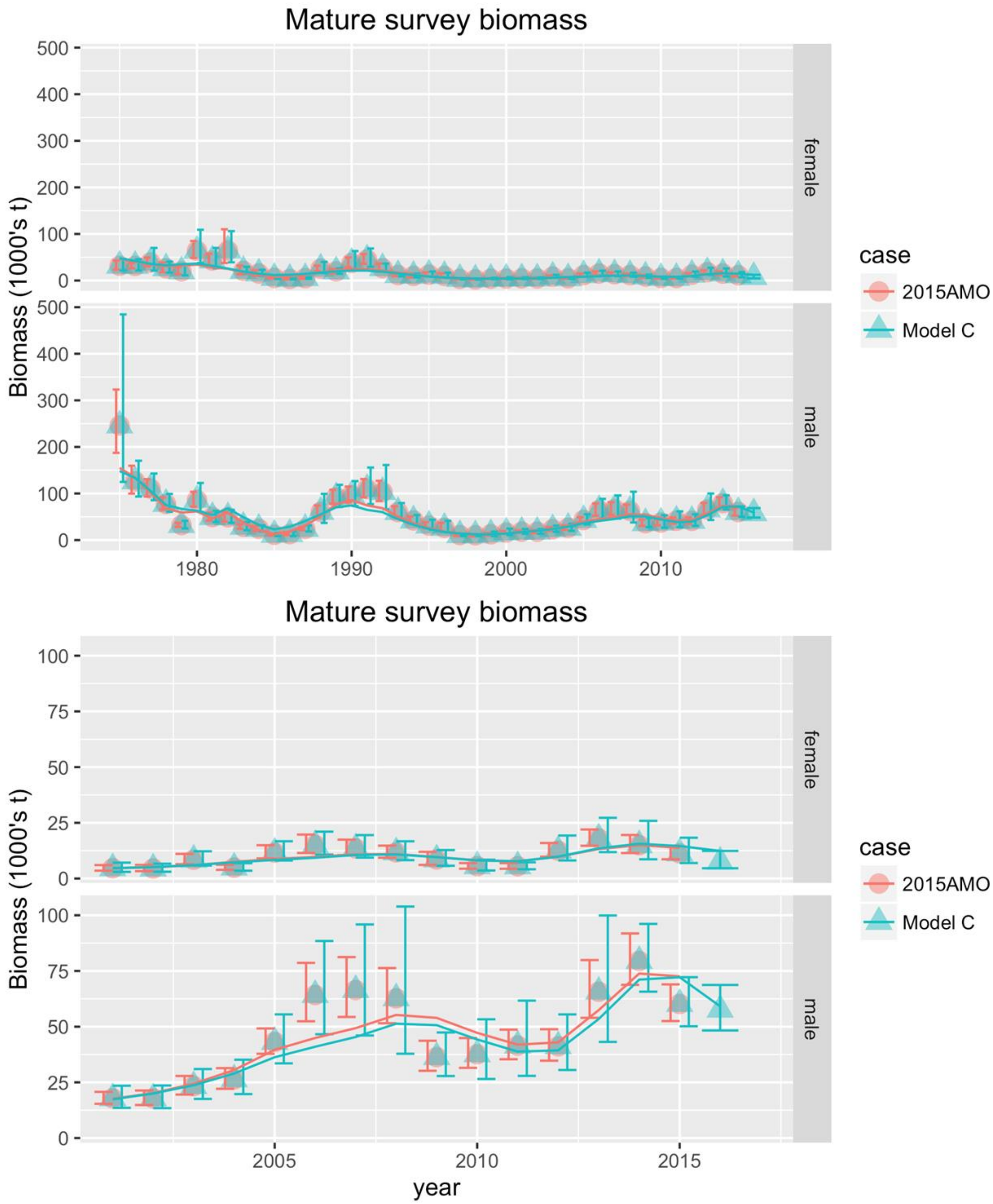


Figure 57. Estimated survey biomass (lines) from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Observed survey biomass (symbols) and associated confidence intervals based on cv's (error bars) are also shown.

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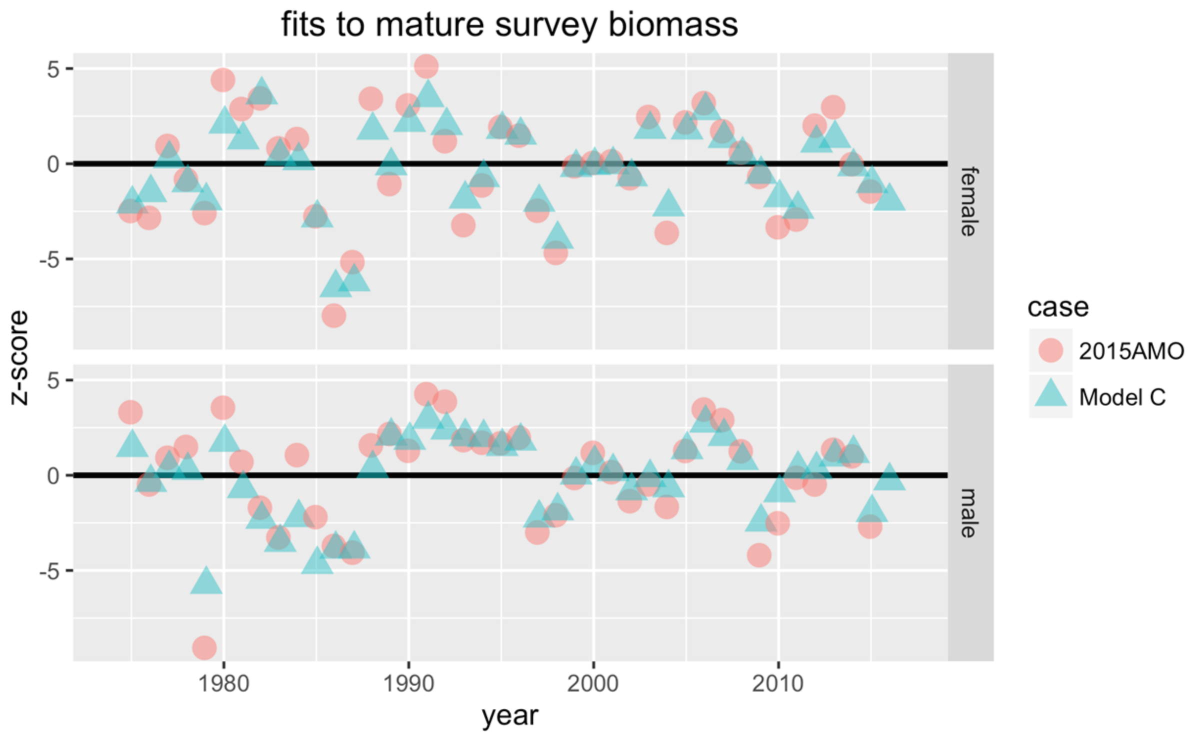

Figure 58. Z-scores for fits to mature survey biomass (lines) from the 2015 assessment (2015AMO) and the author's preferred model (Model C).

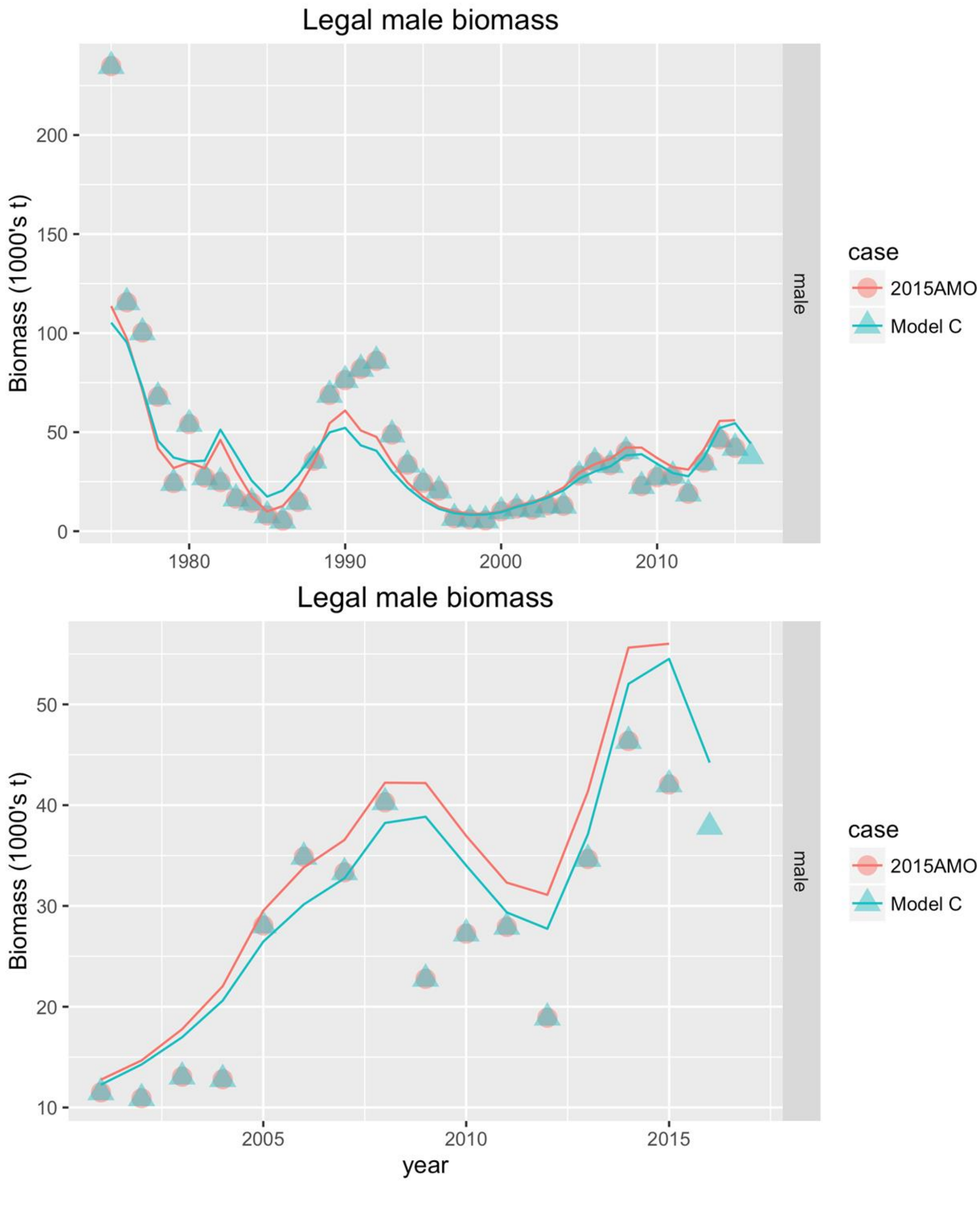

Figure 59. Estimated preferred (≥ 125 mm CW) male biomass in the NMFS trawl survey (lines) from the 2015 assessment (2015AMO) and the author's preferred model (Model C). Observed biomass of legal males in the survey is plotted as symbols.

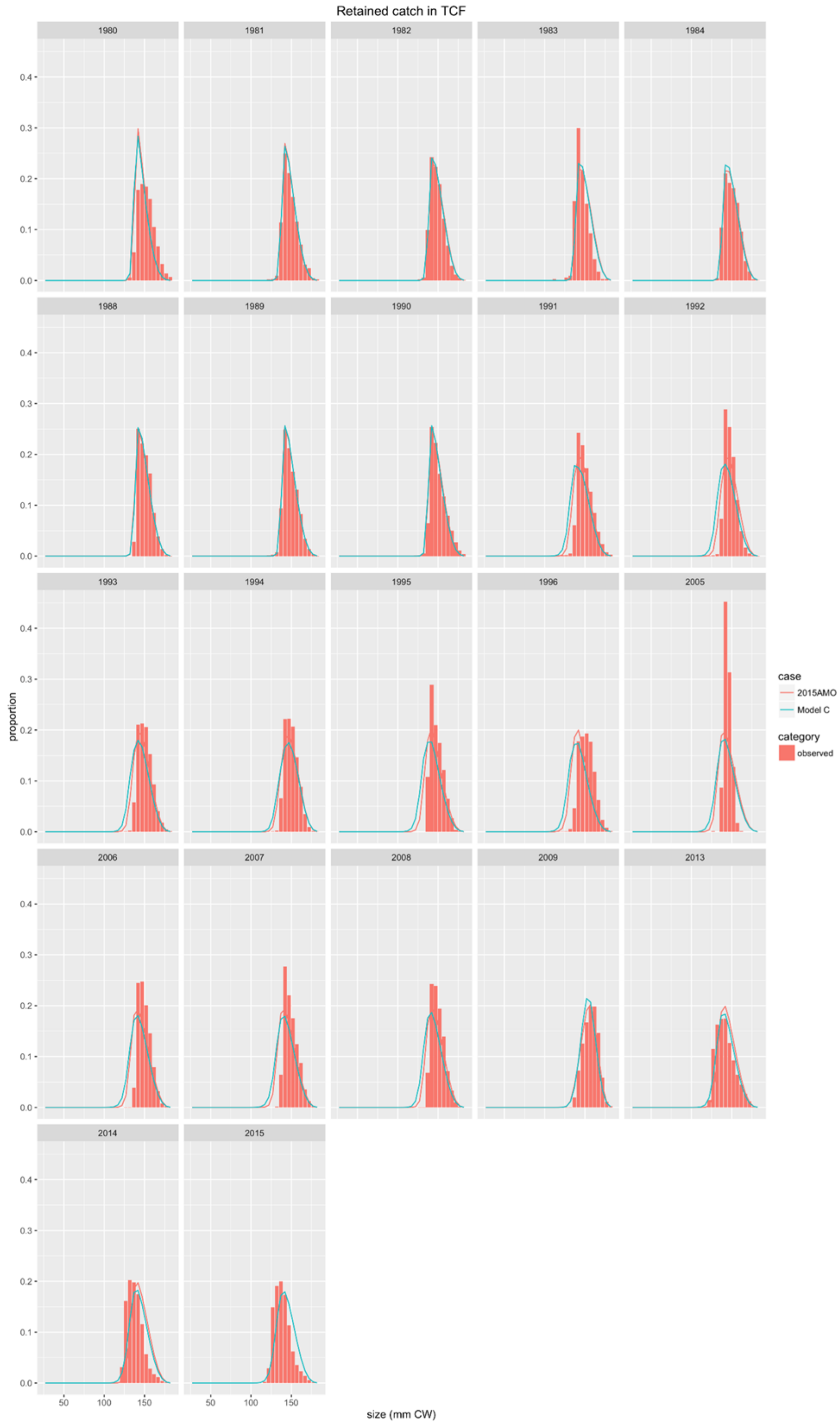

Figure 60. Fits to retained catch (dockside) size compositions from the directed Tanner crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

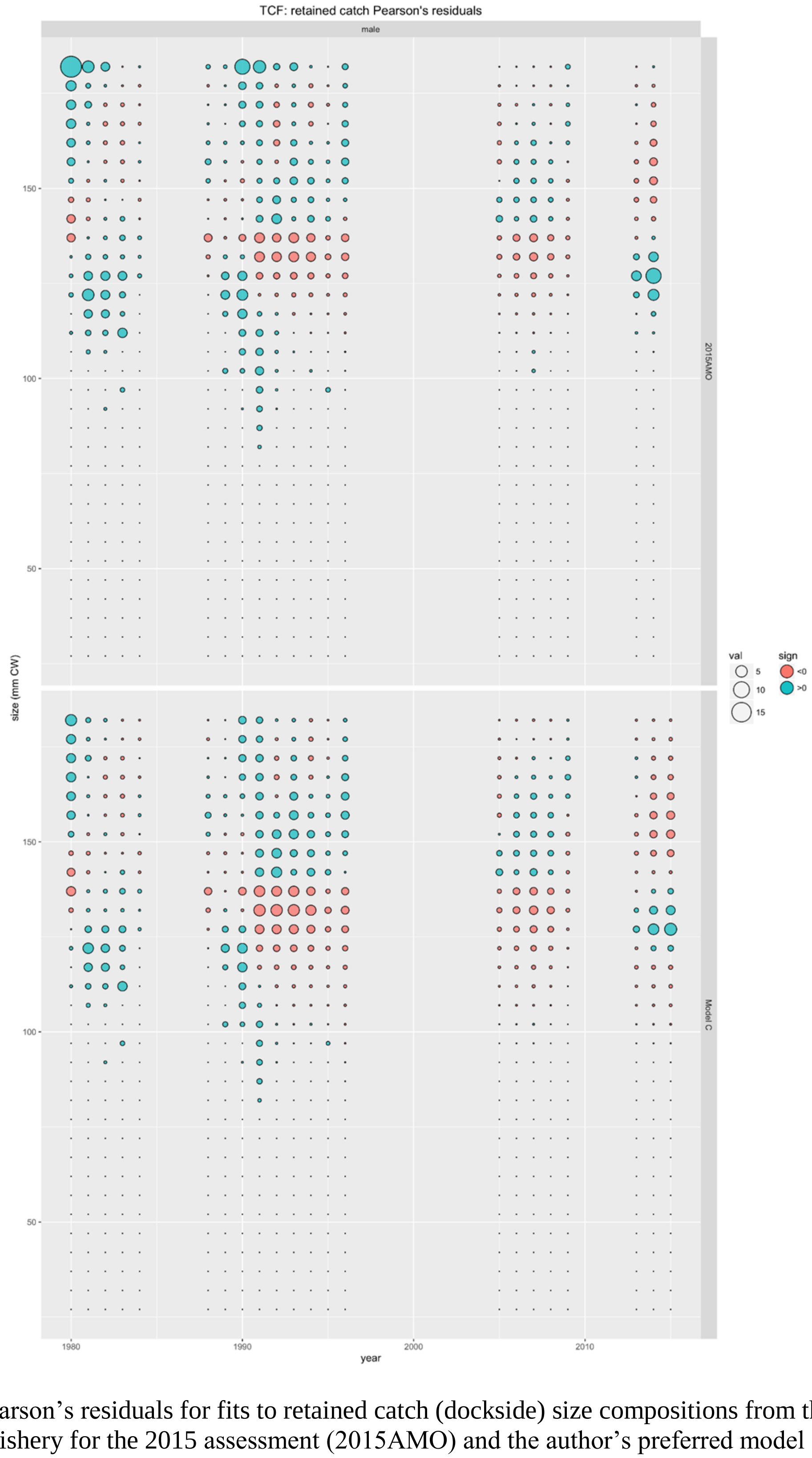

Figure 61. Pearson's residuals for fits to retained catch (dockside) size compositions from the directed Tanner crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C).

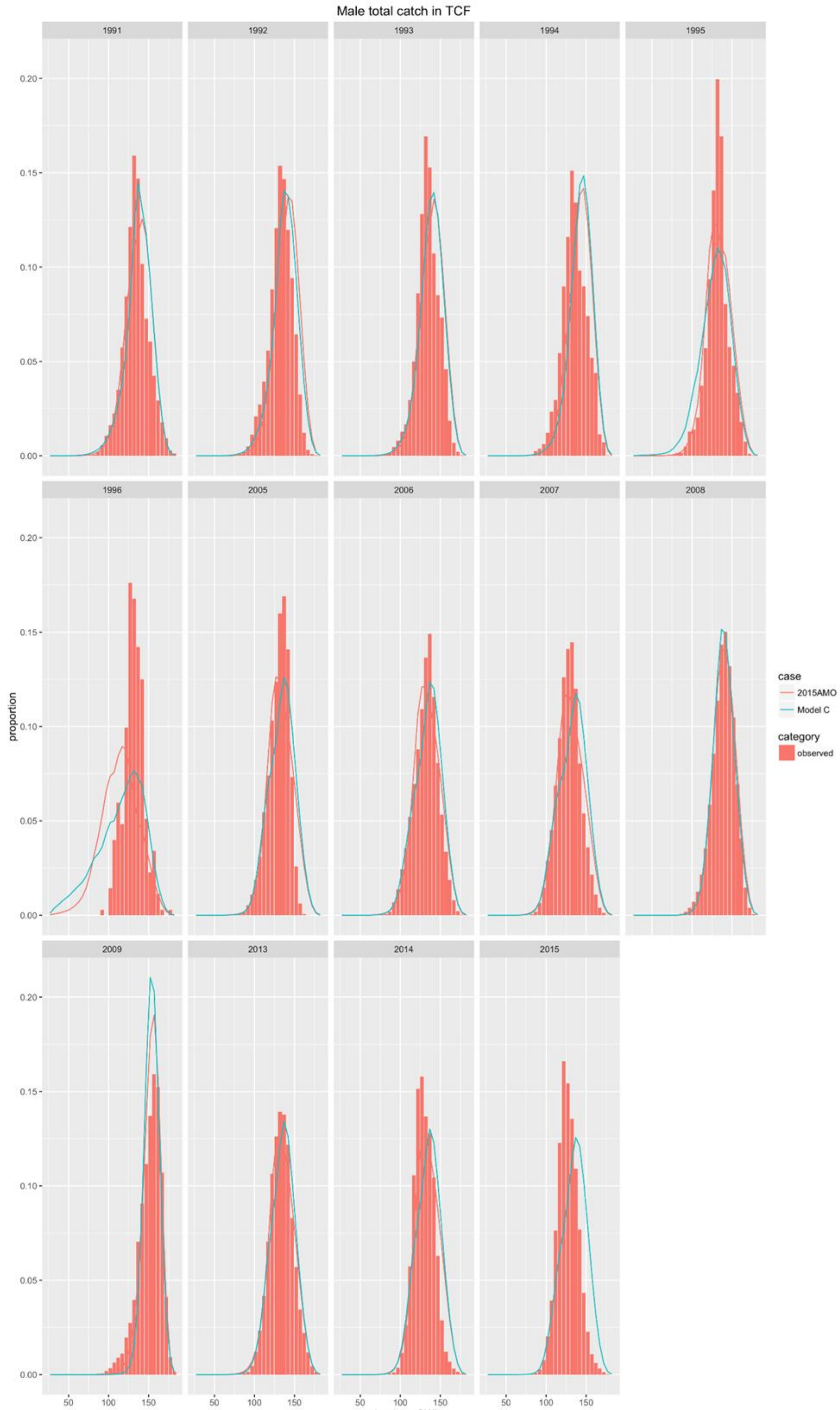

Figure 62. Fits to total catch (at-sea) male size compositions from the directed Tanner crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

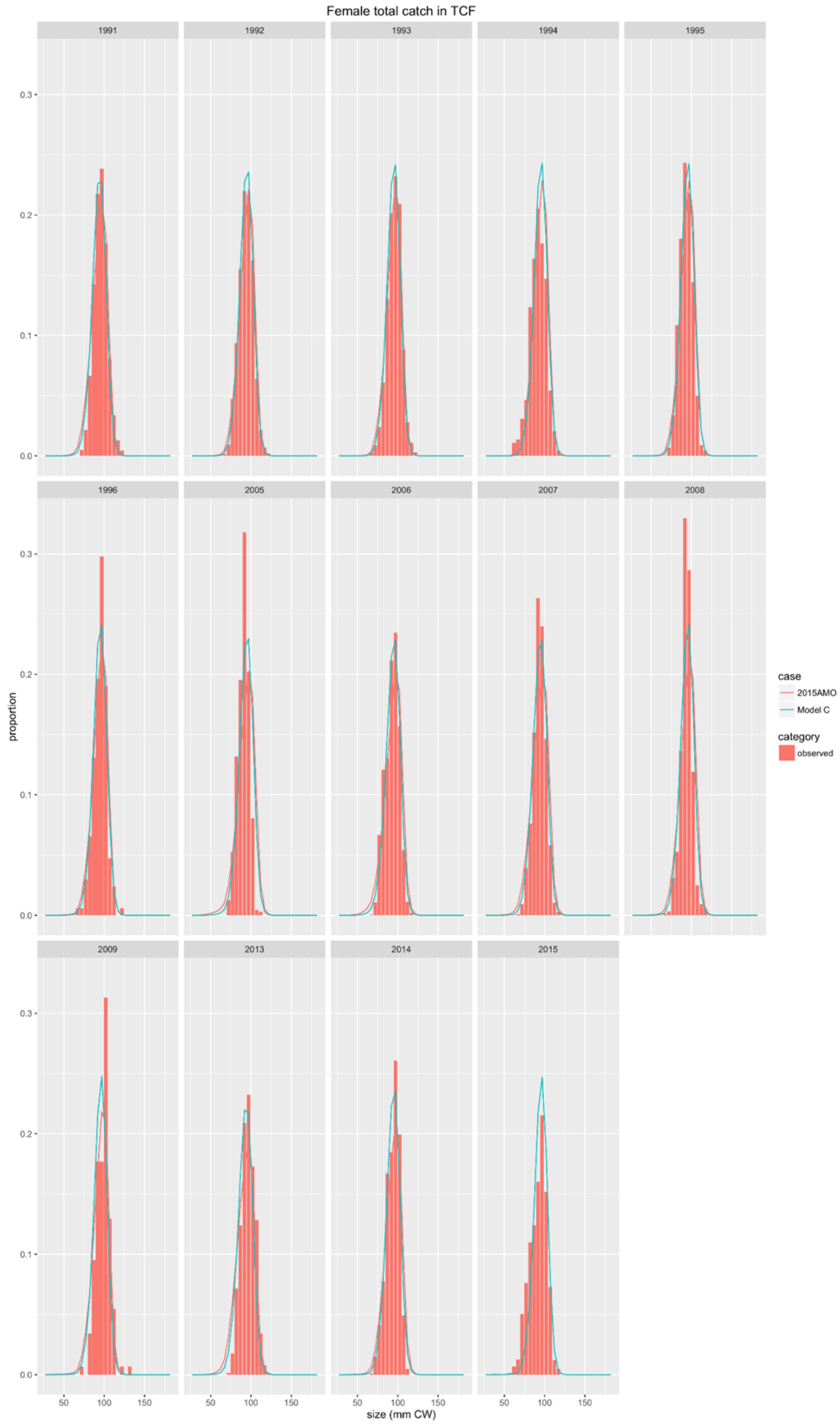

Figure 63. Fits to total catch (at-sea) female size compositions from the directed Tanner crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

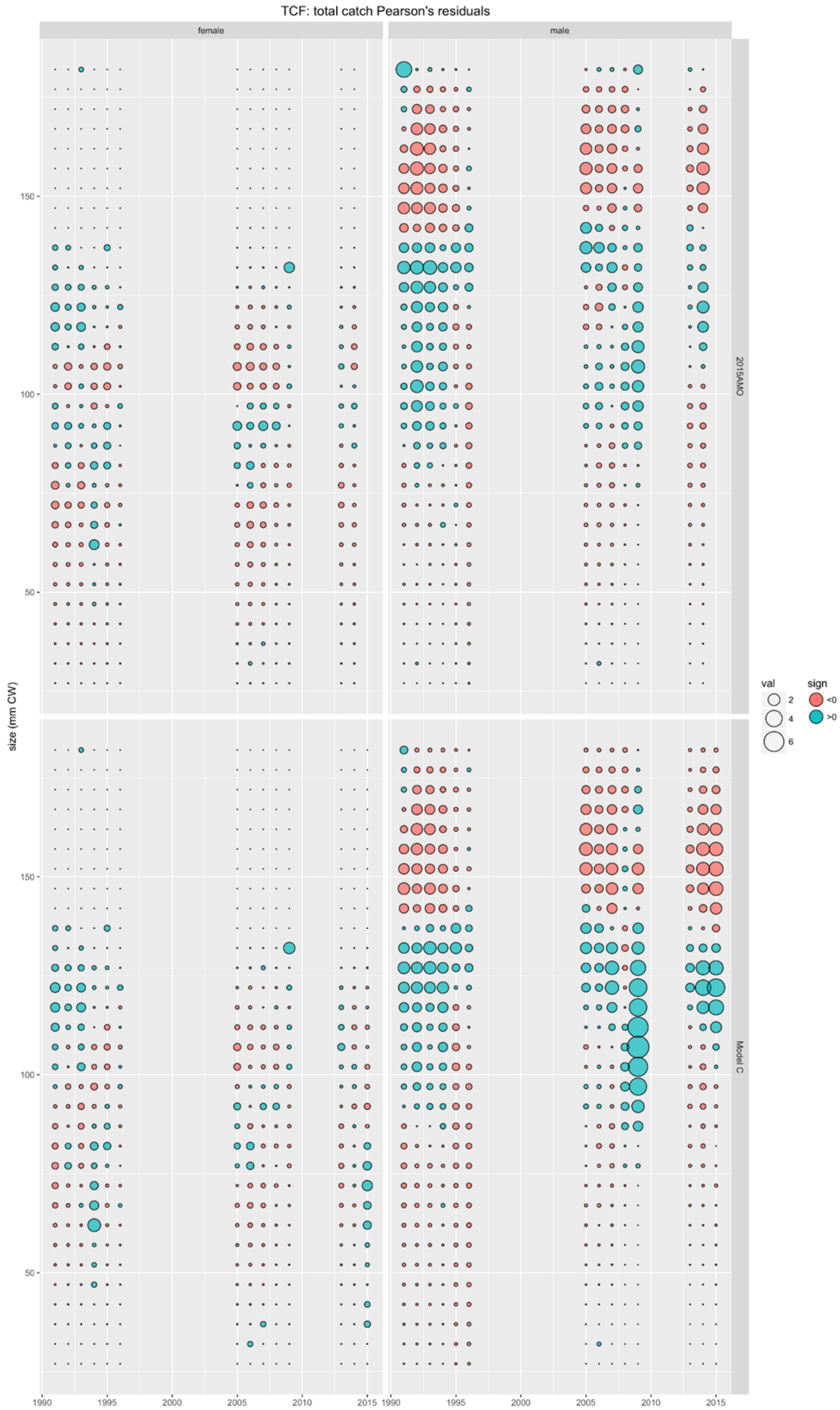

Figure 64. Pearson's residuals for fits to total catch (at-sea) size compositions from the directed fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C).

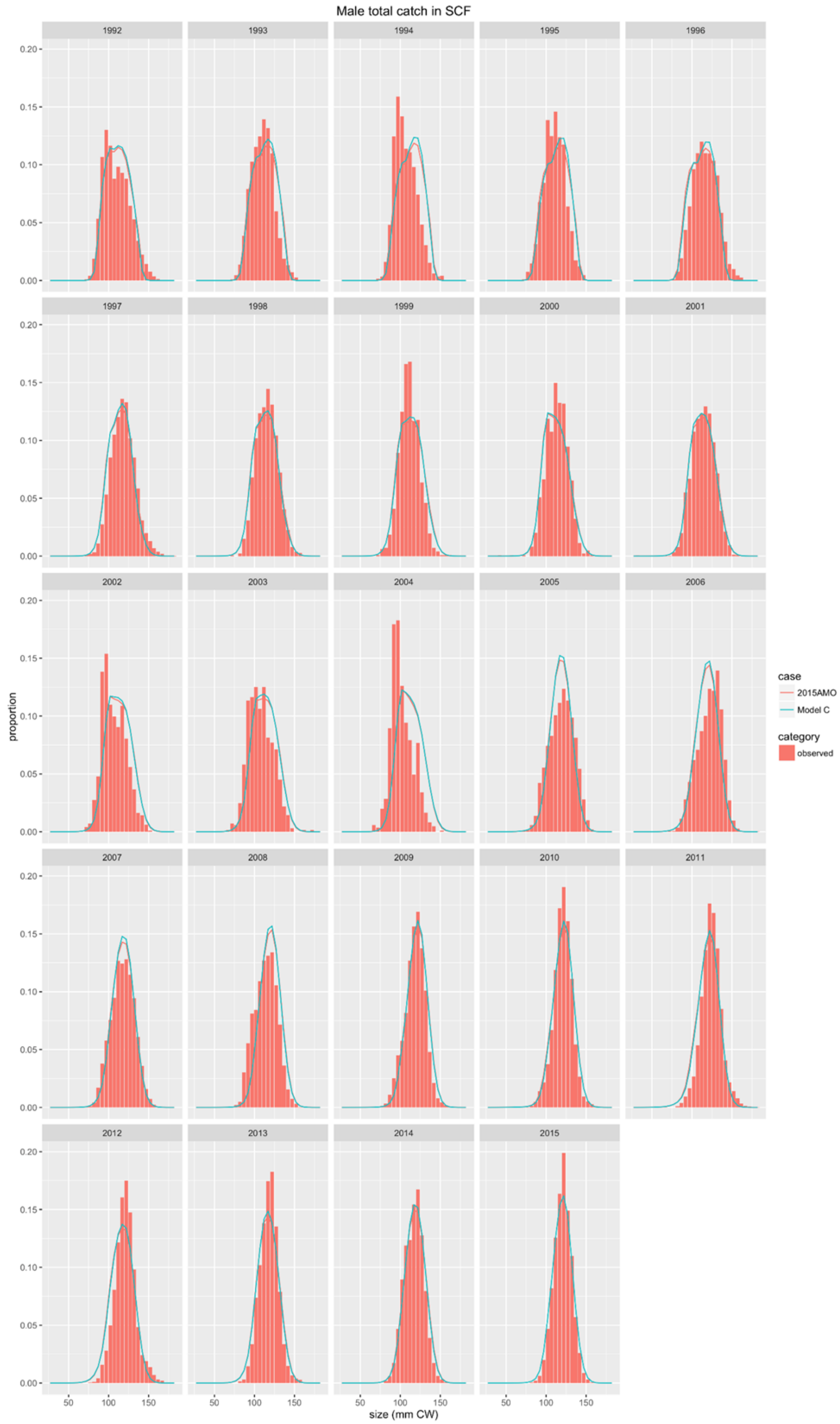

Figure 65. Fits to bycatch male size compositions from the snow crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

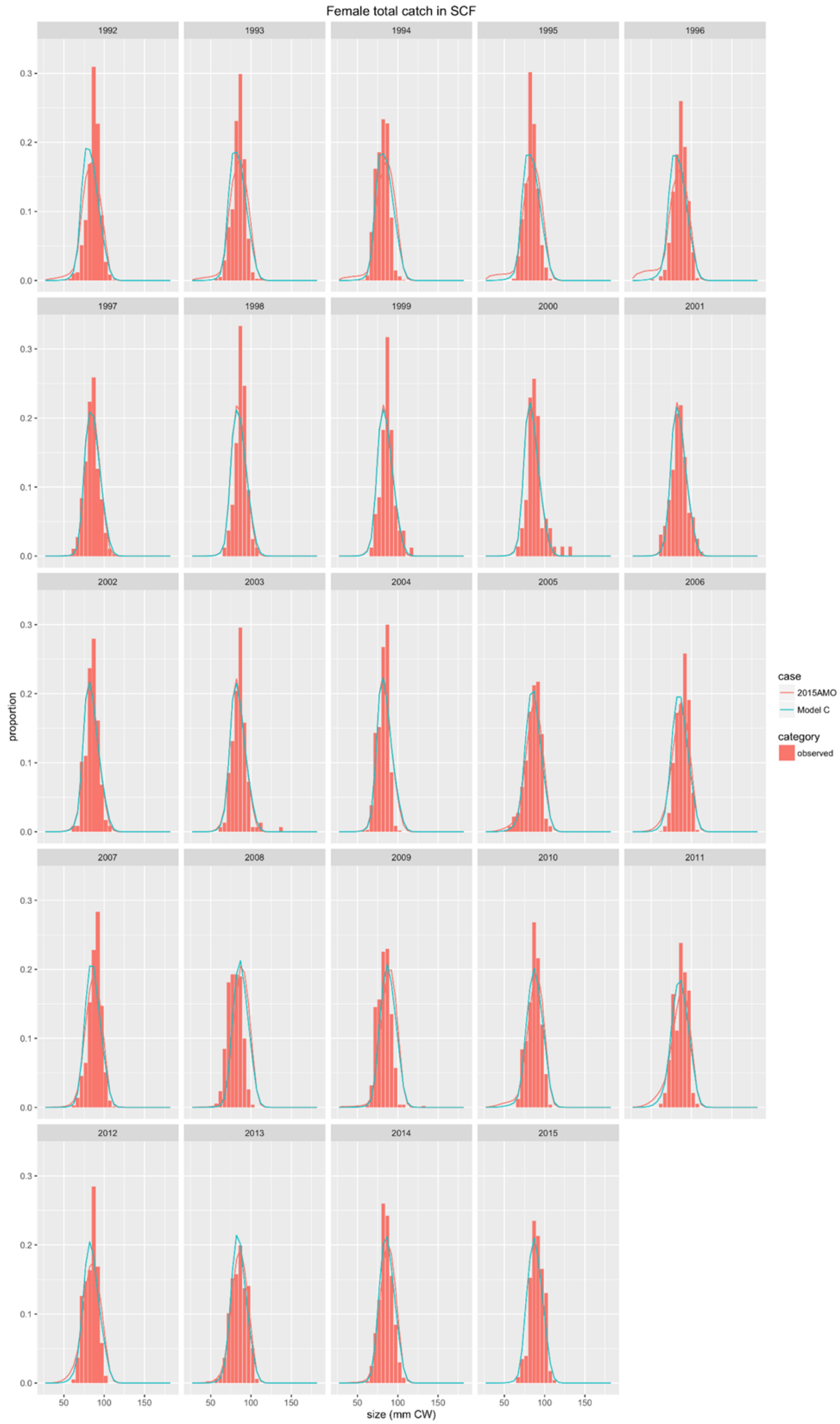

Figure 66. Fits to bycatch female size compositions from the snow crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

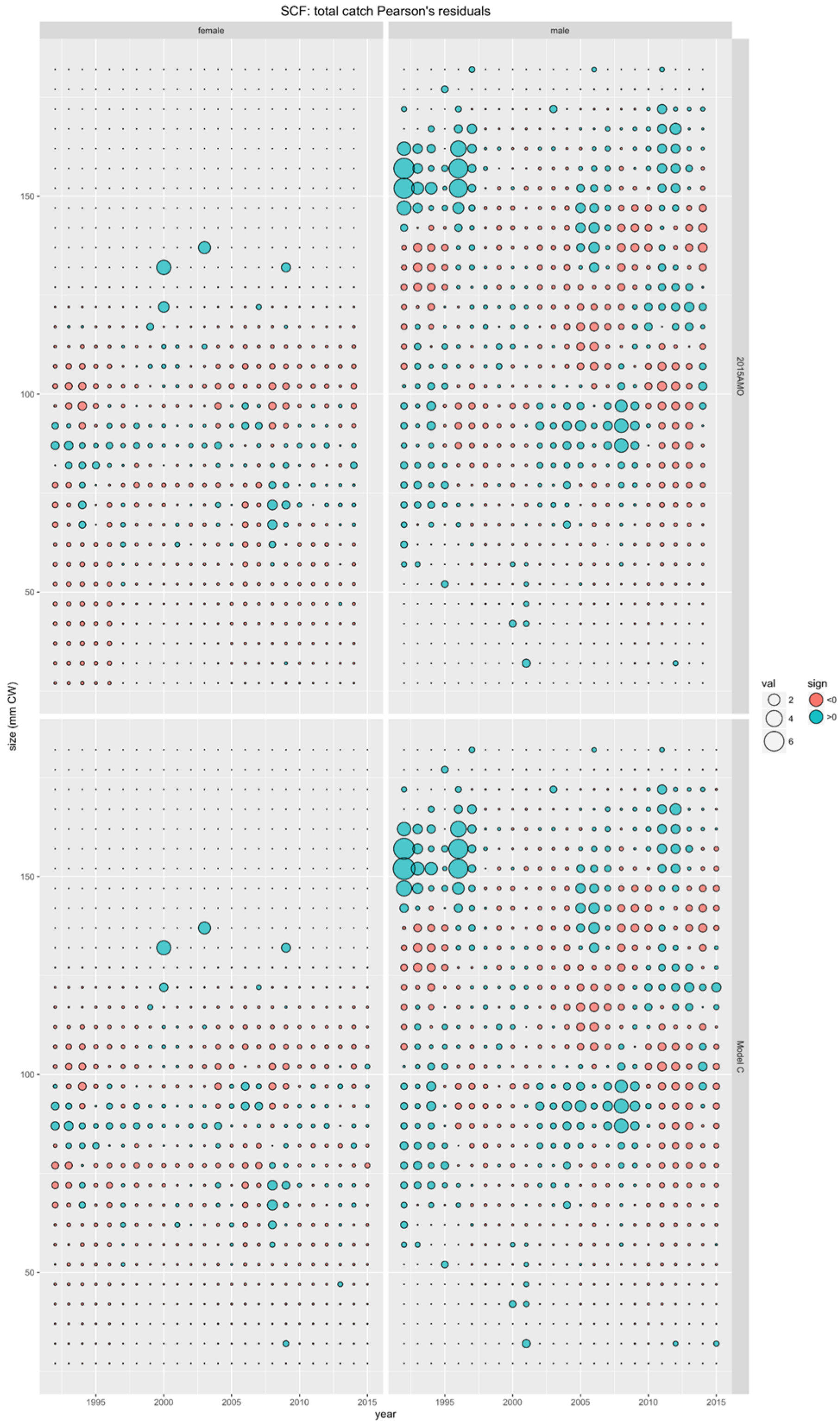

Figure 67. Pearson's residuals for fits to bycatch size compositions from the snow crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C).

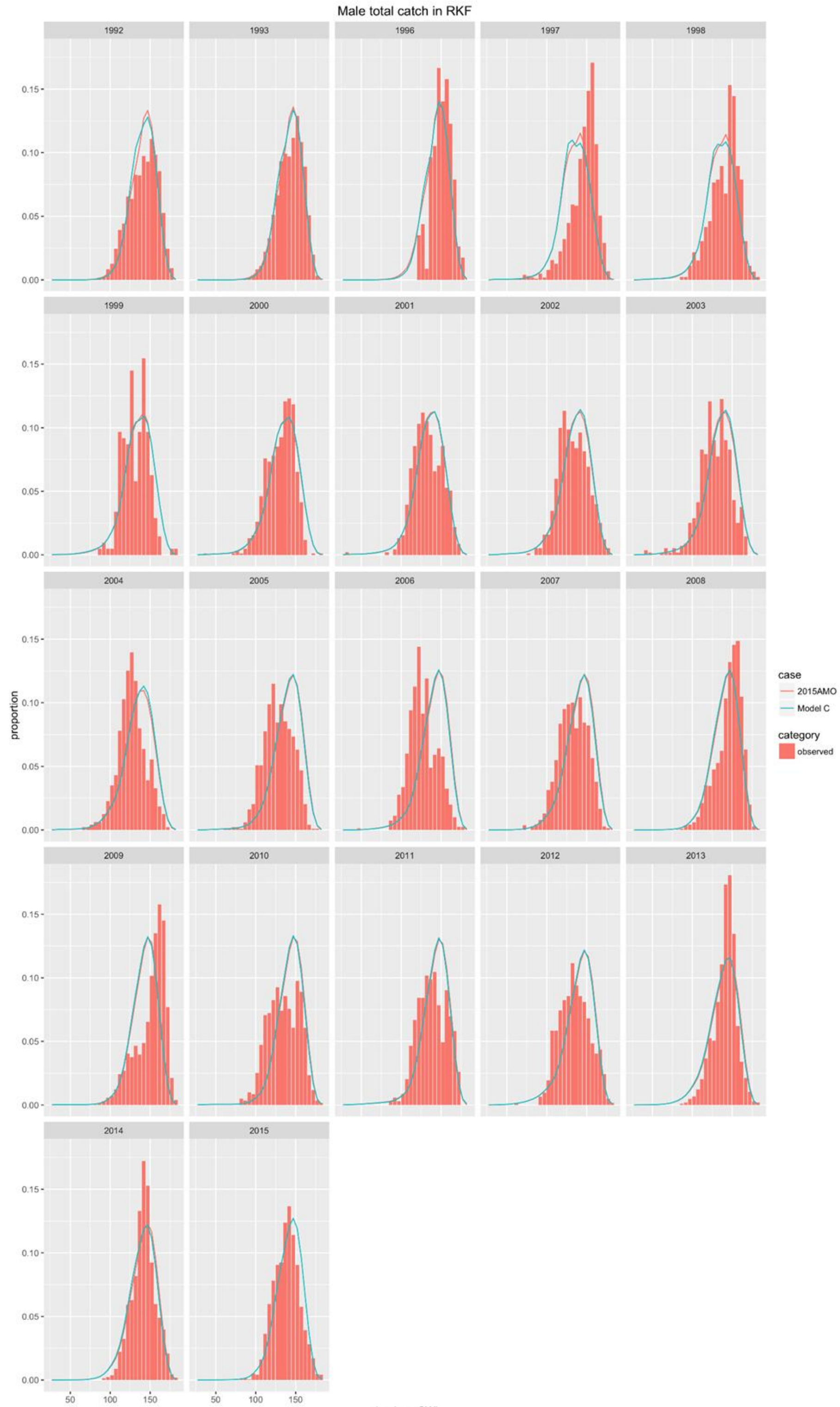

Figure 68. Fits to bycatch male size compositions from the BBRKC fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

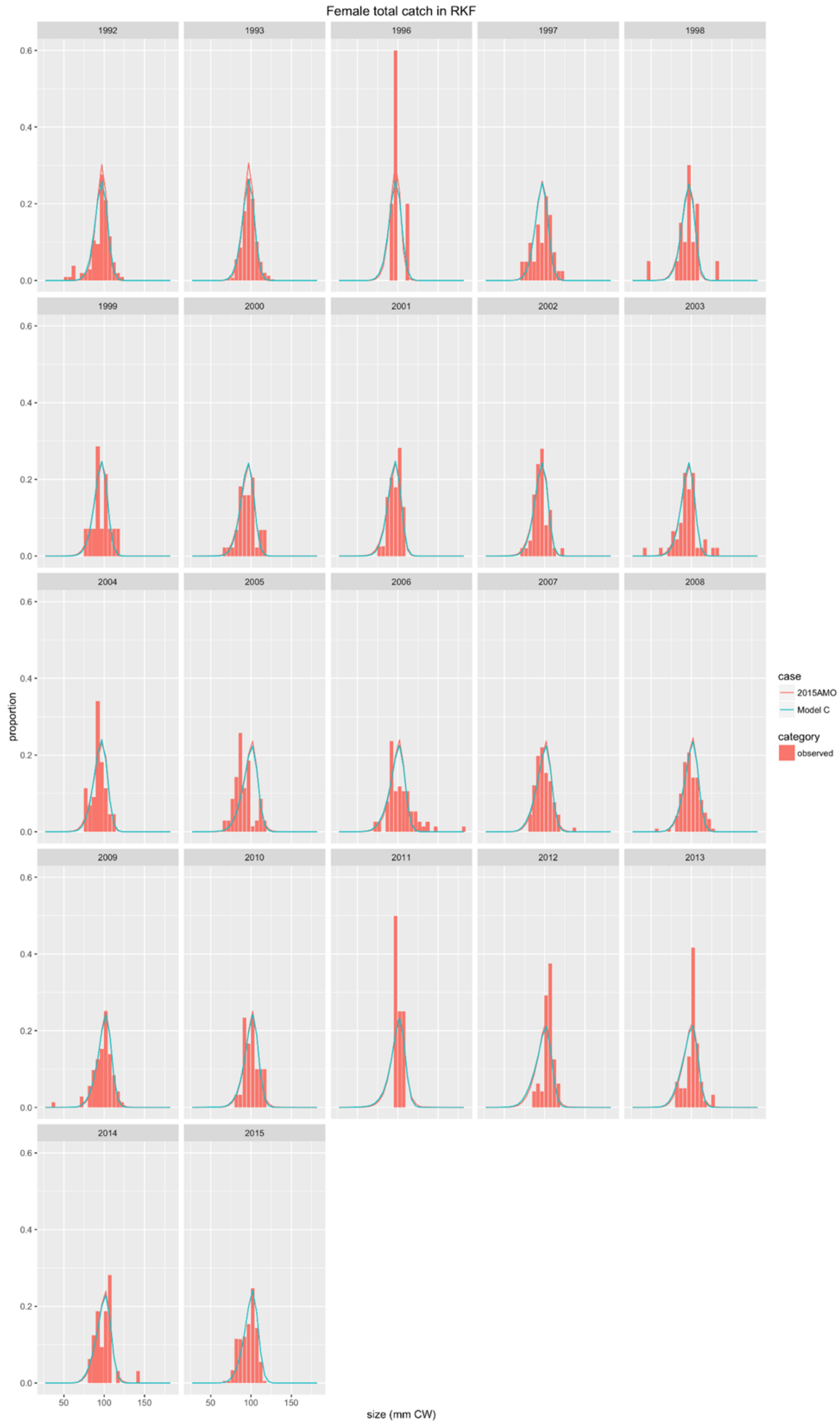

Figure 69. Fits to bycatch female size compositions from the BBRKC fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

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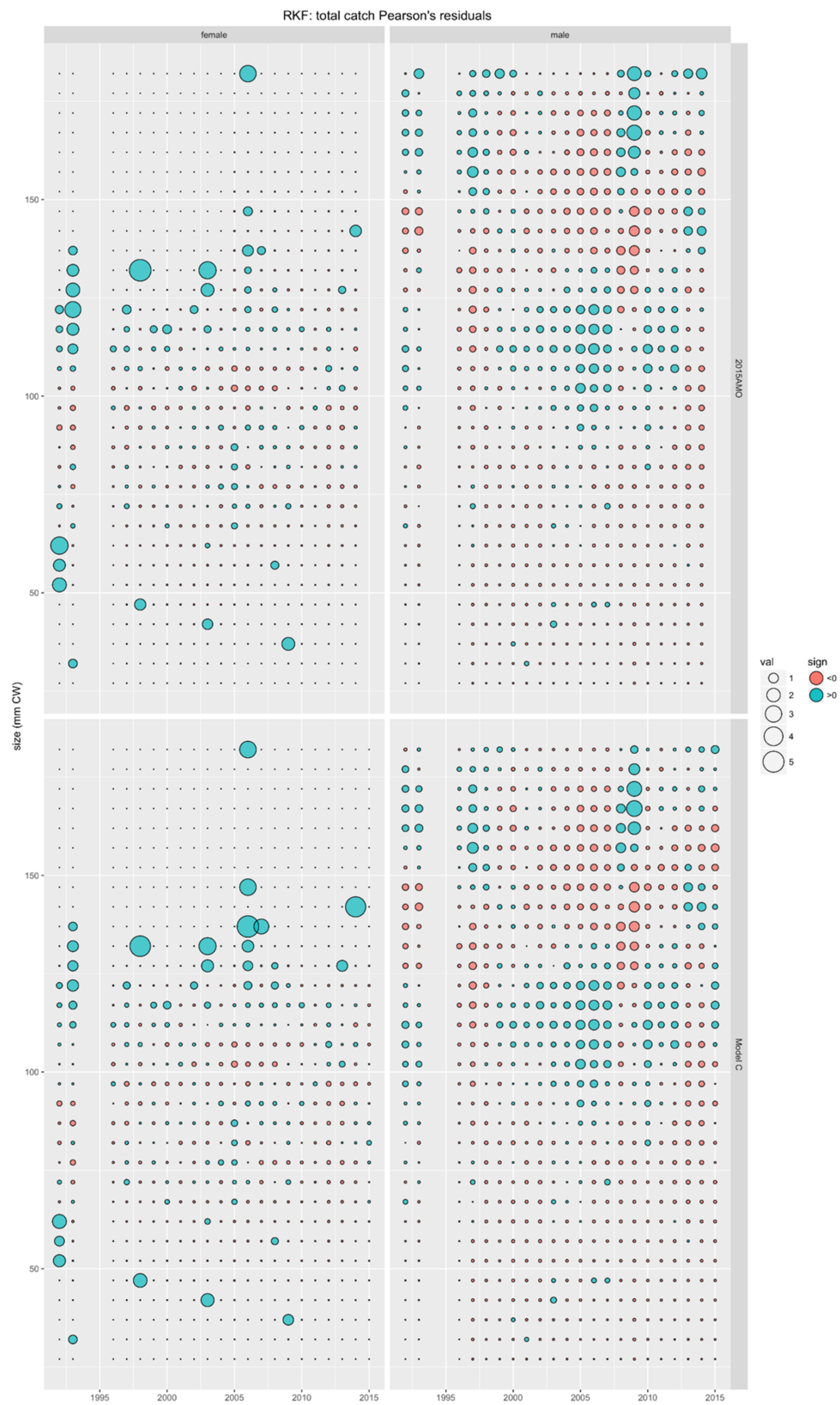

Figure 70. Pearson’s residuals for fits to bycatch size compositions from the BBRKC fishery for the 2015 assessment (2015AMO) and the author’s preferred model (Model C).

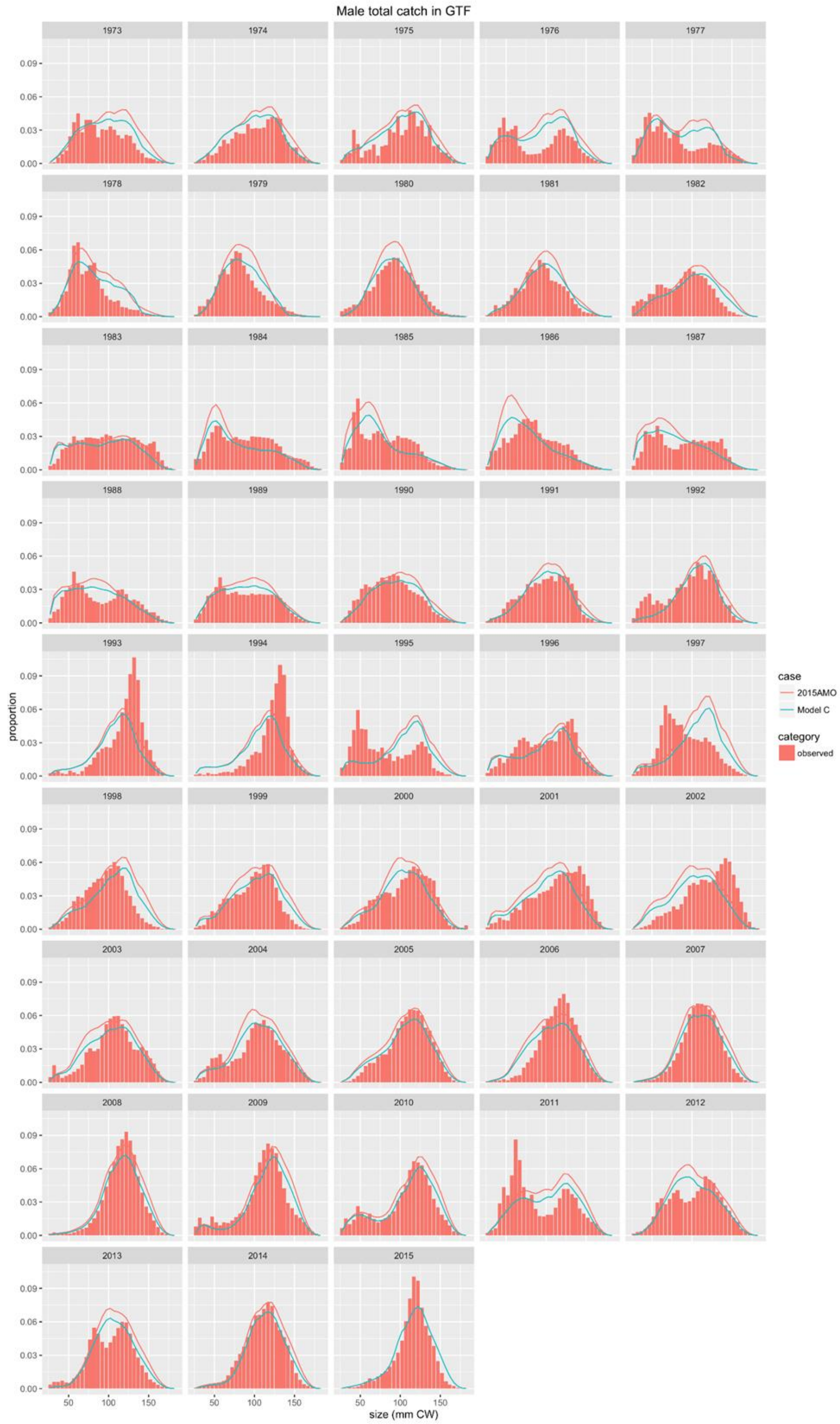

Figure 71. Fits to bycatch male size compositions from the groundfish fisheries for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

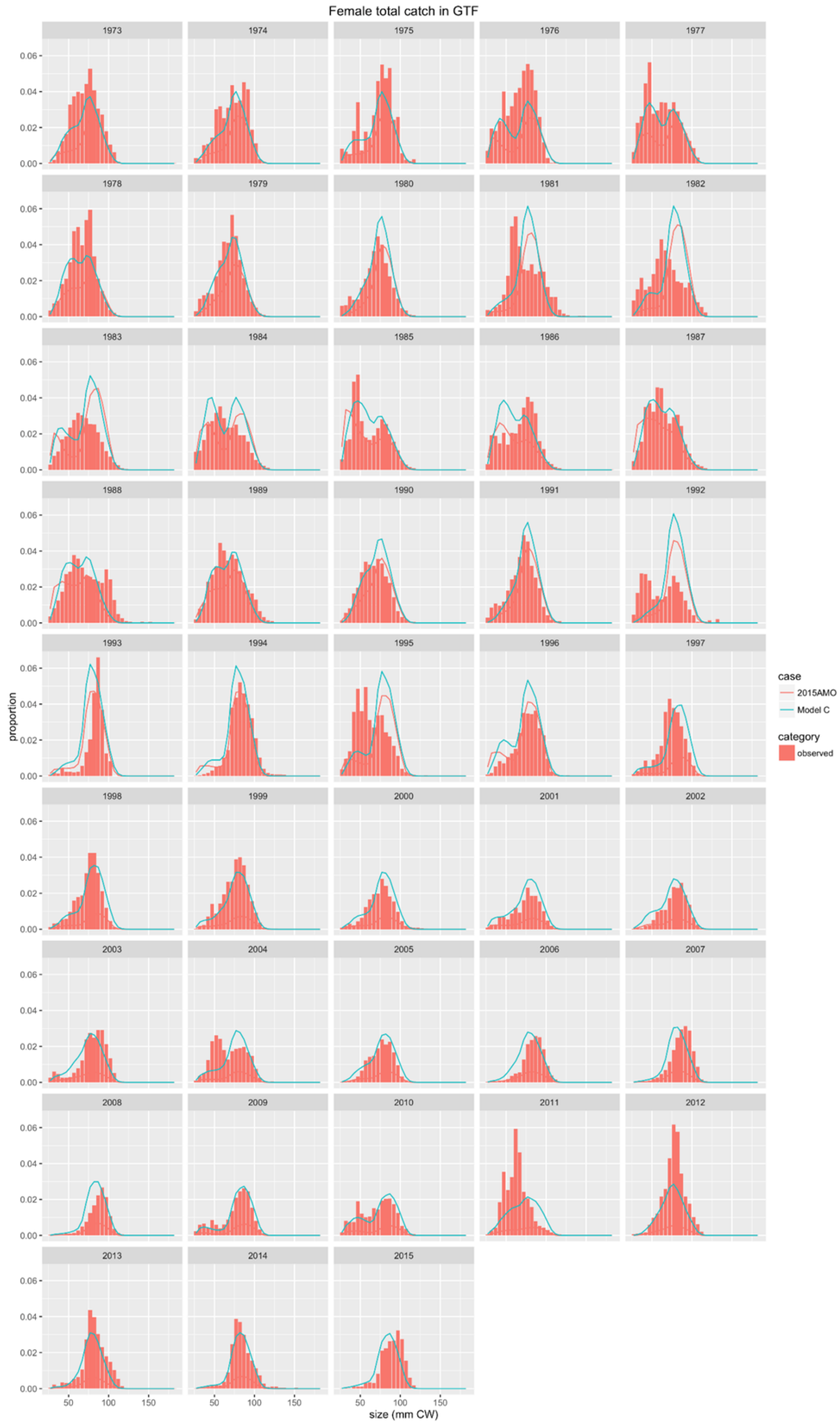

Figure 72. Fits to bycatch female size compositions from the groundfish fisheries for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

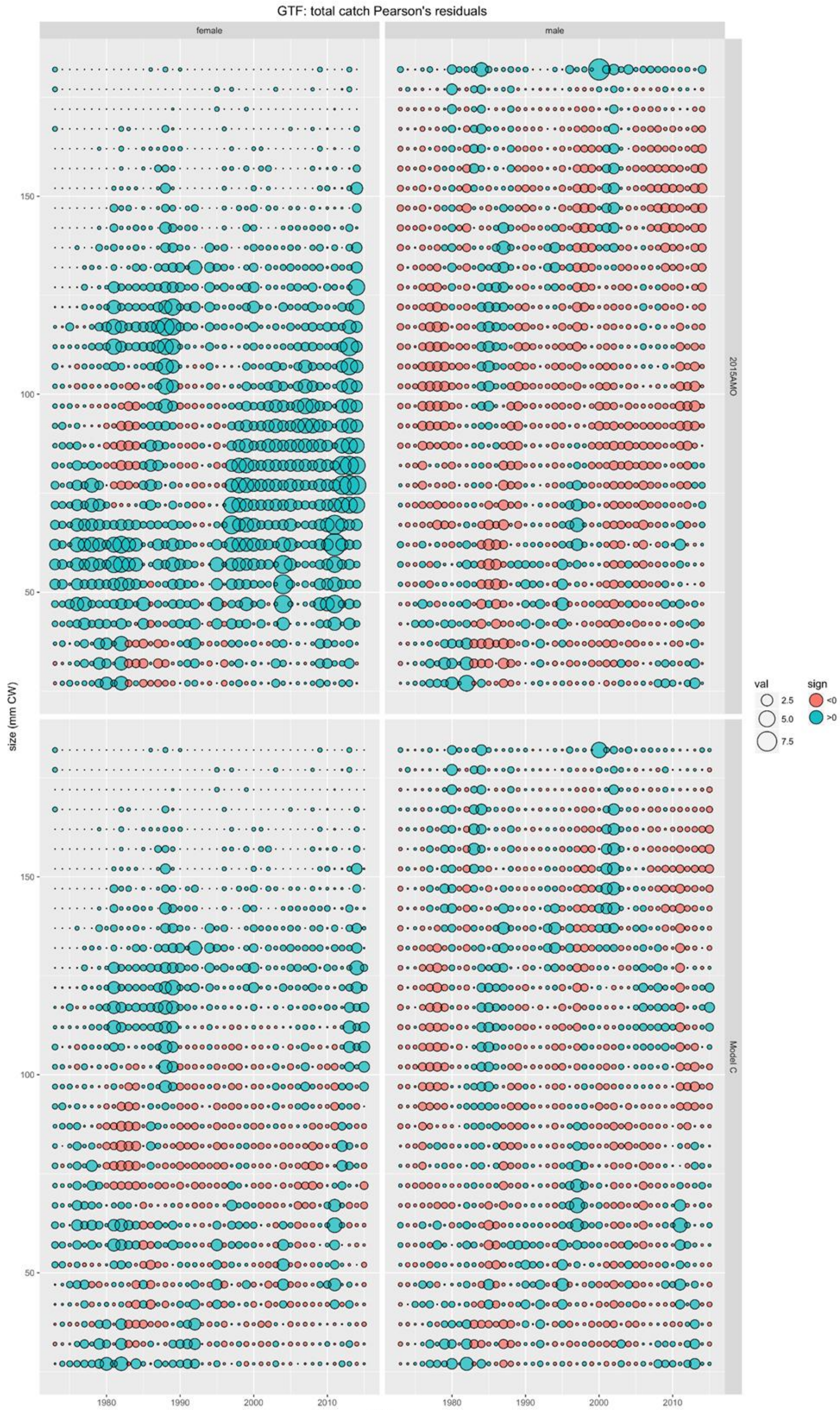

Figure 73. Pearson's residuals for fits to bycatch size compositions from the groundfish fisheries for the 2015 assessment (2015AMO) and the author's preferred model (Model C).

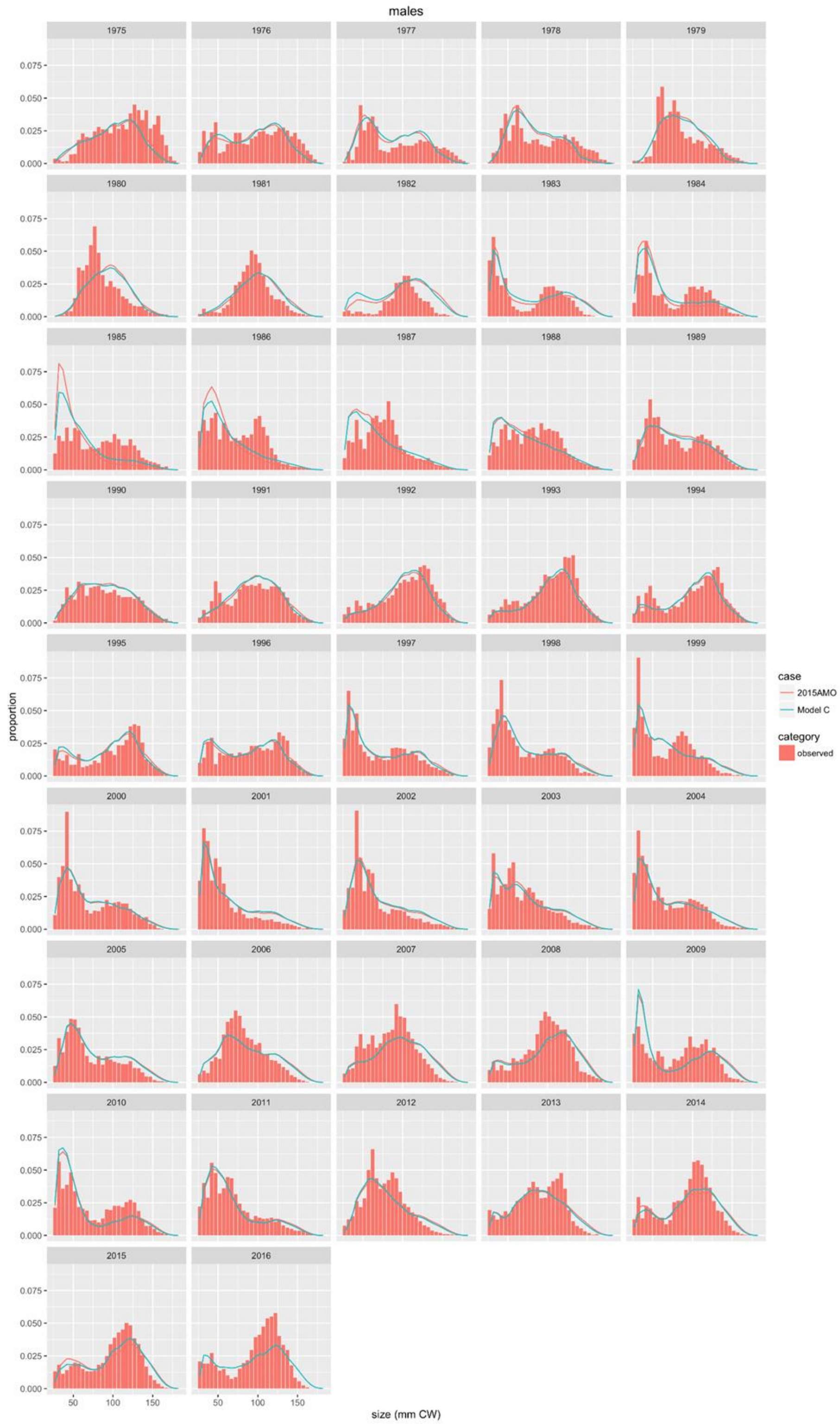

Figure 74. Fits to bycatch male size compositions from the NFS EBS bottom trawl survey for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

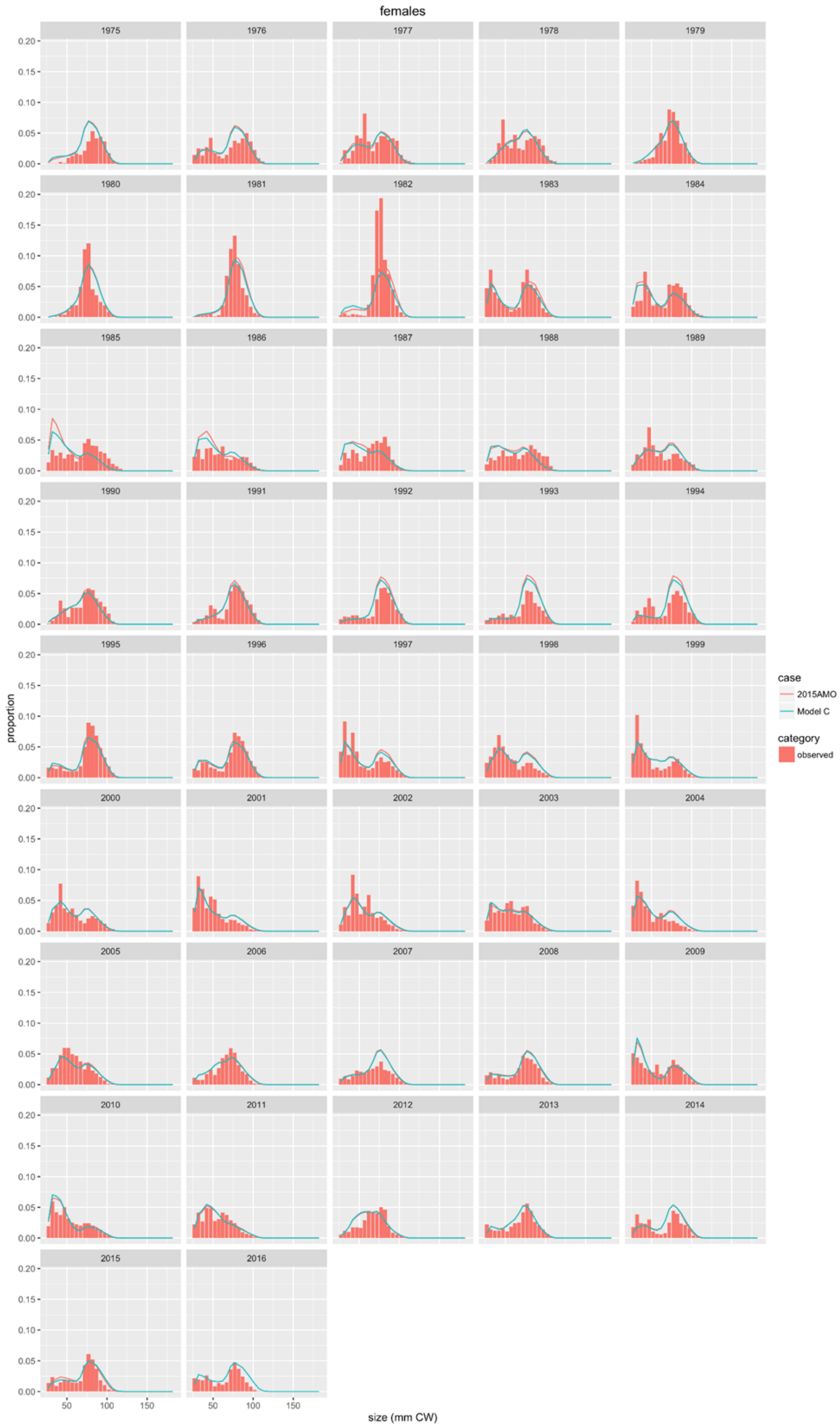

Figure 75. Fits to bycatch female size compositions from the NFS EBS bottom trawl survey for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Bars: observed; lines: predicted.

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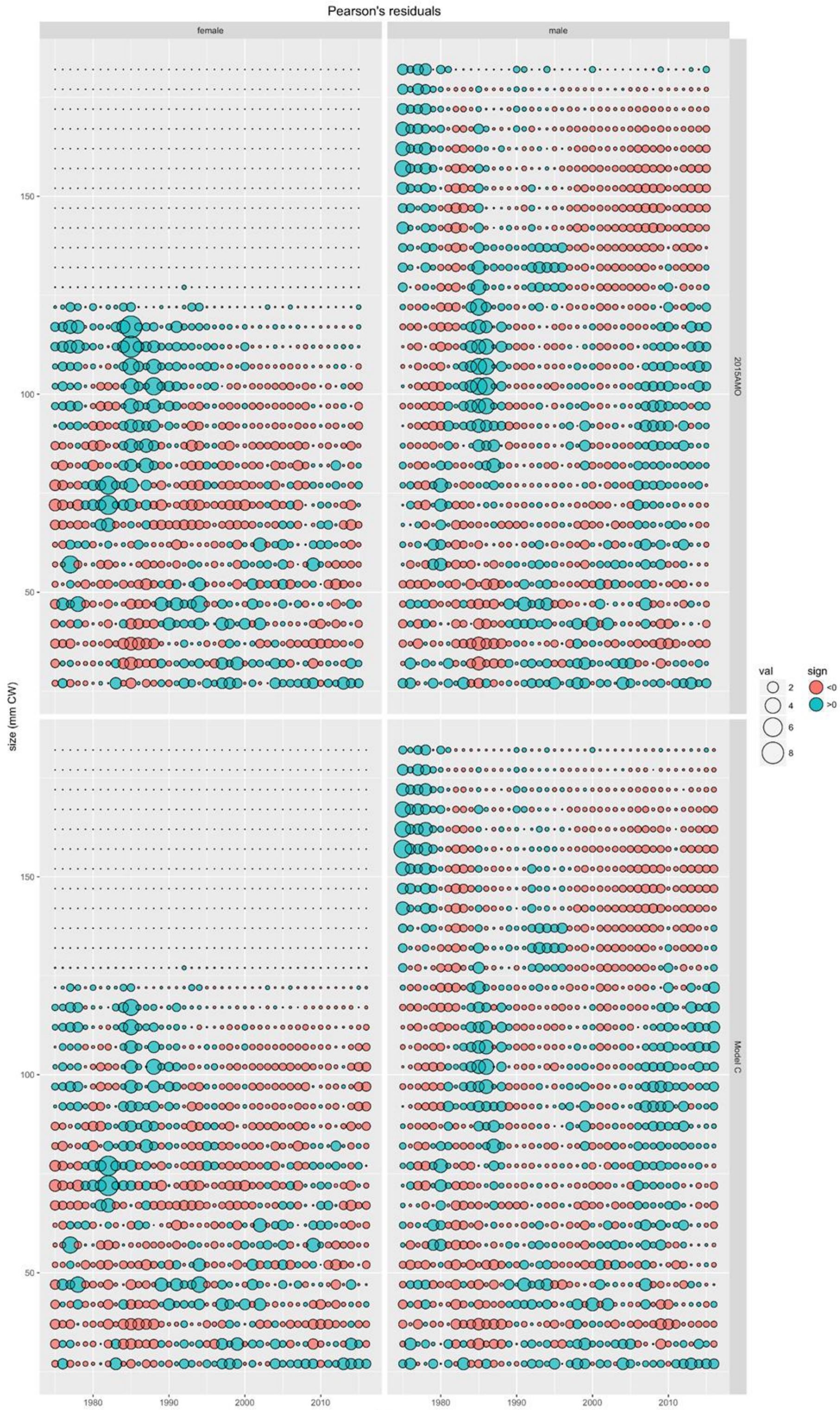


Figure 76. Pearson's residuals for fits to size compositions from the NFS EBS bottom trawl survey for the 2015 assessment (2015AMO) and the author's preferred model (Model C).

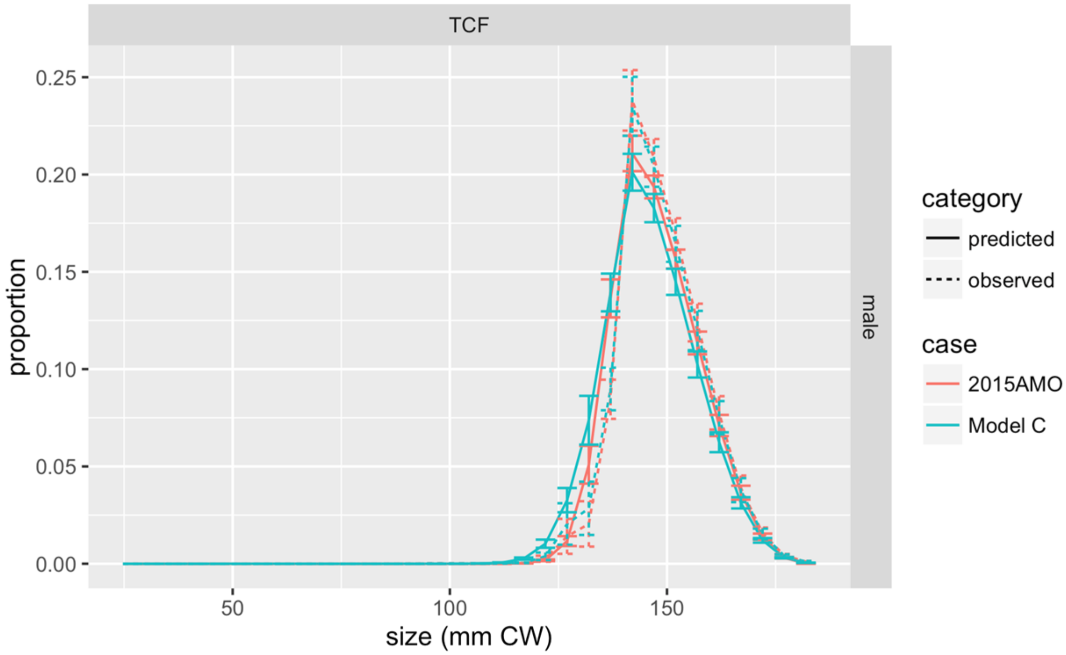


Figure 77. Marginal distributions for retained catch (dockside) size compositions from the directed Tanner crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Dotted lines: observed; solid lines: predicted.

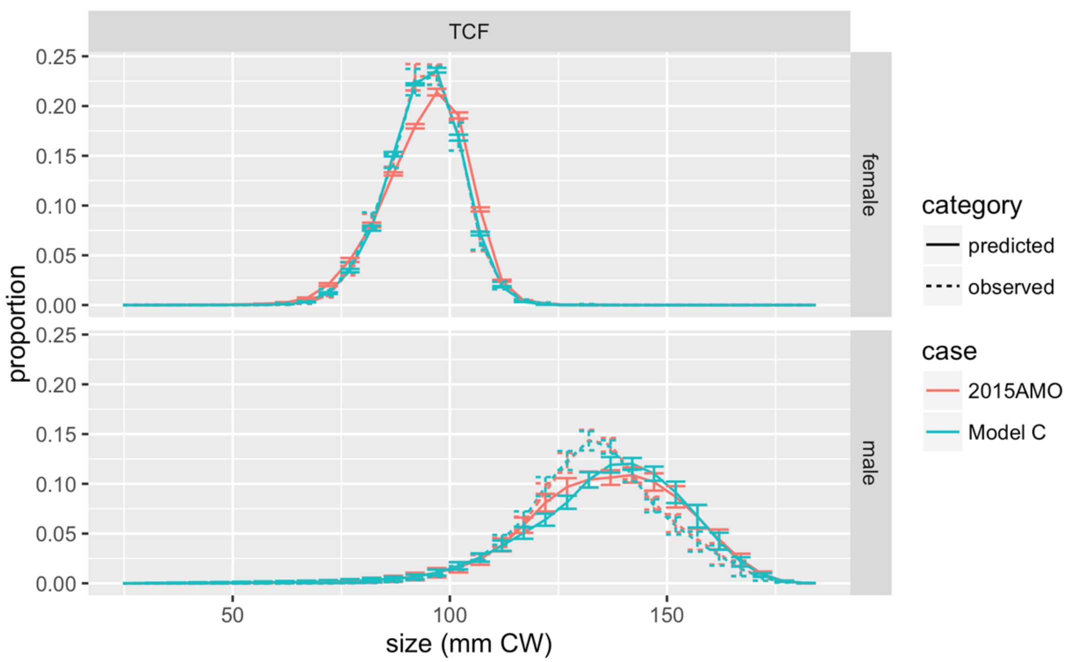


Figure 78. Marginal distributions for total catch (at-sea) size compositions from the directed Tanner crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Dotted lines: observed; solid lines: predicted.

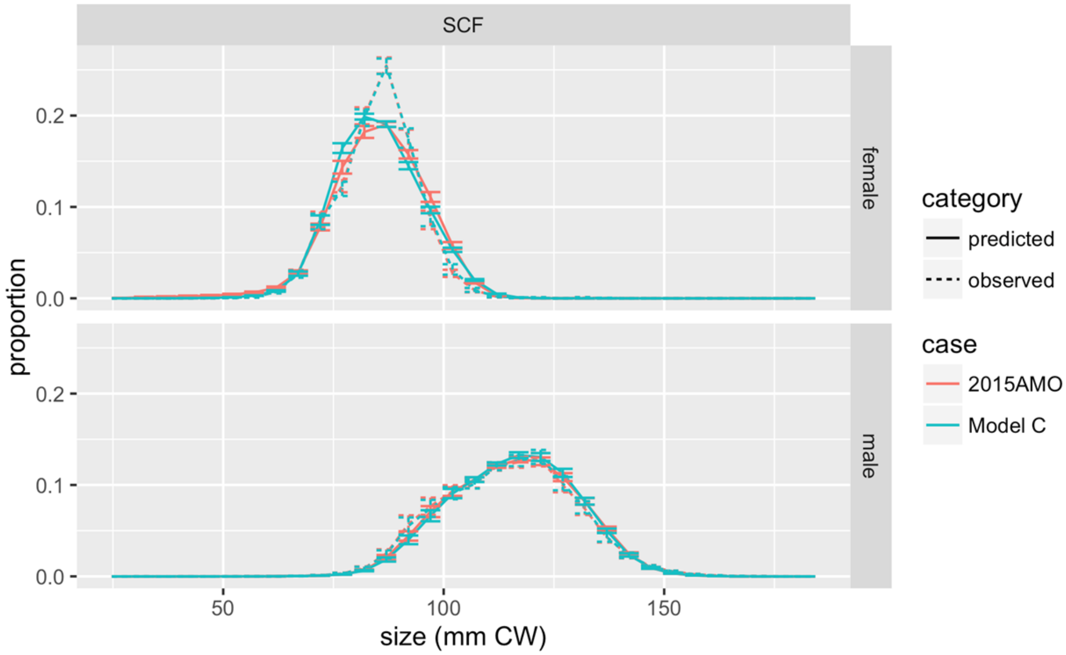


Figure 79. Marginal distributions for bycatch (at-sea) size compositions from the snow crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Dotted lines: observed; solid lines: predicted.

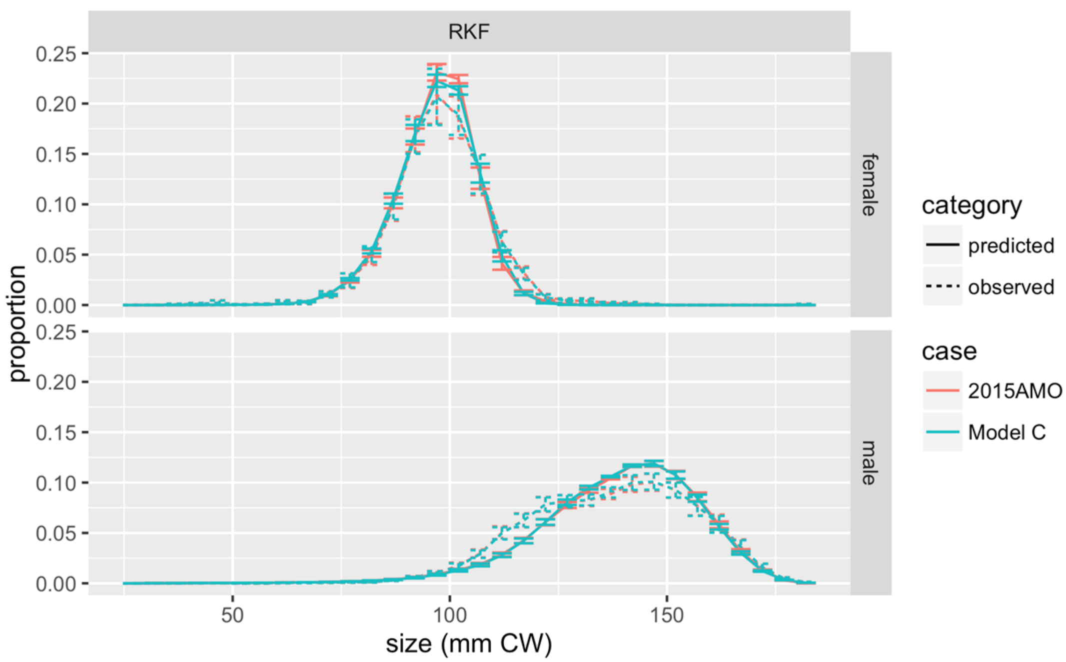


Figure 80. Marginal distributions for bycatch (at-sea) size compositions from the BBRKC fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Dotted lines: observed; solid lines: predicted.

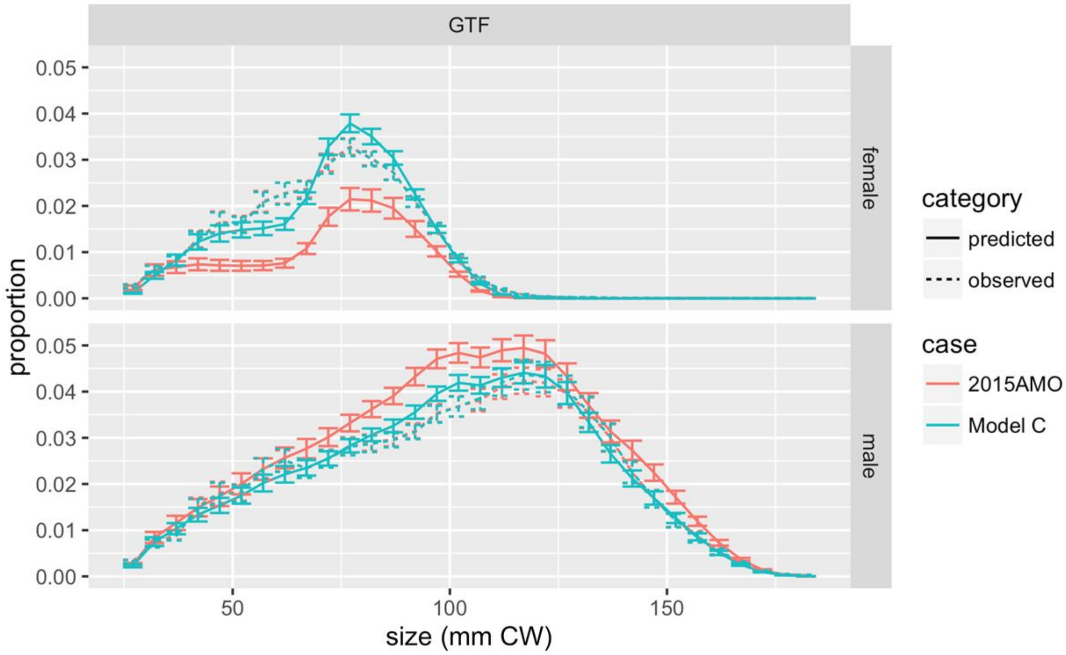


Figure 81. Marginal distributions for bycatch (at-sea) size compositions from the groundfish fisheries for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Dotted lines: observed; solid lines: predicted.

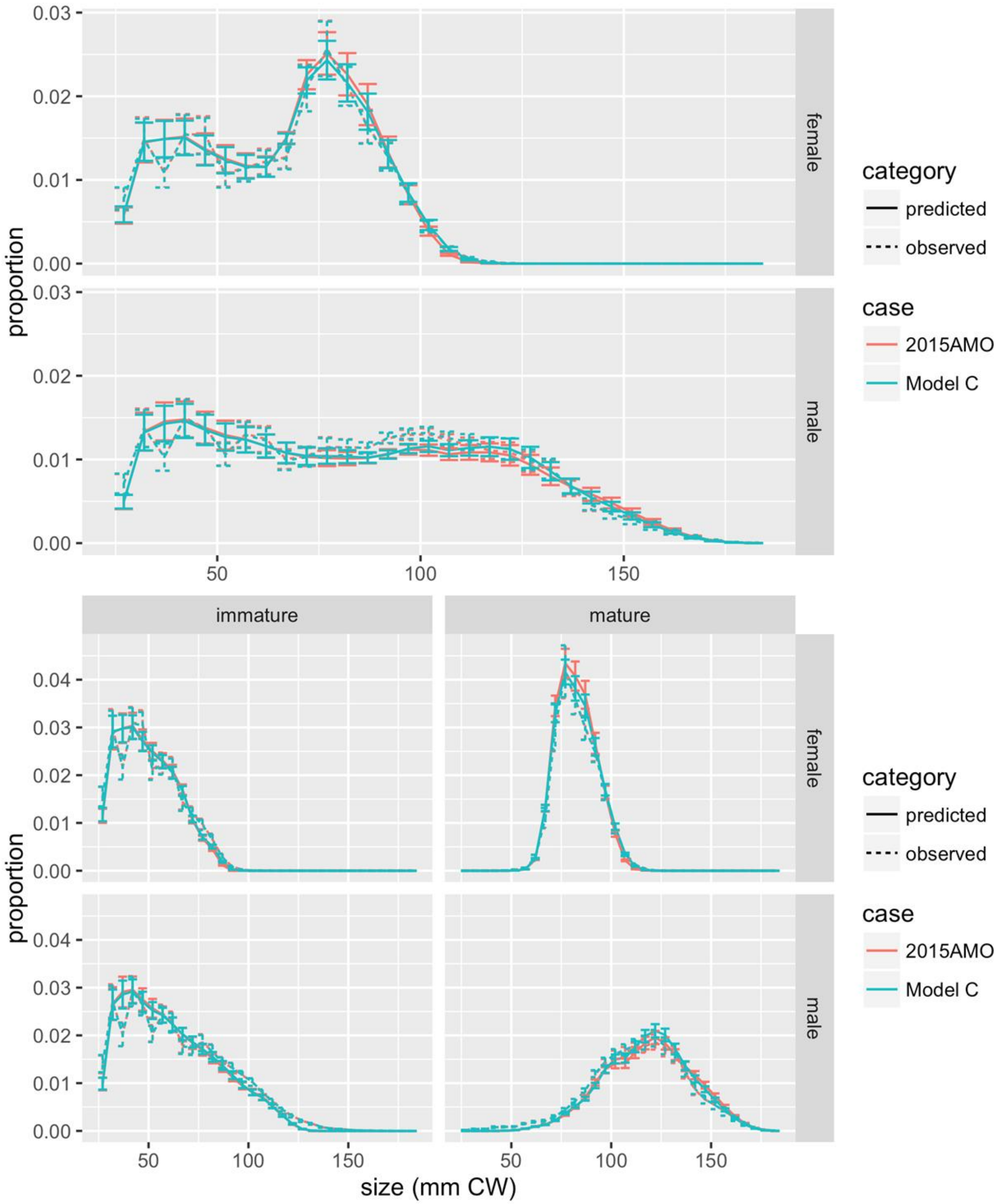


Figure 82. Marginal distributions for size compositions from the NMFS EBS trawl survey for the 2015 assessment (2015AMO) and the author's preferred model (Model C). Dotted lines: observed; solid lines: predicted. Distributions are shown: top) by sex; bottom) by sex and maturity state.

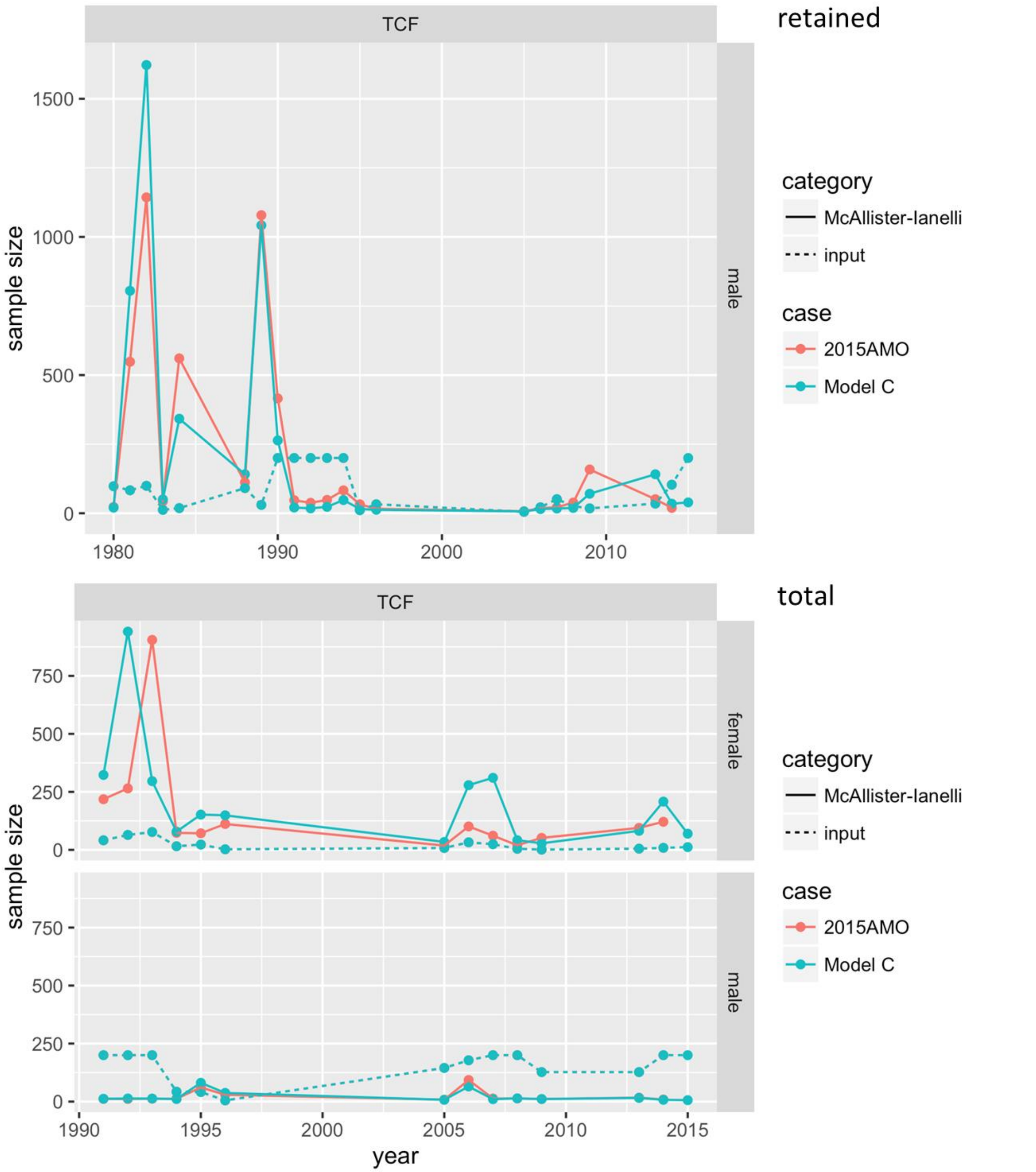


Figure 83. Input and effective (McAllister-Ianelli) sample sizes for retained (upper) and total catch (lower) size compositions from the directed Tanner crab fishery for the 2015 assessment (2015AMO) and the author's preferred model (Model C). dotted lines: input; solid lines: effective.

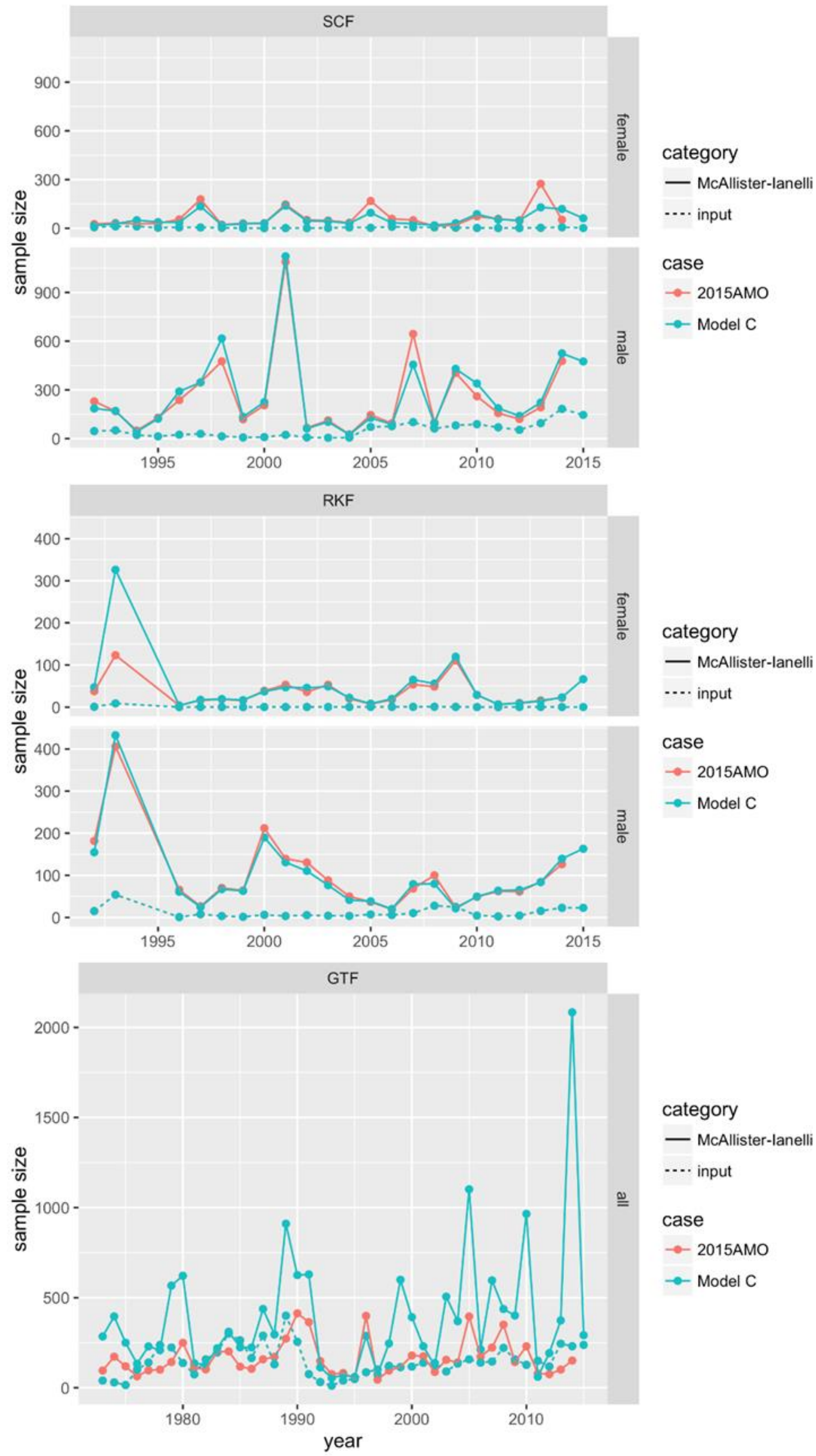


Figure 84. Input and effective (McAllister-Ianelli) sample sizes for bycatch size compositions from the snow crab fishery (upper), BBRKC (middle), and groundfish fisheries (lower) for the 2015 assessment (2015AMO) and the author's preferred model (Model C). dotted lines: input; solid lines: effective.

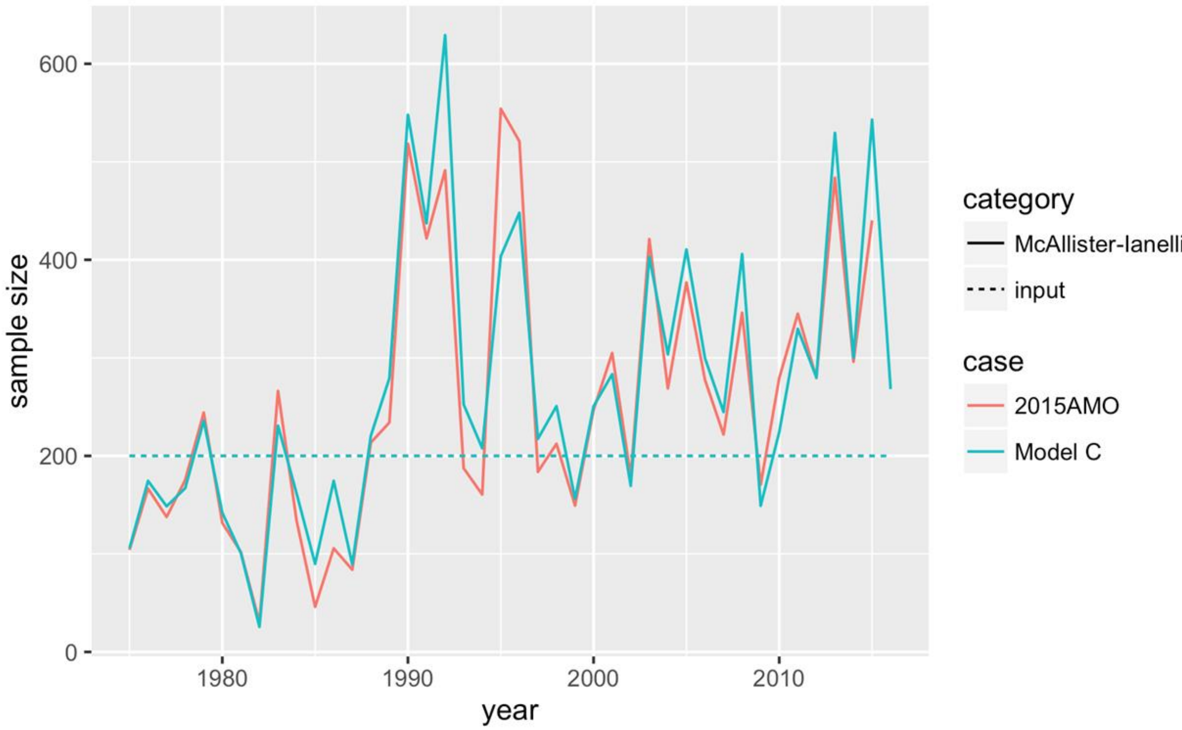


Figure 85. Input and effective (McAllister-Ianelli) sample sizes for size compositions from the NMFS EBS trawl survey for the 2015 assessment (2015AMO) and the author's preferred model (Model C). dotted lines: input; solid lines: effective.

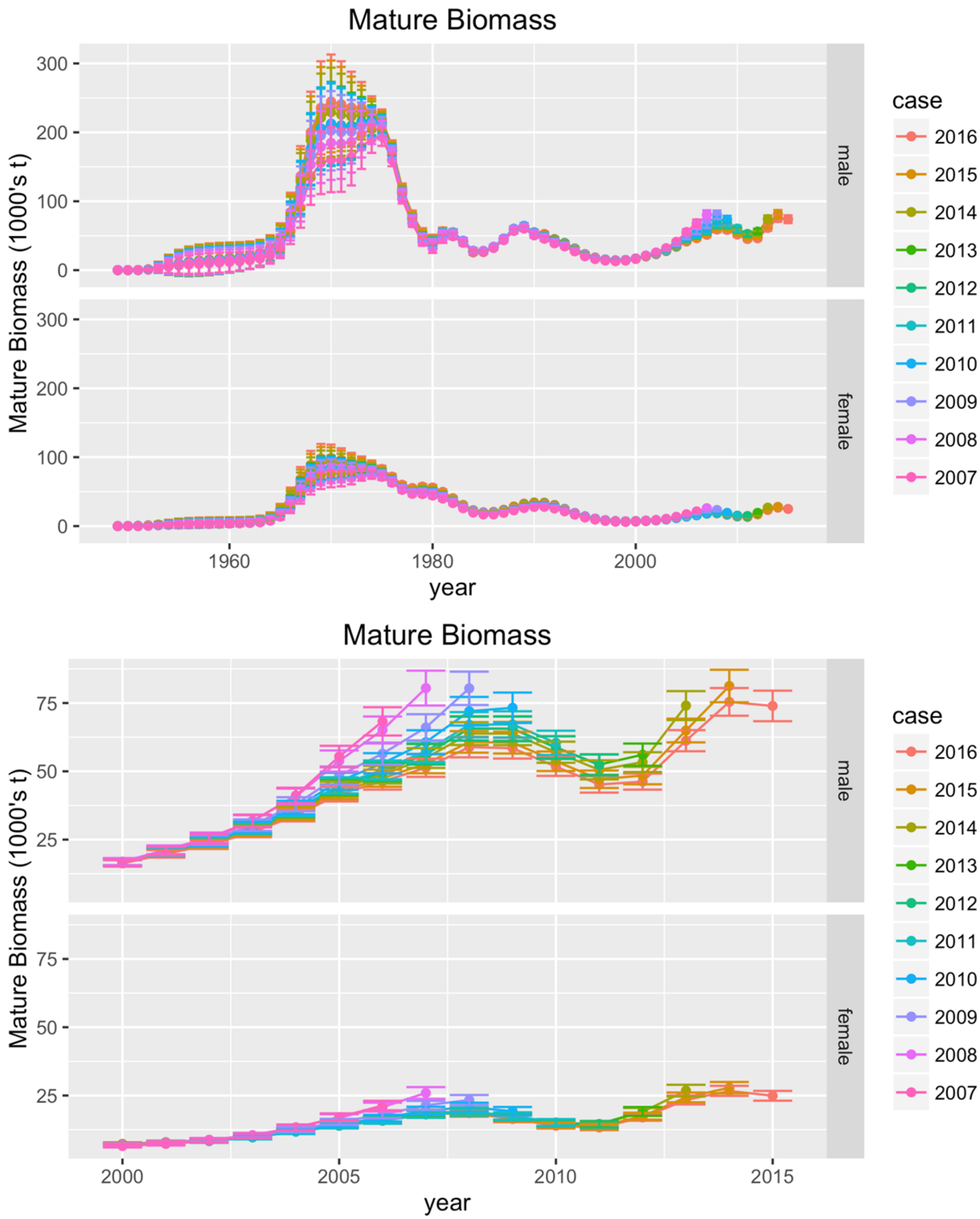


Figure 86. Retrospective analysis for estimated mature biomass-at-mating from the author's preferred model (Model C). Model C was run for each case as though the assessment were conducted in the year indicated by the case name. Upper plot: full model time series; lower plot: recent time period.

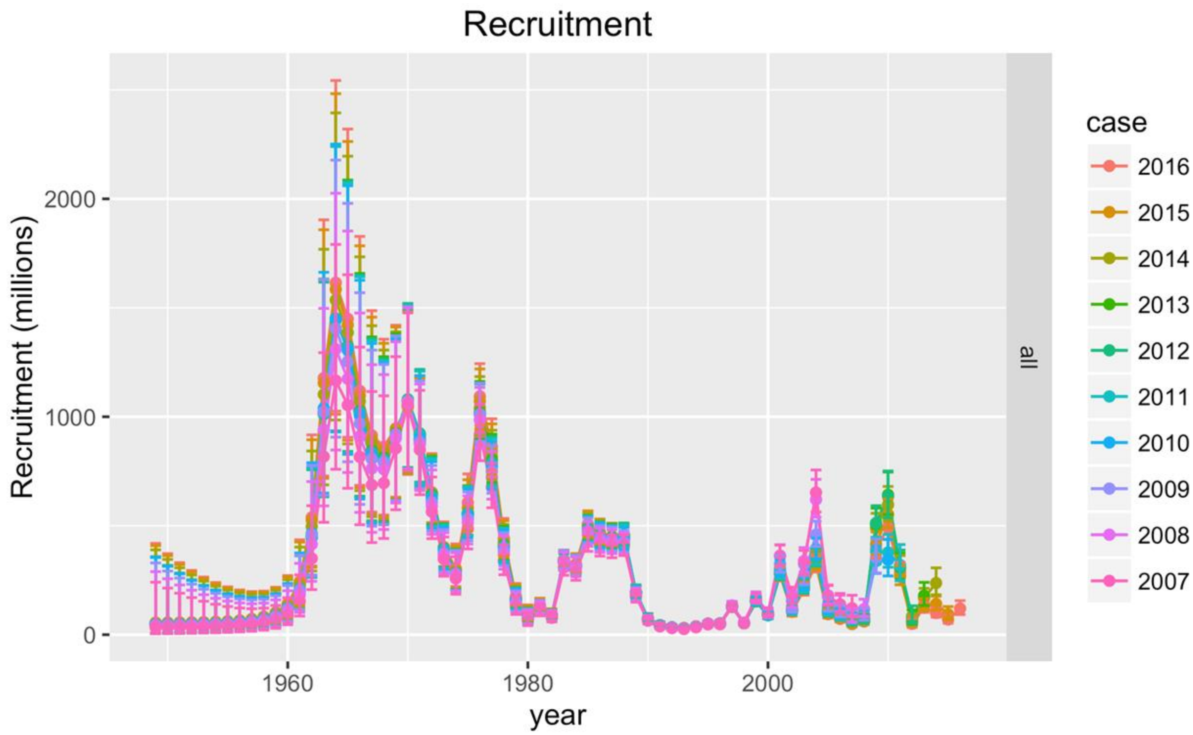
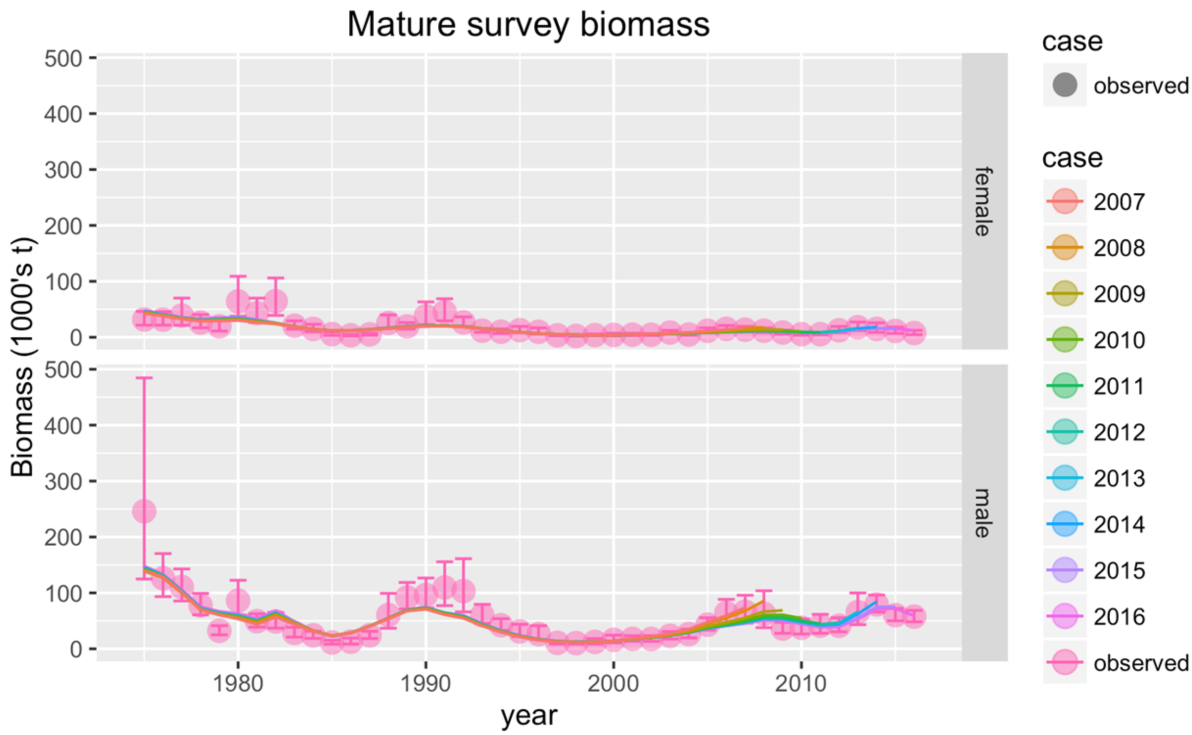


Figure 87. Retrospective analysis for estimated recruitment from the author's preferred model (Model C). Model C was run for each case as though the assessment were conducted in the year indicated by the case name. Upper plot: full model time series; lower plot: recent time period.



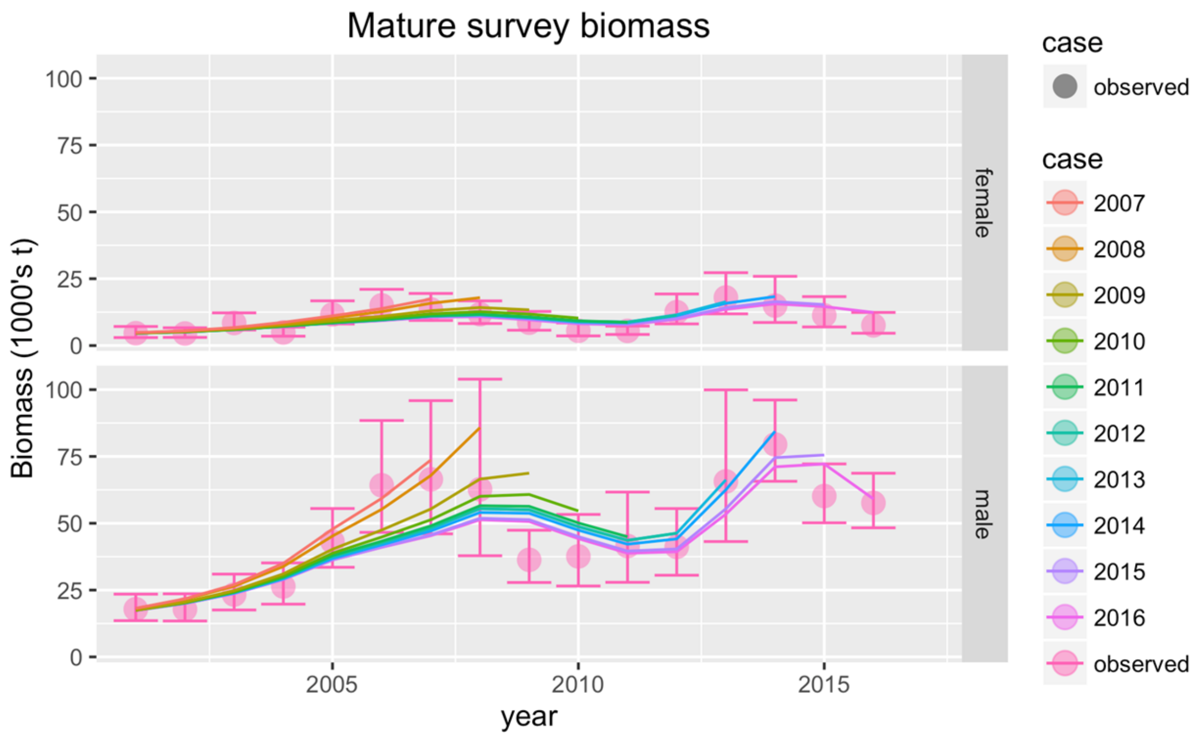


Figure 88. Retrospective analysis for fits to mature survey biomass from the author's preferred model (Model C). Observed: symbols and error bars; lines: predicted. Model C was run for each case as though the assessment were conducted in the year indicated by the case name. Upper plot: full model time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

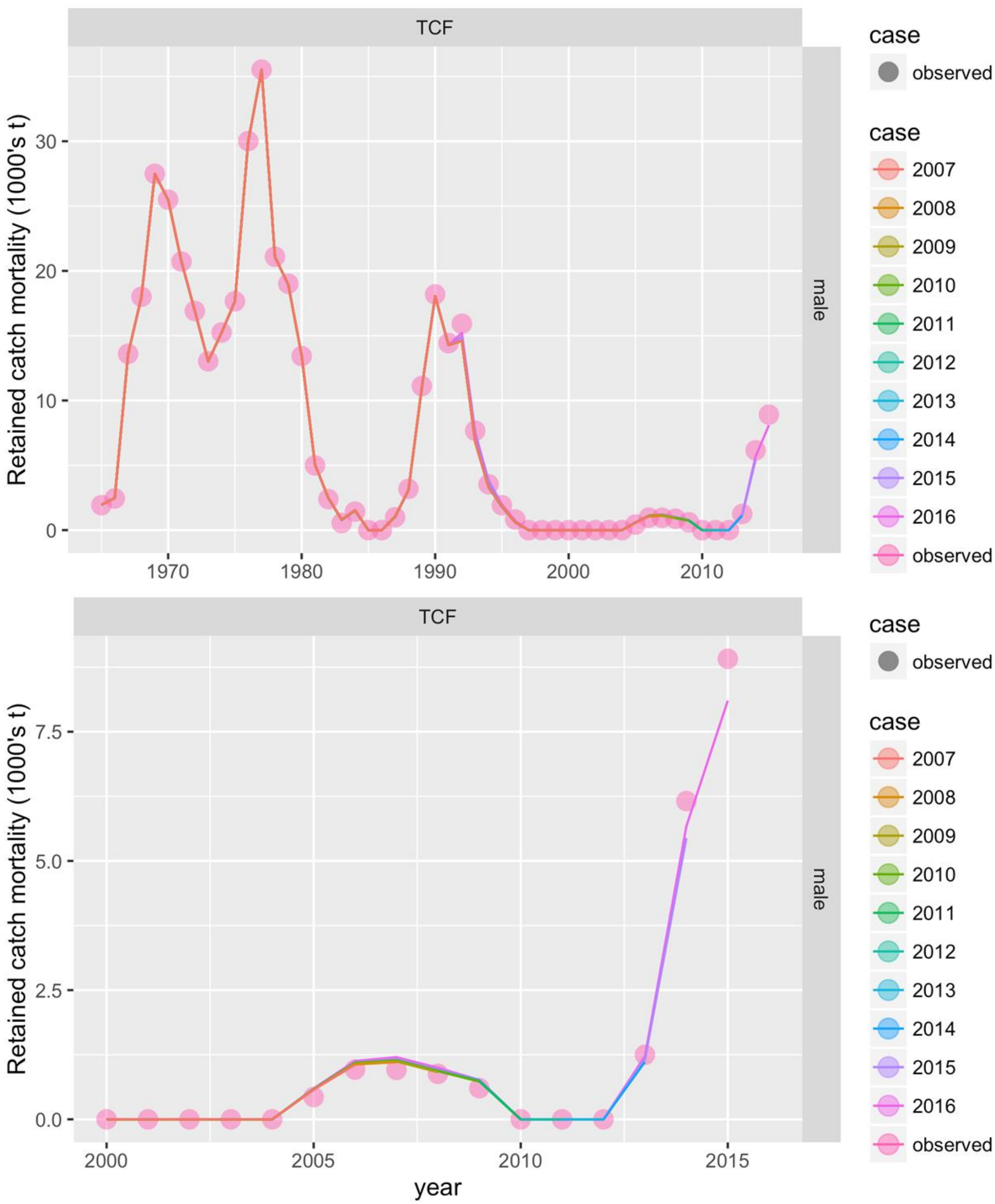


Figure 89. Retrospective analysis for fits to retained catch from the author's preferred model (Model C). Observed: symbols and error bars; lines: predicted. Model C was run for each case as though the assessment were conducted in the year indicated by the case name. Upper plot: full model time series;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

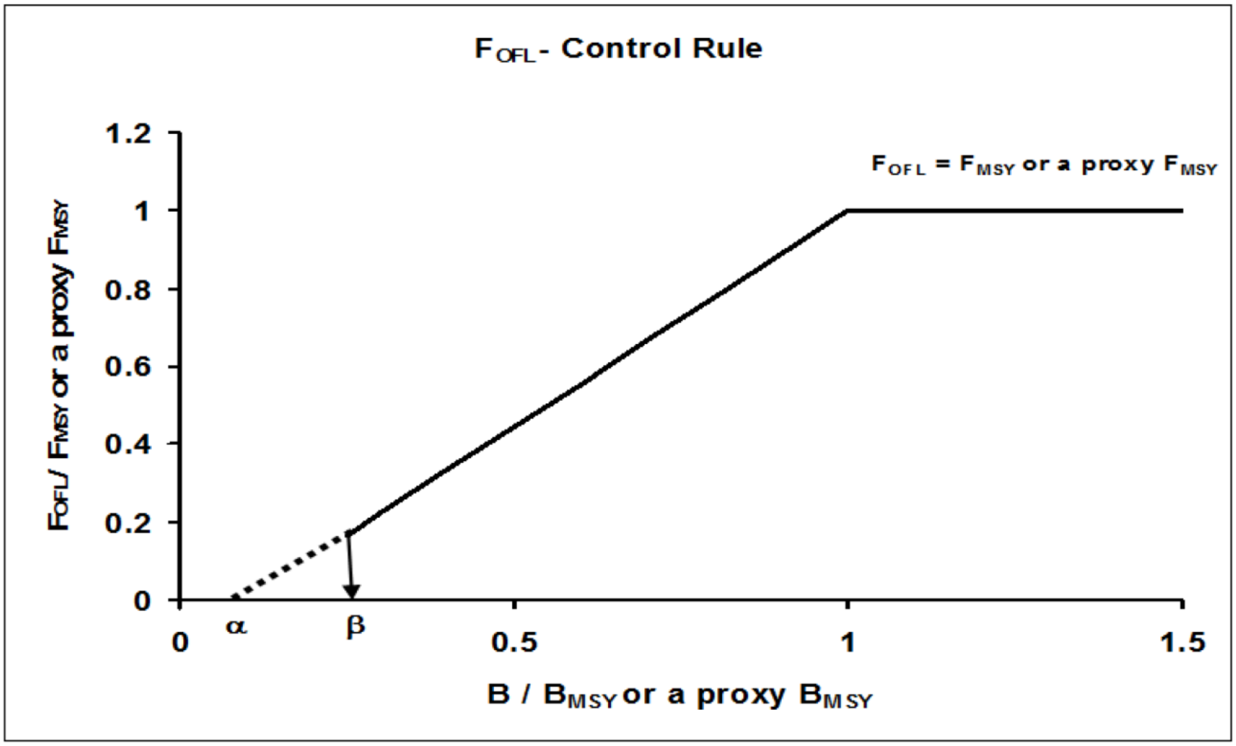


Figure 90. The F_{OFL} harvest control rule. For Tier 3 stocks such as EBS Tanner crab, F_{MSY} and B_{MSY} are based on spawning biomass per recruit proxies, where $F_{MSY} = F_{35\%}$, B_{MSY} = B35%, and MMB at mating time is used as a surrogate for egg production/spawning biomass.

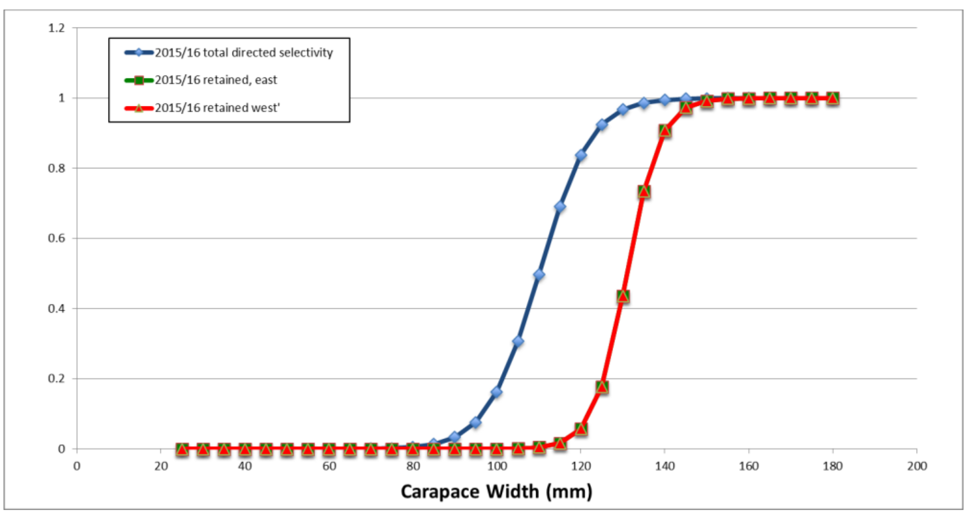


Figure 91. The selectivity and retention curves for males in the directed fishery used to calculate the OFL.

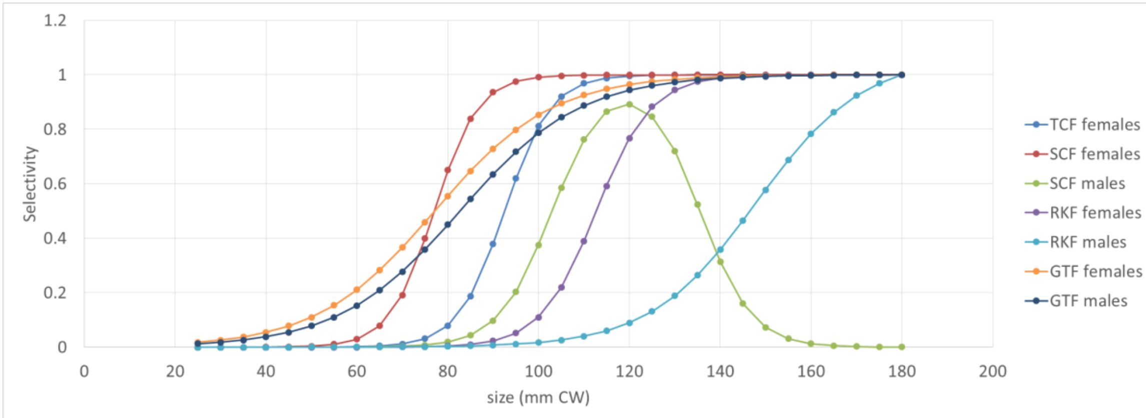


Figure 92. Bycatch fishery selectivity curves used to calculate the OFL.

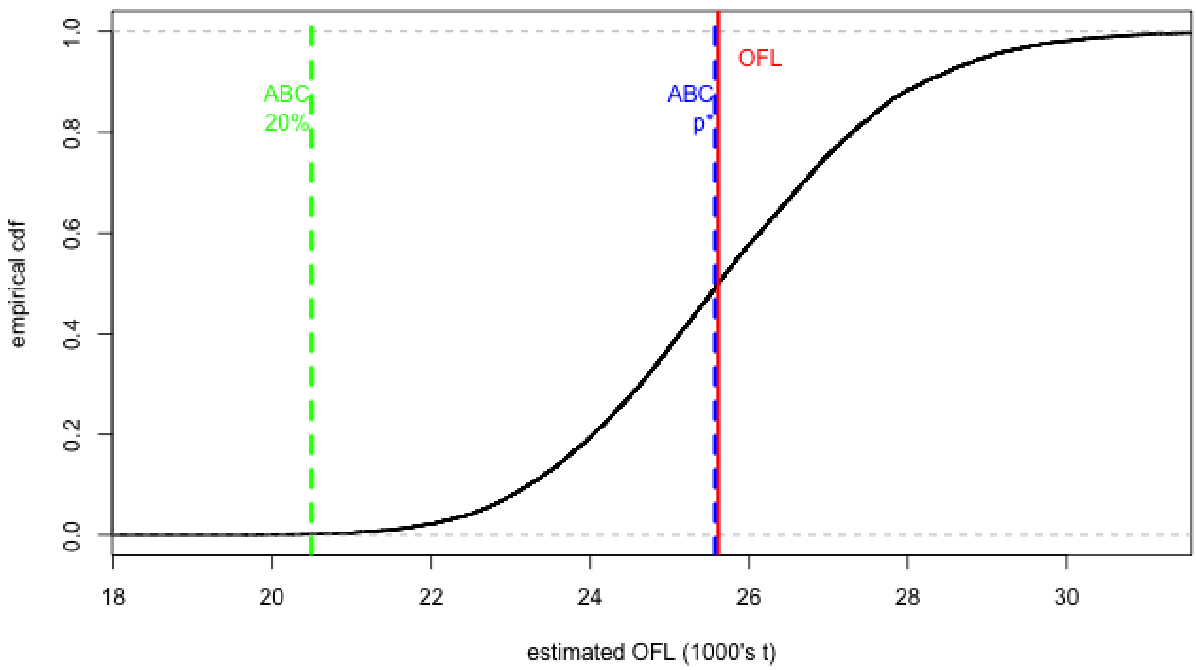


Figure 93. Distribution of OFL, illustrating the estimated p* ABC and 20%-buffer ABC, for Model C.

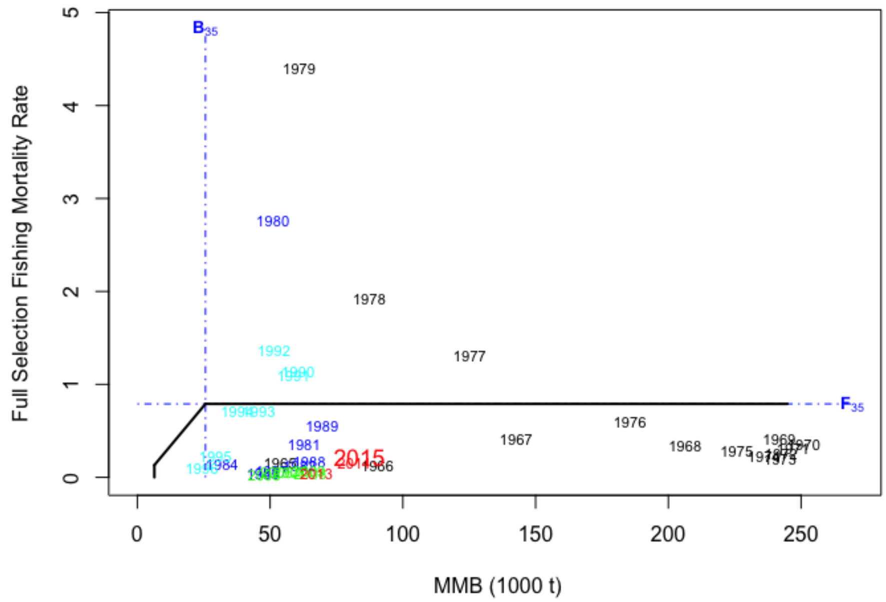


Figure 94. Tier 3 quad plot for the author's preferred model, Model A (Dataset D). Colors indicate different time periods. Black: 1965-1979; blue: 1980-1989; cyan: 1990-1999; green: 2000-2009; red: 2010-2015.

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

William T. Stockhausen
Alaska Fisheries Science Center
6 September 2016

Introduction

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

Evaluation

Objective function values

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

Population processes

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

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

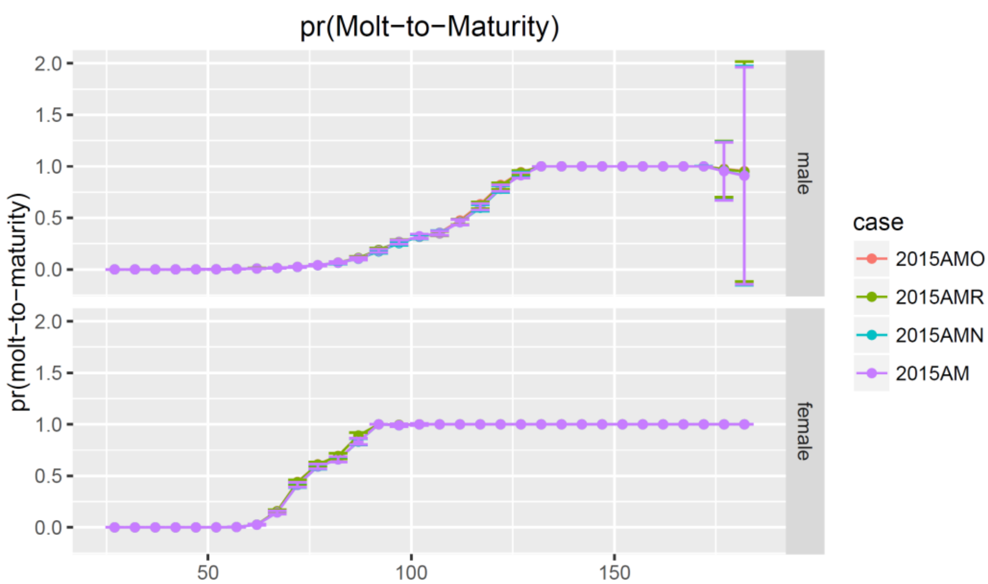


Figure 2. Comparison of estimates of the size-specific probability of undergoing terminal molt-to-maturity from the four models.

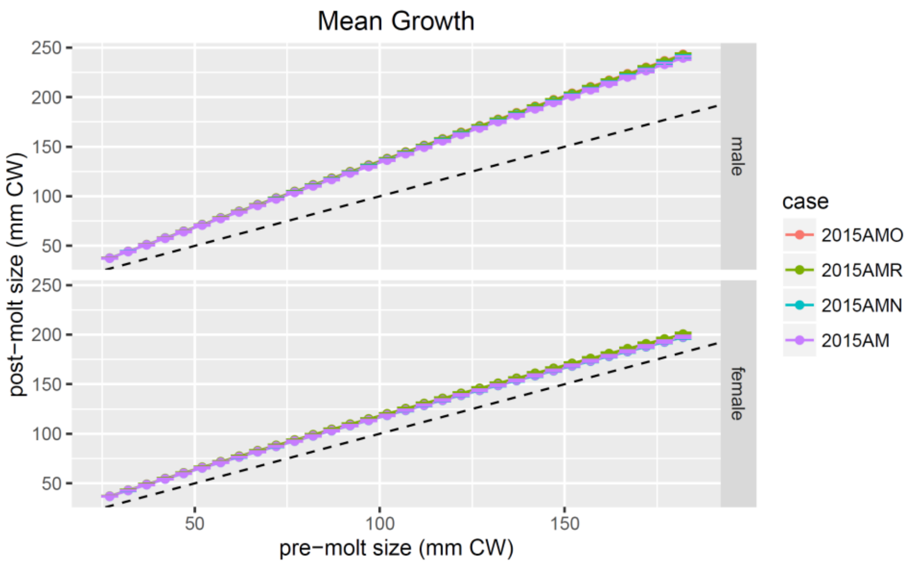


Figure 3. Estimates of the mean post-molt size as a function of pre-molt size from the four models.

Population quantities

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

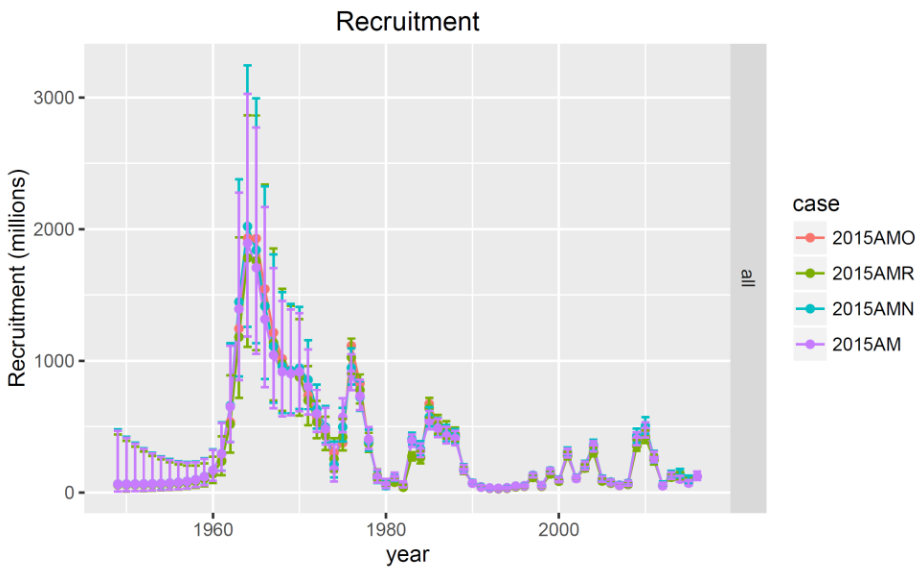


Figure 4. Estimated time series of recruitment from the four models.

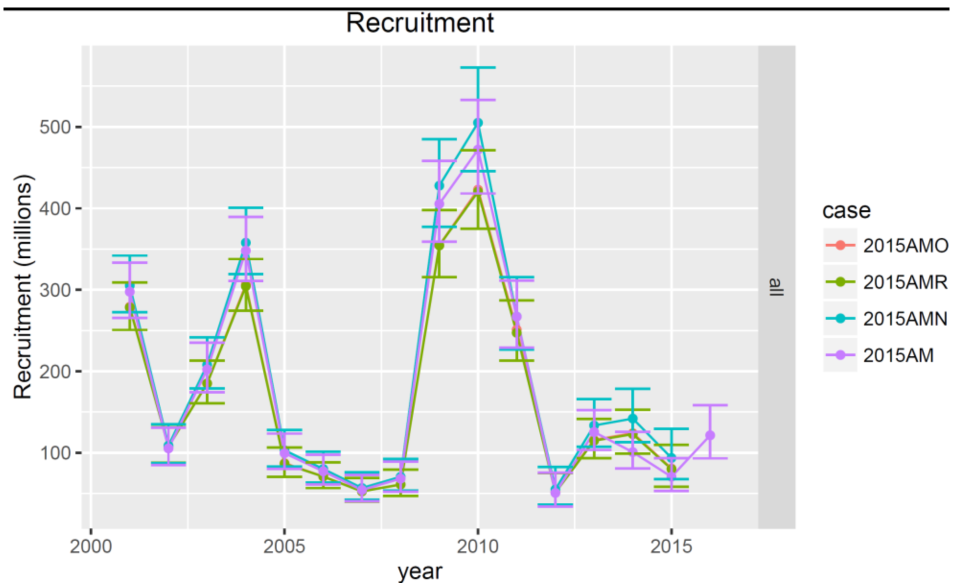


Figure 5. Estimated time series of recruitment from the four models.

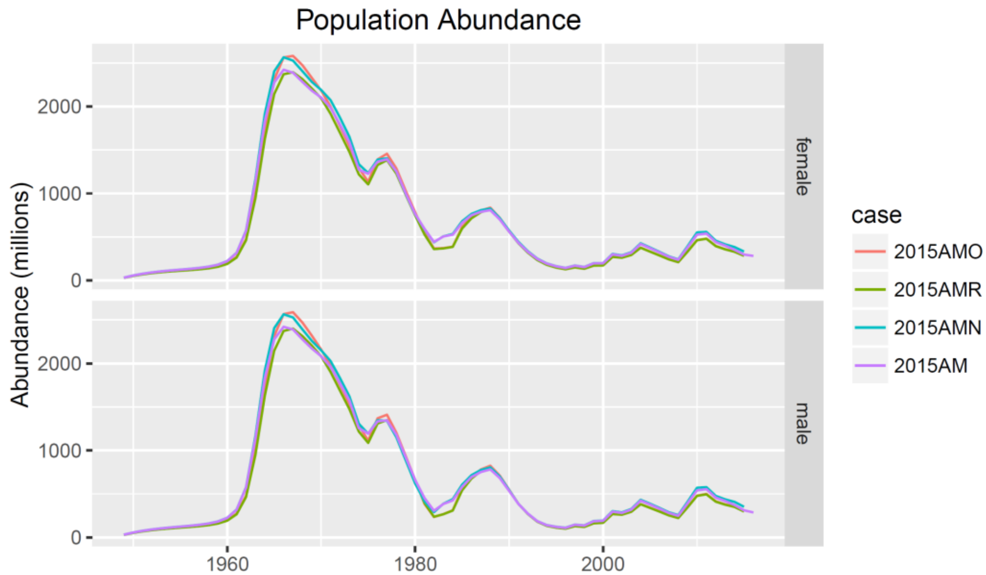


Figure 6. Estimated time series of population abundance from the four models.

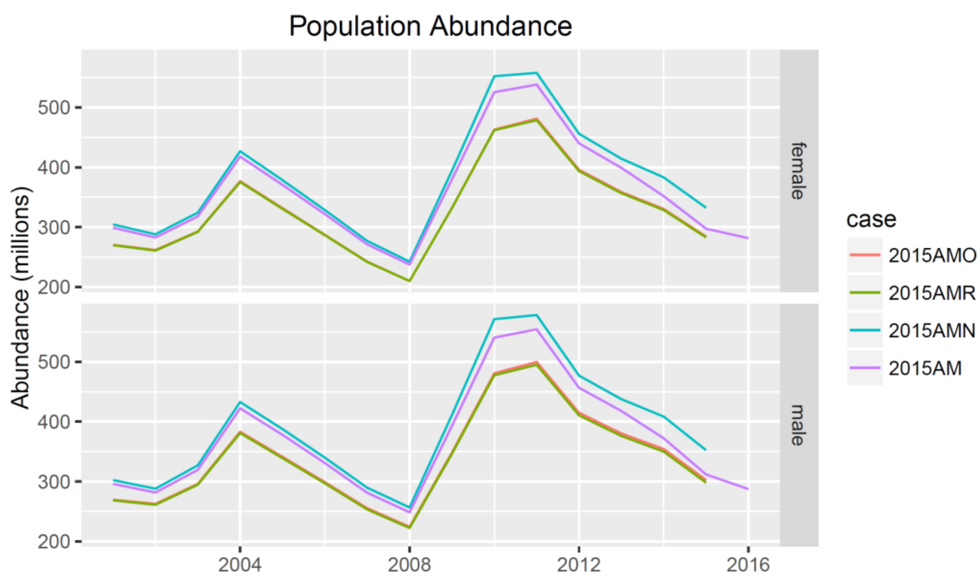


Figure 7. Estimated time series of population abundance from the four models.

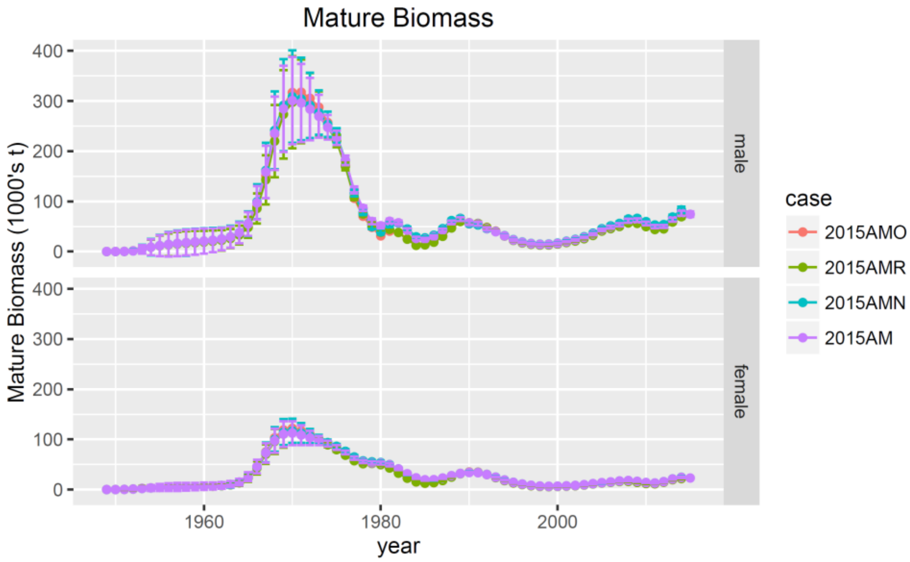


Figure 8. Estimated time series of mature biomass-at-mating from the four models.

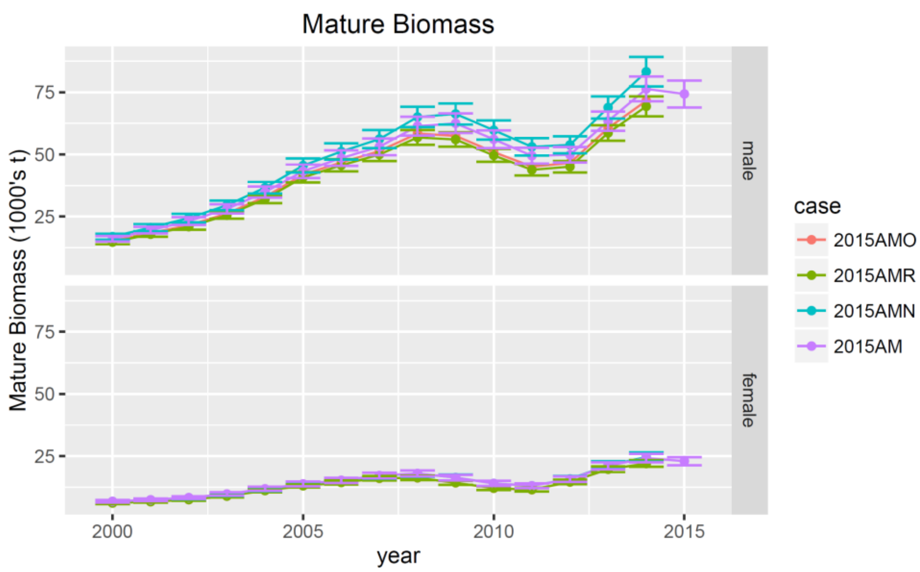


Figure 9. Estimated time series of mature biomass-at-mating from the four models.

Survey selectivity functions

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

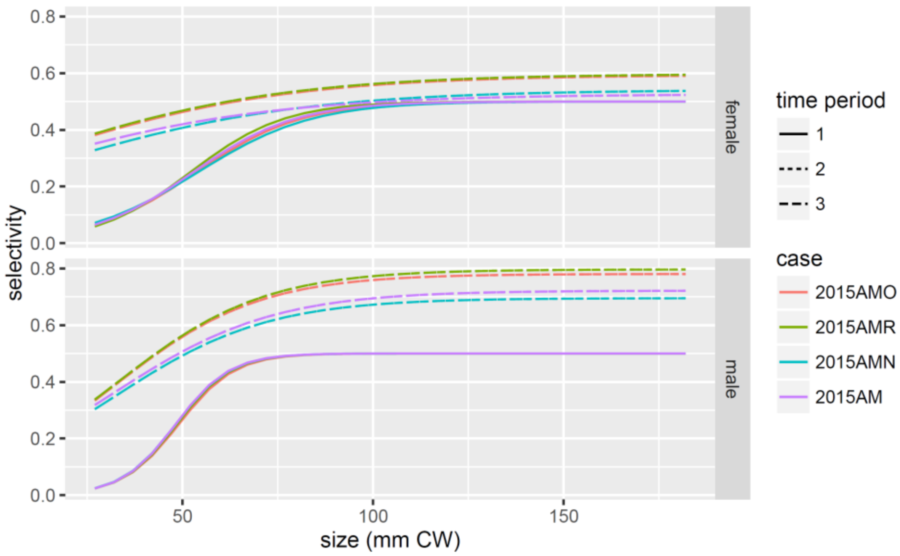


Figure 10. Comparison of estimated survey selectivity functions for the four models.

Fishery selectivity functions

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

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

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

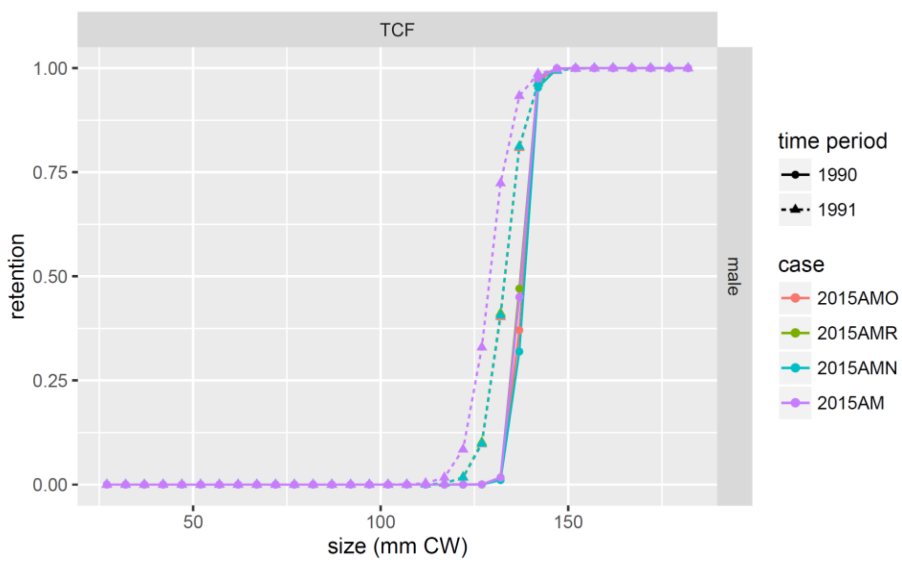


Figure 11. Comparison of estimated retention functions in the directed fishery for the four models.

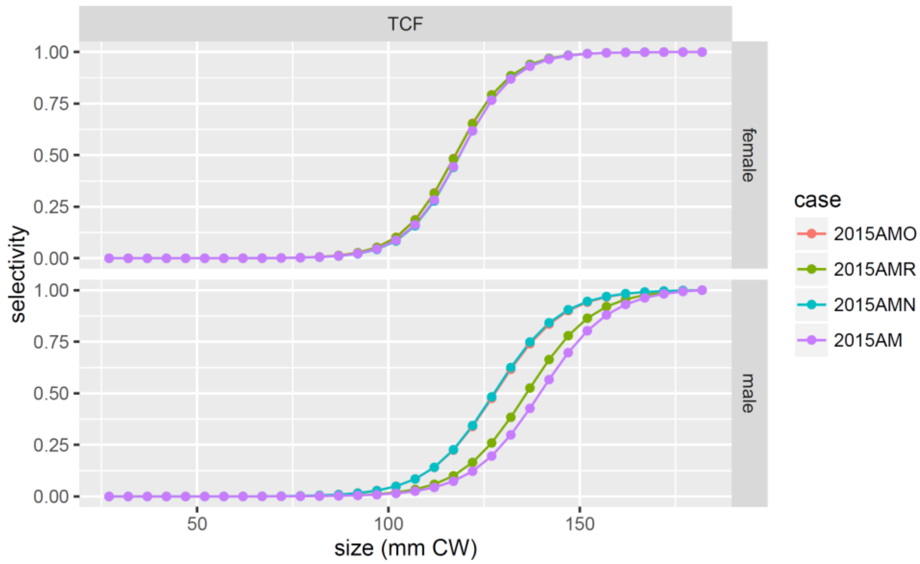


Figure 12. Comparison of estimated female selectivity functions and pre-1991 male total catch mortality selectivity functions in the directed fishery for the four models.

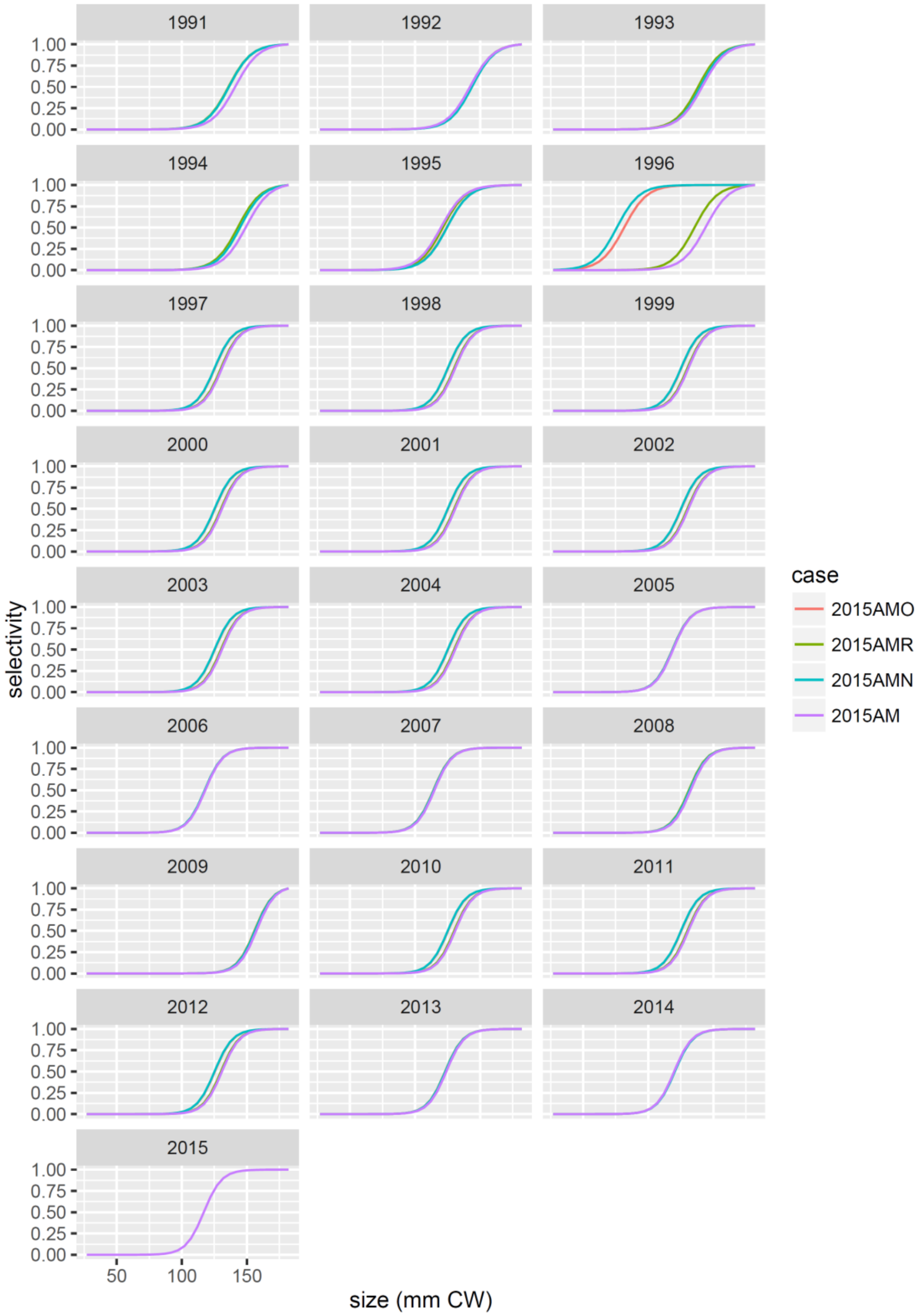


Figure 13. Comparison of estimated annual (post-1990) male total catch mortality selectivity functions in the directed fishery for the four models. The directed fishery was closed during 1997/98-2004/05 and 2010/11-2012/13. The mean selectivity function for 1991-present from

which annual deviations are taken is shown during the closures.

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

William T. Stockhausen
Alaska Fisheries Science Center
6 September 2016

Introduction

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

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

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

Evaluation

Objective function values

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

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

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

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

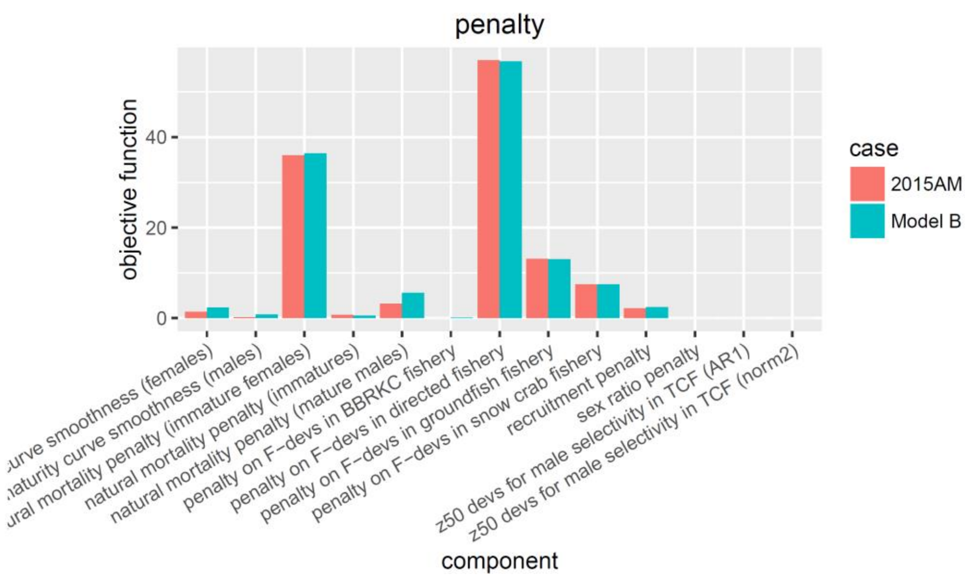


Figure 1. Comparison of penalty components to the model objective function for the two models.

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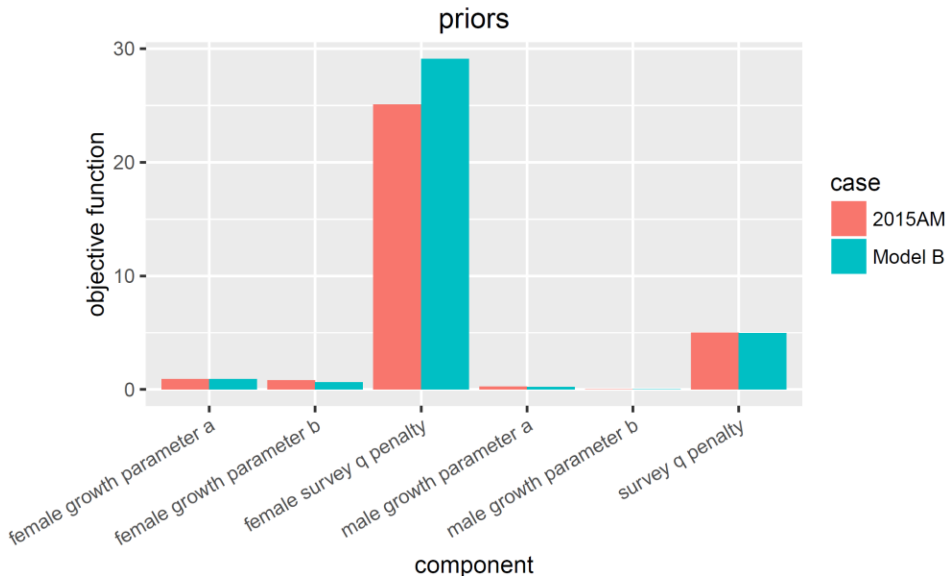

Figure 2. Comparison of prior probability components to the model objective function for the two models.

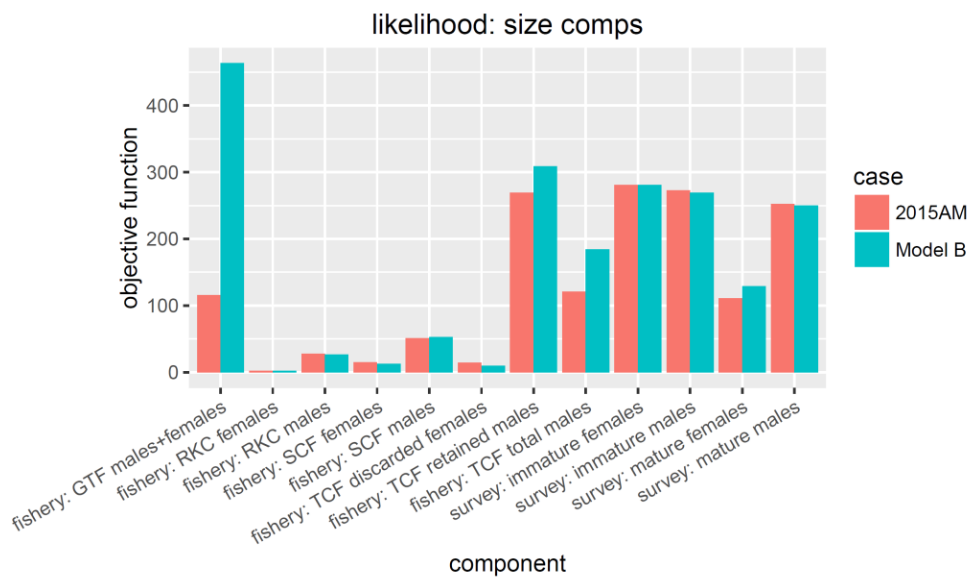

Figure 3. Comparison of multinomial components to the model objective function for the two models.

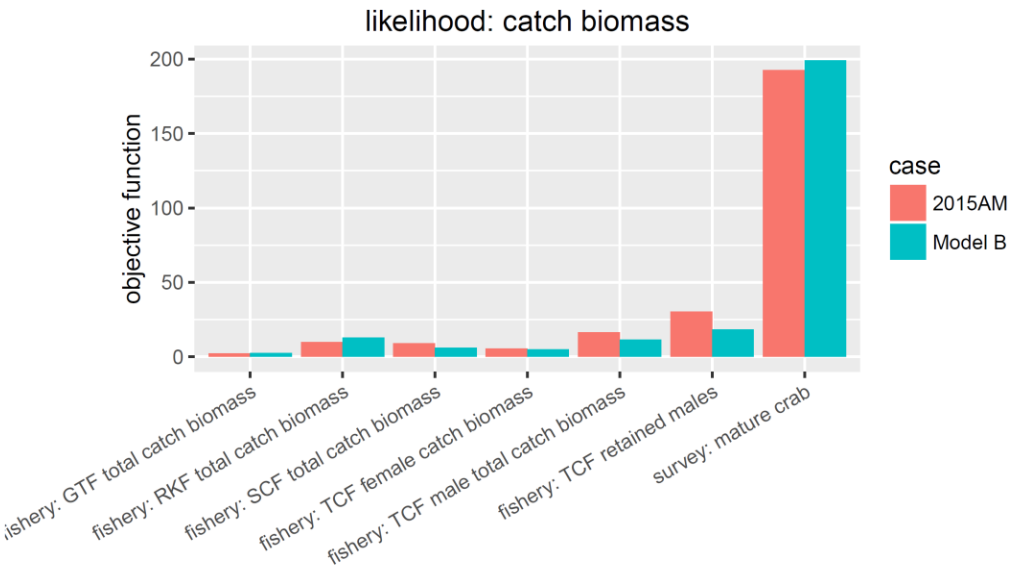

Figure 4. Comparison of biomass components to the model objective function for the two models.

Population processes

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

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

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

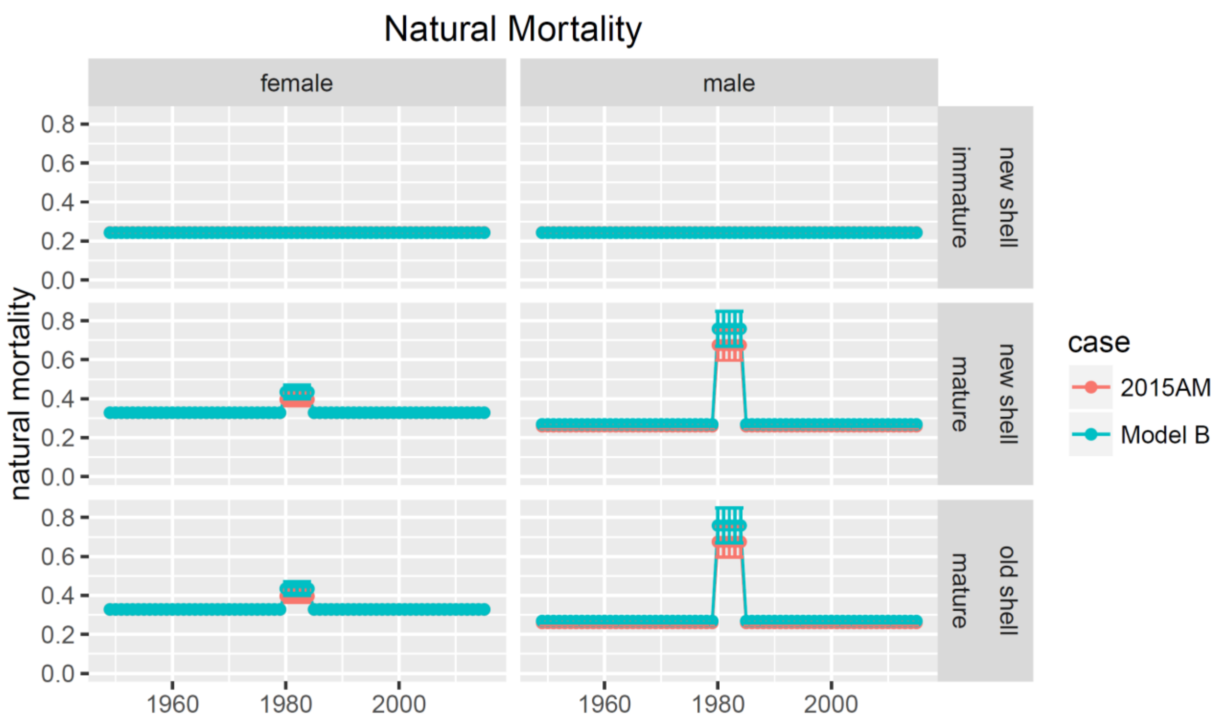

Figure 5. Comparison of estimates of natural mortality from the two models.

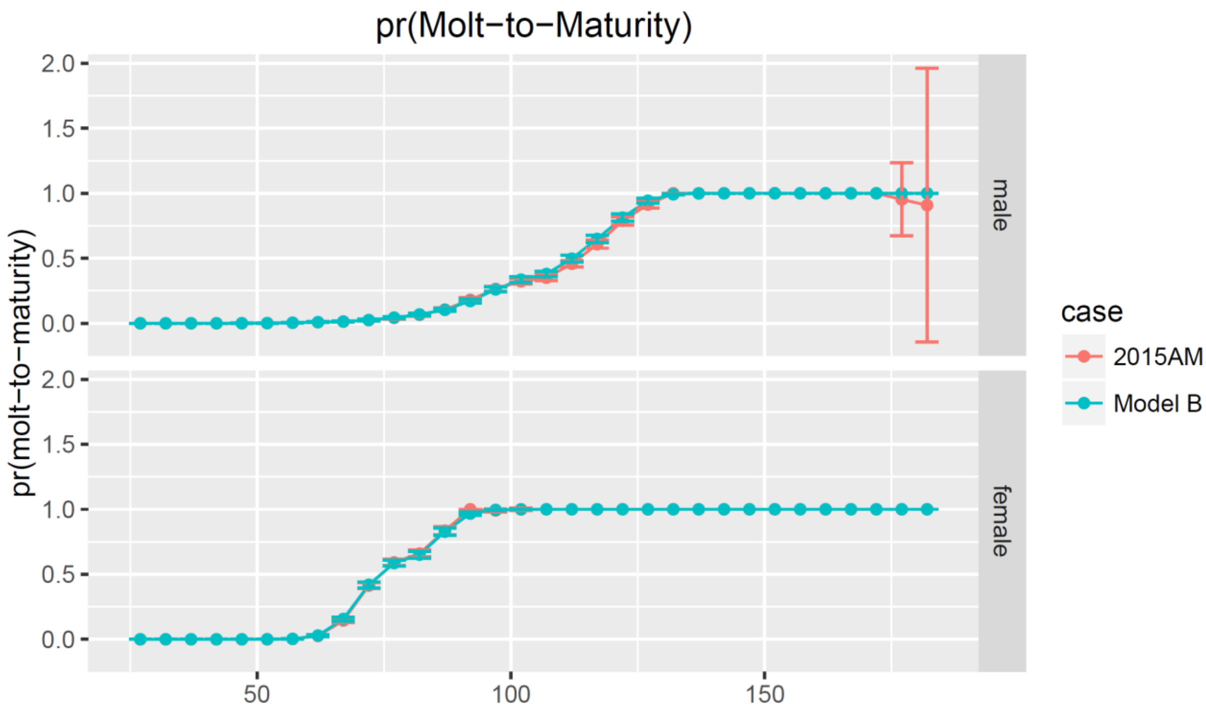

Figure 6. Comparison of estimates of the size-specific probability of undergoing terminal molt-to-maturity for from the four models.

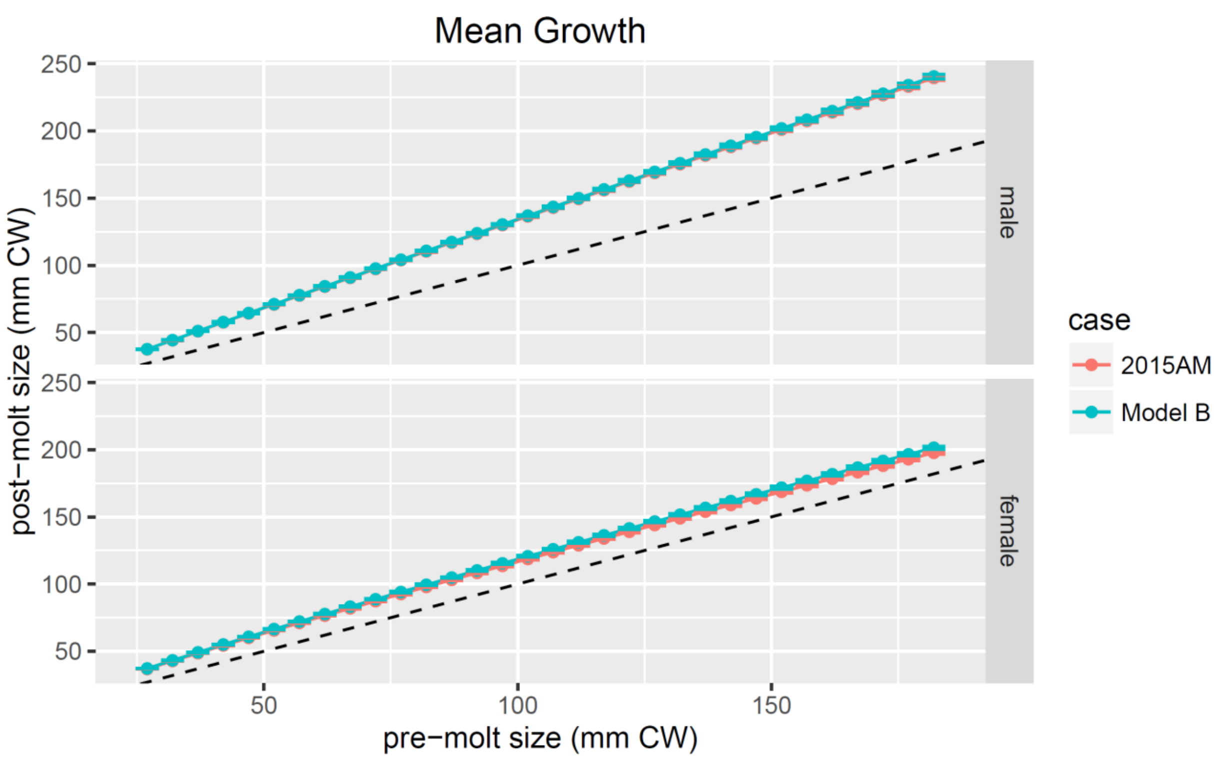

Figure 7. Estimates of the mean post-molt size as a function of pre-molt size from the four models.

Population quantities

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

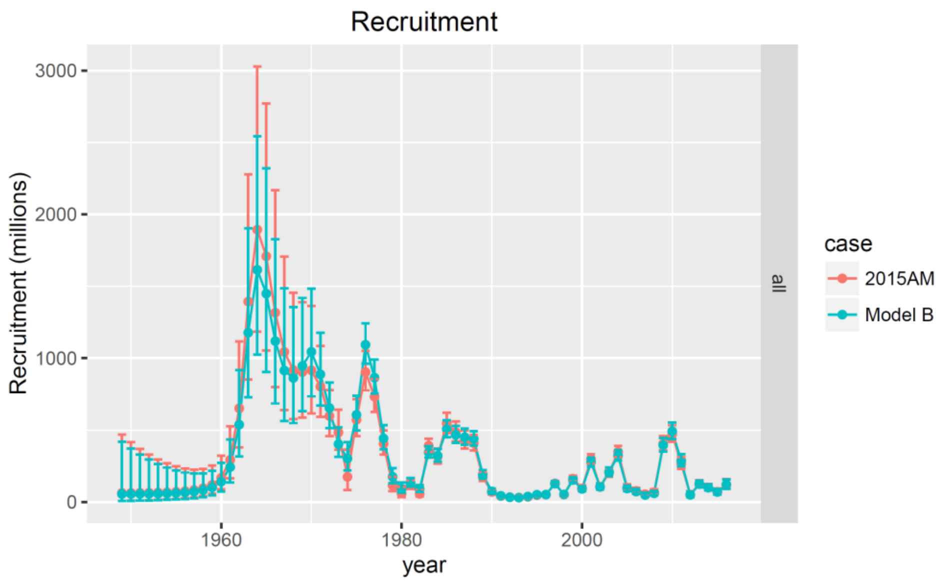

Figure 8. Estimated time series of recruitment from the four models.

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

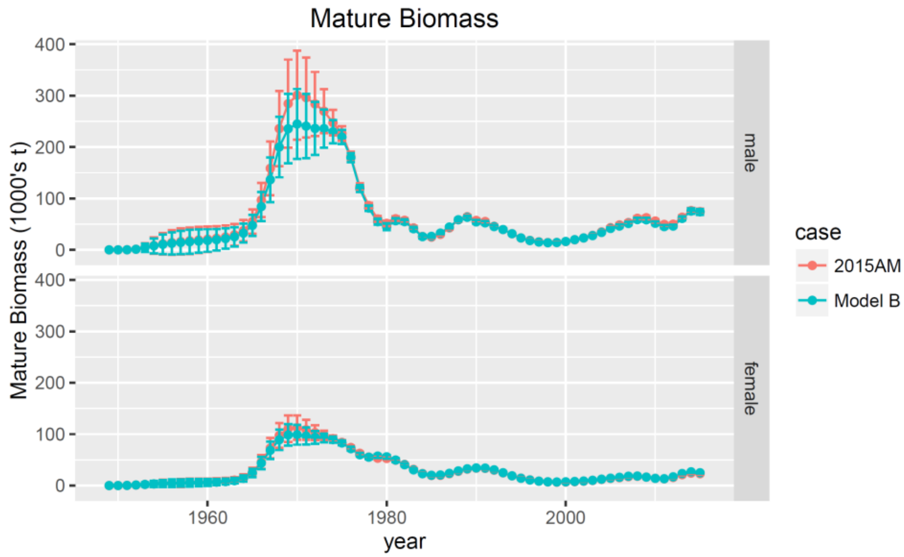

Figure 10. Estimated time series of mature biomass-at-mating from the four models.

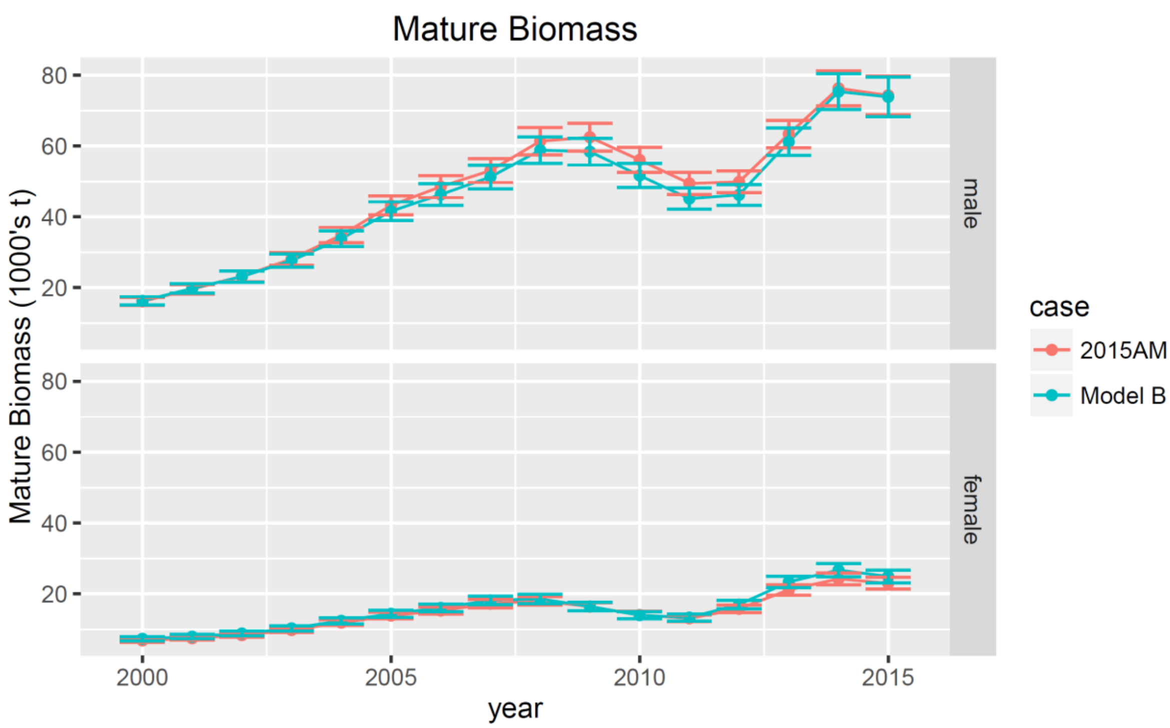

Figure 11. Estimated time series of mature biomass-at-mating from the two models.

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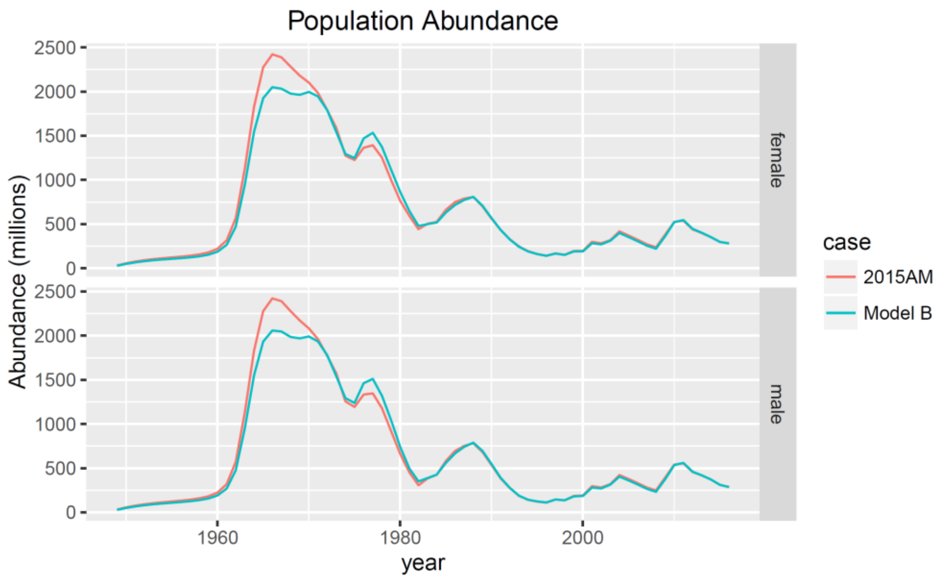

Figure 12. Estimated population abundance time series from the two models.

Survey selectivity functions

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

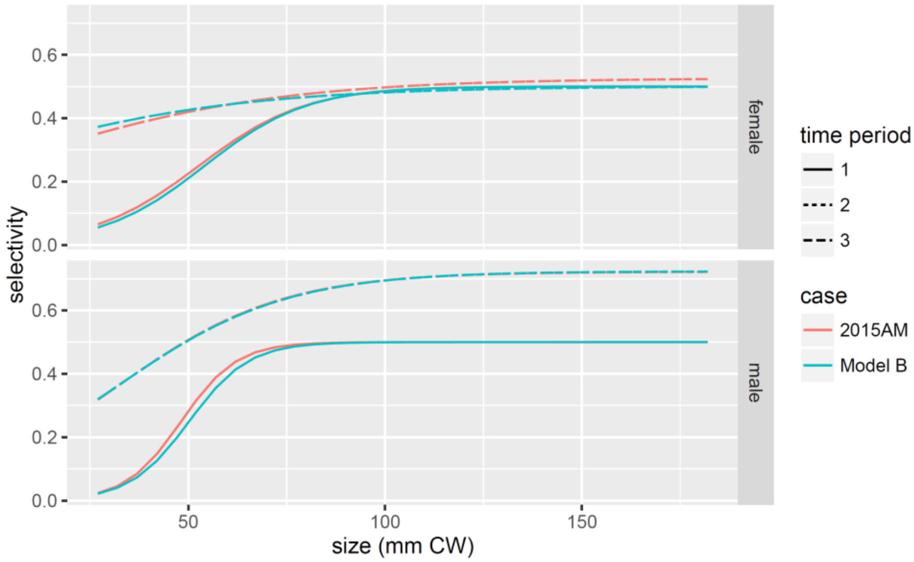

Figure 13. Comparison of estimated survey selectivity functions for the two models.

Fishery selectivity functions

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

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

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

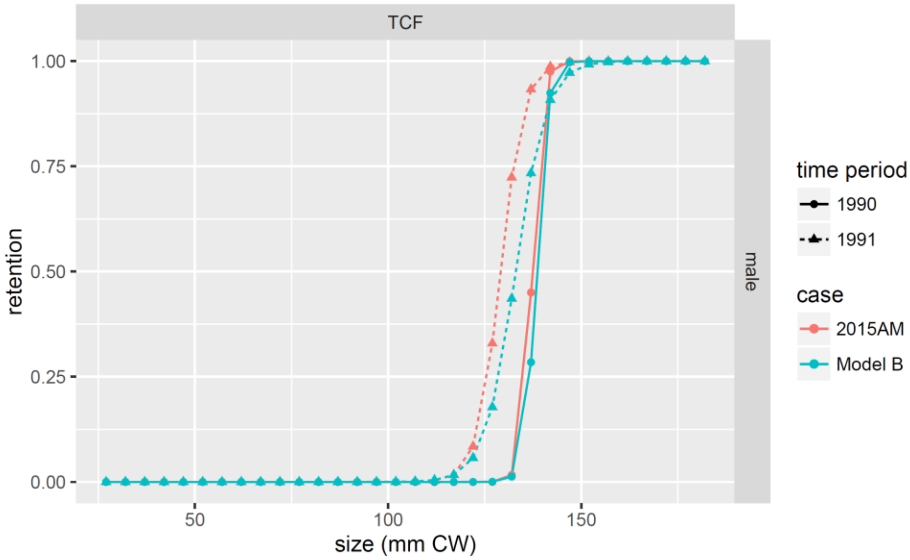

Figure 14. Comparison of estimated retention functions in the directed fishery for the two models.

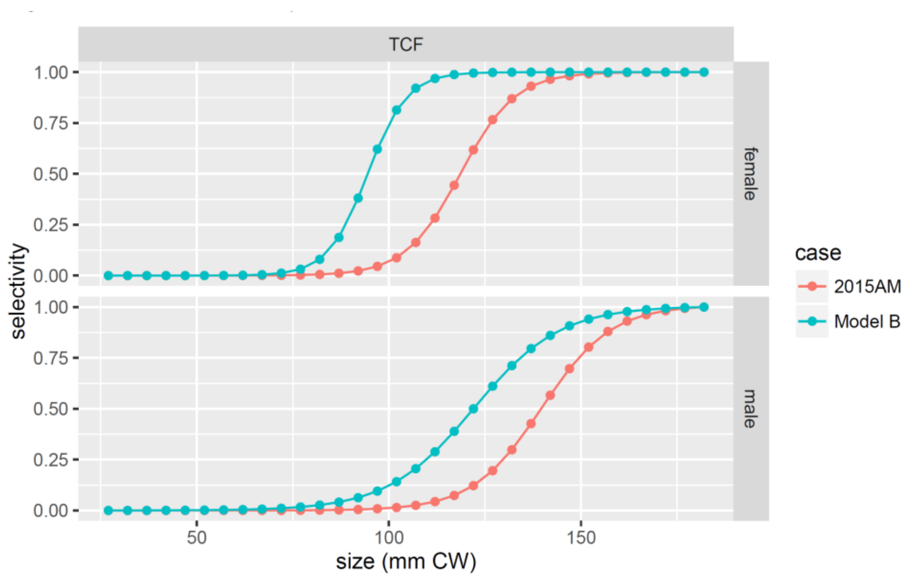

Figure 15. Comparison of estimated female bycatch selectivity and male selectivity prior to 1990 in the directed fishery for the two models.

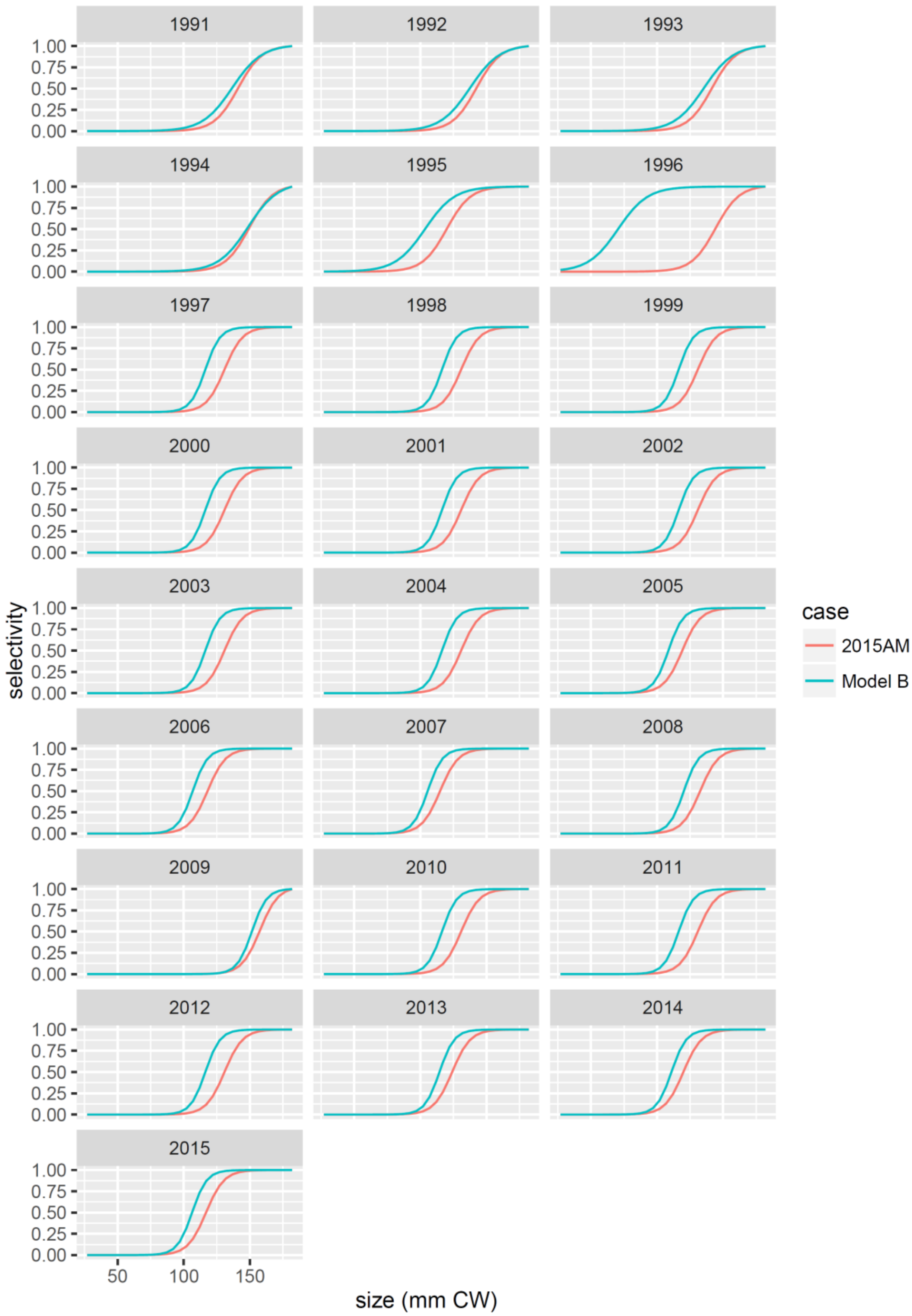

Figure 16. Comparison of estimated annual selectivity functions in the directed fishery for the two models.

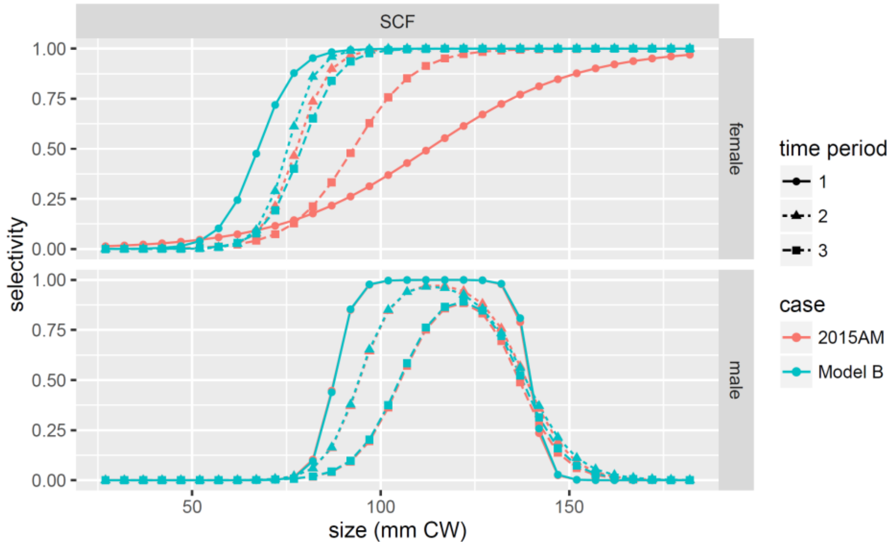

Figure 17. Comparison of estimated bycatch selectivity functions in the snow crab fishery for the two models.

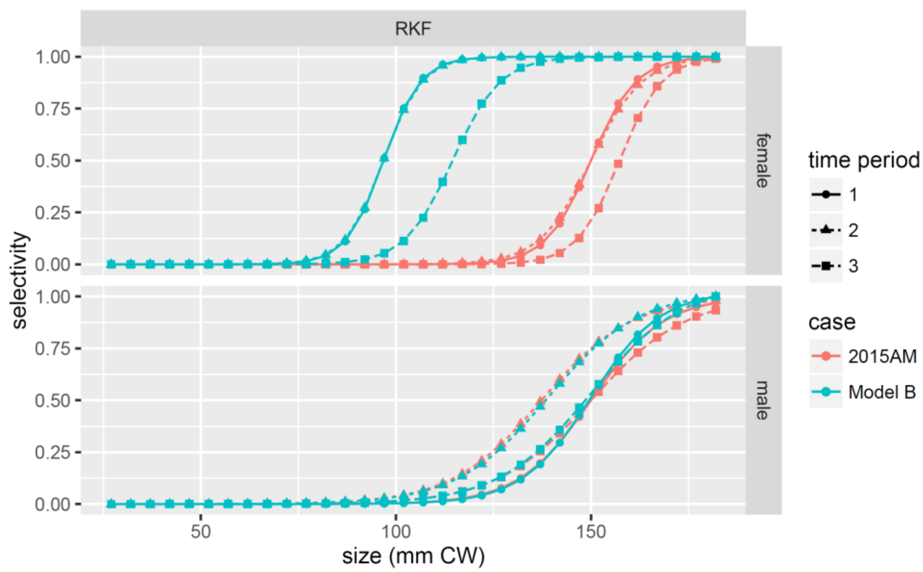

Figure 18. Comparison of estimated bycatch selectivity functions in the BBRKC fishery for the two models.

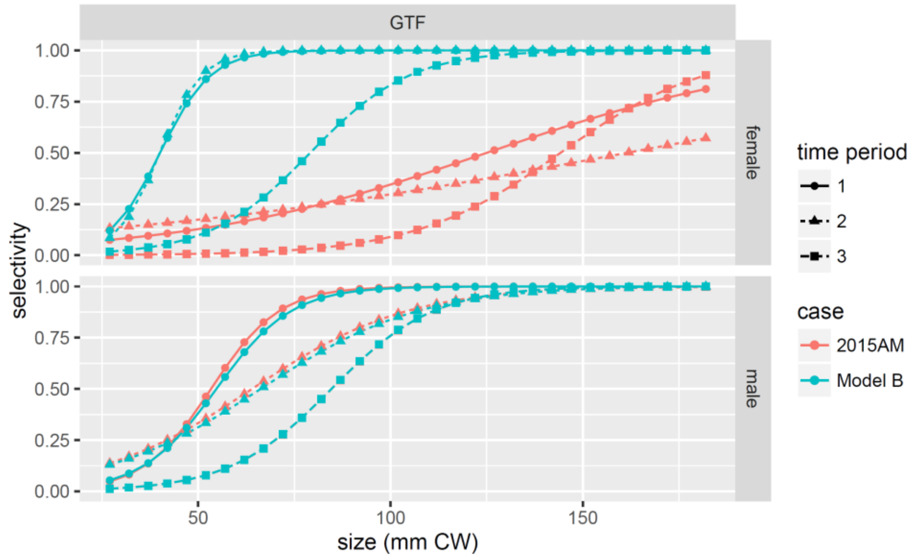

Figure 19. Comparison of estimated bycatch selectivity functions in the groundfish fisheries for the two models.

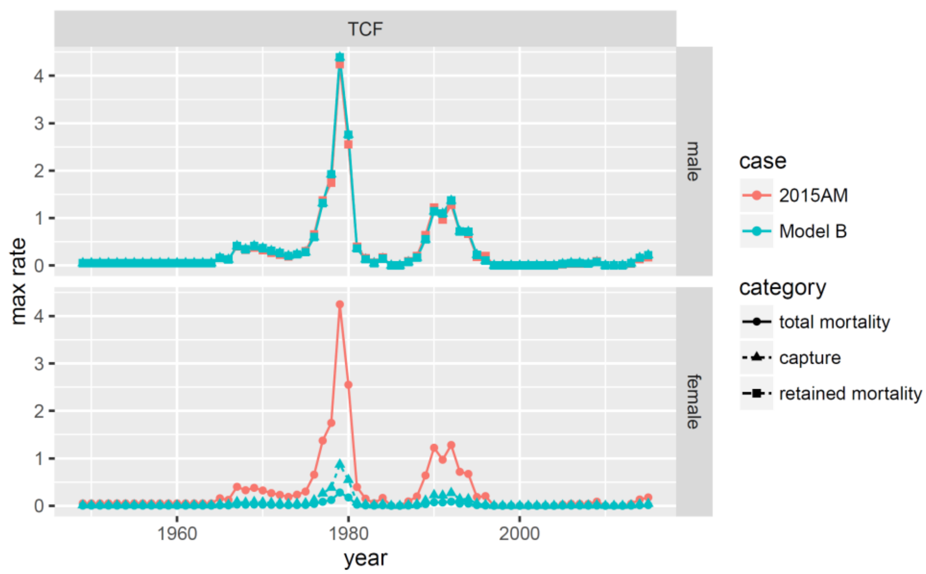

Figure 20. Comparison of estimated mean selectivity functions in the directed fishery for the two models.

Appendix C:
Comparison of Model B and Model C

William T. Stockhausen
Alaska Fisheries Science Center
6 September 2016

Introduction

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

Evaluation

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

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

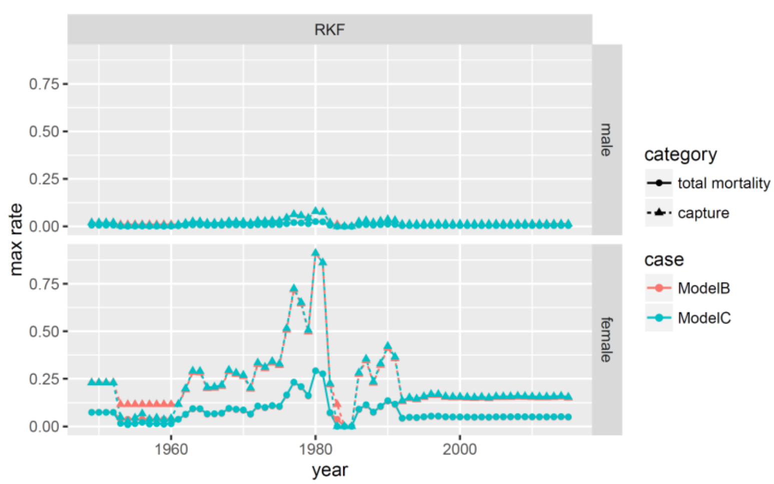

Figure 1. Fully-selected fishery capture/mortality rates in the BBRKC fishery for Models B and C.

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

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Objective function values

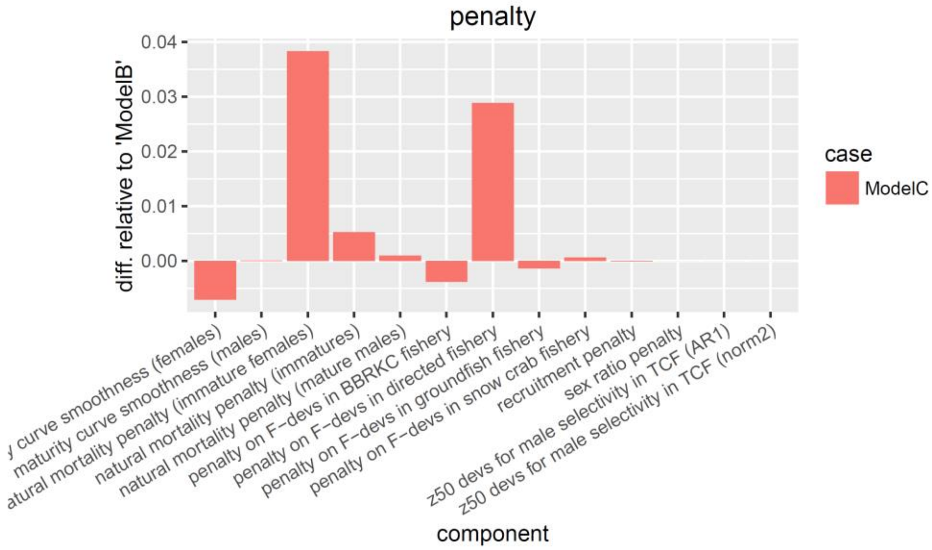

Figure 2. Differences for Model C vis-à-vis Model B (C-B) in penalty components to the model objective function.

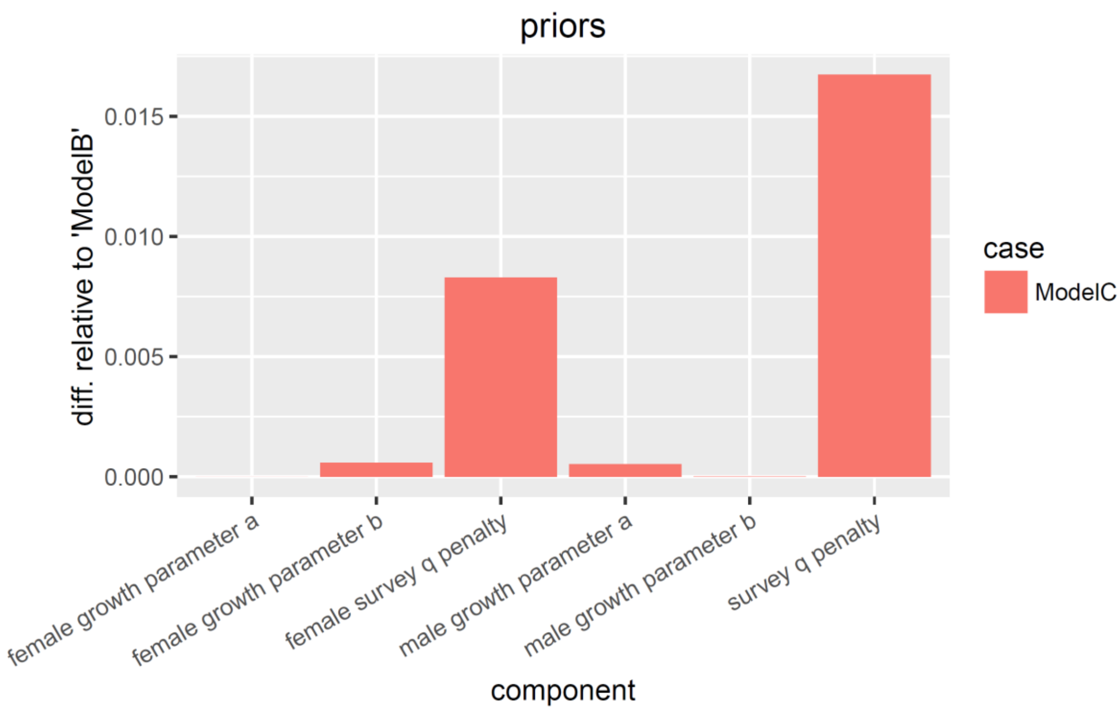

Figure 3. Differences for Model C vis-à-vis Model B (C-B) in prior probability components to the model objective function.

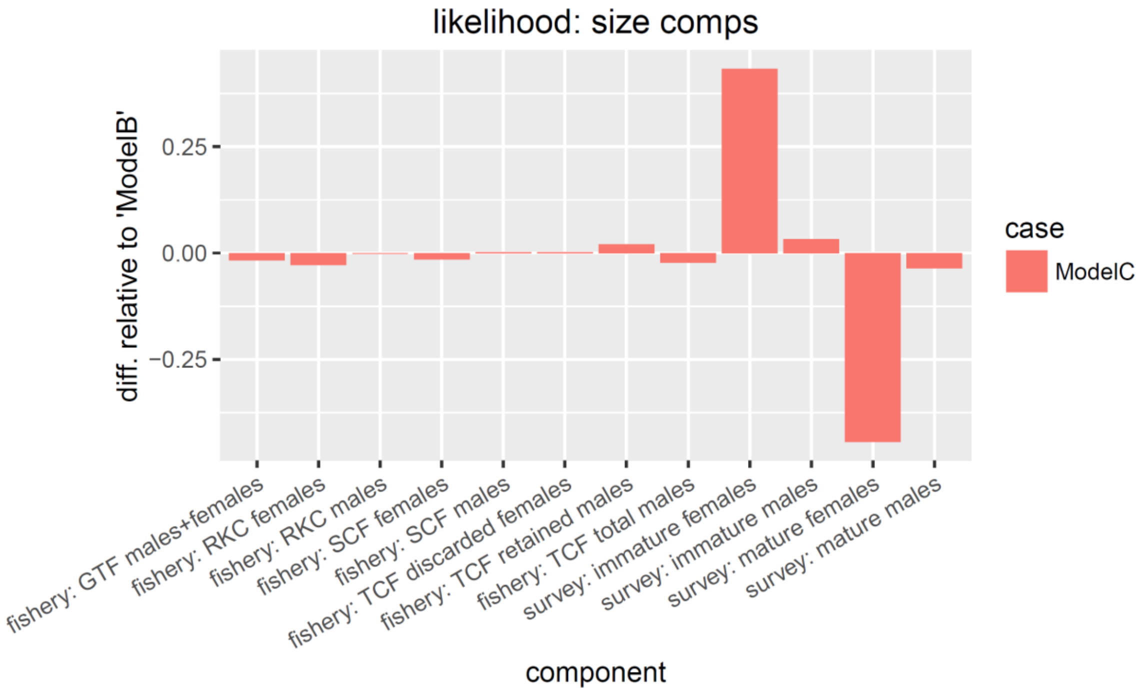

Figure 4. Differences for Model C vis-à-vis Model B (C-B) in prior probability components to the model objective function.

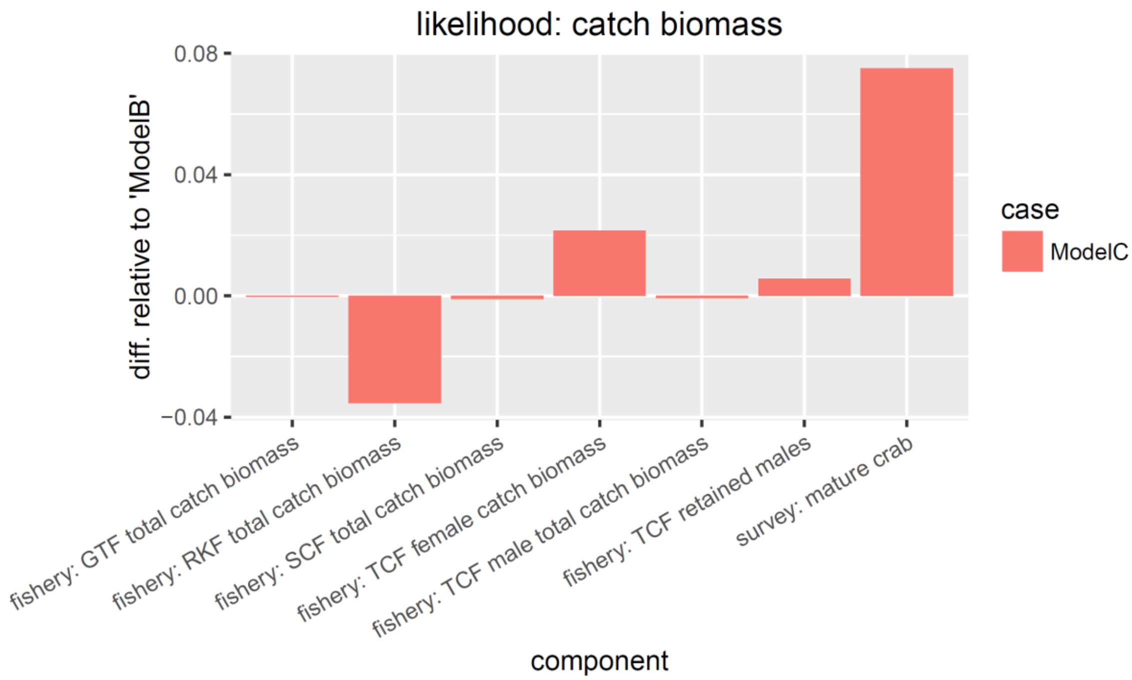

Figure 5. Differences for Model C vis-à-vis Model B (C-B) in prior probability components to the model objective function.

Population processes

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

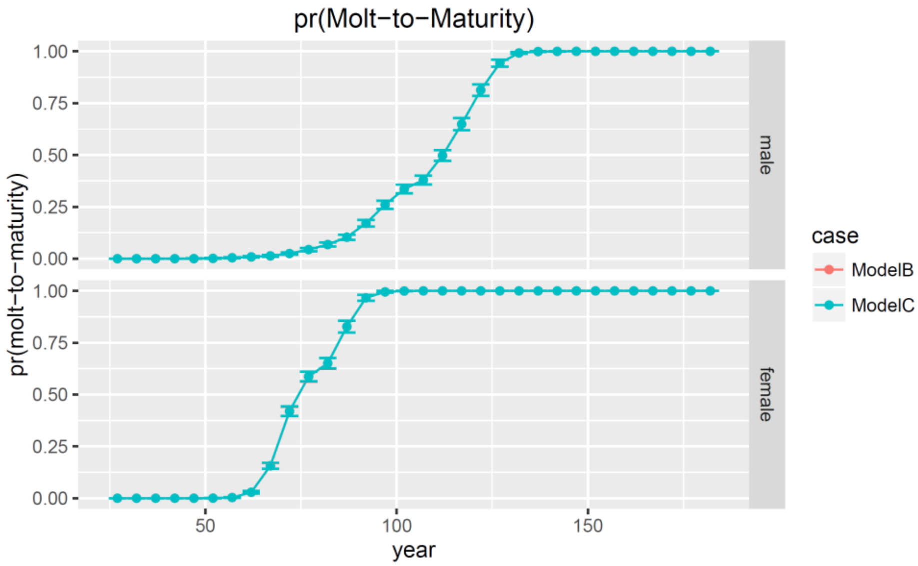

Figure 7. Estimates of the size-specific probability of undergoing terminal molt-to-maturity for Models B and C.

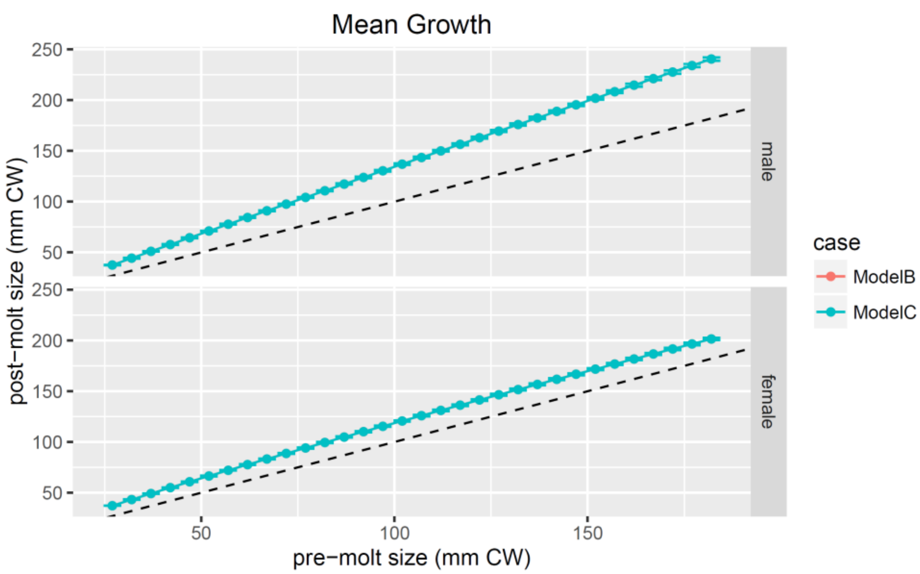

Figure 8. Estimates of the mean post-molt size as a function of pre-molt size for Models B and C.

Population quantities

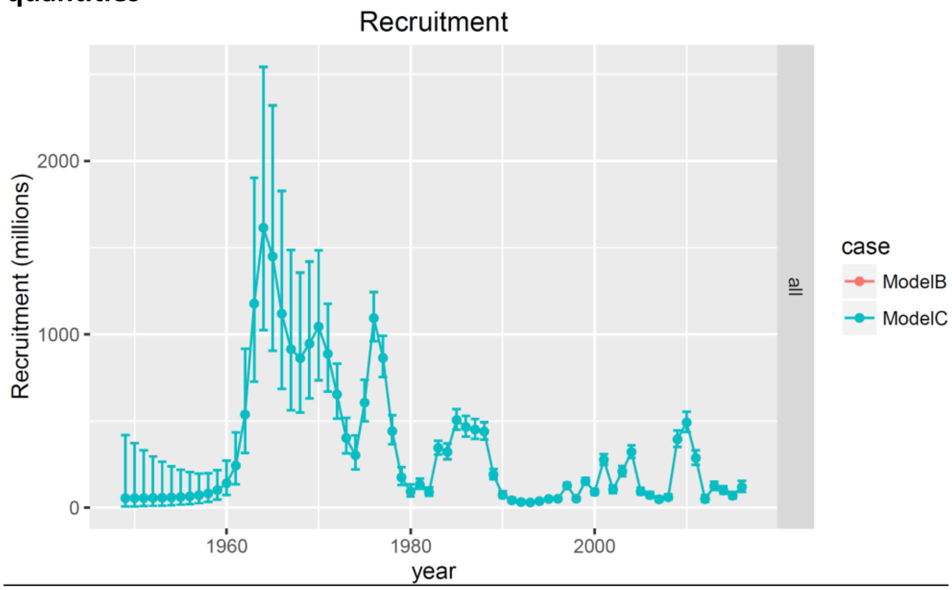

Figure 9. Estimated time series of recruitment from Models B and C.

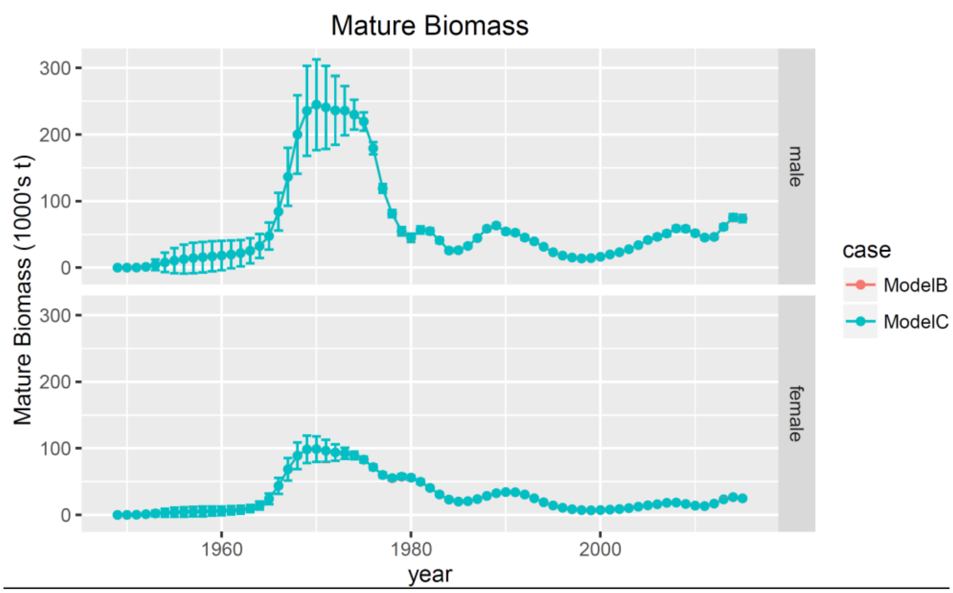

Figure 10. Estimated time series of mature biomass-at-mating from Models B and C.

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

William T. Stockhausen
Alaska Fisheries Science Center
6 September 2016

Introduction

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

Evaluation

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

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

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

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

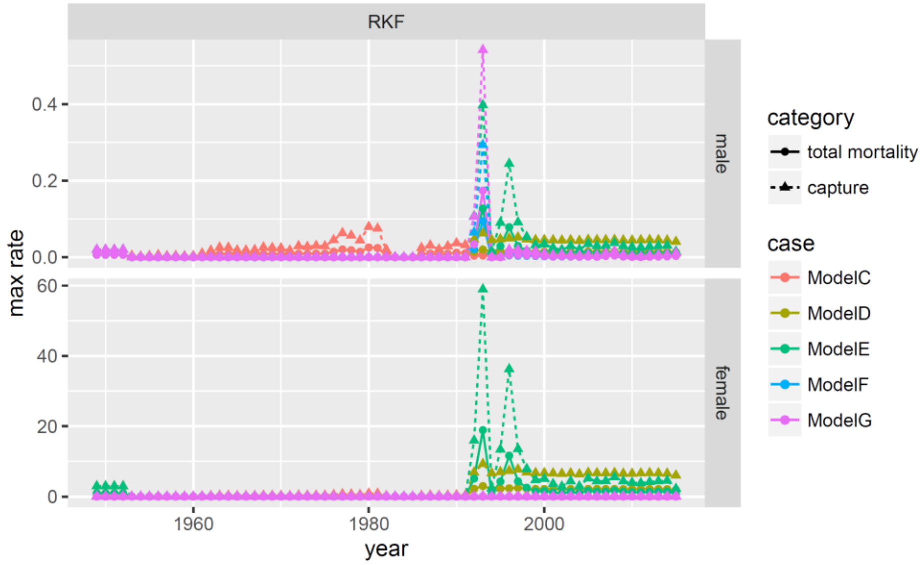

Figure 1. Fully-selected fishery capture/mortality rates in the BBRKC fishery for Models C-G.

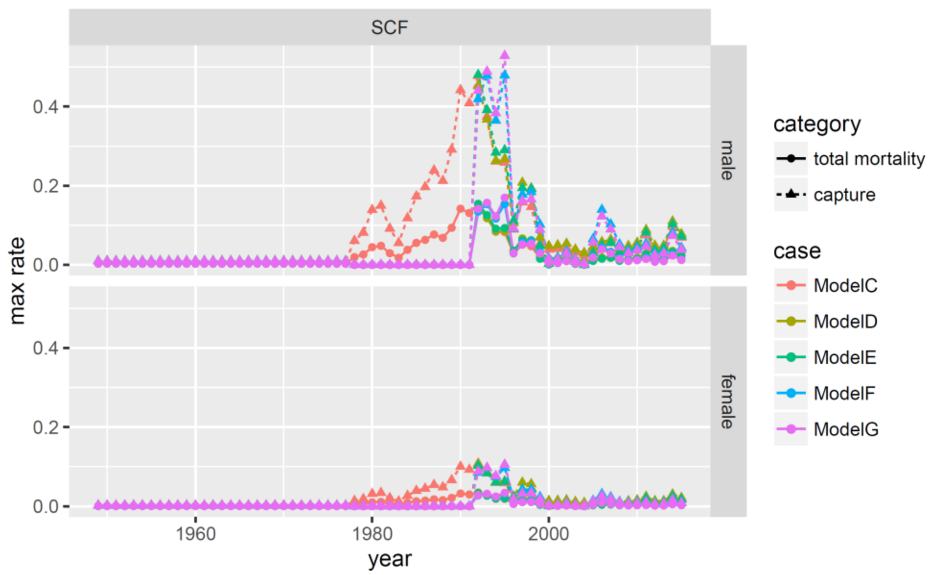

Figure 2. Fully-selected fishery capture/mortality rates in the snow crab fishery for Models C-G.

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

2016 Stock assessment and fishery evaluation report for the Pribilof Island red king crab fishery of the Bering Sea and Aleutian Islands regions

B.J. Turnock, C.S. Szuwalski and R.J. Foy
Alaska Fishery Science Center
National Marine Fishery Service
National Oceanic and Atmospheric Administration
September 23, 2016

Executive summary

1. Stock: Pribilof Islands red king crab, *Paralithodes camtschaticus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch and discards have been increasing in recent years, but are still low relative to the OFL.
3. Stock biomass:
    a. According to a 3-year running average, mature male biomass decreased from 2007 to 2010 and increased during 2011 through 2015, then declined in 2016. MMB at mating was estimated to be above Bmsy in 2015/16.
    b. According to an integrated length-based assessment, mature male biomass increased from 2007 to 2009 and decreased from 2010 through 2016. MMB at mating was estimated to be above Bmsy in 2015/16
    c. Observed survey biomass declined from 15,173 t in 2015 to 4,150 t in 2016.
4. Recruitment: Recruitment is episodic for PIRKC and has been low recently.
5. Recent management statistics:
   Units in tons

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	2,255	2,754[A]	0	0	4.2	349	
2011/12	2,571	2,775[B*]	0	0	5.4	393	307
2012/13	2,609	4,025[C**]	0	0	13.1	569	455
2013/14	2,582	4,679 [D**]	0	0	2.25	903	718
2014/15	2,871	8,894 [D**]	0	0	1.76	1,359	1,019
2015/16	2,756	9,062 [E**]	0	0	0.32[1]	2,119	1,467
2016/17		6,980E[**]				1,462[**]	1,096[**]

Units in millions of pounds

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	4.97	6.07[A]	0	0	0.009	0.77	
2011/12	5.67	6.12[B*]	0	0	0.011	0.87	0.68
2012/13	5.75	8.87[C**]	0	0	0.029	1.25	1.00
2013/14	5.66	10.32[D**]	0	0	0.005	1.99	1.58
2014/15	6.33	19.61[D**]	0	0	0.004	3.00	2.25
2015/16	6.08	19.99[E**]	0	0	<0.001[1]	4.67	3.23
2016/17		15.39[E**]				3.22[**]	2.42[**]

Notes:
A – Based on survey data available to the Crab Plan Team in September 2010 and updated with 2010/2011 catches B – Based on survey data available to the Crab Plan Team in September 2011 and updated with 2011/2012 catches
C – Based on survey data available to the Crab Plan Team in September 2012 and updated with 2012/2013 catches
D – Based on survey data available to the Crab Plan Team in September 2013 and updated with 2012/2013 catches
E – Based on survey data available to the Crab Plan Team in September 2016 and updated with 2015/2016 catches

* – 2011/12 estimates based on 3 year running average

** –estimates based on weighted 3 year running average using inverse variance
1 – catches in 2015/16 from AKFIN through August 12, 2016

The OFL is the total catch OFL for each year. The stock was above MSST in 2015/2016 according to both a 3-year average. The catch in 2015/16 (0.32 t) was below the OFL (2,119 t) and the ABC (1,467 t).

6. 2016/2017 OFL projections:
All biomass in tons

Tier	**Assessment Method**	**OFL**	$\boldsymbol{B_{MSY}}$	**MMB at mating Feb 15 2017**	$\boldsymbol{B/B_{MSY}}$ **(MMB)**	***MMB at mating Feb 15 2016***	γ	**Years to define** $\boldsymbol{B_{MSY}}$	$\mathbf{F_{MSY}}$	ABC (p*=0.49)	**ABC = 0.75* OFL**
4	Running Average	1,462	5,512	6,980	1.25	9,062	1	1991/1992-2015/2016 (MMB)	0.18	1,436	1,096
4	Random Effects Model	119	5,512	2,044	0.37	2,154	1	1991/1992-2015/2016 (MMB)	0.05	114	89
4	Observed Survey	370	5,512	3,332	0.60	13,457	1	1991/1992-2015/2016 (MMB)	0.10	357	278
4	Integrated assessment (males only)	822	3,881	5,160	1.33	6127	1	1991/1992-2015/2016 (MMB)	0.18		617
3	Integrated assessment (males only)	1,931	1,598	4,066	2.5	6127	1	1983-present (recruitment)	0.49		1,448

Units are in millions of pounds.

Tier	**Assessment Method**	**OFL**	$\boldsymbol{B_{MSY}}$	**MMB at mating Feb 15 2017**	$\boldsymbol{B/B_{MSY}}$ **(MMB)**	***MMB at mating Feb 15 2016***	γ	**Years to define** $\boldsymbol{B_{MSY}}$	$\mathbf{F_{MSY}}$	ABC (p*= 0.49)	**ABC = 0.75* OFL**
4	Running Average	3.22	12.16	15.39	1.25	19.99	1	1991/1992-2015/2016 (MMB)	0.18	3.17	2.42
4	Random Effects Model	0.26	12.16	4.51	0.37	4.75	1	1991/1992-2015/2016 (MMB)	0.05	0.25	0.20
4	Observed Survey	0.82	12.16	7.35	0.60	29.68	1		0.10	0.79	0.61
4	Integrated assessment (males only)	1.81	8.56	11.38	1.33	13.51	1	1991/1992-2015/2016 (MMB)	0.18		1.36
3	Integrated assessment (males only)	4.26	3.52	8.97	2.5	13.51	1	1983-present (recruitment)	0.49		3.19

7. Probability distributions of the OFL for tier 4 methods were generated by bootstrapping values of MMB in the current year with an additional sigma of 0.3.
8. Basis for ABC: ABCs were identified as the 49th percentile of the distributions of the OFL given a p-star of 0.49. In addition the ABC was estimated using a 25% buffer from the OFL as recommended by the CPT and SSC for 2015/16.

Summary of Major Changes:

1. Management: None.
2. Input data: Survey (2016) and bycatch (2015) data were incorporated into the assessment.
3. Assessment methodology: Model output for male only fit is presented with the same model configuration as 2015.
4. Assessment results: Male biomass estimates from the 3-year running average and a random effects model fit to survey male biomass >=120mm are used to estimate MMB at mating, OFL and ABC.

CPT comments May 2016

1. *Continue the work on survey biomass and length frequency weighting issues to improve the model fits to abundance data;*

   Addressed in #2 below.

2. *Implement the Francis tuning method to estimate length composition effective sample sizes;*

   The Francis effective N calculation was added to the model. In addition, other multipliers on the survey length frequencies were evaluated.

3. *Provide results for a random effects model and three-year weighted average for the September meeting*

   The random effects model was fit to the survey biomass data and MMB, OFL and ABC estimated. The estimates using the three-year weighted average are also included.

Crab Plan Team September 2015 comments not addressed

Incorporate a mean-unbiased log normal likelihood for survey numbers
Next time.

Discuss the poisson vs. negative binomial for survey estimates of abundance and CVs
Currently all of the data in the model are those that are passed from Bob Foy and the Kodiak lab, but given the over-dispersion in the data, a negative binomial (or something similar) might be more appropriate, particularly for estimates of variance. The CVs sent by Bob are used in the assessment, but bootstrapped variances are much larger.

Consider ADFG pot survey data and retained catch size frequency data
These data area not yet incorporated, but may be useful in exploring the mechanics of time-varying catchability.

1. Introduction

1.1 Distribution

Red king crabs, *Paralithodes camtschaticus*, (Tilesius, 1815) are anomurans in the family lithodidae and are distributed from the Bering Sea south to the Queen Charlotte Islands and to Japan in the western Pacific (Jensen 1995; Figure 1). Red king crabs have also been introduced and become established in the Barents Sea (Jørstad et al. 2002). The Pribilof Islands red king crab stock is located in the Pribilof District of the Bering Sea Management Area Q. The Pribilof District is defined as Bering Sea waters south of the latitude of Cape Newenham (58° 39’ N lat.), west of 168° W long., east of the United States – Russian convention line of 1867 as amended in 1991, north of 54° 36’ N lat. between 168° 00’ N and 171° 00’ W long and north of 55° 30’N lat. between 171° 00’ W. long and the U.S.-Russian boundary (Figure 2).

1.2 Stock structure

Populations of red king crab in the eastern Bering Sea (EBS) for which genetic studies have been performed appear to be composed of four stocks: Aleutian Islands, Norton Sound, Southeast Alaska, and the rest of the EBS. Seeb and Smith (2005) reported micro-satellite samples from Bristol Bay, Port Moller, and the Pribilof Islands were divergent from the Aleutian Islands and Norton Sound. A more recent study describes the genetic distinction of Southeast Alaska red king crab compared to Kodiak and the Bering Sea; the latter two being similar (Grant and Cheng 2012).

1.3 Life history

Red king crabs reproduce annually and mating occurs between hard-shelled males and soft-shelled females. Red king crabs do not have spermathecae and cannot store sperm, therefore a female must mate every year to produce a fertilized clutch of eggs (Powell and Nickerson 1965). A pre-mating embrace is formed 3-7 days prior to female ecdysis, the female molts, and copulation occurs within hours. The male inverts the female so they are abdomen to abdomen and then the male extends his fifth pair of periopods to deposit sperm on the female’s gonopores. Eggs are fertilized after copulation as they are extruded through the gonopores located at the ventral surface of the coxopides of the third periopods. The eggs form a spongelike mass, adhering to the setae on the pleopods where they are brooded until hatching (Powell and Nickerson 1965). Fecundity estimates are not available for Pribilof Islands red king crab, but range from 42,736 to 497,306 for Bristol Bay red king crab (Otto et al. 1990). The estimated size at 50 percent maturity of female Pribilof Islands red king crabs is approximately 102 mm carapace length (CL) which is larger than 89 mm CL reported for Bristol Bay and 71 mm CL for Norton Sound (Otto et al. 1990). Size at maturity has not been determined specifically for Pribilof Islands red king crab males, however, approximately 103 mm CL is reported for eastern Bering Sea male red king crabs (Somerton 1980). Early studies predicted that red king crab become mature at approximately age 5 (Powell 1967; Weber 1967); however, Stevens (1990) predicted mean age at recruitment in Bristol Bay to be 7 to 12 years, and Loher et al. (2001) predicted age to recruitment to be approximately 8 to 9 years after settlement. Based upon a long-term laboratory study, longevity of red king crab males is approximately 21 years and less for females (Matsuura and Takeshita 1990).

Natural mortality of Bering Sea red king crab stocks is poorly known (Bell 2006). Siddeek et al. (2002) reviewed natural mortality estimates from various sources. Natural mortality estimates based upon historical tag-recapture data range from 0.001 to 0.93 for crabs 80-169 mm CL with natural mortality increasing with size. Natural mortality estimates based on more recent tag-recovery data for Bristol Bay red king crab males range from 0.54 to 0.70, however, the authors noted that these estimates appear high considering the longevity of red king crab. Natural mortality estimates based on trawl survey data vary from 0.08 to 1.21 for the size range 85-169 mm CL, with higher mortality for crabs <125 mm CL. In an earlier analysis that utilized the same data sets, Zheng et al. (1995) concluded that natural mortality is dome shaped over length and varies over time. Natural mortality was set at 0.2 for Bering Sea king crab stocks (NPFMC 1998) and was changed to 0.18 with Amendment 24.

The reproductive cycle of Pribilof Islands red king crabs has not been established, however, in Bristol Bay, timing of molting and mating of red king crabs is variable and occurs from the end of January through the end of June (Otto et al. 1990). Primiparous (i.e. brooding their first egg clutch) Bristol Bay red king crab females extrude eggs on average 2 months earlier in the reproductive season and brood eggs longer than multiparous (i.e. brooding their second or subsequent egg clutch) females (Stevens and Swiney 2007a, Otto et al. 1990), resulting in incubation periods that are approximately eleven to twelve months in duration (Stevens and Swiney 2007a, Shirley et al. 1990). Larval hatching among red king crabs is relatively synchronous among stocks and in Bristol Bay occurs March through June with peak hatching in May and June (Otto et al. 1990), however larvae of primiparous females hatch earlier than multiparous females (Stevens and Swiney 2007b, Shirley and Shirley 1989). As larvae, red king crabs exhibit four zoeal stages and a glaucothoe stage (Marukawa 1933).

Growth parameters have not been examined for Pribilof Islands red king crabs; however they have been studied for Bristol Bay red king crab. A review by the Center for Independent Experts (CIE) reported that growth parameters are poorly known for all red king crab stocks (Bell 2006). Growth increments of immature southeastern Bering Sea red king crabs are approximately: 23% at 10 mm CL, 27% at 50 mm CL, 20% at 80 mm CL and 16 mm for immature crabs over 69 mm CL (Weber 1967). Growth of males and females is similar up to approximately 85 mm CL, thereafter females grow more slowly than males (Weber 1967; Loher et al. 2001). In a laboratory study, growth of female red king crabs was reported to vary with age; during their pubertal molt (molt to maturity) females grew on average 18.2%, whereas primiparous females grew 6.3% and multiparous females grew 3.8% (Stevens and Swiney, 2007a). Similarly, based upon tag-recapture data from 1955-1965 researchers observed that adult female growth per molt decreases with increased size (Weber 1974). Adult male growth increment averages 17.5 mm irrespective of size (Weber 1974).

Molting frequency has been studied for Alaskan red king crabs, but Pribilof Islands specific studies have not been conducted. Powell (1967) reports that the time interval between molts increases from a minimum of approximately three weeks for young juveniles to a maximum of four years for adult males. Molt frequency for juvenile males and females is similar and once mature, females molt annually and males molt annually for a few years and then biennially, triennially and quadrennial (Powell 1967). The periodicity of mature male molting is not well understood and males may not molt synchronously like females who molt prior to mating (Stevens 1990).

1.4 Management history

Red king crab stocks in the Bering Sea and Aleutian Islands are managed by the State of Alaska through the federal Fishery Management Plan (FMP) for Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 1998). The Alaska Department of Fish and Game (ADF&G) has not published harvest regulations for the Pribilof district red king crab fishery. The king crab fishery in the Pribilof District began in 1973 with blue king crab *Paralithodes platypus* being targeted (Figure 3). A red king crab fishery in the Pribilof District opened for the first time in September 1993. Beginning in 1995, combined red and blue king crab GHLs were established. Declines in red and blue king crab abundance from 1996 through 1998 resulted in poor fishery performance during those seasons with annual harvests below the fishery GHL. The North Pacific Fishery Management Council (NPFMC) established the Bering Sea Community Development Quota (CDQ) for Bering Sea fisheries including the Pribilof Islands red and blue king crab fisheries which was implemented in 1998. From 1999 to present the Pribilof Islands fishery was not open due to low blue king crab abundance, uncertainty with estimated red king crab abundance, and concerns for blue king crab bycatch associated with a directed red king crab fishery. Pribilof Islands blue king crab was declared overfished in September of 2002 and is still considered overfished (see Bowers et al. 2011 for complete management history).

Amendment 21a to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 4) which prohibits the use of trawl gear in a specified area around the Pribilof Islands year round (NPFMC 1994). The amendment went into effect January 20, 1995 and protects the majority of crab habitat in the Pribilof Islands area from impacts from trawl gear.

Pribilof Islands red king crab often occur as bycatch in the eastern Bering Sea snow crab (*Chionoecetes opilio*), eastern Bering Sea Tanner crab (*Chionoecetes bairdi*), Bering Sea hair crab (*Erimacrus isenbeckii*), and Pribilof Islands blue king crab fisheries (when there is one). Limited non-directed catch exists in crab fisheries and groundfish pot and hook and line fisheries (see bycatch and discards section below). However, bycatch is currently very low compared to historical levels.

2. Data

The standard groundfish discards time series data (updated through 2015) were used in this assessment. The crab fishery retained and discard catch time series were updated with 2015/2016 data. The following sources and years of data are available:

Data source	Years available	Used in integrated assessment?
NMFS trawl survey	1975-2016	Yes
Retained catch	1993-2015	Yes
Trawl bycatch	1991-2015	Yes
Fixed gear bycatch	1991-2015	No
Pot discards	1998-2015	No

2.1 Retained catch

Red king crab were targeted in the Pribilof Islands District from the 1993/1994 season to 1998/1999. Live and deadloss landings data and effort data are available during that time period (Tables 1 and 2), but no retained catch has been allowed since 1999.

2.2 Bycatch and discards

Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers. Catch weight was calculated by first determining the mean weight (g) for crabs in each of three categories: legal non-retained, sublegal, and female. Length to weight parameters were available for two time periods: 1973 to 2009 (males: A=0.000361, B=3.16; females: A=0.022863, B=2.23382) and 2010 to 2013 (males: A=0.000403, B=3.141; ovigerous females: A=0.003593, B=2.666; non-ovigerous females: A=0.000408, B=3.128). The average weight for each category was multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 2).

$$\text{Weight (g)} = A * CL(\text{mm})^{B} \tag{1}$$

$$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \tag{2}$$

Finally, weights, discards, and bycatch were the product of average weight, CPUE, and total pot lifts in the fishery. A 20% handling mortality rate was applied to these estimates (assumed the same as Bristol Bay red king crab).

Historical non-retained catch data are available from 1998/1999 to present from the snow crab, golden king crab (*Lithodes aequispina*), and Tanner crab fisheries (Table 3) although data may be incomplete for some of these fisheries. Limited observer data exists prior to 1998 for catcher-processor vessels only so non-retained catch before this date is not included here. In 2015/2016 there was 0.221 t of Pribilof Islands red king crab mortality from crab fisheries (Table 3).

2.3 Groundfish pot, trawl, and hook and line fisheries

The data through 2015/2016 from the NOAA Fisheries Regional Office (J. Gasper, NMFS, personal communication) assessments of non-retained catch from all groundfish fisheries are included in this SAFE report. Groundfish catches of crab are reported for all crab combined by federal reporting areas and by State of Alaska reporting areas since 2009/2010. Catches from observed fisheries were applied to non-observed fisheries to estimate a total catch. Catch counts were converted to biomass by applying the average weight measured from observed tows from July 2011 to June 2012. Prior to 2011/2012, Areas 513 and 521 were included in the estimate, a practice that likely resulted in an overestimate of the catch of Pribilof Islands red king crab due to the extent of Area 513 into the Bristol Bay District. In 2012/2013 these data were available in State of Alaska reporting areas that overlap specifically with stock boundaries so that the management unit for each stock can be more appropriately represented. To estimate sex ratios it was assumed that the male to female ratio was one. To assess crab mortalities in these groundfish fisheries a 50% handling mortality rate was applied to pot and hook and line estimates and an 80% handling mortality rate was applied to trawl estimates.

Historical non-retained groundfish catch data are available from 1991/1992 to present (J. Mondragon, NMFS, personal communication) although sex ratios have not been determined (Table 3). Prior to 1991, data are only available in INPFC reports. Between 1991 and December 2001 bycatch was estimated using the “blend method”. The blend method combined data from industry production reports and observer reports to make the best, comprehensive accounting of groundfish catch. For shoreside processors, Weekly Production Reports (WPR) submitted by industry were the best source of data for retained groundfish landings. All fish delivered to shoreside processors were weighed on scales, and these weights were used to account for retained catch. Observer data from catcher vessels provided the best data on at-sea discards of groundfish by vessels delivering to shoreside processors. Discard rates from these observer data were applied to the shoreside groundfish landings to estimate total at-sea discards from both observed and unobserved catcher vessels. For observed catcher/processors and motherships, the WPR and the Observer Reports recorded estimates of total catch (retained catch plus discards). If both reports were available, one of them was selected during the “blend method” for incorporation into the catch database. If the vessel was unobserved, only the WPR was available. From January 2003 to December 2007, a new database structure named the Catch Accounting System (CAS) led to large method change. Bycatch estimates were derived from a combination of observer and landing (catcher vessels/production data). Production data included CPs and catcher vessels delivering to motherships. To obtain fishery level estimates, CAS used a ratio estimator derived from observer data (counts of crab/kg groundfish) that is applied to production/landing information. (See http://www.afsc.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-205.pdf). Estimates of crab are in numbers because the PSC is managed on numbers. There were two issues with this dataset that required estimation work outside of CAS:

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

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

Starting in 2013, a new data set based on the CAS system was made available for January 2009 to present. In 2009 reporting State statistical areas was required on groundfish production reports. The level of spatial resolution in CAS was formally federal reporting area since this the highest spatial resolution at which observer data is aggregated to create bycatch rates. The federal reporting area does not follow crab stock boundaries, in particular for species with small stock areas such as Pribilof Islands or St. Matthew Island stocks, so the new data was provided at the State reporting areas. This method uses ratio estimator (weight crab/weight groundfish) applied to the weight of groundfish reported on production/landing reports. Where possible, this dataset aggregates observer data to the stock area level to create bycatch estimates by stock area. There are instances where no observer data is available and aggregation may go outside of a stock area, but this practice is greatly reduced compared with the pre-2009 data, which at best was at the Federal reporting area level.

Total catch in 2014/15 was 1.76 t below the 2014/15 OFL 1,359 t (Tables 3 and 5). Total catch in 2015/16 through August 12, 2016 was 0.32 t. Catch in 2014/15 was 47% from non-pelagic trawl and 53% from hook and line fisheries (Table 4).

2.4 Catch-at-length

Catch-at-length data are not available for this fishery.

2.5 Survey biomass and length frequencies

The 2016 NOAA Fisheries EBS bottom trawl survey results are included in this SAFE report. Data available for estimating the abundance of crab around the Pribilof Islands are relatively sparse. Red king crab have been observed at 35 unique stations in the Pribilof District over the years 1975 to 2016 (22 stations on the 400 nm^2 grid). The number of stations at which at least one crab was observed in a given year ranges from 0-14 over the period from 1975-present (Figure).

Observed survey biomass estimates for males greater than or equal to 120 mm are used in the Tier 4 assessment as an estimate of mature male biomass and to estimate the B_{MSY} proxy, MMB at mating and in fitting the 3-yr running average and the random effects model.

Weight (equation 1) and maturity (equation 3) schedules are applied in the integrated assessment model to calculated abundances and summed to calculate mature male, female, and legal male biomass for the Tier 4 and Tier 3 analysis.

$$\text{Proportion mature male} = 1/(1 + (5.842 * 10^{14}) * e^{((CL(mm)+2.5) * -0.288)})$$
$$\text{Proportion mature female} = 1/(1 + (1.416 * 10^{13}) * e^{((CL(mm)+2.5) * -0.297)}) \qquad (3)$$

Historical survey data are available from 1975 to the present (Tables 6 and 7), and survey data analyses were standardized in 1980 (Stauffer, 2004). Male and female abundance varies widely over the history of the survey time series' (**Error! Reference source not found.**) and uncertainty around area-swept estimates of abundance are large due to relatively low sample sizes (Figure). Male crabs were observed at 9 of 35 stations in the Pribilof District during the 2015 NMFS survey (Figure); female crabs were observed at 5 (Figure). Two (possibly three) cohorts can be seen moving through the length frequencies over time (Figure and Figure). Numbers at length vary dramatically from year to year, but the cohorts can nonetheless also be discerned in these data (Figure and Figure).

The centers of distribution for both males and females have moved within a 40 nm by 40 nm region around St. Paul Island. The center of the red king crab distribution moved to within 20 nm of the northeast side of St. Paul Island as the population abundance increased in the 1980's and remained in that region until the 1990's. Since then, the centers of distribution have been located closer to St. Paul Island the exception of 2000-2003 located towards the north east.

Survey abundance for males >=105 mm declined from 3,662,609 in 2015 to 1,807,323 in 2016 (Table 6). Female biomass (all sizes) declined from 3,859 t in 2015 to 1,898 t in 2016. Survey biomass for males >=120mm declined from 15,173 t in 2015 to 4,150 t in 2016 (Table 11).

3. Analytical approaches

3.1 History of modeling

An inverse-variance weighted 3-year running average of male biomass (>=120mm) based on densities estimated from the NMFS summer trawl survey has been used in recent years to set allowable catches. The natural mortality rate has been used as a proxy for the fishing mortality at which maximum sustainable yield occurs (F_{MSY}) and target biomasses are set by identifying a range of years over which the stock was thought to be near B_{MSY} (i.e. a tier 4 control rule). In 2016, biomass and derived management quantities are estimated by a 3-yr running-average method, a random effects method and by an integrated length-based assessment method (developed in 2014). Tier 3 and tier 4 harvest control rules (HCRs) are applied to the integrated assessment output and are compared to the OFLs calculated by a tier 4 HCR applied to the running-average and random effects estimates of male biomass (>=120mm).

3.2 Model descriptions

3.2.1. Running average

A 3 year running average of male biomass (>=120mm) at survey time was calculated using the weighted average with weights being the inverse of the variance,

$$BWRA_t = \frac{\sum_{t-1}^{t+1} \frac{MMB_t}{w_t}}{\sum_{t-1}^{t+1} \frac{1}{w_t}} \tag{4}$$

Where,

MMB_t Estimated male biomass (>=120mm) from the survey data

w_t The weight associated with the estimate of MMB in year t

w_t is calculated as the variance of the log(biomass) using the CVs of the estimates of MMB from the survey provided by the Kodiak lab:

$$w_t = \ln((CV_t^{MMB})^2 + 1) \tag{5}$$

Where,

CV_t^{MMB} Coefficient of variation associated with the estimate of MMB at time t

3.2.2 Random Effects Model

A random effects model was fit to the survey male biomass (>=120mm) for estimation of current biomass, MMB at mating, OFL and ABC (Model developed for use in NPFMC groundfish assessments). The model uses the CVs as calculated for the 3-yr running average. The random effects model was fit to the survey data at the time of the survey. The biomass estimate in 2016 was projected forward to February 15, 2017 for use in the OFL control rule to estimate the OFL and ABC. The B_{MSY} proxy for both the 3-yr running average and the random effects model was estimated as the average of the 1991 to 2015 observed survey data projected forward to February 15, removing the observed catch. The likelihood equation for the random effects model is,

$$\sum_{i=1}^{yrs}\left\{0.5\left(\log(2\pi\sigma_i^2)+\left(\frac{(\widehat{B}_i-B_i)^2}{\sigma_i^2}\right)\right)\right\}+\sum_{t=2}^{yrs}\left\{0.5\left(\log(2\pi\sigma_p^2\quad)+\left(\frac{(\widehat{B}_i-\hat{B}_{i-1})^2}{\sigma_p^2}\right)\right)\right\}$$

Where,

B_i is the log of observed biomass in year i

$\widehat{B}_i$ is the model estimated log biomass in year i

σ_i^2 is the variance of observed log biomass in year i

σ_p^2 is the variance of the deviations in log survey biomass between years (i.e. process error variance). σ_p^2 was estimated as $e^{(2\alpha)}$, where α is a parameter estimated in the random effects model.

Yrs is the number of years of survey biomass values

3.2.3 Integrated assessment

A length-based integrated assessment method [coded in ADMB (Fournier et al. 2012)] was used to estimate trends in recruitment, fishing mortality (directed and bycatch in the non-pelagic trawl fishery) and male and female numbers in the survey (see appendix A for the model description, likelihood weightings, and estimated and fixed parameters). The assessment is initiated 5 years before data are available to avoid estimating initial numbers at length for both sexes. Males and females are tracked by 5 mm length bins with midpoints ranging from 37.5-207.5mm in the base model. Fishing mortality from the directed fishery during 1993-1998 and bycatch in the non-pelagic trawl fishery from 1991-2016 were accounted for in the model, but discards from the pot fisheries for crab and the fixed gear fishery for cod are not incorporated into the model. The magnitude of the mortality imposed by discards on the population is very small compared to the directed fishery, so the impact of excluding them from the model should be relatively small.

Growth was estimated within the integrated assessment because there are no targeted studies on growth of Pribilof Island red king crab. The presence of a single, large cohort that established the population during the mid-1980s and then was subsequently relatively lightly fished (or not at all in the case of females) makes estimating growth tractable. The modes of the length frequency distributions were well fit by a linear relationship when translated to growth per molt (Figure 12).

Sensitivities to the bin width were performed in 2014 by fitting the assessment method with 10 mm length bins. Estimates of quantities important in management and model fits were not identical between 10 and 5 mm size bin scenarios. Fits to numbers at length and length frequencies were visually similar, but estimated MMB for 2014 was 16% higher when using the 10mm data. A simulation study was undertaken to explore these differences and showed that an assessment method with bin sizes of 5mm estimates MMB without bias (when the data were generated from the underlying population dynamics model), but the estimates from the assessment method fit data binned at 10mm exhibit positive biases compared to the true quantities (Figure). The details of this simulation study were presented at the CAPAM symposium on growth and have been accepted for publication in the special issue (Szuwalski, in press). As a result of this study, the assessment methods presented here use 5mm length bins.

The fits of the 2015 integrated assessment in the recent past were poor for both females and males (Szuwalski, et al. 2015). In this assessment a model fit to males only is presented. The estimation of Francis effective sample sizes was added to the model. However, the model did not converge with sample sizes lowered to the Francis estimate (0.05). Several scenarios were run with samples sizes decreased by multiplying by 0.1, 0.2, 0.4 and 0.6.

4. Model Selection and Evaluation

The running average method with a tier 4 HCR was selected in 2015 by the SSC as the model to determine the OFL and ABC based on concerns around different trends over the last decade between the integrated model and the running average and the lack of fit of the integrated model to survey abundance data. In 2016, four assessment methods are presented for comparison: a running average with a tier 4 HCR, a random effects model, an integrated assessment with tier 3 HCR and an integrated assessment with a tier 4 HCR.

There are trade-offs between using the running average method and the integrated assessment to estimate MMB. The running average methodology is simple to perform and interpret, but estimates of biomass can be sensitive to measurement errors, particularly when relatively few stations report observations of crab or very large tows are taken at a small number of stations. An integrated assessment can smooth over some of the error introduced by imperfect measurement, but it also smooths over process error (e.g. time-varying population processes) that may be captured by a running average. Integrated assessments are also relatively data-hungry and some assumptions must be made about the underlying population processes (e.g. selectivity of the different fleets).

Non-convergence of the integrated models was checked for by examining the maximum gradient components and the ability to invert the Hessian matrix.

5.0 Results

5.1 Tier 4

The 3-yr running average estimates male biomass (>=120mm) at 9,423 t in 2016 at the survey time, while the random effects model estimates 2,431 t (95% CI 2,044 to 2,891 t) (Table 11 and Figure 14). The observed survey male biomass (>=120mm) was 4,150 t in 2016. MMB at mating on February 15, 2016 was estimated at 13,457 t for the observed survey, 9,062 t for the 3-yr weighted average and 2,154 t for the random effects model, projecting forward the respective 2015 biomass (Table 12 and Figure 15). The random effects model estimates no change in biomass over the entire time series. The estimated process error variance of the random effects model that effects smoothness of the fit is estimated at a low value which results in very little change in biomass over time. A prior on the process error variance would be needed to fit the data closer. The use of the 3-yr running average is imposing a prior on smoothness by using 3 biomass values for each estimate. Using more biomass values for the average would result in a smoother fit to the data. The cvs of the survey biomass range from 0.36 to 1.0 with an average of 0.67. The process error variance in the random effects model was fixed at values of 0.005, 0.05, 0.1, 0.2, 0.3 and 0.5 to show the results of fitting with different amounts of smoothness (Figure 26). If a prior ratio of observation error to process error were developed then the process error could be fixed in the random effects model to provide some level of smoothing.

5.2 Assessment Model

The assessment model underestimates abundance in the period 1988 to 2004 (Figure 20). The model fits the abundance better from 2006 to 2016 with some observed values higher and some lower than predicted. Estimated MMB at mating from the integrated assessment peaked during 1992 at 3,901 t then declined to 1095 t in 1997 then increased again to 7,007 t in 2010 then decreased to 6,127 t in 2015 (Table 10 and Figure 21).

Catch biomass was fit well in the model (Figures 16 and 17). Estimates of recruitment showed two main peaks in 1984 and 2002 (Table 10 and Figure 18). The fits to survey length frequency data for males are shown in Figure 22.

Estimated male survey numbers peaked during 2010 at 1.85 million, then declined to 1.54 million in 2016 (Table 10 and Figure 20). Catch and bycatch in the non-pelagic trawl fishery were well fit by the assessment method (Figures 16 and 17). Estimated fishing mortality peaked in 1993 (the first year of the directed fishery) at 0.53 (**Error! Reference source not found.**). Survey selectivity was estimates were sel95% = 160.6 mm and sel50% = 114.8mm (Table A2 and Figure 18). Survey q was fixed at 1.0.

Francis effective sample size multiplier was estimated at 0.05 for the assessment model. However, when sample sizes were reduced using the Francis multiplier (0.05) and for a multiplier of 0.1, the model failed to converge. Model scenarios were run with multipliers of 0.2, 0.4 and 0.6. Lower multipliers resulted in generally higher abundance estimates throughout the time period than the base model (Figure 25). Abundance estimates for 2016 were similar for multipliers of 0.2, 0.4 and 0.6 and lower for the base model. The scenario with multiplier 0.2 had the lowest likelihood for the fit to survey abundance (Table A4). Although the base model seems to fit recent years better than models with lower multipliers (Figure 25).

6. Calculation of reference points

6.1 Tier 4 OFL and B_{MSY}

Natural mortality was used as a proxy for F_{MSY} and a proxy for B_{MSY} was calculated by averaging the biomass of a predetermined period of time thought to represent the time when the stock was at B_{MSY} in the tier 4 HCR. The OFL was calculated by applying a fishing mortality determined by equation 4 to the mature male biomass at the time of fishing.

$$F_{OFL} = \begin{cases} Bycatch\ only & if\ \frac{B_{cur}}{B_{MSY\ proxy}} \leq \beta \\ \frac{\gamma M \left(\frac{B_{cur}}{B_{MSY\ proxy}} - \alpha\right)}{1-\alpha} & if\ \beta < \frac{B_{cur}}{B_{MSY\ proxy}} < 1 \\ \gamma M & if\ B_{cur} > B_{MSY\ proxy} \end{cases} \qquad (4)$$

Where,

B_{cur}	Estimated mature male biomass projected to time of mating fishing at the OFL
$B_{MSY\ proxy}$	Average mature male biomass over the years 1991-present
M	Natural mortality
α	Determines the slope of the descending limb of the HCR (0.05)
β	Fraction of $B_{MSY\ proxy}$ below which directed fishing mortality is zero (here set to 0.25)

In the integrated assessment for the Tier 4 OFL, the F_{OFL} calculated from equation 4 was applied to the legal male population at the time of the fishery (October 15) and biomass was the model estimated biomass.

6.2 Tier 3 OFL, $F_{35\%}$, and $B_{35\%}$

Proxies for biomass and fishing mortality reference points were calculated using spawner-per-recruit methods (e.g. Clark, 1991) in the tier 3 HCR. After fitting the assessment model to the data and estimating population parameters, the model was projected forward 100 years using the estimated parameters under no exploitation to find virgin mature male biomass-per-recruit. Projections were repeated (again for 100 years) to determine the level of fishing mortality that reduced the mature male biomass per recruit to 35% of the virgin level (i.e. $F_{35\%}$ and $B_{35\%}$, respectively) by using the bisection method for identifying the target fishing mortality.

Calculated values of $F_{35\%}$ and $B_{35\%}$ were used in conjunction with a control rule to adjust the proportion of $F_{35\%}$ that is applied based on the status of the population relative to $B_{35\%}$ (Amendment 24, NPFMC).

$$F_{OFL} = \begin{cases} Bycatch\ only & if\ \dfrac{B_{cur}}{B_{35\%}} \leq \beta \\ \dfrac{F_{35\%}\left(\dfrac{B_{cur}}{B_{35\%}} - \alpha\right)}{1-\alpha} & if\ \beta < \dfrac{B_{cur}}{B_{35\%}} < 1 \\ F_{35\%} & if\ B_{cur} > B_{35\%} \end{cases} \tag{5}$$

Where,

B_{cur}	current estimated mature male biomass at mating fishing at the OFL
$B_{35\%}$	mature male biomass at the time of mating resulting from fishing at $F_{35\%}$
$F_{35\%}$	Fishing mortality that reduced the spawners per recruit (measured here as mature male biomass at the time of mating) to 35% of the unfished level
α	Determines the slope of the descending limb of the HCR (0.05)
β	Fraction of $B_{35\%}$ below which directed fishing mortality is zero (here set to 0.25)

6.3 Acceptable biological catches

An acceptable biological catch (ABC) was estimated below the OFL by a proportion based a predetermined probability that the ABC would exceed the OFL (P*). Currently, P* is set at 0.49 and represents a proportion of the OFL distribution that accounts for within assessment uncertainty (σ_w) in the OFL to establish the maximum permissible ABC (ABC_{max}). Any additional uncertainty outside of the assessment methods (σ_b) will be considered as a recommended ABC below ABC_{max}. Additional uncertainty will be included in the application of the ABC by adding the uncertainty components as $\sigma_{\text{total}} = \sqrt{\sigma_b^2 + \sigma_w^2}$.

6.4 Specification of the distributions of the OFL used in the ABC

A distribution for the OFL associated with estimates of MMB from the running average method was constructed by bootstrapping values of MMB_{mating} (assuming that MMB is log-normally distributed) and calculating the OFL according to equation 4. Additional uncertainty (σ_b) equal to 0.3 was added when bootstrapping values of MMB while calculating the distribution for the OFL for the tier 4 HCR. The posterior distribution for the OFL generated from the integrated assessment was used for determining the ABC.

6.5 Tier 3 and integrated assessment: Reference points and OFL

A large year class recruited to the survey gear during 1985 and, lagged to the year of fertilization, would have been produced near the timing of the late 1970s shift in environmental conditions in the North Pacific (Overland et al., 2008). Consequently, $B_{35\%}$ was calculated using only estimates of recruitment from 1983 forward to reflect current environmental conditions (DOC, 2007) and corresponds to a MMB of 1,598 t. The corresponding $F_{35\%}$ was 0.49 and, given a ratio of the MMB at mating to $B_{35\%}$ of 2.5, the calculated F_{OFL} was also 0.49 which resulted in an OFL of 1,931 t. $F_{35\%}$ was relatively high compared to natural mortality because a large fraction of MMB is protected by the 138mm size limit.

6.6 Tier 4 Reference points and OFL

Tier 4 reference points and management quantities were calculated simultaneously in the integrated assessment with the tier 3 reference points. B_{MSY} (based on the MMB over the years 1991-present) was calculated as 3,881 t. F_{MSY} was set equal to natural mortality (0.18) and the resulting OFL was 822 t.

B_{MSY} and projected MMB calculated from the 3-year running average were higher than the estimates from the integrated assessment at 5,512 t (B_{MSY}) and 6,980 t (MMB at mating). The B_{MSY} and projected MMB estimated from the random effects model were 5,512 t and 4,945 t. B_{MSY} is the same for both the random effects model and the 3-yr running average because B_{MSY} is the average of the observed survey biomass. OFL for the 3-yr weighted average was 1,462 t and the random effects model 895 t. MMB at mating and the OFL were similar for the random effects model and the integrated assessment Tier 4 calculation.

6.7 Recommended ABCs

The ABC estimated using a p* of 0.49 with an additional sigma of 0.30 was 1,436 t for the 3-yr running average, 114 t for the random effects model and 357 t for the observed survey. The ABC with a 25% buffer (ABC = OFL * 0.75) (recommended by the CPT and SSC in 2015) was 1,096 t for the 3-yr running average, 89 t for the random effects model and 278 t for the observed survey. ABC for the integrated assessment was estimated using the 25% buffer at 617 t for Tier 4 and 1,448 t for Tier 3.

6.8 Variables related to scientific uncertainty in the OFL probability distribution

Uncertainty in estimates of stock size and OFL for Pribilof Islands red king crab was relatively high due to small sample sizes. The coefficient of variation for the estimate of male abundance for 2016 was 0.72 and has ranged between 0.36 and 0.92 since the 1991 peak in numbers. These CVs were calculated by assuming the data are Poisson distributed, but the data are overdispersed. Using a negative binomial (or other distribution that can allow for overdispersion) would increase the CVs. Growth and survey selectivity were estimated within the integrated assessment (and therefore uncertainty in both processes is accounted for in the posterior distributions), but maturity, survey catchability, fishery selectivity, and natural mortality were fixed. F_{MSY} was assumed to be equal to natural mortality and B_{MSY} was somewhat arbitrarily set to the average MMB over a predetermined range of years for tier 4 HCRs; both of which were assumptions that had a direct impact on the calculated OFL. Sources of mortality from discard in the crab pot fishery and the fixed gear fishery were not included in the integrated assessment because of a lack of length data to apportion removals correctly. Including these sources of mortality may alter the estimated MMB.

A simulation test in which the assessment method was fit to data generated by the population dynamics model within the integrated assessment method and subject to the same measurement error showed that the assessment method was capable of returning unbiased estimates of MMB band other quantities and parameters important in management when size bins were 5mm (Szuwalski, in press).

6.9 Author Recommendation

In the foreseeable future, low sample size will be a problem for the Pribilof Island red king crab, so extra precaution should be taken given the uncertainty associated with MMB estimates. In this respect, the tier 4 HCR is more precautionary in that it sets a higher MSST and a lower $F_{OFL,}$ OFL, and ABC for a given MMB. However, when used in concert with a running average method to estimate MMB, it can be less conservative than the tier 3 HCR that uses estimates from the integrated assessment. If there is a particularly high estimate of MMB from the survey (often associated with high variance–see 2015 for an example), the OFL can be much higher for the Tier 4/running average combination than the Tier3/integrated assessment combination. The random effects model and the integrated assessment can be useful in these years because it smooths over fluctuations in estimates of biomass and numbers, which often appear to be the result of measurement error. The integrated assessment method also provides increased biological realism, allows for the incorporation of multiple data streams into the assessment, and facilitates the use of MCMC to characterize uncertainty in management quantities. MCMC is a cleaner way to account for uncertainty than arbitrarily inflating the variance around survey estimates, particularly when data are available to inform estimation of important population processes.

Females and males experienced similar increases in abundance in the early 1990s, and only in recent years did trends in their abundances deviate from previously correlated trajectories. This suggests that some population process (e.g. natural mortality or catchability) has changed for males or females, but it is difficult to say if the change in trends was a result of a population process for females or for males (or both) changing. It is generally inadvisable to invoke time-varying population processes within an assessment for the sake of improving fits without a hypothesis behind the changes and data to corroborate it. Consequently, it is difficult to make a recommendation on which data scenario to use—the male only scenario did fit the male data better, but that should be expected.

Forcing the model to fit the high estimates of survey numbers during the 1990s (the first cohort seen in the length frequencies) results in a trajectory that is completely unable to fit the most recent numbers estimates (Szuwalski, et al. 2015).

7. Data gaps and research priorities

The largest data gap is the number of observations from which the population size and biomass is extrapolated. Catch-at-length data for the trawl fishery would allow trawl fishery selectivity to be estimated and discard mortality specific to PIRKC to be incorporated into the model. Simulation studies designed to prioritize research on population processes for which additional information would be beneficial in achieving more accurate estimates of management quantities could be useful for this stock (e.g. Szuwalski and Punt, 2012). Research on the probability of molting at length for males would allow the use of data specific to PIRKC in specifying molting probability in the assessment. Research aimed at the catchability and availability of PIRKC may shed some light on divergent changes in abundance in recent years.

8. Ecosystem Considerations

The impact of a directed fishery for Pribilof Islands red king crab on the population of Pribilof island blue king crab will likely continue to be the largest ecosystem consideration facing this fishery and preclude the possibility of a directed fishery for red king crab. Linking changes in productivity as seen in the 1980s with environmental influences is a potential avenue of research useful in selecting management strategies for crab stocks around the Pribilof Islands (e.g. Szuwalski and Punt, 2013a). It is possible that the large year class in the mid-1980s reflected changing environmental conditions, similar to proposed relationships between the Pacific Decadal Oscillation snow crab recruitment in the EBS (Szuwalski and Punt, 2013b). Ocean acidification also appears to have a large detrimental effect on red king crab (Long et al., 2012), which may impact the productivity of this stock in the future.

All code for this assessment can be found at github.com/jturnock/pirkc.

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10. Appendix 1: Population dynamics model for the integrated assessment

An integrated length-based assessment that tracks biannual dynamics of numbers of male and female Pribilof Island red king crabs is used here to provide estimates for quantities used in management. See table A1 for a list of estimated and fixed parameters, table A2 for a list of estimates of parameters, and table A3 for contributions of likelihood components to the objective function and their relative weights. The mode date of the hauls performed in the NMFS trawl survey was June 15th, so this date is used as the beginning of the ‘model year’. Survey to fishery dynamics are described by equation A1:

$$N_{s,y,l} = N_{s,y,l}e^{-3M/12} \qquad \text{(A1)}$$

where $N_{s,y,l}$ is the number of animals of sex *s* in length-class *l* at time step *y*, and –3*M/12* decrements the population by three months of natural mortality. A pulse fishery is modeled three month after the survey (the fishery lasted on average two weeks, so a pulse fishery is a reasonable assumption) in which numbers are updated as in equation A2. Historically, the fishery occurred in September, but the opening day for all crab fisheries is October 15th now. Consequently, the calculated OFL is based on numbers at length decremented by 4 months of natural mortality.

$$N_{s,y,l} = N_{s,y,l}e^{-(F_{dir,y,l}+F_{trawl,y,l})} \qquad \text{(A2)}$$

Molting, growth, and recruitment occur after the fishery (in that order, equation A3):

$$N_{s,y,l} = \begin{cases} \Omega_l N_{s,y,l} \mathrm{X}_{l,l'} \\ (1-\Omega_l)N_{s,y,l} + Pr_l R_y \end{cases} \qquad \text{(A3)}$$

Where Ω_l is the probability of an animal molting at length l, $N_{s,y,l}$, is the number of animals in sex s in length-class l at time step y, $X_{l,l'}$ is the size transition matrix, R_y is recruitment during year y and Pr_l is the proportion recruiting to length-class l.

Mature biomass at the time of mating (which is used in calculation of reference points) is calculated by decrementing the population by 5 months of natural mortality after the fishery. The remaining 4 months of natural mortality are applied to the population between the mating and the survey:

$$N_{s,y+1,l} = N_{s,y,l}e^{-4M/12} \tag{A4}$$

Fishing mortality and selectivity

Historical fishing mortality was primarily caused by landings in the directed fishery. No length frequency data are available to allocate discards from the directed fishery, so discard mortality is assumed to be zero and knife-edge selectivity is specified for the fishery with the ‘edge’ occurring at the minimum legal size—138mm carapace length (**Error! Reference source not found.**). Fishing mortality is calculated by:

$$F_{dir,y,l} = S_{l,dir}e^{\overline{F_{dir}}+n_y} \tag{A5}$$

where $S_{l,dir}$ is the selectivity of the fishery on animals in length-class l, $\overline{F_{dir}}$ is the average (over time) ln-scale fully-selected fishing mortality, and n_y is the ln-scale deviation in fishing mortality for year y from the average fishing mortality. Average fishing mortality and the yearly deviations are estimated parameters.

Fishery selectivity is assumed to be a logistic function of size and constant over time:

$$S_{l,dir} = \left(1+\exp\left(-\frac{\log(19)\left(\bar{L}_l - L_{50,dir}\right)}{L_{95,dir}-L_{50,dir}}\right)\right)^{-1} \tag{A6}$$

where $L_{50,dir}$ is the length at which 50% of animals are selected, $\bar{L}_l$ is the midpoint of length-class l, and $L_{95,dir}$ is the length at which 95% of animals are selected.

A switch that allows mortality due to discarding in the fishery to be modeled based on the Bristol Bay red king crab assessment (Zheng et al., 2014) is included in the code. Discard selectivity, $S_{l,disc}$ is defined as:

$$S_{l,disc} = \vartheta + \varphi * L_l \qquad if\ L_l \le 138 \tag{A7}$$

$$S_{l,disc} = S_{l-1,disc} + 5 * \delta \qquad if\ L_l > 138 \tag{A8}$$

$$S_{l,disc} = 0 \qquad if\ S_{l,disc} < 0 \tag{A9}$$

Where θ, φ, and δ are parameters borrowed from the 2014 BBRKC assessment and L_l is the carapace width of an individual crab. Discard mortality is assumed to be 0.2.

Bycatch in the non-pelagic trawl for groundfish is the second largest historical source of mortality, but it only comprised 3% (on average) of the catch when the directed fishery was operating. Fishing mortality at length attributed to bycatch in the trawl fishery is modeled by equation A7:

$$F_{trawl,y,l} = S_{l,trawl}e^{\overline{F_{trawl}}+n_y} \tag{A10}$$

Selectivity, $S_{l,trawl}$, in the non-pelagic trawl fishery for groundfish is assumed to be a logistic function of size and constant over time:

$$S_{l,trawl} = \left(1 + \exp\left(-\frac{\log(19)\left(\bar{L}_l - L_{50,trawl}\right)}{L_{95,trawl} - L_{50,trawl}}\right)\right)^{-1} \quad \text{(A11)}$$

where $L_{50,\text{trawl}}$ is the length at which 50% of animals are selected, $\bar{L}_l$ is the midpoint of length-class l, and $L_{95,\text{trawl}}$ is the length at which 95% of animals are selected. Parameters are fixed to those reported in the Bristol Bay red king crab assessment because there are no length frequency data available to inform estimation for Pribilof Island red king crab (**Error! Reference source not found.**).

Survey selectivity is assumed to be a logistic function of size and constant over time. :

$$S_{l,surv} = Surv_q * \left(1 + \exp\left(-\frac{\log(19)\left(\bar{L}_l - L_{50,surv}\right)}{L_{95,surv} - L_{50,surv}}\right)\right)^{-1} \quad \text{(A12)}$$

where $Surv_q$, is the catchability coefficient for the survey gear, $L_{50,\text{surv}}$ is the length at which 50% of animals are selected, $\bar{L}_l$ is the midpoint of length-class l, and $L_{95,\text{surv}}$ is the length at which 95% of animals are selected. Survey selectivity parameters are estimated, except for $Surv_q$, which is fixed to a value of 1. A switch has been added to the code to allow $Surv_q$ to be estimated annually. This is to be used as an exploratory tool, not to provide estimated of numbers during the survey.

Survey numbers at length

The model prediction of the number of male crab at length at the time of the survey, $\hat{N}^{surv}_{s,y,l}$, is given by:

$$\hat{N}^{surv}_{s,y,l} = S_{l,surv} N_{s,y,l} \quad \text{(A13)}$$

Catch

The model prediction of the directed catch at length is given by:

$$\hat{C}^{dir}_{y,l} = S_{l,dir} N_{s,y=fishtime,l}(1 - e^{-F_{y,l}}) \quad \text{(A14)}$$

where $\hat{C}^{dir}_{y,l}$ is the model estimate of the total catch of animals in length-class l during year y in numbers, $N_{s,y=fishtime,l}$ is the number of animals of sex s in length-class l when the fishery occurs during year y. ($1-e^{-F_{y,l}}$) is the proportion of crab taken by the fishery during year y.

Growth

Molting and growth occur before the survey. Female crab are assumed to molt every year, but the probability of molting for male crab is a declining logistic function of length. The parameters are fixed based on Powell (1967) such that the probability of molting is 1 until approximately the age of maturity at which time it steadily declines (**Error! Reference source not found.**):

$$P_l = 1 - \left(1 + \exp\left(-\frac{\log(19)\left(\bar{L}_l - L_{50,molt}\right)}{L_{95,molt} - L_{50,molt}}\right)\right)^{-1} \quad \text{(A15)}$$

where $L_{50,\text{molt}}$ is the length at which 50% of animals molt, and $L_{95,\text{molt}}$ is the length at which 95% of animals molt. The growth increment for animals that do molt is based on a gamma distribution, i.e.:

$$X_{l,l'} = Y_{l,l'} / \sum_{l'} Y_{l,l'} \quad \text{(A16)}$$

$$Y_{l,l'} = (\Delta_{l,l'})^{(L_l - (\bar{L}_l - 2.5))/\beta} e^{-\Delta_{l,l'}/\beta} \quad \text{(A17)}$$

where L_l is the expected length for an animal in length-class l given that it moults:

$$L_l = \delta_1 + \delta_2 \bar{L}_l \quad \text{(A18)}$$

δ_1, δ_2 are the parameters of the relationship between length and growth increment, $\Delta_{l,l'}$ is the difference in length between midpoints of length-classes *i* and *j*:

$$\Delta_{l,l'} = \bar{L}_{l'} + 2.5 - \bar{L}_l \qquad \text{(A19)}$$

β is the parameter which defines the variability in growth increment and was set to 0.75 for this analysis. The constant "2.5" is half a length bin's length. The size transition matrix can be seen in **Error! Reference source not found.**.

Recruitment

The fraction of the annual recruitment in an area which recruits to length-class *l* is based on a gamma function, i.e.:

$$Pr_l = (\Delta_{l,l'})^{\mu_1/\mu_2} e^{-\Delta_{l,l'}/\mu_2} / \sum_{l'} (\Delta_{l,l'})^{\mu_1/\mu_2} e^{-\Delta_{l,l'}/\mu_2} \qquad \text{(A20)}$$

Where μ_1 and μ_2 are the parameters that define the recruitment fractions. Mean recruitment, annual recruitments and fraction recruiting are treated as estimable parameters, resulting 42 total estimated parameters related to recruitment (Table A1). The fraction recruiting was estimated and changes depending on whether both males and females are fit or if only males are fit (compare **Error! Reference source not found.** and Figure).

Likelihood components

The model is fit to survey length frequencies (L1, A21), a survey index of abundance (L2, A22), directed catch (L3, A23) and non-pelagic trawl bycatch (L4, A24).

$$L_1 = \begin{cases} \sum_s \sum_y \sum_l -\gamma_y p^{obs}_{surv,l,y,s} \ln\left(p^{pred}_{surv,l,y,s} + \kappa\right) & if\ p^{obs}_{surv,l,y,s} \geq 0.01 \\ 0 & if\ p^{obs}_{surv,l,y,s} < 0.01 \end{cases} \qquad \text{(A21)}$$

where L_1 is the contribution to the objective function of the fit to survey length frequencies; γ_y is the sample size for year *y*, $p^{pred}_{surv,l,y,s}$ is the model-estimate of the length-frequency for sex *s* for length-class *l* in year *y*; $p^{obs}_{surv,l,y,s}$ is the observed survey length-frequency for sex *s* for length-class *l* during year *y*; κ is a small number (0.001 here) added to all log calculations. Fits to the observed length frequencies only contribute to the objective function if the observed proportion is greater than 0.01. The reported number of samples used to calculate the length frequencies were used to weight the survey length frequency likelihoods unless they exceeded 200, at which point they were set to 200.

$$L_2 = \sum_s \sum_y \frac{\left(\ln\left(N^{pred}_{y,s} + \kappa\right) - \ln\left(N^{obs}_{y,s} + \kappa\right)\right)^2}{\ln\left(\left(CV_{y,s}\right)^2 + 1\right)} \qquad \text{(A22)}$$

where $N^{pred}_{y,s}$ is the model-estimate of the number of crab of sex *s* caught in the survey in during year *y*, $N^{obs}_{y,s}$ is the observed number of crab of sex *s* in the survey in during year *y*, and $CV_{y,s}$ is the observed coefficient of variation for $N^{obs}_{y,s}$. κ is a small number (equal to 0.001 here) added to avoid taking the log of zero. Historically calculated CVs were used to fit the survey numbers

$$L_3 = \sum_y \frac{\left(\ln\left(C^{pred}_y + \kappa\right) - \ln\left(C^{obs}_y + \kappa\right)\right)^2}{\ln\left(\left(CV_y{}^{cat}\right)^2 + 1\right)} \qquad \text{(A23)}$$

where C^{pred}_y is the catch in numbers predicted by the model for year *y*, C^{obs}_y is the observed catch in numbers for year *y*, $CV_y{}^{cat}$ is the assumed coefficient of variation for the observed data for year *y*, and κ is a small number added to avoid taking the log of zero when catches do not occur (here 0.001 is used).

$$L_3 = \sum_y \frac{\left(\ln\left(\sum_s byC_{y,s}^{pred} + \kappa\right) - \ln\left(byC_{y,s}^{obs} + \kappa\right)\right)^2}{\ln\left(\left(CV_y{}^{bycatch}\right)^2 + 1\right)} \tag{A24}$$

where $byC_{y,s}^{pred}$ is the bycatch in tonnes of sex *s* from the non-pelagic trawl fishery predicted by the model for year *y*, byC_y^{obs} is the observed bycatch in tonnes for during year *y*, $CV_y{}^{bycatch}$ is the assumed coefficient of variation for the observed data for year *y*, and κ is a small number added to avoid taking the log of zero when catches do not occur (here 0.001 is used).

Penalty components

A penalty is placed on the between year deviations in estimated recruitment deviates and fishing mortality deviates (both directed and trawl) of the form:

$$P_2 = \gamma_w \sum_l (\ln(\eta_l) - \ln(\eta_{l-1}))\ \hat{}2 \tag{A25}$$

where, η_l, is the quantity in question (e.g. recruitment deviations) and γ_w is the weighting factor (equal to 1 in the assessment presented for all quantities).

11. Tables

Table 1. Total retained catches from directed fisheries for Pribilof Islands District red king crab (Bowers et al. 2011; D. Pengilly, ADF&G, personal communications).

Year	Catch (count)	Catch (t)	Avg CPUE (legal crab count pot^{-1})
1973/1974	0	0	0
1974/1975	0	0	0
1975/1976	0	0	0
1976/1977	0	0	0
1977/1978	0	0	0
1978/1979	0	0	0
1979/1980	0	0	0
1980/1981	0	0	0
1981/1982	0	0	0
1982/1983	0	0	0
1983/1984	0	0	0
1984/1985	0	0	0
1985/1986	0	0	0
1986/1987	0	0	0
1987/1988	0	0	0
1988/1989	0	0	0
1989/1990	0	0	0
1990/1991	0	0	0
1991/1992	0	0	0
1992/1993	0	0	0
1993/1994	380,286	1183.02	11
1994/1995	167,520	607.34	6
1995/1996	110,834	407.32	3
1996/1997	25,383	90.87	<1
1997/1998	90,641	343.29	3
1998/1999	68,129	246.91	3
1999/2000 to 2015/2016	0	0	0

Table 2. Fishing effort during Pribilof Islands District commercial red king crab fisheries, (Bowers et al. 2011).

Season	Number of Vessels	Number of Landings	Number of Pots Registered	Number of Pots Pulled
1993	112	135	4,860	35,942
1994	104	121	4,675	28,976
1995	117	151	5,400	34,885
1996	66	90	2,730	29,411
1997	53	110	2,230	28,458
1998	57	57	2,398	23,381
1999-2015/16			Fishery Closed	

Table 3. Non-retained total catch mortalities from directed and non-directed fisheries for Pribilof Islands District red king crab. Handling mortalities (crab pot =0.2, groundfish pot and hook/line= 0.5, trawl = 0.8) were applied to the catches. (Bowers et al. 2011; D. Pengilly, ADF&G; J. Mondragon, NMFS). **** NEW 2013 calculation of bycatch using AKRO Catch Accounting System with data reported from State of Alaska reporting areas that encompass the Pribilof Islands red king crab district. 2015/16 data through August 11, 2016.**

	Crab pot fisheries			Groundfish fisheries	
Year	Legal male (t)	Sublegal male (t)	Female (t)	All fixed (t)	All trawl (t)
1991/1992				0.48	45.71
1992/1993				16.12	175.93
1993/1994				0.60	131.87
1994/1995				0.27	15.29
1995/1996				4.81	6.32
1996/1997				1.78	2.27
1997/1998				4.46	7.64
1998/1999	0.00	0.91	11.34	10.40	6.82
1999/2000	1.36	0.00	8.16	12.40	3.13
2000/2001	0.00	0.00	0.00	2.08	4.71
2001/2002	0.00	0.00	0.00	2.71	6.81
2002/2003	0.00	0.00	0.00	0.50	9.11
2003/2004	0.00	0.00	0.00	0.77	9.83
2004/2005	0.00	0.00	0.00	3.17	3.52
2005/2006	0.00	0.18	1.81	4.53	24.72
2006/2007	1.36	0.14	0.91	6.99	21.35
2007/2008	0.91	0.05	0.09	1.92	2.76
2008/2009	0.09	0.00	0.00	1.64	6.94
2009/2010	0.00	0.00	0.00	0.33	2.45
**2009/2010				0.19	1.05
2010/2011	0.00	0.00	0.00	0.30	3.87
**2010/2011				0.45	6.25
2011/2012	0.00	0.00	0.00	0.62	4.78
**2011/2012				0.35	4.47
**2012/2013	0.00	0.00	0.00	0.12	12.98
2013/2014	0.00	0.00	0.00	0.25	1.99
2014/2015	0.00	0.00	0.00	0.73	1.03
2015/2016	0.167	0.00	0.053	0.03	0.07

Table 4. Percent by weight of the Pribilof Islands red king crab bycatch using the new 2014 calculation of bycatch using AKRO Catch Accounting System with data reported from State of Alaska reporting areas that encompass the Pribilof Islands red king crab district.

Crab fishing season	hook and line %	non-pelagic trawl %	pot %	pelagic trawl %	TOTAL (# crabs)
2009/10	19	77	3	1	813
2010/11	10	90	<1	<1	3,026
2011/12	10	89	1		2,167
2012/13	1	99	<1		4,517
2013/14	11	89	0	0	640
2014/2015	53	47	0	0	1,439
2015/16	40	60	0	0	382

Table 5. Total bycatch (t) and total catch (t) with mortality applied for Pribilof red king crab from 1991 to August 12, 2015/16.

Year	total bycatch (t)	Total catch (t)
1991/1992	46.19	46.19
1992/1993	192.05	192.05
1993/1994	132.47	1315.49
1994/1995	15.56	622.9
1995/1996	11.13	418.45
1996/1997	4.05	94.92
1997/1998	12.1	355.39
1998/1999	29.47	276.38
1999/2000	25.05	25.05
2000/2001	6.79	6.79
2001/2002	9.52	9.52
2002/2003	9.61	9.61
2003/2004	10.6	10.6
2004/2005	6.69	6.69
2005/2006	31.24	31.24
2006/2007	30.75	30.75
2007/2008	5.73	5.73
2008/2009	8.67	8.67
2009/2010	1.24	1.24
2010/2011	6.7	6.7
2011/2012	4.82	4.82
2012/2013	13.1	13.1
2013/2014	2.24	2.24
2014/2015	1.76	1.76
2015/2016	0.32	0.32

Table 6. 2016 Pribilof Islands District red king crab male abundance, male biomass (>= 105mm), and female biomass estimated based on the NMFS annual EBS bottom trawl survey with no running average.

Year	Total Male Abundance	Total males at survey (t)	Total females at survey (t)
1975/1976	0	0	11
1976/1977	50778	165	102
1977/1978	228477	213	148
1978/1979	367140	1250	52
1979/1980	279707	556	93
1980/1981	400513	1269	262
1981/1982	80928	312	35
1982/1983	352166	1482	933
1983/1984	144735	553	309
1984/1985	64331	317	112
1985/1986	16823	61	0
1986/1987	38419	138	79
1987/1988	18611	54	31
1988/1989	1963775	525	836
1989/1990	1844076	1720	2251
1990/1991	6354076	8019	2723
1991/1992	3100675	4979	5032
1992/1993	1861538	3361	3432
1993/1994	3787997	10156	6478
1994/1995	3669755	9538	3964
1995/1996	7693368	18417	5149
1996/1997	683611	2378	2007
1997/1998	3155556	7254	1962
1998/1999	1192015	2655	1719
1999/2000	9102898	5751	5418
2000/2001	1674067	4477	995
2001/2002	6157584	10186	5774
2002/2003	1910263	7037	787
2003/2004	1506201	5373	2269
2004/2005	2196795	3622	1292
2005/2006	302997	1262	3118
2006/2007	1459278	7097	2183
2007/2008	1883489	5371	1811
2008/2009	1721467	5603	3017
2009/2010	923133	2545	826
2010/2011	927825	4449	840
2011/2012	1052228	3878	817
2012/2013	1609444	4753	663
2013/2014	1831377	7854	169
2014/2015	3036807	12129	1093
2015/2016	3662609	15252	3859
2016/2017	1807323	4676	1898

Table 7. 2016 Pribilof Islands District male red king crab abundance CV and total male and female biomass CVs estimated from the NMFS annual EBS bottom trawl survey data.

Year	Total Male Abundance CV	Total male at survey CV	Total female at survey CV
1975/1976	0.00	0.00	1.00
1976/1977	1.00	1.00	0.78
1977/1978	1.00	1.00	1.00
1978/1979	0.83	0.83	1.00
1979/1980	0.49	0.52	1.00
1980/1981	0.40	0.38	0.73
1981/1982	0.57	0.58	1.00
1982/1983	0.70	0.70	0.77
1983/1984	0.64	0.55	0.48
1984/1985	0.48	0.55	0.57
1985/1986	1.00	1.00	0.00
1986/1987	0.70	0.70	1.00
1987/1988	1.00	1.00	1.00
1988/1989	0.74	0.56	0.67
1989/1990	0.69	0.77	0.68
1990/1991	0.87	0.89	0.72
1991/1992	0.78	0.80	0.60
1992/1993	0.68	0.61	0.91
1993/1994	0.93	0.92	0.72
1994/1995	0.81	0.78	0.88
1995/1996	0.57	0.60	0.66
1996/1997	0.37	0.37	0.74
1997/1998	0.56	0.54	0.57
1998/1999	0.42	0.37	0.77
1999/2000	0.79	0.58	0.82
2000/2001	0.40	0.38	0.63
2001/2002	0.90	0.83	0.99
2002/2003	0.67	0.69	0.52
2003/2004	0.66	0.66	0.91
2004/2005	0.83	0.60	0.53
2005/2006	0.53	0.57	0.78
2006/2007	0.39	0.38	0.61
2007/2008	0.61	0.51	0.77
2008/2009	0.52	0.50	0.68
2009/2010	0.70	0.64	0.53
2010/2011	0.45	0.43	0.71
2011/2012	0.63	0.64	0.73
2012/2013	0.65	0.59	0.55
2013/2014	0.58	0.61	0.58
2014/2015	0.71	0.78	0.94
2015/2016	0.72	0.74	0.96
2016/2017	0.72	0.69	0.61

Table 10. Estimated recruitment (numbers), male mature biomass (t) at time of mating, total male abundance (1000s) from the integrated assessment method when males only are fit (updated).

Year	Recruitment	MMB (t)	Male
1975	9407.1	74	33.5
1976	14102.8	158	51.6
1977	10063.5	224	65.6
1978	7485.4	256	71.2
1979	8530.3	261	69.7
1980	15456.6	249	64.5
1981	53831.7	231	58.3
1982	300177.7	213	52.8
1983	169936.2	195	49.8
1984	3960476.5	177	48.2
1985	972586.8	162	73.9
1986	370107.0	154	105.8
1987	552229.2	185	162.0
1988	257667.6	306	270.0
1989	133827.5	793	456.4
1990	132344.4	2209	725.5
1991	928923.6	3452	1000.7
1992	433556.7	3901	1143.2
1993	310040.0	2464	1117.5
1994	1957708.4	1827	700.5
1995	1570327.9	1345	532.9
1996	170718.6	1243	452.8
1997	74019.3	1095	480.0
1998	113248.9	1115	488.1
1999	454678.2	1521	547.0
2000	691971.3	2338	708.4
2001	1870682.9	3248	875.5
2002	4092438.1	3684	980.2
2003	651297.5	3666	1007.8
2004	263785.9	3475	983.4
2005	305410.3	3335	993.5
2006	788052.4	3469	1083.2
2007	936513.8	4295	1280.7
2008	483788.2	5832	1557.9
2009	983490.3	6845	1787.5
2010	1394605.9	7007	1850.3
2011	233935.4	6755	1784.6
2012	111497.7	6496	1694.1
2013	83897.8	6337	1630.5
2014	75499.6	6169	1593.0
2015	73406.2	6127	1565.4
2016	73406.2		1537.2

Table 11. Estimates of survey male >= 120mm biomass (t) at the time of the survey, cv, 3-year running weighted average and the random effects model with lower and upper confidence intervals for the random effects estimates.

Year	MB GE120	CV MB GE120	3-yr running avg	random effects	RE LCI	RE UCI
1976	165	1.00	NA	2,283	1,918	2,719
1977	119	1.00	585	2,284	1,919	2,718
1978	1,250	0.83	648	2,284	1,920	2,717
1979	556	0.52	1,042	2,285	1,922	2,717
1980	1,269	0.38	850	2,287	1,924	2,718
1981	312	0.58	1,060	2,289	1,927	2,719
1982	1,464	0.70	691	2,292	1,930	2,722
1983	527	0.53	679	2,295	1,933	2,724
1984	317	0.55	368	2,298	1,936	2,727
1985	61	1.00	211	2,302	1,940	2,732
1986	138	0.70	95	2,307	1,945	2,737
1987	54	1.00	107	2,313	1,950	2,743
1988	107	1.00	609	2,319	1,956	2,749
1989	1,529	0.91	961	2,325	1,962	2,756
1990	1,141	0.93	2,526	2,332	1,968	2,764
1991	4,430	0.80	3,133	2,339	1,974	2,771
1992	3,305	0.60	5,172	2,346	1,980	2,779
1993	9,873	0.92	6,597	2,353	1,986	2,786
1994	9,139	0.77	13,423	2,359	1,992	2,794
1995	18,056	0.60	7,350	2,365	1,997	2,800
1996	2,362	0.37	6,816	2,371	2,002	2,806
1997	6,159	0.62	2,955	2,376	2,007	2,813
1998	2,324	0.36	3,783	2,381	2,011	2,819
1999	5,523	0.67	3,614	2,386	2,016	2,825
2000	4,320	0.37	5,298	2,391	2,020	2,831
2001	8,603	0.79	5,614	2,396	2,023	2,837
2002	7,037	0.69	6,853	2,400	2,027	2,842
2003	5,373	0.66	5,194	2,404	2,030	2,847
2004	3,622	0.59	3,283	2,407	2,033	2,852
2005	1,238	0.59	4,805	2,411	2,035	2,856
2006	7,003	0.38	5,190	2,415	2,038	2,861
2007	5,224	0.49	6,086	2,418	2,040	2,865
2008	5,462	0.51	4,642	2,420	2,041	2,869
2009	2,500	0.64	4,333	2,422	2,043	2,873
2010	4,405	0.44	3,779	2,424	2,044	2,876
2011	3,834	0.65	4,292	2,426	2,044	2,879
2012	4,477	0.57	5,350	2,428	2,045	2,882
2013	7,749	0.62	7,455	2,429	2,045	2,885
2014	12,047	0.78	11,235	2,430	2,045	2,888
2015	15,173	0.74	10,218	2,431	2,045	2,890
2016	4,150	0.70	9,423	2,431	2,044	2,891

Table 12. Projected MMB at mating for survey males >= 120mm, the 3-yr running average and the random effects model fit.

	projected GE120mm to feb 15 removing catch		
	Observed survey	3-yr weighted average	Random Effects
1976	146	NA	2,025
1977	105	519	2,025
1978	1,108	575	2,026
1979	493	924	2,027
1980	1,125	754	2,028
1981	277	940	2,030
1982	1,298	613	2,033
1983	467	602	2,035
1984	281	326	2,038
1985	55	187	2,042
1986	122	84	2,046
1987	48	95	2,051
1988	95	540	2,057
1989	1,357	852	2,063
1990	1,012	2,240	2,068
1991	3,929	2,779	2,075
1992	2,739	4,395	2,034
1993	7,441	4,536	1,894
1994	7,482	11,282	777
1995	15,596	6,101	1,475
1996	2,000	5,950	1,684
1997	5,107	2,266	2,012
1998	1,796	3,091	1,756
1999	4,881	3,189	1,851
2000	3,825	4,692	2,104
2001	7,621	4,970	2,118
2002	6,232	6,068	2,119
2003	4,755	4,596	2,122
2004	3,206	2,905	2,125
2005	1,069	4,232	2,132
2006	6,181	4,573	2,112
2007	4,627	5,392	2,114
2008	4,836	4,108	2,141
2009	2,216	3,841	2,140
2010	3,900	3,345	2,149
2011	3,396	3,801	2,145
2012	3,958	4,732	2,148
2013	6,871	6,610	2,141
2014	10,683	9,963	2,153
2015	13,457	9,062	2,154

Table A1. List of estimated and fixed parameters.

Fixed parameters (14)	Number
Natural mortality	1
Molting probability	3
Fishery selectivity	2
Discard selectivity	3
Weight	4
Survey catchability	1
Estimated parameters (89)	
Growth	6
Proportion recruiting	2
Log recruitment deviations	46
Log average fishing mortality (directed)	1
Log fishing mortality deviations (directed)	6
Log average fishing mortality (trawl)	1
Log fishing mortality deviations (trawl)	26
Survey selectivity	2

Table A2. List of estimated parameter values from 2014 and 2015.

Parameter	2014	2015	2016
srv_q	1	1	1
fish_sel50	138	138	138
fish_sel95	138.05	138.05	138.05
srv_sel50	102.15	100.3	114.78
srv_sel95	141.06	147.88	160.63
log_avg_fmort_dir	-0.98	-1.72	-1.11
log_avg_fmort_trawl	-4.88	-5.5	-5.39
mean_log_rec	11.21	11.62	12.11
A_f (growth)	25.42	25.3	NA
A_m (growth)	9.77	7.76	5.78
B_f (growth)	0.86	0.86	NA
B_m (growth)	1.13	1.15	1.13
growth_beta_males	0.72	1.12	0.78
alpha_rec	0.86	5.56	0.98
beta_rec	0.16	1.53	0.19

Table A3. Likelihood component contribution to the likelihood and associated weights for the assessment model fit to males only.

Likelihood component	negLogLike (males only)	Weighting
Survey numbers (males)	45.7	.36 -1 (CVs)
Survey length frequencies (male)	10,012.3	18-200 (sample size)
Catch	0.003	.005(CV)
Trawl	0.019	.01 (CV)
Smoothness penalties		
Trawl fishing mortality	38.6	1 (CV)
Fishing mortality	4.3	1 (CV)
Recruitment	48.9	1 (CV)

Table A4. Likelihood component contribution to the likelihood and associated weights for the assessment model scenarios with multipliers on the survey length sample sizes of 0.2, 0.4, 0.6 and the base model (1.0).

Likelihood component	Base Model (1.0)	0.2	0.4	0.6	Weighting
Survey numbers (males)	45.7	29.9	32.7	36.1	.36 -1 (CVs)
Survey length frequencies (male)	10,012.3	2018.9	4024.6	6023.7	18-200 (Base model sample size)
Catch	0.003	0.001	0.001	0.001	.005(CV)
Trawl	0.019	0.019	0.019	0.019	.01 (CV)
Smoothness penalties					
Trawl fishing mortality	38.6	38.4	38.3	38.4	1 (CV)
Fishing mortality	4.3	4.3	4.3	4.3	1 (CV)
Recruitment	48.9	20.4	30.1	37.5	1 (CV)

12. Figures

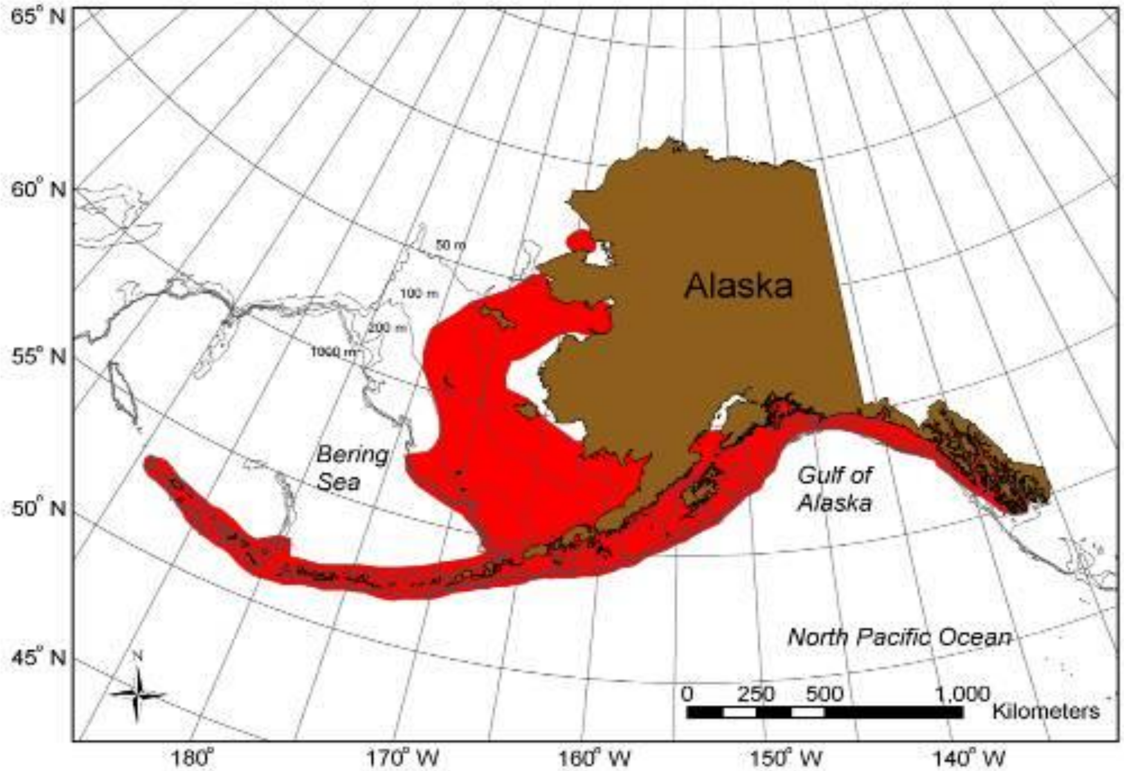

Figure 1. Red king crab distribution.

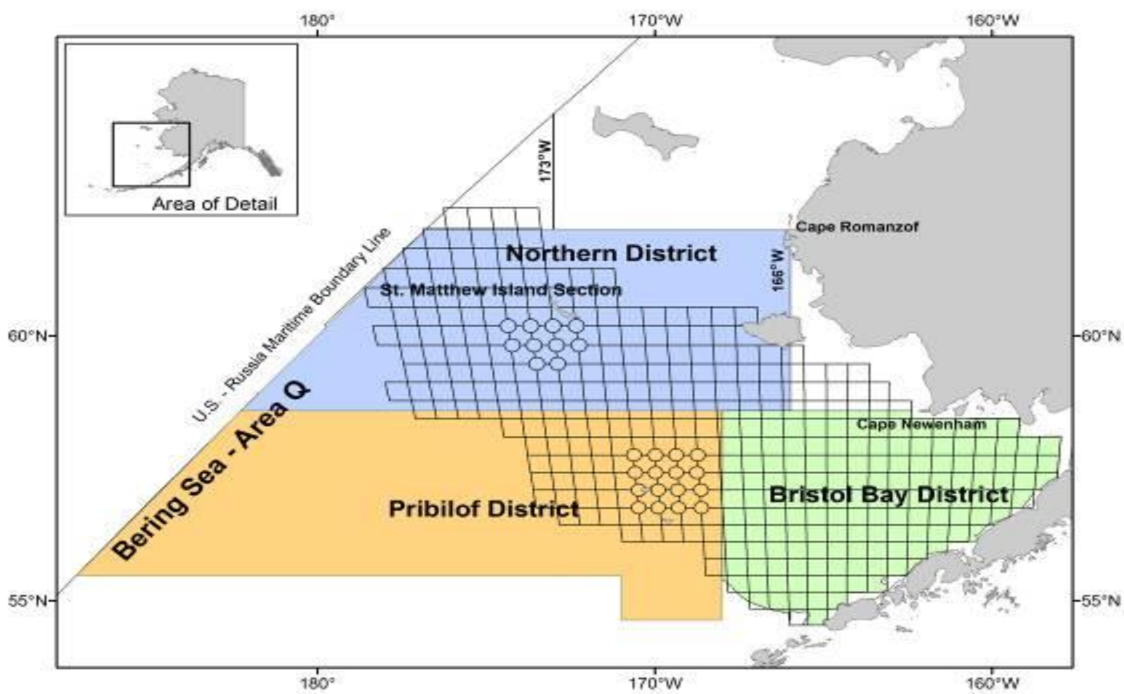

Figure 2. King crab registration area Q (Bering Sea) showing the Pribilof District.

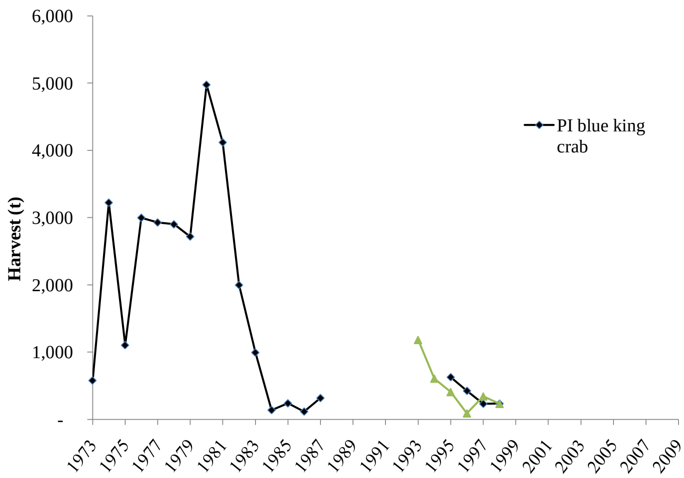

Figure 3. Historical harvests and GHLs for Pribilof Island blue (diamonds) and red king crab (triangles) (Bowers et al. 2011).

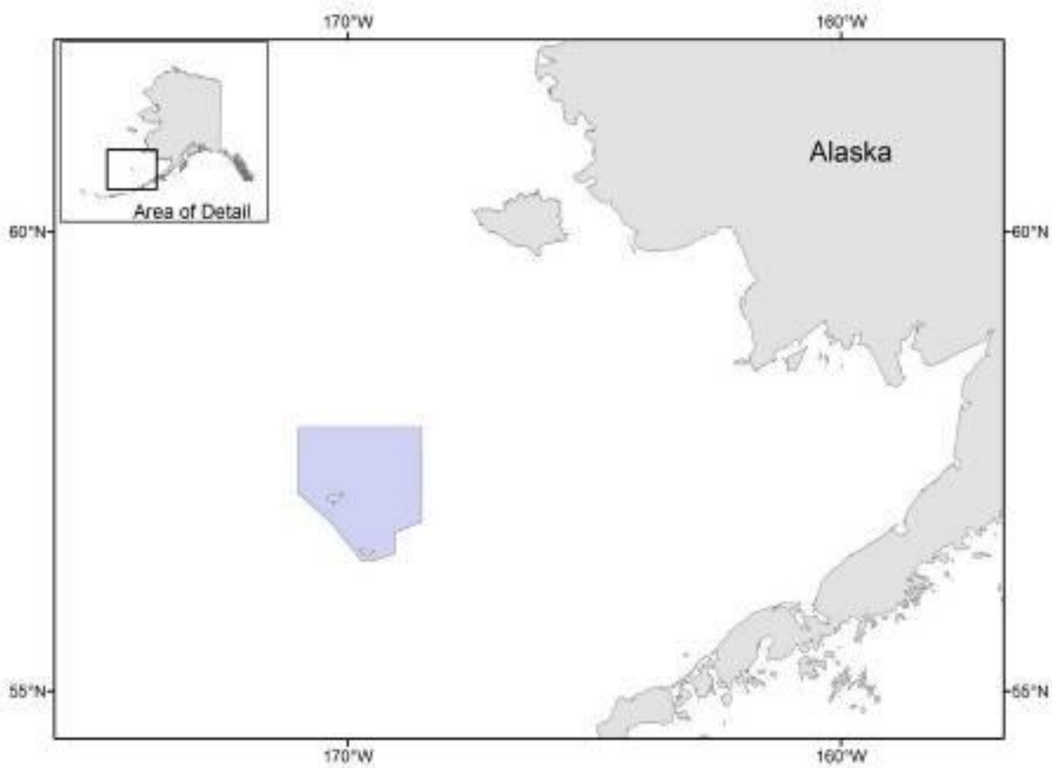

Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation area.

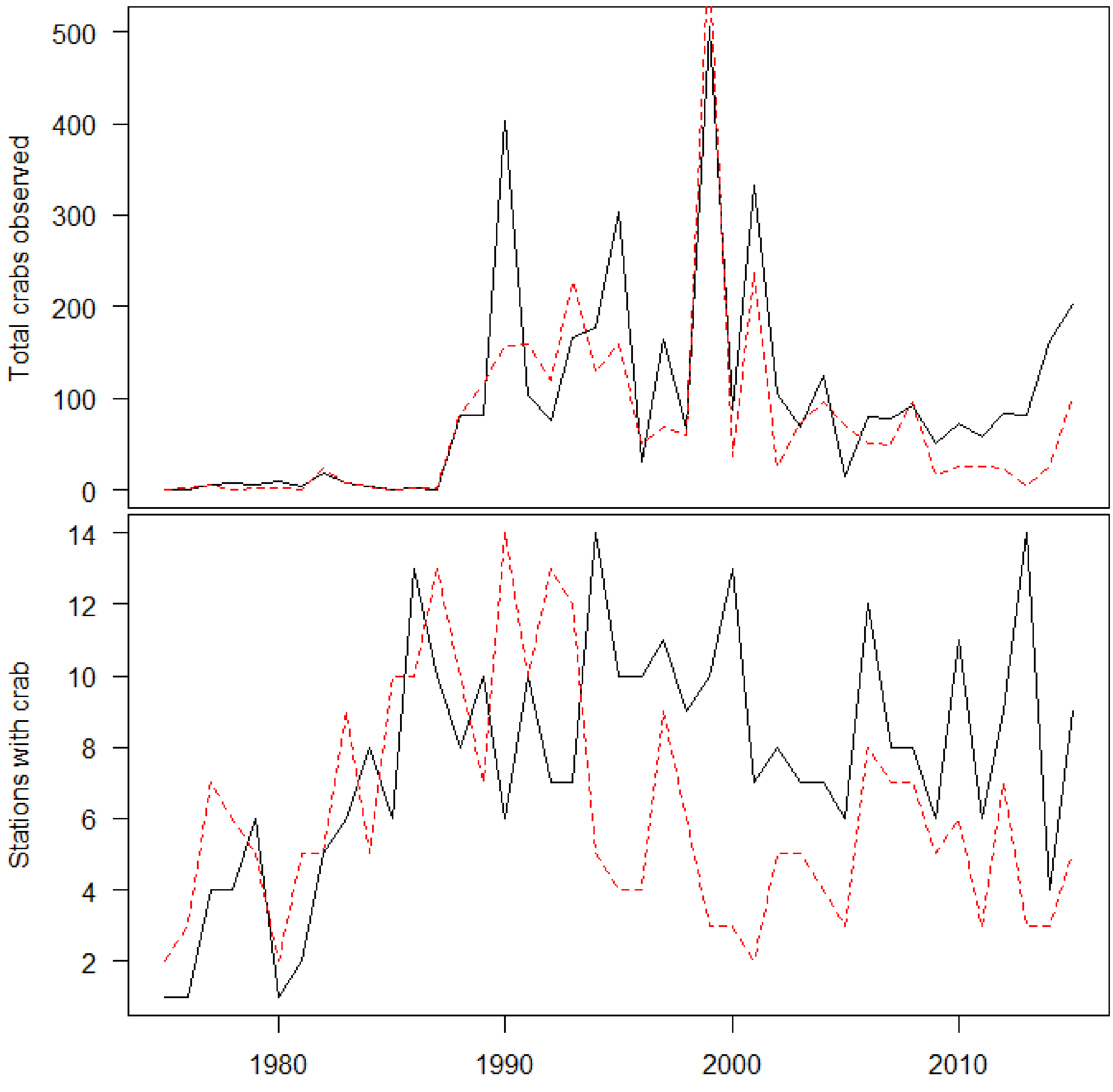

Figure 5. Total number of observed crab (top) and the number of stations that reported observations of crab (female = dashed line, male = solid line) from 1975-2014.

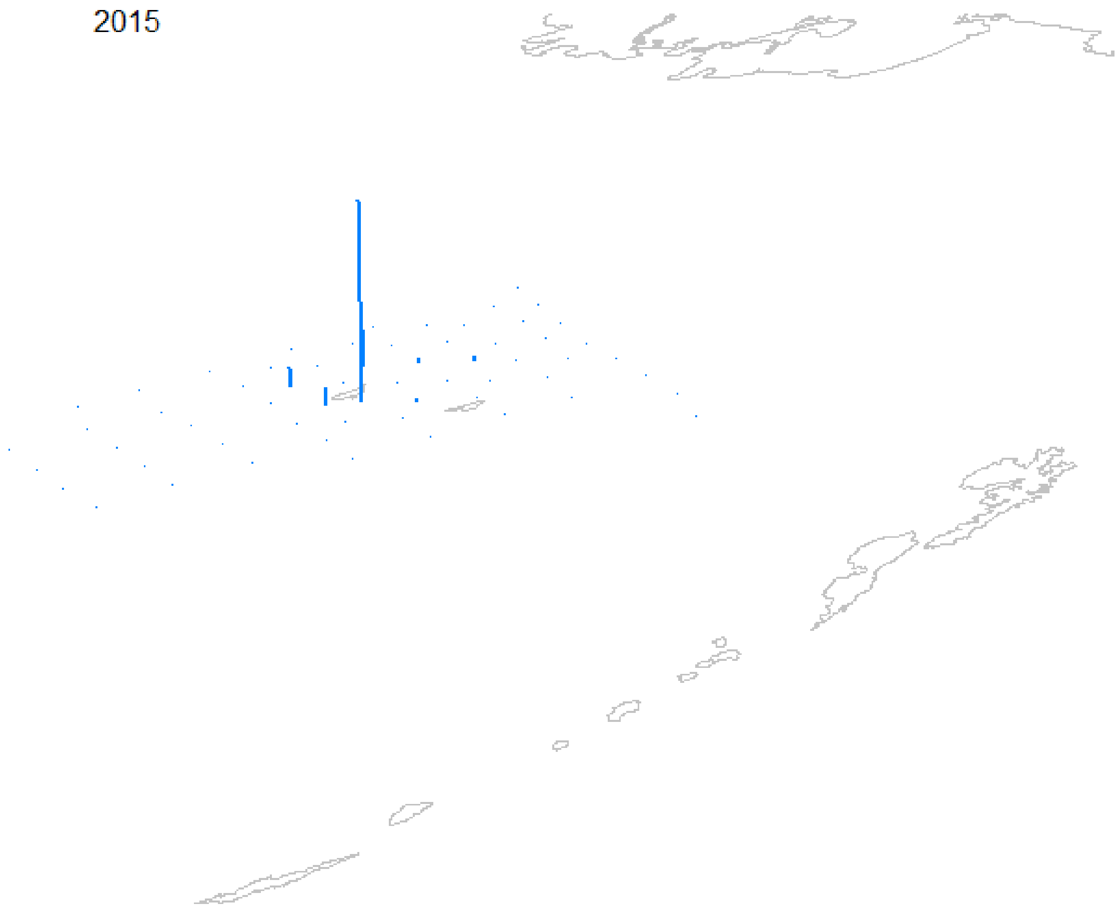

Figure 6. Male red king crab relative density by station in the Pribilof Island district in 2015. Blue bars represent the relative magnitude of the density calculated from the NMFS trawl survey.

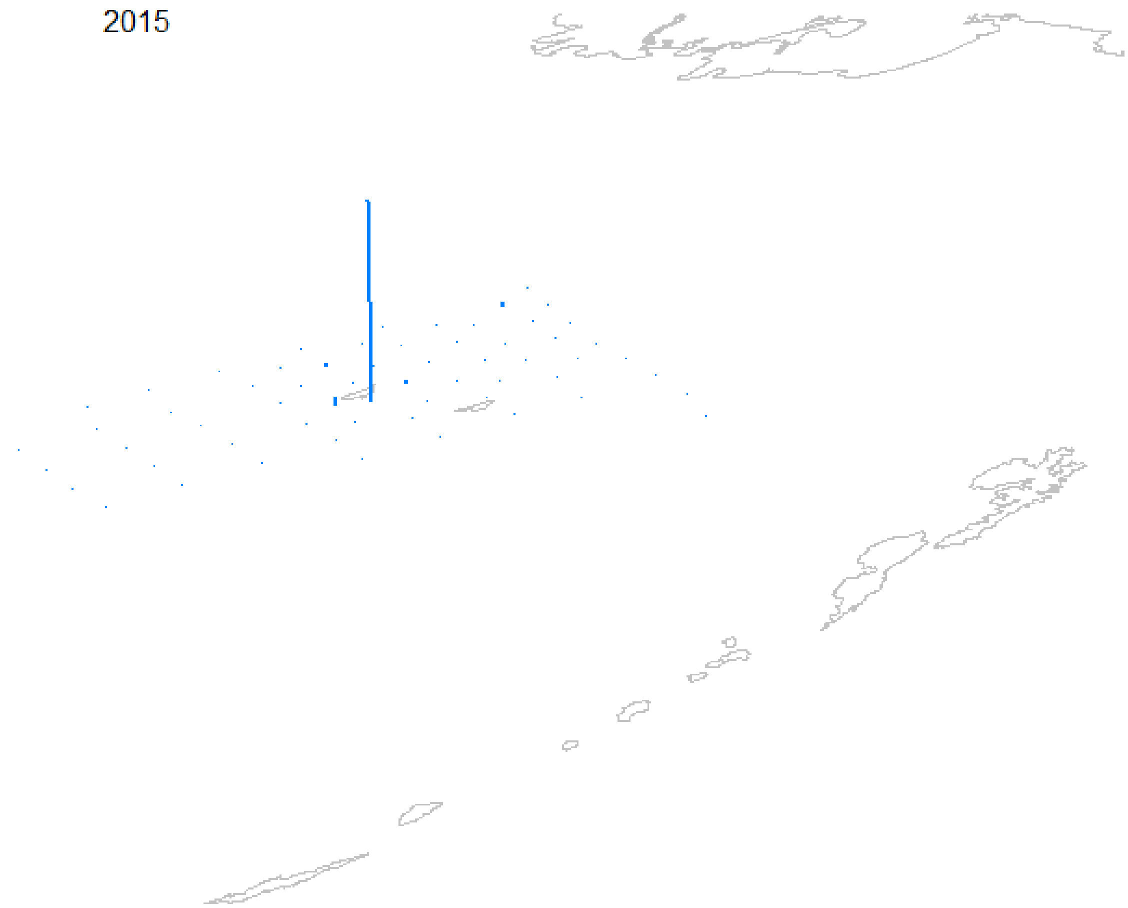

Figure 7. Female red king crab relative density by station in the Pribilof Island district in 2015. Blue bars represent the relative magnitude of the density calculated from the NMFS trawl survey.

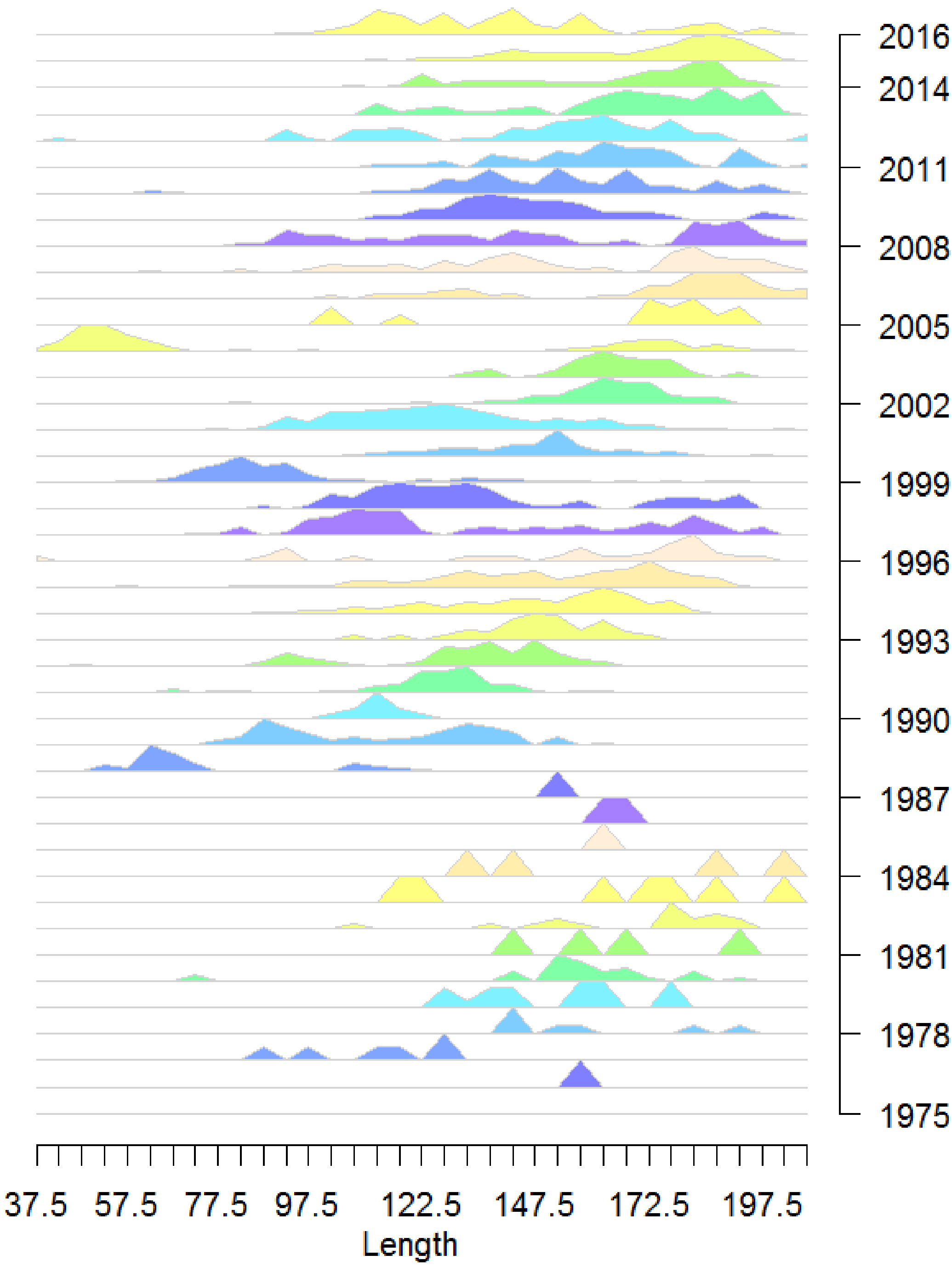

Figure 8. Observed length frequencies (proportions sum to 1.0) by 5 mm length classes of Pribilof Islands male red king crab (Paralithodes camtschaticus) from 1975 to 2016.

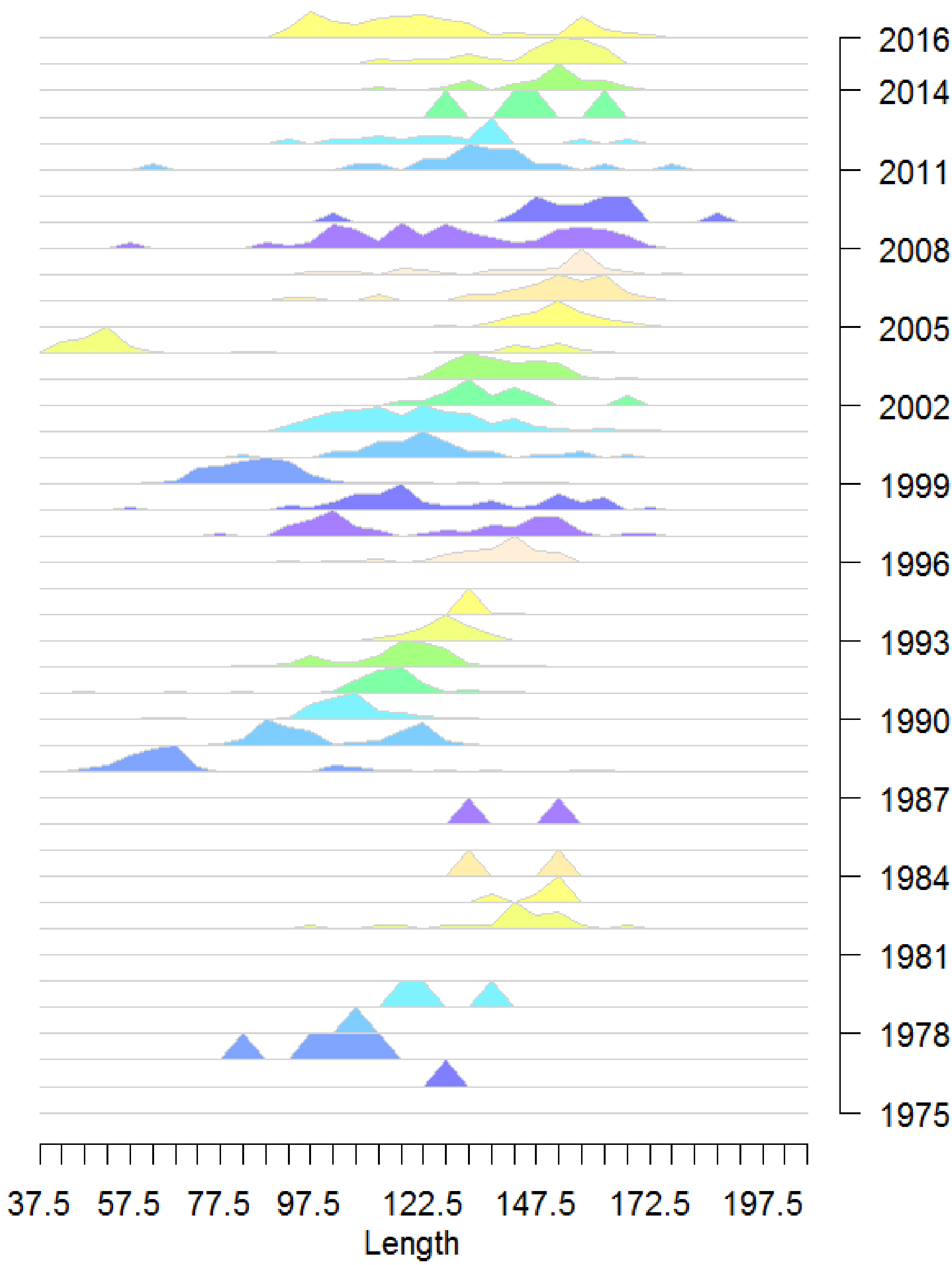

Figure 9. Observed length frequencies (proportions sum to 1.0) by 5 mm length classes of Pribilof Islands female red king crab (Paralithodes camtschaticus) from 1975 to 2016.

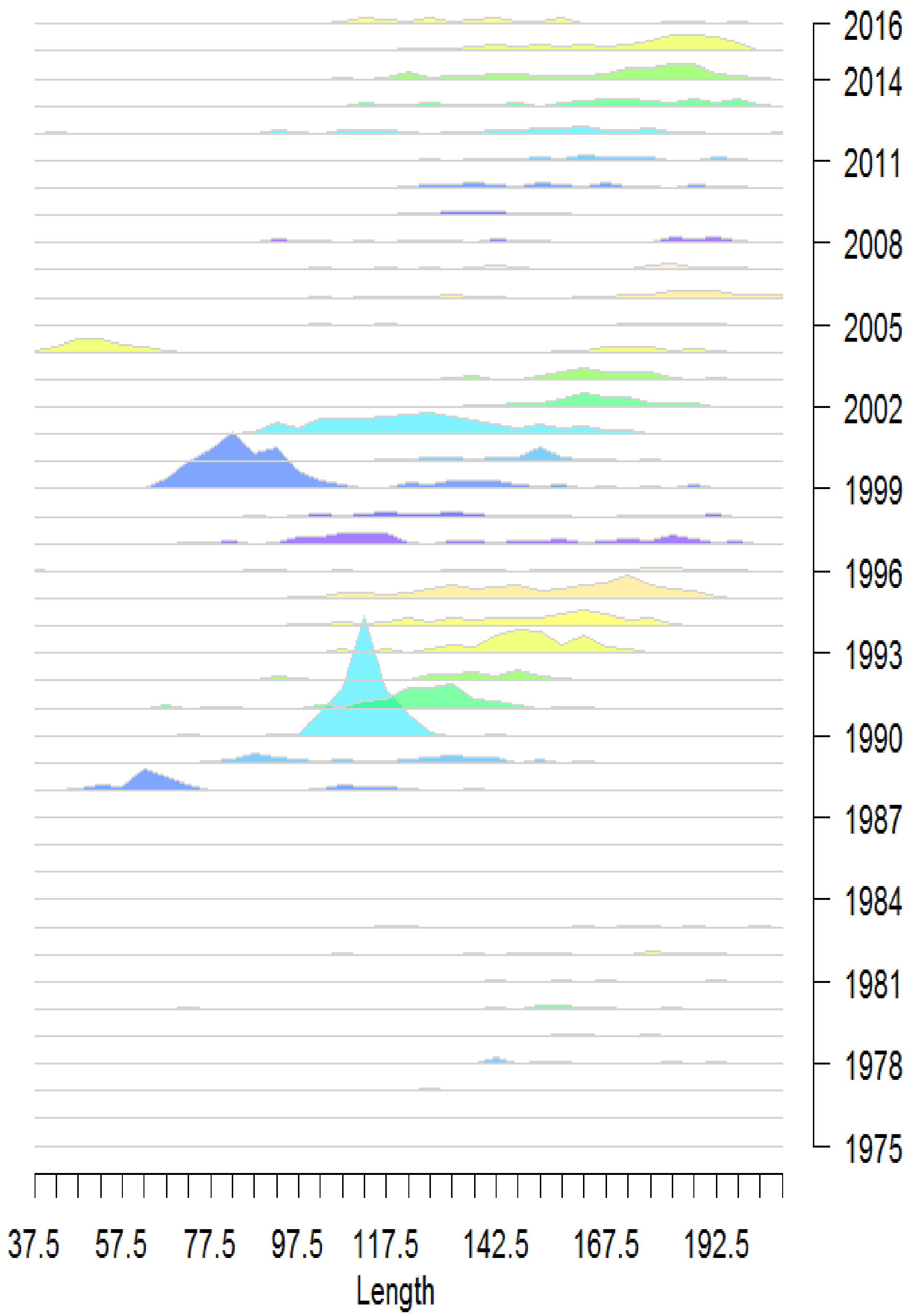

Figure 10. Observed numbers at length by 5 mm length classes of Pribilof Islands male red king crab (Paralithodes camtschaticus) from 1975 to 2016.

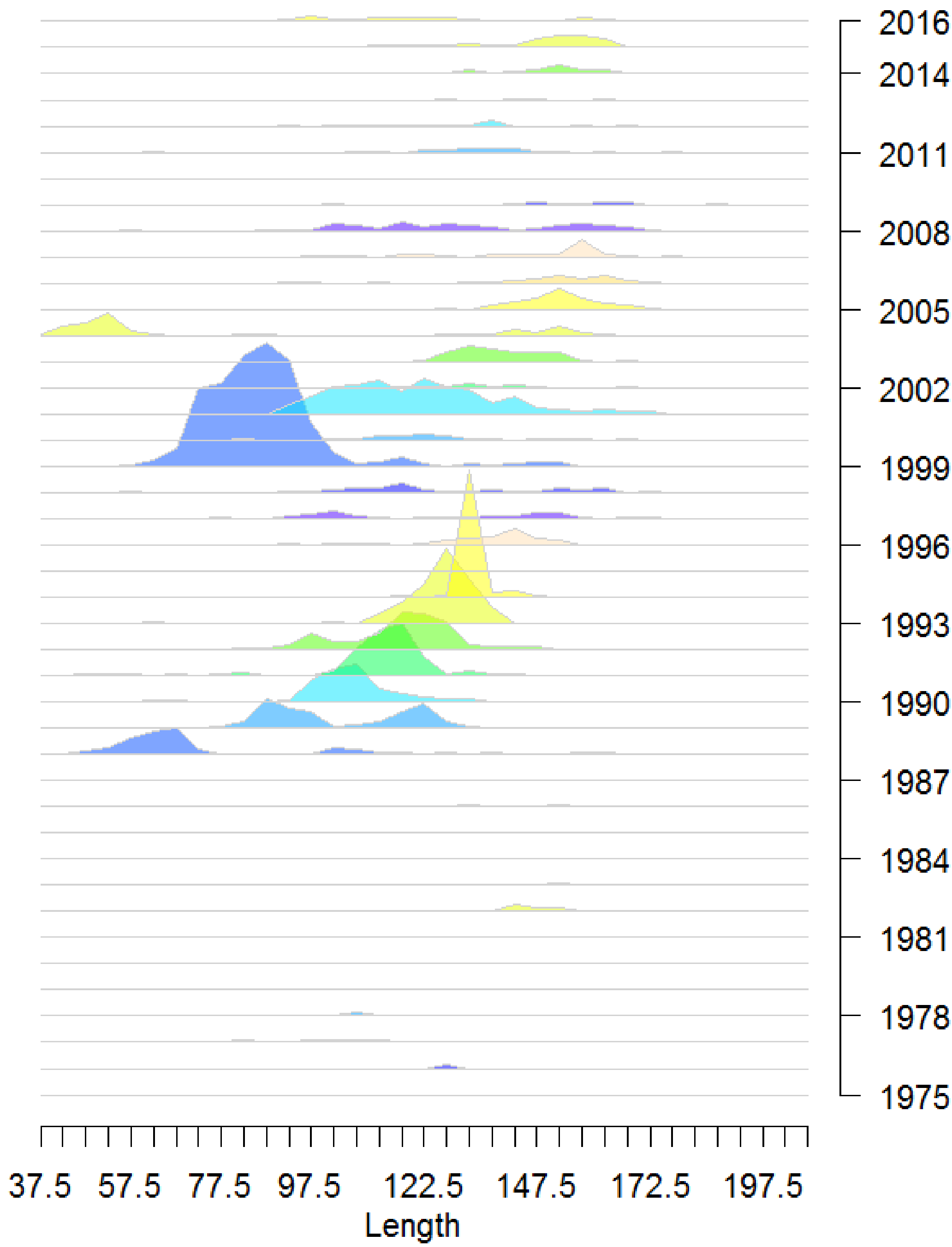

Figure 11. Observed numbers at length by 5 mm length classes of Pribilof Islands female red king crab (Paralithodes camtschaticus) from 1975 to 2016.

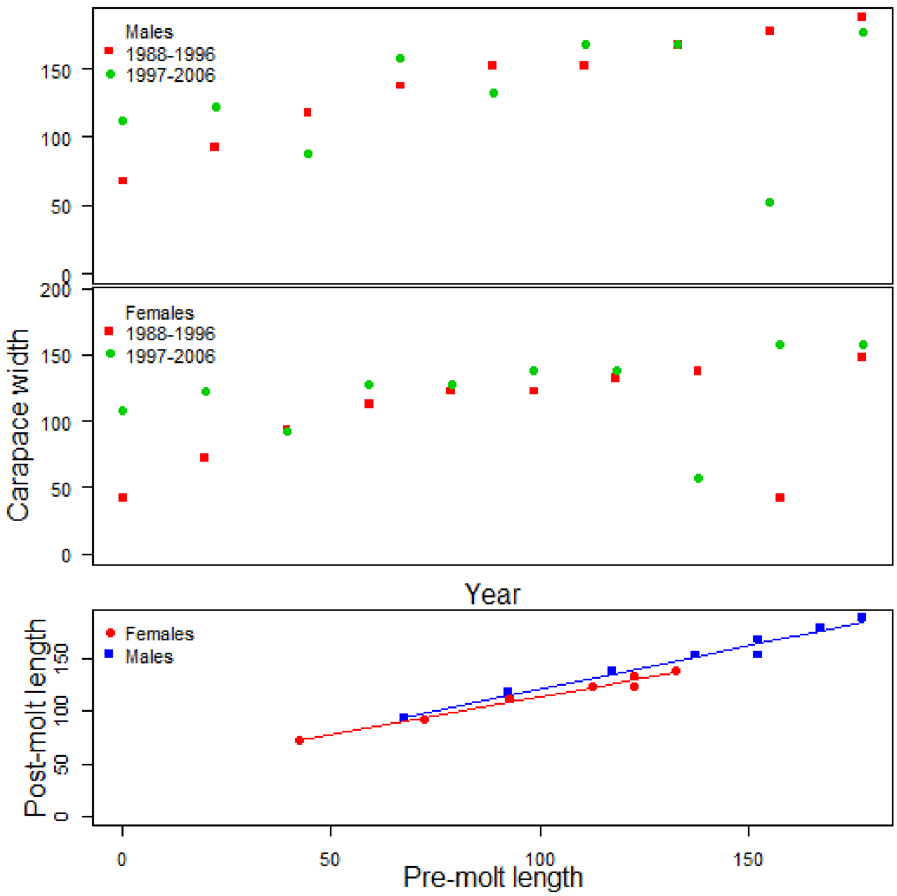

Figure 12. Modes of the length frequency distribution for males and females plotted for two time periods over which two cohorts were observed to move through the population. Growth per molt calculated from the modes from the length frequencies with fitted linear relationship (bottom).

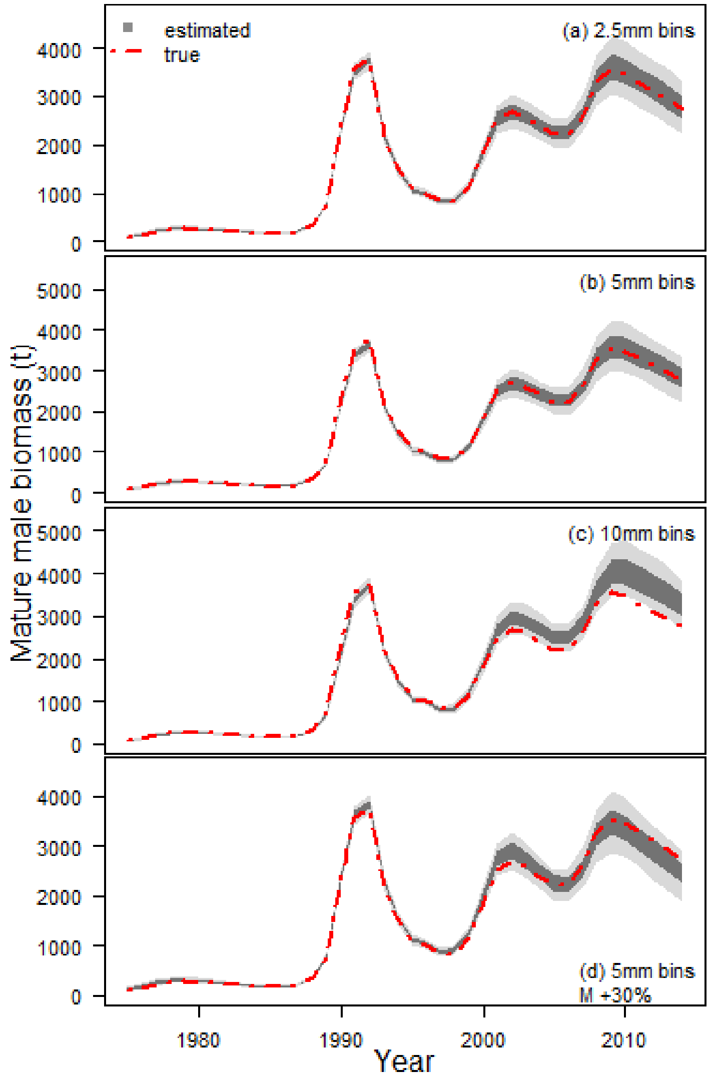

Figure 13. Estimates of MMB in simulation aimed at the testing of the integrated assessment method when binning data into different size bins. Panel (d) shows a case in which M was mis-specified. Red dashed lines are the true quantity; grey shading indicates the intersimulation quantiles for estimated MMB.

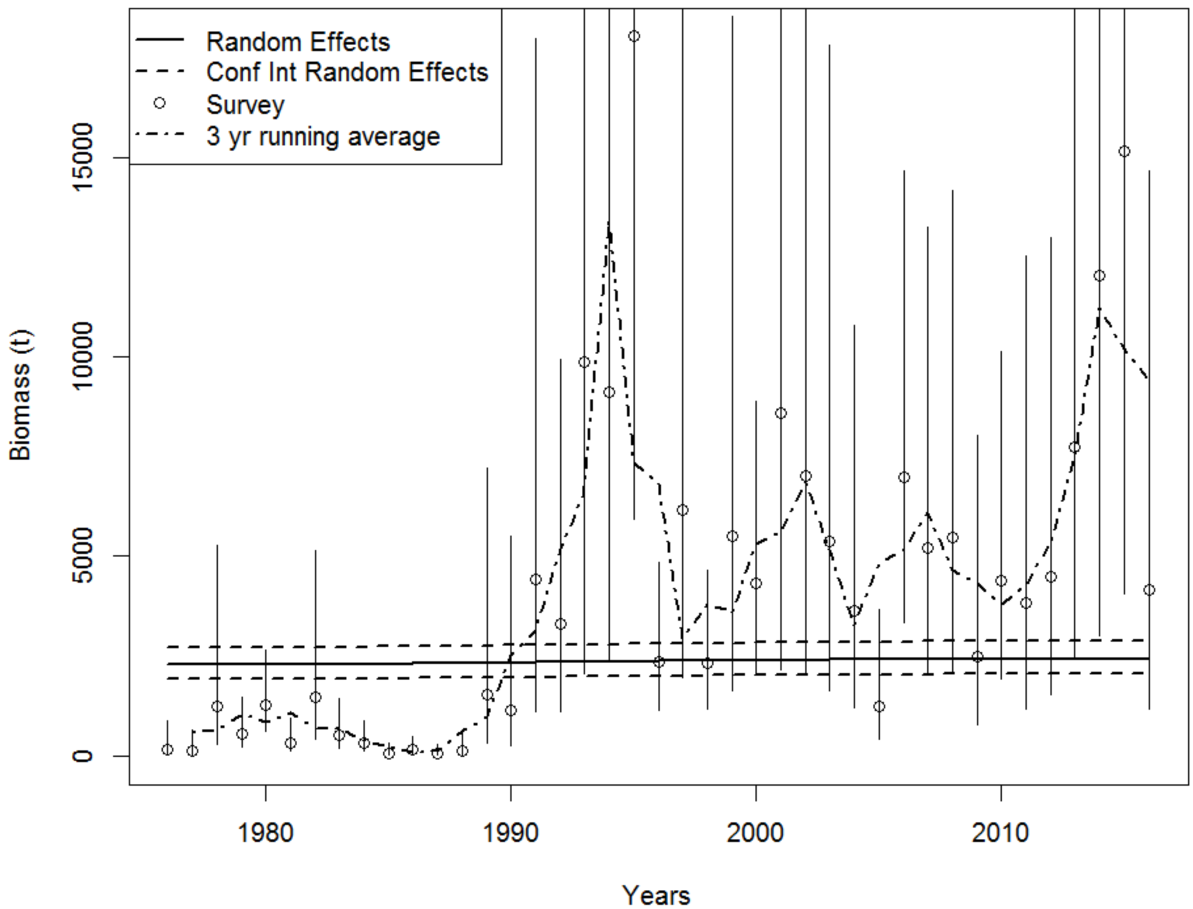

Figure 14. Three-year running average and random effects model fit to male biomass > 120mm at survey time.

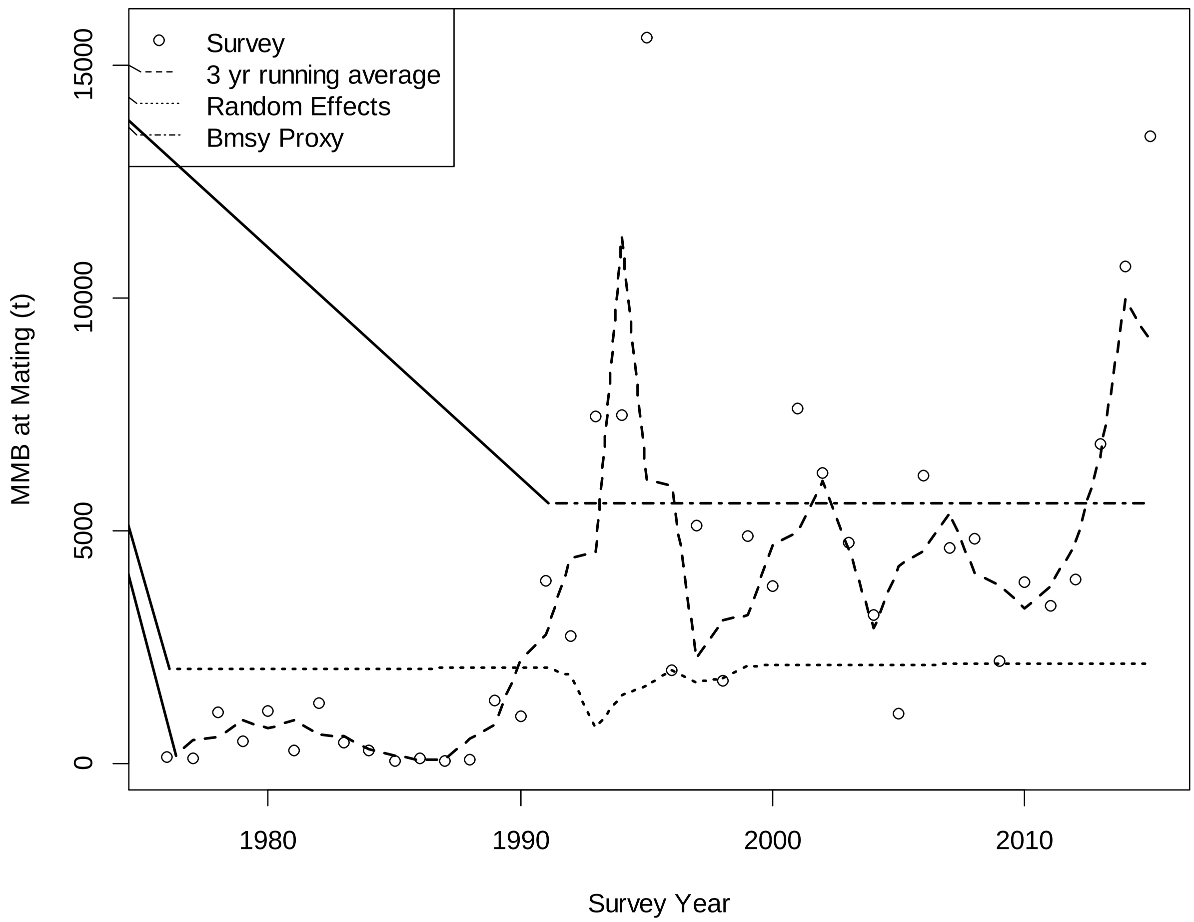

Figure 15. MMB at mating (February 15 of survey year +1) estimated from the survey data, 3 yr running average and the Random effects model. Bmsy proxy is the average of the 1991 to 2015 MMB at mating survey data (February 15 1992 to February 15 2016).

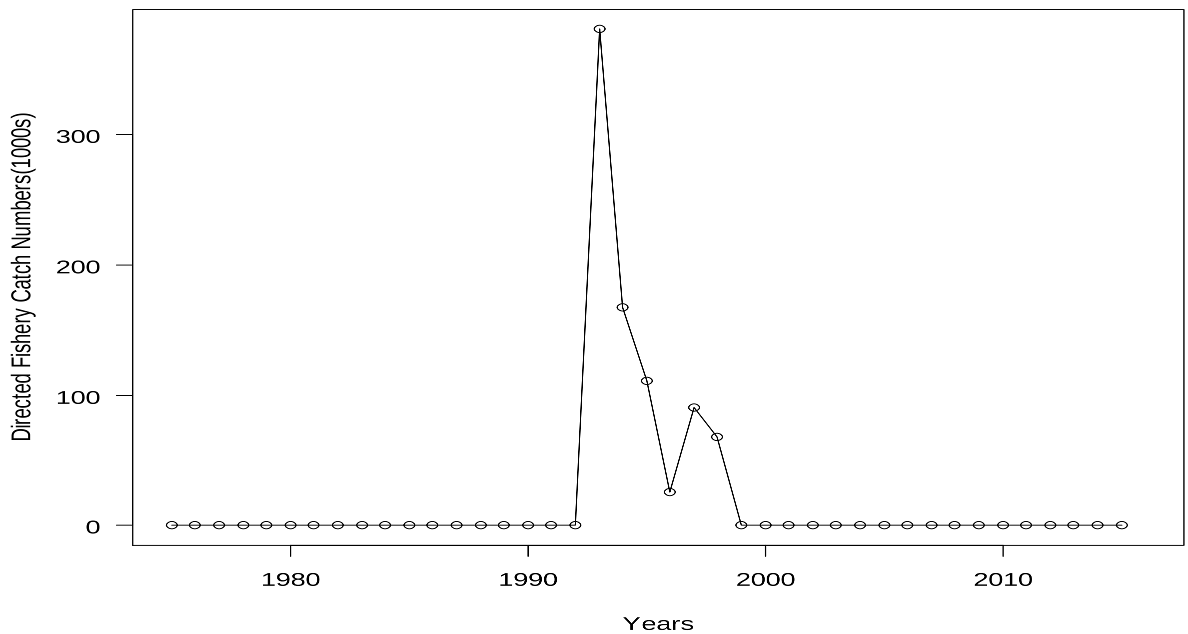

Figure 16. Model fit to directed fishery catch.

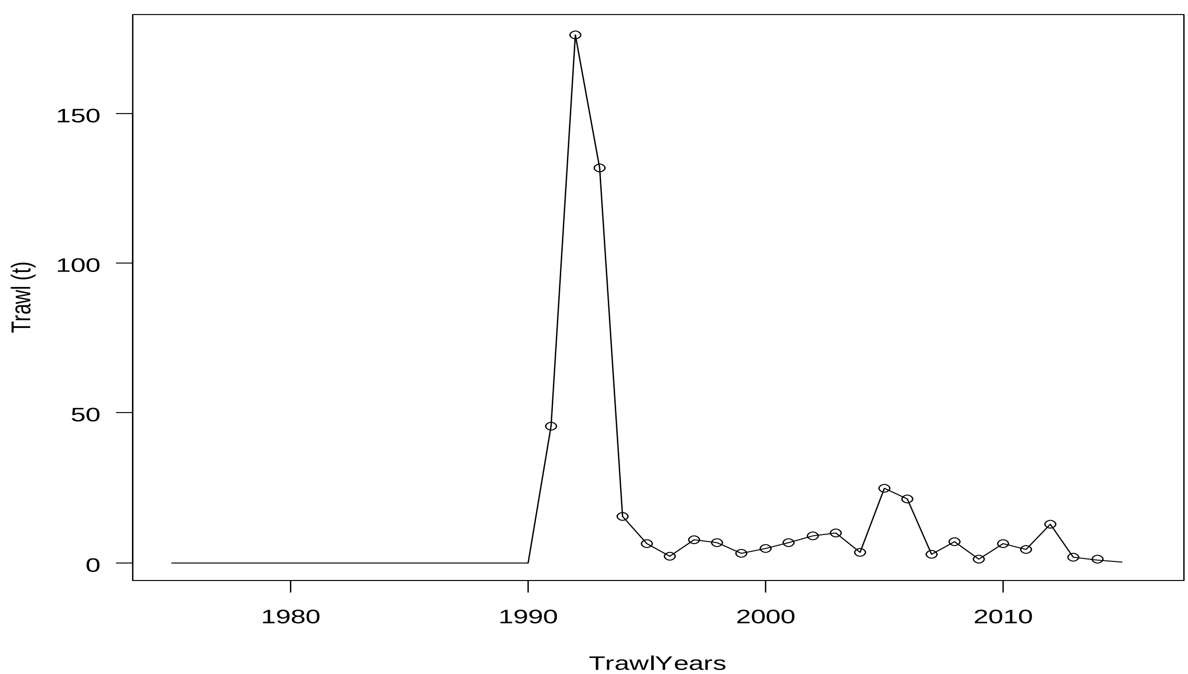

Figure 17. Model fit to Trawl bycatch.

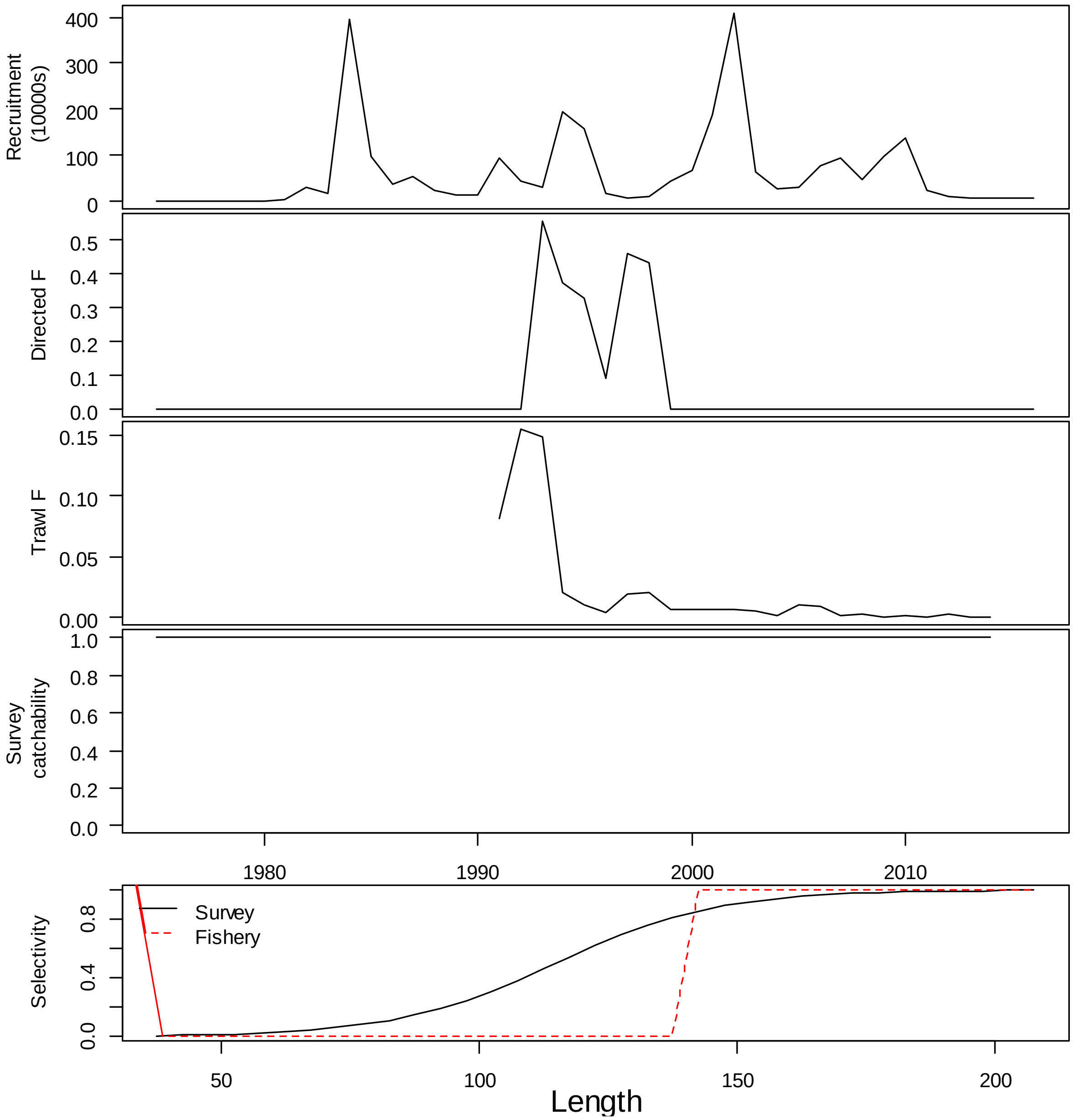

Figure 18. Model estimates of recruitment, directed F, trawl bycatch F, survey catchability, fishery selectivity and survey selectivity.

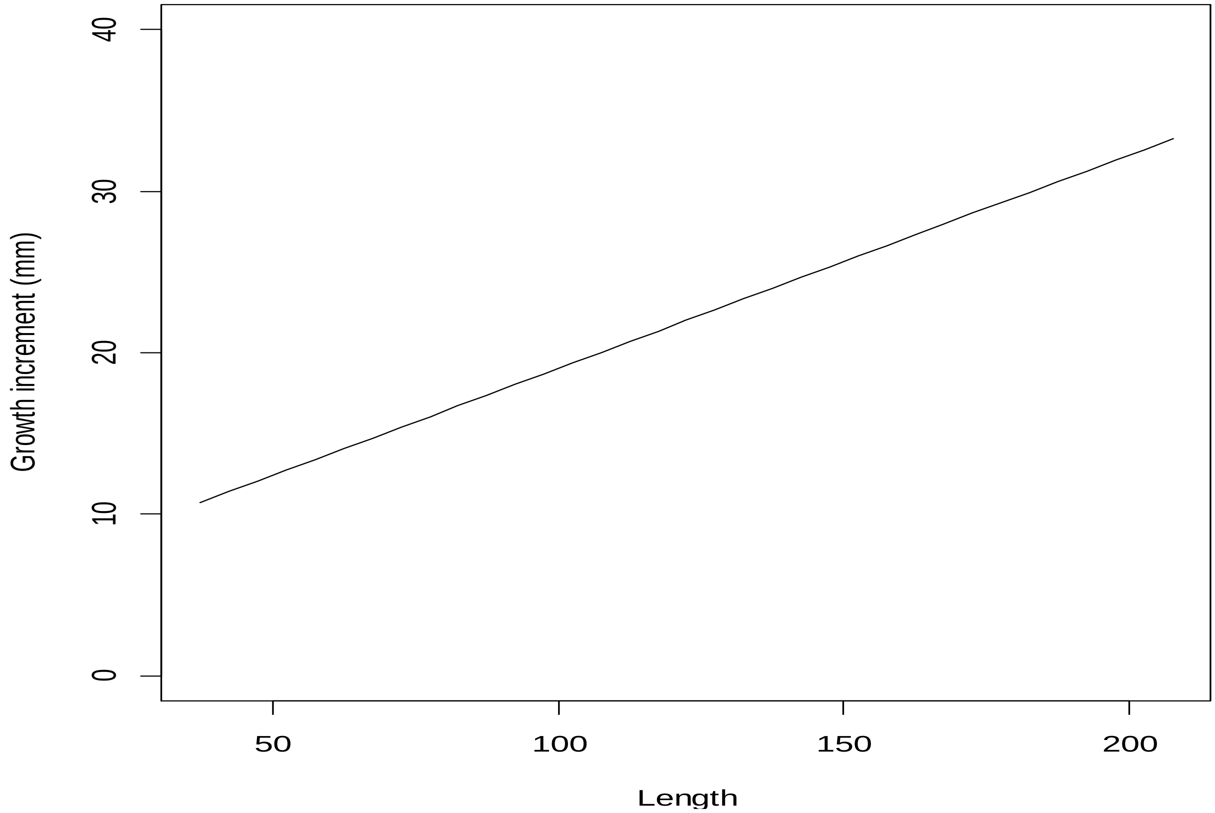

Figure 19. Model estimated growth increment for male crab.

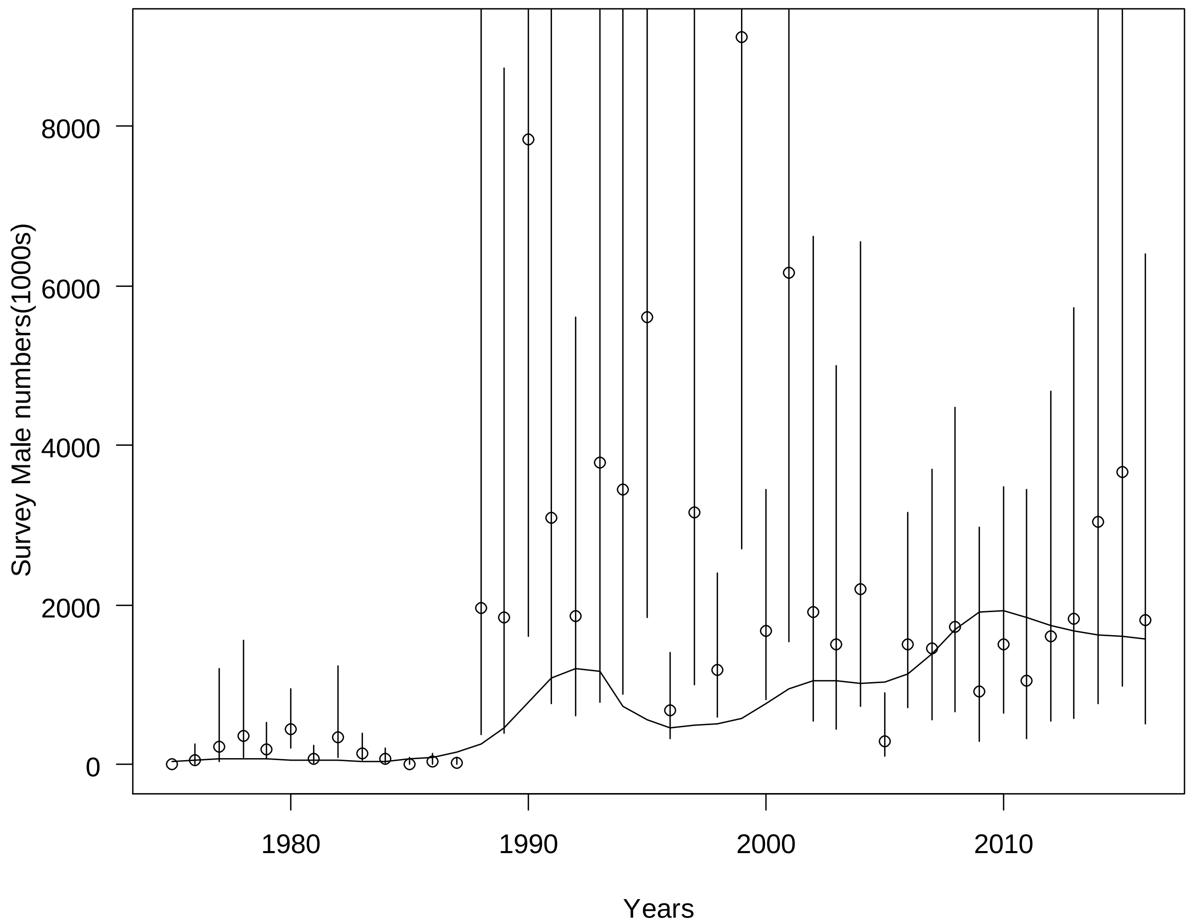

Figure 20. Model fit to survey male numbers.

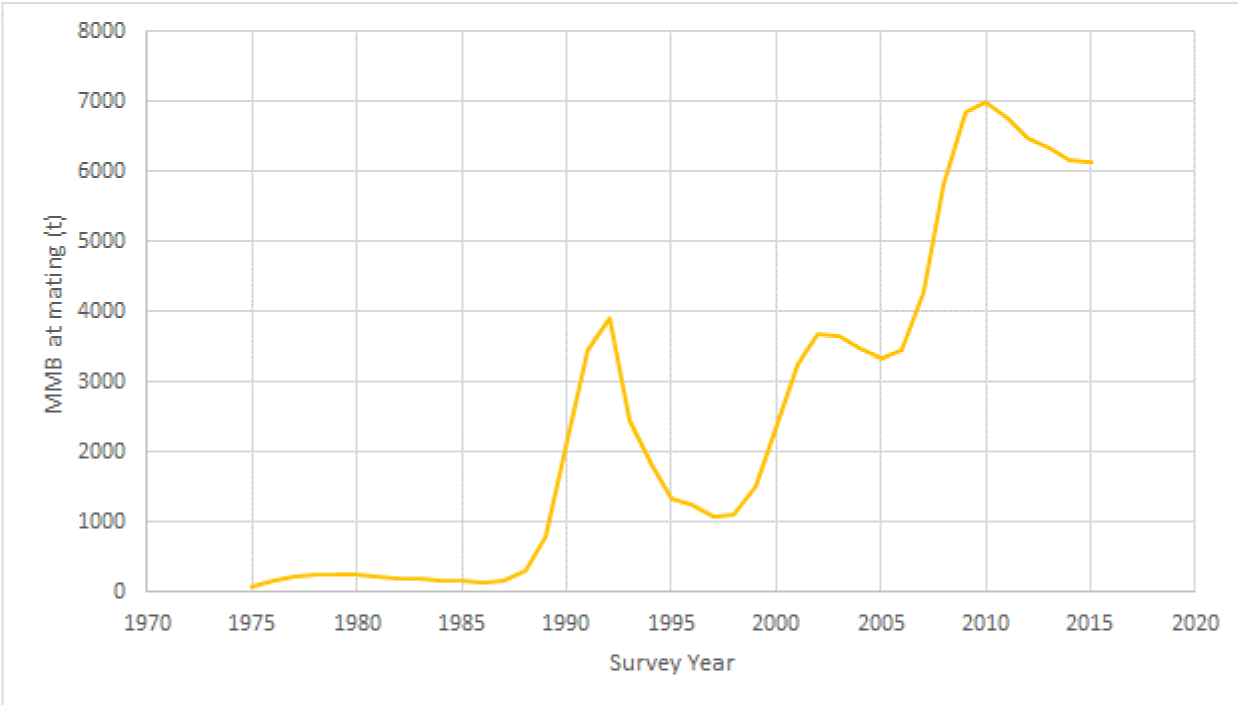

Figure 21. Assessment Model estimate of Mature male biomass at mating.

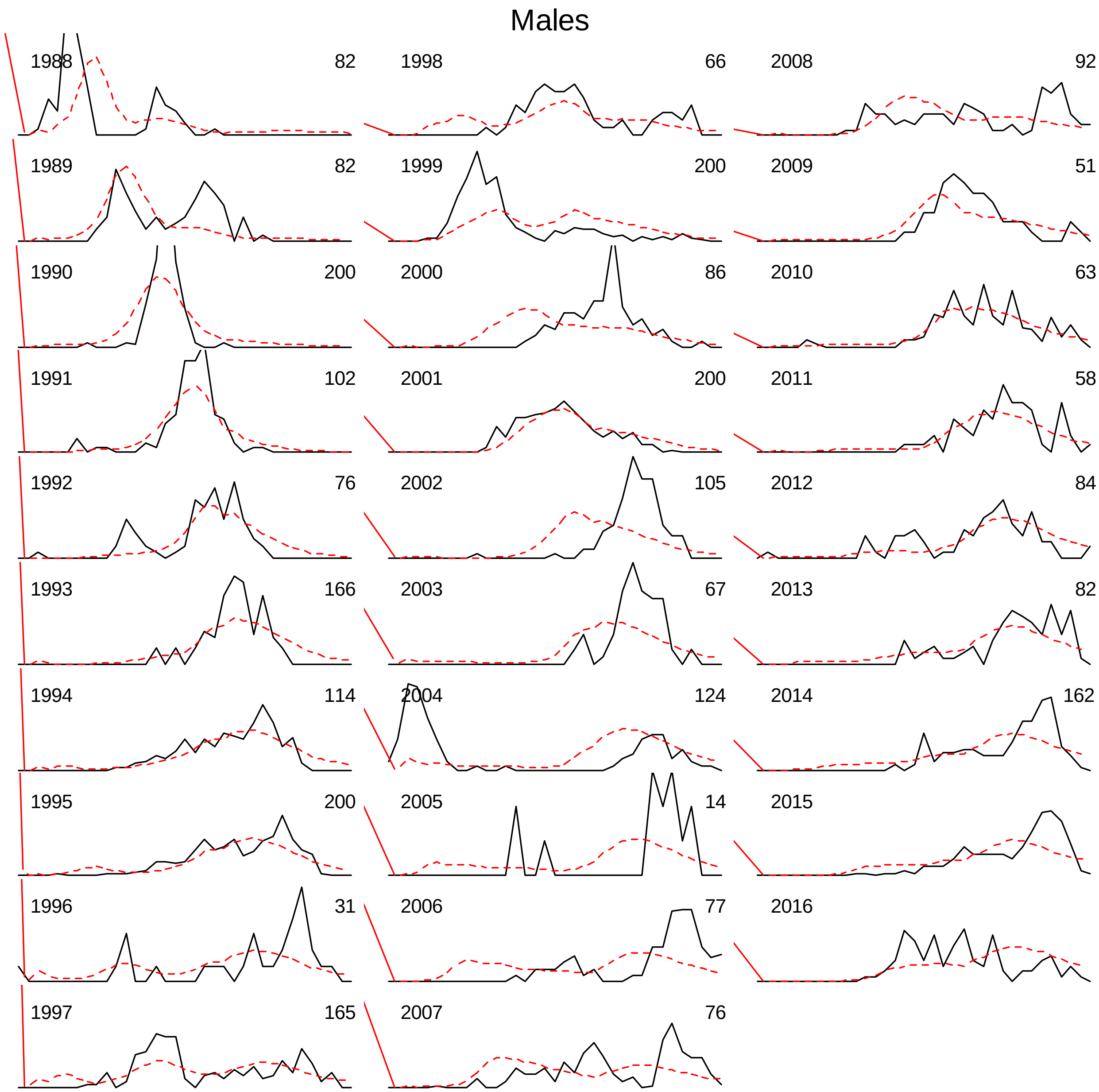

Figure 22. Model fits (red dashed line) to observed male length frequencies in the survey (solid line) by year using 5 mm length bins and fitting only males. Sample size is noted in the top right hand corner of each plot. Length frequencies for the years 1975-1987 are not shown because the associated sample sizes were <=18 and therefore held very little information.

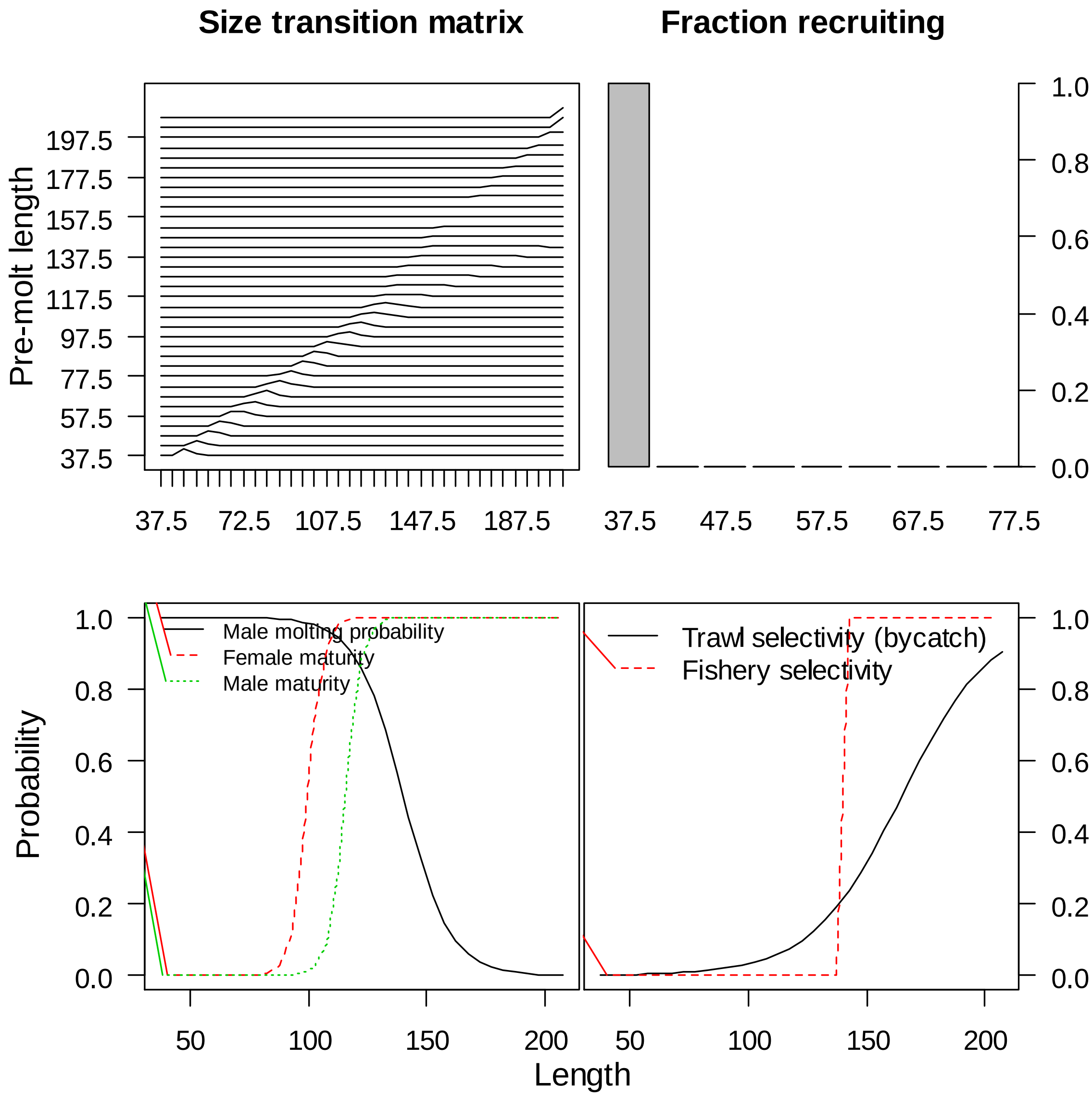

Figure 23. Size transition matrix (top left), fraction recruiting to a given size class (top right), probability of molting (males only) and maturing (females and males; bottom left), probability of being selected in the directed and trawl fisheries (bottom right).

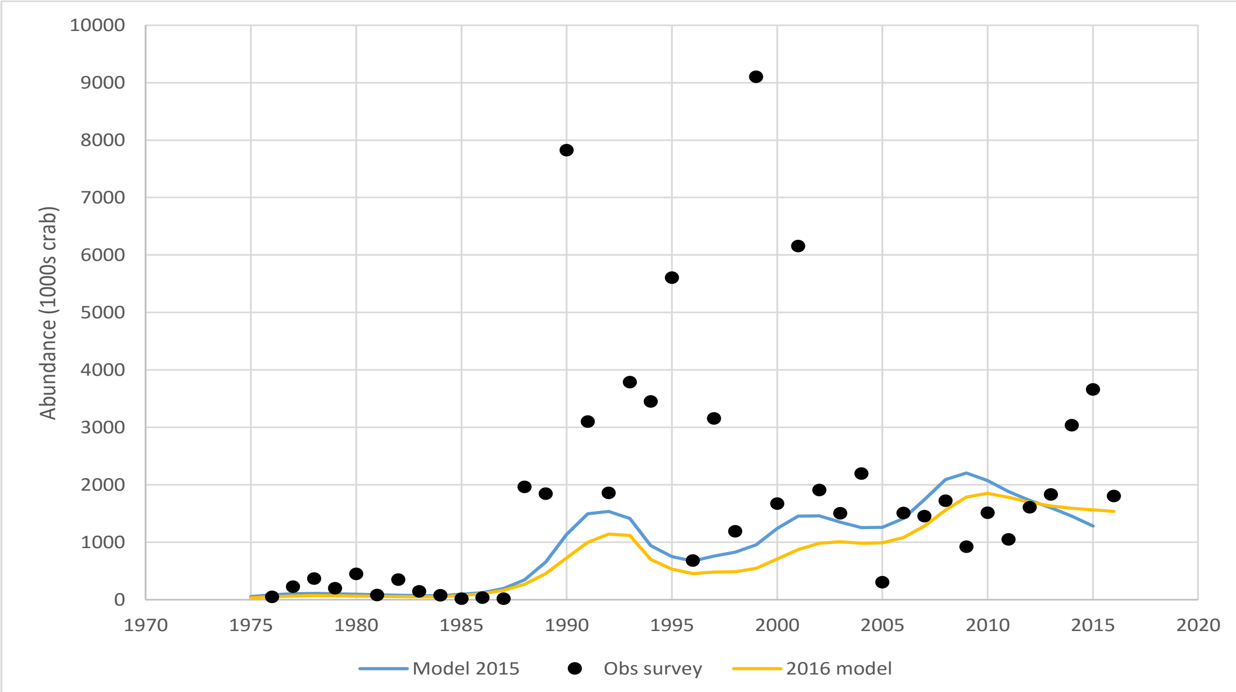

Figure 24. Fit to male abundance for the 2015 assessment model and the 2016 assessment model.

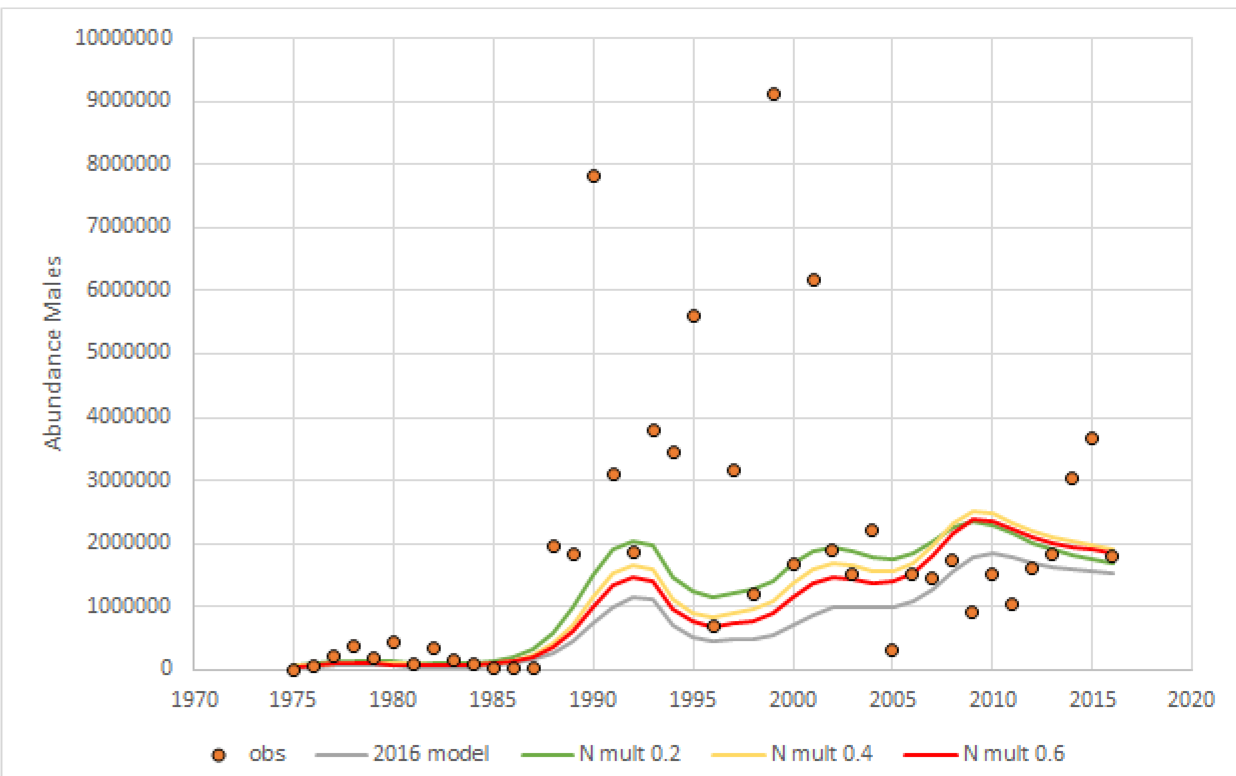

Figure 25. Fit to male abundance for the 2016 base model and model scenarios with multipliers on the survey length sample size of 0.2, 0.4 and 0.6.

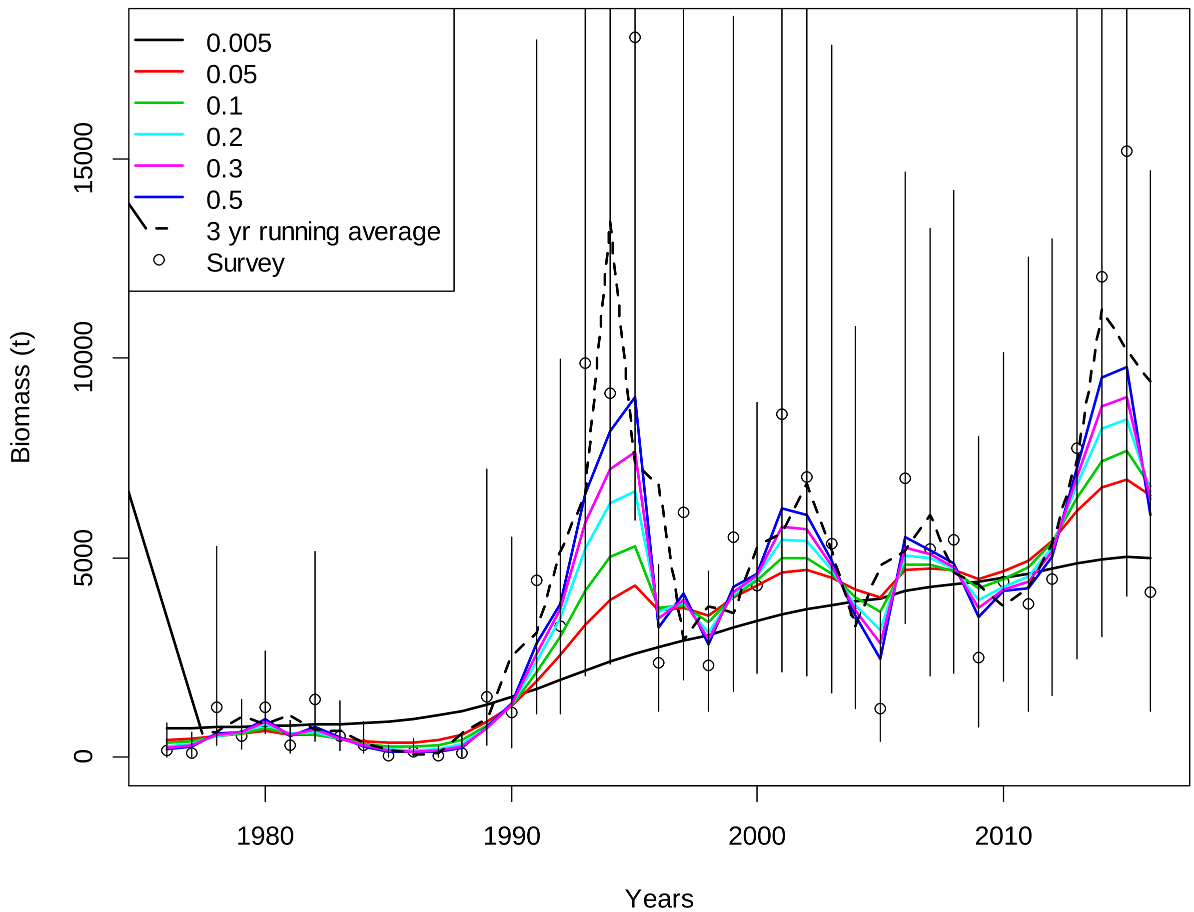

Figure 26. Random effects model estimates of biomass with process error fixed at 0.005, 0.05, 0.1,0.2,0.3 and 0.5.

2016 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

W.T. Stockhausen
Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA
August 26, 2016

Executive Summary

1. Stock: Pribilof Islands blue king crab (PIBKC), *Paralithodes platypus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch has been relatively small in recent years, with most bycatch mortality occurring in the BSAI groundfish fixed gear (pot and hook-and-line) fisheries (5-year average: 0.12 t [0.0003 million lbs]) and trawl fisheries (5-year average: 0.24 t [0.0005 million lbs]). In 2015/16, the estimated PIBKC bycatch mortality in the groundfish fixed gear fisheries was 0.372 t (< 0.0008 million lbs) and 0.646 t (< 0.0014 million lbs) in the groundfish trawl fisheries. The estimated bycatch mortality for PIBKC in other crab fisheries in 2015/16 was 0.166 t (0.0004 million lbs). This was the first non-zero bycatch mortality in other crab fisheries since 2010/11.
3. Stock biomass: Stock biomass decreased between the 1995 and 2008 surveys, and continues to fluctuate at low abundances in all size classes. Any short-term trends are questionable given the high uncertainty associated with recent survey results.
4. Recruitment: Recruitment indices are not well understood for Pribilof Islands blue king crab. Pre-recruits may not be well-assessed by the survey, but have remained consistently low in the past 10 years.
5. Management performance: The stock is below MSST and consequently is overfished. Overfishing also occurred during the 2015/2016 fishing year. The following results are based on determining B_{MSY}/MSST by averaging the MMB-at-mating time series estimated using the smoothed survey data from a random effects model; the current (2016/17) MMB-at-mating is also based on the smoothed survey data. [Note: MSST changed substantially between 2013/14 and 2014/15 as a result of changes to the NMFS EBS trawl survey dataset used to calculate the (proxy) B_{MSY}. MSST changed slightly between 2014/15 and 2015/16 due to small differences in the random effects model results with the addition of 2016 survey data.]

All units are tons of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2012/13	1,994 A	579 A	closed	0	0.61	1.16	1.04
2013/14	2,001 A	225 A	closed	0	0.03	1.16	1.04
2014/15	2,055 A	344 A	closed	0	0.07	1.16	0.87
2015/16	2,058 A	361 A	closed	0	1.18	1.16	0.87
2016/17	--	233 B	--	--	--	1.16	0.87

All units are million pounds of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2012/13	4.39 A	1.09 A	closed	0	0.0013	0.003	0.002
2013/14	4.41 A	0.50 A	closed	0	0.0001	0.003	0.002
2014/15	4.53 A	0.76 A	closed	0	0.0002	0.003	0.002
2015/16	4.54 A	0.79 A	closed	0	0.0026	0.003	0.002
2016/17	--	0.51 B	--	--	--	0.003	0.002

Notes:
A – Based on data available to the Crab Plan Team at the time of the assessment following the end of the crab fishing year.
B – Based on data available to the Crab Plan Team at the time of the assessment for the crab fishing year.

6. Basis for the 2016/17 OFL: The OFL was based on Tier 4 considerations. The ratio of estimated 2016/17 MMB-at-mating to B_{MSY} is less than β (0.25) for the F_{OFL} Control Rule, so directed fishing is not allowed. As per the rebuilding plan (NPFMC, 2014a), the OFL is based on a Tier 5 calculation of average bycatch mortalities between 1999/2000 and 2005/2006, which is a time period thought to adequately reflect the conservation needs associated with this stock and to acknowledge existing non-directed catch mortality. Using this approach, the OFL was determined to be 1.16 t (0.003 million lbs) for 2016/17. The following results are based on determining B_{MSY}/MSST by averaging the MMB-at-mating time series estimated using the smoothed survey data from a random effects model; the current (2016/17) MMB-at-mating is also based on the smoothed survey data.

All weights in t:

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2012/13	4c	4,494	496	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	3,988	278	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	4,002	218	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2015/16	4c	4,109	361	0.09	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2016/17	4c	4,116	233	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

All weights in million lbs:

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2012/13	4c	9.91	1.09	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	8.79	0.61	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	8.82	0.48	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2015/16	4c	9.06	0.79	0.09	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2016/17	4c	9.07	0.51	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

7. Probability density function for the OFL: Not applicable for this stock.
8. The ABC was calculated using a 25% buffer on the OFL, as in the 2015 assessment. The ABC is thus 0.87 t (= 0.25*x*1.16 t).
9. Rebuilding analyses results summary: In 2009, NMFS determined that the PIBKC stock was not rebuilding in a timely manner and would not meet a rebuilding horizon of 2014. A preliminary assessment model developed by NMFS (not used in this assessment) suggested that rebuilding could occur within 50 years due to random recruitment (NPFMC, 2014a). Subsequently, Amendment 43 to the King and Tanner Crab Fishery Management Plan (Crab FMP) and Amendment 103 to the Bering Sea and Aleutian Islands Groundfish FMP (BSAI Groundfish FMP) to rebuild the PIBKC stock were adopted by the Council in 2012 and approved by the Secretary of Commerce in early 2015. The function of these amendments is to promote bycatch reduction on PIBKC by closing the Pribilof Islands Habitat Conservation Zone to pot fishing for Pacific cod. No pot fishing for Pacific cod occurred within the Pribilof Islands Habitat Conservation Zone in 2015/16.

A. Summary of Major Changes:

1. Management: In 2002, NMFS notified the NPFMC that the PIBKC stock was overfished. A rebuilding plan was implemented in 2003 that included the closure of the stock to directed fishing until the stock was rebuilt. In 2009, NMFS determined that the PIBKC stock was not rebuilding in a timely manner and would not meet the rebuilding horizon of 2014. Subsequently, Amendment 43 to the Crab FMP and Amendment 103 to the BSAI Groundfish FMP to rebuild the PIBKC stock were adopted by the Council in 2012 and approved by the Secretary of Commerce in early 2015. Amendment 103 closed the Pribilof Islands Habitat Conservation Zone to pot fishing for Pacific cod to promote bycatch reduction on PIBKC. Amendment 43 amended the prior rebuilding plan to incorporate new information on the likely rebuilding timeframe for the stock, taking into account environmental conditions and the status and population biology of the stock. No pot fishing for Pacific cod occurred within the Pribilof Islands Habitat Conservation Zone in 2015/16.
2. Input data: Retained and discard catch time series were updated with 2015/2016 data from the crab and groundfish fisheries. Abundance and biomass for PIBKC in the annual summer NMFS EBS bottom trawl survey were updated for the 2016 survey.
3. Assessment methodology: No changes from the 2015 assessment. The Tier 4 approach used in this assessment for status determination, based on smoothing the raw survey biomass time series using a random effects model, is identical to that adopted by the CPT and SSC last year (Stockhausen, 2015).
4. Assessment results: Total catch mortality in 2015/16 was 1.18 t, which exceeded the OFL (1.16 t). Consequently, overfishing occurred in 2015/16. The projected MMB-at-mating for 2016/17 decreased somewhat from that in 2015/16 and remained below the MSST. Consequently, the stock remains overfished and a directed fishery is prohibited in 2016/17. The OFL, based on average catch, and ABC are identical to last year's values.

B. Responses to SSC and CPT Comments

<u>CPT comments September 2014:</u>

Specific remarks pertinent to this assessment

1. The CPT expressed interest in seeing information about whether the amount of observer coverage has changed since the new groundfish observer program was implemented in 2013.

2. The CPT would like to see the spatial distribution of bycatch by State statistical area.

Responses to CPT Comments:

1. The amount of observer coverage since the new groundfish observer program was implemented has been similar each year (unofficial estimates for all BSAI vessels: 65% in 2013, 75% in 2014, 73% in 2015; C. Faunce, NMFS, pers. comm.).

2. Maps of the spatial distribution of bycatch in the groundfish fisheries are included in Appendix B.

<u>SSC comments October 2014:</u>

Specific remarks pertinent to this assessment
none

<u>CPT comments May 2015:</u>

Specific remarks pertinent to this assessment
none

<u>SSC comments June 2015:</u>

Specific remarks pertinent to this assessment
none

<u>CPT comments September 2015:</u>

Specific remarks pertinent to this assessment
Use results from the random effects smoothing model to calculate both B_{MSY} and current B for status determination.

Responses to CPT Comments:

Done.

<u>SSC comments October 2015:</u>

Specific remarks pertinent to this assessment
none

<u>CPT comments May 2016:</u>

Specific remarks pertinent to this assessment
none

<u>SSC comments June 2016:</u>

Specific remarks pertinent to this assessment
none

C. Introduction

1. **Stock -** Pribilof Islands blue king crab (PIBKC), *Paralithodes platypus*

2. **Distribution** - Blue king crab are anomurans in the family Lithodidae, which also includes the red king crab (*Paralithodes camtschaticus*) and golden or brown king crab (*Lithodes aequispinus*) in Alaska. Blue king crabs are found in widely-separated populations across the North Pacific (Figure 1). In the western Pacific, blue king crabs occur off Hokkaido in Japan and isolated populations have been observed in the Sea of Okhotsk and along the Siberian coast to the Bering Straits. In North America, they are found in the Diomede Islands, Point Hope, outer Kotzebue Sound, King Island, and the outer parts of Norton Sound. In the remainder of the Bering Sea, they are found in the waters off St. Matthew Island and the Pribilof Islands. In more southerly areas, blue king crabs are found in the Gulf of Alaska in widely-separated populations that are frequently associated with fjord-like bays (Figure 1). The insular distribution of blue king crab relative to the similar but more broadly distributed red king crab is likely the result of post-glacial-period increases in water temperature that have limited the distribution of this cold-water adapted species (Somerton 1985). Factors that may be directly responsible for limiting the distribution include the physiological requirements for reproduction, competition with the more warm-water adapted red king crab, exclusion by warm-water predators, or habitat requirements for settlement of larvae (Armstrong et al 1985, 1987; Somerton, 1985).

   During the years when the fishery was active (1973-1989, 1995-1999), the Pribilof Islands blue king crab (PIBKC) were managed under the Bering Sea king crab Registration Area Q Pribilof District. The southern boundary of this district is formed by a line from 54° 36’ N lat., 168° W long., to 54° 36’ N lat., 171° W long., to 55° 30’ N lat., 171° W. long., to 55° 30’ N lat., 173° 30’ E long., while its northern boundary is a line at the latitude of Cape Newenham (58° 39’ N lat.), its eastern boundary is a line from 54° 36’ N lat., 168° W long., to 58° 39’ N lat., 168° W long., to Cape Newenham (58° 39’ N lat.), and its western boundary is the United States-Russia Maritime Boundary Line of 1991 (ADF&G 2008) (Figure 2). In the Pribilof District, blue king crab occupied the waters adjacent to and northeast of the Pribilof Islands (Armstrong et al. 1987).

3. **Stock structure** - Stock structure of blue king crab in the North Pacific is largely unknown. Samples were collected in 2009-2011 by a graduate student at the University of Alaska to support a genetic study on blue king crab population structure. Aspects of blue king crab harvest and abundance trends, phenotypic characteristics, behavior, movement, and genetics will be evaluated by the author following the guidelines in the AFSC report entitled “Guidelines for determination of spatial management units for exploited populations in Alaskan groundfish fishery management plans” by P. Spencer (unpublished report).

   The potential for species interactions between blue king crab and red king crab as a potential reason for PIBKC shifts in abundance and distribution were addressed in a previous assessment (Foy, 2013). Foy (2013) compared the spatial extent of both speices in the Pribilof Islands from 1975 to 2009 and found that, in the early 1980’s when red king crab first became abundant, blue king crab males and females dominated the 1 to 7 stations where the species co-occurred in the Pribilof Islands District. Spatially, the stations with co-occurance were all dominated by blue king crab and broadly distributed around the Pribilof Islands. In the 1990’s, the red king crab population biomass increased substantially as the blue king crab population biomass decreased. During this time period, the number of stations with co-occurance remained around a maximum of 8, but they were equally dominated by both blue king crab and red king crab—sugggesting a direct overlap in distribution at the scale of a survey station. During this time period, the stations dominated by red king crab were dispersed around the Pribilof Islands. Between 2001 and 2009 the blue king crab population decreased dramatically while the red king crab fluctuated. The number of stations dominated by blue king crab in 2001-2009 was similar to that for stations dominated by red king crab for both males and females, suggesting continued competition for similar habitat. The only stations dominated by blue king crab in the latter period are to the north and east of St. Paul Island. Although blue king crab protection measures also afford protection for the red king crab in this region, red king crab stocks continue to fluctuate (more so than simply accounted for by the uncertainty in the survey).

4. **Life History** - Blue king crab are similar in size and appearance, except for color, to the more widespread red king crab, but are typically biennial spawners with lesser fecundity and somewhat larger sized (*ca*. 1.2 mm) eggs (Somerton and Macintosh 1983; 1985; Jensen et al. 1985; Jensen and Armstrong 1989; Selin and Fedotov 1996). Blue king crab fecundity increases with size, from approximately 100,000 embryos for a 100-110 mm CL female to approximately 200,000 for a female >140-mm CL (Somerton and MacIntosh 1985). Blue king crab have a biennial ovarian cycle with embryos developing over a 12 or 13-month period depending on whether or not the female is primiparous or multiparous, respectively (Stevens 2006a). Armstrong et al. (1985, 1987), however, estimated the embryonic period for Pribilof blue king crab at 11-12 months, regardless of previous reproductive history. Somerton and MacIntosh (1985) placed development at 14-15 months. It may not be possible for large female blue king crabs to support the energy requirements for annual ovary development, growth, and egg extrusion due to limitations imposed by their habitat, such as poor quality or low abundance of food or reduced feeding activity due to cold water (Armstrong et al. 1987; Jensen and Armstrong 1989). Both the large size reached by Pribilof Islands blue king crab and the generally high productivity of the Pribilof area, however, argue against such environmental constraints. Development of the fertilized embryos occurs in the egg cases attached to the pleopods beneath the abdomen of the female crab and hatching occurs February through April (Stevens 2006b). After larvae are released, large female Pribilof blue king crab will molt, mate, and extrude their clutches the following year in late March through mid April (Armstrong et al. 1987).

   Female crabs require an average of 29 days to release larvae, and release an average of 110,033 larvae (Stevens 2006b). Larvae are pelagic and pass through four zoeal larval stages which last about 10 days each, with length of time being dependent on temperature: the colder the temperature the slower the development and vice versa (Stevens et al. 2008). Stage I zoeae must find food within 60 hours as starvation reduces their ability to capture prey (Paul and Paul 1980) and successfully molt. Zoeae consume phytoplankton, the diatom *Thalassiosira* spp. in particular, and zooplankton. The fifth larval stage is the non-feeding (Stevens et al. 2008) and transitional glaucothoe stage in which the larvae take on the shape of a small crab but retain the ability to swim by using their extended abdomen as a tail. This is the stage at which the larvae searches for appropriate settling substrate and, upon finding it, molts to the first juvenile stage and henceforth remains benthic. The larval stage is estimated to last for 2.5 to 4 months and larvae metamorphose and settle during July through early September (Armstrong et al. 1987; Stevens et al. 2008).

   Blue king crab molt frequently as juveniles, growing a few mm in size with each molt. Unlike red king crab juveniles, blue king crab juveniles are not known to form pods. Female king crabs typically reach sexual maturity at approximately five years of age while males may reach maturity at six years of age (NPFMC 2003). Female size at 50% maturity for Pribilof blue king crab is estimated to be 96-mm carapace length (CL) and size at maturity for males, estimated from chela height relative to CL, is estimated to be 108-mm CL (Somerton and MacIntosh 1983). Skip molting occurs with increasing probability for those males larger than 100 mm CL (NMFS 2005).

   Longevity is unknown for this species due to the absence of hard parts retained through molts with which to age crabs. Estimates of 20 to 30 years in age have been suggested (Blau 1997). Natural mortality for male Pribilof blue king crabs has been estimated at 0.34-0.94 with a mean of

0.79 (Otto and Cummiskey 1990) and a range of 0.16 to 0.35 for Pribilof and St. Matthew Island stocks combined (Zheng et al. 1997). An annual natural mortality of 0.2 yr^{-1} for all king crab species was adopted in the federal crab fishery management plan for the BSAI areas (Siddeek et al. 2002). A rate of 0.18 yr^{-1} is currently used for PIBKC.

5. **Management history -** The blue king crab fishery in the Pribilof District began in 1973 with a reported catch of 590 t by eight vessels (Fig. 3). Landings increased during the 1970s and peaked at a harvest of 5,000 t in the 1980/81 season (Fig. 3), with an associated increase in effort to 110 vessels (ADF&G 2008). The fishery occurred September through January, but usually lasted less than 6 weeks (Otto and Cummiskey 1990; ADF&G 2008). The fishery was male only, and legal size was >16.5 cm carapace width (NPFMC 1994). Guideline harvest levels (GHL) were 10 percent of the abundance of mature males or 20 percent of the number of legal males (ADF&G 2006).

   PIBKC have occurred as bycatch in the eastern Bering Sea snow crab (*Chionoecetes opilio*) fishery, the western Bering Sea Tanner crab (*Chionoecetes bairdi*) fishery, the Bering Sea hair crab (*Erimacrus isenbeckii*) fishery, and the Pribilof red and blue king crab fisheries. In addition, blue king crab have been taken as bycatch in flatfish, sablefish, halibut, pollock, and Pacific cod fisheries.

   Amendment 21a to the BSAI Groundfish FMP prohibits the use of trawl gear in the Pribilof Islands Habitat Conservation Area (Fig. 4; subsequently renamed the Pribilof Islands Habitat Conservation Zone in Amendment 43), which the amendment also established (NPFMC 1994). The amendment went into effect January 20, 1995 and protects the majority of crab habitat in the Pribilof Islands area from the impact from trawl gear.

   Declines in the PIBKC stock after 1995 resulted in a closure of directed fishing from 1999 to the present. The stock was declared overfished in September 2002, and ADFG developed a rebuilding harvest strategy as part of the NPFMC comprehensive rebuilding plan for the stock. The rebuilding plan also included the closure of the stock to directed fishing until it was rebuilt. In 2009, NMFS determined that the PIBKC stock was not rebuilding in a timely manner and would not meet the rebuilding horizon of 2014. Subsequently, Amendment 43 to the King and Tanner Crab Fishery Management Plan (FMP) and Amendment 103 to the BSAI Groundfish FMP to rebuild the PIBKC stock were adopted by the Council in 2012 and approved by the Secretary of Commerce in early 2015. Amendment 103 closes the Pribilof Islands Habitat Conservation Zone (Fig. 4) to pot fishing for Pacific cod to promote bycatch reduction on PIBKC. Amendment 43 amends the prior rebuilding plan to incorporate new information on the likely rebuilding timeframe for the stock, taking into account environmental conditions and the status and population biology of the stock (NPFMC 2014a).

D. Data

1. *Summary of new information:* The time series of retained and discarded catch in the crab fisheries was updated for 2015/16 from ADFG data (no retained catch, 0.166 t bycatch mortality; Tables 1 and 2). The time series of discards in the groundfish pot and trawl fisheries (Tables 2-4) were updated for 2014/15 and calculated for the 2015/16 crab fishery season (July 1-June 30) using NMFS Alaska Regional Office (AKRO) estimates obtained from the AKFIN database (as updated on Aug. 15, 2016). Results from the 2016 NMFS EBS bottom trawl survey were added to the assessment (Table 5), based on the “new” standardization described in the 2015 assessment (Stockhausen, 2015).

2. *a. Total catch:*

Crab pot fisheries

Retained pot fishery catches (live and deadloss landings data) are provided for 1973/74 to 2015/16 (Table 1, Fig. 3), including the 1973/74 to 1987/88 and 1995/96 to 1998/99 seasons when blue king crab were targeted in the Pribilof Islands District. In the 1995/96 to 1998/99 seasons, blue king crab and red king crab were fished under the same Guideline Harvest Level (GHL). Total allowable catch (TAC) for a directed fishery has been set at zero since 1999/2000; there was no retained catch in the 2015/16 crab fishing season.

b. Bycatch and discards:

Crab pot fisheries

Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers in the crab fisheries (Table 2). Catch weight was calculated by first determining the mean weight (in grams) for crabs in each of three categories: legal non-retained, sublegal, and female. The average weight for each category was then calculated from length frequency tables, where the carapace length (*z*; in mm) was converted to weight (*w*; in g) using the following equation:

$$w = \alpha \cdot z^{\beta} \qquad (1)$$

Values for the length-to-weight conversion parameters α and β were applied across the 1975-2016 time period: males) α =0.000508, β =3.106409; females) α =0.02065, β =2.27 (Daly et al. 2014). Average weights ($\overline{W}$) for each category were calculated using the following equation:

$$\overline{W} = \frac{\sum_z W_z \cdot n_z}{\sum_z n_z} \qquad (2)$$

where w_z is crab weight-at-size *z* (i.e., carapace length) using Eq. 1, and n_z is the number of crabs observed at that size in the category.

Finally, estimated total non-retained weights for each crab fishery were the product of average weight ($\overline{W}$), CPUE based on observer data, and total effort (pot lifts) in each fishery. A 50% handling mortality rate was applied to the bycatch estimates to calculate non-retained crab mortality in these pot fisheries.

Historical non-retained catch data are available from 1996/97 to present from the snow crab general, snow crab CDQ, and Tanner crab fisheries (Table 2, Bowers et al. 2011), although data may be incomplete for some of these fisheries. Prior to 1998/99, limited observer data exists (for catcher-processor vessels only), so non-retained catch before this date is not included here.

In 2015/16, several PIBKC were incidentally caught in the crab fisheries, yielding an expanded estimate of 0.166 t bycatch mortality (Table 2). The expanded estimates were obtained by multiplying the biomass of the observed fishery-specific bycatch by the ratio of unobserved to observed effort in the relevant crab fishery, then applying an assumed handling mortality rate of 50%. Bycatch mortality during 2015/16 was the first non-zero bycatch mortality in the crab fisheries since 2010/11.

Groundfish pot, trawl, and hook and line fisheries

The AKRO estimates of non-retained catch from all groundfish fisheries in 2015/16, as available through the AKFIN database (accessed Aug. 15, 2016), are included in this report (Tables 2-4). Updated estimates for 2009/10-2014/15 were also obtained through the AKFIN database.

Groundfish bycatch data from before 1999 are available only in INPFC reports and are not included in this assessment. Non-retained crab catch data in the groundfish fisheries are available from 1991/92 to present. Between 1991 and December 2001, bycatch was estimated using the "blend method." From January 2003 to December 2007, bycatch was estimated using the Catch Accounting System (CAS), based on substantially different methods than the "blend." Starting in January 2008, the groundfish observer program changed the method in which they speciate crab to better reflect their hierarchal sampling method and to account for broken crab that in the past were only identified to genus. In addition, the haul-level weights collected by observers were used to estimate the crab weights through CAS instead of applying an annual (global) weight factor to convert numbers to biomass. Spatial resolution was at the NMFS statistical area. Beginning in January 2009, ADF&G statistical areas (1^o longitude *x* 0.5^o latitude) were included in groundfish production reports and allowed an increase in the spatial resolution of bycatch estimates from the NMFS statistical areas to the state statistical areas. Bycatch estimates (2009-present) based on the state statistical areas were first provided in the 2013 assessment, and improved methods for aggregating observer data were used in the 2014 and 2015 assessments (see Stockhausen, 2015). The estimates obtained this year are based on the same methods as those used in 2014 and 2015.

To assess crab mortalities in the groundfish fisheries, an 80% handling mortality rate was applied to estimates of bycatch in trawl fisheries, and a 50% handling mortality rate was applied to fixed gear fisheries using pot and hook and line gear (Tables 2 and 3).

In 2015/16, fisheries targeting Pacific cod (*Gadus microcephalus*) accounted for 48% of the estimated total PIBKC bycatch (by weight) in the groundfish fisheries, with fisheries targeting yellowfin sole (*Limanda aspera*) accounting for another 43% (Table 4). In contrast, in 2014/15 and 2013/14 bycatch of PIBKC occurred almost exclusively in the Pacific cod fisheries (99.4% by weight, Table 4). However, in 2012/13 the Pacific cod fisheries accounted for only 20% of the bycatch while those targeting yellowfin sole accounted for 77.2%. The flathead sole (*Hippoglossoides elasodon*) fishery also accounted for a substantial fraction of the bycatch in 2010/11 (59%).

Since the 2009/10 crab fishing season, Pribilof Islands blue king crab have been taken as bycatch in the groundfish fisheries only by hook and line and non-pelagic trawl gear (Table 5). Starting in 2015, as a consequence of Amendment 43 to the BSAI Groundfish FMP, the Pribilof Islands Habitat Conservation Area was formally closed to pot fishing for Pacific cod in order to promote recovery of the PIBKC stock. In 2015/16, non-pelagic trawl gear accounted for 52% (by weight) of bycatch of PIBKC in the groundfish fisheries. In 2013/14 and 2014/15, hook and line gear accounted for the total bycatch of PIBKC. In 2012/13, it accounted for only 20% of the bycatch (by weight), whereas non-pelagic trawl gear accounted for 80%. Although these appear to be large interannual changes, the actual bycatch amounts involved are small and interannual variability is consequently expected to be rather high.

c. Catch-at-length: NA

d. Survey biomass:

The 2016 NMFS EBS bottom trawl survey was conducted between May and August of this year. Survey results for PIBKC are based on the stock area first defined in the 2013 assessment (Foy, 2013), which includes the Pribilof District (Fig. 2) and a 20 nm strip adjacent to the eastern edge of the District (not shown in Fig. 2). This new area was defined as a result of the new rebuilding plan and the concern that crab outside the Pribilof District were not being accounted for in the assessment.

In 2016, the survey caught 33 blue king crab in 86 stations across the stock area, while 20 and 28 crab were caught across the same stations in 2014 and 2015, respectively (Table 6). Five immature males were caught in 2016, similar to numbers caught in 2014 and 2015 (5 and 4, respectively). Only three mature males (one of which was legal size) were caught in 2016, compared with 5 and 13 in 2014 and 2015, respectively. Five immature females were caught in 2016; only one was caught in 2014 and none in 2015. Finally, 19 mature females were caught in 2016, compared with only 4 in 2014 and 11 in 2015.

The area-swept estimate of mature male abundance in the stock area at the time of the survey was 56,000 (±62,000) in 2016, representing a substantial (but not statistically significant) decline from 234,000 (± 168,000) in 2015 and 92,000 (±128,000) in 2014. The abundance estimate for immature males in 2016 was 94,000 (±95,000), not substantially (or significantly) different from those in 2015 (76,000) or 2014 (91,000). The area-swept estimate for immature female abundance in 2016 was 132,000 (±130,000), while that for mature females was 323,000 (±328,000). These were both larger than (but not significantly different from) abundance estimates in 2015 (0 and 202,000, respectively) and 2014 (28,000 and 74,000, respectively).

The area-swept estimate of mature male biomass in the stock area at the time of the survey was 129 t (±154 t) in 2016, representing a substantial (but not statistically significant) decline from 622 t (± 480 t) in 2015 and 233 t (±320 t) in 2014. The biomass estimate for immature males in 2016 was 70 t (±67 t), not substantially (or significantly) different from those in 2015 (82 t) or 2014 (83 t). The area-swept estimate for immature female biomass in 2016 was 49 t (±48 t), while that for mature females was 352 t (±340 t). These were both larger than (but not significantly different from) abundance estimates in 2015 (0 and 160 t, respectively) and 2014 (16 t and 91 t, respectively).

One feature that characterizes survey-based estimates of abundance and biomass for PIBKC is the large uncertainty (cv's on the order of 0.5) associated with the estimates, which complicates the interpretation of sometimes large interannual swings in estimates (Tables 7 and 8; Fig.s 5 and 6). Estimated total abundance of male PIBKC from the NMFS EBS bottom trawl survey declined from ~24 million crab in 1975, the first year of the "standardized" survey, to ~150,000 in 2016 (the lowest estimated abundance since 2004, which was the minimum for the time series; Table 7). Following a general decline to a low-point in 1985 (~500,000 males), abundance increased by a factor of 10 in the early1990s, then generally declined (with small amplitude oscillations superimposed) to the present. Estimated female abundance generally followed a similar trend. It spiked at 180 million crab in 1980, from ~13 million crab in 1975 and only ~1 million in 1979, then returned to more typical levels in 1981 (~6 million crab). More recently, abundance has fluctuated around 200,000 females. Estimated biomass for both males and females have followed similar trends similar to those in abundance (Table 8, Fig.s 5 and 6).

Size frequencies for males by shell condition from the five most recent surveys (2012-2016) are illustrated in Figure 7. Size frequencies for all males across the time series are shown in Fig. 8 for both the new time series and the old time series. While Fig. 7 suggested a recent trend toward larger sizes in 2014-15, this does not appear to have continued in 2016. These plots provide little evidence of recent recruitment.

Size frequencies for females by shell condition are presented in Fig. 9 for the five most recent surveys (2012-2016). Size frequencies for all females are shown in Fig. 10. These also provide little indication of recent recruitment.

The spatial pattern of PIBKC abundance in recent surveys is generally centered fairly compactly within the Pribilof District to the east of St. Paul Island (although 2015 is an exception) and north of St. George Island, within a 60 nm radius of St. Paul (Figures 11-13). There is some suggestion that PIBKC may segregate by sex and maturity state (at least during the early summer time period when the survey is conducted; Fig. 12), but its validity is questionable given the overall sampling variability associated with this stock.

E. Analytic Approach

1. *History of modeling approaches*

A catch survey analysis has been used for assessing the stock in the past, although it is not currently in use. In October 2013, the SSC concurred with the CPT that the PIBKC stock falls under Tier 4 for status determination but it recommended that the OFL be calculated using a Tier 5 approach, with ABC based on a 10% buffer.

In the 2013 and 2014 assessments (Foy 2013; Stockhausen 2014), "current" MMB-at-mating was projected from the time of the latest survey using an inverse-variance averaging approach to smoothing annual survey biomass estimates because the uncertainties associated with the annual estimates are extremely large. In the 2015 assessment, an alternative approach to smoothing based on a Random Effects model was presented and subsequently adopted by the CPT and SSC to use in estimating B_{MSY} and "current" MMB-at-mating. The Random Effects model (Appendix A) is used in this assessment.

2. *Model Description:* See Appendix A.
3. *Model Selection and Evaluation: Not applicable*
4. *Results:* See Appendix A.

F. Calculation of the OFL

1. *Tier Level:*

Based on available data, the ***author recommended classification for this stock is Tier 4*** for stock status level determination defined by Amendment 24 to the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 2008a).

In Tier 4, stock status is based on the ratio of "current" spawning stock biomass (B) to B_{MSY} (or a proxy thereof, B_{MSY}^{proxy}, also referred to as B_{REF}). MSY (maximum sustained yield) is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions. The fishing mortality that, if applied over the long-term, would result in MSY is F_{MSY}. B_{MSY} is the long-term average stock size when fished at F_{MSY}, and is based on mature male biomass at the time of mating (MMB_{mating}), which serves as an approximation for egg production. MMB_{mating} is used as a basis for B_{MSY} because of the complicated female crab life history, unknown sex ratios, and male only fishery. Although B_{MSY} cannot be calculated for a Tier 4 stock, a proxy value (B_{MSY}^{proyx} or B_{REF}) is defined as the average biomass over a specified time period that satisfies the conditions under which B_{MSY} would occur (i.e., equilibrium biomass yielding MSY under an applied F_{MSY}).

The time period for establishing B_{MSY}^{proxy} is assumed to be representative of the stock being fished at an average rate near F_{MSY} and fluctuating around B_{MSY}. The SSC has endorsed using the time periods 1980-84 and 1990-97 to calculate B_{MSY}^{proxy} for Pribilof Islands blue king crab to avoid time periods of low abundance possibly caused by high fishing pressure. Alternative time periods (e.g., 1975 to 1979) have also been considered but rejected (Foy 2013). Considerations for choosing the current time periods included:

A. Production potential

1) Between 2006 and 2013 the stock does appears to be below a threshold for responding to increased production based on the lack of response of the adult stock biomass to slight fluctuations in recruitment (male crab 120-134 mm) (Fig. 20).

2) An estimate of surplus production (ASP = $MMB_{t+1} - MMB_t$ + total $catch_t$) suggested that only meaningful surplus existed only in the late 1970s and early 1980s while minor surplus production in the early 1990s may have led to the increases in biomass observed in the late 1990s.
3) Although a climate regime shift where temperature and current structure changes are likely to impact blue king crab larval dispersal and subsequent juvenile crab distribution, no apparent trends in production before or after 1978 were observed (Foy 2013). There are few empirical data to identify trends that may allude to a production shift. However, further analysis is warranted given the paucity of surplus production and recruitment subsequent to 1981 and the spikes in recruits (male crab 120-134 mm) /spawner (MMB) observed in the early 1990s and 2009 (Fig. 21 in Foy 2013).

B. Exploitation rates fluctuated during the open fishery periods from 1975 to 1987 and 1995 to 1998 (Fig. 20 in Foy 2013) while total catch increased until 1980, before the fishery was closed in 1987, and increased again in 1995 before closing again in 1999 (Fig. 22 in Foy 2013). The current $F_{\mathrm{MSY}}^{proxy} = M$ is 0.18, so time periods with greater exploitation rates should not be considered to represent a period with an average rate of fishery removals.

C. Subsequent to increases in exploitation rates in the late 1980s and 1990s, the quantity ln(recruits/MMB) dropped, suggesting that exploitation rates at the levels of $F_{\mathrm{MSY}}^{proxy} = M$ were not sustainable.

Thus, MMB_{mating} is the basis for calculating B_{MSY}^{proxy}. The formulas used to calculate MMB_{mating} from MMB at the time of the survey (MMB_{survey}) are documented in Appendix A. For this stock, B_{MSY}^{proxy} was calculated using the random effects model-smoothed estimates for MMB_{survey} from the survey time series in the formula for MMB_{mating}. B_{MSY}^{proxy} is the average of MMB_{mating} for the years 1980/81-1984/85 and 1990/91-1997/98 (see Table 7) and was calculated as 4,116 t.

In this assessment, "current *B*" is the MMB_{mating} projected for 2016/17. Details of this calculation are also provided in Appendix A. For 2016/17, current B = 233 t.

Overfishing is defined as any amount of fishing in excess of a maximum allowable rate, F_{OFL}, which would result in a total catch greater than the OFL. For Tier 4 stocks, a minimum stock size threshold (MSST) is specified as 0.5 B_{MSY}^{proxy} and if current B drops below the MSST, the stock is considered to be overfished.

2. *List of parameter and stock sizes:*

- B_{MSY}^{proxy} (B_{REF}) = 4,116 t
- M = 0.18 yr^{-1}
- Current B = 233 t

3. *OFL specification:*

a. In the Tier 4 OFL-setting approach, the "total catch OFL" and the "retained catch OFL" are calculated by applying the F_{OFL} to all crab at the time of the fishery (total catch OFL) or to the mean retained catch determined for a specified period of time (retained catch OFL).

The Tier 4 F_{OFL} is derived using the F_{OFL} Control Rule (Fig. 17), where the Stock Status Level (level a, b or c; equations 4-6) is based on the relationship of current B to B_{MSY}^{proxy}.

<u>Stock Status Level</u>:	<u>F_{OFL}</u>:	
a. $B/B_{\mathrm{MSY}}^{\mathrm{prox}} > 1.0$	$F_{\mathrm{OFL}} = \gamma \cdot M$	(4)

b. $\beta < B/B_{MSY}^{prox} \leq 1.0$ $\qquad F_{OFL} = \gamma \cdot M\,[(B/B_{MSY}^{prox} - \alpha)/(1 - \alpha)]$ (5)

c. $B/B_{MSY}^{prox} \leq \beta$ $\qquad F_{directed} = 0;\ F_{OFL} \leq F_{MSY}$ (6)

When B/B_{MSY}^{proxy} is greater than 1 (Stock Status Level a), F_{OFL}^{proxy} is given by the product of a scalar (γ=1.0, nominally) and M. When B/B_{MSY}^{proxy} is less than 1 and greater than the critical threshold β (= 0.25) (Stock Status Level b), the scalar α (= 0.1) determines the slope of the non-constant portion of the control rule for F_{OFL}^{proxy}. Directed fishing mortality is set to zero when the ratio B/B_{MSY}^{proxy} drops below β (Stock Status Level c). Values for α and β are based on a sensitivity analysis of the effects on B/B_{MSY}^{proxy} (NPFMC 2008a).

b. The basis for projecting MMB from the survey to the time of mating is discussed in detail in Appendix A.

c. Specification of F_{OFL}, OFL and other applicable measures:

All weights in t:

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2012/13	4c	4,494	496	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	3,988	278	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	4,002	218	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2015/16	4c	4,109	361	0.09	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2016/17	4c	4,116	233	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

All weights in million lbs:

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2012/13	4c	9.91	1.09	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	8.79	0.61	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	8.82	0.48	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2015/16	4c	9.06	0.79	0.09	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2016/17	4c	9.07	0.51	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

4. *Specification of the retained catch portion of the total catch OFL:*

   a. The retained portion of the catch for this stock is zero (0 t).

5. *Recommendations:*

For 2016/2017, B_{MSY}^{proxy} = *4,116 t, derived as the mean MMB_{mating} from 1980/81 to 1984/85 and 1990/91 to 1997/98 using the random effects model-smoothed survey time series*. The stock demonstrated highly variable levels of MMB during both of these periods, likely leading to uncertain approximations for B_{MSY}. Crabs were highly concentrated during the EBS bottom trawl surveys and male biomass estimates were characterized by poor precision due to limited numbers of tows with crab catches.

MMB$_{mating}$* for 2016/17 was estimated at 233 t for B_{MSY}^{proxy}. The B/B_{MSY}^{proxy} ratio corresponding to the biomass reference is 0.06**. B/B_{MSY}^{proxy} is < β, therefore the ***stock status level is c, $F_{directed}$ = 0, and $F_{OFL} \leq F_{MSY}$ (as determined in the Pribilof Islands District blue king crab rebuilding plan). Total catch OFL calculations were explored in 2008 to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality (NPFMC 2008a). The preferred method was a total catch OFL equivalent to the average catch mortalities between 1999/2000 and 2005/06. This period was after the targeted fishery was closed and did not include recent changes to the groundfish fishery that led to increased blue king crab bycatch. ***The OFL for 2016/17, based on an average catch mortality, is 1.16 t***.

G. Calculation of the ABC

To calculate an Annual Catch Limit (ACL) to account for scientific uncertainty in the OFL, an acceptable biological catch (ABC) control rule was developed such that ACL=ABC. For Tier 3 and 4 stocks, the ABC is set below the OFL by a proportion based a predetermined probability that the ABC would exceed the OFL (P*). Currently, P* is set at 0.49 and represents a proportion of the OFL distribution that accounts for within assessment uncertainty (σ_w) in the OFL to establish the maximum permissible ABC (ABC_{max}). Any additional uncertainty to account for uncertainty outside of the assessment methods (σ_b) is considered as a recommended ABC below ABC_{max}. Additional uncertainty is included in the application of the ABC by adding the uncertainty components as $\sigma_{total} = \sqrt{\sigma_b^2 + \sigma_w^2}$. For the PIBKC stock, the CPT has recommended, and the SSC has approved, a constant buffer of 25% to the OFL (NPFMC, 2014b).

1. *Specification of the probability distribution of the OFL used in the ABC:* The OFL was set based on a Tier 5 calculation of average catch mortalities between 1999/2000 and 2005/06 to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality. As such, the OFL does not have an associated probability distribution.

2. *List of variables related to scientific uncertainty considered in the OFL probability distribution:* None. The OFL is based on a Tier 5 calculation and does not have an associated probability distribution. However, compared to other BSAI crab stocks, the uncertainty associated with the estimates of stock size and OFL for Pribilof Islands blue king crab is very high due to insufficient data and the small spatial extent of the stock relative to the survey sampling density. The coefficient of variation for the estimate of mature male biomass from the surveys for the most recent year is 0.61, and has ranged between 0.17 and 1.00 since the 1980 peak in biomass.

3. *List of additional uncertainties considered for alternative σ_b applications to the ABC.*

   Several sources of uncertainty are not included in the measures of uncertainty reported as part of the stock assessment:

   - Survey catchability and natural mortality uncertainties are not estimated but rather are pre-specified.

   - F_{MSY} is assumed to be equal to γM when applying the OFL control rule, where the proportionality constant γ is assumed to be equal to 1 and M is assumed to be known.

   - The coefficients of variation for the survey estimates of abundance for this stock are very high.

   - B_{MSY} is assumed to be equivalent to average mature male biomass. However, stock biomass has fluctuated greatly and targeted fisheries only occurred from 1973-1987 and 1995-1998 so considerable uncertainty exists with this estimate of B_{MSY}.

4. *Recommendations:*

   For 2016/17, $F_{directed}$ = 0 and the total catch OFL is based on catch biomass would maintain the conservation needs with this stock and acknowledge the existing non-directed catch mortality. In this case, the ***ABC_{max}* based on a 25% buffer of the average catch between 1999/2000 and 2005/2006 would be 0.87 t.**

All units are tons of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2012/13	1,994 A	579 A	closed	0	0.61	1.16	1.04
2013/14	2,001 A	225 A	closed	0	0.03	1.16	1.04
2014/15	2,055 A	344 A	closed	0	0.07	1.16	0.87
2015/16	2,058 A	361 A	closed	0	1.18	1.16	0.87
2016/17	--	233 B	--	--	--	1.16	0.87

All units are million pounds of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2012/13	4.39 A	1.09 A	closed	0	0.0013	0.003	0.002
2013/14	4.41 A	0.50 A	closed	0	0.0001	0.003	0.002
2014/15	4.53 A	0.76 A	closed	0	0.0002	0.003	0.002
2015/16	4.54 A	0.79 A	closed	0	0.0026	0.003	0.002
2016/17	--	0.51 B	--	--	--	0.003	0.002

Notes:
A – Based on data available to the Crab Plan Team at the time of the assessment following the end of the crab fishing year.
B – Based on data available to the Crab Plan Team at the time of the assessment for the crab fishing year.

H. Rebuilding Analyses

Rebuilding analyses results summary: A revised rebuilding plan analysis was submitted to the U.S. Secretary of Commerce in 2014 because NMFS determined that the stock was not rebuilding in a timely manner and would not meet the rebuilding horizon of 2014. The Secretary approved the plan in 2015, as well as the two amendments that implement it (Amendment 43 to the King and Tanner Crab Fishery Management Plan and Amendment 103 to the BSAI Groundfish Fishery Management Plan). These amendments impose a closure to all fishing for Pacific cod with pot gear in the Pribilof Islands Habitat Conservation Zone. This measure was designed to protect the main concentration of the stock from the fishery with the highest observed rates of bycatch (NPFMC, 2014a). The area has been closed to trawling since 1995.

I. Data Gaps and Research Priorities

Given the large CVs associated with the survey abundance and biomass estimates for the Pribilof Islands blue king crab stock, assessment of this species might benefit from additional surveys using alternative gear at finer spatial resolution. Further data gaps include stock-specific natural mortality rates and a lack of understanding regarding processes apparently preventing successful recruitment to the Pribilof District.

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Table 1. Total retained catches from directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2011; D. Pengilly and J. Webb, ADF&G, personal communications).

Year	Retained Catch		Avg. CPUE
	Abundance	Biomass (t)	legal crabs/pot
1973/1974	174,420	579	26
1974/1975	908,072	3,224	20
1975/1976	314,931	1,104	19
1976/1977	855,505	2,999	12
1977/1978	807,092	2,929	8
1978/1979	797,364	2,901	8
1979/1980	815,557	2,719	10
1980/1981	1,497,101	4,976	9
1981/1982	1,202,499	4,119	7
1982/1983	587,908	1,998	5
1983/1984	276,364	995	3
1984/1985	40,427	139	3
1985/1986	76,945	240	3
1986/1987	36,988	117	2
1987/1988	95,130	318	2
1988/1989	0	0	--
1989/1990	0	0	--
1990/1991	0	0	--
1991/1992	0	0	--
1992/1993	0	0	--
1993/1994	0	0	--
1994/1995	0	0	--
1995/1996	190,951	628	5
1996/1997	127,712	425	4
1997/1998	68,603	232	3
1998/1999	68,419	234	3
1999/2000 - 2015/2016	0	0	--

Table 2. Total bycatch (non-retained catch) from the directed and non-directed fisheries for Pribilof Islands District blue king crab. Crab fishery bycatch data is not available prior to 1996/1997 (Bowers et al. 2011; D. Pengilly ADF&G). Gear-specific groundfish fishery data is not available prior to 1991/1992 (J. Mondragon, NMFS).

fishery year	crab (pot) fisheries (t)			groundfish fisheries (t)	
	females	legal males	sublegal males	fixed gear	trawl gear
1991/92	--	--	--	0.067	6.199
1992/93	--	--	--	0.879	60.791
1993/94	--	--	--	0.000	34.232
1994/95	--	--	--	0.035	6.856
1995/96	--	--	--	0.108	1.284
1996/97	0.000	0.000	0.807	0.031	0.067
1997/98	0.000	0.000	0.000	1.462	0.130
1998/99	3.715	2.295	0.467	19.800	0.079
1999/00	1.969	3.493	4.291	0.795	0.020
2000/01	0.000	0.000	0.000	0.116	0.023
2001/02	0.000	0.000	0.000	0.833	0.029
2002/03	0.000	0.000	0.000	0.071	0.297
2003/04	0.000	0.000	0.000	0.345	0.227
2004/05	0.000	0.000	0.000	0.816	0.002
2005/06	0.050	0.000	0.000	0.353	1.339
2006/07	0.104	0.000	0.000	0.138	0.074
2007/08	0.136	0.000	0.000	3.993	0.132
2008/09	0.000	0.000	0.000	0.141	0.473
2009/10	0.000	0.000	0.000	0.216	0.207
2010/11	0.000	0.000	0.186	0.039	0.056
2011/12	0.000	0.000	0.000	0.112	0.007
2012/13	0.000	0.000	0.000	0.167	0.669
2013/14	0.000	0.000	0.000	0.064	0.000
2014/15	0.000	0.000	0.000	0.142	0.000
2015/16	0.103	0.000	0.230	0.745	0.808

Table 3. Total bycatch (discard) *mortality* from directed and non-directed fisheries for Pribilof Islands District blue king crab. Gear-specific handling mortalities were applied to estimates of non-retained catch from Table 2 for fixed gear (i.e., pot and hook/line; 0.5) and trawl gear (0.8).

fishery year	crab (pot) fisheries (t)			groundfish fisheries (t)		total bycatch mortality (t)
	females	legal males	sublegal males	fixed gear	trawl gear	
1991/92	--	--	--	0.034	4.959	4.993
1992/93	--	--	--	0.440	48.633	49.072
1993/94	--	--	--	0.000	27.386	27.386
1994/95	--	--	--	0.018	5.485	5.502
1995/96	--	--	--	0.054	1.027	1.081
1996/97	0.000	0.000	0.404	0.016	0.054	0.473
1997/98	0.000	0.000	0.000	0.731	0.104	0.835
1998/99	1.857	1.148	0.234	9.900	0.063	13.202
1999/00	0.984	1.746	2.145	0.398	0.016	5.290
2000/01	0.000	0.000	0.000	0.058	0.018	0.076
2001/02	0.000	0.000	0.000	0.417	0.023	0.440
2002/03	0.000	0.000	0.000	0.036	0.238	0.273
2003/04	0.000	0.000	0.000	0.173	0.182	0.354
2004/05	0.000	0.000	0.000	0.408	0.002	0.410
2005/06	0.025	0.000	0.000	0.177	1.071	1.273
2006/07	0.052	0.000	0.000	0.069	0.059	0.180
2007/08	0.068	0.000	0.000	1.997	0.106	2.170
2008/09	0.000	0.000	0.000	0.071	0.378	0.449
2009/10	0.000	0.000	0.000	0.108	0.165	0.273
2010/11	0.000	0.000	0.093	0.020	0.045	0.158
2011/12	0.000	0.000	0.000	0.056	0.006	0.062
2012/13	0.000	0.000	0.000	0.084	0.535	0.619
2013/14	0.000	0.000	0.000	0.032	0.000	0.032
2014/15	0.000	0.000	0.000	0.071	0.000	0.071
2015/16	0.051	0.000	0.115	0.372	0.646	1.185

Table 4. Proportion by weight of the estimated total Pribilof Islands blue king crab bycatch in the groundfish fisheries among trip targets. For the 2003/2004-2008/2009 crab fishing seasons, these were calculated using bycatch from NMFS Statistical Area 513. For 2009/10-2015/16, these were calculated using the AKRO Catch Accounting System, with data reported from State of Alaska statistical areas that encompass the Pribilof Islands Blue King Crab District. Groundfish fishery target species that caught blue king crab but made up less than 2% of the blue king crab bycatch across all years are not shown in the table. The estimated total bycatch of Pribilof Islands blue king crab in numbers across all groundfish fisheries is also shown.

Crab Fishery Year	% bycatch (biomass) by trip target				total bycatch (# crabs)
	yellowfin sole %	Pacific cod %	flathead sole %	rocksole %	
2003/04	47	22	31	< 1	252
2004/05	< 1	100	< 1	< 1	259
2005/06	< 1	97	3	< 1	757
2006/07	54	20	< 1	26	96
2007/08	3	96	1	< 1	2,950
2008/09	77	23	< 1	< 1	295
2009/10	31	51	17	< 1	281
2010/11	< 1	39	59	< 1	48
2011/12	< 1	100	< 1	< 1	62
2012/13	77	20	3	< 1	410
2013/14	< 1	99	< 1	< 1	39
2014/15	< 1	99	< 1	< 1	64
2015/16	43	48	9	< 1	609

Table 5. Proportion by weight of the estimated total Pribilof Islands blue king crab bycatch in the groundfish fisheries among gear types. For the 2003/2004-2008/2009 crab fishing seasons, these were calculated using bycatch from NMFS Statistical Area 513. For 2009/10-2015/16, these were calculated using the AKRO Catch Accounting System, with data reported from State of Alaska statistical areas that encompass the Pribilof Islands Blue King Crab District. The estimated total bycatch of Pribilof Islands blue king crab in numbers across all groundfish fisheries is also shown.

Crab Fishery Year	% bycatch (biomass) by gear type				total bycatch (# crabs)
	non-pelagic trawl %	pelagic trawl %	hook and line %	pot %	
2003/04	79	0	21	0	252
2004/05	1	0	99	0	259
2005/06	3	0	18	79	757
2006/07	20	0	20	0	96
2007/08	3	0	1	95	2,950
2008/09	77	0	23	0	295
2009/10	49	0	7	44	281
2010/11	59	0	41	0	48
2011/12	6	0	94	0	62
2012/13	80	0	20	0	410
2013/14	0	0	100	0	39
2014/15	0	0	100	0	64
2015/16	52	0	48	0	609

Table 6. Summaries of the a) 2016, b) 2015, and c) 2014 NMFS annual EBS bottom trawl surveys for the Pribilof Islands District blue king crab by stock component.

a) 2016 survey results.

Stock Component	Number of tows in District	Tows with crab	Number of crab measured	Number of crab caught	Abundance (millions)		Biomass (mt)	
					estimate	95% CI	estimate	95% CI
Immature male	86	4	5	5	0.094	0.095	70	67
Mature male	86	3	3	3	0.056	0.062	129	154
Legal male	86	1	1	1	0.019	0.038	68	133
Immature female	86	4	5	5	0.132	0.130	49	48
Mature female	86	7	19	19	0.323	0.328	352	340

b) 2015 survey results.

Stock Component	Number of tows in District	Tows with crab	Number of crab measured	Number of crab caught	Abundance (millions)		Biomass (mt)	
					estimate	95% CI	estimate	95% CI
Immature male	86	2	4	4	0.076	0.113	82	120
Mature male	86	8	13	13	0.234	0.168	622	480
Legal male	86	5	7	7	0.125	0.109	428	385
Immature female	86	0	0	0	0.000	0.000	0	0
Mature female	86	4	11	11	0.202	0.260	160	207

c) 2014 survey results.

Stock Component	Number of tows in District	Tows with crab	Number of crab measured	Number of crab caught	Abundance (millions)		Biomass (mt)	
					estimate	95% CI	estimate	95% CI
Immature male	86	3	5	5	0.091	0.105	83	102
Mature male	86	2	5	5	0.092	0.128	233	320
Legal male	86	2	5	5	0.092	0.128	233	320
Immature female	86	1	1	1	0.028	0.054	16	32
Mature female	86	3	4	4	0.074	0.088	91	108

Table 7. Abundance time series for Pribilof Islands blue king crab from the NMFS annual EBS bottom trawl survey.

Year	Males								Females	
	immature		mature		legal		total		total	
	abundance	cv	abundance	cv	abundance	cv	abundance	cv	abundance	cv
1975	8,475,781	0.57	15,288,169	0.50	9,051,486	0.50	23,763,950	0.47	13,147,587	0.61
1976	4,959,559	0.95	4,782,105	0.45	4,012,289	0.47	9,741,664	0.59	8,138,538	0.91
1977	4,215,865	0.46	13,043,983	0.74	11,768,927	0.77	17,259,848	0.63	14,731,651	0.86
1978	2,421,458	0.50	6,140,638	0.50	3,922,874	0.62	8,562,096	0.43	5,987,437	0.66
1979	79,355	0.70	4,107,868	0.33	3,017,119	0.31	4,187,222	0.32	1,311,351	0.77
1980	2,732,728	0.47	7,842,342	0.41	6,244,058	0.42	10,575,070	0.40	183,684,143	0.98
1981	2,099,475	0.32	3,834,431	0.18	3,245,951	0.18	5,933,906	0.21	6,260,015	0.42
1982	1,371,283	0.28	2,353,813	0.18	2,071,468	0.19	3,725,096	0.17	8,713,260	0.63
1983	1,030,732	0.36	1,851,301	0.19	1,321,395	0.17	2,882,033	0.22	9,771,695	0.76
1984	517,574	0.40	770,643	0.22	558,226	0.25	1,288,217	0.21	3,234,663	0.37
1985	67,765	0.60	428,076	0.28	270,242	0.29	495,841	0.27	746,266	0.36
1986	18,904	1.00	480,198	0.31	460,311	0.31	499,102	0.30	2,138,616	0.88
1987	621,541	0.83	903,180	0.41	830,151	0.42	1,524,721	0.43	1,072,008	0.48
1988	1,238,053	0.84	237,868	0.51	237,868	0.51	1,475,921	0.71	1,363,093	0.64
1989	3,514,764	0.59	239,948	0.62	239,948	0.62	3,754,712	0.58	3,777,855	0.58
1990	2,449,864	0.60	1,470,419	0.63	571,708	0.54	3,920,283	0.58	4,223,169	0.56
1991	1,920,443	0.37	2,014,086	0.36	1,237,558	0.44	3,934,529	0.34	3,572,899	0.35
1992	2,435,796	0.59	1,935,278	0.42	1,154,465	0.45	4,371,074	0.48	3,946,863	0.52
1993	1,483,524	0.52	1,875,500	0.31	1,114,301	0.30	3,359,024	0.34	2,663,329	0.38
1994	638,520	0.37	1,294,263	0.34	935,269	0.34	1,932,783	0.33	5,191,978	0.44
1995	1,146,803	0.89	3,101,712	0.60	2,186,409	0.62	4,248,514	0.67	4,697,035	0.49
1996	719,430	0.63	1,712,015	0.28	1,269,275	0.26	2,431,445	0.33	5,321,557	0.46
1997	467,234	0.53	1,201,296	0.29	932,852	0.28	1,668,530	0.34	2,934,717	0.39
1998	949,447	0.46	967,098	0.25	797,187	0.25	1,916,545	0.31	2,329,750	0.37
1999	159,536	0.37	617,258	0.33	452,740	0.34	776,794	0.33	2,755,976	0.49
2000	163,835	0.56	725,051	0.30	527,589	0.30	888,885	0.31	1,363,070	0.46
2001	92,918	0.65	522,239	0.71	445,863	0.74	615,157	0.69	1,715,981	0.74
2002	0	0.00	225,476	0.47	207,146	0.49	225,476	0.47	1,240,582	0.78
2003	45,271	0.72	228,897	0.39	213,572	0.40	274,168	0.34	1,187,583	0.72
2004	87,651	0.59	47,905	0.56	15,584	1.00	135,556	0.42	168,094	0.51
2005	1,981,338	0.96	91,932	0.71	91,932	0.71	2,073,270	0.92	2,557,310	0.89
2006	138,118	0.49	55,579	0.56	38,242	0.70	193,697	0.42	542,588	0.62
2007	246,165	0.72	110,080	0.85	54,403	0.75	356,245	0.64	288,245	0.59
2008	233,919	0.93	18,256	1.00	18,256	1.00	252,174	0.86	779,488	0.75
2009	267,717	0.63	248,626	0.73	68,117	0.59	516,343	0.68	629,385	0.76
2010	101,151	0.84	130,465	0.49	64,703	0.48	231,616	0.61	414,660	0.62
2011	0	0.00	165,525	0.79	129,098	0.87	165,525	0.79	54,601	0.56
2012	194,522	1.00	272,233	0.80	164,165	0.68	466,755	0.88	346,777	0.70
2013	76,351	1.00	104,361	0.86	68,726	0.80	180,712	0.64	195,644	0.53
2014	90,990	0.59	91,856	0.71	91,856	0.71	182,846	0.57	102,088	0.51
2015	75,575	0.77	233,630	0.37	124,592	0.45	309,205	0.41	202,464	0.65
2016	94,022	0.52	55,852	0.56	19,345	1.00	149,874	0.49	454,449	0.50

Table 8. Biomass time series for Pribilof Islands blue king crab from the NMFS annual EBS bottom trawl survey.

Year	Males								Females	
	immature		mature		legal		total		total	
	biomass (t)	cv	biomass (t)	cv	biomass (t)	cv	biomass (t)	cv	biomass (t)	cv
1975	8,341	0.52	38,054	0.50	27,016	0.50	46,395	0.47	12,442	0.64
1976	4,129	0.94	14,059	0.45	12,649	0.47	18,188	0.45	5,792	0.89
1977	3,713	0.44	42,618	0.77	40,366	0.78	46,332	0.73	13,572	0.87
1978	2,765	0.51	17,370	0.56	13,517	0.64	20,135	0.51	6,492	0.72
1979	61	0.79	10,959	0.32	9,040	0.31	11,021	0.31	1,189	0.76
1980	2,084	0.49	23,553	0.43	20,679	0.45	25,637	0.42	212,303	0.98
1981	1,704	0.30	11,628	0.17	10,554	0.17	13,332	0.18	6,484	0.46
1982	1,152	0.23	7,389	0.19	6,893	0.19	8,541	0.17	9,377	0.67
1983	962	0.36	5,409	0.18	4,474	0.17	6,371	0.19	10,248	0.78
1984	130	0.36	2,216	0.23	1,824	0.25	2,345	0.22	3,085	0.38
1985	39	0.73	1,055	0.27	755	0.28	1,094	0.26	525	0.44
1986	4	1.00	1,505	0.30	1,473	0.31	1,508	0.30	2,431	0.90
1987	191	0.78	2,923	0.41	2,781	0.41	3,115	0.40	913	0.53
1988	170	0.71	842	0.53	842	0.53	1,012	0.46	718	0.47
1989	1,275	0.62	827	0.64	827	0.64	2,102	0.55	1,746	0.50
1990	2,004	0.66	3,078	0.60	1,514	0.52	5,082	0.61	2,929	0.49
1991	1,377	0.39	4,690	0.39	3,326	0.45	6,067	0.37	2,776	0.38
1992	1,801	0.51	4,391	0.42	3,035	0.45	6,192	0.43	2,649	0.46
1993	1,088	0.54	4,556	0.31	3,203	0.30	5,644	0.30	2,092	0.40
1994	619	0.39	3,410	0.34	2,806	0.35	4,029	0.34	4,893	0.44
1995	968	0.86	8,360	0.60	6,787	0.62	9,328	0.63	4,279	0.50
1996	745	0.61	4,641	0.27	3,873	0.27	5,386	0.28	5,585	0.49
1997	381	0.55	3,233	0.28	2,765	0.27	3,614	0.29	3,028	0.41
1998	692	0.41	2,798	0.25	2,510	0.25	3,490	0.25	2,182	0.39
1999	161	0.40	1,729	0.34	1,426	0.35	1,890	0.33	2,868	0.47
2000	113	0.68	2,091	0.30	1,746	0.31	2,205	0.30	1,462	0.46
2001	87	0.76	1,599	0.73	1,461	0.76	1,686	0.73	1,817	0.72
2002	0	0.00	680	0.51	647	0.52	680	0.51	1,401	0.78
2003	19	0.98	702	0.40	671	0.41	721	0.39	1,307	0.73
2004	36	0.65	107	0.58	48	1.00	143	0.46	123	0.50
2005	326	0.94	344	0.71	344	0.71	670	0.59	847	0.61
2006	87	0.58	166	0.60	139	0.70	253	0.46	576	0.71
2007	197	0.74	306	0.80	206	0.73	503	0.66	282	0.71
2008	212	0.95	46	1.00	46	1.00	258	0.80	672	0.70
2009	254	0.68	497	0.71	187	0.60	751	0.70	625	0.82
2010	92	0.85	303	0.46	190	0.48	395	0.52	394	0.63
2011	0	0.00	461	0.84	399	0.89	461	0.84	37	0.67
2012	165	1.00	644	0.74	459	0.64	809	0.79	237	0.64
2013	15	1.00	250	0.80	190	0.75	265	0.75	166	0.65
2014	83	0.62	233	0.70	233	0.70	317	0.57	108	0.53
2015	82	0.75	622	0.39	428	0.46	703	0.39	160	0.66
2016	70	0.49	129	0.61	68	1.00	199	0.52	401	0.48

Table 9. Estimates of mature male biomass (MMB) at the time of mating for Pribilof Islands blue king crab using: (1) the "raw" survey biomass time series and (2) the survey biomass time series smoothed using the Random Effects Model. Shaded rows signify averaging time period for B_{MSY}/MSST. The 2016/17 estimates are projected values (see Appendix A).

year	"Raw" Survey Biomass (t)	Random Effects Model (t)
1975/76	33,223	23,279
1976/77	9,834	15,099
1977/78	35,611	16,450
1978/79	12,904	12,561
1979/80	7,304	9,418
1980/81	16,519	9,420
1981/82	6,590	6,414
1982/83	4,769	4,823
1983/84	3,934	3,644
1984/85	1,862	1,977
1985/86	723	983
1986/87	1,244	1,288
1987/88	2,333	1,441
1988/89	758	1,278
1989/90	745	1,430
1990/91	2,771	2,343
1991/92	4,220	3,440
1992/93	3,930	3,748
1993/94	4,089	3,888
1994/95	3,068	3,611
1995/96	6,937	3,877
1996/97	3,776	3,553
1997/98	2,692	2,773
1998/99	2,291	2,208
1999/00	1,555	1,775
2000/01	1,883	1,657
2001/02	1,439	1,141
2002/03	612	705
2003/04	632	494
2004/05	96	248
2005/06	309	238
2006/07	149	202
2007/08	275	206
2008/09	41	188
2009/10	447	265
2010/11	273	289
2011/12	415	336
2012/13	579	360
2013/14	225	311
2014/15	210	305
2015/16	559	361
2016/17*	116	233

Figures

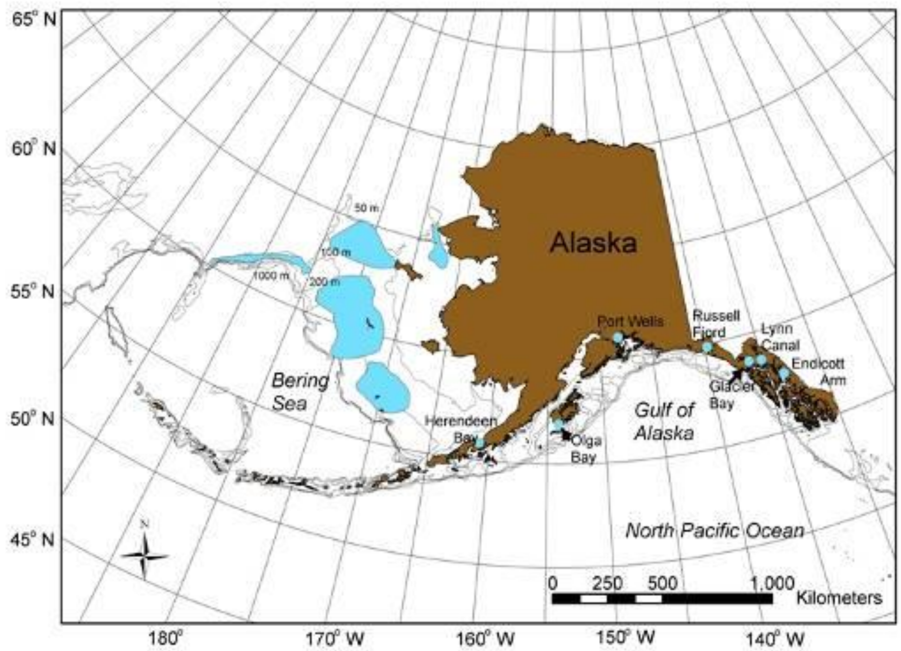


Figure 1. Distribution of blue king crab (*Paralithodes platypus*) in Alaskan waters.

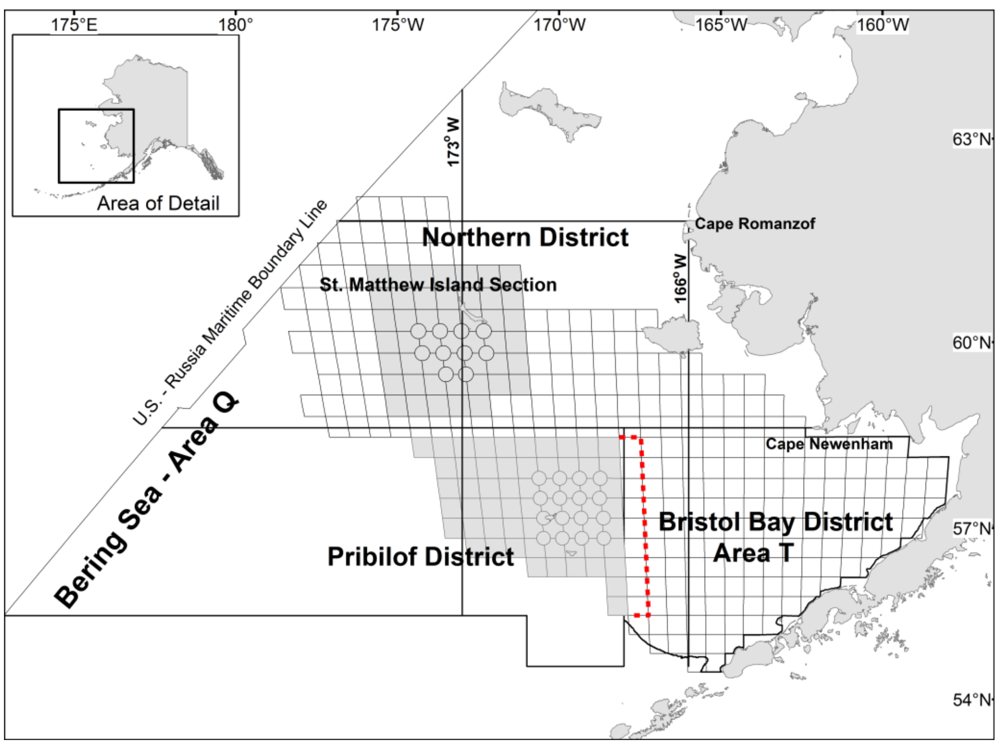


Figure 2. King crab Registration Area Q (Bering Sea) showing, among others, the Pribilof District. This figure also indicates the additional 20 nm strip (red dotted line) considered starting in 2013 year for biomass and catch data in the Pribilof District.

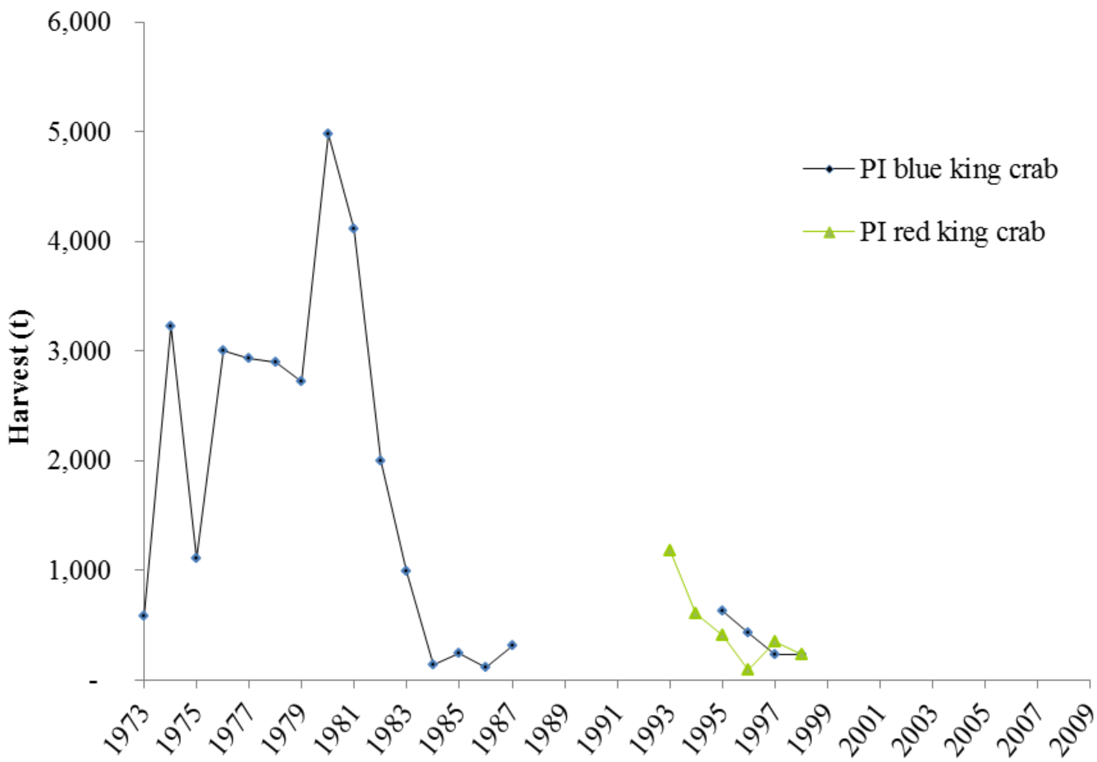


Figure 3. Historical harvests (t) and GHLs for Pribilof Island blue and red king crab (Bowers et al. 2011).

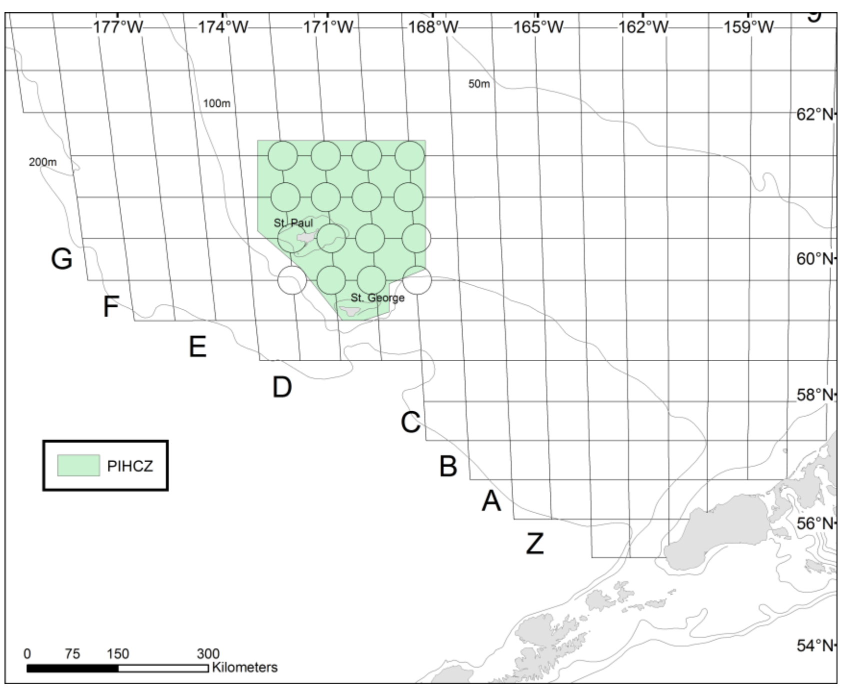
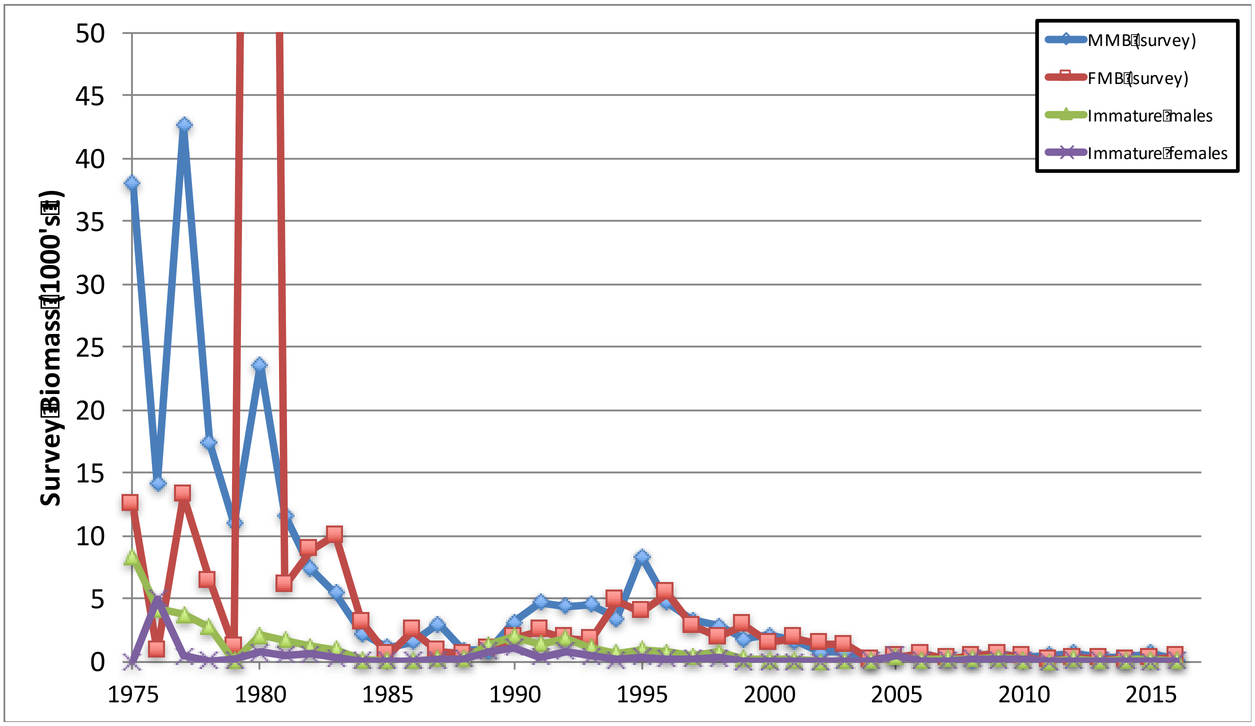


Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation Zone (PIHCZ). Trawl fishing is prohibited year-round in this zone (as of 1995), as is pot fishing for Pacific cod (as of 2015). Also shown is a portion of the NMFS annual EBS bottom trawl survey grid.



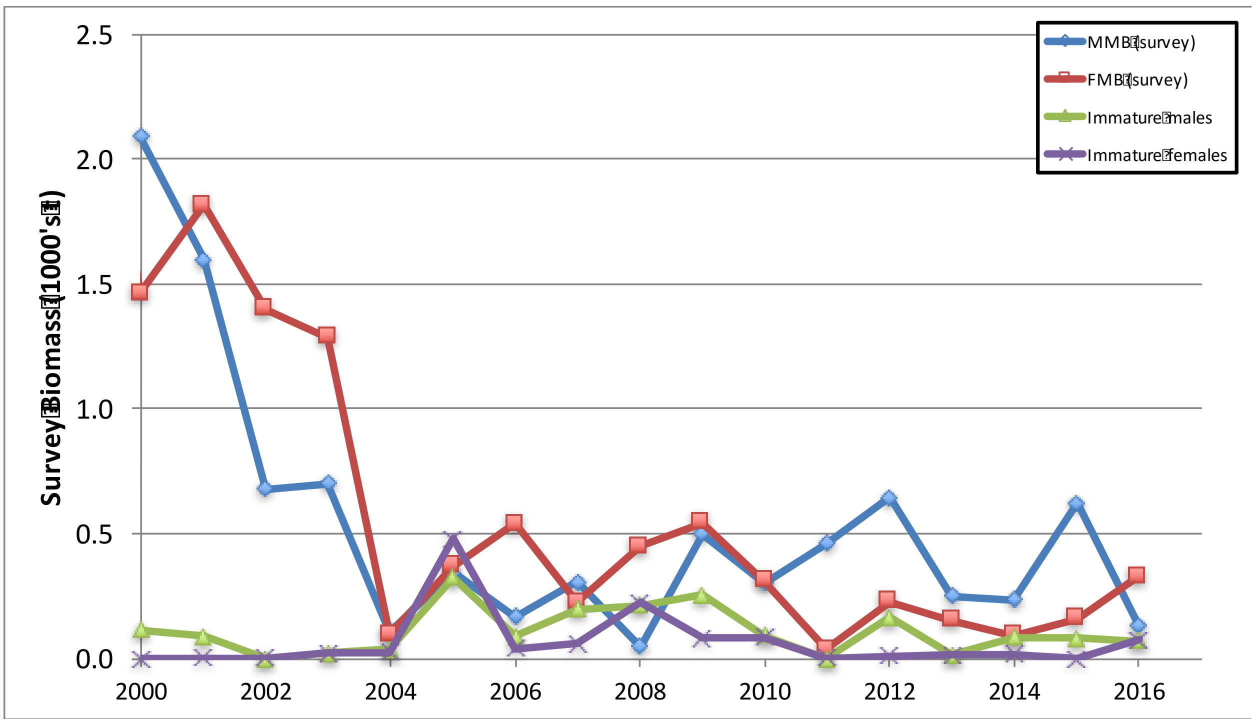


Figure 5. Time series of area-swept biomass estimates for various stock components of Pribilof Islands blue king crab estimated using the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2016. Lower graph: 2000-2015. MMB (blue): mature male biomass at survey time; FMB (red): female mature biomass at survey time. The estimate for FMB in 1980 (off the upper chart) is 212,000 t. To facilitate comparison confidence intervals are not shown.

Figure 6. Time series for MMB at the time of the survey estimated from the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2015. Lower graph: 1990-2015. Red line: “raw” time series. Green line: random effects (RE) model-smoothed time series. Error bars show 80% CIs.

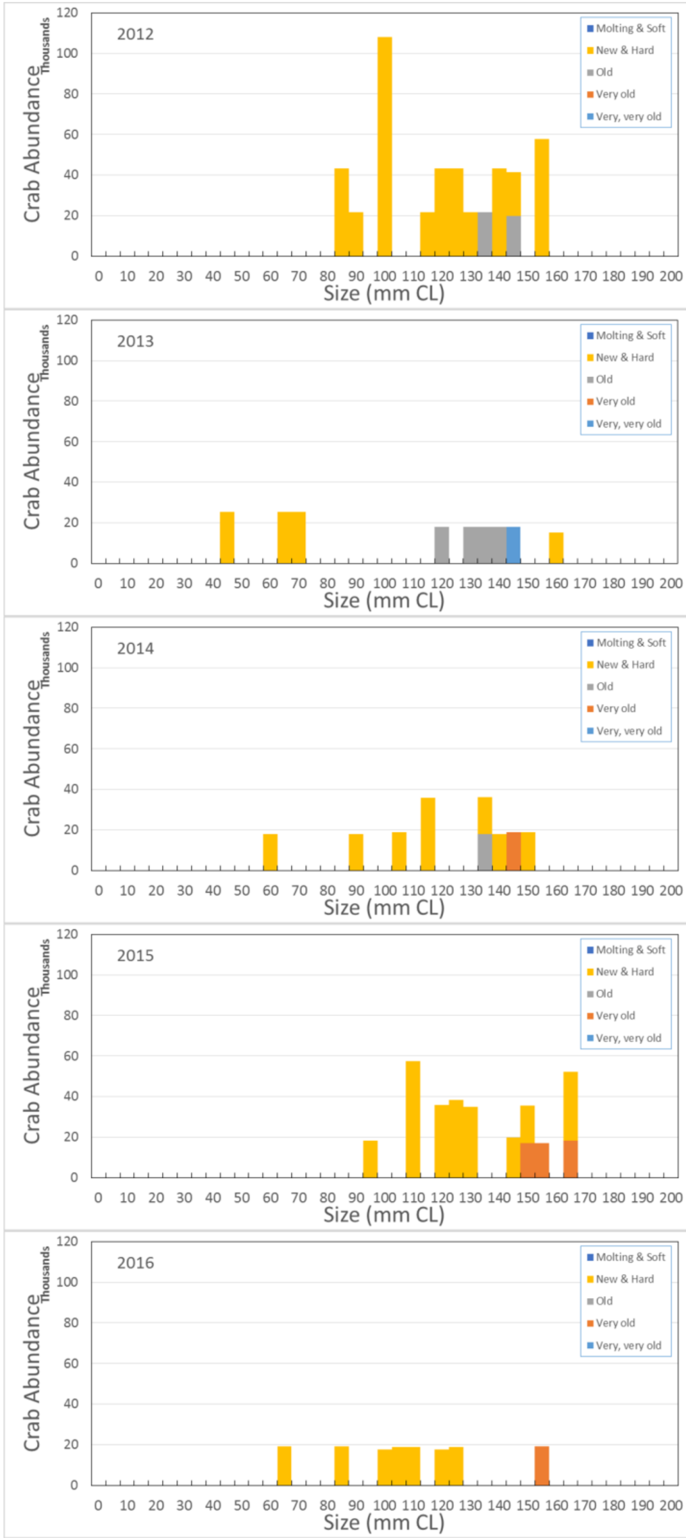


Figure 7. Size frequencies by shell condition for male Pribilof Island blue king crab in 5 mm length bins from the last five NMFS EBS bottom trawl surveys.

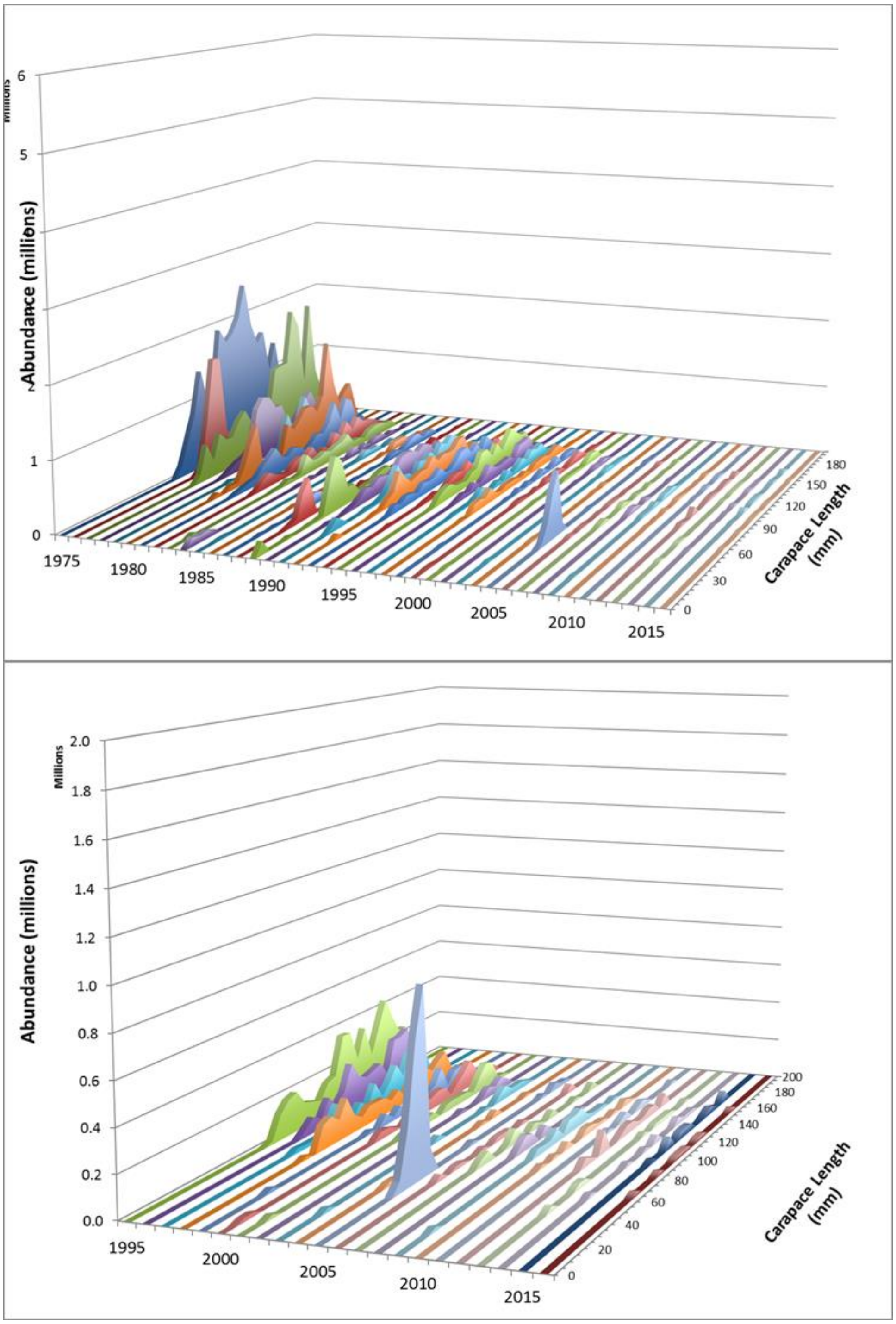


Figure 8. Size frequencies from the annual NMSF bottom trawl survey for male Pribilof Islands blue king crab by 5 mm length bins. The top row shows the entire time series, the bottom shows the size compositions since 1995.

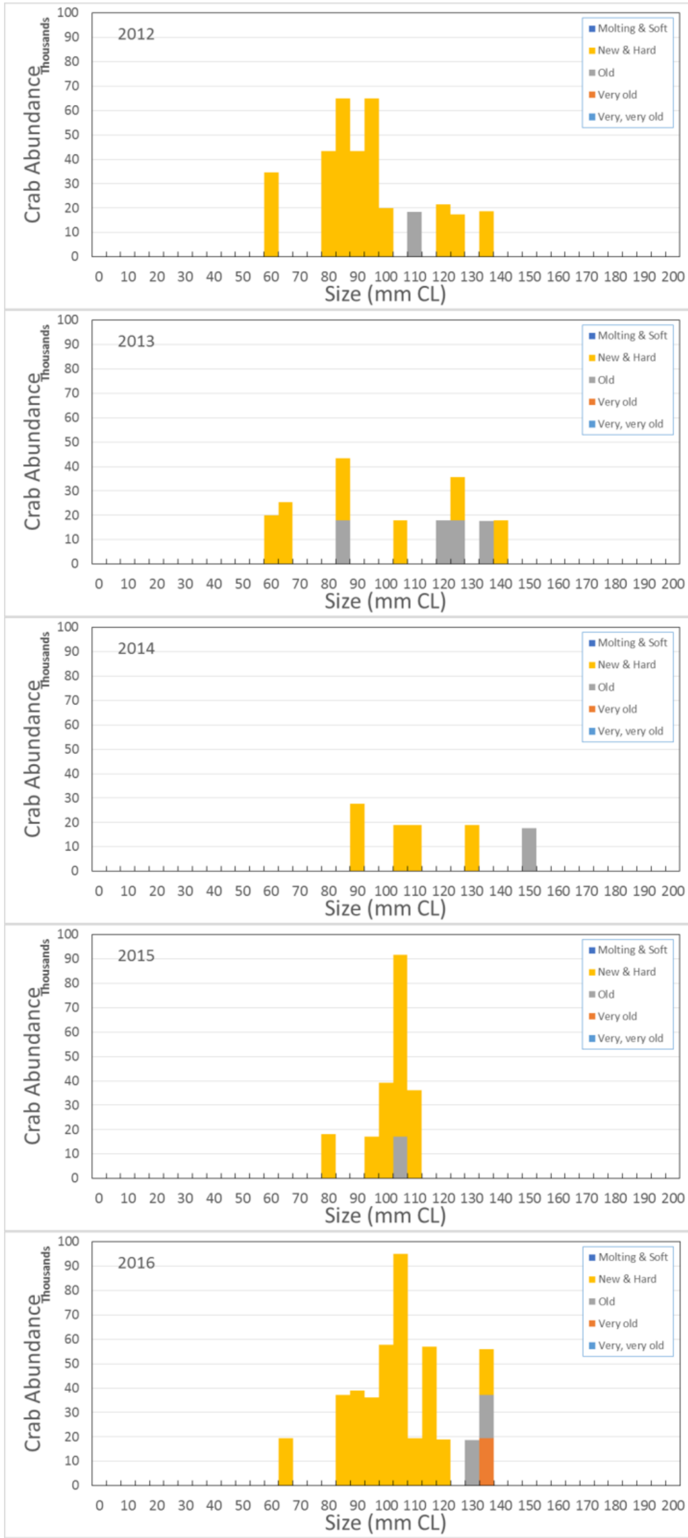


Figure 9. Size-frequencies by shell condition for female Pribilof Island blue king crab by 5 mm length bins from the last five NMFS bottom trawl surveys.

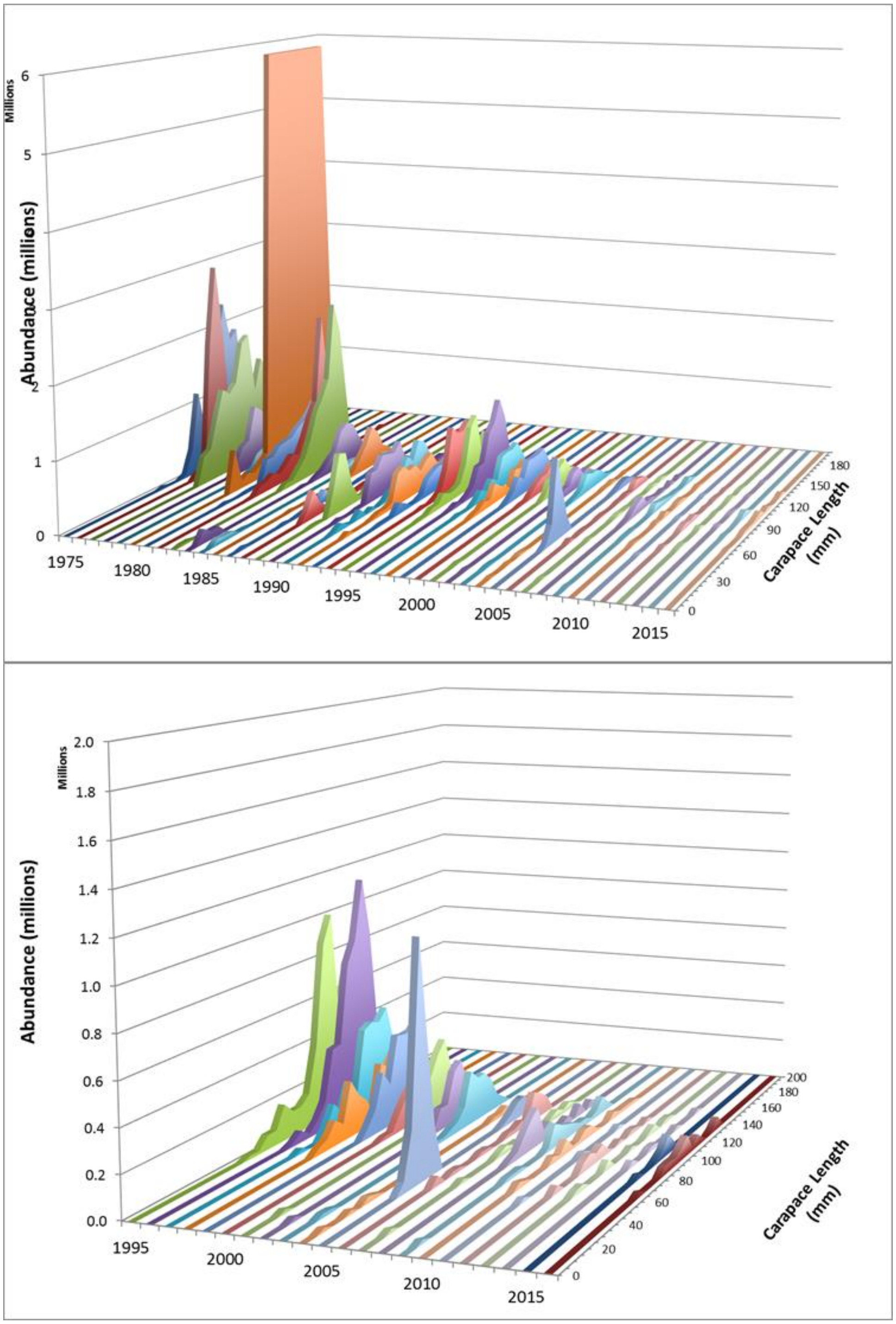


Figure 10. Size frequencies from the annual NMSF bottom trawl survey for female Pribilof Islands blue king crab by 5 mm length bins. The top row shows the entire time series, the bottom shows the size compositions since 1995.

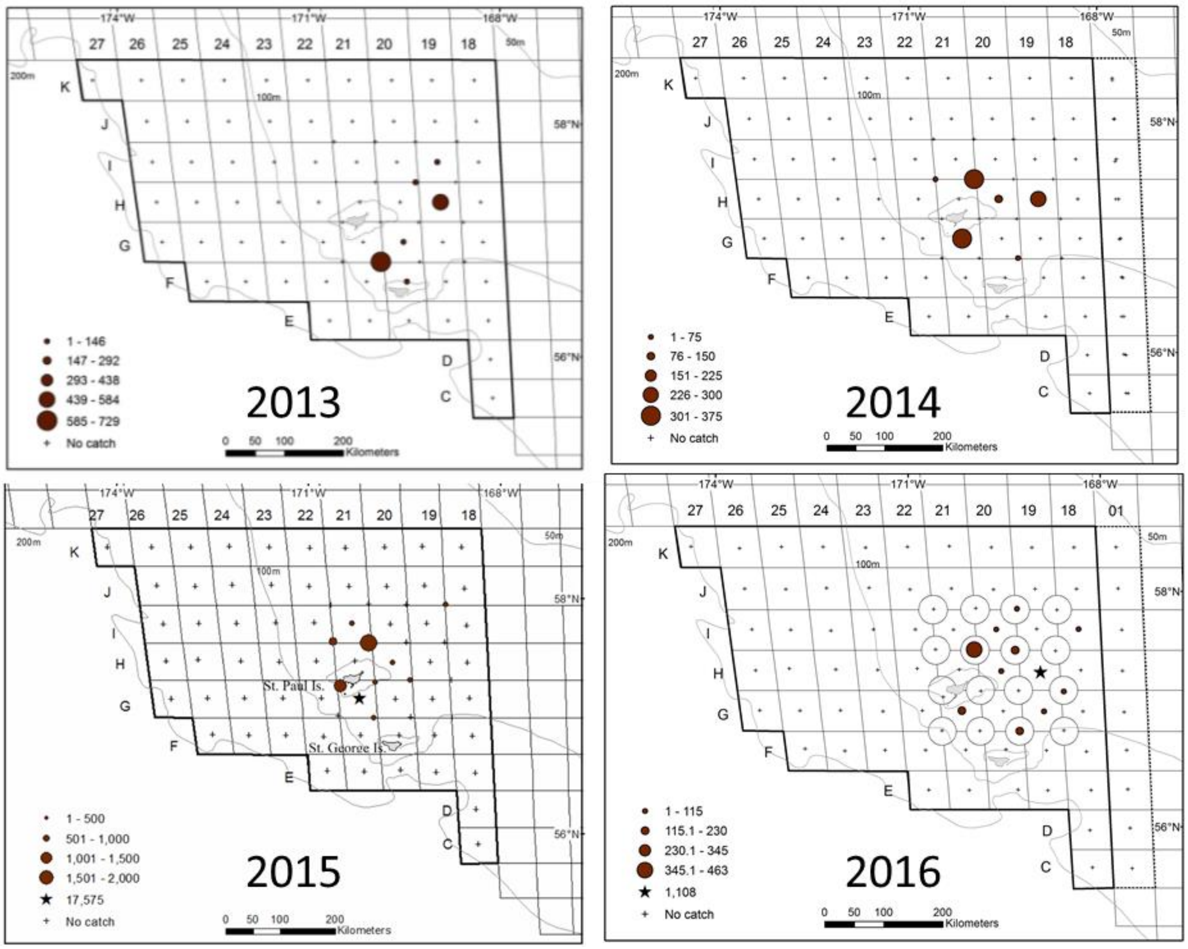


Figure 11. Total density (number/nm^2) of blue king crab in the Pribilof District in the 2013-2016 NMFS EBS bottom trawl surveys. Note that each ma uses a different scale.

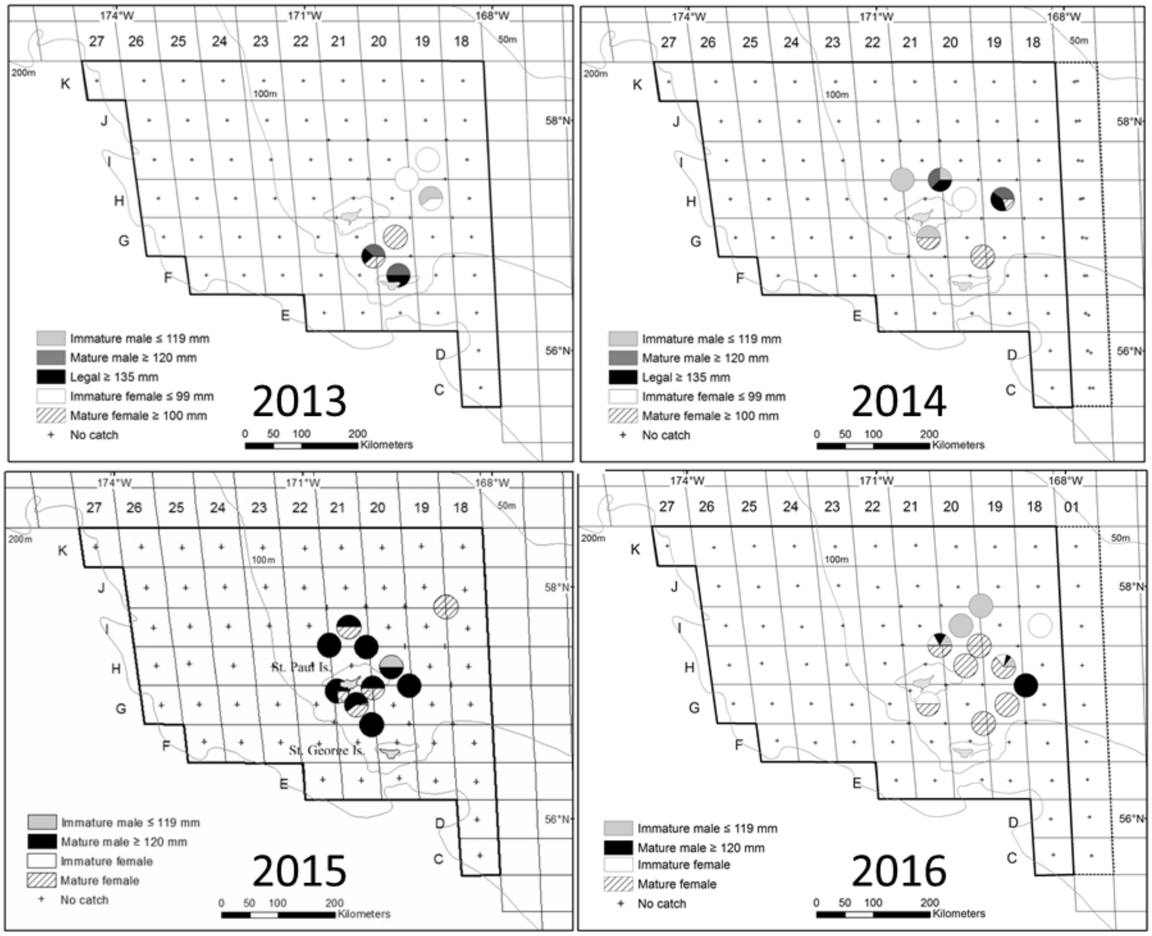


Figure 12. Size class distribution of blue king crab in the Pribilof District during the 2013-2016 NMFS EBS bottom trawl surveys.

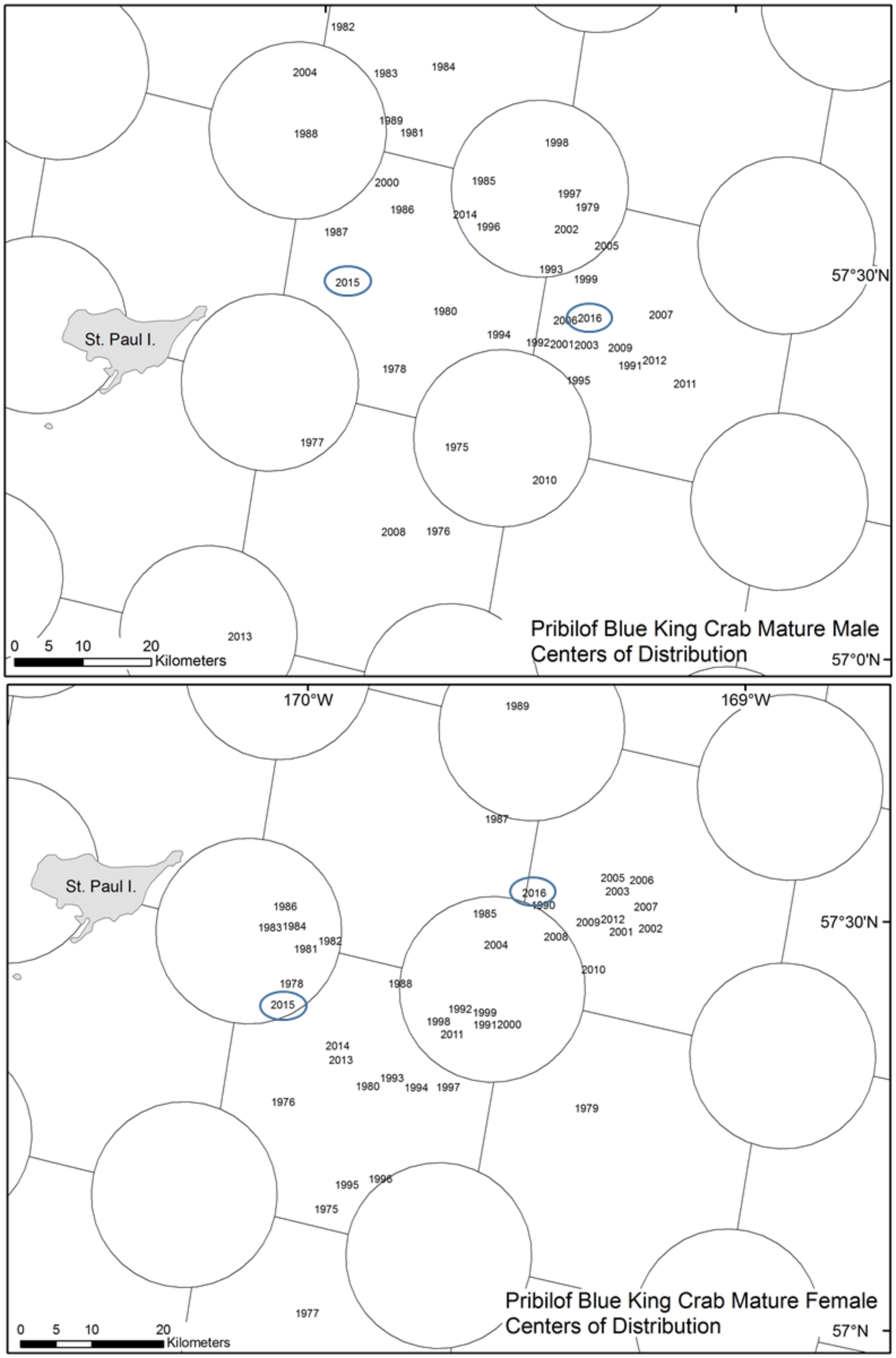


Figure 13. Centers of distribution for mature male (upper) and mature female (lower) blue king crab in the Pribilof District during the 1975-2016 NMFS EBS bottom trawl surveys. Positions for 2015 and 2016 are circled.

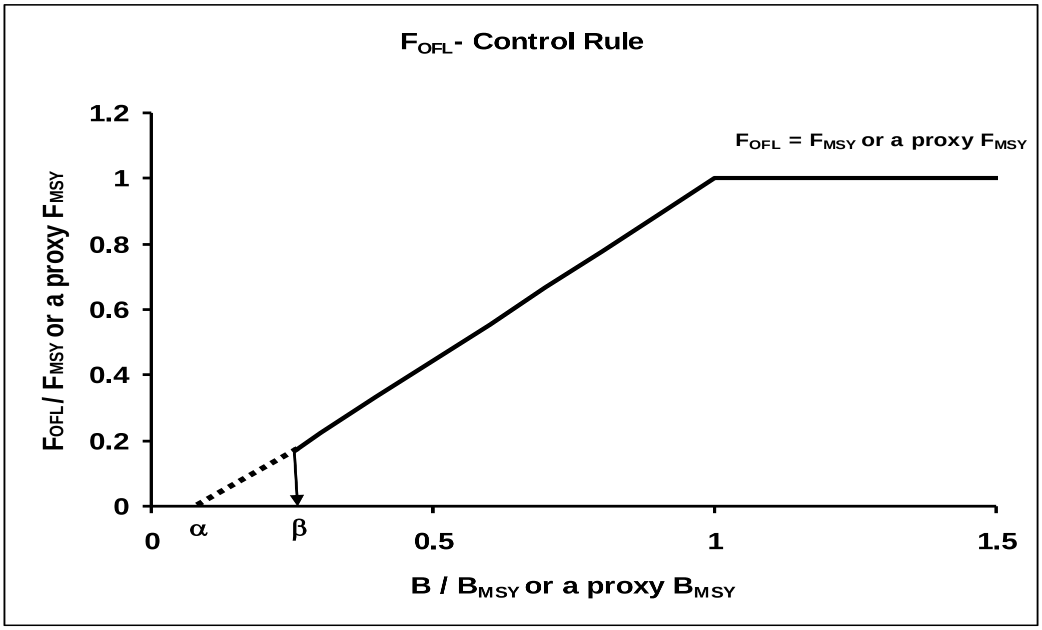


Figure 14. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β (= 0.25).

Appendix A: PIBKC 2016 Status Determination

William Stockhausen
02 September, 2016

Introduction

This is an appendix to the 2016 stock assessment chapter for the Pribilof Islands blue king crab stock (PIBKC). It presents results for current status determination (is overfishing occurring?, is the stock overfished?) for the current year using the "rPIBKC"" R package developed by the assessment author. The rPIBKC package (source code and R package) is available under version control at https://github.com/wStockhausen/rPIBKC.git.

This appendix is the result of processing an R Markdown document to create a Word document. Markdown is a simple formatting syntax for authoring HTML, PDF, and MS Word documents that can encapsulate R code. Following changes to the fishery and/or survey data used for this assessment, the R Markdown document can be re-evaluated to produce an updated version of this appendix using one mouse click. For more details on using R Markdown see http://rmarkdown.rstudio.com.

Status Determination and OFL calculations

For all crab stocks managed by the NPFMC, overfishing is evaluated by comparing the previous year's catch mortality (retained + discard mortality) to the previous year's OFL: if the former is greater than the latter, then overfishing is occurring. Overfished status is assessed with respect to MSST, the Minimum Stock Size Threshold. If stock biomass drops below the MSST, the stock is considered to be overfished. For crab stocks, MSST is one-half B_{MSY}, where B_{MSY} is the resulting spawning stock biomass when the stock is fished at maximum sustainable yield. Thus, the stock is overfished if $B/B_{MSY} < 0.5$, where B is "current"" spawning stock biomass. In general, the overfishing limit (OFL) for the subsequent year is based on B/B_{MSY} and an "F_{OFL}" harvest control rule, where F_{OFL} is the fishing mortality rate that yields the OFL. Furthermore, if $B/B_{MSY} < \beta(= 0.25)$, directed fishing on the stock is prohibited. For PIBKC, OFL is based on average historic catch mortality over a specified time period (a Tier 5 approach) and is consequently fixed at 1.16 t.

PIBKC falls into Tier 4 for status determination. For Tier 4 stocks, it is not possible to determine B_{MSY} and MSST directly. Instead, average mature male biomass (MMB) at the time of mating ("MMB at mating"") is used as a proxy for B_{MSY}, where the averaging is over some time period assumed to be representative of the stock being fished at an average rate near F_{MSY} and is thus fluctuating around B_{MSY}. For PIBKC, the NPFMC's Science and Statistical Committee (SSC) has endorsed using the disjoint time periods [1980-84, 1990-97] to calculate $B_{MSY_{proxy}}$ to avoid time periods of low abundance possibly caused by high fishing pressure. Alternative time periods (e.g., 1975 to 1979) have also been considered but rejected. Once $B_{MSY_{proxy}}$ has been calculated, overfished status is then determined by the ratio $B/B_{MSY_{proxy}}$: the stock is overfished if the ratio is less than 0.5, where B is taken as "current" MMB-at-mating.

MMB-at-mating

MMB-at-mating (MMB_m) is calculated from MMB at the time of the annual NMFS EBS bottom traw survey (MMB_s) by accounting for natural and fishing mortality from the time of the survey to mating. MMB at the time of the survey in year y is calculated from survey data using:

$$MMB_{s_y} = \sum zw_z \cdot P_z \cdot n_{z,y}$$

where w_z is male weight at size z (mm CL), P_z is the probability of maturity at size z, and $n_{z,y}$ is survey-estimated male abundance at size z in year y.

For a year y prior to the assessment year, MMB_{m_y} is given by

1. $MMB_{f_y} = MMB_{s_y} \cdot e^{-M \cdot t_{sf}}$
2. $MMB_{m_y} = [MMB_{f_y} - RM_y - DM_y] \cdot e^{-M \cdot t_{fm}}$

where MMB_{f_y} is the MMB in year y just prior to the fishery, M is natural mortality, RM_y is retained mortality on MMB in the directed fishery in year y, DM_y is discard mortality on MMB (NOT all crab) in all fisheries in year y, t_{sf} is the time between the survey and the fishery, and t_{fm} is the time between the fishery and mating.

For the assessment year, the fishery has not occurred so RM and DM are unknown. The amount of fishing mortality presumably depends on the (as yet-to-be-determined) overfishing limit, so an iterative procedure is used to estimate MMB-at-mating for the fishery year. This procedure involves:

1. "guess" a value for F_{OFL}, the directed fishing mortality rate that yields OFL ($F_{OFL_{max}} = \gamma \cdot M$ is used)
2. determine the OFL corresponding to fishing at F_{OFL} using the following equations:
   - $MMB_f = MMB_s \cdot e^{-M \cdot t_{sf}}$
   - $RM_{OFL} = (1 - e^{-F_{OFL}}) \cdot MMB_s \cdot e^{-M \cdot t_{sf}}$
   - $DM_{OFL} = \theta \cdot \frac{MMB_f}{p_{male}}$
   - $OFL = RM_{OFL} + DM_{OFL}$
3. project MMB-at-mating from the "current" survey MMB and the OFL:
   - $MMB_m = [MMB_{f_y} - (RM_{OFL} + p_{male} \cdot DM_{OFL})] \cdot e^{-M \cdot t_{fm}}$

4. use the harvest control rule to determine the F_{OFL} corresponding to the projected MMB-at-mating.
5. update the "guess" in 1. for the result in 4.
6. repeat steps 2-5 until the process has converged, yielding self-consistent values for F_{OFL} and MMB-at-mating.

where p_{male} is the assumed fraction of discard mortality on males. Note that this procedure determines the OFL for the assessment year as well as the current MMB-at-mating. Also note that, while the retained mortality RM_{OFL} is based on the F_{OFL}, the discard mortality DM_{OFL} is assumed to be proportional to the MMB at the time of the fishery, with proportionality constant $\frac{\theta}{p_{male}}$. The constant θ is determined by the average ratio of discard mortality on MMB (DM_{MMB}) to MMB at the time of the fishery (MMB_f) over a recent time interval:

$$\theta = \frac{1}{N} \sum y \frac{DM_{MMB_y}}{MMB_{f_y}}$$

where the sum is over the last N years. In addition, DM_{MMB} is assumed to be proprtional to total discard mortality, with that proportionality given by the percenatge of males in the stock.

Data

Data from the following files were used in this assessment:

- fishery data: ./Data2016AM.Fisheries.csv
- survey data : ./Data2016AM.Surveys.csv

The following figures illustrate the time series of retained PIBKC in the directed fishery and PIBKC incidentally taken in the crab and groundfish fisheries (i.e., bycatch):

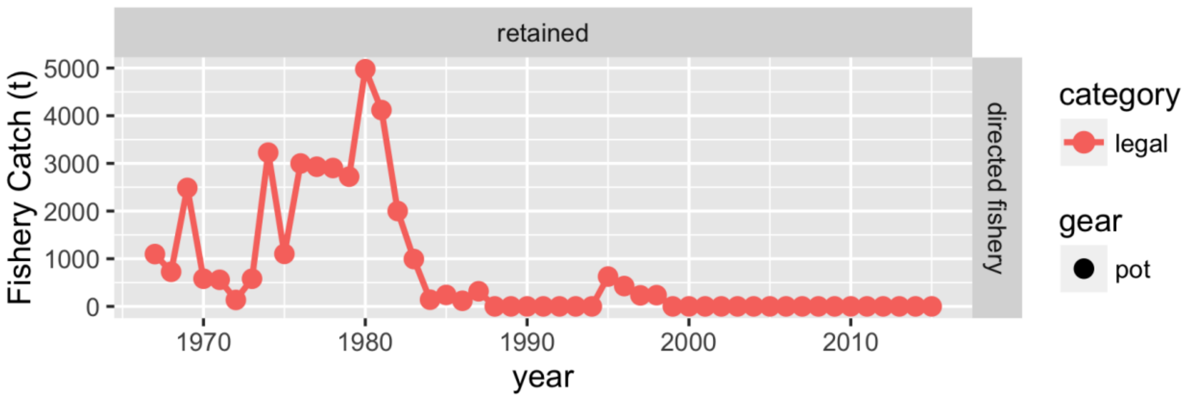


Figure 1. Time series of retained PIBKC catch in the directed fishery.

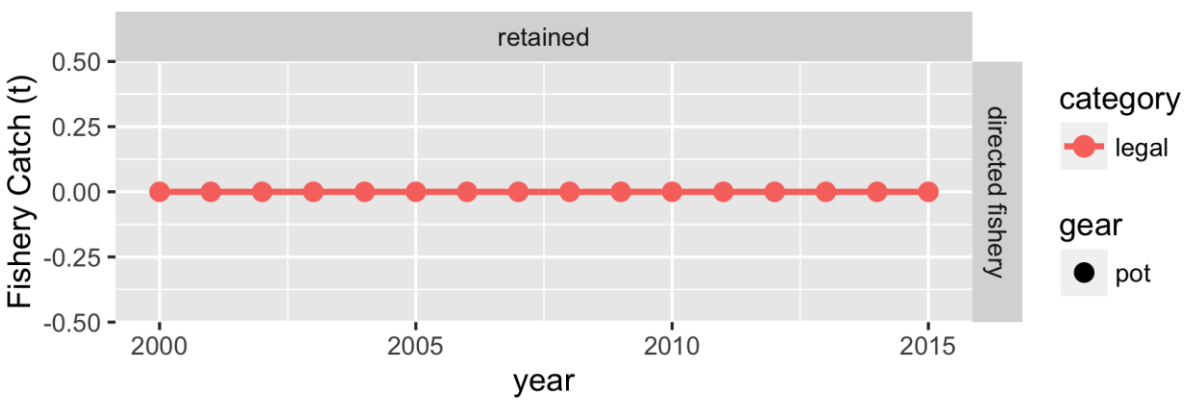


Figure 2. Time series of retained PIBKC catch in the directed fishery (recent time period).

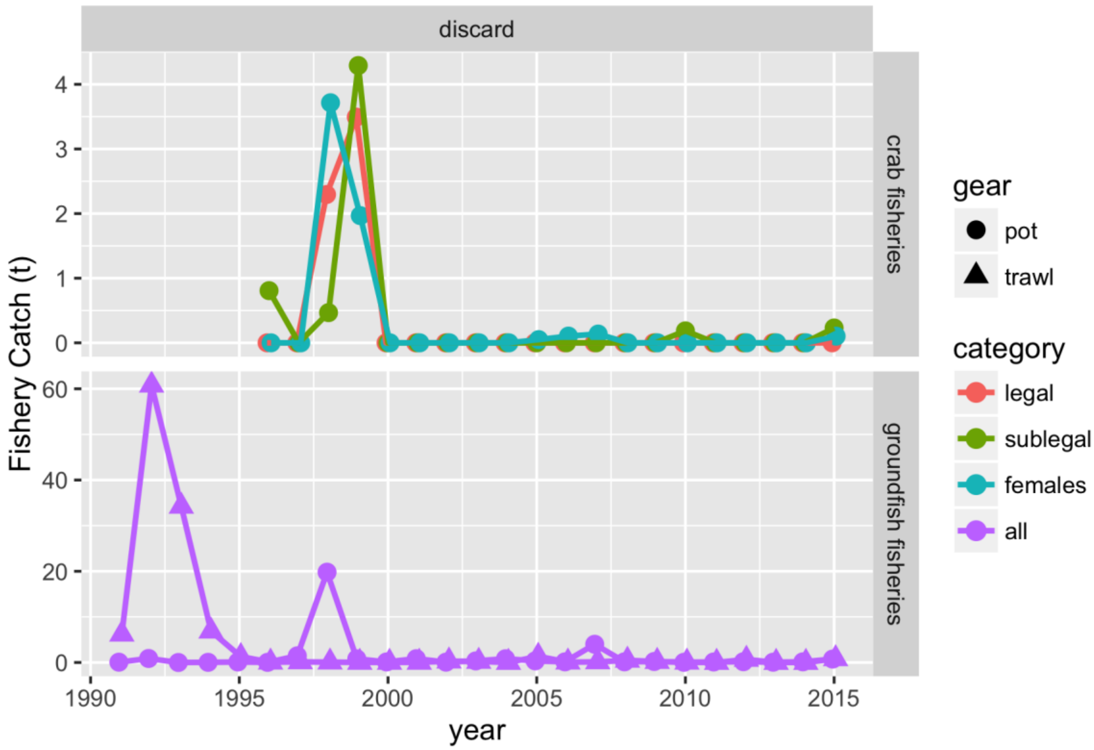


Figure 3. Time series of PIBKC bycatch in the crab and groundfish fisheries.

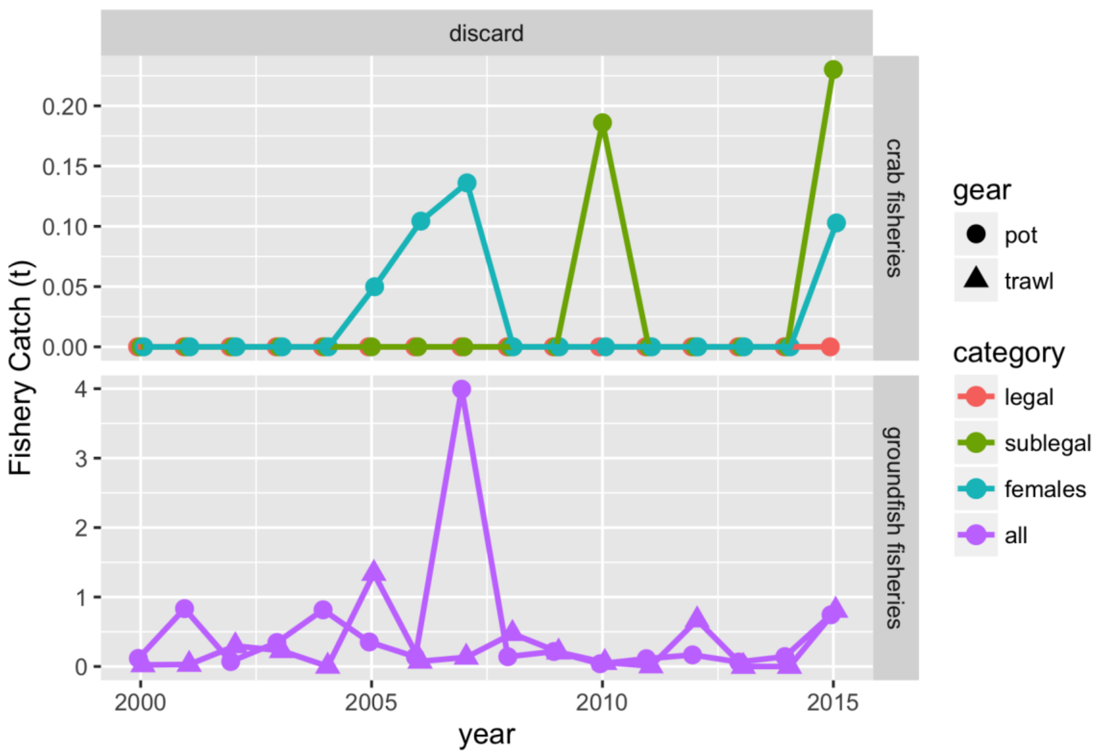


Figure 4. Time series of PIBKC bycatch in the crab and groundfish fisheries (recent time period).

The following figures illustrate the time series of PIBKC survey biomass in the NMFS EBS bottom trawl survey:

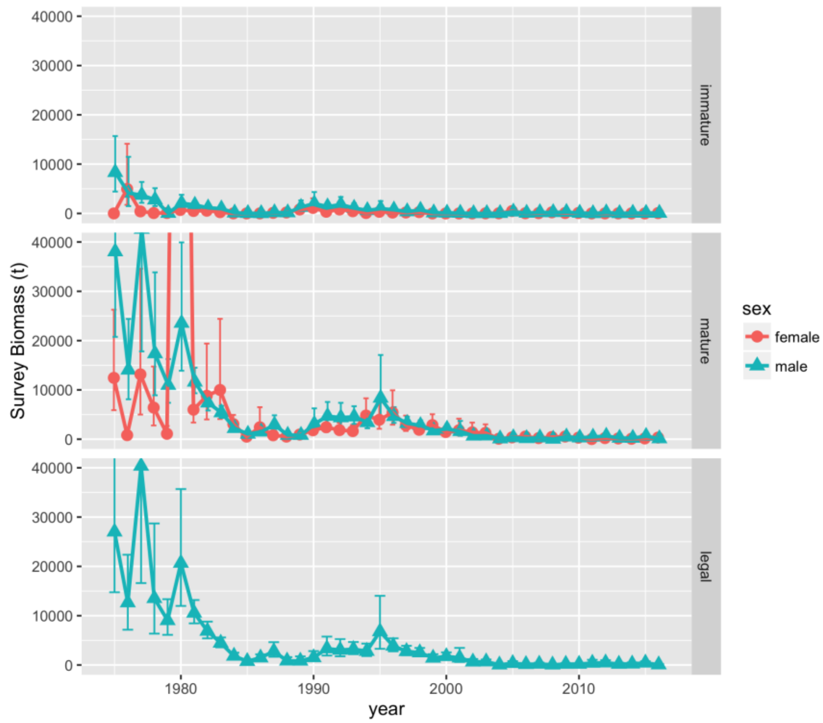


Figure 5. Time series of NMFS EBS bottom trawl survey biomass for PIKC. Confidence intervals shown are 80 CI's, assuming lognormal error distributions.

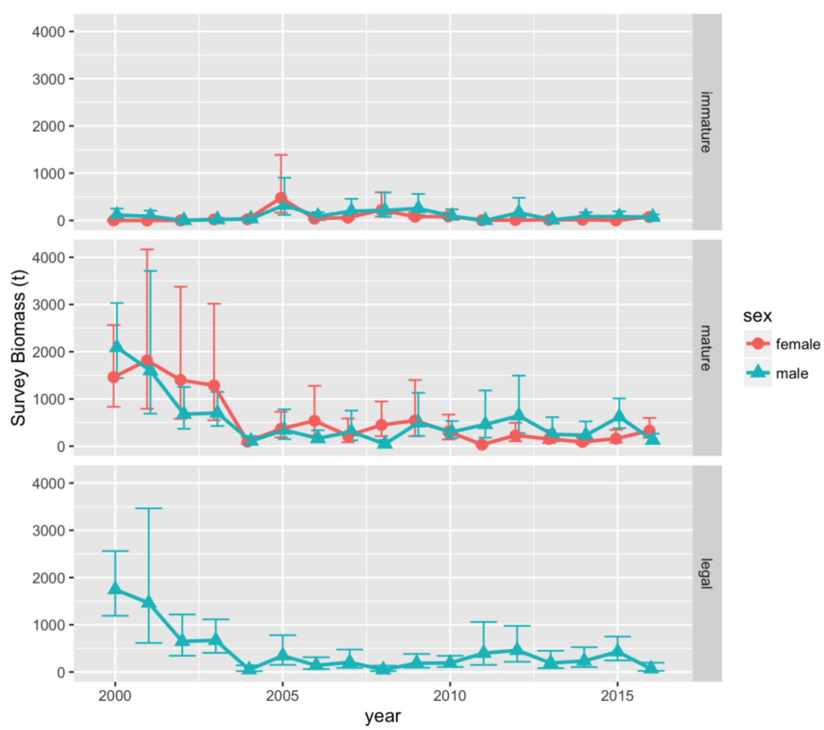


Figure 6. Time series of NMFS EBS bottom trawl survey biomass for PIKC (recent time period). Confidence intervals shown are 80 CI's, assuming lognormal error distributions.

Figure 7. Log10-scale time series of NMFS EBS bottom trawl survey biomass for PIKC. Confidence intervals shown are 80 CI's, assuming lognormal error distributions.

Survey smoothing

For PIBKC, the variances associated with annual survey estimates of MMB are so large that, prior to estimating B_{MSY} and "current" MMB-at-mating, the survey MMB time series is first smoothed to reduce overall variability. Starting with the 2015 assessment (Stockhausen, 2015), a random effects (RE) model based on code developed by Jim Ianelli (NOAA/NMFS/AFSC) has been used to perform the smoothing. This is a statistical approach which models annual log-scale changes in "true" survey MMB as a random walk process using

$$< ln(MMB_s) >_y = < ln(MMB_s) >_{y-1} + \epsilon_y, \text{where } \epsilon_y \sim N(0, \phi^2)$$

as the state equation and

$$ln(MMB_{s_y}) = < ln(MMB_s) >_y + \eta_y, \text{where } \eta_y \sim N(0, \sigma_{s_y}^2)$$

as the observation equation, where $< ln(MMB_s) >_y$ is the estimated "true" log-scale survey MMB in year y, ϵ_y represents normally-distributed process error in year y with standard deviation ϕ, MMB_{s_y} is the observed survey MMB in year y, η_y represents normally-distributed ln-scale observation error, and σ_{s_y} is the log-scale survey MMB standard deviation in year y. The MMB_s's and σ_s's are observed quantities, the $< ln(MMB_s) >$'s and ϕ are estimated parameters, and the ϵ's are random effects (essentially nuisance parameters) that are integrated out in the solution.

Parameter estimates are obtained by minimizing the objective function

$$\Lambda = \sum y[\, ln(2\pi\phi) + (\frac{< ln(MMB_s) >_y - < ln(MMB_s) >_{y-1}}{\phi})^2] + \sum y(\frac{ln(MMB_{s_y}) - < ln(MMB_s) >_y}{\sigma_{s_y}})^2$$

The model is coded in C++ and uses AD Model Builder (Fournier et al., 2012) to minimize the objective function.

Smoothing results

For comparison, the raw and RE-smoothed survey MMB time series are shown in Figures 8-10, on both arithmetic and natural log scales:

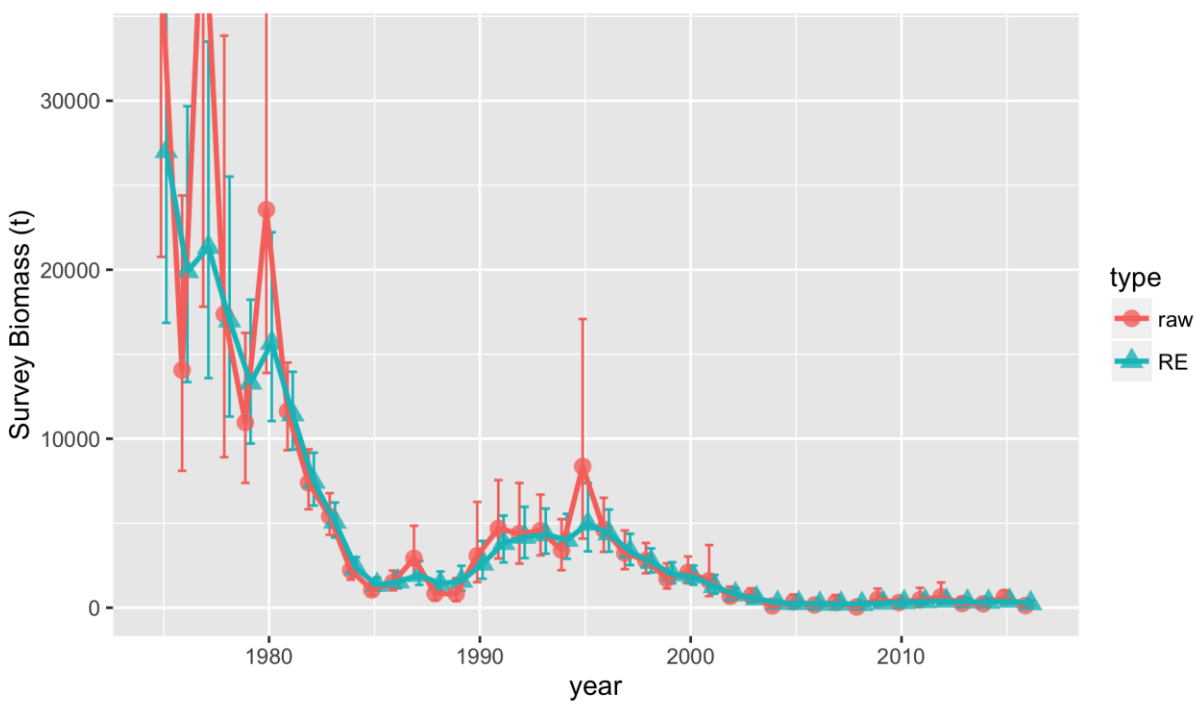


Figure. 8. Arithmetic-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormal error distributions.

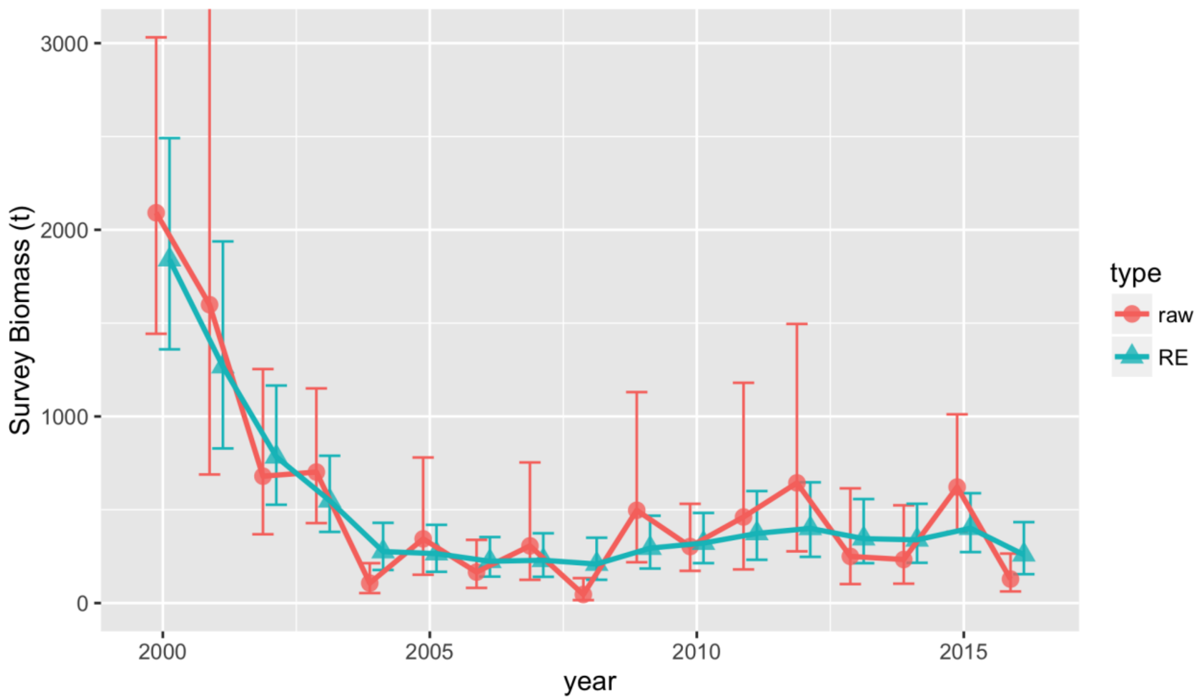


Figure. 9. Arithmetic-scale raw and smoothed survey MMB time series, since 2000. Confidence intervals shown are 80% CIs, assuming lognormal error distributions.

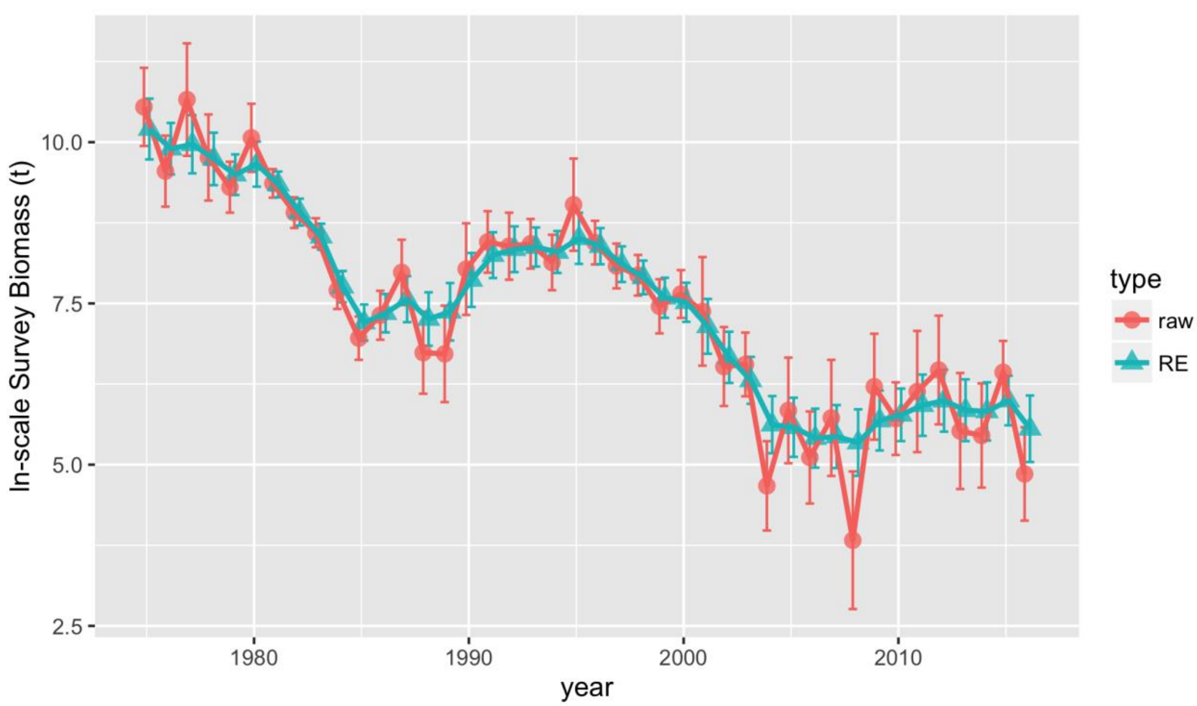


Fig. 10. Log-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormal error distributions.

Status determination

Overfishing status

For PIBKC, the total fishing mortality in 2015/16 was 1.1848941 t while the OFL was 1.16 t. Thus, overfishing occurred in 2015/16.

Overfished status

As discussed previously, overfished status is determined by the ratio $B/B_{MSY_{proxy}}$: the stock is overfished if the ratio is less than 0.5, where B is taken as "current" MMB-at-mating. For PIBKC, $B_{MSY_{proxy}}$ is obtained by averaging estimated MMB-at-mating over the period [1980/81-1984/85,1990/91-1997/98]. Following recommendations made by the CPT and SSC in 2015 (CPT, 2015; SSC, 2015), B and $B_{MSY_{proxy}}$ are based on MMB-at-mating calculated using the RE-smoothed time series of survey biomass projected forward to mating time.

MMB-at-mating

For comparison, time series for MMB-at-mating using both the raw (unsmoothed) survey MMB time series and the RE-smoothed survey MMB time series were calculated. The results are shown below in Figures 11 and 12:

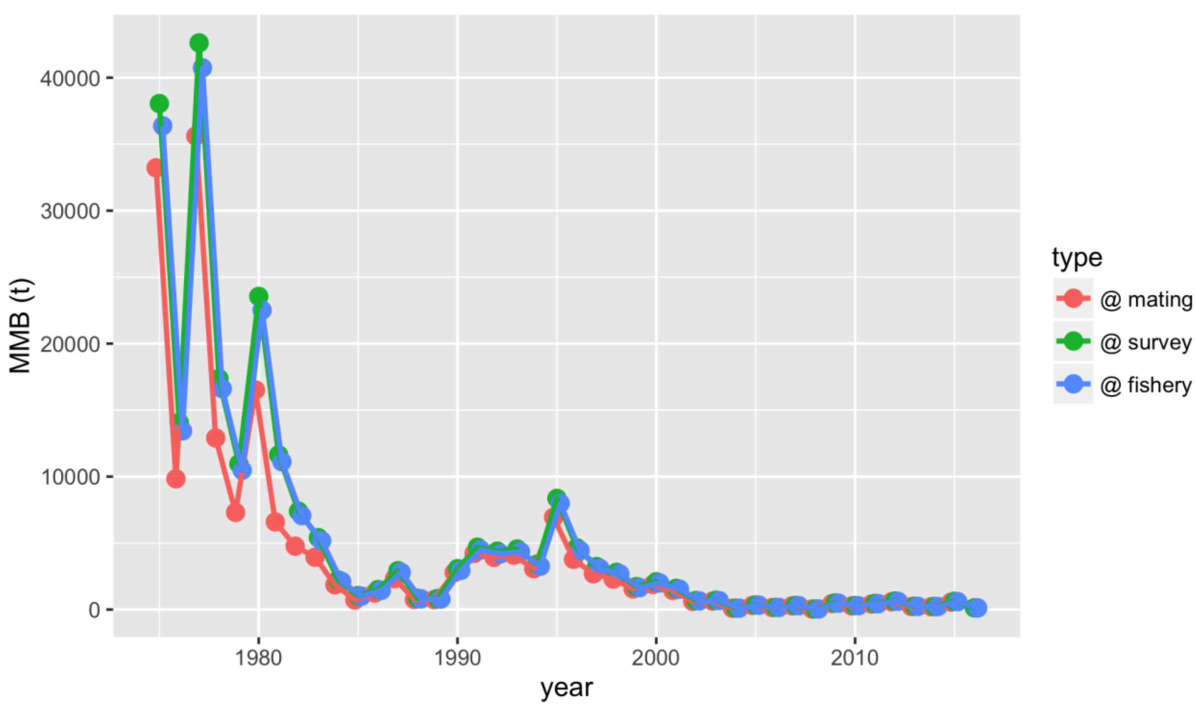


Fig. 11. Estimated time series for MMB at the time of the survey (no smoothing), at the time of the fishery, and at the time of mating.

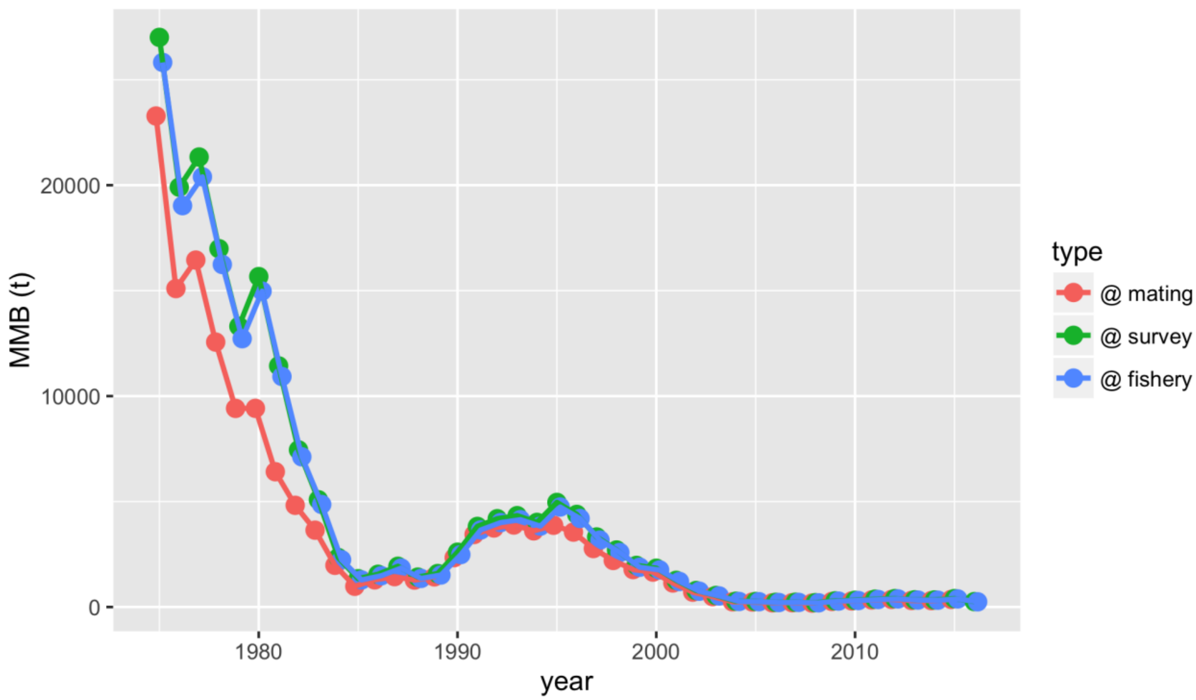


Fig. 12. Estimated time series for MMB using the RE method at the time of the survey (the random effects time series), at the time of the fishery, and at the time of mating.

Values for $B_{MSY_{proxy}}$ and the estimated current (2016) MMB *at the time of the survey* from the raw survey data and the RE-smoothed results are:

Estimation Type	Current survey MMB (t)	$B_{MSY_{proxy}}$ (t)
raw data	128.5542681	5012.1154242
RE-smoothed	259.016	4116.1607184

The value above for $B_{MSY_{proxy}}$ using the raw data is shown for illustration only. As noted previously, $B_{MSY_{proxy}}$ for this assessment is based on averaging the MMB-at-mating calculated from the RE-smoothed survey MMB (i.e., 4116.1607184 t).

Values for θ, used in the projected MMB calculations, based on averaging over the last three years, are:

Estimation Type	θ
raw data	3.6101753×10^{-4}
RE-smoothed	4.954664×10^{-4}

Results from the calculations for B ("current" MMB), overfished status, and an illustrative Tier 4-based OFL for 2016/17 (not used for PIBKC) are:

quantity	units	raw data	RE-smoothed
B ("current" MMB)	t	115.6987757	233.0829145
B_{MSY}	t	5012.1154242	4116.1607184
stock status	–	overfished	overfished
F_{OFL}	$year^{-1}$	0	0
RM_{OFL}	t	0	0
DM_{OFL}	t	0.0887363	0.2453734
OFL	t	0.0887363	0.2453734

Because B/B_{MSY} using RE-smoothed MMB-at-mating from the table above is 0.0566 < 0.5, the stock is overfished.

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SSC. 2015. SCIENTIFIC AND STATISTICAL COMMITTEE to the NORTH PACIFIC FISHERY MANAGEMENT COUNCIL. October 5th – 7th, 2015. 33 pp. http://npfmc.legistar.com/gateway.aspx?M=F&ID=acaba646-c746-4ad5-acb4-f6d70d72b06f.pdf

Stockhausen, W. 2015. 2015 stock assessment for the Pribilof Islands blue king crab fisherereis 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 Regions 2015 Final Crab SAFE. North Pacific Fishery Management Council, 605 W. 4th Avenue, #306, Anchorage, AK 99501. p. 511-561.

Appendix B: Bycatch Estimation

W.T. Stockhausen
Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA

J. Gasper, J. Keating
Alaska Regional Office
National Marine Fisheries Service, NOAA

September 1, 2016

Introduction

For the Pribilof Islands blue king crab (PIBKC) stock, because the directed fishery is closed, estimated bycatch mortality of incidentally-taken blue king crab in the groundfish and (other) crab fisheries is the only source of fishery-related mortality included in the assessment. This Appendix outlines how observer data on incidentally-taken (bycatch) PIBKC in the groundfish and crab fisheries is used to estimate total bycatch of PIBKC in these fisheries for determining whether or not overfishing has occurred.

Bycatch Estimation in the Groundfish Fisheries

Data collected by at-sea observers are used to estimate total bycatch of blue king crab in the groundfish fisheries in the Pribilof Islands blue king crab (PIBKC) stock area; total bycatch estimates (weight and numbers) are provided by the Alaska Fisheries Information Network (AKFIN). In the 2015/16 crab year, all bycatch of blue king crab in the PIBCK stock area occurred on vessels that used either trawl or longline gear; these vessels had at least one groundfish fishery observer onboard (many vessels had two observers onboard), with the result that all trawl haul and longline sets were sampled by observers. Vessels fishing pot gear were only partially observed (i.e., not all trips had observers on board); however, very little pot effort occurred in the stock area. A brief description of the estimation methods follows, and readers are directed to Cahalan et al. (2010 and 2014) for more detail on estimation. In addition, detailed descriptions of the observer sampling methods can be found in the Observer Sampling Manual, prepared each year by AFSC (http://www.afsc.noaa.gov/FMA/default.htm).

AKFIN estimation methods for BSAI crab incidentally caught in the groundfish fisheries are a modification of the estimation methods used in the Alaska Region's Catch Accounting System (CAS). CAS was designed for the management of groundfish and Prohibited Species Catch (PSC) by the NMFS Alaska Region. It provides estimates of crab bycatch by federal reporting area and Groundfish Fishery Management Plan (FMP) area as numbers of crab, which is how crab PSC is managed. The AKFIN methods modify how observer data are aggregated across space and also provide estimates in weight, as well as in numbers. Most importantly, the AKFIN method restricts estimates of crab bycatch to their respective stock area as defined in each crab stock assessment.

The sampling design on trawl vessels follows a hierarchical random sampling scheme. Observers randomly sample hauls within a trip. Within each haul, a random sample of catch is taken. Generally, observers will sample all hauls on a trip, and the amount of catch sampled depends on the size of the haul and species diversity in the haul. All catch on trawl vessels fishing in the PIBKC stock area is weighed on motion-compensated flow scales, and observers divert catch from the flow scale to take species composition. The species-specific weight is expanded by the sampling fraction to estimate the total catch of that species. In some situations, crab cannot be identified beyond the genus level (e.g., carapace is crushed); in these situations, unidentified crab are speciated using identified species from sampled hauls within a federal reporting area.

Catch estimation on hook-and-line vessels also uses a hierarchical sampling design. Observers select multiple random subsets of hooks from all hooks fished on a set. Within each sampled set of hooks, observers record the species and disposition for each hook sampled. This tally of fish is expanded by the sampling fraction (the fraction of total hooks sampled) to estimate the total number of fish caught. Observers collect species-specific weight data from a random subset of hooks. An average weight per crab (by species) is applied to the total estimated number of crab (by species) per set to obtain the total estimated weight of crab on a set. Unsampled sets are factored in by calculating an average discard ratio (discarded crab divided by total groundfish and halibut) for observed hauls on a trip (based on week for catcher-processor vessels) and within the stock area. Total catch is then obtained as the product of the ratio estimator and the total groundfish weight by ADFG area for a trip.

Blue king crab bycatch in the groundfish fishery is estimated by ADFG statistical areas within the Pribilof island stock area. Haul-specific information is assigned to an ADFG statistical area based on its retrieval location. Total groundfish and halibut catch is assigned to ADFG statistical areas based on haul retrieval locations for catcher-processors and as reported on ADFG fish tickets for catcher vessels. The ADFG statistical area is the smallest spatial scale that is estimated since this is finest resolution that landed catch is reported on trips.

In 2015/16, nearly all catch in the hook-and-line fishery occurred on trips with onboard observers, thus expansion to unsampled trips was unnecessary. The total estimated PIBKC bycatch by the groundfish fishery was simply the sum of the estimated incidental catch on observed trips for all ADFG areas within the stock area. Unfortunately, the stock area boundaries do not follow ADFG area boundaries on the eastern and northern sides of the stock area. This may result in a small underestimate of catch on the northern boundary, and an overestimate of catch on the eastern boundary for trawl. However, the extent of this uncertainty is unknown since trawl vessels regularly bisect the boundary when making tows, complicating estimation in a way that does not occur for hook-and-line (since that effort generally occurs entirely within the PIBKC boundary).

Figures 1 and 2 show the spatial distribution of blue king crab incidentally caught in the groundfish non-pelagic trawl fisheries by ADFG statistical area for the 2015/16 crab year and the average bycatch for the five-year period 2010/11-2014/15. Also shown is the corresponding groundfish catch. Note that fishing with non-pelagic trawl gear is not allowed with the Pribilof Islands Habitat Conservation Area. In 2015/16, most PIBKC bycatch in the trawl fisheries occurred in the northeast corner of the Pribilof blue king crab stock boundary (i.e., the Pribilof Island District), as did most groundfish catch (Figure 1). This was a much different spatial pattern than occurred during 2010/11-2014/15, when most PIBKC bycatch occurred to the northwest of St. Paul and none occurred in the northeast corner of the Pribilof Island District (Figure 2).

Figures 3 and 4 show the spatial distribution of blue king crab incidentally caught in the groundfish hook-and-line fisheries by ADFG statistical area for the 2015/16 crab year and the average bycatch for the five-year period 2010/11-2014/15. Also shown is the corresponding groundfish catch. In contrast to trawl gear, fishing with hook-and-line gear is allowed with the Pribilof Islands Habitat Conservation Area. Most PIBKC bycatch in the hook-and-line fisheries in 2015/16 occurred in the statistical area centered on St. Paul Island and eastward, as well as north of St. George Island, whereas the majority of groundfish catch in the hook-and-line fisheries occurred more to the south of St. Paul and west and south of St. George (Figure 3). These patterns are broadly consistent with the 5-year average spatial patterns (Figure 4), although the color scales are fairly coarse and may somewhat obscure finer-scale variation.

Bycatch Estimation in the Crab Fisheries

Beginning in 1988, ADFG has required varying levels of observer coverage aboard vessels participating in crab fisheries in the Bering Sea and Aleutian Islands for fishery management and data-gathering needs

(Gaeuman, 2014). Regulations (5 AAC 39.645) require deployment of observers on all vessels that process snow crab *Chionoecetes opilio*, Tanner crab *C. bairdi*, grooved Tanner crab *C. tanneri*, triangle Tanner crab *C. angulatus*, red king crab *Paralithodes camtschaticus*, blue king crab *P. platypus* or golden king crab *Lithodes aequispinus*. Those regulations additionally charge ADFG with deploying observers as needed on catcher vessels participating in commercial BSAI king and Tanner crab fisheries, excluding those of Norton Sound and St. Lawrence Island Sections.

Per Gaeuman (2014):

> ADFG observers deployed on fishing vessels in the BSAI crab fisheries record the gear type, location, depth and soak time of a daily random sample of pot lifts, the species composition of their contents, and the sex and legal status of commercially important captured crabs. For a subset of sampled pot lifts, a range of biological measurements and assessments of commercially important crabs and other species of interest is also obtained. In addition, ADFG onboard observers and dockside samplers document overall vessel catch and effort, take size-frequency samples, conduct legal tallies and estimate the average weight of delivered catch. ADFG Westward Region staff maintain the information collected by observers and dockside samplers in a database that is used in research and management of Alaska's BSAI crab stocks.

Observers are deployed on three types of vessels: floating-processor vessels, catcher-processor vessels, and catcher vessels (Gaeuman, 2014). Duties vary somewhat depending on vessel type. Observers deployed on floating-processor vessels primarily monitor deliveries from catcher vessels. Sampling duties during each delivery include obtaining a size-frequency sample, conducting a legal tally and determining average weight of retained crabs. For observers deployed on catch-processor vessels, sampling duties include pot lift sampling, size-frequency sampling, legal-tally sampling and determination of average weight of retained crab for each day the vessel retained catch. Occasionally, catcher vessels delivered to a catcher-processor vessel. In those situations, the observer samples the catcher-vessel catch as if deployed on a floating processor. On rare occasions, a catcher-processor vessel will deliver to a shore side processor, in which case the observer assumes the responsibilities of an observer deployed on a catcher vessel. Observers deployed on catcher vessels are tasked with pot lift sampling on each day a vessel fishes. When the vessel delivers to a processing facility, whether at sea or on shore, the observer obtains a size-frequency sample, conducts a legal tally and determines average weight of retained crab. If deliveries are made at sea to a floating-processor vessel, all sampling is completed by the observer deployed on the catcher vessel. Observers are assigned to all participating catcher-processor vessels and by simple random sampling to a subset of all participating catcher vessels. Sampled pot lifts are selected by simple random sampling from all pot lifts on each vessel fishing day, independently across days.

For this assessment, estimation of PIBKC bycatch in the other crab fisheries by ADFG was based on a simple expansion of incidentally-taken PIBKC in "observed" pots enumerated, sexed and sized by ADFG observers onboard catcher vessels (pers. comm., J. Webb, ADFG). Total bycatch biomass is estimated by: 1) estimating CPUE by bycatch class (female , sublegal male, legal non-retained male) per observer sampled potlift for each directed crab fishery in which bycatch is observed; then 2) expanding CPUE to total bycatch (numbers) by total directed fishery effort. 3) The weighted mean size of crab in each bycatch class in each directed fishery is estimated from the size-frequency distribution and converted to mean weight using the NMFS published weight-length relationship; then 4) total bycatch in numbers is converted to biomass by bycatch class in each directed fishery using average crab weight. Finally, 5) the sum of the biomasses by bycatch class in each directed fishery, converted to metric tons, is the overall estimate of annual bycatch biomass for the species.

For PIBKC, the size-weight regressions developed from the NMFS EBS bottom trawl survey (Foy et al., 2016) were used to convert measured size to weight in grams using $w_{x,z} = a \cdot z^{b}$:

sex	a	b

males	0.000508	3.106409
females	0.02065	2.27

For 2015/16, numbers/weights of observed PIBKC bycatch were expanded to estimated total bycatch numbers/weight using:

Fishery	Sampled Pots	Total Effort (Pot lifts)	% Pots Observed	Expansion Factor
EBS snow	1,857	201,650	0.921	108.589
Tanner-West	898	85,244	1.053	94.927

where $\left(\frac{N_f^T}{N_f^O}\right)$ is the expansion factor (and % observed pots is the inverse, multiplied by 100).

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Figures

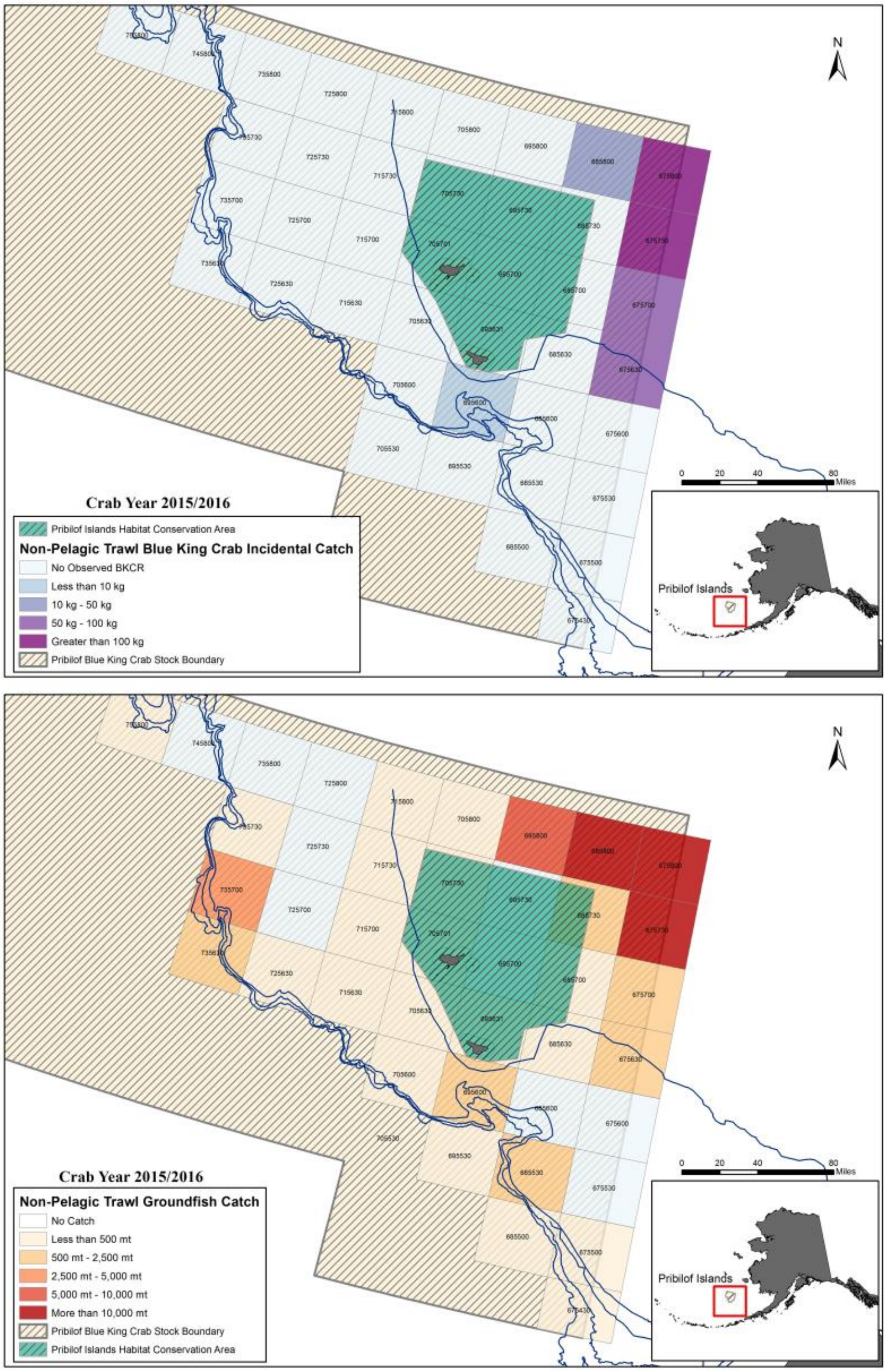

Figure 1. Spatial distribution of estimated total PIBKC bycatch (upper) and groundfish catch using non-pelagic trawl gear in the 2015/16 BSAI groundfish fisheries, by ADFG stat area. Squares denote ADFG stat (1^{o} long. x 0.5^{o} lat.) areas, the yellow hatched area denotes the PIBKC stock boundary, and the hatched green area represents the Pribilof Islands Habitat Conservation Area closed to non-pelagic trawl gear.

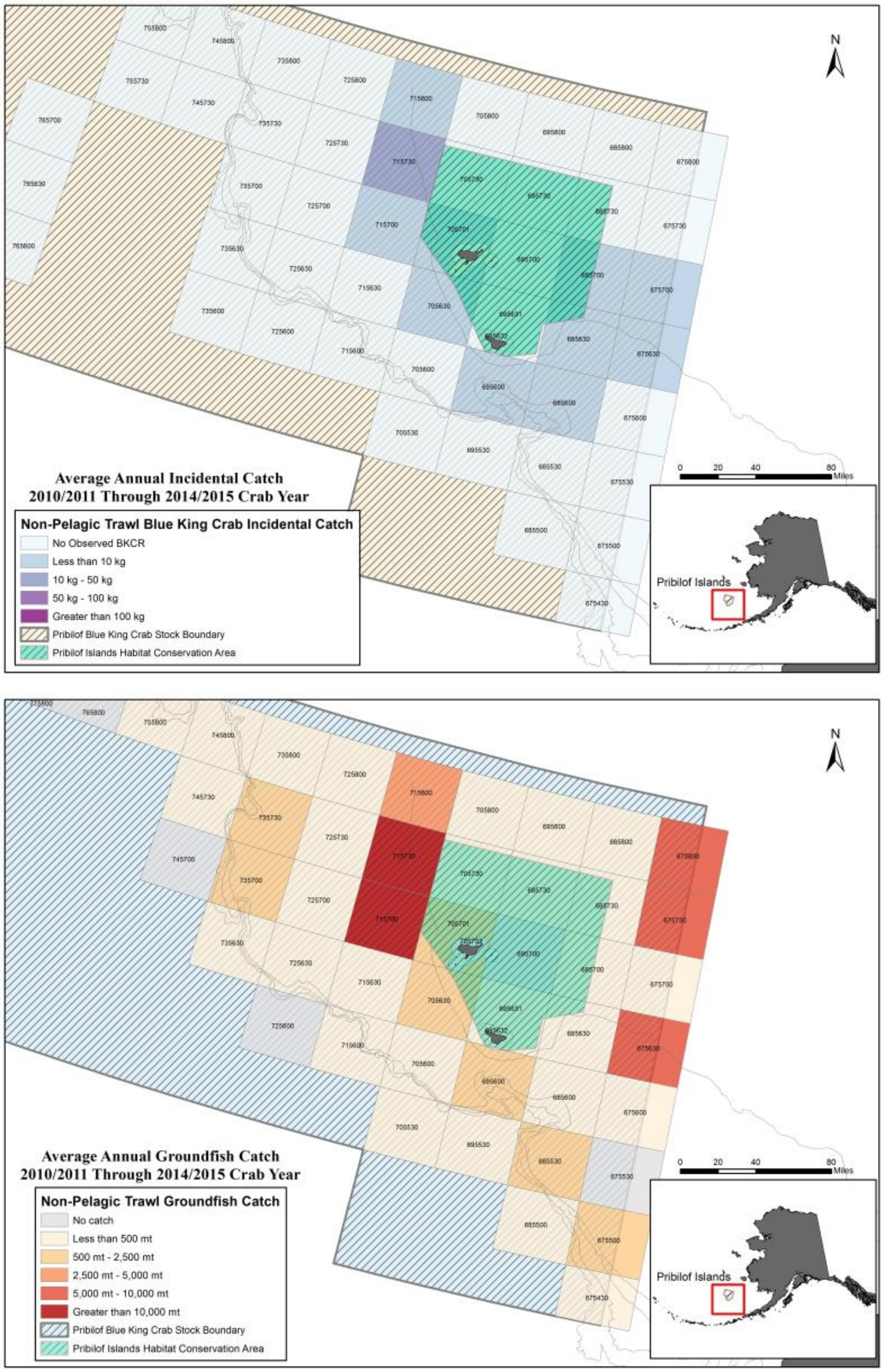

Figure 2. Average spatial distribution of estimated total PIBKC bycatch (upper) and groundfish catch using non-pelagic trawl gear in the 2010/11-2014/15 BSAI groundfish fisheries, by ADFG stat area. Squares denote ADFG stat (1º long. x 0.5º lat.) areas, the yellow hatched area denotes the PIBKC stock boundary, and the hatched green area represents the Pribilof Islands Habitat Conservation Area closed to non-pelagic trawl gear.

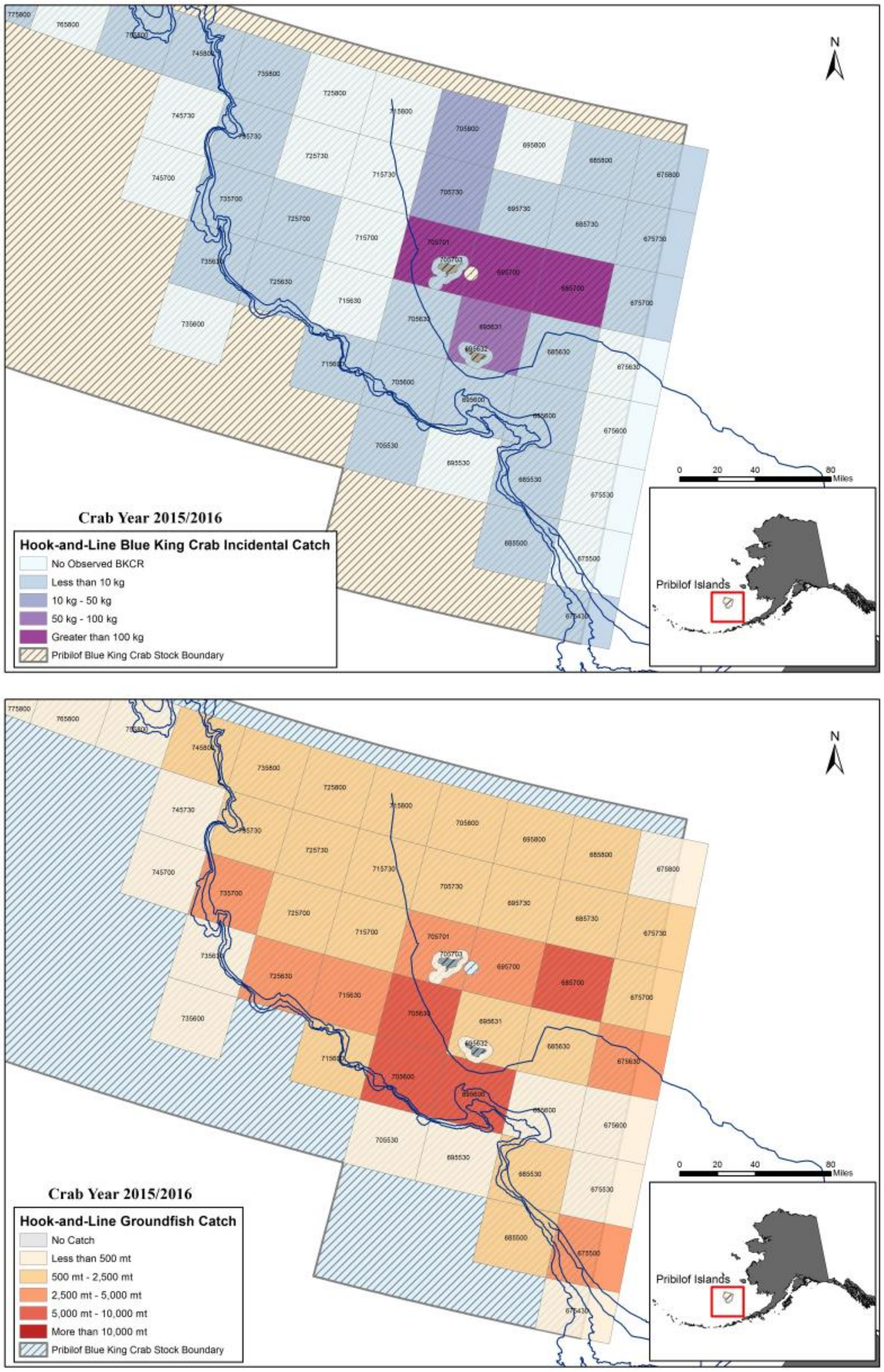

Figure 3. Spatial distribution of estimated total PIBKC bycatch (upper) and groundfish catch using hook-and-line trawl gear in the 2015/16 BSAI groundfish fisheries, by ADFG stat area. Squares denote ADFG stat areas (1° long. x 0.5° lat.); the yellow hatched area denotes the PIBKC stock boundary.

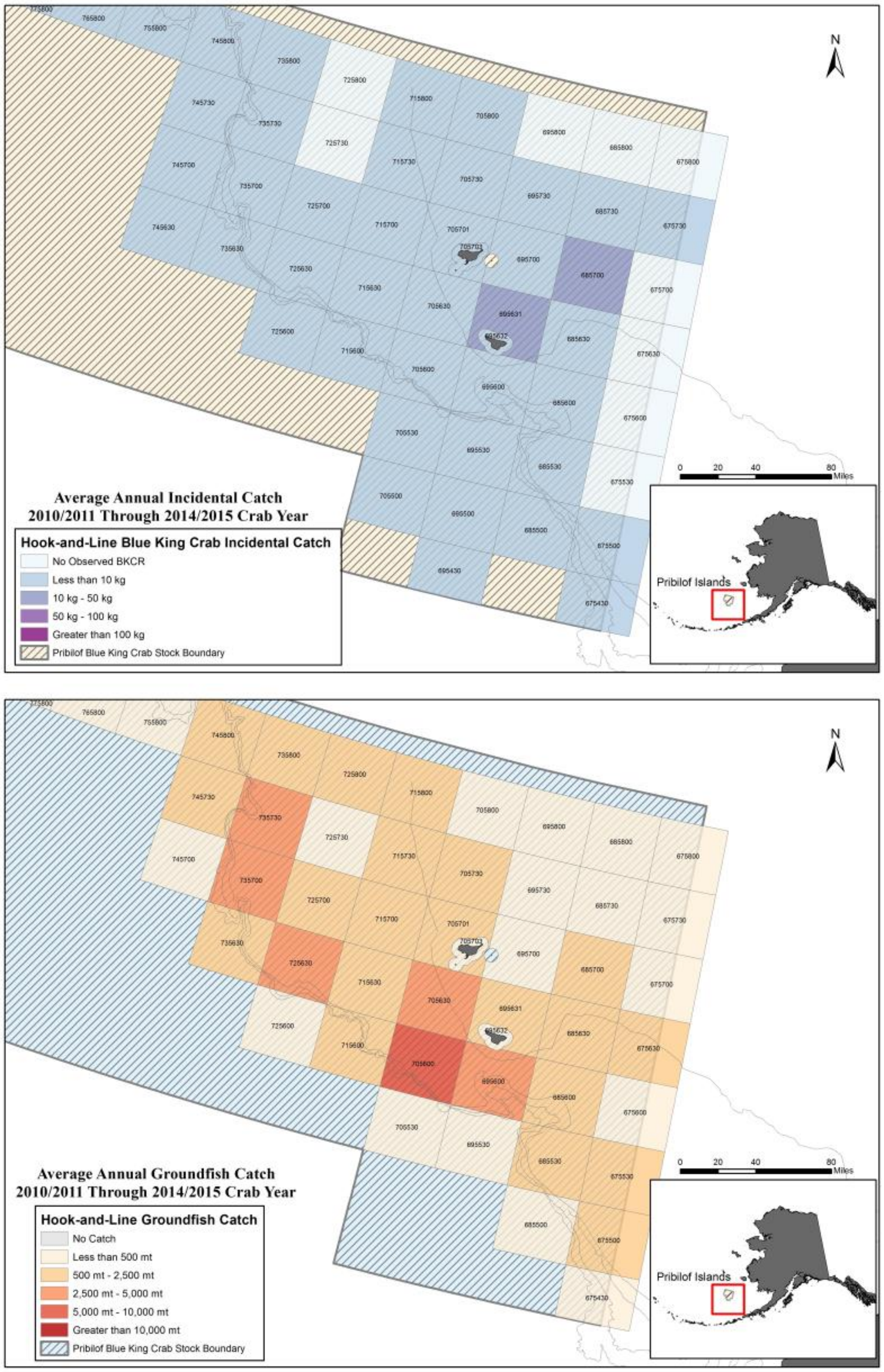

Figure 4. Average spatial distribution of estimated total PIBKC bycatch (upper) and groundfish catch using hook-and-line trawl gear in the 2010/11-2014/15 BSAI groundfish fisheries, by ADFG stat area. Squares denote ADFG stat areas (1º long. x 0.5º lat.); the yellow hatched area denotes the PIBKC stock boundary.

Saint Matthew Island Blue King Crab Stock Assessment 2016

D'Arcy Webber[1], Jie Zheng[2], and James Ianelli[3]
[1]Quantifish, darcy@quantifish.co.nz
[2]Alaska Department of Fish and Game, jie.zheng@alaska.gov
[3]NOAA, jim.ianelli@noaa.gov

September 2016

Executive Summary

1. **Stock**: Blue king crab, *Paralithodes platypus*, Saint Matthew Island (SMBKC), Alaska.
2. **Catches**: Peak historical harvest was 4288 tonnes (9.454 million pounds) in 1983/84[1]. The fishery was closed for 10 years after the stock was declared overfished in 1999. Fishing resumed in 2009/10 with a fishery-reported retained catch of 209 tonnes (0.461 million pounds), less than half the 529.3 tonne (1.167 million pound) TAC. Following three more years of modest harvests supported by a fishery catch per unit effort (CPUE) of around 10 crab per pot lift, the fishery was again closed in 2013/14 due to declining trawl-survey estimates of abundance and concerns about the health of the stock. The directed fishery resumed again in 2014/15 with a TAC of 300 tonnes (0.655 million pounds), but the fishery performance was relatively poor with a retained catch of 140 tonnes (0.309 million pounds). The retained catch in 2015/16 was even lower at 48 tonnes (0.105 million pounds).
3. **Stock biomass**: Following a period of low numbers (below 30% of the 1978-2016 mean of 5,865 tonnes) after the stock was declared overfished in 1999, trawl-survey indices of SMBKC stock abundance and biomass generally increased to well above average from 2007-2012. In 2013 the survey biomass estimate was low (~40% of the mean value) but was followed by average biomass estimates in 2014 and 2015 (with sampling CVs of 77% and 45%, respectively). The 2016 survey biomass estimate was 3,500 tonnes (7.7 million lbs with a CV of 39%). This value represents about 60% of the long term mean with the most recent 3-year average surveys at 87% of the mean value. This suggests a general decline in biomass compared to the recent peak survey estimate of nearly twice the average. The assessment model estimates dampen the interannual variability observed in the survey biomass and suggest that the stock (in survey biomass units) is presently at about 45% of the long term model-predicted survey biomass average. The trend from these values suggest a slight decline.
4. **Recruitment**: Because little information about the abundance of small crab is available for this stock, recruitment has been assessed in terms of the number of male crab within the 90-104 mm carapace length (CL) size class in each year. The 2013 trawl-survey area-swept estimate of 0.335 million male SMBKC in this size class marked a three-year decline and was the lowest since 2005. That decline did not continue as the 2014 survey estimate was 0.723 million. Survey recruitment was 0.992 million in 2015, but the majority of this survey estimate is from one tow with a great deal of uncertainty. In 2016, survey recruitment declined to 0.535 million.
5. **Management performance**: In recent assessments, estimated total male catch has been determined as the sum of fishery-reported retained catch, estimated male discard mortality in the directed fishery, and estimated male bycatch mortality in the groundfish fisheries, as these have been the only sources of non-negligible fishing mortality to consider. The stock was above the minimum stock-size threshold (MSST) in 2015/16 and is hence not overfished. Overfishing did not occur in 2015/16 (Tables 1 and 2).

[1]1983/84 refers to a fishing year that extends from 1 July 1983 to 30 June 1984.

Table 1: Status and catch specifications (1000 tonnes) (scenario **Gmacs base**). Notes: A - calculated from the assessment reviewed by the Crab Plan Team in September 2013, B - calculated from the assessment reviewed by the Crab Plan Team in September 2014, C - calculated from the assessment reviewed by the Crab Plan Team in September 2015, D - calculated from the assessment reviewed by the Crab Plan Team in September 2016.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained catch	Total male catch	OFL	ABC
2012/13	1.80^A	2.85^A	0.74	0.73	0.82	1.02	0.92
2013/14	1.50^B	3.01^B	0.00	0.00	0.00	0.56	0.45
2014/15	1.86^C	2.48^C	0.30	0.14	0.15	0.43	0.34
2015/16	1.84^D	2.11^D	0.19	0.05	0.05	0.28	0.22
2016/17		2.23^D				0.14	0.11

Table 2: Status and catch specifications (million pounds) (scenario **Gmacs base**).

Year	MSST	Biomass (MMB_{mating})	TAC	Retained catch	Total male catch	OFL	ABC
2012/13	4.0^A	6.29^A	1.630	1.616	1.81	2.24	2.02
2013/14	3.4^B	6.64^B	0.000	0.000	0.0006	1.24	0.99
2014/15	4.1^C	5.47^C	0.655	0.309	0.329	0.94	0.75
2015/16	4.0^D	4.65^D	0.41	0.105	0.105	0.62	0.49
2016/17		4.91^D				0.31	0.25

6. **Basis for the OFL**: Estimated mature-male biomass (MMB) on 15 February is used as the measure of biomass for this Tier 4 stock, with males measuring 105 mm CL or more considered mature. The B_{MSY} proxy is obtained by averaging estimated MMB over a specific reference time period, and current CPT/SSC guidance recommends using the full assessment time frame as the default reference period (Table 3).

Table 3: Basis for the OFL (1000 tonnes) (scenario **Gmacs base**).

Year	Tier	B_{MSY}	Biomass (MMB_{mating})	B/B_{MSY}	F_{OFL}	γ	Basis for B_{MSY}	Natural mortality
2012/13	4a	3.56	5.63	1.56	0.18	1	1978-2012	0.18
2013/14	4b	3.06	3.01	0.98	0.18	1	1978-2013	0.18
2014/15	4b	3.28	2.71	0.82	0.14	1	1978-2014	0.18
2015/16	4b	3.71	2.45	0.66	0.11	1	1978-2015	0.18
2016/17	4b	3.67	2.23	0.61	0.09	1	1978-2016	0.18

A. Summary of Major Changes

Changes in Management of the Fishery

There are no new changes in management of the fishery.

Changes to the Input Data

Data used in this assessment have been updated to include the most recently available fishery and survey numbers. This assessment makes use of two new survey data points including the 2016 NMFS trawl-survey estimate of abudance, and the 2016 ADF&G pot survey CPUE. Both of these surveys have associated size compositon data. The assessment also uses updated 1993-2015 groundfish and fixed gear bycatch estimates based on AKRO data. The 2015/16 directed fishery catch data and associated size composition data were also used.

Changes in Assessment Methodology

This assessment is done using Gmacs. The model is based upon the 3-stage length-based assessment model first presented in May 2011 by Bill Gaeuman and accepted by the CPT in May 2012. There are several differences between the Gmacs assessment model and the previous model. One of the major differences being that natural and fishing mortality are continuous within 5 discrete seasons (using the "correct" catch equation rather than being applied as a pulse). Season length in Gmacs is controlled by changing the proportion of natural mortality that is applied during each season. A detailed outline of the Gmacs implementation of the SMBKC model is provided in Appendix A.

Changes in Assessment Results

One of the Gmacs model scenarios (**Gmacs match**) attempts to match the 2015 assessment as closely as possible by specifying the same (or similar) dynamics and some of the same (fixed) parameter values. There are some minor differences between the 2015 model and the **Gmacs match** model, but given that Gmacs and the 2015 model have different underpinning population dynamics, these differences should be of little concern. Four other Gmacs scenarios are presented as well, each providing a slightly different fit to the data.

B. Responses to SSC and CPT Comments

CPT and SSC Comments on Assessments in General

Comment: *Regarding general code development, the CPT had the following requests:*

1. *1-year projection for calculating Tier 3 or 4 OFLs*
2. *specify catchability as a fixed or estimated parameter or use the analytic calculation for the MLE*
3. *specify priors (e.g., gamma) using mean and variance/standard deviation for all parameters to ease specifying priors*
4. *include an option to calculate dynamic* B_{MSY}
5. *add the ability to "jitter" initial parameter values*
6. *add the ability to conduct retrospective analyses*
7. *add ability to estimate bycatch fishing mortality rates when observer data are missing but effort data is available*
8. *allow different phases for "rec_ini", "rec_dev" estimation*

Response:

1. Done
2. Done
3. Not yet implemented
4. Not yet implemented
5. Not yet implemented
6. Not yet implemented
7. Not yet implemented
8. Done

Comment: *Andre Punt pointed out the need to use a fixed-iteration Newton's method to calculate OFL, not bisection, to keep the calculation differentiable so that OFL can be reported as an sdreport variable.*

Response: This has been done and the F_{OFL} and OFL have both been reported as an sdreport variables in this document.

CPT and SSC Comments Specific to the SMBKC Stock Assessment

Comment: *the CPT requests that some evaluation should also be included in the September report to the CPT which compares against the previous assessment model corrected for the error.*

Response: The error in the 2015 was fixed and this model was run again. Comparisons between the Gmacs models and the 2015 model are presented throughout this document. One of the Gmacs model scenarios (**Gmacs match**) attempts to match the 2015 assessment as closely as possible by specifying the same (or similar) dynamics and some of the same (fixed) parameter values.

Comment: *The SSC and CPT requested the following models for review at the spring 2016 meeting:*

1. *Base: try to match 2015 model but prevent dome shaped selectivity*
2. *Base + add CV for both surveys*
3. *Above + Francis re-weighting*
4. *Above + remove M spike*

Response: Models 1, 3, and 4 are all included and evaluated in this document as the **Gmacs base**, **Gmacs Francis**, and **Gmacs M** scenarios. Model 2 was not included in this document for two reasons. Firstly, if doing Francis iterative re-weighting then additional CV should not be added as well (as the two methods basically do the same thing). Secondly, the SSC recommended against the model runs with additional CV (see the comment from the SSC below).

Comment: *The SSC is not convinced that the model runs with extra CV are very informative. The inclusion of extra CV seems to be rather arbitrary based on the numbers of points that fall within confidence intervals estimated from trawl surveys. The SSC recommends coming up with some alternative way to consider extra variability, which could be informed by simulation testing.*

Response: All model runs that estimate additional CV were dropped from this document. Instead we provide two model runs that use the Francis iterative re-weighting method to re-weight the length-frequency data relative to the abundance indices. These runs are the **Gmacs Francis**, and **Gmacs force** scenarios. The final Gmacs scenario (**Gmacs force**) is an exploratory model run that upweights both the trawl-survey and pot survey abundance indices (it upweights the pot survey more than the trawl survey).

Comment: *The descriptions of seasons in the model is confusing and currently reads as if M differs among seasons. More justification is needed on how seasons are defined and how they were selected, as well as clarification on M during these seasons.*

Response: This description has been updated and justification provided in Appendix A.

Comment: *During the presentation to the SSC, uncertainty was expressed about the origins of the growth transition matrix, but page 7 of the report indicates that the matrix was derived by Otto and Cummiskey (1990). As this matrix is critical to the model, the origin and integrity of the growth transition matrix should be carefully explained in the assessment for fall 2016. In some other models, the transition matrix can be estimated. If there are doubts about the veracity of the transition matrix, perhaps this can be explored in the modeling framework.*

Response: The report is correct, the growth matrix was derived by Otto and Cummiskey (1990) and used in this assessment.

Comment: *The selectivities were constrained so that they do not exceed 1.0, but the tables of log-transformed parameter estimates do not indicate that this upper bound was approached. This should be clarified.*

Response: After fixing the error in the 2015 SMBKC model code, it was found that the NMFS trawl survey selectivity does exceed 1 for stage-2 crab. The **Gmacs match** scenario does allow selectivity to be greater than 1 (it uses the same fixed selectvity values as the 2015 model). At the request of the CPT an upper bound of 1 was specified for the remaining Gmacs scenarios. Tables 14, 15, 16, and 17 all show that this upper bound was approached for at least one selectivity parameter in all of these scenarios.

Comment: *It would be helpful to include a table of NMFS trawl survey CPUE by crab stage, just as was provided for the ADF&G pot survey (Table 1).*

Response: This table has been added.

Comment: *Page 10 refers to a table of observed and estimated sample size, but no such table was provided.*

Response: This table has been added.

Comment: *As with the 2015 model, GMACS consistently overestimates trawl survey estimates of male biomass in the last decade, whereas GMACS tends to underestimate the last couple of pot survey estimates (Figure 9, 12). This is also reflected in patterns in residuals, and the proportions of stage-3 crab tend to be overestimated in recent years (Figure 14). These patterns should be discussed in the assessment.*

Response: Done.

Comment: *The SSC discussed the possibility that these patterns could be indicative of spatial patterns in stock distribution. The trawl survey covers a much larger geographic distribution than the pot survey (Figure 4). Crab distribution may vary with sex (females tend to be found close to shore) and life stage. Thus, the trawl and pot surveys may sample the crab stock differentially. Moreover, the geographic distributions of these stages may vary with stock density and temperature. It could be informative to conduct some spatial analyses, which could include: (1) estimation of survey catchability as a function of temperature, (2) a stock assessment model run that includes pot surveys and only those trawl stations that fall within the pot survey distribution as a comparison the runs that include the full trawl survey data, and (3) analysis of the spatial distribution of surveyed crabs by stage at high and low biomass and during warm and cold years.*

Response: In the past Jie has tried to estimate survey catchability as a function of temperature with little success. We will try again this year, but this run will not be presented in this document.

C. Introduction

Scientific Name

The blue king crab is a lithodid crab, *Paralithodes platypus* (Brant 1850).

Distribution

Blue king crab are sporadically distributed throughout the North Pacific Ocean from Hokkaido, Japan, to southeastern Alaska (Figure 1). In the eastern Bering Sea small populations are distributed around St. Matthew Island, the Pribilof Islands, St. Lawrence Island, and Nunivak Island. Isolated populations also exist in some other cold water areas of the Gulf of Alaska (NPFMC 1998). The St. Matthew Island Section for blue king crab is within Area Q2 (Figure 2), which is the Northern District of the Bering Sea king crab registration area and includes the waters north of Cape Newenham (58°39' N. lat.) and south of Cape Romanzof (61°49' N. lat.).

Stock Structure

The Alaska Department of Fish and Game (ADF&G) Gene Conservation Laboratory division has detected regional population differences between blue king crab collected from St. Matthew Island and the Pribilof

Figure 1: Distribution of blue king crab (*Paralithodes platypus*) in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters (shown in blue).

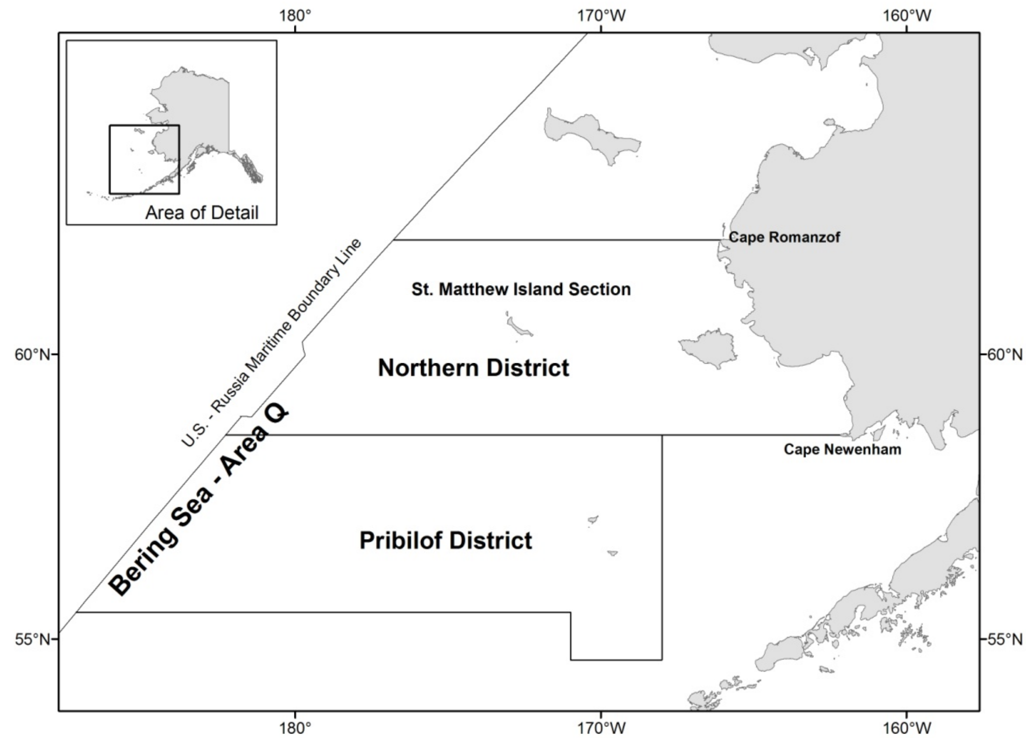

Figure 2: King crab Registration Area Q (Bering Sea).

Islands[2]. NMFS tag-return data from studies on blue king crab in the Pribilof Islands and St. Matthew Island support the idea that legal-sized males do not migrate between the two areas (Otto and Cummiskey 1990). St. Matthew Island blue king crab tend to be smaller than their Pribilof conspecifics, and the two stocks are managed separately.

Life History

Like the red king crab, *Paralithodes camtshaticus*, the blue king crab is considered a shallow water species by comparison with other lithodids such as golden king crab, *Lithodes aequispinus*, and the scarlet king crab, *Lithodes couesi* (Donaldson and Byersdorfer 2005). Adult male blue king crab are found at an average depth of 70 m (NPFMC 1998). The reproductive cycle appears to be annual for the first two reproductive cycles and biennial thereafter (cf. Jensen and Armstrong 1989) and mature crab seasonally migrate inshore where they molt and mate. Unlike red king crab, juvenile blue king crab do not form pods, but instead rely on cryptic coloration for protection from predators and require suitable habitat such as cobble and shell hash. Somerton and MacIntosh (1983) estimated SMBKC male size at sexual maturity to be 77 mm carapace length (CL). Paul et al. (1991) found that spermatophores were present in the vas deferens of 50% of the St. Matthew Island blue king crab males examined with sizes of 40-49 mm CL and in 100% of the males at least 100 mm CL. Spermataphore diameter also increased with increasing CL with an asymptote at ~ 100 mm CL. They noted, however, that although spermataphore presence indicates physiological sexual maturity, it may not be an indicator of functional sexual maturity. For purposes of management of the St. Matthew Island blue king crab fishery, the State of Alaska uses 105 mm CL to define the lower size bound of functionally mature males (Pengilly and Schmidt 1995). Otto and Cummiskey (1990) report an average growth increment of 14.1 mm CL for adult SMBKC males.

Management History

The SMBKC fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990). Ten U.S. vessels harvested 545 tonnes (1.202 million pounds) in 1977, and harvests peaked in 1983 when 164 vessels landed 4288 tonnes (9.454 million pounds) (Fitch et al. 2012; Table 4).

The fishing seasons were generally short, often lasting only a few days. The fishery was declared overfished and closed in 1999 when the stock biomass estimate was below the minimum stock-size threshold (MSST) of 4990 tonnes (11.0 million pounds) as defined by the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner crabs (NPFMC 1999). Zheng and Kruse (2002) hypothesized a high level of SMBKC natural mortality from 1998 to 1999 as an explanation for the low catch per unit effort (CPUE) in the 1998/99 commercial fishery and the low numbers across all male crab size groups caught in the annual NMFS eastern Bering Sea trawl survey from 1999 to 2005 (Table 8). In November 2000, Amendment 15 to the FMP for Bering Sea/Aleutian Islands king and Tanner crabs was approved to implement a rebuilding plan for the SMBKC stock (NPFMC 2000). The rebuilding plan included a regulatory harvest strategy (5 AAC 34.917), area closures, and gear modifications. In addition, commercial crab fisheries near St. Matthew Island were scheduled in fall and early winter to reduce the potential for bycatch mortality of vulnerable molting and mating crab.

NMFS declared the stock rebuilt on 21 September 2009, and the fishery was reopened after a 10-year closure on 15 October 2009 with a TAC of 529 tonnes (1.167 million pounds), closing again by regulation on 1 February 2010. Seven participating vessels landed a catch of 209 tonnes (460,859 pounds) with a reported effort of 10,697 pot lifts and an estimated CPUE of 9.9 retained individual crab per pot lift. The fishery remained open the next three years with modest harvests and similar CPUE, but large declines in the NMFS trawl-survey estimate of stock abundance raised concerns about the health of the stock, prompting ADF&G to close the fishery again for the 2013/14 season. Due to an abundance above thresholds, the fishery was reopened for the 2014/15 season with a low TAC of 297 tonnes (0.655 million pounds) and in 2015/16 the TAC was further reduced to 186 tonnes (0.411 million pounds).

[2] NOAA grant Bering Sea Crab Research II, NA16FN2621, 1997.

Table 4: The 1978/79 to 2015/16 directed St. Matthew Island blue king crab pot fishery. The Guideline Harvest Level (GHL) and Total Allowable Catch (TAC) are in millions of pounds. Harvest includes deadloss. Catch per unit effort (CPUE) in this table is simply the harvest number / pot lifts. The average weight is the harvest weight / harvest number in pounds. The average CL is the average of retained crab in mm from dockside sampling of delivered crab. Source: Fitch et al 2012; ADF&G Dutch Harbor staff, pers. comm.

			Harvest					
Year	Dates	GHL/TAC	Crab	Pounds	Pot lifts	CPUE	avg wt	avg CL
1978/79	07/15 - 09/03		436,126	1,984,251	43,754	10	4.5	132.2
1979/80	07/15 - 08/24		52,966	210,819	9,877	5	4.0	128.8
1980/81	07/15 - 09/03			CONFIDENTIAL				
1981/82	07/15 - 08/21		1,045,619	4,627,761	58,550	18	4.4	NA
1982/83	08/01 - 08/16		1,935,886	8,844,789	165,618	12	4.6	135.1
1983/84	08/20 - 09/06	8.0	1,931,990	9,454,323	133,944	14	4.9	137.2
1984/85	09/01 - 09/08	2.0-4.0	841,017	3,764,592	73,320	11	4.5	135.5
1985/86	09/01 - 09/06	0.9-1.9	436,021	2,175,087	46,988	9	5.0	139.0
1986/87	09/01 - 09/06	0.2-0.5	219,548	1,003,162	22,073	10	4.6	134.3
1987/88	09/01 - 09/05	0.6-1.3	227,447	1,039,779	28,230	8	4.6	134.1
1988/89	09/01 - 09/05	0.7-1.5	280,401	1,236,462	21,678	13	4.4	133.3
1989/90	09/01 - 09/04	1.7	247,641	1,166,258	30,803	8	4.7	134.6
1990/91	09/01 - 09/07	1.9	391,405	1,725,349	26,264	15	4.4	134.3
1991/92	09/16 - 09/20	3.2	726,519	3,372,066	37,104	20	4.6	134.1
1992/93	09/04 - 09/07	3.1	545,222	2,475,916	56,630	10	4.5	134.1
1993/94	09/15 - 09/21	4.4	630,353	3,003,089	58,647	11	4.8	135.4
1994/95	09/15 - 09/22	3.0	827,015	3,764,262	60,860	14	4.9	133.3
1995/96	09/15 - 09/20	2.4	666,905	3,166,093	48,560	14	4.7	135.0
1996/97	09/15 - 09/23	4.3	660,665	3,078,959	91,085	7	4.7	134.6
1997/98	09/15 - 09/22	5.0	939,822	4,649,660	81,117	12	4.9	139.5
1998/99	09/15 - 09/26	4.0	635,370	2,968,573	91,826	7	4.7	135.8
1999/00 - 2008/09				FISHERY CLOSED				
2009/10	10/15 - 02/01	1.17	103,376	460,859	10,697	10	4.5	134.9
2010/11	10/15 - 02/01	1.60	298,669	1,263,982	29,344	10	4.2	129.3
2011/12	10/15 - 02/01	2.54	437,862	1,881,322	48,554	9	4.3	130.0
2012/13	10/15 - 02/01	1.63	379,386	1,616,054	37,065	10	4.3	129.8
2013/14				FISHERY CLOSED				
2014/15	10/15 - 02/05	0.66	69,109	308,582	10,133	7	4.5	132.3
2015/16	10/19 - 11/28	0.41	24,076	105,010	5,475	4	4.4	132.6

Though historical observer data are limited due to very limited sampling, bycatch of female and sublegal male crab from the directed blue king crab fishery off St. Matthew Island was relatively high historically, with estimated total bycatch in terms of number of crab captured sometimes more than twice as high as the catch of legal crab (Moore et al. 2000; ADF&G Crab Observer Database). Pot-lift sampling by ADF&G crab observers (Gaeuman 2013; ADF&G Crab Observer Database) indicates similar bycatch rates of discarded male crab since the reopening of the fishery (Table 5), with total male discard mortality in the 2012/13 directed fishery estimated at about 12% (88 tonnes or 0.193 million pounds) of the reported retained catch weight, assuming 20% handling mortality.

On the other hand, these same data suggest a significant reduction in the bycatch of females, which may be attributable to the later timing of the contemporary fishery and the more offshore distribution of fishery effort since reopening in 2009/10[3]. Some bycatch of discarded blue king crab has also been observed historically in the eastern Bering Sea snow crab fishery, but in recent years it has generally been negligible, and observers recorded no bycatch of blue king crab in sampled pot lifts during 2013/14. The St. Matthew Island golden king crab fishery, the third commercial crab fishery to have taken place in the area, typically occurred in areas

[3] D. Pengilly, ADF&G, pers. comm.

Table 5: Observed proportion of crab by size class during the ADF&G crab observer pot-lift sampling. Source: ADF&G Crab Observer Database.

Year	Total pot lifts	Pot lifts sampled	Number of crab (90 mm+ CL)	Stage 1	Stage 2	Stage 3
1990/91	26,264	10	150	0.113	0.393	0.493
1991/92	37,104	125	3,393	0.133	0.177	0.690
1992/93	56,630	71	1,606	0.191	0.268	0.542
1993/94	58,647	84	2,241	0.281	0.210	0.510
1994/95	60,860	203	4,735	0.294	0.271	0.434
1995/96	48,560	47	663	0.148	0.212	0.640
1996/97	91,085	96	489	0.160	0.223	0.618
1997/98	81,117	133	3,195	0.182	0.205	0.613
1998/99	91,826	135	1.322	0.193	0.216	0.591
1999/00 - 2008/09			FISHERY CLOSED			
2009/10	10,484	989	19,802	0.141	0.324	0.535
2010/11	29,356	2,419	45,466	0.131	0.315	0.553
2011/12	48,554	3,359	58,666	0.131	0.305	0.564
2012/13	37,065	2,841	57,298	0.141	0.318	0.541
2013/14			FISHERY CLOSED			
2014/15	10,133	895	9,906	0.094	0.228	0.679
2015/16	5,475	419	3,248	0.115	0.252	0.633

with depths exceeding blue king crab distribution. NMFS observer data suggest that variable but mostly limited SMBKC bycatch has also occurred in the eastern Bering Sea groundfish fisheries (Table 6).

D. Data

Summary of New Information

Data used in this assessment have been updated to include the most recently available fishery and survey numbers. This assessment makes use of two new survey data points including the 2016 NMFS trawl-survey estimate of abudance, and the 2016 ADF&G pot survey CPUE. Both of these surveys have associated size compositon data. The assessment also uses updated 1993-2015 groundfish and fixed gear bycatch estimates based on AKRO data. The 2015/16 directed fishery catch data and associated size composition data were also used. The data used in each of the new models is shown in Figure 3.

Major Data Sources

Major data sources used in this assessment include annual directed-fishery retained-catch statistics from fish tickets (1978/79-1998/99, 2009/10-2012/13, and 2014/15-2015/16; Table 4); results from the annual NMFS eastern Bering Sea trawl survey (1978-2016; Table 8); results from the triennial ADF&G SMBKC pot survey (every third year during 1995-2013), the 2015 pot survey, and the 2016 pot survey (Table 7); size-frequency information from ADF&G crab-observer pot-lift sampling (1990/91-1998/99, 2009/10-2012/13, and 2014/15-2015/16; Table 5); and NMFS groundfish-observer bycatch biomass estimates (1992/93-2015/16; Table 6).

Figure 4 maps stations from which SMBKC trawl-survey and pot-survey data were obtained. Further information concerning the NMFS trawl survey as it relates to commercial crab species is available in Daly et al. (2014); see Gish et al. (2012) for a description of ADF&G SMBKC pot-survey methods. It should be noted that the two surveys cover different geographic regions and that each has in some years encountered proportionally large numbers of male blue king crab in areas where the other is not represented (Figure 5). Crab-observer sampling protocols are detailed in the crab-observer training manual (ADF&G 2013).

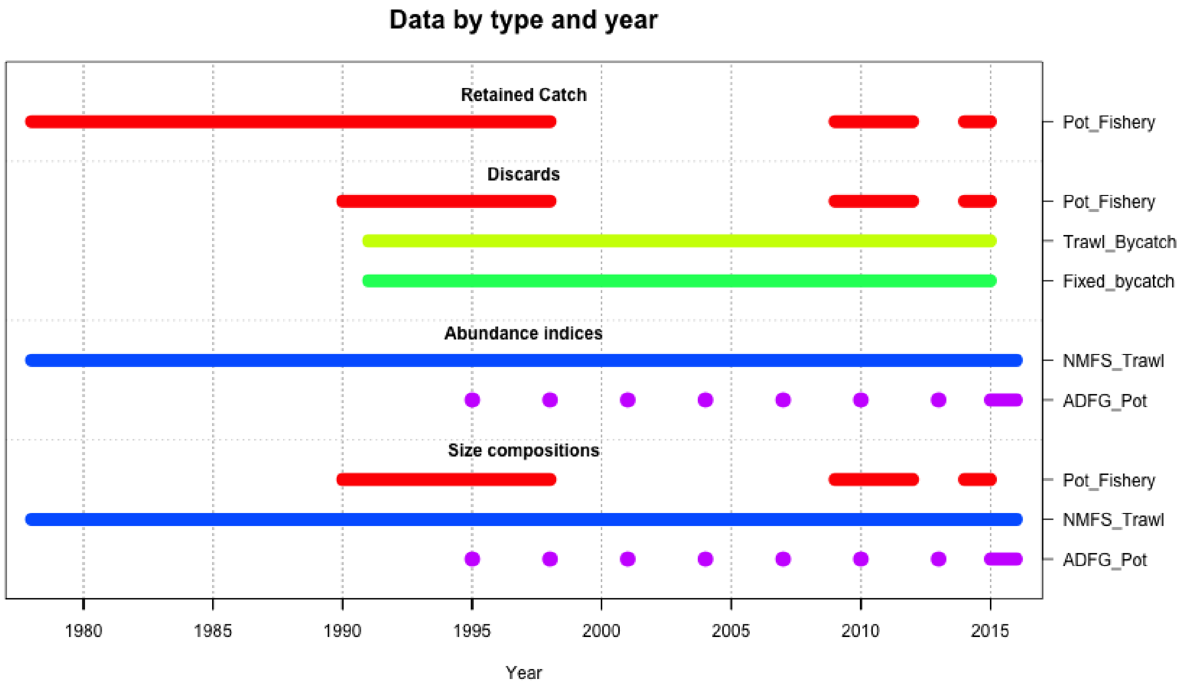

Figure 3: Data extent for the SMBKC assessment.

Groundfish SMBKC bycatch data come from NMFS Bering Sea reporting areas 521 and 524 (Figure 6). Note that for this assessment the newly available NMFS groundfish observer data reported by ADF&G statistical area was not used.

Other Data Sources

Recent model configurations developed for SMBKC makes use of a growth transition matrix based on Otto and Cummiskey (1990), the same growth transition matrix is used in this assessment. Other relevant data sources, including assumed population and fishery parameters, are presented in Appendix A, which also provides a detailed description of the model configuration used for this assessment.

Excluded Data Sources

Groundfish bycatch size-frequency data are available for selected years. These data were used in model-based assessments prior to 2011. However, they have since been excluded because these data tend to be severely limited: for example, 2012/13 data include a total of just 4 90 mm+ CL male blue king crab from reporting areas 521 and 524.

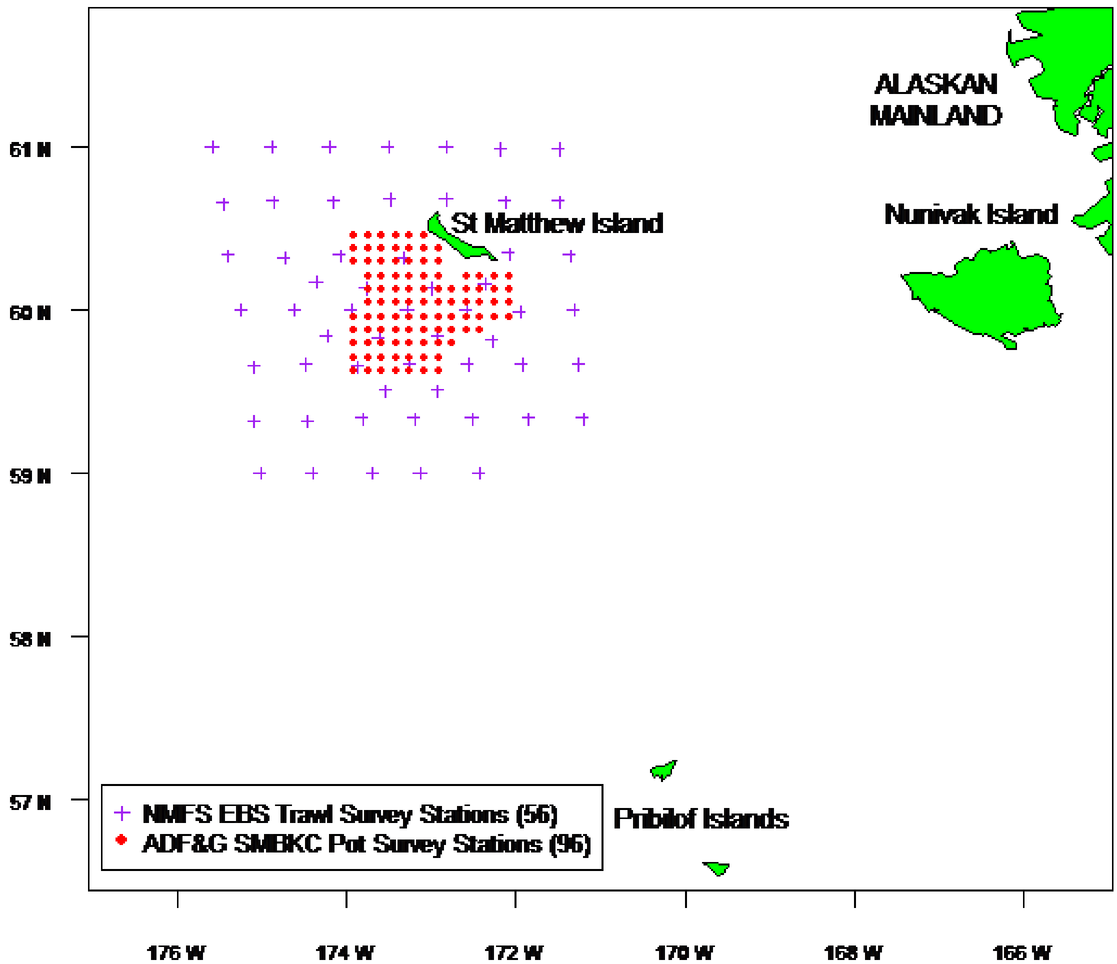

Figure 4: Trawl and pot-survey stations used in the SMBKC stock assessment.

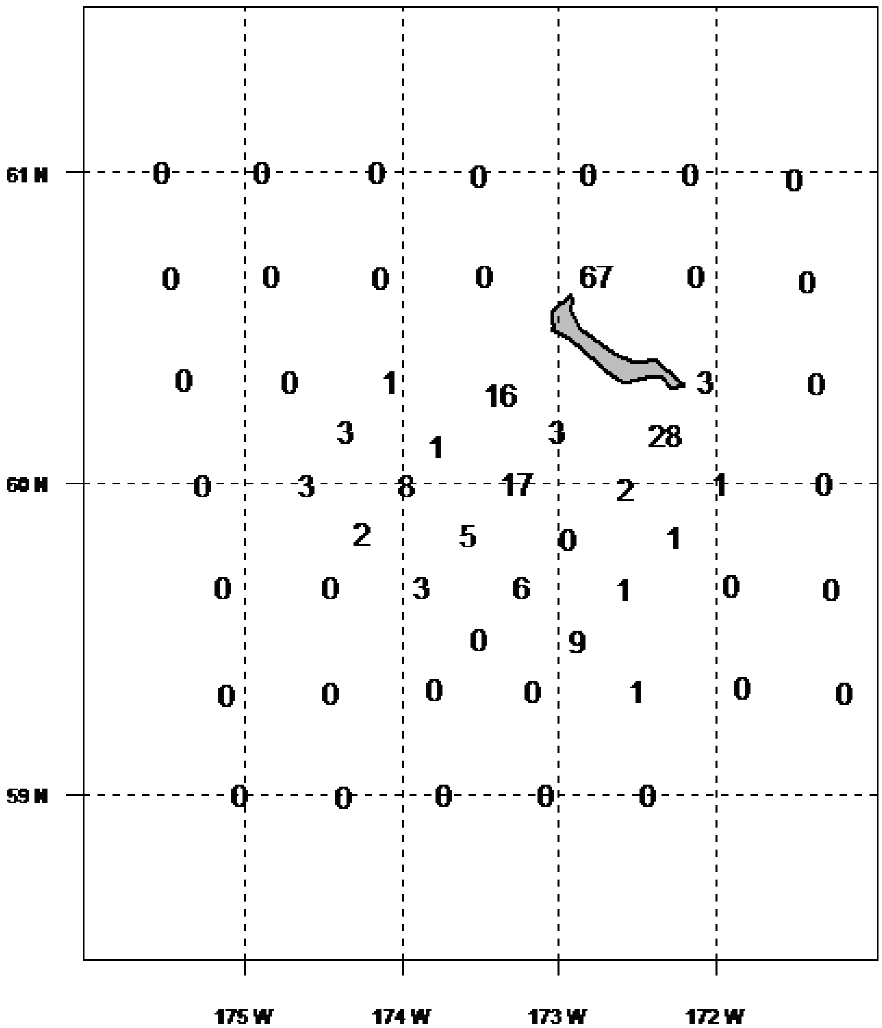

Figure 5: Catches of 181 male blue king crab measuring at least 90 mm CL from the 2014 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock. Note that the area north of St. Matthew Island, which includes the large catch of 67 crab at station R-24, is not represented in the ADF&G pot-survey data used in the assessment.

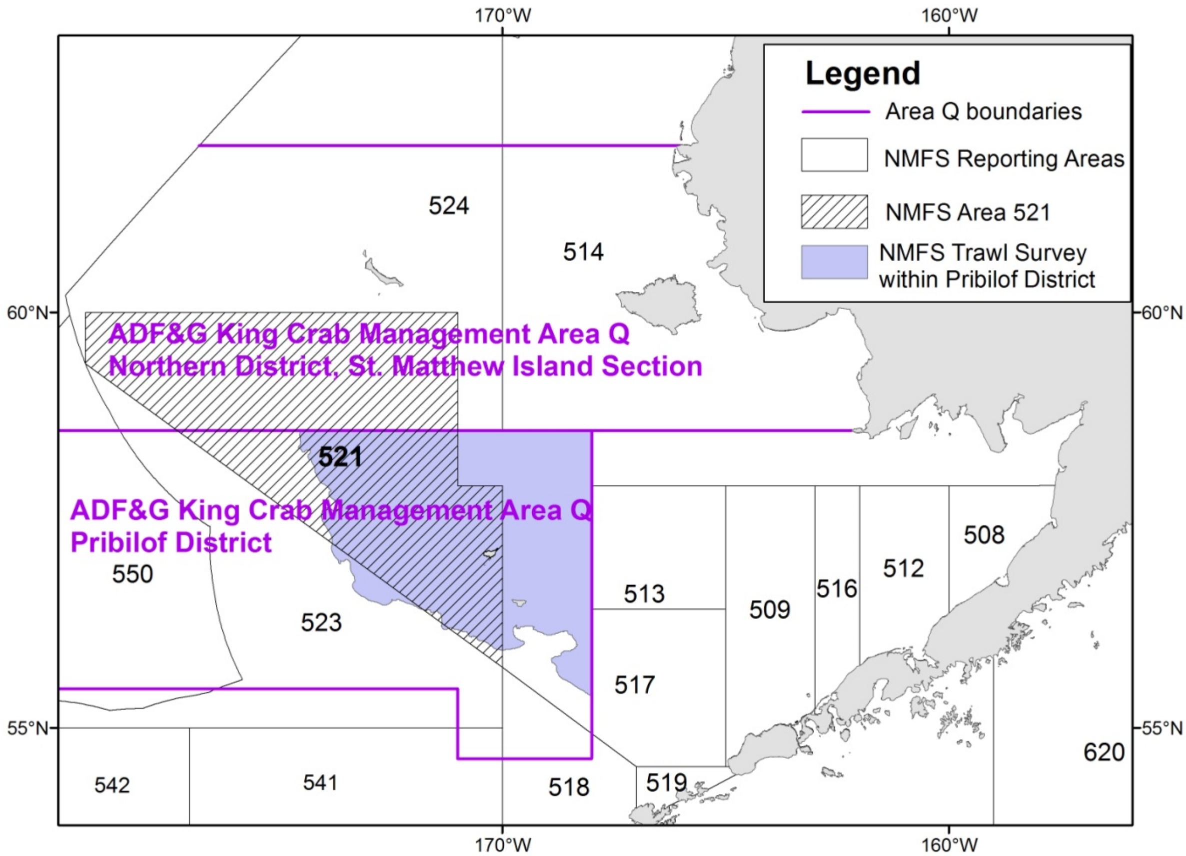

Figure 6: NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521.

Table 6: Groundfish SMBKC male bycatch biomass (tonnes) estimates. Trawl includes pelagic trawl and non-pelagic trawl types. Source: J. Zheng, ADF&G, and author estimates based on data from R. Foy, NMFS. AKRO estimates used after 2008/09.

Year	Trawl bycatch	Fixed gear bycatch
1978	0.000	0.000
1979	0.000	0.000
1980	0.000	0.000
1981	0.000	0.000
1982	0.000	0.000
1983	0.000	0.000
1984	0.000	0.000
1985	0.000	0.000
1986	0.000	0.000
1987	0.000	0.000
1988	0.000	0.000
1989	0.000	0.000
1990	0.000	0.000
1991	3.538	0.045
1992	1.996	2.268
1993	1.542	0.000
1994	0.318	0.091
1995	0.635	0.136
1996	0.000	0.045
1997	0.000	0.181
1998	0.000	0.907
1999	0.000	1.361
2000	0.000	0.000
2001	0.000	0.862
2002	0.726	0.408
2003	0.998	1.134
2004	0.091	0.635
2005	0.000	0.590
2006	2.812	1.451
2007	0.045	69.717
2008	0.272	6.622
2009	0.635	7.530
2010	0.363	9.571
2011	0.181	0.590
2012	0.000	0.590
2013	0.181	0.272
2014	0.000	0.272
2015	0.000	0.635

Table 7: Size-class and total CPUE (90+ mm CL) with estimated CV and total number of captured crab (90+ mm CL) from the 96 common stations surveyed during the seven triennial ADF&G SMBKC pot surveys and the 2015 and 2016 surveys. Source: D. Pengilly and R. Gish, ADF&G.

Year	Stage-1 (90-104 mm)	Stage-2 (105-119 mm)	Stage-3 (120+ mm)	Total CPUE	CV	Number of crabs
1995	1.919	3.198	6.922	12.042	0.13	4624
1998	0.964	2.763	8.804	12.531	0.06	4812
2001	1.266	1.737	5.487	8.477	0.08	3255
2004	0.112	0.414	1.141	1.667	0.15	640
2007	1.086	2.721	4.836	8.643	0.09	3319
2010	1.326	3.276	5.607	10.209	0.13	3920
2013	0.878	1.398	3.367	5.643	0.19	2167
2015	0.198	0.682	1.924	2.805	0.18	1077
2016	0.198	0.456	1.724	2.378	0.186	777

Table 8: NMFS EBS trawl-survey area-swept estimates of male crab abundance (10^6 crab) and of mature male biomass (10^6 lbs). Total number of captured male crab $\geq$ 90 mm CL is also given. Source: R. Foy, NMFS. The "+" refer to plus group.

	Abundance					Biomass		
Year	Stage-1 (90-104 mm)	Stage-2 (105-119 mm)	Stage-3 (120+ mm)	Total	CV	Total (90+ mm CL)	CV	Number of crabs
1978	2.213	1.991	1.521	5.726	0.411	15.064	0.394	157
1979	3.061	2.281	1.808	7.150	0.472	17.615	0.463	178
1980	2.856	2.563	2.541	7.959	0.572	22.017	0.507	185
1981	0.483	1.213	2.263	3.960	0.368	14.443	0.402	140
1982	1.669	2.431	5.884	9.984	0.401	35.763	0.344	271
1983	1.061	1.651	3.345	6.057	0.332	21.240	0.298	231
1984	0.435	0.497	1.452	2.383	0.175	8.976	0.179	105
1985	0.379	0.376	1.117	1.872	0.216	6.858	0.210	93
1986	0.203	0.447	0.374	1.025	0.428	3.124	0.388	46
1987	0.325	0.631	0.715	1.671	0.302	5.024	0.291	71
1988	0.410	0.816	0.957	2.183	0.285	6.963	0.252	81
1989	2.169	1.154	1.786	5.109	0.314	13.974	0.271	208
1990	1.053	1.031	2.338	4.422	0.302	14.837	0.274	170
1991	1.147	1.665	2.233	5.046	0.259	15.318	0.248	197
1992	1.074	1.382	2.291	4.746	0.206	15.638	0.201	220
1993	1.521	1.828	3.276	6.626	0.185	21.051	0.169	324
1994	0.883	1.298	2.257	4.438	0.187	14.416	0.176	211
1995	1.025	1.188	1.741	3.953	0.187	12.574	0.178	178
1996	1.238	1.891	3.064	6.193	0.263	20.746	0.241	285
1997	1.165	2.228	3.789	7.182	0.367	24.084	0.337	296
1998	0.660	1.661	2.849	5.170	0.373	17.586	0.355	243
1998	0.223	0.222	0.558	1.003	0.192	3.515	0.182	52
2000	0.282	0.285	0.740	1.307	0.303	4.623	0.310	61
2001	0.419	0.502	0.938	1.859	0.243	6.242	0.245	91
2002	0.111	0.230	0.640	0.981	0.311	3.820	0.320	38
2003	0.449	0.280	0.465	1.194	0.399	3.454	0.336	65
2004	0.247	0.184	0.562	0.993	0.369	3.360	0.305	48
2005	0.319	0.310	0.501	1.130	0.403	3.620	0.371	42
2006	0.917	0.642	1.240	2.798	0.339	8.585	0.334	126
2007	2.518	2.020	1.193	5.730	0.420	14.266	0.385	250
2008	1.352	0.801	1.457	3.609	0.289	10.261	0.284	167
2009	1.573	2.161	1.410	5.144	0.263	13.892	0.256	251
2010	3.937	3.253	2.458	9.648	0.544	24.539	0.466	388
2011	1.800	3.255	3.207	8.263	0.587	24.099	0.558	318
2012	0.705	1.970	1.808	4.483	0.361	13.669	0.339	193
2013	0.335	0.452	0.807	1.593	0.215	5.043	0.217	74
2014	0.723	1.627	1.809	4.160	0.503	13.292	0.449	181
2015	0.992	1.269	1.979	4.240	0.774	12.958	0.770	153
2016	0.535	0.660	1.178	2.373	0.447	7.685	0.393	108

E. Analytic Approach

History of Modeling Approaches for this Stock

A four-stage catch-survey-analysis (CSA) assessment model was used before 2011 to estimate abundance and biomass and prescribe fishery quotas for the SMBKC stock (2010 SAFE; Zheng et al. 1997). The four-stage CSA is similar to a full length-based analysis, the major difference being coarser length groups, which are more suited to a small stock with consistently low survey catches. In this approach, the abundance of male crab with a CL of 90 mm or above is modeled in terms of four crab stages: stage 1: 90-104 mm CL; stage 2: 105-119 mm CL; stage 3: newshell 120-133 mm CL; and stage 4: oldshell $\geq$ 120 mm CL and newshell $\geq$ 134 mm CL. Motivation for these stage definitions comes from the fact that for management of the SMBKC stock, male crab measuring at least 105 mm CL are considered mature, whereas 120 mm CL is considered a proxy for the legal size of 5.5 in carapace width, including spines. Additional motivation for these stage definitions comes from an estimated average growth increment of about 14 mm per molt for SMBKC (Otto and Cummiskey 1990).

Concerns about the pre-2011 assessment model led to the CPT and SSC recommendations that included development of an alternative model with provisional assessment based on survey biomass or some other index of abundance. An alternative 3-stage model was proposed to the CPT in May 2011 but was requested to proceed with a survey-based approach for the Fall 2011 assessment. In May 2012 the CPT approved a slightly revised and better documented version of the alternative model for assessment.

The 2015 SMBKC stock assessment model, first used in Fall 2012, was a variant of the previous four-stage SMBKC CSA model and similar in complexity to that described by Collie et al. (2005). Like the earlier model, it considered only male crab at least 90 mm in CL, but it combined stages 3 and 4 of the earlier model resulting in just three stages (male size classes) determined by CL measurements of (1) 90-104 mm, (2) 105-119 mm, and (3) 120 mm+ (i.e., 120 mm and above). This consolidation was driven by concern about the accuracy and consistency of shell-condition information, which had been used in distinguishing stages 3 and 4 of the earlier model.

Assessment Methodology

The 2016 SMBKC assessment model makes use of the modeling framework Gmacs. The aim when developing this model was to first provide a fit to the data that best matched the 2015 SMBKC stock assessment model. A detailed description of the Gmacs model and its implementation is presented in Appendix A.

Model Selection and Evaluation

Five different Gmacs model scenarios were considered, in this document results from these models and the 2015 model are compared. The models inlcude:

1. **2015 Model**: the 2015 approach with a correction[4]. This modification was made prior to comparisons (note that this modification caused the NMFS trawl survey selectivity to exceed 1 for stage-2 crab).
2. **Gmacs match**: tries to match as closely as possible with the 2015 Model by fixing the stage-1 and stage-2 selectivity parameters and the catchability coefficient (q) for the ADF&G pot survey at those values estimated in the 2015 model (and allows the NMFS trawl survey selectivity to exceed 1 for stage-2 crab). The parameters that are estimated in this model include the average recruitment ($\bar{R}$), the recruitment deviations (δ_y^R), the initial numbers in each stage ($\boldsymbol{n}^0$), the natural mortality deviation 1998 (δ_{1998}^M), and the fishing mortalities for the directed pot fishery, the trawl bycatch fishery, and the

[4] A correction to the 2015 model code was made in the population dynamics function involving how the growth transition matrix was applied to the numbers at length to calculate the numbers during the following time-step, specifically `N(t+1,3)=TM(2,3)*NN(2)+NN(3);` was changed to `N(t+1,3)=TM(1,3)*NN(1)+TM(2,3)*NN(2)+NN(3);`.

fixed bycatch fishery ($\bar{F}^{\rm df}$, $\bar{F}^{\rm tb}$, $\bar{F}^{\rm fb}$, $\delta^{\rm df}_{t,y}$, $\delta^{\rm tb}_{t,y}$, $\delta^{\rm fb}_{t,y}$). As in the 2015 model, the robust multinomial distribution was used to model the length-frequency data.

3. **Gmacs base**: directed pot, NMFS trawl survey and ADF&G pot survey selectivities are estimated for stage-1 and stage-2 crab (and fixed at 1 for stage-3 crab). These selectivities are bounded so that they cannot be greater than 1. This model also estimates the catchability coefficient (q) for the ADF&G pot survey as well as the average recruitment ($\bar{R}$), the recruitment deviations (δ^R_y), the initial numbers in each stage ($\boldsymbol{n}^0$), the natural mortality deviation 1998 (δ^M_{1998}), and the fishing mortalities for the directed pot fishery, the trawl bycatch fishery, and the fixed bycatch fishery ($\bar{F}^{\rm df}$, $\bar{F}^{\rm tb}$, $\bar{F}^{\rm fb}$, $\delta^{\rm df}_{t,y}$, $\delta^{\rm tb}_{t,y}$, $\delta^{\rm fb}_{t,y}$). As in the 2015 model, the robust multinomial distribution was used to model the length-frequency data.
4. **Gmacs M**: is the same as above except that natural mortality (M) is fixed at 0.18 yr^{-1} during all years.
5. **Gmacs Francis**: is similar to the scenario above except that it also uses the Francis iterative re-weighting method (Francis 2011), to re-weight the size-composition data relative to the abundance indices. The trawl survey and pot survey weights were left as is (i.e. a weight of 1) because upweighting these series resulted in worse standard deviation of the normalised residual (SDNR) and median of the absolute residual (MAR) values for each of the surveys. Down-weighting the two surveys actually improved the SDNR and MAR values, but it would be unwise to down-weight either of these series. When applying the Francis iterative re-weighting method only once iteration was done (i.e. the model was run once with the size composition likelihood weights set to one, the new Francis weights were calculated, and the model was run once more using these weights). In this scenario the multinomial distribution was used instead as the theory underpinning the Francis weighting method is based on this distribution.
6. **Gmacs force**: is an exploratory scenario that the same as above except the NMFS trawl survey is up-weighted by $\lambda^{\rm NMFS} = 1.5$ and the ADF&G pot survey is up-weighted by $\lambda^{\rm ADFG} = 2$. After this, the Francis weights for each of the size-compostitons were recalculated and applied again in this model. This scenario should not be used for overfishing determination as it upweights the trawl and pot survey abundance indices to force a better fit to each of these data sets and provide some contrast among the Gmacs model runs. This scenario forces a better fit to the trawl and pot surveys at the expense of the SDNR (and MAR) for each of these series.

Table 9 outlines the major features of each of the models.

Table 9: Outline of the major features of the five different Gmacs scenarios.

Scenario	Selectivity estimated	Use Francis LF weighting	Estimate M_{1998}
Gmacs match	No	No	Yes
Gmacs base	Yes	No	Yes
Gmacs M	Yes	No	No
Gmacs Francis	Yes	Yes	No
Gmacs force	Yes	Yes	No

Results

Results for all Gmacs scenarios are provided with comparisons to the 2015 model. We recommend the **Gmacs base** scenario for management purposes since it provides the best fit to the data and is most consistent with previous model specifications.

a. Effective sample sizes and weighting factors.

Observed and estimated effective sample sizes are compared in Table 12. Effective sample sizes are also shown on size-composition plots (Figures 14, 15, and 16).

Data weighting factors, SDNRs, and MARs are presented in Table 19. The SDNR for the trawl survey is acceptable at 1.44 in the **Gmacs match** scenario, and improves to 1.41 in the **Gmacs base** scenario. In the **Gmacs M** model the SDNR of the trawl survey is slightly worse at 1.59, and is much worse in the exploratory **Gmacs force** scenario at 2.16. The SDNRs for the pot surveys show much the same pattern between each of the scenarios, but are much higher values (ranging from 3.95 to 5.19). These values are very high, and whilst they can be improved by down-weighting the pot survey, it is recommended that they be left as they are as the pot survey is one of the most important data series in this model. The MAR for the trawl and pot surveys shows the same pattern among each of the scenarios as the SDNR. The SDNR (and MAR) values for the trawl survey and pot survey size compositions were excellent, ranging from 0.78 to 1.30 (except for in the **Gmacs force** scenario where the weights were a little high). The SDNRs for the directed pot fishery size compositions are a little low, ranging from 0.64 to 0.79. However, the SDNRs (and MARs) were not used when weighting the size composition data sets in those scenarios that used the Francis weighting method (i.e. in the **Gmacs Francis**, and **Gmacs Force** scenarios). Instead, the Francis size composition weights were used (Francis 2011).

b. Tables of estimates.

Model parameter estimates for each of the Gmacs scenarios are summarized in Tables 13, 14, 15, 16, and 17. These parameter estimates are compared in Table 18. Negative log-likelihood values and management measures for each of the Gmacs scenarios are compared in Tables 20 and 10.

There is little difference in the parameter estimates within the **Gmacs match** and **Gmacs base** scenarios. This is reflected in the log-likelihood components and the management quantities. The parameter estimates in the **Gmacs M** scenario are a little different to the previous scenarios, particularly the estimate of the ADF&G pot survey catchability (q) (see Table 18).

c. Graphs of estimates.

Estimated (and fixed) selectivities are compared in Figure 7.

The various model fits to total male (> 89 mm CL) trawl survey biomass are compared in Figures 8 and 9. The fits to pot survey CPUE are compared in Figures 10 and 11. Standardized residuals of total male trawl survey biomass and pot survey CPUE are plotted in Figures 12 and 13.

Fits to stage compositions for trawl survey, pot survey, and commercial observer data are shown in Figures 14, 15, and 16 for the all scenarios. Bubble plots of stage composition residuals for trawl survey, pot survey, and commercial observer data are shown for the **Gmacs base**, **Gmacs M**, **Gmacs Francis**, and **Gmacs force** scenarios in Figures 17, 19, 18, and 20, respectively.

Fits to retained catch numbers and bycatch biomass are shown for all Gmacs scenarios in Figure 21.

Estimated recruitment is compared in Figure 22. Estimated abundances by stage and mature male biomasses for all scenarios (including the 2015 model) are shown in Figures 26 and 23. Estimated natural mortality each year (M_t) is presented in Figure 27.

d. Graphic evaluation of the fit to the data.

There is little difference between model estimated survey biomass in the gmacs scenarios when compared with the 2015 model (Figures 8 and 10). Looking at the model fits to the NMFS trawl survey biomass (Figure 8), the **Gmacs match** scenario is the most similar to the 2015 model, and the **Gmacs base** model is very similar as well. In all scenarios, Gmacs produces a better fit during the mid-late 1980s. However, since about 2010 Gmacs estimates a slighly lower survey biomass than the 2015 model in an attempt to better fit the ADF&G pot survey CPUE (Figure 10). The three Gmacs scenarios that do not attempt to estimate natural mortality in 1998/99 (**Gmacs M**, **Gmacs Francis**, and **Gmacs force**) predict lower survey biomass from 1992 to 1998 than the other scenarios and the 2015 model. These same two runs also predict a lower survey biomass in recent years (since about 2010). While these two models may result in slightly worse fits to the data, they do not risk over-fitting the data in the same way the other scenarios do. As exptected the model that upweights the NMFS survey biomass and ADF&G pot survey CPUE (**Gmacs force**) provides a better fit to the survey biomass during the mid-late 1980s and a much better fit to the pot survey CPUE in the most recent two years (Figures 8, 9, 10, and 11). Keep in mind that this scenario was only included for exploratory purposes and forcing these weights resulted in worse SDNR and MAR values for the two abundance indices.

Estimated recruitment to the model is variable over time (Figure 22). Estimated recruitment during recent years is generally low in all scenarios. Estimated mature male biomass on 15 February also fluctuates strongly over time (Figure 23).

e. Retrospective and historic analyses.

Gmacs retrospective analyses under development.

f. Uncertainty and sensitivity analyses.

Estimated standard deviations of parameters and selected management measures for the five Gmacs scenarios are summarized in Tables 13, 14, 15, 16, and 17. Probabilities for mature male biomass and OFL in 2016 are illustrated in Section F.

g. Comparison of alternative model scenarios.

Both the **Gmacs match** and **Gmacs base** scenarios provide adequate matches between the 2015 model and its Gmacs equivalent. In fact, despite a few minor differences, estimates produced by the 2015 model are generally encompassed the in the uncertainty bounds of the **Gmacs match** model.

Looking at the plot of mature male biomass (Figure 23), the **Gmacs force** scenario stands out as being quite different to the other models (including the 2015 model). This scenario results in a lower MMB from the mid-1908s through to the late-1990s, and is again lower in the most recent 5 years. This scenario upweights both the trawl survey and the pot survey abundance indices (it upweights the pot survey more than the trawl survey) and represents a model run that places greater trust in the abundance indices, particularly the pot survey, than other data sources.

Although the **Gmacs M** scenario presents a worse fit to the data, particularly the NMFS trawl-survey time series, this model does not simply allow a better fit to by estimating an unconstrained pulse in natural mortality. Although doing so produces a better fit to the model, it reduces predictive power and support for such a phenomena, anecdotal or otherwise, seems to be limited. It also raises concerns about what the implications would be for an "average" true natural mortality which can affect the management measures. Despite these concerns, more work is needed in the future to explore more parsimonious alternatives that provide better fits to the data.

In summary, we recommend the **Gmacs base** scenario for management purposes since it provides the best fit to the data and is most consistent with previous model specifications. Our initial preference was for **Gmacs M** since we had difficulty justifying an abrubt, single-year anomaly in natural mortality. However, the fact that the residual pattern is worse and until further work can be completed on alternative model specifications (e.g., better accounting of spatial processes affecting the data), the **Gmacs base** model was considered reasonable and should be used for overfishing determination for this stock in 2016.

F. Calculation of the OFL and ABC

The overfishing level (OFL) is the fishery-related mortality biomass associated with fishing mortality F_{OFL}. The SMBKC stock is currently managed as Tier 4 (2013 SAFE), and only a Tier 4 analysis is presented here. Thus given stock estimates or suitable proxy values of B_{MSY} and F_{MSY}, along with two additional parameters α and β, F_{OFL} is determined by the control rule

$$F_{OFL} = \begin{cases} F_{MSY}, & \text{when } B/B_{MSY} > 1 \\ F_{MSY}\frac{(B/B_{MSY}-\alpha)}{(1-\alpha)}, & \text{when } \beta < B/B_{MSY} \leq 1 \end{cases} \tag{1}$$
$$F_{OFL} < F_{MSY} \text{ with directed fishery } F = 0 \text{ when } B/B_{MSY} \leq \beta$$

where B is quantified as mature-male biomass (MMB) at mating with time of mating assigned a nominal date of 15 February. Note that as B itself is a function of the fishing mortality F_{OFL} (therefore numerical approximation of F_{OFL} is required). As implemented for this assessment, all calculations proceed according to the model equations given in Appendix A. F_{OFL} is taken to be full-selection fishing mortality in the directed pot fishery and groundfish trawl and fixed-gear fishing mortalities set at their model geometric mean values over years for which there are data-based estimates of bycatch-mortality biomass.

The currently recommended Tier 4 convention is to use the full assessment period, currently 1978-2016, to define a B_{MSY} proxy in terms of average estimated MMB and to set $\gamma = 1.0$ with assumed stock natural mortality $M = 0.18$ yr^{-1} in setting the F_{MSY} proxy value γM. The parameters α and β are assigned their default values $\alpha = 0.10$ and $\beta = 0.25$. The F_{OFL}, OFL, ABC, and MMB in 2016 for all scenarios are summarized in Table 10. ABC is 80% of the OFL.

Table 10: Comparisons of management measures for the five Gmacs model scenarios. Biomass and OFL are in tonnes.

Component	Gmacs match	Gmacs base	Gmacs M	Gmacs Francis	Gmacs force
MMB_{2016}	2240.516	2229.091	1824.133	1796.937	1502.294
B_{MSY}	3681.513	3671.965	3541.377	3453.784	3272.897
F_{OFL}	0.089	0.088	0.072	0.073	0.062
OFL_{2016}	140.623	140.253	94.640	95.928	71.499
ABC_{2016}	112.499	112.203	75.712	76.742	57.199

G. Rebuilding Analysis

This stock is not currently subject to a rebuilding plan.

H. Data Gaps and Research Priorities

1. Growth increments and molting probabilities as a function of size.
2. Trawl survey catchability and selectivities.
3. Temporal changes in spatial distributions near the island.
4. Natural mortality.

I. Projections and Future Outlook

With the decline of estimated population biomass during recent years, outlook for this stock is not promising. If the decline continues, the stock will fall to depleted status soon.

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Table 11: Mean weight (kg) by stage in used in all of the models (provided as a vector of weights at length each year to Gmacs).

Year	Stage-1	Stage-2	Stage-3
1978	0.7	1.2	1.9
1979	0.7	1.2	1.7
1980	0.7	1.2	1.9
1981	0.7	1.2	1.9
1982	0.7	1.2	1.9
1983	0.7	1.2	2.1
1984	0.7	1.2	1.9
1985	0.7	1.2	2.1
1986	0.7	1.2	1.9
1987	0.7	1.2	1.9
1988	0.7	1.2	1.9
1989	0.7	1.2	2.0
1990	0.7	1.2	1.9
1991	0.7	1.2	2.0
1992	0.7	1.2	1.9
1993	0.7	1.2	2.0
1994	0.7	1.2	1.9
1995	0.7	1.2	2.0
1996	0.7	1.2	2.0
1997	0.7	1.2	2.1
1998	0.7	1.2	2.0
1999	0.7	1.2	1.9
2000	0.7	1.2	1.9
2001	0.7	1.2	1.9
2002	0.7	1.2	1.9
2003	0.7	1.2	1.9
2004	0.7	1.2	1.9
2005	0.7	1.2	1.9
2006	0.7	1.2	1.9
2007	0.7	1.2	1.9
2008	0.7	1.2	1.9
2009	0.7	1.2	1.9
2010	0.7	1.2	1.8
2011	0.7	1.2	1.8
2012	0.7	1.2	1.8
2013	0.7	1.2	1.9
2014	0.7	1.2	1.9
2015	0.7	1.2	1.9
2016	0.7	1.2	1.9

Table 12: Observed and assumed sample sizes for observer data from the directed pot fishery, the NMFS trawl survey, and the ADF&G pot survey.

	Observed sample sizes			Assumed sample sizes		
Year	Observer pot	NMFS trawl	ADF&G pot	Observer pot	NMFS trawl	ADF&G pot
1978		157			50	
1979		178			50	
1980		185			50	
1981		140			50	
1982		271			50	
1983		231			50	
1984		105			50	
1985		93			46.5	
1986		46			23	
1987		71			35.5	
1988		81			40.5	
1989		208			50	
1990	150	170		15	50	
1991	3393	197		25	50	
1992	1606	220		25	50	
1993	2241	324		25	50	
1994	4735	211		25	50	
1995	663	178	4624	25	50	100
1996	489	285		25	50	
1997	3195	296		25	50	
1998	1323	243	4812	25	50	100
1999		52			26	
2000		61			30.5	
2001		91	3255		45.5	100
2002		38			19	
2003		65			32.5	
2004		48	640		24	100
2005		42			21	
2006		126			50	
2007		250	3319		50	100
2008		167			50	
2009	19802	251		50	50	
2010	45466	388	3920	50	50	100
2011	58667	318		50	50	
2012	57282	193		50	50	
2013		74	2167		37	100
2014	9906	181		50	50	
2015	3248	153	1077	50	50	100
2016		108	777		50	100

Table 13: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the **Gmacs match** model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.668	0.116
$\log(\bar{R})$	13.390	0.048
$\log(n^0_1)$	14.894	0.169
$\log(n^0_2)$	14.477	0.194
$\log(n^0_3)$	14.285	0.200
$\log(\bar{F}^{\mathrm{df}})$	-1.519	0.045
$\log(\bar{F}^{\mathrm{tb}})$	-12.228	0.068
$\log(\bar{F}^{\mathrm{fb}})$	-9.130	0.068
F_{OFL}	0.089	0.009
OFL	140.620	25.900

Table 14: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the **Gmacs base** model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.669	0.127
$\log(\bar{R})$	13.399	0.059
$\log(n^0_1)$	14.860	0.171
$\log(n^0_2)$	14.524	0.197
$\log(n^0_3)$	14.224	0.210
ADF&G pot survey catchability ($q \times 1000$)	3.967	0.304
$\log(\bar{F}^{\mathrm{df}})$	-1.512	0.054
$\log(\bar{F}^{\mathrm{tb}})$	-12.245	0.082
$\log(\bar{F}^{\mathrm{fb}})$	-9.147	0.082
log Stage-1 directed pot selectivity 1978-2008	-0.713	0.174
log Stage-2 directed pot selectivity 1978-2008	-0.406	0.127
log Stage-1 directed pot selectivity 2009-2016	-0.629	0.164
log Stage-2 directed pot selectivity 2009-2016	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.203	0.067
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.856	0.135
log Stage-2 ADF&G pot selectivity	-0.106	0.078
F_{OFL}	0.088	0.011
OFL	140.250	32.767

Table 15: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the **Gmacs M** model.

Parameter	Estimate	SD
$\log(\bar{R})$	13.250	0.054
$\log(n_1^0)$	14.861	0.174
$\log(n_2^0)$	14.602	0.195
$\log(n_3^0)$	14.278	0.212
ADF&G pot survey catchability ($q \times 1000$)	4.649	0.341
$\log(\bar{F}^{\mathrm{df}})$	-1.455	0.053
$\log(\bar{F}^{\mathrm{tb}})$	-12.152	0.080
$\log(\bar{F}^{\mathrm{fb}})$	-9.055	0.080
log Stage-1 directed pot selectivity 1978-2008	-0.621	0.179
log Stage-2 directed pot selectivity 1978-2008	-0.367	0.127
log Stage-1 directed pot selectivity 2009-2016	-0.609	0.166
log Stage-2 directed pot selectivity 2009-2016	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.111	0.064
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.810	0.140
log Stage-2 ADF&G pot selectivity	-0.031	0.078
F_{OFL}	0.072	0.010
OFL	94.640	22.264

Table 16: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the **Gmacs Francis** model.

Parameter	Estimate	SD
$\log(\bar{R})$	13.229	0.057
$\log(n_1^0)$	14.815	0.276
$\log(n_2^0)$	14.600	0.295
$\log(n_3^0)$	14.269	0.309
ADF&G pot survey catchability ($q \times 1000$)	4.347	0.287
$\log(\bar{F}^{\mathrm{df}})$	-1.402	0.061
$\log(\bar{F}^{\mathrm{tb}})$	-12.188	0.080
$\log(\bar{F}^{\mathrm{fb}})$	-9.091	0.080
log Stage-1 directed pot selectivity 1978-2008	-0.511	0.159
log Stage-2 directed pot selectivity 1978-2008	-0.414	0.132
log Stage-1 directed pot selectivity 2009-2016	-0.516	0.149
log Stage-2 directed pot selectivity 2009-2016	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.051	0.079
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.705	0.126
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.073	0.010
OFL	95.928	22.287

Table 17: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the **Gmacs force** model.

Parameter	Estimate	SD
$\log(\bar{R})$	13.005	0.058
$\log(n_1^0)$	14.737	0.380
$\log(n_2^0)$	14.563	0.391
$\log(n_3^0)$	14.209	0.400
ADF&G pot survey catchability ($q \times 1000$)	3.645	0.154
$\log(\bar{F}^{\text{df}})$	-1.278	0.055
$\log(\bar{F}^{\text{tb}})$	-12.205	0.071
$\log(\bar{F}^{\text{fb}})$	-9.109	0.071
log Stage-1 directed pot selectivity 1978-2008	-0.691	0.163
log Stage-2 directed pot selectivity 1978-2008	-0.564	0.138
log Stage-1 directed pot selectivity 2009-2016	-0.165	0.164
log Stage-2 directed pot selectivity 2009-2016	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.000	0.000
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.000	0.000
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.062	0.005
OFL	71.499	10.210

Table 18: Comparisons of model parameter estimates for the five Gmacs model scenarios.

Parameter	Match	Base	M	Francis	Force
$\log(\bar{R})$	13390.000	13399.000	13250.000	13229.000	13005.000
$\log(n_1^0)$	14.894	14.860	14.861	14.815	14.737
$\log(n_2^0)$	14.477	14.524	14.602	14.600	14.563
$\log(n_3^0)$	14.285	14.224	14.278	14.269	14.209
$\log(\bar{F}^{\text{df}})$	-1.519	-1.512	-1.455	-1.402	-1.278
$\log(\bar{F}^{\text{fb}})$	-9.130	-9.147	-9.055	-9.091	-9.109
$\log(\bar{F}^{\text{tb}})$	-12.228	-12.245	-12.152	-12.188	-12.205
ADF&G pot survey catchability (q)	-	0.004	0.005	0.004	0.004
log Stage-1 ADF&G pot selectivity	-	-0.856	-0.810	-0.705	-0.000
log Stage-1 directed pot selectivity 1978-2008	-	-0.713	-0.621	-0.511	-0.691
log Stage-1 directed pot selectivity 2009-2015	-	-0.629	-0.609	-0.516	-0.165
log Stage-1 NMFS trawl selectivity	-	-0.203	-0.111	-0.051	-0.000
log Stage-2 ADF&G pot selectivity	-	-0.106	-0.031	-0.000	-0.000
log Stage-2 directed pot selectivity 1978-2008	-	-0.406	-0.367	-0.414	-0.564
log Stage-2 directed pot selectivity 2009-2015	-	-0.000	-0.000	-0.000	-0.000
log Stage-2 NMFS trawl selectivity	-	-0.000	-0.000	-0.000	-0.000
Natural mortality deviation in 1998/99 (δ_{1998}^M)	1.668	1.669	-	-	-

Table 19: Comparisons of data weights, Francis LF weights (i.e. the new weights that should be applied to the LFs), SDNR values, and MAR values for the five Gmacs model scenarios.

Component	Match	Base	M	Francis	Force
NMFS trawl survey weight	1.00	1.00	1.00	1.00	1.50
ADF&G pot survey weight	1.00	1.00	1.00	1.00	2.00
Directed pot LF weight	1.00	1.00	1.00	1.59	1.35
NMFS trawl survey LF weight	1.00	1.00	1.00	0.55	0.28
ADF&G pot survey LF weight	1.00	1.00	1.00	1.31	0.39
Francis weight for directed pot LF	1.72	1.75	1.53	1.85	1.82
Francis weight for NMFS trawl survey LF	0.54	0.53	0.57	0.45	0.15
Francis weight for ADF&G pot survey LF	2.17	2.22	1.68	1.30	0.15
SDNR NMFS trawl survey	1.44	1.41	1.59	1.49	2.16
SDNR ADF&G pot survey	3.95	3.87	3.85	3.68	5.19
SDNR directed pot LF	0.68	0.64	0.67	0.79	0.89
SDNR NMFS trawl survey LF	1.22	1.27	1.30	1.07	1.21
SDNR ADF&G pot survey LF	0.78	0.80	0.89	1.08	1.60
MAR NMFS trawl survey	1.06	1.10	1.39	1.20	1.63
MAR ADF&G pot survey	3.03	2.90	3.30	3.19	3.75
MAR directed pot LF	0.47	0.45	0.39	0.57	0.61
MAR NMFS trawl survey LF	0.55	0.55	0.63	0.56	0.72
MAR ADF&G pot survey LF	0.53	0.53	0.57	0.51	0.82

Table 20: Comparisons of negative log-likelihood values for the five Gmacs model scenarios. It is important to note that not all of these model runs are directly comparable as the **Gmacs Francis** and **Gmacs force** models implement the Francis iterative reweighting method (Francis 2011).

Component	Match	Base	M	Francis	Force
Pot Retained Catch	-69.05	-69.19	-68.99	-69.14	-68.28
Pot Discarded Catch	6.44	6.00	5.61	6.82	10.90
Trawl bycatch Discarded Catch	-6.88	-6.88	-6.88	-6.88	-6.88
Fixed bycatch Discarded Catch	-6.85	-6.86	-6.86	-6.87	-6.88
NMFS Trawl Survey	-6.21	-7.60	4.32	-1.43	33.33
ADF&G Pot Survey CPUE	56.31	53.35	55.02	48.26	104.03
Directed Pot LF	-12.12	-12.98	-12.28	6.73	12.25
NMFS Trawl LF	16.82	22.39	26.16	58.17	88.01
ADF&G Pot LF	-7.05	-6.49	-4.83	0.23	20.19
Recruitment deviations	57.24	57.11	58.28	58.50	66.51
F penalty	14.49	14.49	14.49	14.49	14.49
M penalty	6.47	6.47	0.00	0.00	0.00
Prior	13.72	13.71	13.71	13.71	13.71
Total	63.34	63.53	77.74	122.59	281.38
Total estimated parameters	282.00	291.00	289.00	289.00	289.00

Table 21: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey and mature male biomass (MMB) in tonnes on 15 February for the **2015 model**.

Year	n_1	n_2	n_3	MMB
1978	3018380	1953510	1597980	4075
1979	3919060	2341120	2147490	5802
1980	3467980	3064710	3243990	9074
1981	1395090	3047670	4504000	9239
1982	1368260	1777680	4466940	6370
1983	707216	1318650	3036760	3355
1984	683165	782950	1543430	1990
1985	2244990	616447	986160	1686
1986	1338560	1445520	916977	2727
1987	1432180	1228070	1383660	3375
1988	1306640	1222920	1677970	3723
1989	2279000	1148700	1865710	4245
1990	1445840	1690250	2098040	4744
1991	2024880	1377550	2361620	4400
1992	2321500	1583990	2169580	4531
1993	2514290	1829500	2290170	4977
1994	1465290	2012460	2447020	4912
1995	1572620	1462710	2400370	4768
1996	1807950	1360970	2267560	4351
1997	1086810	1459480	2125050	3718
1998	684461	1059430	1727860	1804
1999	373686	342335	653347	1560
2000	412027	332743	748221	1725
2001	380490	352080	826139	1889
2002	169056	340032	898096	2008
2003	336657	212374	934340	1942
2004	235762	267626	914402	1963
2005	525625	227222	917421	1927
2006	799432	383194	923952	2099
2007	590277	594788	1029430	2455
2008	1019370	530589	1177800	2720
2009	928263	772468	1333420	2992
2010	873520	791923	1475900	2755
2011	723104	753585	1409700	2350
2012	458036	646078	1187950	1959
2013	532334	461243	984254	2294
2014	466341	465305	1097620	2327
2015	389087	424535	1123020	2511

Table 22: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tonnes on 15 February for the **Gmacs match** model.

Year	n_1	n_2	n_3	MMB
1978	2940912	1937321	1599485	4443
1979	4214746	2366729	2186198	6293
1980	3530461	3255079	3319758	9985
1981	1339907	3151773	4671239	10382
1982	1423213	1836341	4716859	7421
1983	703526	1445516	3354759	4515
1984	627868	894099	1961366	3104
1985	933225	665758	1432033	2802
1986	1338578	768053	1239446	2797
1987	1329964	1039251	1346574	3294
1988	1226021	1124816	1564678	3617
1989	2674536	1092640	1736620	4139
1990	1666073	1928817	2012719	5144
1991	1762209	1618513	2457709	5111
1992	1851674	1570399	2396923	5251
1993	2090492	1606677	2482221	5419
1994	1515487	1758741	2518683	5130
1995	1675780	1473533	2412962	5059
1996	1511565	1471942	2333159	4852
1997	853687	1375503	2256106	4212
1998	614040	958573	1853684	2887
1999	363364	313057	693876	1650
2000	409999	316943	766549	1791
2001	375285	345618	833361	1948
2002	132240	334836	900466	2060
2003	328086	189126	930652	1952
2004	211796	254862	898980	1968
2005	467209	208953	896146	1911
2006	745199	342948	892153	2052
2007	436309	549673	978199	2416
2008	921106	432887	1113856	2568
2009	819128	682462	1222934	2679
2010	757131	706071	1339466	2456
2011	643942	677524	1270850	2089
2012	363765	602723	1067516	1762
2013	457408	413959	889357	2032
2014	450828	405706	988406	2041
2015	358504	399119	1006285	2106
2016	354174	342919	1048939	2241

Table 23: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tonnes on 15 February for the **Gmacs base** model.

Year	n_1	n_2	n_3	MMB
1978	2842553	2030682	1504270	4369
1979	4115791	2340416	2145183	6194
1980	3529677	3188432	3264045	9803
1981	1338668	3129048	4591236	10207
1982	1469061	1828043	4638329	7259
1983	754807	1469572	3288146	4406
1984	637458	932143	1921506	3073
1985	890400	684083	1418367	2795
1986	1336767	749141	1233575	2764
1987	1287378	1031877	1332012	3258
1988	1179403	1097457	1545228	3550
1989	2660962	1056248	1702720	4031
1990	1673076	1908726	1964979	5034
1991	1754214	1615905	2408100	5012
1992	1871458	1564858	2352908	5161
1993	2128922	1616393	2443968	5354
1994	1515844	1784461	2494344	5112
1995	1695295	1482349	2404947	5052
1996	1570907	1486308	2331832	4864
1997	874137	1415011	2266545	4276
1998	627570	983746	1883218	2960
1999	377384	320461	711071	1690
2000	416083	327613	785793	1839
2001	386596	352741	855291	1997
2002	136181	343829	923298	2113
2003	332125	194435	954559	2003
2004	214753	258999	921946	2015
2005	507024	212065	917650	1955
2006	757084	367265	915000	2123
2007	499106	564749	1010460	2494
2008	936580	474418	1153889	2690
2009	783535	705391	1278475	2801
2010	746606	692962	1394496	2534
2011	635953	667031	1309638	2144
2012	370619	594551	1094544	1800
2013	458732	415238	908815	2068
2014	418921	406908	1005411	2072
2015	349833	380865	1018496	2107
2016	348100	331752	1049276	2229

Table 24: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tonnes on 15 February for the **Gmacs M** model.

Year	n_1	n_2	n_3	MMB
1978	2844973	2195389	1588390	4719
1979	4110087	2396856	2298179	6515
1980	3504524	3203953	3419646	10116
1981	1293582	3119527	4726883	10448
1982	1468552	1798501	4743129	7427
1983	782500	1459406	3361031	4543
1984	637587	944938	1979946	3197
1985	852726	688432	1473851	2915
1986	1389641	728567	1279108	2827
1987	1267935	1055918	1364176	3346
1988	1145447	1094120	1582546	3615
1989	2644837	1035279	1729430	4060
1990	1596822	1892291	1975463	5035
1991	1646575	1565827	2402363	4945
1992	1715503	1485208	2314322	4998
1993	1883778	1498615	2358939	5055
1994	1234640	1601787	2343918	4625
1995	1374680	1256899	2164403	4329
1996	1109763	1223525	1991476	3916
1997	523695	1057582	1812169	2950
1998	339307	659419	1295777	1966
1999	211666	418571	890427	2136
2000	356763	263533	970915	2112
2001	324958	296647	972848	2153
2002	117101	289060	988226	2173
2003	282399	164992	979748	2016
2004	194870	220109	924069	1975
2005	447192	187449	898272	1891
2006	649340	324060	881479	2011
2007	483558	487361	951792	2298
2008	886038	439504	1064938	2484
2009	717789	664164	1182462	2589
2010	687674	640746	1288198	2302
2011	560374	615122	1190110	1889
2012	300192	533015	963261	1516
2013	380889	353497	763245	1742
2014	334618	340765	846376	1722
2015	275889	309476	845449	1735
2016	274946	264666	862770	1824

Table 25: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tonnes on 15 February for the **Gmacs Francis** model.

Year	n_1	n_2	n_3	MMB
1978	2718048	2190894	1573381	4685
1979	4066560	2321146	2272826	6385
1980	3195064	3153205	3356890	9938
1981	1196087	2921633	4623182	10027
1982	1247326	1675385	4549235	6913
1983	733806	1288932	3118593	3850
1984	559278	859519	1685268	2548
1985	753090	614099	1177647	2219
1986	1188583	645469	985994	2178
1987	1326820	910597	1060897	2607
1988	1313123	1079995	1261297	3012
1989	3100392	1128595	1467915	3656
1990	1309643	2189817	1841686	5129
1991	1611260	1497310	2415653	4891
1992	1727255	1441687	2287235	4897
1993	2082136	1490945	2315142	4960
1994	1299776	1715187	2319894	4708
1995	1296461	1332865	2206551	4496
1996	1174846	1203177	2057671	4019
1997	608593	1088844	1862273	3085
1998	403869	719509	1359492	2160
1999	203306	476396	980888	2371
2000	327565	277968	1074753	2323
2001	338227	284398	1064377	2310
2002	125856	292730	1059647	2310
2003	295442	171338	1041973	2140
2004	168527	229857	980314	2092
2005	420908	175307	947935	1970
2006	722360	304639	914679	2051
2007	537333	523547	975904	2384
2008	901010	482858	1108074	2614
2009	739628	687411	1241466	2717
2010	666165	661294	1351034	2429
2011	516677	609458	1251531	1987
2012	312152	505584	1008418	1561
2013	376174	351333	788128	1784
2014	314984	337286	865681	1752
2015	237031	296835	858175	1743
2016	220838	237727	863789	1797

Table 26: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tonnes on 15 February for the **Gmacs force** model.

Year	n_1	n_2	n_3	MMB
1978	2513295	2112431	1482198	4421
1979	4213666	2175227	2140256	5995
1980	3027196	3190463	3185316	9656
1981	1132816	2835931	4484522	9672
1982	1218566	1609772	4386043	6528
1983	625728	1250211	2948187	3456
1984	440201	783402	1512983	2138
1985	536200	519049	984947	1712
1986	655220	486898	758901	1569
1987	1153546	545767	747222	1599
1988	1563733	856801	802078	1921
1989	3342908	1200549	993561	2813
1990	1109096	2355639	1501812	4697
1991	1564083	1435442	2198110	4405
1992	1698097	1393408	2069837	4432
1993	2150895	1457738	2106414	4511
1994	1292455	1744275	2133157	4386
1995	688846	1338295	2062112	4223
1996	1982484	849762	1890143	3301
1997	879242	1443004	1613426	2978
1998	726412	996034	1351023	2443
1999	181953	757332	1133629	2973
2000	215098	359341	1341341	2913
2001	277137	245826	1318437	2742
2002	73393	244137	1247418	2607
2003	76741	124445	1170073	2326
2004	40917	86399	1045511	2052
2005	693708	52788	919832	1779
2006	990792	423196	852599	2069
2007	562997	719946	1005941	2662
2008	950581	563229	1233830	2939
2009	681725	743266	1390915	3038
2010	557963	646181	1499035	2656
2011	453465	541294	1357331	2086
2012	268384	445872	1054316	1567
2013	259282	305806	789703	1738
2014	233292	253738	834413	1607
2015	124628	221159	782981	1532
2016	83083	146732	753555	1502

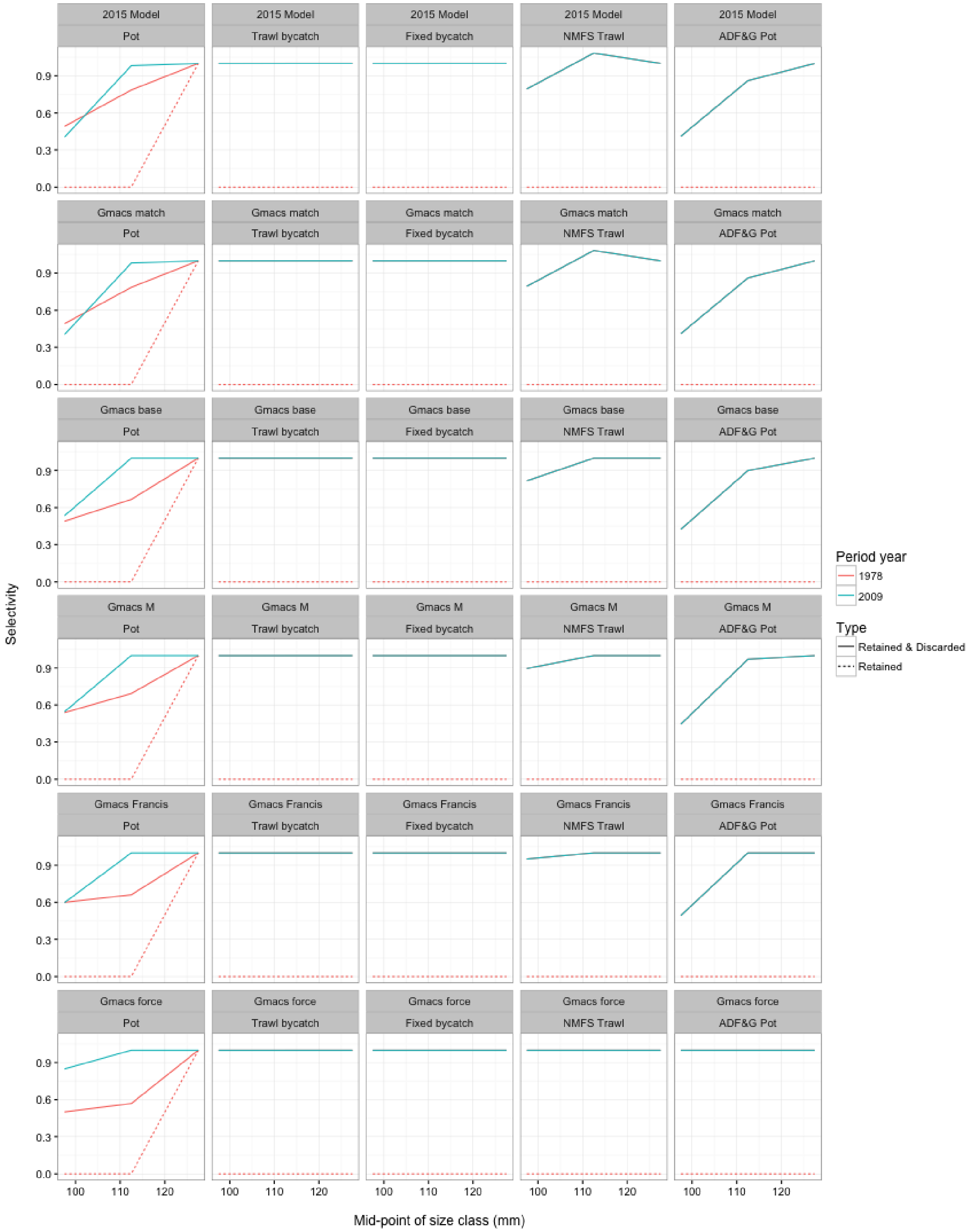


Figure 7: Comparisons of the estimated (and fixed to match the 2015 model selectivities in the Gmacs base scenario) stage-1 and stage-2 selectivities for each of the different model scenarios (the stage-3 selectivities are all fixed at 1). Estimated selectivities are shown for the directed pot fishery, the trawl bycatch fishery, the fixed bycatch fishery, the NMFS trawl survey, and the ADF&G pot survey. Two selectivity periods are estimated in the directed pot fishery, from 1978-2008 and 2009-2016.

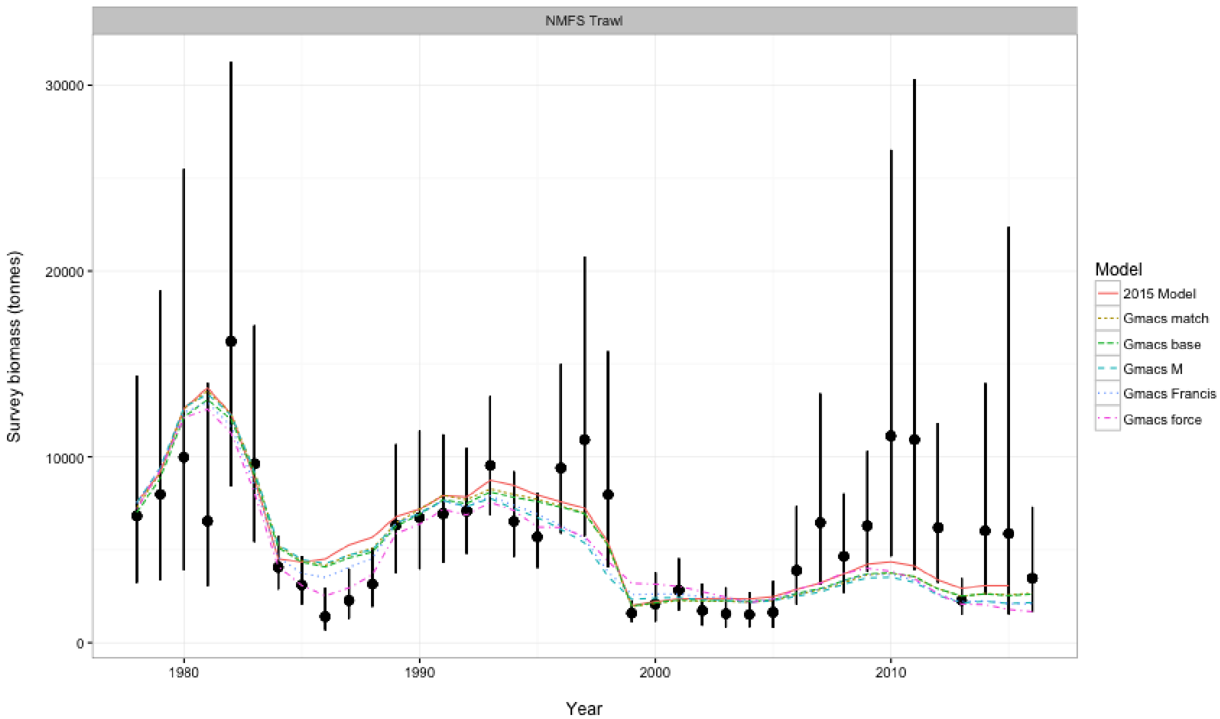


Figure 8: Comparisons of area-swept estimates of total male survey biomass (tonnes) and model predictions for the 2015 model and each of the Gmacs model scenarios. The error bars are plus and minus 2 standard deviations.

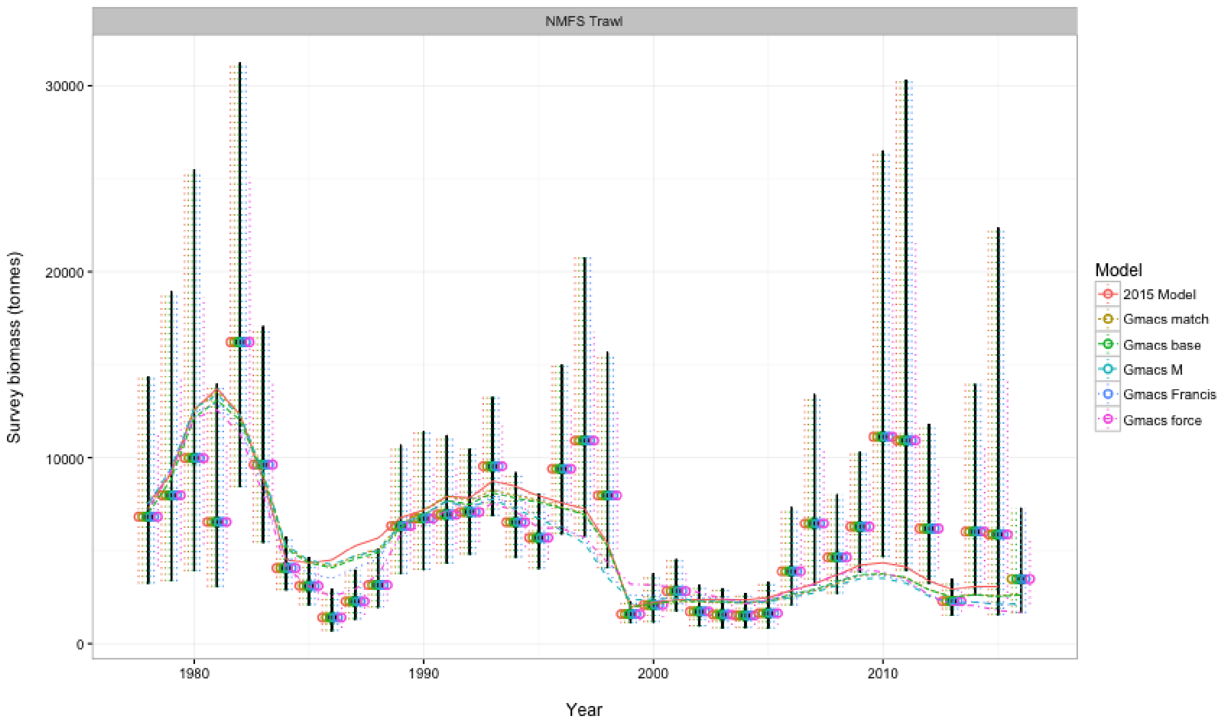


Figure 9: Comparisons of area-swept estimates of total male survey biomass (tonnes) and model predictions for the 2015 model and each of the Gmacs model scenarios. The solid black error bars are plus and minus 2 standard deviations derived using the original survey CVs. The dotted error bars are plus and minus 2 standard deviations but represent the weighted survey CVs.

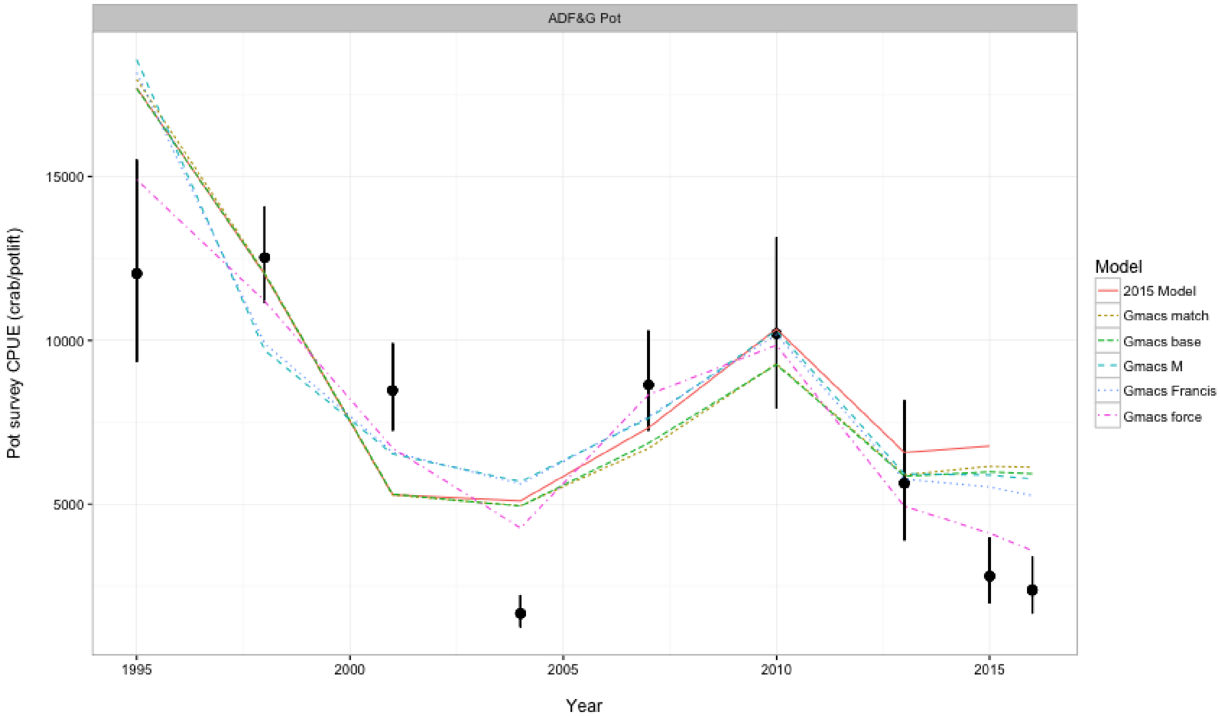


Figure 10: Comparisons of total male pot survey CPUEs and model predictions for the 2015 model and each of the Gmacs model scenarios. The error bars are plus and minus 2 standard deviations.

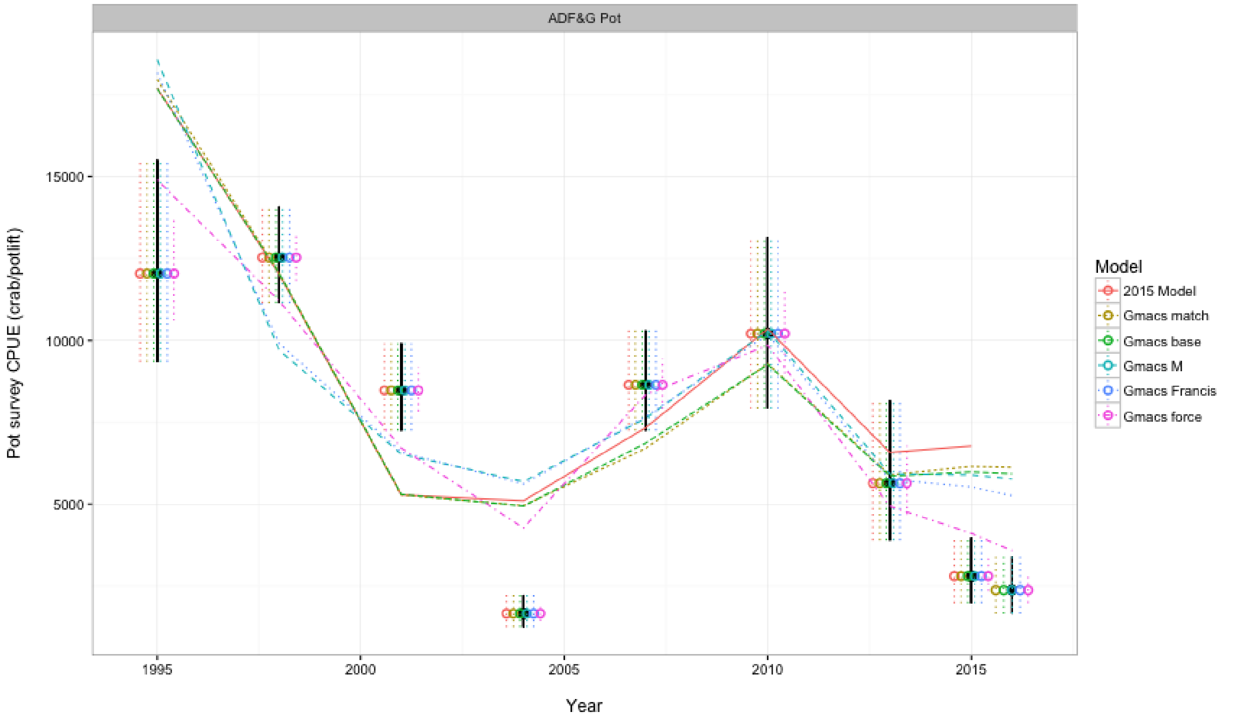


Figure 11: Comparisons of total male pot survey CPUEs and model predictions for the 2015 model and each of the Gmacs model scenarios. The solid black error bars are plus and minus 2 standard deviations derived using the original survey CVs. The dotted error bars are plus and minus 2 standard deviations but represent the weighted survey CVs.

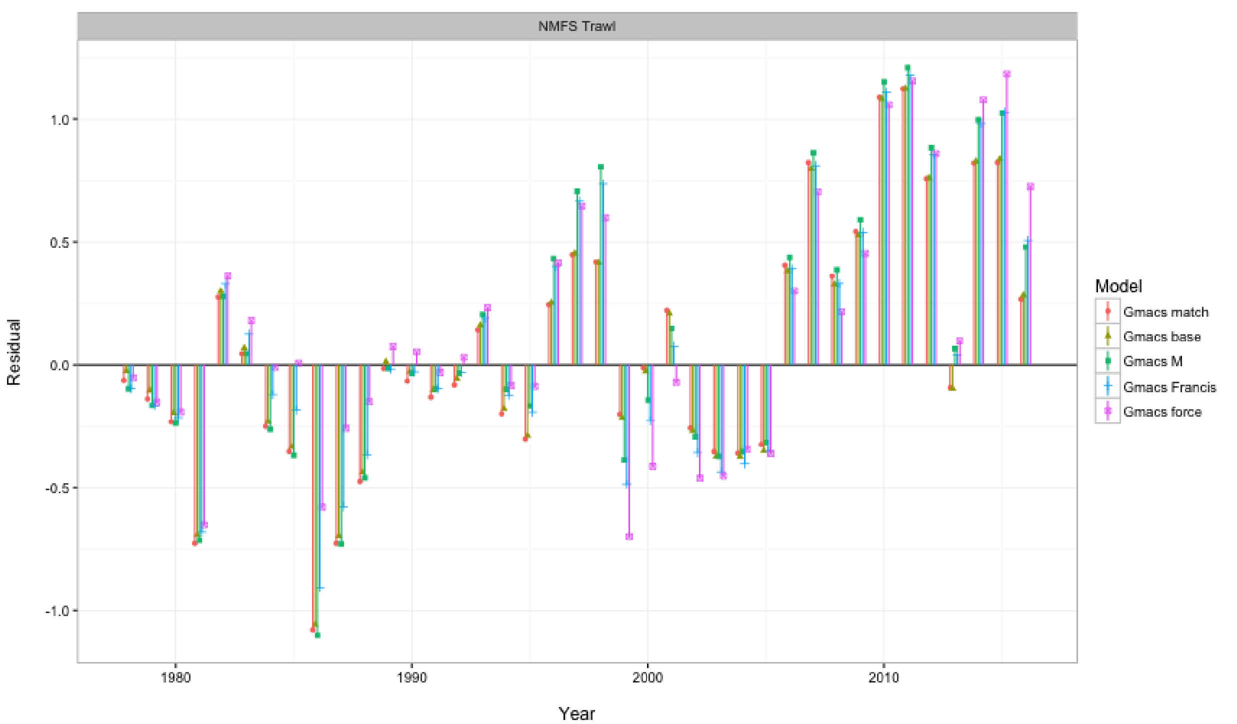


Figure 12: Standardized residuals for area-swept estimates of total male survey biomass for each of the Gmacs model scenarios.

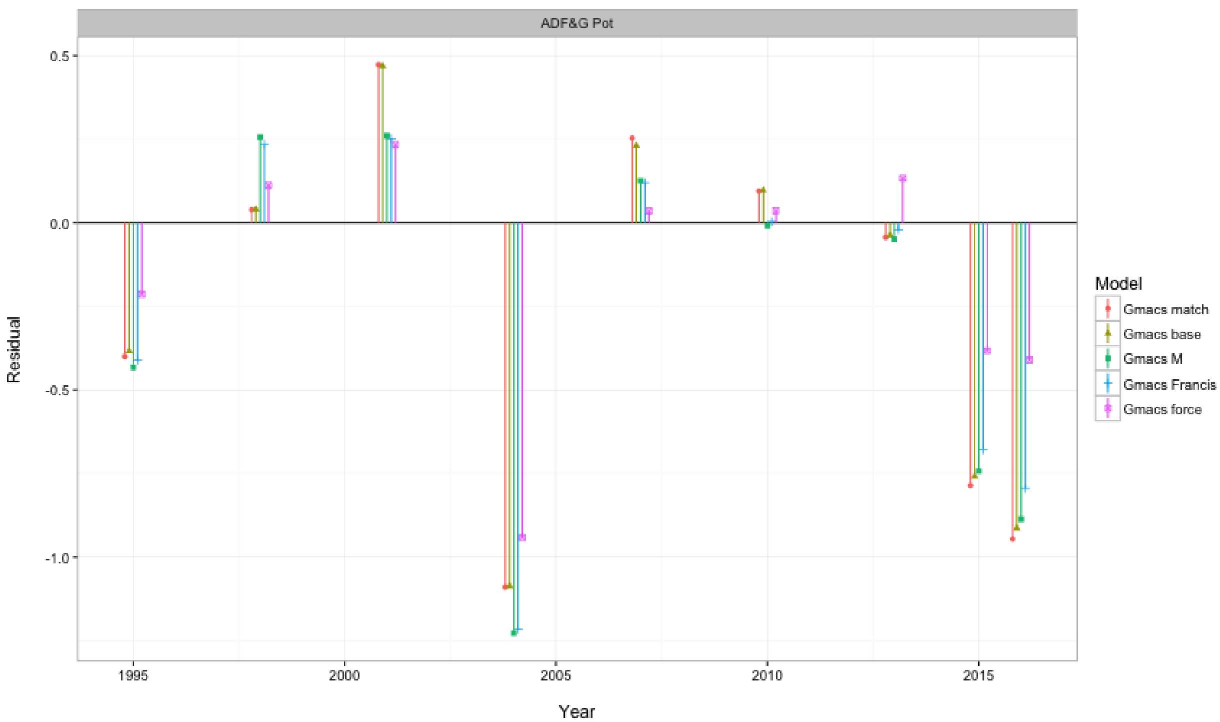


Figure 13: Standardized residuals for total male pot survey CPUEs for each of the Gmacs model scenarios.

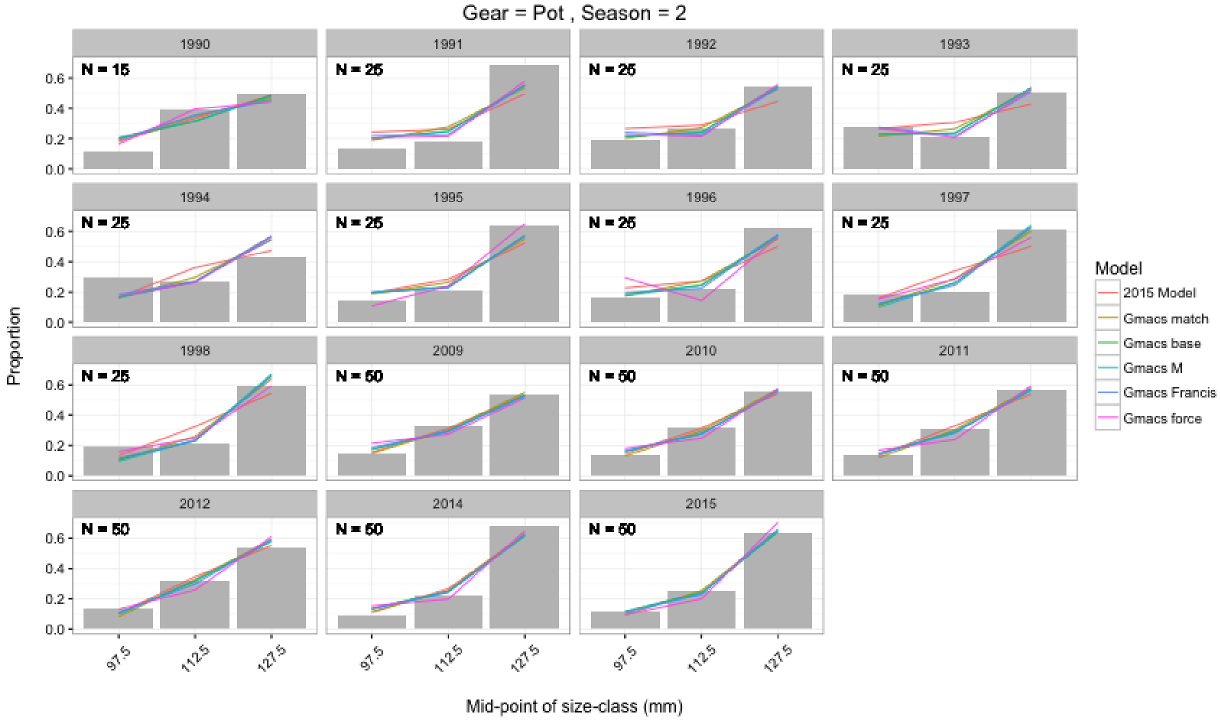


Figure 14: Observed and model estimated size-frequencies of SMBKC by year retained in the directed pot fishery for the 2015 model and each of the Gmacs model scenarios. Note that there is no model estimated size-frequency for the 2015 model during the 2015 year.

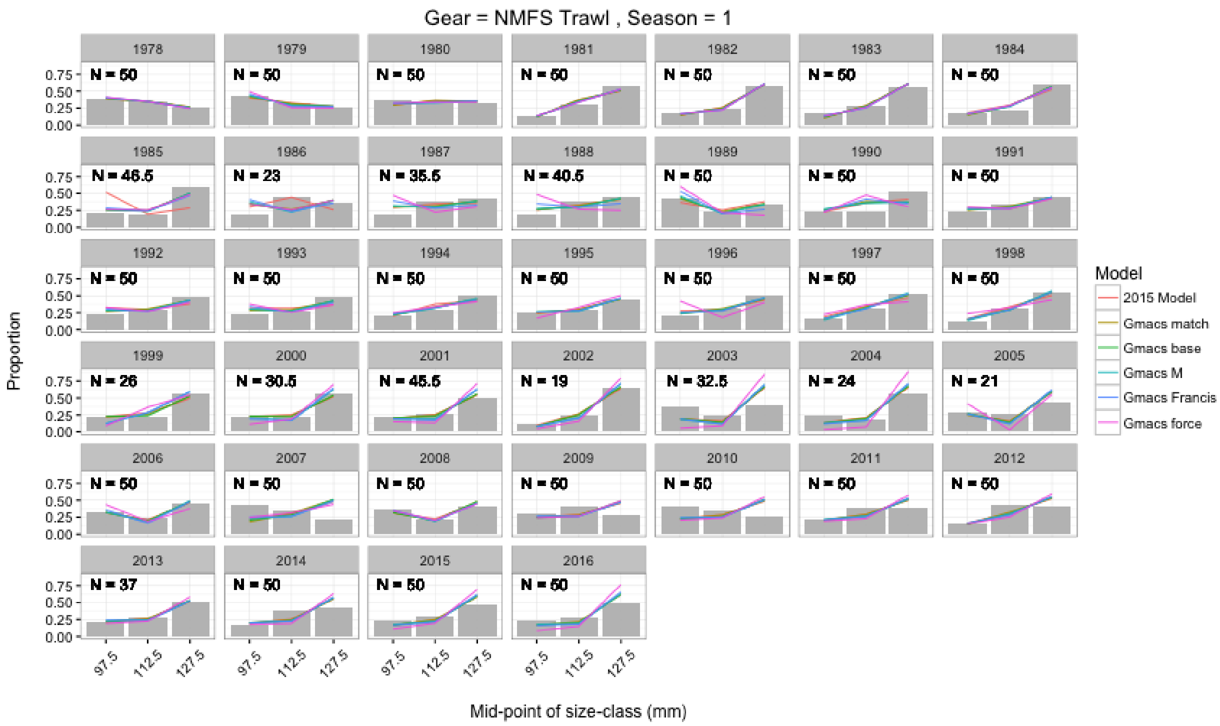


Figure 15: Observed and model estimated size-frequencies of discarded male SMBKC by year in the NMFS trawl survey for the 2015 model and each of the Gmacs model scenarios. Note that there is no model estimated size-frequency for the 2016 year.

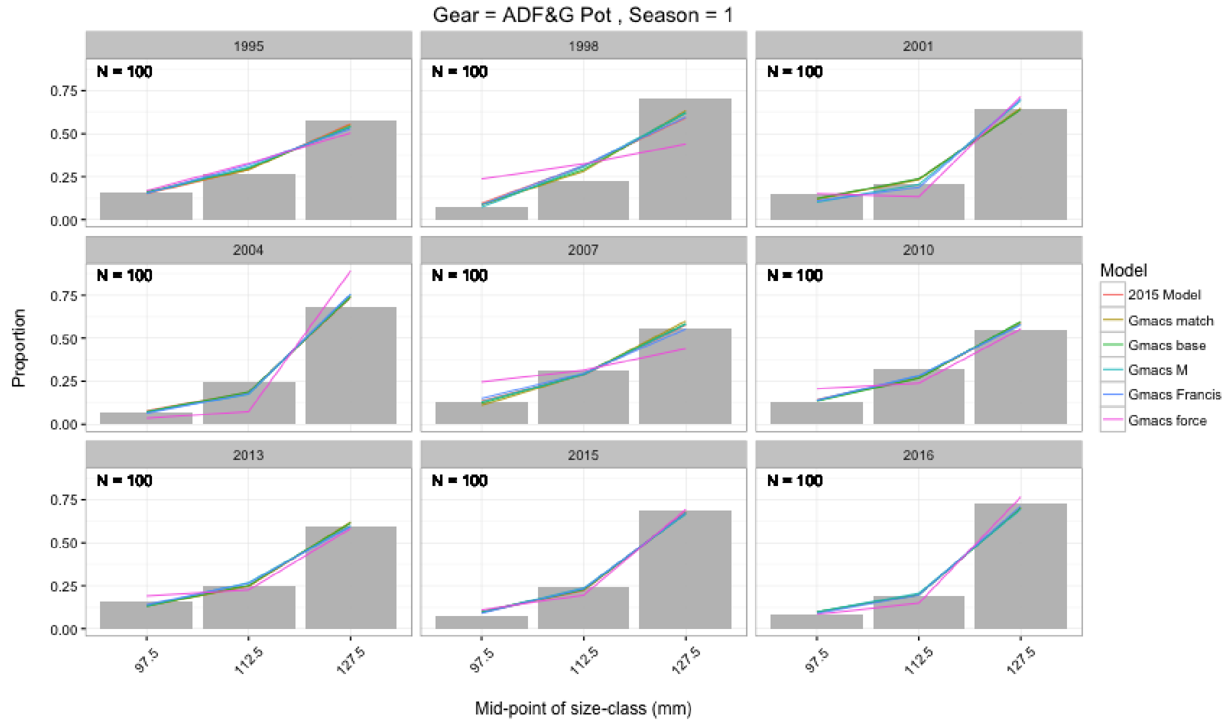


Figure 16: Observed and model estimated size-frequencies of discarded SMBKC by year in the ADF&G pot survey for the 2015 model and each of the Gmacs model scenarios. Note that there is no model estimated size-frequency for the 2015 model during the 2016 year.

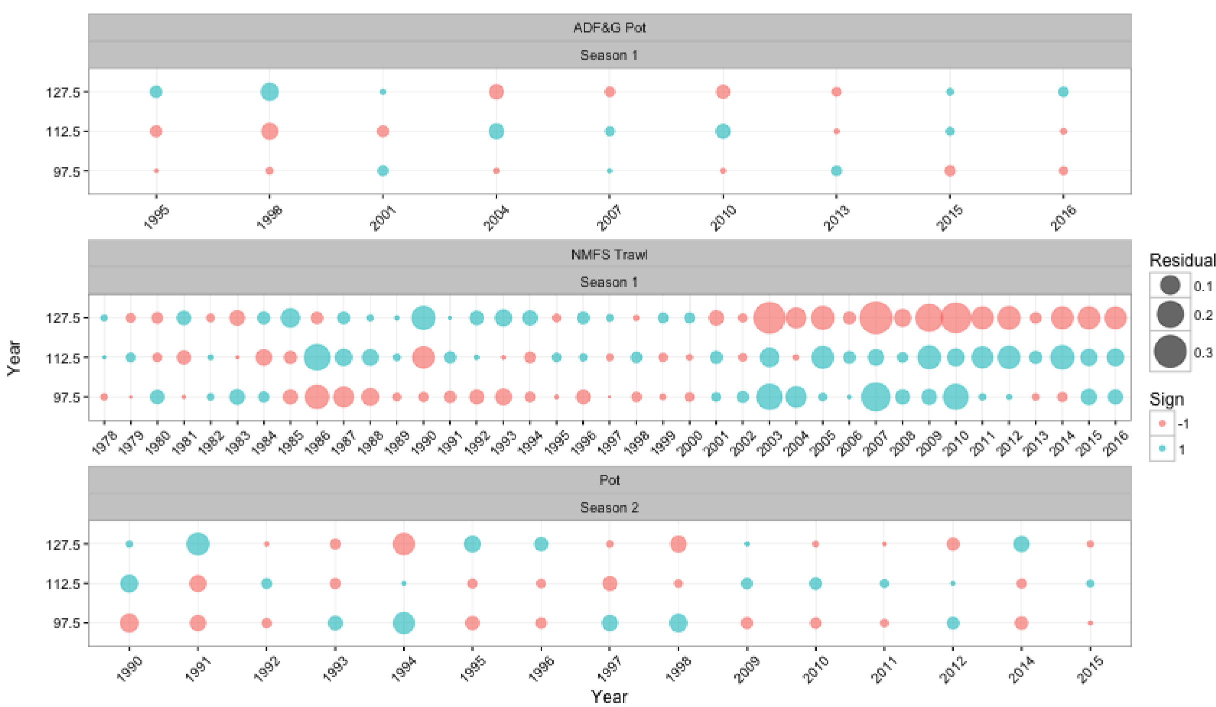


Figure 17: Bubble plots of residuals by stage and year for the directed pot fishery size composition data for St. Mathew Island blue king crab (SMBKC) in the **Gmacs base** model.

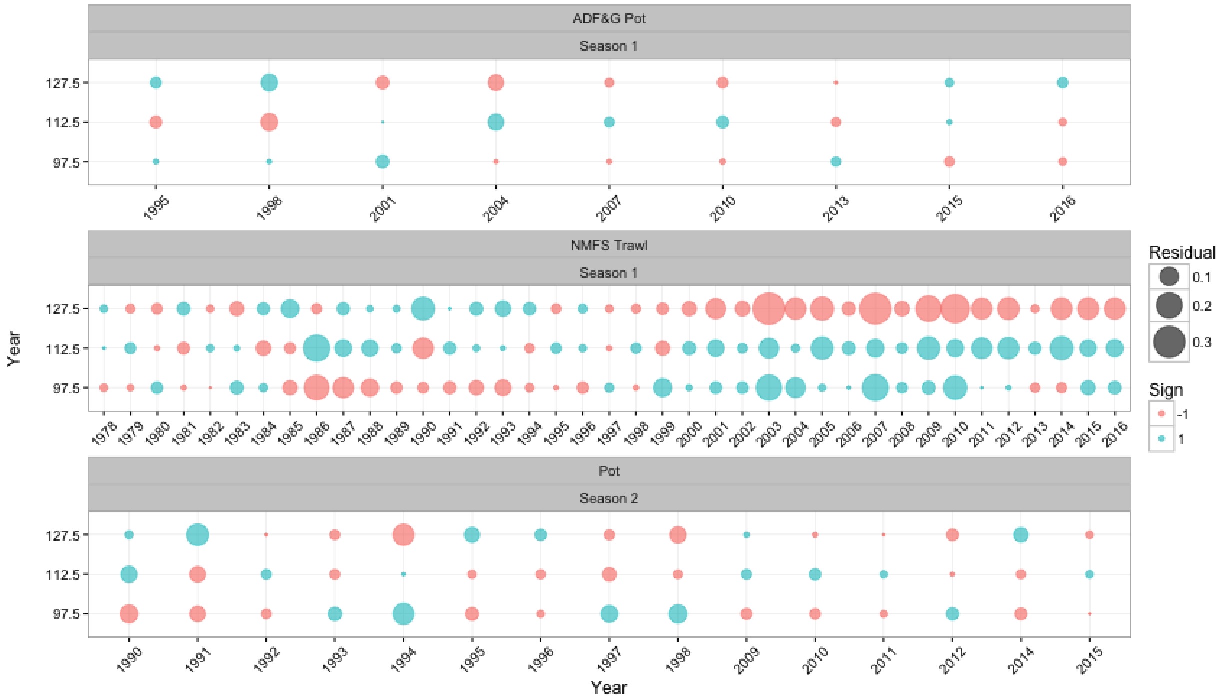


Figure 18: Bubble plots of residuals by stage and year for the NMFS trawl survey size composition data for St. Mathew Island blue king crab (SMBKC) in the **Gmacs M** model.

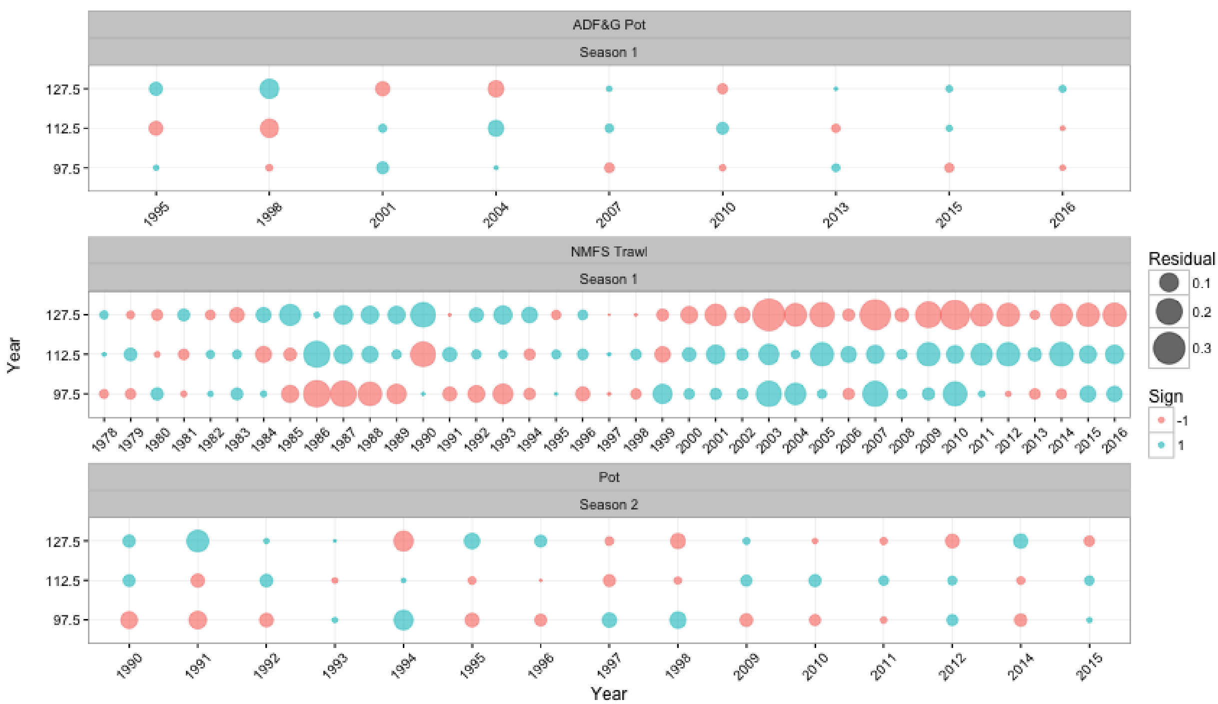


Figure 19: Bubble plots of residuals by stage and year for the NMFS trawl survey size composition data for St. Mathew Island blue king crab (SMBKC) in the **Gmacs Francis** model.

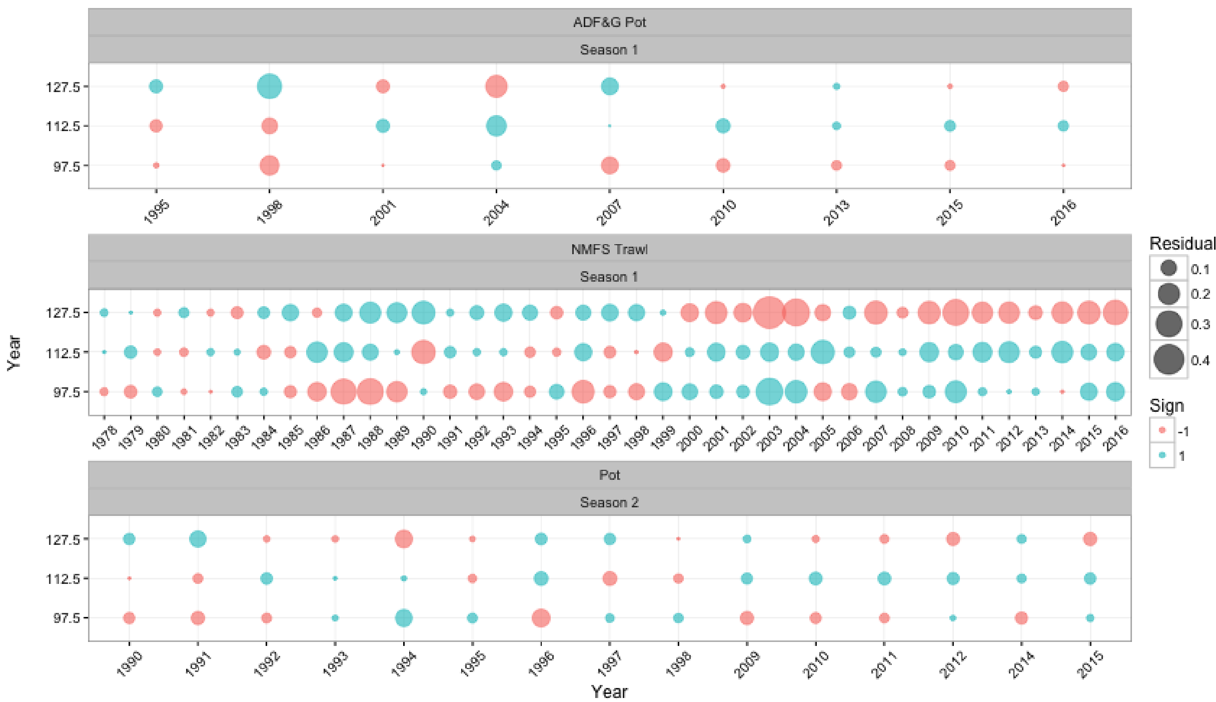


Figure 20: Bubble plots of residuals by stage and year for the ADF&G pot survey size composition data for St. Mathew Island blue king crab (SMBKC) in the **Gmacs force** model.

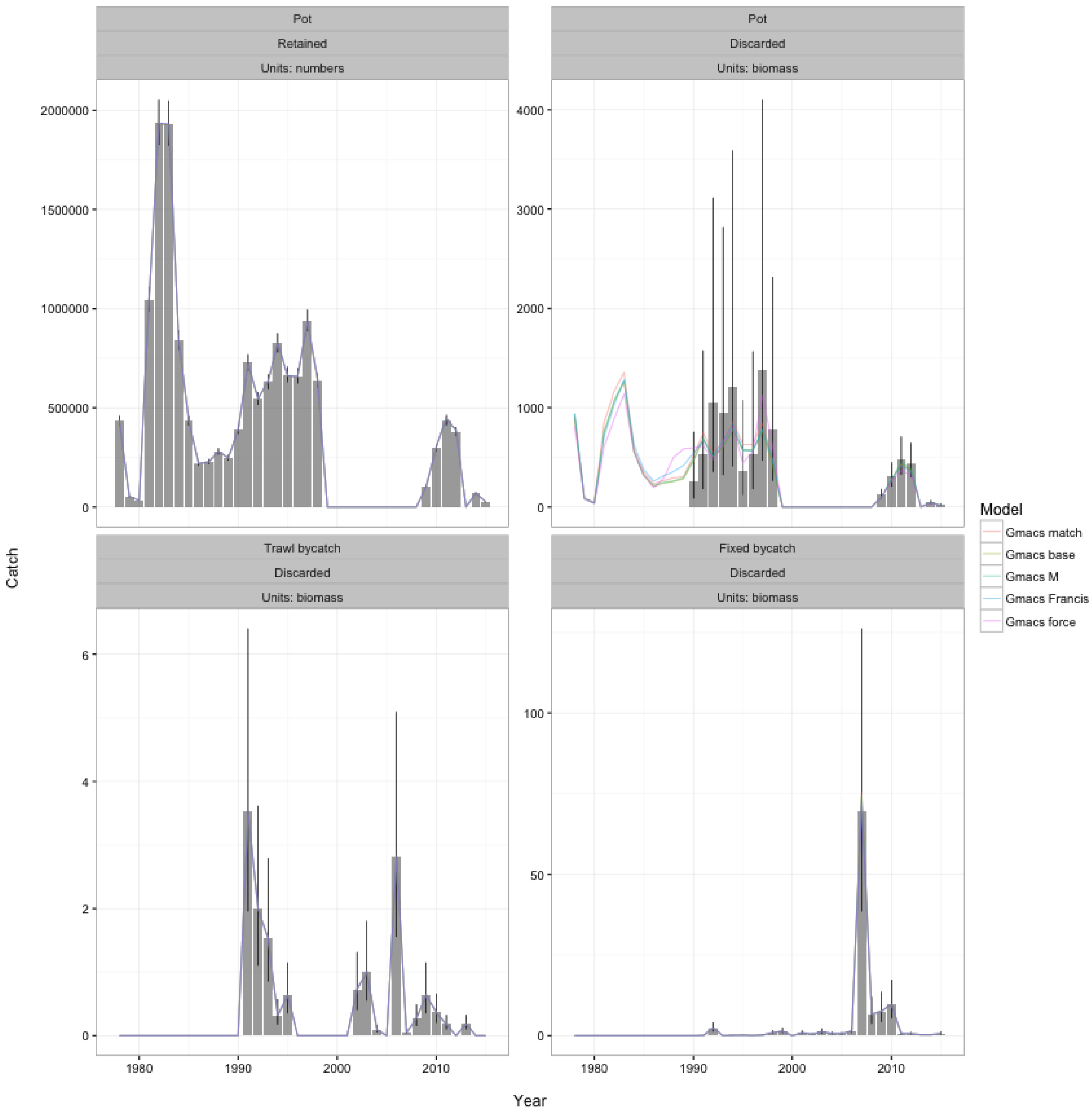


Figure 21: Comparison of observed and model predicted retained catch and bycatches in each of the Gmacs models. Note that difference in units between each of the panels, some panels are expressed in numbers of crab, some as biomass (tonnes).

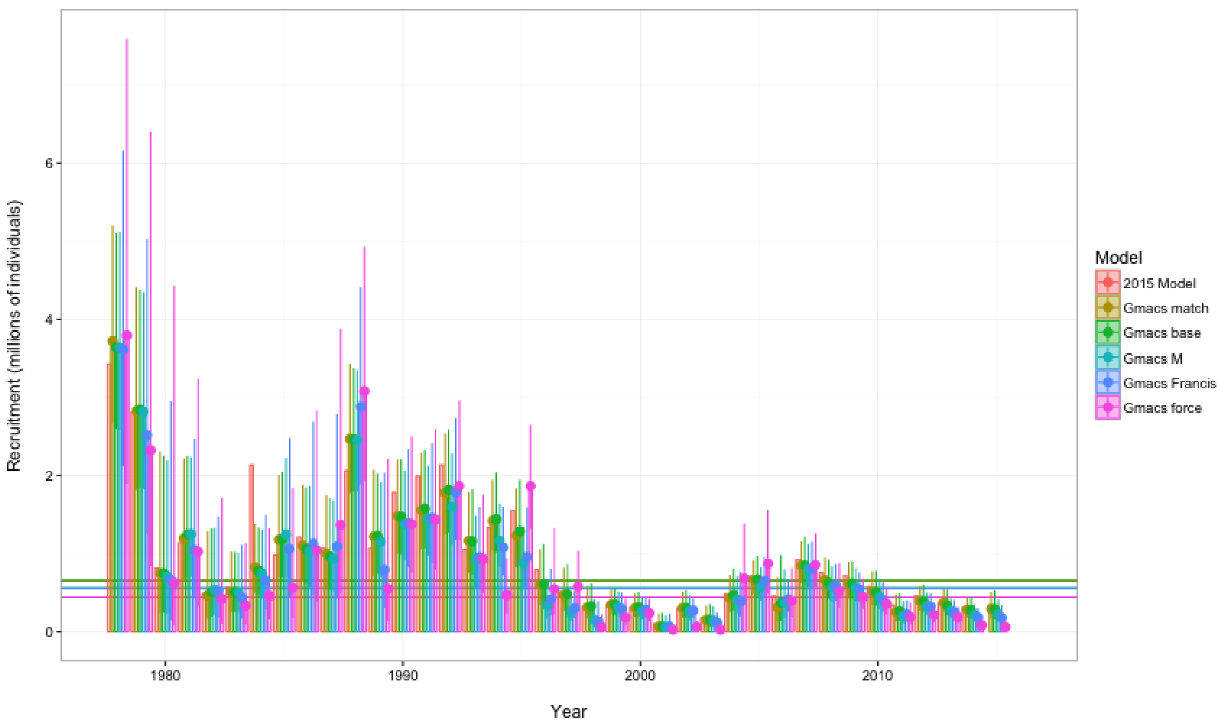


Figure 22: Comparisons of estimated recruitment time series during 1979-2016 in each of the scenarios. The solid horizontal lines in the background represent the estimate of the average recruitment parameter ($\bar{R}$) in each model scenario.

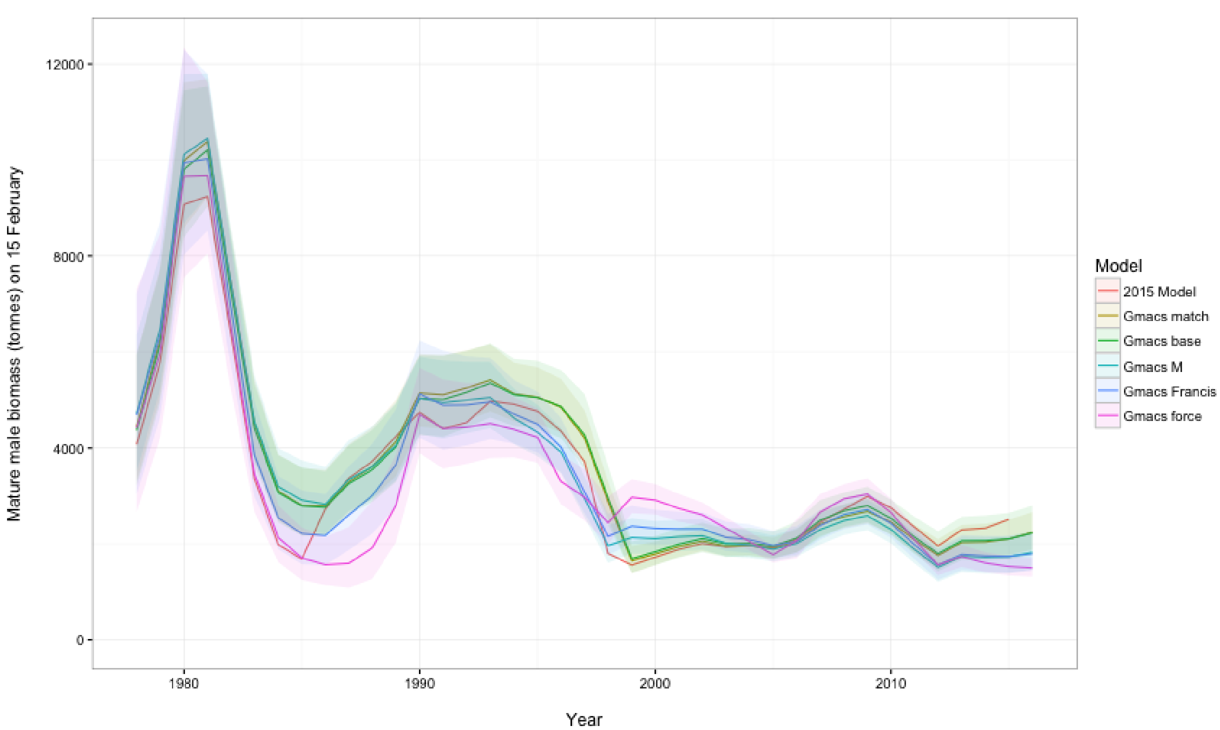


Figure 23: Comparisons of estimated mature male biomass (MMB) time series on 15 February during 1978-2016 for each of the model scenarios.

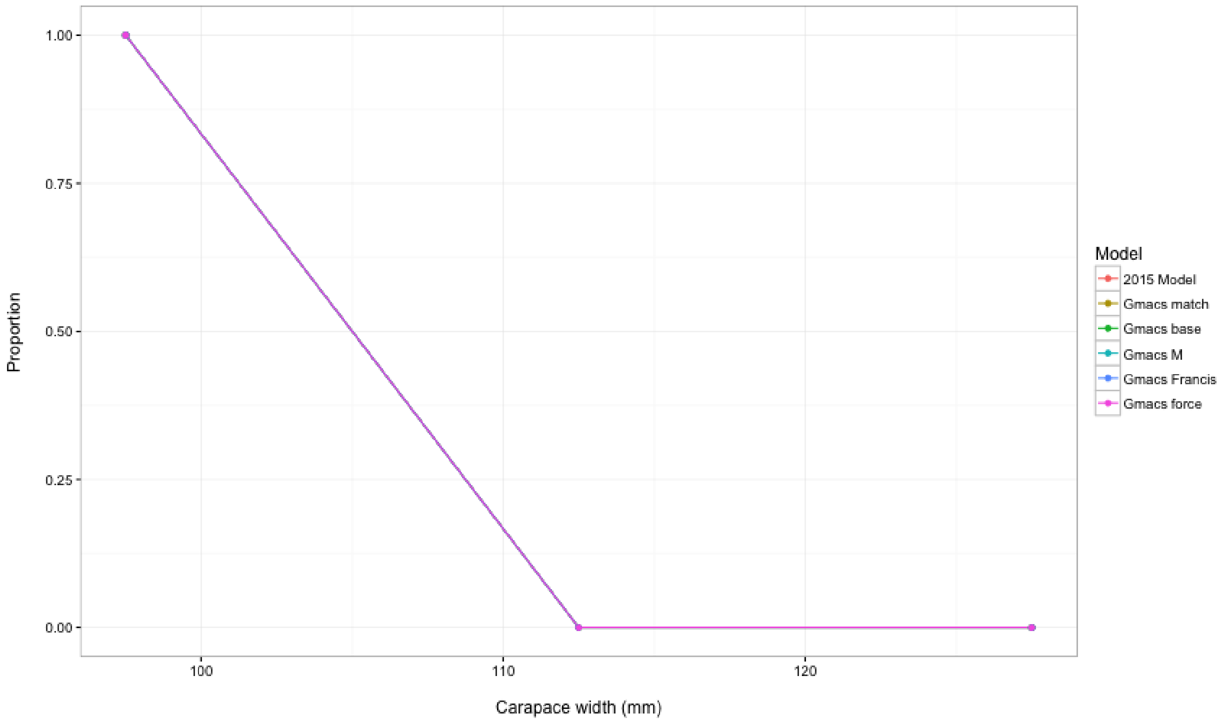


Figure 24: Distribution of carapace width (mm) at recruitment.

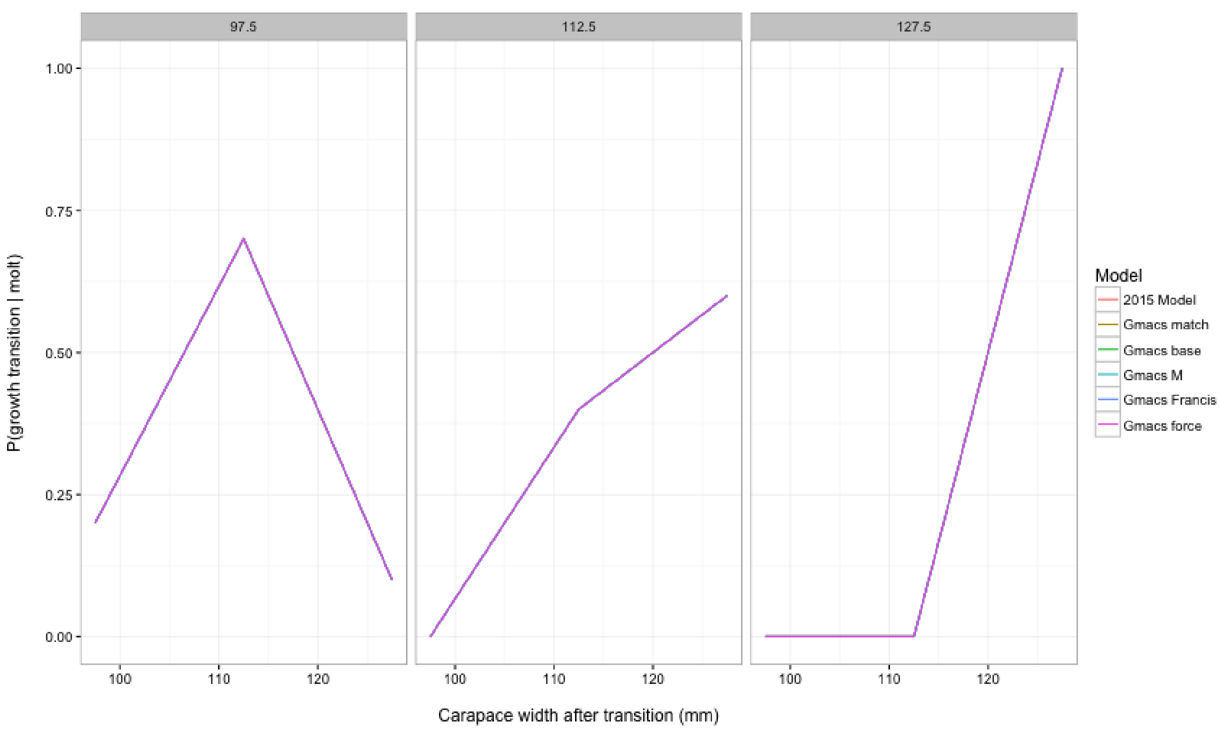


Figure 25: Probability of size transition by stage (i.e. the combination of the growth matrix and molting probabilities). Each of the panels represent the stage before a transition. The x-axes represent the stage after a transition. The size transition matrix was provided as an input directly to Gmacs (as it was during the 2015 SMBKC assessment).

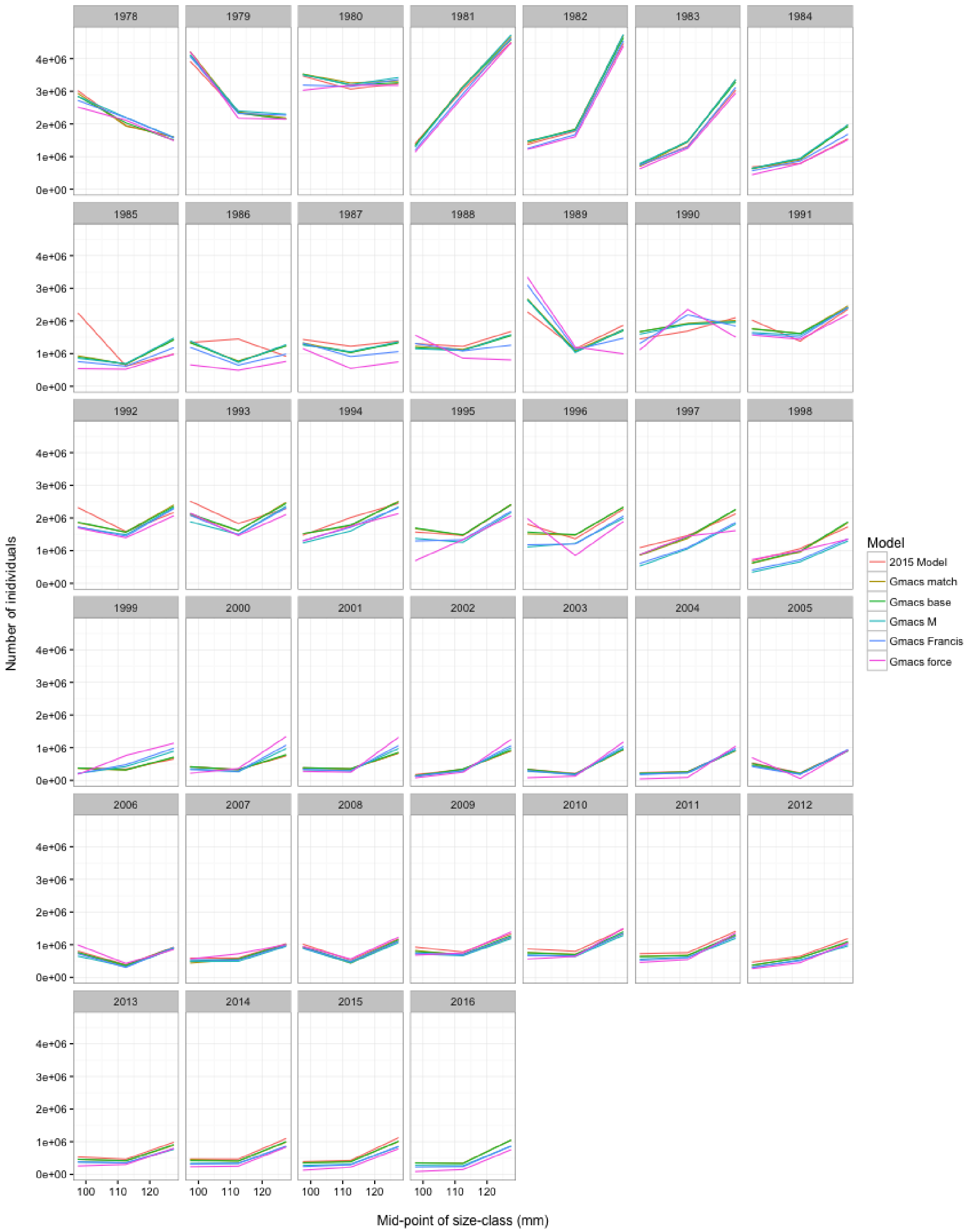


Figure 26: Numbers by stage each year (at the beginning of the model year, i.e. 1 July, season 1) in each of the models including the 2015 model.

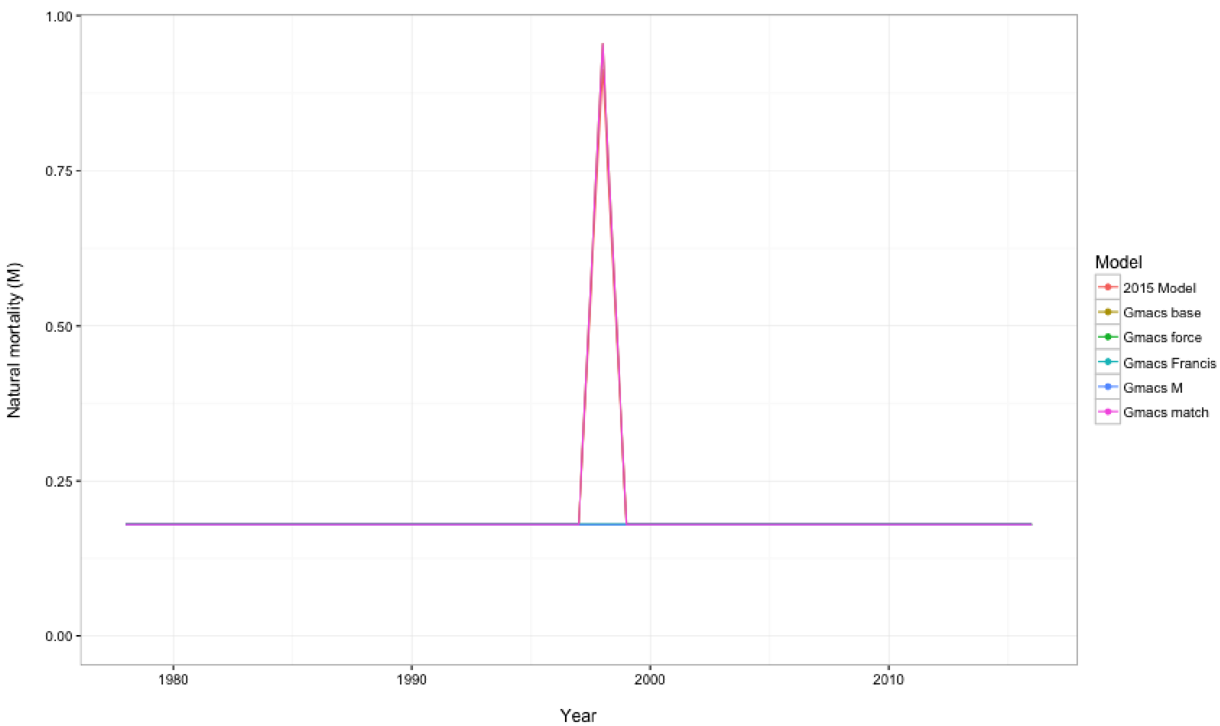


Figure 27: Time-varying natural mortality (M_t). Estimated pulse period occurs in 1998/99 (i.e. M_{1998}).

Appendix A: SMBKC Model Description

1. Introduction

The Gmacs model has been specified to account only for male crab at least 90 mm in carapace length (CL). These are partitioned into three stages (size-classes) determined by CL measurements of (1) 90-104 mm, (2) 105-119 mm, and (3) 120+ mm. For management of the St. Matthew Island blue king crab (SMBKC) fishery, 120 mm CL is used as the proxy value for the legal measurement of 5.5 mm in carapace width (CW), whereas 105 mm CL is the management proxy for mature-male size (5 AAC 34.917 (d)). Accordingly, within the model only stage-3 crab are retained in the directed fishery, and stage-2 and stage-3 crab together comprise the collection of mature males. Some justification for the 105 mm value is presented in Pengilly and Schmidt (1995), who used it in developing the current regulatory SMBKC harvest strategy. The term "recruit" here designates recruits to the model, i.e., annual new stage-1 crab, rather than recruits to the fishery. The following description of model structure reflects the Gmacs base model configuration.

2. Model Population Dynamics

Within the model, the beginning of the crab year is assumed contemporaneous with the NMFS trawl survey, nominally assigned a date of 1 July. Although the timing of the fishery is different each year, MMB is measured 15 February, which is the reference date for calculation of federal management biomass quantities. To accommodate this, each model year is split into 5 seasons (t) and a proportion of the natural mortality (τ_t) is applied in each of these seasons where $\sum_{t=1}^{t=5} \tau_t = 1$. Each model year consists of the following processes:

1. Season 1
   - Beginning of the SMBKC fishing year (1 July)
   - $\tau_1 = 0$
   - Surveys
2. Season 2
   - τ_2 ranges from 0.05 to 0.44 depending on the time of year the fishery begins each year (i.e. a higher value indicates the fishery begins later in the year; see Table 4)
3. Season 3
   - $\tau_3 = 0$
   - Fishing mortality applied
4. Season 4
   - $\tau_4 = 0.63 - \sum_{i=1}^{i=4} \tau_i$
   - Calculate MMB (15 February)
5. Season 5
   - $\tau_5 = 0.37$
   - Growth and molting
   - Recruitment (all to stage-1)

The proportion of natural mortality (τ_t) applied during each season in the model is provided in Table 27. The beginning of the year (1 July) to the date that MMB is measured (15 February) is 63% of the year. Therefore 63% of the natural mortality must be applied before the MMB is calculated. Because the timing of the fishery is different each year τ_2 is different each year and thus τ_4 differs each year.

With boldface lower-case letters indicating vector quantities we designate the vector of stage abundances during season t and year y as

$$\boldsymbol{n}_{t,y} = n_{l,t,y} = \left[n_{1,t,y}, n_{2,t,y}, n_{3,t,y}\right]^\top . \tag{2}$$

The number of new crab, or recruits, of each stage entering the model each season t and year y is represented as the vector $\boldsymbol{r}_{t,y}$. The SMBKC formulation of Gmacs specifies recruitment to stage-1 only during season $t = 5$, thus the recruitment size distribution is

$$\phi_l = \left[1, 0, 0\right]^\top , \tag{3}$$

and the recruitment is

$$\boldsymbol{r}_{t,y} = \begin{cases} 0 & \text{for} \quad t < 5 \\ \bar{R}\phi_l\delta^R_y & \text{for} \quad t = 5. \end{cases} \tag{4}$$

where $\bar{R}$ is the average annual recruitment and δ^R_y are the recruitment deviations each year y

$$\delta^R_y \sim \mathcal{N}\left(0, \sigma^2_R\right) . \tag{5}$$

Using boldface upper-case letters to indicate a matrix, we describe the size transition matrix $\boldsymbol{G}$ as

$$\boldsymbol{G} = \begin{bmatrix} 1 - \pi_{12} - \pi_{13} & \pi_{12} & \pi_{13} \\ 0 & 1 - \pi_{23} & \pi_{23} \\ 0 & 0 & 1 \end{bmatrix} , \tag{6}$$

with π_{jk} equal to the proportion of stage-j crab that molt and grow into stage-k within a season or year.

The natural mortality each season t and year y is

$$M_{t,y} = \bar{M}\tau_t + \delta^M_y \text{ where } \delta^M_y \sim \mathcal{N}\left(0, \sigma^2_M\right) \tag{7}$$

Fishing mortality by year y and season t is denoted $F_{t,y}$ and calculated as

$$F_{t,y} = F^{\text{df}}_{t,y} + F^{\text{tb}}_{t,y} + F^{\text{fb}}_{t,y} \tag{8}$$

where $F^{\text{df}}_{t,y}$ is the fishing mortality associated with the directed fishery, $F^{\text{tb}}_{t,y}$ is the fishing mortality associated with the trawl bycatch fishery, $F^{\text{fb}}_{t,y}$ is the fishing mortality associated with the fixed bycatch fishery. Each of these are derived as

$$\begin{aligned} F^{\text{df}}_{t,y} &= \bar{F}^{\text{df}} + \delta^{\text{df}}_{t,y} \quad \text{where} \quad \delta^{\text{df}}_{t,y} \sim \mathcal{N}\left(0, \sigma^2_{\text{df}}\right) , \\ F^{\text{tb}}_{t,y} &= \bar{F}^{\text{tb}} + \delta^{\text{tb}}_{t,y} \quad \text{where} \quad \delta^{\text{df}}_{t,y} \sim \mathcal{N}\left(0, \sigma^2_{\text{tb}}\right) , \\ F^{\text{fb}}_{t,y} &= \bar{F}^{\text{fb}} + \delta^{\text{fb}}_{t,y} \quad \text{where} \quad \delta^{\text{df}}_{t,y} \sim \mathcal{N}\left(0, \sigma^2_{\text{fb}}\right) , \end{aligned} \tag{9}$$

where $\delta^{\text{df}}_{t,y}$, $\delta^{\text{tb}}_{t,y}$, and $\delta^{\text{fb}}_{t,y}$ are the fishing mortality deviations for each of the fisheries, each season t during each year y, $\bar{F}^{\text{df}}$, $\bar{F}^{\text{tb}}$, and $\bar{F}^{\text{fb}}$ are the average fishing mortalities for each fishery. The total mortality $Z_{l,t,y}$ represents the combination of natural mortality $M_{t,y}$ and fishing mortality $F_{t,y}$ during season t and year y

$$\boldsymbol{Z}_{t,y} = Z_{l,t,y} = M_{t,y} + F_{t,y}. \tag{10}$$

The survival matrix $\boldsymbol{S}_{t,y}$ during season t and year y is

$$\boldsymbol{S}_{t,y} = \begin{bmatrix} 1 - e^{-Z_{1,t,y}} & 0 & 0 \\ 0 & 1 - e^{-Z_{2,t,y}} & 0 \\ 0 & 0 & 1 - e^{-Z_{3,t,y}} \end{bmatrix}. \tag{11}$$

The basic population dynamics underlying Gmacs can thus be described as

$$\begin{aligned} \boldsymbol{n}_{t+1,y} &= \boldsymbol{S}_{t,y}\boldsymbol{n}_{t,y}, && \text{if } t < 5 \\ \boldsymbol{n}_{t,y+1} &= \boldsymbol{G}\boldsymbol{S}_{t,y}\boldsymbol{n}_{t,y} + \boldsymbol{r}_{t,y} && \text{if } t = 5. \end{aligned} \tag{12}$$

3. Model Data

Data inputs used in model estimation are listed in Table 28.

4. Model Parameters

Table 29 lists fixed (externally determined) parameters used in model computations. In all scenarios, the stage-transition matrix is

$$\boldsymbol{G} = \begin{bmatrix} 0.2 & 0.7 & 0.1 \\ 0 & 0.4 & 0.6 \\ 0 & 0 & 1 \end{bmatrix} \tag{13}$$

which is the combination of the growth matrix and molting probabilities.

Estimated parameters are listed in Table 30 and include an estimated natural mortality deviation parameter in 1998/99 (δ^{M}_{1998}) assuming an anomalous mortality event in that year, as hypothesized by Zheng and Kruse (2002), with natural mortality otherwise fixed at 0.18 yr^{-1}.

5. Model Objective Function and Weighting Scheme

The objective function consists of the sum of several “negative log-likelihood” terms characterizing the hypothesized error structure of the principal data inputs (Table 20). A lognormal distribution is assumed to characterize the catch data and is modelled as

$$\sigma^{\text{catch}}_{t,y} = \sqrt{\log\left(1 + \left(CV^{\text{catch}}_{t,y}\right)^2\right)} \tag{14}$$

$$\delta^{\text{catch}}_{t,y} = \mathcal{N}\left(0, \left(\sigma^{\text{catch}}_{t,y}\right)^2\right) \tag{15}$$

where $\delta^{\text{catch}}_{t,y}$ is the residual catch. The relative abudance data is also assumed to be lognormally distributed

$$\sigma^{\mathrm{I}}_{t,y} = \frac{1}{\lambda}\sqrt{\log\left(1+\left(CV^{\mathrm{I}}_{t,y}\right)^{2}\right)} \tag{16}$$

$$\delta^{\mathrm{I}}_{t,y} = \log\left(I^{\mathrm{obs}}/I^{\mathrm{pred}}\right)/\sigma^{\mathrm{I}}_{t,y} + 0.5\sigma^{\mathrm{I}}_{t,y} \tag{17}$$

and the likelihood is

$$\sum \log\left(\delta^{\mathrm{I}}_{t,y}\right) + \sum 0.5\left(\sigma^{\mathrm{I}}_{t,y}\right)^{2} \tag{18}$$

Gmacs calculates standard deviation of the normalised residual (SDNR) values and median of the absolute residual (MAR) values for all abundance indices and size compositions to help the user come up with resonable likelihood weights. For an abundance data set to be well fitted, the SDNR should not be much greater than 1 (a value much less than 1, which means that the data set is fitted better than was expected, is not a cause for concern). What is meant by "much greater than 1" depends on m (the number of years in the data set). Francis (2011) suggests upper limits of 1.54, 1.37, and 1.26 for m = 5, 10, and 20, respectively. Although an SDNR not much greater than 1 is a necessary condition for a good fit, it is not sufficient. It is important to plot the observed and expected abundances to ensure that the fit is good.

Gmacs also calculates Francis weights for each of the size composition data sets supplied (Francis 2011). If the user wishes to use the Francis iterative re-weighting method, first the weights applied to the abundance indices should be adjusted by trial and error until the SDNR (and/or MAR) are adequte. Then the Francis weights supplied by Gmacs should be used as the new likelihood weights for each of the size composition data sets the next time the model is run. The user can then iteratively adjust the abudance index and size composition weights until adequate SDNR (and/or MAR) values are achieved, given the Francis weights.

6. Estimation

The model was implemented using the software AD Model Builder (Fournier et al. 2012), with parameter estimation by minimization of the model objective function using automatic differentiation. Parameter estimates and standard deviations provided in this document are AD Model Builder reported values assuming maximum likelihood theory asymptotics.

Table 27: Proportion of the natural mortality (τ_t) that is applied during each season (t) in the model.

Year	Season 1	Season 2	Season 3	Season 4	Season 5
1978	0.00	0.07	0.00	0.56	0.37
1979	0.00	0.06	0.00	0.57	0.37
1980	0.00	0.07	0.00	0.56	0.37
1981	0.00	0.05	0.00	0.58	0.37
1982	0.00	0.07	0.00	0.56	0.37
1983	0.00	0.12	0.00	0.51	0.37
1984	0.00	0.10	0.00	0.53	0.37
1985	0.00	0.14	0.00	0.49	0.37
1986	0.00	0.14	0.00	0.49	0.37
1987	0.00	0.14	0.00	0.49	0.37
1988	0.00	0.14	0.00	0.49	0.37
1989	0.00	0.14	0.00	0.49	0.37
1990	0.00	0.14	0.00	0.49	0.37
1991	0.00	0.18	0.00	0.45	0.37
1992	0.00	0.14	0.00	0.49	0.37
1993	0.00	0.18	0.00	0.45	0.37
1994	0.00	0.18	0.00	0.45	0.37
1995	0.00	0.18	0.00	0.45	0.37
1996	0.00	0.18	0.00	0.45	0.37
1997	0.00	0.18	0.00	0.45	0.37
1998	0.00	0.18	0.00	0.45	0.37
1999	0.00	0.18	0.00	0.45	0.37
2000	0.00	0.18	0.00	0.45	0.37
2001	0.00	0.18	0.00	0.45	0.37
2002	0.00	0.18	0.00	0.45	0.37
2003	0.00	0.18	0.00	0.45	0.37
2004	0.00	0.18	0.00	0.45	0.37
2005	0.00	0.18	0.00	0.45	0.37
2006	0.00	0.18	0.00	0.45	0.37
2007	0.00	0.18	0.00	0.45	0.37
2008	0.00	0.18	0.00	0.45	0.37
2009	0.00	0.44	0.00	0.19	0.37
2010	0.00	0.44	0.00	0.19	0.37
2011	0.00	0.44	0.00	0.19	0.37
2012	0.00	0.44	0.00	0.19	0.37
2013	0.00	0.44	0.00	0.19	0.37
2014	0.00	0.44	0.00	0.19	0.37
2015	0.00	0.44	0.00	0.19	0.37
2016	0.00	0.44	0.00	0.19	0.37

Table 28: Data inputs used in model estimation.

Data	Years	Source
Directed pot-fishery retained-catch number (not biomass)	1978/79 - 1998/99 2009/10 - 2015/16	Fish tickets (fishery closed 1999/00 - 2008/09)
Groundfish trawl bycatch biomass	1992/93 - 2015/16	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93 - 2015/16	NMFS groundfish observer program
NMFS trawl-survey biomass index (area-swept estimate) and CV	1978-2016	NMFS EBS trawl survey
ADF&G pot-survey abundance index (CPUE) and CV	Triennial 1995-2016	ADF&G SMBKC pot survey
NMFS trawl-survey stage proportions and total number of measured crab	1978-2016	NMFS EBS trawl survey
ADF&G pot-survey stage proportions and total number of measured crab	Triennial 1995-2016	ADF&G SMBKC pot survey
Directed pot-fishery stage proportions and total number of measured crab	1990/91 - 1998/99 2009/10 - 2015/16	ADF&G crab observer program (fishery closed 1999/00 - 2008/09)

Table 29: Fixed model parameters for all scenarios.

Parameter	Symbol	Value	Source/rationale
Trawl-survey catchability	q	1.0	Default
Natural mortality	M	0.18 yr^{-1}	NPFMC (2007)
Size transition matrix	$\boldsymbol{G}$	Equation 13	Otto and Cummiskey (1990)
Stage-1 and stage-2 mean weights	w_1, w_2	0.7, 1.2 kg	Length-weight equation (B. Foy, NMFS) applied to stage midpoints
Stage-3 mean weight	$w_{3,y}$	Depends on year Table 11	Fishery reported average retained weight from fish tickets, or its average, and mean weights of legal males
Recruitment SD	σ_R	1.2	High value
Natural mortality SD	σ_M	10.0	High value (basically free parameter)
Directed fishery handling mortality		0.2	2010 Crab SAFE
Groundfish trawl handling mortality		0.8	2010 Crab SAFE
Groundfish fixed-gear handling mortality		0.5	2010 Crab SAFE

Table 30: The lower bound (LB), upper bound (UB), initial value, prior, and estimation phase for each estimated model parameter.

Parameter	LB	Initial value	UB	Prior	Phase
Average recruitment $\log(\bar{R})$	-7	10.0	20	Uniform(-7,20)	1
Stage-1 initial numbers $\log(n_1^0)$	5	14.5	20	Uniform(5,20)	1
Stage-2 initial numbers $\log(n_2^0)$	5	14.0	20	Uniform(5,20)	1
Stage-3 initial numbers $\log(n_3^0)$	5	13.5	20	Uniform(5,20)	1
ADF&G pot survey catchability q	0	4.0	5	Uniform(0,5)	1
Stage-1 directed fishery selectivity 1978-2008	0	0.4	1	Uniform(0,1)	3
Stage-2 directed fishery selectivity 1978-2008	0	0.7	1	Uniform(0,1)	3
Stage-1 directed fishery selectivity 2009-2015	0	0.4	1	Uniform(0,1)	3
Stage-2 directed fishery selectivity 2009-2015	0	0.7	1	Uniform(0,1)	3
Stage-1 NMFS trawl survey selectivity	0	0.4	1	Uniform(0,1)	4
Stage-2 NMFS trawl survey selectivity	0	0.7	1	Uniform(0,1)	4
Stage-1 ADF&G pot survey selectivity	0	0.4	1	Uniform(0,1)	4
Stage-2 ADF&G pot survey selectivity	0	0.7	1	Uniform(0,1)	4
Natural mortality deviation during 1998 δ_{1998}^M	-3	0.0	3	Normal(0, σ_M^2)	4
Recruitment deviations δ_y^R	-7	0.0	7	Normal(0, σ_R^2)	3
Average directed fishery fishing mortality $\bar{F}^{\text{df}}$	-	0.2	-	-	1
Average trawl bycatch fishing mortality $\bar{F}^{\text{tb}}$	-	0.001	-	-	1
Average fixed gear bycatch fishing mortality $\bar{F}^{\text{fb}}$	-	0.001	-	-	1

Appendix B: SMBKC Stock Assessment Input Files

The data file:

```
## #=====================================================================================
## # Gmacs Main  Data  File  Version 1.1:  SM15 example
## # GEAR_INDEX   DESCRIPTION
## #    1        : Pot fishery retained catch.
## #    1        : Pot fishery with discarded catch.
## #    2        : Trawl bycatch
## #    3        : Fixed bycatch
## #    4        : Trawl survey
## #    5        : Pot survey
##
## # Fisheries:  1 Pot Fishery,  2 Pot Discard,  3 Trawl by-catch, 3 Fixed by-catch
## # Surveys:    4 NMFS Trawl Survey, 5 Pot Survey
## #=====================================================================================
##
## 1978  # Start year
## 2016  # End year
## 2017  # Projection year
## 5     # Number of seasons
## 5     # Number of distinct data groups (among fishing fleets and surveys)
## 1     # Number of sexes
## 1     # Number of shell condition types
## 1     # Number of maturity types
## 3     # Number of size-classes in the model
## 5     # Season recruitment occurs
## 5     # Season molting and growth occurs
## 4     # Season to calculate SSB
## 1     # Season for N output
## # size_breaks (a vector giving the break points between size intervals with dimension nclass+1)
## 90  105  120  135
## # weight-at-length input method (1 = allometry i.e. w_l = a*l^b, 2 = vector by sex, 3 = matrix by se
## 3
## # weight-at-length allometry w_l = a*l^b
## 4.03E-07
## # b (male, female)
## 3.141334
## # Male weight-at-length
## 0.000748427     0.001165731     0.001930510
## 0.000748427     0.001165731     0.001688886
## 0.000748427     0.001165731     0.001922246
## 0.000748427     0.001165731     0.001877957
## 0.000748427     0.001165731     0.001938634
## 0.000748427     0.001165731     0.002076413
## 0.000748427     0.001165731     0.001899330
## 0.000748427     0.001165731     0.002116687
## 0.000748427     0.001165731     0.001938784
## 0.000748427     0.001165731     0.001939764
## 0.000748427     0.001165731     0.001871067
## 0.000748427     0.001165731     0.001998295
## 0.000748427     0.001165731     0.001870418
## 0.000748427     0.001165731     0.001969415
## 0.000748427     0.001165731     0.001926859
## 0.000748427     0.001165731     0.002021492
```

```
## 0.000748427     0.001165731     0.001931318
## 0.000748427     0.001165731     0.002014407
## 0.000748427     0.001165731     0.001977471
## 0.000748427     0.001165731     0.002099246
## 0.000748427     0.001165731     0.001982478
## 0.000748427     0.001165731     0.001930932
## 0.000748427     0.001165731     0.001930932
## 0.000748427     0.001165731     0.001930932
## 0.000748427     0.001165731     0.001930932
## 0.000748427     0.001165731     0.001930932
## 0.000748427     0.001165731     0.001930932
## 0.000748427     0.001165731     0.001930932
## 0.000748427     0.001165731     0.001930932
## 0.000748427     0.001165731     0.001930932
## 0.000748427     0.001165731     0.001930932
## 0.000748427     0.001165731     0.001891628
## 0.000748427     0.001165731     0.001795721
## 0.000748427     0.001165731     0.001823113
## 0.000748427     0.001165731     0.001807433
## 0.000748427     0.001165731     0.001930932
## 0.000748427     0.001165731     0.001894627
## 0.000748427     0.001165731     0.001850611
## 0.000748427     0.001165731     0.001930932
## # Male mature weight-at-length (weight * proportion  mature)
## 0 0.001165732 0.001945911
## # Proportion mature by sex
## 0 1 1
## # Natural mortality per season input type (1 = vector by season, 2 = matrix by season/year)
## 2
## # Proportion of the total natural mortality to be applied each season (each row must add to 1)
## #0  0.0025  0  0.6245  0.373
##    0.0000   0.0700   0.0000   0.5600   0.3700
##    0.0000   0.0600   0.0000   0.5700   0.3700
##    0.0000   0.0700   0.0000   0.5600   0.3700
##    0.0000   0.0500   0.0000   0.5800   0.3700
##    0.0000   0.0700   0.0000   0.5600   0.3700
##    0.0000   0.1200   0.0000   0.5100   0.3700
##    0.0000   0.1000   0.0000   0.5300   0.3700
##    0.0000   0.1400   0.0000   0.4900   0.3700
##    0.0000   0.1400   0.0000   0.4900   0.3700
##    0.0000   0.1400   0.0000   0.4900   0.3700
##    0.0000   0.1400   0.0000   0.4900   0.3700
##    0.0000   0.1400   0.0000   0.4900   0.3700
##    0.0000   0.1400   0.0000   0.4900   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.1400   0.0000   0.4900   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
```

```
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.1800   0.0000   0.4500   0.3700
##    0.0000   0.4400   0.0000   0.1900   0.3700
##    0.0000   0.4400   0.0000   0.1900   0.3700
##    0.0000   0.4400   0.0000   0.1900   0.3700
##    0.0000   0.4400   0.0000   0.1900   0.3700
##    0.0000   0.4400   0.0000   0.1900   0.3700
##    0.0000   0.4400   0.0000   0.1900   0.3700
##    0.0000   0.4400   0.0000   0.1900   0.3700
##    0.0000   0.4400   0.0000   0.1900   0.3700
## # Fishing fleet names (delimited with : no spaces in names)
## Pot_Fishery:Trawl_Bycatch:Fixed_bycatch
## # Survey names (delimited with : no spaces in names)
## NMFS_Trawl:ADFG_Pot
## # Number  of  catch data  frames
## 4
## # Number  of  rows  in  each  data  frame
## 27  15  25  25
## ##  CATCH DATA
## ##  Type of catch: 1 = retained, 2 = discard
## ##  Units of catch: 1 = biomass, 2 = numbers
## ##  for SMBKC Units are in number of crab for landed & 1000 kg for discards.
## ##  Male Retained
## # year  seas    fleet   sex     obs     cv      type    units   mult    effort  discard_mortality
## 1978    2       1       1       436126  0.03    1       2       1       0       0
## 1979    2       1       1       52966   0.03    1       2       1       0       0
## 1980    2       1       1       33162   0.03    1       2       1       0       0
## 1981    2       1       1       1045619 0.03    1       2       1       0       0
## 1982    2       1       1       1935886 0.03    1       2       1       0       0
## 1983    2       1       1       1931990 0.03    1       2       1       0       0
## 1984    2       1       1       841017  0.03    1       2       1       0       0
## 1985    2       1       1       436021  0.03    1       2       1       0       0
## 1986    2       1       1       219548  0.03    1       2       1       0       0
## 1987    2       1       1       227447  0.03    1       2       1       0       0
## 1988    2       1       1       280401  0.03    1       2       1       0       0
## 1989    2       1       1       247641  0.03    1       2       1       0       0
## 1990    2       1       1       391405  0.03    1       2       1       0       0
## 1991    2       1       1       726519  0.03    1       2       1       0       0
## 1992    2       1       1       545222  0.03    1       2       1       0       0
## 1993    2       1       1       630353  0.03    1       2       1       0       0
## 1994    2       1       1       827015  0.03    1       2       1       0       0
## 1995    2       1       1       666905  0.03    1       2       1       0       0
## 1996    2       1       1       660665  0.03    1       2       1       0       0
## 1997    2       1       1       939822  0.03    1       2       1       0       0
## 1998    2       1       1       635370  0.03    1       2       1       0       0
## 2009    2       1       1       103376  0.03    1       2       1       0       0
## 2010    2       1       1       298669  0.03    1       2       1       0       0
## 2011    2       1       1       437862  0.03    1       2       1       0       0
```

```
## 2012    2       1       1       379386  0.03    1       2       1       0       0
## 2014    2       1       1       69109   0.03    1       2       1       0       0
## 2015    2       1       1       24407   0.03    1       2       1       0       0
## # Male  discards  Pot fishery
## 1990    2       1       1     254.9787861     0.6     2       1       1       0       0.2
## 1991    2       1       1     531.4483252     0.6     2       1       1       0       0.2
## 1992    2       1       1     1050.387026     0.6     2       1       1       0       0.2
## 1993    2       1       1     951.4626128     0.6     2       1       1       0       0.2
## 1994    2       1       1     1210.764588     0.6     2       1       1       0       0.2
## 1995    2       1       1     363.112032      0.6     2       1       1       0       0.2
## 1996    2       1       1     528.5244687     0.6     2       1       1       0       0.2
## 1997    2       1       1     1382.825328     0.6     2       1       1       0       0.2
## 1998    2       1       1     781.1032977     0.6     2       1       1       0       0.2
## 2009    2       1       1     123.3712279     0.2     2       1       1       0       0.2
## 2010    2       1       1     304.6562225     0.2     2       1       1       0       0.2
## 2011    2       1       1     481.3572126     0.2     2       1       1       0       0.2
## 2012    2       1       1     437.3360731     0.2     2       1       1       0       0.2
## 2014    2       1       1     45.4839749      0.2     2       1       1       0       0.2
## 2015    2       1       1     21.19378597     0.2     2       1       1       0       0.2
## # Trawl fishery discards
## 1991    2       2       1       3.538   0.31    2       1       1       0       0.8
## 1992    2       2       1       1.996   0.31    2       1       1       0       0.8
## 1993    2       2       1       1.542   0.31    2       1       1       0       0.8
## 1994    2       2       1       0.318   0.31    2       1       1       0       0.8
## 1995    2       2       1       0.635   0.31    2       1       1       0       0.8
## 1996    2       2       1       0.000   0.31    2       1       1       0       0.8
## 1997    2       2       1       0.000   0.31    2       1       1       0       0.8
## 1998    2       2       1       0.000   0.31    2       1       1       0       0.8
## 1999    2       2       1       0.000   0.31    2       1       1       0       0.8
## 2000    2       2       1       0.000   0.31    2       1       1       0       0.8
## 2001    2       2       1       0.000   0.31    2       1       1       0       0.8
## 2002    2       2       1       0.726   0.31    2       1       1       0       0.8
## 2003    2       2       1       0.998   0.31    2       1       1       0       0.8
## 2004    2       2       1       0.091   0.31    2       1       1       0       0.8
## 2005    2       2       1       0.000   0.31    2       1       1       0       0.8
## 2006    2       2       1       2.812   0.31    2       1       1       0       0.8
## 2007    2       2       1       0.045   0.31    2       1       1       0       0.8
## 2008    2       2       1       0.272   0.31    2       1       1       0       0.8
## 2009    2       2       1       0.635   0.31    2       1       1       0       0.8
## 2010    2       2       1       0.363   0.31    2       1       1       0       0.8
## 2011    2       2       1       0.181   0.31    2       1       1       0       0.8
## 2012    2       2       1       0.000   0.31    2       1       1       0       0.8
## 2013    2       2       1       0.181   0.31    2       1       1       0       0.8
## 2014    2       2       1       0.000   0.31    2       1       1       0       0.8
## 2015    2       2       1       0.000   0.31    2       1       1       0       0.8
## # Fixed fishery discards
## 1991    2       3       1       0.045   0.31    2       1       1       0       0.5
## 1992    2       3       1       2.268   0.31    2       1       1       0       0.5
## 1993    2       3       1       0.000   0.31    2       1       1       0       0.5
## 1994    2       3       1       0.091   0.31    2       1       1       0       0.5
## 1995    2       3       1       0.136   0.31    2       1       1       0       0.5
## 1996    2       3       1       0.045   0.31    2       1       1       0       0.5
## 1997    2       3       1       0.181   0.31    2       1       1       0       0.5
## 1998    2       3       1       0.907   0.31    2       1       1       0       0.5
```

```
## 1999    2       3       1       1.361   0.31    2       1       1       0       0.5
## 2000    2       3       1       0.000   0.31    2       1       1       0       0.5
## 2001    2       3       1       0.862   0.31    2       1       1       0       0.5
## 2002    2       3       1       0.408   0.31    2       1       1       0       0.5
## 2003    2       3       1       1.134   0.31    2       1       1       0       0.5
## 2004    2       3       1       0.635   0.31    2       1       1       0       0.5
## 2005    2       3       1       0.590   0.31    2       1       1       0       0.5
## 2006    2       3       1       1.451   0.31    2       1       1       0       0.5
## 2007    2       3       1       69.717  0.31    2       1       1       0       0.5
## 2008    2       3       1       6.622   0.31    2       1       1       0       0.5
## 2009    2       3       1       7.530   0.31    2       1       1       0       0.5
## 2010    2       3       1       9.571   0.31    2       1       1       0       0.5
## 2011    2       3       1       0.590   0.31    2       1       1       0       0.5
## 2012    2       3       1       0.590   0.31    2       1       1       0       0.5
## 2013    2       3       1       0.272   0.31    2       1       1       0       0.5
## 2014    2       3       1       0.272   0.31    2       1       1       0       0.5
## 2015    2       3       1       0.635   0.31    2       1       1       0       0.5
## ##  RELATIVE  ABUNDANCE DATA
## ##  Units of abundance: 1 = biomass, 2 = numbers
## ##  for SMBKC Units are in  crabs for Abundance.
## ##  Number  of  relative  abundance indicies
## 2
## ##  Number  of  rows  in  each  index
## 39  9
## # Survey data (abundance indices, units are mt for trawl survey and crab/potlift for pot survey)
## # Year, Seas, Fleet,  Sex,  Abundance,  CV     units
## 1978  1 4 1 6832.819  0.394 1
## 1979  1 4 1 7989.881  0.463 1
## 1980  1 4 1 9986.830  0.507 1
## 1981  1 4 1 6551.132  0.402 1
## 1982  1 4 1 16221.933 0.344 1
## 1983  1 4 1 9634.250  0.298 1
## 1984  1 4 1 4071.218  0.179 1
## 1985  1 4 1 3110.541  0.210 1
## 1986  1 4 1 1416.849  0.388 1
## 1987  1 4 1 2278.917  0.291 1
## 1988  1 4 1 3158.169  0.252 1
## 1989  1 4 1 6338.622  0.271 1
## 1990  1 4 1 6730.130  0.274 1
## 1991  1 4 1 6948.184  0.248 1
## 1992  1 4 1 7093.272  0.201 1
## 1993  1 4 1 9548.459  0.169 1
## 1994  1 4 1 6539.133  0.176 1
## 1995  1 4 1 5703.591  0.178 1
## 1996  1 4 1 9410.403  0.241 1
## 1997  1 4 1 10924.107 0.337 1
## 1998  1 4 1 7976.839  0.355 1
## 1999  1 4 1 1594.546  0.182 1
## 2000  1 4 1 2096.795  0.310 1
## 2001  1 4 1 2831.440  0.245 1
## 2002  1 4 1 1732.599  0.320 1
## 2003  1 4 1 1566.675  0.336 1
## 2004  1 4 1 1523.869  0.305 1
## 2005  1 4 1 1642.017  0.371 1
```

```
## 2006  1 4 1 3893.875  0.334 1
## 2007  1 4 1 6470.773  0.385 1
## 2008  1 4 1 4654.473  0.284 1
## 2009  1 4 1 6301.470  0.256 1
## 2010  1 4 1 11130.898 0.466 1
## 2011  1 4 1 10931.232 0.558 1
## 2012  1 4 1 6200.219  0.339 1
## 2013  1 4 1 2287.557  0.217 1
## 2014  1 4 1 6029.220  0.449 1
## 2015  1 4 1 5877.433  0.770 1
## 2016  1 4 1 3485.909  0.393 1
## 1995  1 5 1 12042.000 0.130 2
## 1998  1 5 1 12531.000 0.060 2
## 2001  1 5 1 8477.000  0.080 2
## 2004  1 5 1 1667.000  0.150 2
## 2007  1 5 1 8643.000  0.090 2
## 2010  1 5 1 10209.000 0.130 2
## 2013  1 5 1 5643.000  0.190 2
## 2015  1 5 1 2805.000  0.180 2
## 2016  1 5 1 2378.000  0.186 2
## ##  Number  of  length  frequency matrices
## 3
## ##  Number  of  rows  in  each  matrix
## 15  39  9
## ##  Number  of  bins  in  each  matrix  (columns  of  size  data)
## 3  3  3
## ##  SIZE  COMPOSITION DATA  FOR ALL FLEETS
## ##  SIZE  COMP  LEGEND
## ##  Sex:  1 = male, 2 = female, 0 = both  sexes combined
## ##  Type  of  composition:  1 = retained, 2 = discard,  0 = total composition
## ##  Maturity  state:  1 = immature, 2 = mature, 0 = both  states  combined
## ##  Shell condition:  1 = new shell,  2 = old shell,  0 = both  shell types combined
## ##length  proportions of  pot discarded males
## ##Year, Seas, Fleet,  Sex,  Type, Shell,  Maturity, Nsamp,  DataVec
##   1990  2 1 1 0 0 0 15  0.1133  0.3933  0.4933
##   1991  2 1 1 0 0 0 25  0.1329  0.1768  0.6902
##   1992  2 1 1 0 0 0 25  0.1905  0.2677  0.5417
##   1993  2 1 1 0 0 0 25  0.2807  0.2097  0.5096
##   1994  2 1 1 0 0 0 25  0.2942  0.2714  0.4344
##   1995  2 1 1 0 0 0 25  0.1478  0.2127  0.6395
##   1996  2 1 1 0 0 0 25  0.1595  0.2229  0.6176
##   1997  2 1 1 0 0 0 25  0.1818  0.2053  0.6128
##   1998  2 1 1 0 0 0 25  0.1927  0.2162  0.5911
##   2009  2 1 1 0 0 0 50  0.1413  0.3235  0.5352
##   2010  2 1 1 0 0 0 50  0.1314  0.3152  0.5534
##   2011  2 1 1 0 0 0 50  0.1314  0.3051  0.5636
##   2012  2 1 1 0 0 0 50  0.1417  0.3178  0.5406
##   2014  2 1 1 0 0 0 50  0.0939  0.2275  0.6786
##   2015  2 1 1 0 0 0 50  0.1148  0.2518  0.6333
## ##length  proportions of  trawl survey  males
## ##Year, Seas, Fleet,  Sex,  Type, Shell,  Maturity, Nsamp,  DataVec
##   1978  1 4 1 0 0 0 50   0.3865  0.3478  0.2657
##   1979  1 4 1 0 0 0 50   0.4281  0.3190  0.2529
##   1980  1 4 1 0 0 0 50   0.3588  0.3220  0.3192
```

```
##   1981  1 4 1 0 0 0 50   0.1219  0.3065  0.5716
##   1982  1 4 1 0 0 0 50   0.1671  0.2435  0.5893
##   1983  1 4 1 0 0 0 50   0.1752  0.2726  0.5522
##   1984  1 4 1 0 0 0 50   0.1823  0.2085  0.6092
##   1985  1 4 1 0 0 0 46.5 0.2023  0.2010  0.5967
##   1986  1 4 1 0 0 0 23   0.1984  0.4364  0.3652
##   1987  1 4 1 0 0 0 35.5 0.1944  0.3779  0.4277
##   1988  1 4 1 0 0 0 40.5 0.1879  0.3737  0.4384
##   1989  1 4 1 0 0 0 50   0.4246  0.2259  0.3496
##   1990  1 4 1 0 0 0 50   0.2380  0.2332  0.5288
##   1991  1 4 1 0 0 0 50   0.2274  0.3300  0.4426
##   1992  1 4 1 0 0 0 50   0.2263  0.2911  0.4826
##   1993  1 4 1 0 0 0 50   0.2296  0.2759  0.4945
##   1994  1 4 1 0 0 0 50   0.1989  0.2926  0.5085
##   1995  1 4 1 0 0 0 50   0.2593  0.3005  0.4403
##   1996  1 4 1 0 0 0 50   0.1998  0.3054  0.4948
##   1997  1 4 1 0 0 0 50   0.1622  0.3102  0.5275
##   1998  1 4 1 0 0 0 50   0.1276  0.3212  0.5511
##   1999  1 4 1 0 0 0 26   0.2224  0.2214  0.5562
##   2000  1 4 1 0 0 0 30.5 0.2154  0.2180  0.5665
##   2001  1 4 1 0 0 0 45.5 0.2253  0.2699  0.5048
##   2002  1 4 1 0 0 0 19   0.1127  0.2346  0.6527
##   2003  1 4 1 0 0 0 32.5 0.3762  0.2345  0.3893
##   2004  1 4 1 0 0 0 24   0.2488  0.1848  0.5663
##   2005  1 4 1 0 0 0 21   0.2825  0.2744  0.4431
##   2006  1 4 1 0 0 0 50   0.3276  0.2293  0.4431
##   2007  1 4 1 0 0 0 50   0.4394  0.3525  0.2081
##   2008  1 4 1 0 0 0 50   0.3745  0.2219  0.4036
##   2009  1 4 1 0 0 0 50   0.3057  0.4202  0.2741
##   2010  1 4 1 0 0 0 50   0.4081  0.3371  0.2548
##   2011  1 4 1 0 0 0 50   0.2179  0.3940  0.3881
##   2012  1 4 1 0 0 0 50   0.1573  0.4393  0.4034
##   2013  1 4 1 0 0 0 37   0.2100  0.2834  0.5065
##   2014  1 4 1 0 0 0 50   0.1738  0.3912  0.4350
##   2015  1 4 1 0 0 0 50   0.2340  0.2994  0.4666
##   2016  1 4 1 0 0 0 50   0.2255  0.2780  0.4965
##   ##length  proportions of  pot survey
##   ##Year, Seas, Fleet,  Sex,  Type, Shell,  Maturity, Nsamp,  DataVec
##   1995  1 5 1 0 0 0 100 0.1594  0.2656  0.5751
##   1998  1 5 1 0 0 0 100  0.0769  0.2205  0.7026
##   2001  1 5 1 0 0 0 100  0.1493  0.2049  0.6457
##   2004  1 5 1 0 0 0 100  0.0672  0.2484  0.6845
##   2007  1 5 1 0 0 0 100  0.1257  0.3148  0.5595
##   2010  1 5 1 0 0 0 100  0.1299  0.3209  0.5492
##   2013  1 5 1 0 0 0 100  0.1556  0.2477  0.5967
##   2015  1 5 1 0 0 0 100  0.0706  0.2431  0.6859
##   2016  1 5 1 0 0 0 100  0.0832  0.1917  0.7251
## ##  Growth data (increment)
## # nobs_growth
## 3
## # MidPoint Sex Increment CV
##  97.5  1  14.1  0.2197
## 112.5  1  14.1  0.2197
## 127.5  1  14.1  0.2197
```

```
## #  97.5   1 13.8 0.2197
## #  112.5  1 14.1 0.2197
## #  127.5  1 14.4 0.2197
## # Use custom transition matrix (0=no, 1=growth matrix, 2=transition matrix, i.e. growth and molting)
## 2
## # The custom growth matrix (if not using just fill with zeros)
## # Alternative TM (loosely) based on Otto and Cummiskey (1990)
## 0.2  0.7  0.1
## 0.0  0.4  0.6
## 0.0  0.0  1.0
## ## eof
## 9999
##
```

The match model control file:

```
## # Set up to do Stock Reduction Analysis using Catch data and informative priors.
## # Controls for leading parameter vector theta
## # LEGEND FOR PRIOR:
## #                  0 -> uniform
## #                  1 -> normal
## #                  2 -> lognormal
## #                  3 -> beta
## #                  4 -> gamma
## # ntheta
##   12
## # ival        lb        ub        phz   prior     p1      p2         # parameter         #
##   0.18      0.01         1        -4       2   0.18    0.02         # M
##   14.3      -7.0        30        -2       0    -7       30         # log(R0)
##   10.0      -7.0        20        -1       1   -10.0     20         # log(Rini)
##   10.0      -7.0        20         1       0    -7       20         # log(Rbar)
##   80.0      30.0       310        -2       1    72.5    7.25        # Recruitment size distribution
##   0.25       0.1         7        -4       0    0.1     9.0         # Recruitment size scale (variar
##   0.2      -10.0      0.75        -4       0  -10.0    0.75         # log(sigma_R)
##   0.75      0.20      1.00        -2       3    3.0    2.00         # steepness
##   0.01      0.00      1.00        -3       3    1.01   1.01         # recruitment autocorrelation
##  14.5       5.00     20.00         1       0    5.00  20.00         # logN0 vector of initial number
##  14.0       5.00     20.00         1       0    5.00  20.00         # logN0 vector of initial number
##  13.5       5.00     20.00         1       0    5.00  20.00         # logN0 vector of initial number
## ## GROWTH PARAM CONTROLS                                                                   ##
## ## Two lines for each parameter if split sex, one line if not                             ##
## # ival        lb        ub          phz  prior     p1      p2         # parameter        #
##   14.1      10.0      30.0          -3       0    0.0   999.0        # alpha males or combined
##    0.0001    0.0       0.01         -3       0    0.0   999.0        # beta males or combined
##    0.45      0.01      1.0          -3       0    0.0   999.0        # gscale males or combined
##  121.5      65.0     145.0          -4       0    0.0   999.0        # molt_mu males or combined
##    0.060     0.0       1.0          -3       0    0.0   999.0        # molt_cv males or combined
##
## ## ------------------------------------------------------------------------------------ ##
## ## SELECTIVITY CONTROLS                                                                 ##
## ##     Each gear must have a selectivity and a retention selectivity. If a uniform      ##
## ##     prior is selected for a parameter then the lb and ub are used (p1 and p2 are     ##
## ##     ignored)                                                                         ##
```

```
## ## LEGEND                                                                          ##
## ##     sel type: 0 = parametric, 1 = coefficients, 2 = logistic, 3 = logistic95,        ##
## ##               4 = double normal (NIY)                                             ##
## ##     gear index: use +ve for selectivity, -ve for retention                          ##
## ##     sex dep: 0 for sex-independent, 1 for sex-dependent                             ##
## ## ---------------------------------------------------------------------------------- ##
## ## ivector for number of year periods or nodes                                        ##
## ## POT       TBycatch FBycatch  NMFS_S   ADFG_pot
## ## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
##    2         1        1         1        1         # Selectivity periods
##    0         0        0         0        0         # sex specific selectivity
##    0         3        3         0        0         # male selectivity type
## ## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
##    1         1        1         1        1         # Retention periods
##    0         0        0         0        0         # sex specific retention
##    3         2        2         2        2         # male retention type
##    1         0        0         0        0         # male retention flag (0 -> no, 1 -> yes)
## ## gear  par   sel                                                phz    start  end        ##
## ## index index par sex  ival  lb    ub     prior p1     p2      mirror period period     ##
## # Gear-1
##    1     1     1   0    0.490680567427 0.001 2.0    0       0      1    -2     1978   2008
##    1     2     2   0    0.785300542244 0.001 2.0    0       0      1    -2     1978   2008
##    1     3     3   0    1.0            0.001 2.0    0       0      1    -2     1978   2008
##    1     1     1   0    0.402423912257 0.001 2.0    0       0      1    -2     2009   2016
##    1     2     2   0    0.981647895824 0.001 2.0    0       0      1    -2     2009   2016
##    1     3     3   0    1.0            0.001 2.0    0       0      1    -2     2009   2016
## # Gear-2
##    2     7     1   0    40       10.0  200    0      10     200    -3     1978   2016
##    2     8     2   0    60       10.0  200    0      10     200    -3     1978   2016
## # Gear-3
##    3     9     1   0    40       10.0  200    0      10     200    -3     1978   2016
##    3    10     2   0    60       10.0  200    0      10     200    -3     1978   2016
## # Gear-4
##    4     8     1   0    0.793562338771 0.001 2.0    0       0      1    -2     1978   2016
##    4     9     2   0    1.08339465666 0.001 2.0    0       0      1    -2     1978   2016
##    4     10    3   0    1.0           0.001 2.0    0       0      1    -2     1978   2016
## # Gear-5
##    5     11    1   0    0.411256448303 0.001 2.0    0       0      1    -2     1978   2016
##    5     12    2   0    0.861094630732 0.001 2.0    0       0      1    -2     1978   2016
##    5     13    3   0    1.0            0.001 2.0    0       0      1    -2     1978   2016
## ## Retained
## # Gear-1
##   -1     14    1   0   120    100    200     0      1     900    -1      1978    2016
##   -1     15    2   0   123    110    200     0      1     900    -1      1978    2016
## # Gear-2
##   -2     16    1   0   595     1     700     0      1     900    -3      1978    2016
##   -2     17    2   0    10     1     700     0      1     900    -3      1978    2016
## # Gear-3
##   -3     18    1   0   590     1     700     0      1     900    -3      1978    2016
##   -3     19    2   0    10     1     700     0      1     900    -3      1978    2016
## # Gear-4
##   -4     20    1   0   580     1     700     0      1     900    -3      1978    2016
##   -4     21    2   0    20     1     700     0      1     900    -3      1978    2016
## # Gear-5
```

```
##   -5     22    1   0   580    1    700    0      1    900   -3     1978   2016
##   -5     23    2   0    20    1    700    0      1    900   -3     1978   2016
##
## ## ---------------------------------------------------------------------------------- ##
## ## PRIORS FOR CATCHABILITY
## ##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
## ##     and p2 are ignored). ival must be > 0                                            ##
## ## LEGEND                                                                               ##
## ##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma               ##
## ## ---------------------------------------------------------------------------------- ##
## ##  LAMBDA: Arbitrary relative weights for each series, 0 = do not fit.
## ## SURVEYS/INDICES ONLY
## ## ival    lb       ub    phz   prior   p1       p2    Analytic?   LAMBDA
##    1.0     0        2     -1    0       0        9.0   0           1       # NMFS trawl
## 0.00411135867487 0 5      -1    0       0        9.0   0           1       # ADF&G pot
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## ADDITIONAL CV FOR SURVEYS/INDICES                                                    ##
## ##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
## ##     and p2 are ignored). ival must be > 0                                            ##
## ## LEGEND                                                                               ##
## ##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma               ##
## ## ---------------------------------------------------------------------------------- ##
## ## ival        lb        ub        phz   prior     p1      p2
##    0.0000001      0.00000001   10.0      -4    4         1.0     100   # NMFS
##    0.0000001      0.00000001   10.0      -4    4         1.0     100   # ADF&G
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## PENALTIES FOR AVERAGE FISHING MORTALITY RATE FOR EACH GEAR
## ## ---------------------------------------------------------------------------------- ##
## ## Mean_F  STD_PHZ1  STD_PHZ2     PHZ
##    0.2       0.05     50.0       1   # Pot
##    0.001     0.05     50.0       1   # Trawl
##    0.001     0.05     50.0       1   # Fixed
##    0.00      2.00     20.00     -1   # NMFS
##    0.00      2.00     20.00     -1   # ADF&G
## ## ---------------------------------------------------------------------------------- ##
##
## ## --------------------------------------------------------------------------------- ##
## ## OPTIONS FOR SIZE COMPOSTION DATA (COLUMN FOR EACH MATRIX)
## ## ---------------------------------------------------------------------------------- ##
## ## LIKELIHOOD OPTIONS
## ##   -1) Multinomial with estimated/fixed sample size
## ##   -2) Robust approximation to multinomial
## ##   -3) logistic normal (NIY)
## ##   -4) multivariate-t (NIY)
## ##   -5) Dirichlet
## ## AUTOTAIL COMPRESSION
## ##   pmin is the cumulative proportion used in tail compression.
## ## ---------------------------------------------------------------------------------- ##
## #  1   1   1  # Type of likelihood
##   2   2   2  # Type of likelihood
```

```
## #  5   5   5   # Type of likelihood
##   0   0   0   # Auto tail compression (pmin)
##   1   1   1   # Initial value for effective sample size multiplier
##  -4  -4  -4   # Phz for estimating effective sample size (if appl.)
##   1   2   3   # Composition aggregator
##   1   1   1   # LAMBDA
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## TIME VARYING NATURAL MORTALIIY RATES                                               ##
## ## ---------------------------------------------------------------------------------- ##
## ## TYPE:
## ##      0 = constant natural mortality
## ##      1 = Random walk (deviates constrained by variance in M)
## ##      2 = Cubic Spline (deviates constrained by nodes & node-placement)
## ##      3 = Blocked changes (deviates constrained by variance at specific knots)
## ##      4 = Time blocks
## ## ---------------------------------------------------------------------------------- ##
## ## Type
## 3
## ## Phase of estimation
## 4
## ## STDEV in m_dev for Random walk
## 10.0
## ## Number of nodes for cubic spline or number of step-changes for option 3
## 2
## ## Year position of the knots (vector must be equal to the number of nodes)
## 1998 1999
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## OTHER CONTROLS
## ## ---------------------------------------------------------------------------------- ##
##   3       # Estimated rec_dev phase
##   3       # Estimated rec_ini phase
##   0       # VERBOSE FLAG (0 = off, 1 = on, 2 = objective func)
##   2       # Initial conditions (0 = Unfished, 1 = Steady-state fished, 2 = Free parameters)
##   1978    # First year for average recruitment for Bspr calculation
##   2016    # Last year for average recruitment for Bspr calculation
##   0.35    # Target SPR ratio for Bmsy proxy
##   1       # Gear index for SPR calculations (i.e. directed fishery)
##   1       # Lambda (proportion of mature male biomass for SPR reference points)
##   1       # Use empirical molt increment data (0 = FALSE, 1 = TRUE)
##   0       # Stock-Recruit-Relationship (0 = None, 1 = Beverton-Holt)
## ## EOF
## 9999
```

The base model control file:

```
## # Set up to do Stock Reduction Analysis using Catch data and informative priors.
## # Controls for leading parameter vector theta
## # LEGEND FOR PRIOR:
## #                  0 -> uniform
## #                  1 -> normal
## #                  2 -> lognormal
## #                  3 -> beta
## #                  4 -> gamma
## # ntheta
##   12
## # ival       lb       ub       phz   prior    p1      p2         # parameter         #
##   0.18      0.01       1        -4      2   0.18    0.02         # M
##   14.3      -7.0      30        -2      0    -7       30         # log(R0)
##   10.0      -7.0      20        -1      1   -10.0     20         # log(Rini)
##   10.0      -7.0      20         1      0    -7       20         # log(Rbar)
##   80.0      30.0     310        -2      1    72.5    7.25        # Recruitment size distribution
##   0.25       0.1       7        -4      0    0.1     9.0         # Recruitment size scale (varia
##   0.2      -10.0     0.75       -4      0  -10.0    0.75         # log(sigma_R)
##   0.75      0.20     1.00       -2      3    3.0    2.00         # steepness
##   0.01      0.00     1.00       -3      3    1.01   1.01         # recruitment autocorrelation
##  14.5       5.00    20.00        1      0    5.00  20.00         # logN0 vector of initial numbe
##  14.0       5.00    20.00        1      0    5.00  20.00         # logN0 vector of initial numbe
##  13.5       5.00    20.00        1      0    5.00  20.00         # logN0 vector of initial numbe
## ## GROWTH PARAM CONTROLS                                                              ##
## ## Two lines for each parameter if split sex, one line if not                         ##
## # ival       lb       ub         phz  prior    p1      p2        # parameter        #
##   14.1      10.0     30.0         -3      0    0.0   999.0       # alpha males or combined
##    0.0001    0.0      0.01        -3      0    0.0   999.0       # beta males or combined
##    0.45      0.01     1.0         -3      0    0.0   999.0       # gscale males or combined
##  121.5      65.0    145.0         -4      0    0.0   999.0       # molt_mu males or combined
##    0.060     0.0      1.0         -3      0    0.0   999.0       # molt_cv males or combined
##
## ## ---------------------------------------------------------------------------------- ##
## ## SELECTIVITY CONTROLS                                                               ##
## ##    Each gear must have a selectivity and a retention selectivity. If a uniform      ##
## ##    prior is selected for a parameter then the lb and ub are used (p1 and p2 are     ##
## ##    ignored)                                                                        ##
## ## LEGEND                                                                             ##
## ##    sel type: 0 = parametric, 1 = coefficients, 2 = logistic, 3 = logistic95,        ##
## ##              4 = double normal (NIY)                                               ##
## ##    gear index: use +ve for selectivity, -ve for retention                          ##
## ##    sex dep: 0 for sex-independent, 1 for sex-dependent                             ##
## ## ---------------------------------------------------------------------------------- ##
## ## ivector for number of year periods or nodes                                        ##
## ## POT       TBycatch FBycatch  NMFS_S   ADFG_pot
## ## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
##    2         1        1         1        1         # Selectivity periods
##    0         0        0         0        0         # sex specific selectivity
##    0         3        3         0        0         # male selectivity type
## ## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
##    1         1        1         1        1         # Retention periods
##    0         0        0         0        0         # sex specific retention
```

```
##    3         2        2         2        2         # male retention type
##    1         0        0         0        0         # male retention flag (0 -> no, 1 -> yes)
## ## gear  par   sel                                                      phz    start  end
## ## index index par sex  ival  lb    ub     prior  p1     p2     mirror period period
## # Gear-1
##    1     1     1   0    0.4   0.001 1.0    0       0      1      3      1978   2008
##    1     2     2   0    0.7   0.001 1.0    0       0      1      3      1978   2008
##    1     3     3   0    1.0   0.001 2.0    0       0      1     -3      1978   2008
##    1     4     1   0    0.4   0.001 1.0    0       0      1      3      2009   2016
##    1     5     2   0    0.7   0.001 1.0    0       0      1      3      2009   2016
##    1     6     3   0    1.0   0.001 2.0    0       0      1     -3      2009   2016
## # Gear-2
##    2     7     1   0    40    10.0  200    0      10    200     -3      1978   2016
##    2     8     2   0    60    10.0  200    0      10    200     -3      1978   2016
## # Gear-3
##    3     9     1   0    40    10.0  200    0      10    200     -3      1978   2016
##    3     10    2   0    60    10.0  200    0      10    200     -3      1978   2016
## # Gear-4
##    4     11    1   0    0.4   0.001 1.0    0       0      1      4      1978   2016
##    4     12    2   0    0.7   0.001 1.0    0       0      1      4      1978   2016
##    4     13    3   0    1.0   0.001 2.0    0       0      1     -4      1978   2016
## # Gear-5
##    5     14    1   0    0.4   0.001 1.0    0       0      1      4      1978   2016
##    5     15    2   0    0.7   0.001 1.0    0       0      1      4      1978   2016
##    5     16    3   0    1.0   0.001 2.0    0       0      1     -4      1978   2016
## ## Retained
## # Gear-1
##   -1     17    1   0    120   100   200    0       1    900     -1      1978   2016
##   -1     18    2   0    123   110   200    0       1    900     -1      1978   2016
## # Gear-2
##   -2     19    1   0    595    1    700    0       1    900     -3      1978   2016
##   -2     20    2   0     10    1    700    0       1    900     -3      1978   2016
## # Gear-3
##   -3     21    1   0    590    1    700    0       1    900     -3      1978   2016
##   -3     22    2   0     10    1    700    0       1    900     -3      1978   2016
## # Gear-4
##   -4     23    1   0    580    1    700    0       1    900     -3      1978   2016
##   -4     24    2   0     20    1    700    0       1    900     -3      1978   2016
## # Gear-5
##   -5     25    1   0    580    1    700    0       1    900     -3      1978   2016
##   -5     26    2   0     20    1    700    0       1    900     -3      1978   2016
## ## ------------------------------------------------------------------------------------ ##
##
## ## ------------------------------------------------------------------------------------ ##
## ## PRIORS FOR CATCHABILITY
## ##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
## ##     and p2 are ignored). ival must be > 0                                            ##
## ## LEGEND                                                                               ##
## ##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma               ##
## ## ------------------------------------------------------------------------------------ ##
## ##  LAMBDA: Arbitrary relative weights for each series, 0 = do not fit.
## ## SURVEYS/INDICES ONLY
## ## ival    lb       ub    phz   prior   p1       p2    Analytic?   LAMBDA
##    1.0     0        2     -1    0       0        9.0   0           1       # NMFS trawl
```

```
##    4e-06   0        5      1    0       0        9.0   0           1       # ADF&G pot
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## ADDITIONAL CV FOR SURVEYS/INDICES                                                  ##
## ##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
## ##     and p2 are ignored). ival must be > 0                                          ##
## ## LEGEND                                                                             ##
## ##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma             ##
## ## ---------------------------------------------------------------------------------- ##
## ## ival        lb        ub        phz   prior     p1      p2
##    0.00001      0.000001   10.0      -4    4         1.0     100   # NMFS
##    0.00001      0.000001   10.0      -4    4         1.0     100   # ADF&G
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## PENALTIES FOR AVERAGE FISHING MORTALITY RATE FOR EACH GEAR
## ## ---------------------------------------------------------------------------------- ##
## ## Mean_F  STD_PHZ1  STD_PHZ2     PHZ
##    0.2       0.05     50.0       1   # Pot
##    0.001     0.05     50.0       1   # Trawl
##    0.001     0.05     50.0       1   # Fixed
##    0.00      2.00     20.00     -1   # NMFS
##    0.00      2.00     20.00     -1   # ADF&G
## ## ---------------------------------------------------------------------------------- ##
##
## ## --------------------------------------------------------------------------------- ##
## ## OPTIONS FOR SIZE COMPOSTION DATA (COLUMN FOR EACH MATRIX)
## ## ---------------------------------------------------------------------------------- ##
## ## LIKELIHOOD OPTIONS
## ##   -1) Multinomial with estimated/fixed sample size
## ##   -2) Robust approximation to multinomial
## ##   -3) logistic normal (NIY)
## ##   -4) multivariate-t (NIY)
## ##   -5) Dirichlet
## ## AUTOTAIL COMPRESSION
## ##   pmin is the cumulative proportion used in tail compression.
## ## ---------------------------------------------------------------------------------- ##
## #  1   1   1  # Type of likelihood
##   2   2   2  # Type of likelihood
## #  5   5   5   # Type of likelihood
##   0   0   0   # Auto tail compression (pmin)
##   1   1   1   # Initial value for effective sample size multiplier
##  -4  -4  -4   # Phz for estimating effective sample size (if appl.)
##   1   2   3   # Composition aggregator
##   1   1   1   # LAMBDA
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## TIME VARYING NATURAL MORTALIIY RATES                                               ##
## ## ---------------------------------------------------------------------------------- ##
## ## TYPE:
## ##      0 = constant natural mortality
## ##      1 = Random walk (deviates constrained by variance in M)
```

```
## ##      2 = Cubic Spline (deviates constrained by nodes & node-placement)
## ##      3 = Blocked changes (deviates constrained by variance at specific knots)
## ##      4 = Time blocks
## ## ------------------------------------------------------------------------------------ ##
## ## Type
## 3
## ## Phase of estimation
## 4
## ## STDEV in m_dev for Random walk
## 10.0
## ## Number of nodes for cubic spline or number of step-changes for option 3
## 2
## ## Year position of the knots (vector must be equal to the number of nodes)
## 1998 1999
## ## ------------------------------------------------------------------------------------ ##
##
## ## ------------------------------------------------------------------------------------ ##
## ## OTHER CONTROLS
## ## ------------------------------------------------------------------------------------ ##
##   3       # Estimated rec_dev phase
##   3       # Estimated rec_ini phase
##   0       # VERBOSE FLAG (0 = off, 1 = on, 2 = objective func)
##   2       # Initial conditions (0 = Unfished, 1 = Steady-state fished, 2 = Free parameters)
##   1978    # First year for average recruitment for Bspr calculation
##   2016    # Last year for average recruitment for Bspr calculation
##   0.35    # Target SPR ratio for Bmsy proxy
##   1       # Gear index for SPR calculations (i.e. directed fishery)
##   1       # Lambda (proportion of mature male biomass for SPR reference points)
##   1       # Use empirical molt increment data (0 = FALSE, 1 = TRUE)
##   0       # Stock-Recruit-Relationship (0 = None, 1 = Beverton-Holt)
## ## EOF
## 9999
```

The Francis model control file:

```
## # Set up to do Stock Reduction Analysis using Catch data and informative priors.
## # Controls for leading parameter vector theta
## # LEGEND FOR PRIOR:
## #                  0 -> uniform
## #                  1 -> normal
## #                  2 -> lognormal
## #                  3 -> beta
## #                  4 -> gamma
## # ntheta
##   12
## # ival        lb        ub        phz   prior     p1      p2         # parameter         #
##   0.18      0.01         1        -4       2   0.18    0.02         # M
##   14.3      -7.0        30        -2       0     -7       30         # log(R0) - unfished recruits
##   10.0      -7.0        20        -1       1   -10.0      20         # log(Rini) - initial recruitmen
##   10.0      -7.0        20         1       0     -7       20         # log(Rbar) - average recruits(s
##   80.0      30.0       310        -2       1   72.5    7.25         # Recruitment size distribution
##   0.25       0.1         7        -4       0    0.1     9.0         # Recruitment size scale (varian
##   0.2      -10.0      0.75        -4       0  -10.0    0.75         # log(sigma_R)
##   0.75      0.20      1.00        -2       3    3.0    2.00         # steepness
##   0.01      0.00      1.00        -3       3   1.01    1.01         # recruitment autocorrelation
##  14.5       5.00     20.00         1       0   5.00   20.00         # logN0 vector of initial number
##  14.0       5.00     20.00         1       0   5.00   20.00         # logN0 vector of initial number
##  13.5       5.00     20.00         1       0   5.00   20.00         # logN0 vector of initial number
## ## GROWTH PARAM CONTROLS                                                                   ##
## ## Two lines for each parameter if split sex, one line if not                             ##
## # ival        lb        ub         phz  prior     p1      p2         # parameter         #
##   14.1      10.0      30.0         -3       0    0.0   999.0         # alpha males or combined
##    0.0001    0.0       0.01        -3       0    0.0   999.0         # beta males or combined
##    0.45      0.01      1.0         -3       0    0.0   999.0         # gscale males or combined
##  121.5      65.0     145.0         -4       0    0.0   999.0         # molt_mu males or combined
##    0.060     0.0       1.0         -3       0    0.0   999.0         # molt_cv males or combined
##
## ## ------------------------------------------------------------------------------------ ##
## ## SELECTIVITY CONTROLS                                                                   ##
## ##    Each gear must have a selectivity and a retention selectivity. If a uniform      ##
## ##    prior is selected for a parameter then the lb and ub are used (p1 and p2 are     ##
## ##    ignored)                                                                           ##
## ## LEGEND                                                                                 ##
## ##    sel type: 0 = parametric, 1 = coefficients, 2 = logistic, 3 = logistic95,        ##
## ##              4 = double normal (NIY)                                                  ##
## ##    gear index: use +ve for selectivity, -ve for retention                             ##
## ##    sex dep: 0 for sex-independent, 1 for sex-dependent                                ##
## ## ------------------------------------------------------------------------------------ ##
## ## ivector for number of year periods or nodes                                           ##
## ## POT       TBycatch FBycatch  NMFS_S   ADFG_pot
## ## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
##    2         1        1         1        1         # Selectivity periods
##    0         0        0         0        0         # sex specific selectivity
##    0         3        3         0        0         # male selectivity type
## ## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
##    1         1        1         1        1         # Retention periods
##    0         0        0         0        0         # sex specific retention
```

```
##    3         2        2         2        2         # male retention type
##    1         0        0         0        0         # male retention flag (0 -> no, 1 -> yes)
## ## gear  par   sel                                                phz    start  end
## ## index index par sex  ival  lb    ub     prior  p1      p2     mirror period period
## # Gear-1
##    1     1     1   0    0.4   0.001 1.0    0       0       1      3      1978   2008
##    1     2     2   0    0.7   0.001 1.0    0       0       1      3      1978   2008
##    1     3     3   0    1.0   0.001 2.0    0       0       1     -3      1978   2008
##    1     4     1   0    0.4   0.001 1.0    0       0       1      3      2009   2016
##    1     5     2   0    0.7   0.001 1.0    0       0       1      3      2009   2016
##    1     6     3   0    1.0   0.001 2.0    0       0       1     -3      2009   2016
## # Gear-2
##    2     7     1   0    40    10.0  200    0      10     200     -3      1978   2016
##    2     8     2   0    60    10.0  200    0      10     200     -3      1978   2016
## # Gear-3
##    3     9     1   0    40    10.0  200    0      10     200     -3      1978   2016
##    3     10    2   0    60    10.0  200    0      10     200     -3      1978   2016
## # Gear-4
##    4     11    1   0    0.4   0.001 1.0    0       0       1      4      1978   2016
##    4     12    2   0    0.7   0.001 1.0    0       0       1      4      1978   2016
##    4     13    3   0    1.0   0.001 2.0    0       0       1     -4      1978   2016
## # Gear-5
##    5     14    1   0    0.4   0.001 1.0    0       0       1      4      1978   2016
##    5     15    2   0    0.7   0.001 1.0    0       0       1      4      1978   2016
##    5     16    3   0    1.0   0.001 2.0    0       0       1     -4      1978   2016
## ## Retained
## # Gear-1
##   -1     17    1   0    120   100   200    0       1     900     -1      1978   2016
##   -1     18    2   0    123   110   200    0       1     900     -1      1978   2016
## # Gear-2
##   -2     19    1   0    595    1    700    0       1     900     -3      1978   2016
##   -2     20    2   0     10    1    700    0       1     900     -3      1978   2016
## # Gear-3
##   -3     21    1   0    590    1    700    0       1     900     -3      1978   2016
##   -3     22    2   0     10    1    700    0       1     900     -3      1978   2016
## # Gear-4
##   -4     23    1   0    580    1    700    0       1     900     -3      1978   2016
##   -4     24    2   0     20    1    700    0       1     900     -3      1978   2016
## # Gear-5
##   -5     25    1   0    580    1    700    0       1     900     -3      1978   2016
##   -5     26    2   0     20    1    700    0       1     900     -3      1978   2016
## ## -------------------------------------------------------------------------------------- ##
##
## ## -------------------------------------------------------------------------------------- ##
## ## PRIORS FOR CATCHABILITY
## ##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
## ##     and p2 are ignored). ival must be > 0                                            ##
## ## LEGEND                                                                               ##
## ##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma               ##
## ## -------------------------------------------------------------------------------------- ##
## ##  LAMBDA: Arbitrary relative weights for each series, 0 = do not fit.
## ## SURVEYS/INDICES ONLY
## ## ival     lb       ub    phz   prior   p1       p2    Analytic?   LAMBDA
##    1.0     0        2     -1    0       0        9.0   0           1       # NMFS trawl
```

```
##    4.2e-6  0        5      1    0       0        9.0   0           1       # ADF&G pot
## ## -------------------------------------------------------------------------------------- ##
##
## ## -------------------------------------------------------------------------------------- ##
## ## ADDITIONAL CV FOR SURVEYS/INDICES                                                      ##
## ##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
## ##     and p2 are ignored). ival must be > 0                                              ##
## ## LEGEND                                                                                 ##
## ##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma                 ##
## ## -------------------------------------------------------------------------------------- ##
## ## ival        lb        ub        phz   prior     p1      p2
##    0.00001      0.000001   10.0      -4    4         1.0     100   # NMFS
##    0.00001      0.000001   10.0      -4    4         1.0     100   # ADF&G
## ## -------------------------------------------------------------------------------------- ##
##
## ## -------------------------------------------------------------------------------------- ##
## ## PENALTIES FOR AVERAGE FISHING MORTALITY RATE FOR EACH GEAR
## ## -------------------------------------------------------------------------------------- ##
## ## Mean_F  STD_PHZ1  STD_PHZ2     PHZ
##    0.2       0.05     50.0       1   # Pot
##    0.001     0.05     50.0       1   # Trawl
##    0.001     0.05     50.0       1   # Fixed
##    0.00      2.00     20.00     -1   # NMFS
##    0.00      2.00     20.00     -1   # ADF&G
## ## -------------------------------------------------------------------------------------- ##
##
## ## ------------------------------------------------------------------------------------- ##
## ## OPTIONS FOR SIZE COMPOSTION DATA (COLUMN FOR EACH MATRIX)
## ## -------------------------------------------------------------------------------------- ##
## ## LIKELIHOOD OPTIONS
## ##   -1) Multinomial with estimated/fixed sample size
## ##   -2) Robust approximation to multinomial
## ##   -3) logistic normal (NIY)
## ##   -4) multivariate-t (NIY)
## ##   -5) Dirichlet
## ## AUTOTAIL COMPRESSION
## ##   pmin is the cumulative proportion used in tail compression.
## ## -------------------------------------------------------------------------------------- ##
##   2   2   2  # Type of likelihood
##   0   0   0   # Auto tail compression (pmin)
##   1   1   1   # Initial value for effective sample size multiplier
##  -4  -4  -4   # Phz for estimating effective sample size (if appl.)
##   1   2   3   # Composition aggregator
##   1   1   1
## ## -------------------------------------------------------------------------------------- ##
##
## ## -------------------------------------------------------------------------------------- ##
## ## TIME VARYING NATURAL MORTALIIY RATES                                                    ##
## ## -------------------------------------------------------------------------------------- ##
## ## TYPE:
## ##      0 = constant natural mortality
## ##      1 = Random walk (deviates constrained by variance in M)
## ##      2 = Cubic Spline (deviates constrained by nodes & node-placement)
## ##      3 = Blocked changes (deviates constrained by variance at specific knots)
```

```
## ##      4 = Time blocks
## ## ---------------------------------------------------------------------------------- ##
## ## Type
## 0
## ## Phase of estimation
## 4
## ## STDEV in m_dev for Random walk
## 10.0
## ## Number of nodes for cubic spline or number of step-changes for option 3
## 2
## ## Year position of the knots (vector must be equal to the number of nodes)
## 1998 1999
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## OTHER CONTROLS
## ## ---------------------------------------------------------------------------------- ##
##   3       # Estimated rec_dev phase
##   3       # Estimated rec_ini phase
##   0       # VERBOSE FLAG (0 = off, 1 = on, 2 = objective func)
##   2       # Initial conditions (0 = Unfished, 1 = Steady-state fished, 2 = Free parameters)
##   1978    # First year for average recruitment for Bspr calculation
##   2016    # Last year for average recruitment for Bspr calculation
##   0.35    # Target SPR ratio for Bmsy proxy
##   1       # Gear index for SPR calculations (i.e. directed fishery)
##   1       # Lambda (proportion of mature male biomass for SPR reference points)
##   1       # Use empirical molt increment data (0 = FALSE, 1 = TRUE)
##   0       # Stock-Recruit-Relationship (0 = None, 1 = Beverton-Holt)
## ## EOF
## 9999
```

The no M_{1998} model control file:

```
## # Set up to do Stock Reduction Analysis using Catch data and informative priors.
## # Controls for leading parameter vector theta
## # LEGEND FOR PRIOR:
## #                 0 -> uniform
## #                 1 -> normal
## #                 2 -> lognormal
## #                 3 -> beta
## #                 4 -> gamma
## # ntheta
##   12
## # ival        lb        ub        phz   prior     p1      p2         # parameter         #
##   0.18      0.01         1        -4       2   0.18    0.02         # M
##   14.3      -7.0        30        -2       0    -7       30         # log(R0)
##   10.0      -7.0        20        -1       1   -10.0     20         # log(Rini)
##   10        -7.0        20         1       0    -7       20         # log(Rbar)
##   80.0      30.0       310        -2       1    72.5    7.25        # Recruitment size distribution
##   0.25       0.1         7        -4       0    0.1     9.0         # Recruitment size scale (varia
##   0.2      -10.0      0.75        -4       0  -10.0    0.75         # log(sigma_R)
##   0.75      0.20      1.00        -2       3    3.0    2.00         # steepness
##   0.01      0.00      1.00        -3       3    1.01   1.01         # recruitment autocorrelation
##  14.5       5.00     20.00         1       0    5.00  20.00         # logN0 vector of initial numbe
##  14.0       5.00     20.00         1       0    5.00  20.00         # logN0 vector of initial numbe
##  13.5       5.00     20.00         1       0    5.00  20.00         # logN0 vector of initial numbe
## ## GROWTH PARAM CONTROLS                                                               ##
## ## Two lines for each parameter if split sex, one line if not                          ##
## # ival        lb        ub         phz  prior     p1      p2         # parameter        #
##   14.1      10.0      30.0         -3       0     0.0   999.0        # alpha males or combined
##    0.0001    0.0       0.01        -3       0     0.0   999.0        # beta males or combined
##    0.45      0.01      1.0         -3       0     0.0   999.0        # gscale males or combined
##  121.5      65.0     145.0         -4       0     0.0   999.0        # molt_mu males or combined
##    0.060     0.0       1.0         -3       0     0.0   999.0        # molt_cv males or combined
##
## ## ---------------------------------------------------------------------------------- ##
## ## SELECTIVITY CONTROLS                                                               ##
## ##     Each gear must have a selectivity and a retention selectivity. If a uniform    ##
## ##     prior is selected for a parameter then the lb and ub are used (p1 and p2 are   ##
## ##     ignored)                                                                       ##
## ## LEGEND                                                                             ##
## ##     sel type: 0 = parametric, 1 = coefficients, 2 = logistic, 3 = logistic95,      ##
## ##               4 = double normal (NIY)                                              ##
## ##     gear index: use +ve for selectivity, -ve for retention                         ##
## ##     sex dep: 0 for sex-independent, 1 for sex-dependent                            ##
## ## ---------------------------------------------------------------------------------- ##
## ## ivector for number of year periods or nodes                                        ##
## ## POT       TBycatch FBycatch  NMFS_S   ADFG_pot
## ## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
##    2         1        1         1        1          # Selectivity periods
##    0         0        0         0        0          # sex specific selectivity
##    0         3        3         0        0          # male selectivity type
## ## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
##    1         1        1         1        1          # Retention periods
##    0         0        0         0        0          # sex specific retention
```

```
##    3         2        2         2        2         # male retention type
##    1         0        0         0        0         # male retention flag (0 -> no, 1 -> yes)
## ## gear  par   sel                                                   phz    start  end
## ## index index par sex  ival  lb    ub     prior  p1      p2     mirror period period
## # Gear-1
##    1     1     1   0    0.4   0.001 1.0    0       0       1      3      1978   2008
##    1     2     2   0    0.7   0.001 1.0    0       0       1      3      1978   2008
##    1     3     3   0    1.0   0.001 2.0    0       0       1     -3      1978   2008
##    1     4     1   0    0.4   0.001 1.0    0       0       1      3      2009   2016
##    1     5     2   0    0.7   0.001 1.0    0       0       1      3      2009   2016
##    1     6     3   0    1.0   0.001 2.0    0       0       1     -3      2009   2016
## # Gear-2
##    2     7     1   0    40    10.0  200    0      10     200     -3      1978   2016
##    2     8     2   0    60    10.0  200    0      10     200     -3      1978   2016
## # Gear-3
##    3     9     1   0    40    10.0  200    0      10     200     -3      1978   2016
##    3     10    2   0    60    10.0  200    0      10     200     -3      1978   2016
## # Gear-4
##    4     11    1   0    0.4   0.001 1.0    0       0       1      4      1978   2016
##    4     12    2   0    0.7   0.001 1.0    0       0       1      4      1978   2016
##    4     13    3   0    1.0   0.001 2.0    0       0       1     -4      1978   2016
## # Gear-5
##    5     14    1   0    0.4   0.001 1.0    0       0       1      4      1978   2016
##    5     15    2   0    0.7   0.001 1.0    0       0       1      4      1978   2016
##    5     16    3   0    1.0   0.001 2.0    0       0       1     -4      1978   2016
## ## Retained
## # Gear-1
##   -1     17    1   0    120   100   200    0       1     900     -1      1978   2016
##   -1     18    2   0    123   110   200    0       1     900     -1      1978   2016
## # Gear-2
##   -2     19    1   0    595    1    700    0       1     900     -3      1978   2016
##   -2     20    2   0     10    1    700    0       1     900     -3      1978   2016
## # Gear-3
##   -3     21    1   0    590    1    700    0       1     900     -3      1978   2016
##   -3     22    2   0     10    1    700    0       1     900     -3      1978   2016
## # Gear-4
##   -4     23    1   0    580    1    700    0       1     900     -3      1978   2016
##   -4     24    2   0     20    1    700    0       1     900     -3      1978   2016
## # Gear-5
##   -5     25    1   0    580    1    700    0       1     900     -3      1978   2016
##   -5     26    2   0     20    1    700    0       1     900     -3      1978   2016
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## PRIORS FOR CATCHABILITY
## ##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
## ##     and p2 are ignored). ival must be > 0                                            ##
## ## LEGEND                                                                               ##
## ##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma               ##
## ## ---------------------------------------------------------------------------------- ##
## ##  LAMBDA: Arbitrary relative weights for each series, 0 = do not fit.
## ## SURVEYS/INDICES ONLY
## ## ival    lb       ub    phz   prior   p1       p2    Analytic?   LAMBDA
##    1.0     0        2     -1    0       0        9.0   0           1       # NMFS trawl
```

```
##    4e-06   0        5      1    0       0       9.0   0           1       # ADF&G pot
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## ADDITIONAL CV FOR SURVEYS/INDICES                                                  ##
## ##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
## ##     and p2 are ignored). ival must be > 0                                          ##
## ## LEGEND                                                                             ##
## ##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma             ##
## ## ---------------------------------------------------------------------------------- ##
## ## ival        lb        ub        phz   prior     p1      p2
##    0.00001      0.000001   10.0      -4    4         1.0     100   # NMFS
##    0.00001      0.000001   10.0      -4    4         1.0     100   # ADF&G
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## PENALTIES FOR AVERAGE FISHING MORTALITY RATE FOR EACH GEAR
## ## ---------------------------------------------------------------------------------- ##
## ## Mean_F  STD_PHZ1  STD_PHZ2     PHZ
##    0.2       0.05     50.0       1   # Pot
##    0.001     0.05     50.0       1   # Trawl
##    0.001     0.05     50.0       1   # Fixed
##    0.00      2.00     20.00     -1   # NMFS
##    0.00      2.00     20.00     -1   # ADF&G
## ## ---------------------------------------------------------------------------------- ##
##
## ## --------------------------------------------------------------------------------- ##
## ## OPTIONS FOR SIZE COMPOSTION DATA (COLUMN FOR EACH MATRIX)
## ## ---------------------------------------------------------------------------------- ##
## ## LIKELIHOOD OPTIONS
## ##   -1) Multinomial with estimated/fixed sample size
## ##   -2) Robust approximation to multinomial
## ##   -3) logistic normal (NIY)
## ##   -4) multivariate-t (NIY)
## ##   -5) Dirichlet
## ## AUTOTAIL COMPRESSION
## ##   pmin is the cumulative proportion used in tail compression.
## ## ---------------------------------------------------------------------------------- ##
##   1   1   1  # Type of likelihood
##   0   0   0   # Auto tail compression (pmin)
##   1   1   1   # Initial value for effective sample size multiplier
##  -4  -4  -4   # Phz for estimating effective sample size (if appl.)
##   1   2   3   # Composition aggregator
##    1.5938   0.5537   1.3113
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## TIME VARYING NATURAL MORTALIIY RATES                                               ##
## ## ---------------------------------------------------------------------------------- ##
## ## TYPE:
## ##      0 = constant natural mortality
## ##      1 = Random walk (deviates constrained by variance in M)
## ##      2 = Cubic Spline (deviates constrained by nodes & node-placement)
## ##      3 = Blocked changes (deviates constrained by variance at specific knots)
```

```
## ##      4 = Time blocks
## ## ------------------------------------------------------------------------------------ ##
## ## Type
## 0
## ## Phase of estimation
## -4
## ## STDEV in m_dev for Random walk
## 10.0
## ## Number of nodes for cubic spline or number of step-changes for option 3
## 2
## ## Year position of the knots (vector must be equal to the number of nodes)
## 1998 1999
## ## ------------------------------------------------------------------------------------ ##
##
## ## ------------------------------------------------------------------------------------ ##
## ## OTHER CONTROLS
## ## ------------------------------------------------------------------------------------ ##
##   3       # Estimated rec_dev phase
##   3       # Estimated rec_ini phase
##   0       # VERBOSE FLAG (0 = off, 1 = on, 2 = objective func)
##   2       # Initial conditions (0 = Unfished, 1 = Steady-state fished, 2 = Free parameters)
##   1978    # First year for average recruitment for Bspr calculation
##   2016    # Last year for average recruitment for Bspr calculation
##   0.35    # Target SPR ratio for Bmsy proxy
##   1       # Gear index for SPR calculations (i.e. directed fishery)
##   1       # Lambda (proportion of mature male biomass for SPR reference points)
##   1       # Use empirical molt increment data (0 = FALSE, 1 = TRUE)
##   0       # Stock-Recruit-Relationship (0 = None, 1 = Beverton-Holt)
## ## EOF
## 9999
```

The force model control file:

```
## # Set up to do Stock Reduction Analysis using Catch data and informative priors.
## # Controls for leading parameter vector theta
## # LEGEND FOR PRIOR:
## #                 0 -> uniform
## #                 1 -> normal
## #                 2 -> lognormal
## #                 3 -> beta
## #                 4 -> gamma
## # ntheta
##   12
## # ival        lb        ub        phz   prior     p1      p2         # parameter
##   0.18      0.01         1        -4       2   0.18    0.02         # M
##   14.0      -7.0        30        -2       0    -7       30         # log(R0)
##   10.0      -7.0        20        -1       1   -10.0     20         # log(Rini)
##   10.0      -7.0        20         1       0    -7       20         # log(Rbar)
##   80.0      30.0       310        -2       1    72.5    7.25        # Recruitment size distribution
##   0.25       0.1         7        -4       0    0.1     9.0         # Recruitment size scale (variar
##   0.2      -10.0      0.75        -4       0  -10.0    0.75         # log(sigma_R)
##   0.75      0.20      1.00        -2       3    3.0    2.00         # steepness
##   0.01      0.00      1.00        -3       3    1.01   1.01         # recruitment autocorrelation
```

```
##  14.5       5.00     20.00         1       0    5.00  20.00          # logN0 vector of initial numbe
##  14.0       5.00     20.00         1       0    5.00  20.00          # logN0 vector of initial numbe
##  13.5       5.00     20.00         1       0    5.00  20.00          # logN0 vector of initial numbe
## ## GROWTH PARAM CONTROLS                                                                    ##
## ## Two lines for each parameter if split sex, one line if not                              ##
## # ival        lb        ub         phz  prior     p1      p2         # parameter         #
##   14.1      10.0      30.0         -3      0    0.0   999.0          # alpha males or combined
##    0.0001    0.0       0.01        -3      0    0.0   999.0          # beta males or combined
##    0.45      0.01      1.0         -3      0    0.0   999.0          # gscale males or combined
##  121.5      65.0     145.0         -4      0    0.0   999.0          # molt_mu males or combined
##    0.060     0.0       1.0         -3      0    0.0   999.0          # molt_cv males or combined
##
## ## ---------------------------------------------------------------------------------------- ##
## ## SELECTIVITY CONTROLS                                                                     ##
## ##     Each gear must have a selectivity and a retention selectivity. If a uniform          ##
## ##     prior is selected for a parameter then the lb and ub are used (p1 and p2 are         ##
## ##     ignored)                                                                             ##
## ## LEGEND                                                                                   ##
## ##     sel type: 0 = parametric, 1 = coefficients, 2 = logistic, 3 = logistic95,            ##
## ##               4 = double normal (NIY)                                                    ##
## ##     gear index: use +ve for selectivity, -ve for retention                               ##
## ##     sex dep: 0 for sex-independent, 1 for sex-dependent                                  ##
## ## ---------------------------------------------------------------------------------------- ##
## ## ivector for number of year periods or nodes                                              ##
## ## POT       TBycatch FBycatch  NMFS_S   ADFG_pot
## ## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
##    2         1        1         1        1         # Selectivity periods
##    0         0        0         0        0         # sex specific selectivity
##    0         3        3         0        0         # male selectivity type
## ## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
##    1         1        1         1        1         # Retention periods
##    0         0        0         0        0         # sex specific retention
##    3         2        2         2        2         # male retention type
##    1         0        0         0        0         # male retention flag (0 -> no, 1 -> yes)
## ## gear  par   sel                                             phz    start  end
## ## index index par sex  ival  lb    ub     prior  p1     p2     mirror period period
## # Gear-1
##    1     1     1   0    0.4   0.001 1.0    0       0      1      3      1978   2008
##    1     2     2   0    0.7   0.001 1.0    0       0      1      3      1978   2008
##    1     3     3   0    1.0   0.001 2.0    0       0      1     -3      1978   2008
##    1     4     1   0    0.4   0.001 1.0    0       0      1      3      2009   2016
##    1     5     2   0    0.7   0.001 1.0    0       0      1      3      2009   2016
##    1     6     3   0    1.0   0.001 2.0    0       0      1     -3      2009   2016
## # Gear-2
##    2     7     1   0    40    10.0  200    0      10    200     -3      1978   2016
##    2     8     2   0    60    10.0  200    0      10    200     -3      1978   2016
## # Gear-3
##    3     9     1   0    40    10.0  200    0      10    200     -3      1978   2016
##    3     10    2   0    60    10.0  200    0      10    200     -3      1978   2016
## # Gear-4
##    4     11    1   0    0.4   0.001 1.0    0       0      1      4      1978   2016
##    4     12    2   0    0.7   0.001 1.0    0       0      1      4      1978   2016
##    4     13    3   0    1.0   0.001 2.0    0       0      1     -4      1978   2016
## # Gear-5
```

```
##    5     14    1   0    0.4   0.001 1.0    0       0      1     4      1978   2016
##    5     15    2   0    0.7   0.001 1.0    0       0      1     4      1978   2016
##    5     16    3   0    1.0   0.001 2.0    0       0      1    -4      1978   2016
## ## Retained
## # Gear-1
##   -1     17    1   0    120   100   200    0       1    900    -1      1978   2016
##   -1     18    2   0    123   110   200    0       1    900    -1      1978   2016
## # Gear-2
##   -2     19    1   0    595    1    700    0       1    900    -3      1978   2016
##   -2     20    2   0     10    1    700    0       1    900    -3      1978   2016
## # Gear-3
##   -3     21    1   0    590    1    700    0       1    900    -3      1978   2016
##   -3     22    2   0     10    1    700    0       1    900    -3      1978   2016
## # Gear-4
##   -4     23    1   0    580    1    700    0       1    900    -3      1978   2016
##   -4     24    2   0     20    1    700    0       1    900    -3      1978   2016
## # Gear-5
##   -5     25    1   0    580    1    700    0       1    900    -3      1978   2016
##   -5     26    2   0     20    1    700    0       1    900    -3      1978   2016
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## PRIORS FOR CATCHABILITY
## ##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
## ##     and p2 are ignored). ival must be > 0                                            ##
## ## LEGEND                                                                               ##
## ##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma               ##
## ## ---------------------------------------------------------------------------------- ##
## ##  LAMBDA: Arbitrary relative weights for each series, 0 = do not fit.
## ## SURVEYS/INDICES ONLY
## ## ival    lb       ub    phz   prior   p1       p2    Analytic?   LAMBDA
##    1.0     0        2     -1    0       0        2.0   0           1.5     # NMFS trawl
##    4e-06   0        5      1    0       0        5.0   0           2     # ADF&G pot
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## ADDITIONAL CV FOR SURVEYS/INDICES                                                    ##
## ##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
## ##     and p2 are ignored). ival must be > 0                                            ##
## ## LEGEND                                                                               ##
## ##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma               ##
## ## ---------------------------------------------------------------------------------- ##
## ## ival        lb        ub         phz   prior     p1      p2
##    0.00001      0.000001   10.0    -4    4         1.0     100   # NMFS
##    0.00001      0.000001   10.0    -4    4         1.0     100   # ADF&G
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## PENALTIES FOR AVERAGE FISHING MORTALITY RATE FOR EACH GEAR
## ## ---------------------------------------------------------------------------------- ##
## ## Mean_F  STD_PHZ1  STD_PHZ2     PHZ
##    0.2       0.05     50.0        1   # Pot
##    0.001     0.05     50.0        1   # Trawl
##    0.001     0.05     50.0        1   # Fixed
```

```
##    0.00      2.00     20.00     -1   # NMFS
##    0.00      2.00     20.00     -1   # ADF&G
## ## ---------------------------------------------------------------------------------- ##
##
## ## --------------------------------------------------------------------------------- ##
## ## OPTIONS FOR SIZE COMPOSTION DATA (COLUMN FOR EACH MATRIX)
## ## ---------------------------------------------------------------------------------- ##
## ## LIKELIHOOD OPTIONS
## ##   -1) Multinomial with estimated/fixed sample size
## ##   -2) Robust approximation to multinomial
## ##   -3) logistic normal (NIY)
## ##   -4) multivariate-t (NIY)
## ##   -5) Dirichlet
## ## AUTOTAIL COMPRESSION
## ##   pmin is the cumulative proportion used in tail compression.
## ## ---------------------------------------------------------------------------------- ##
##   1   1   1  # Type of likelihood
##   0   0   0   # Auto tail compression (pmin)
##   1   1   1   # Initial value for effective sample size multiplier
##  -4  -4  -4   # Phz for estimating effective sample size (if appl.)
##   1   2   3   # Composition aggregator
##   1.3479   0.2796   0.3908
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## TIME VARYING NATURAL MORTALIIY RATES                                               ##
## ## ---------------------------------------------------------------------------------- ##
## ## TYPE:
## ##      0 = constant natural mortality
## ##      1 = Random walk (deviates constrained by variance in M)
## ##      2 = Cubic Spline (deviates constrained by nodes & node-placement)
## ##      3 = Blocked changes (deviates constrained by variance at specific knots)
## ##      4 = Time blocks
## ## ---------------------------------------------------------------------------------- ##
## ## Type
## 0
## ## Phase of estimation
## -4
## ## STDEV in m_dev for Random walk
## 10.0
## ## Number of nodes for cubic spline or number of step-changes for option 3
## 2
## ## Year position of the knots (vector must be equal to the number of nodes)
## 1998 1999
## ## ---------------------------------------------------------------------------------- ##
##
## ## ---------------------------------------------------------------------------------- ##
## ## OTHER CONTROLS
## ## ---------------------------------------------------------------------------------- ##
##   3       # Estimated rec_dev phase
##   3       # Estimated rec_ini phase
##   0       # VERBOSE FLAG (0 = off, 1 = on, 2 = objective func)
##   2       # Initial conditions (0 = Unfished, 1 = Steady-state fished, 2 = Free parameters)
##   1978    # First year for average recruitment for Bspr calculation
```

```
##   2016    # Last year for average recruitment for Bspr calculation
##   0.35    # Target SPR ratio for Bmsy proxy
##   1       # Gear index for SPR calculations (i.e. directed fishery)
##   1       # Lambda (proportion of mature male biomass for SPR reference points)
##   1       # Use empirical molt increment data (0 = FALSE, 1 = TRUE)
##   0       # Stock-Recruit-Relationship (0 = None, 1 = Beverton-Holt)
## ## EOF
## 9999
```

Draft - Norton Sound Red King Crab Stock Assessment January 15, 2016

Norton Sound Red King Crab Stock Assessment for the fishing year 2016

Toshihide Hamazaki[1] and Jie Zheng [2]
Alaska Department of Fish and Game Commercial Fisheries Division
[1]333 Raspberry Rd., Anchorage, AK 99518-1565
Phone: 907-267-2158
Email: Toshihide.Hamazaki@alaska.gov
[2]P.O. Box 115526, Juneau, AK 99811-5526
Phone : 907-465-6102
Email : Jie.Zheng@alaska.gov

Executive Summary

1. Stock. Red king crab, *Paralithodes camtschaticus*, in Norton Sound, Alaska.

2. Catches. This stock supports three main fisheries: summer commercial, winter commercial, and winter subsistence fisheries. Of those, the summer commercial fishery accounts for more than 90% of total harvest. The summer commercial fishery started in 1977, and catch peaked in the late 1970s with retained catch of over 2.9 million pounds. Since 1982, retained catches have been below 0.5 million pounds, averaging 0.275 million pounds, including several low years in the 1990s. Retained catches have increased to about 0.4 million pounds in recent years coincident with increases in estimated abundance,.

3. Stock Biomass. Following a peak in 1977, abundance or the stock collapsed to a historic low in 1982. Estimated mature male biomass (MMB) has shown an increasing trend since 1997. However, uncertainty in historical biomass is high due in part to infrequent trawl surveys (every 3 to 5 years) and limited winter pot surveys.

4. Recruitment. Model estimated recruitment was weak during the late 1970s and high during the early 1980s, with a slight downward trend from 1983 to 1993. Estimated recruitment has been highly variable but on an increasing trend in recent years.

5. Management performance.

Status and catch specifications (million lb.)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2012/13	1.76[A]	4.59	0.47	0.47	0.47	0.53[A]	0.48
2013/14	2.06[B]	5.00	0.50	0.35	0.35	0.58[B]	0.52
2014/15	2.11[C]	3.71	0.38	0.39	0.39	0.46[C]	0.42
2015	2.41[D]	5.13	0.39	0.40	0.52	0.72[D]	0.58
2016	2.26 [E]	5.87	TBD	TBD	TBD	0.71[E]	0.57

Status and catch specifications (1000t)

Draft - Norton Sound Red King Crab Stock Assessment January 15, 2016

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2012/13	0.80[A]	1.93	0.21	0.21	0.21	0.24[A]	0.22
2013/14	0.93[B]	2.27	0.23	0.16	0.16	0.26[B]	0.24
2014/15	0.96[C]	1.68	0.17	0.18	0.18	0.21[C]	0.19
2015	1.09[D]	2.33	0.18	0.18	0.24	0.33[D]	0.26
2016	1.03	2.66	TBD	TBD	TBD	0.32 [E]	0.26

Notes:
MSST was calculated as $B_{MSY}/2$
A-Calculated from the assessment reviewed by the Crab Plan Team in May 2012
B-Calculated from the assessment reviewed by the Crab Plan Team in May 2013
C-Calculated from the assessment reviewed by the Crab Plan Team in May 2014
D-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2015
E-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2016
Conversion to Metric ton: 1 Metric ton = 2.2046× 1000 lb

Biomass in millions of pounds

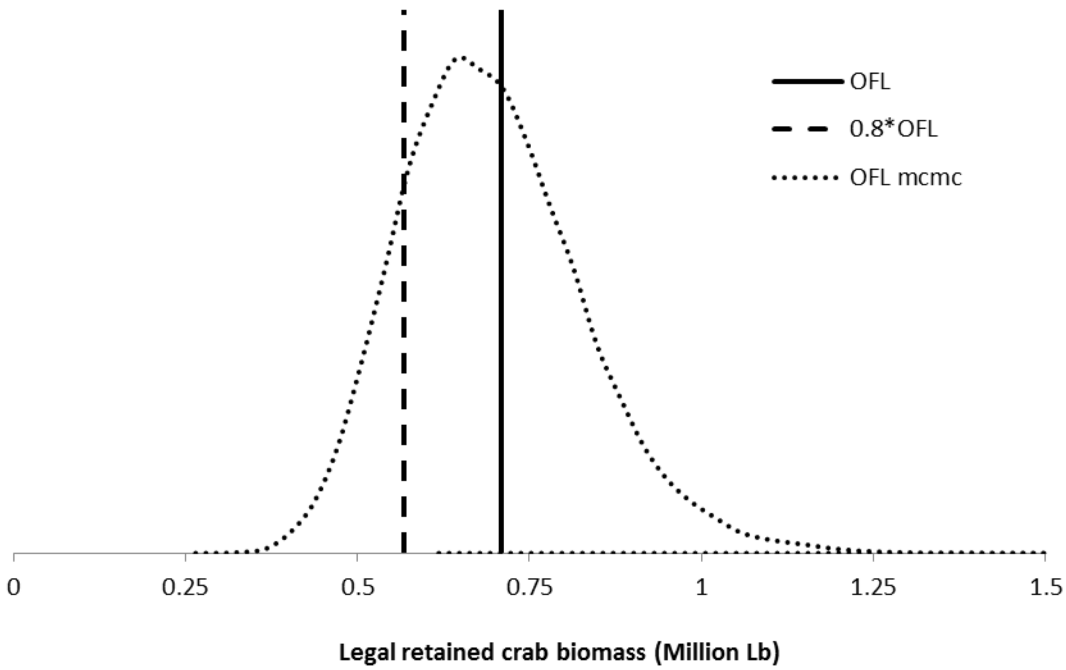
Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	ABC
2012/13	4a	3.51	4.59	1.2	0.18	1980-2012	0.18	0.9	0.48
2013/14	4b	4.12	5.00	1.2	0.18	1980-2013	0.18	0.9	0.52
2014/15	4b	4.19	3.71	0.9	0.16	1980-2014	0.18	0.9	0.42
2015	4a	4.81	5.13	1.1	0.18	1980-2015	0.18	0.8	0.58
2016	4a	4.53	5.87	1.3	0.18	1980-2016	0.18	0.8	0.57

Biomass in 1000t

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	ABC
2012/13	4a	1.59	1.93	1.2	0.18	1980-2012	0.18	0.9	0.22
2013/14	4a	1.86	2.27	1.2	0.18	1980-2013	0.18	0.9	0.24
2014/15	4b	1.90	1.68	0.9	0.16	1980-2014	0.18	0.9	0.19
2015	4a	2.18	2.33	1.1	0.18	1980-2015	0.18	0.8	0.26
2016	4a	2.06	2.66	1.3	0.18	1980-2016	0.18	0.8	0.26

Draft - Norton Sound Red King Crab Stock Assessment January 15, 2016

6. Probability Density Function of the OFL, OFL profile, and mcmc estimates.



7. The basis for the ABC recommendation

   For Tier 4 stocks, the default maximum ABC is based on P*=49% that is essentially identical to the OFL. Accounting for uncertainties in assessment and model results, the SSC chose to use 90% OFL (10% Buffer) for the Norton Sound red king crab stock from 2011 to 2014. In 2015, the buffer was increased to 20% (ABC = 80% OFL).

8. A summary of the results of any rebuilding analyses.

   N/A

A. *Summary of Major Changes in 2015*

1. Changes to the management of the fishery**:**

   None

2. Changes to the input data
   a. Data update: 2015 summer commercial fishery (total catch, catch length comp, discards length comp), 2014/2015 winter commercial and subsistence catch
   b. Data update: 1977-2015 standardized commercial catch CPUE and CV. No changes in standardization methodology (SAFE 2013).

3. Changes to the assessment methodology:

   None

4. Changes to the assessment results.

   None

B. ***Response to SSC and CPT Comments***

Crab Plan Team - Jan 16 2015

- Provide trawl survey documentation

  Trawl survey report is published as ADFG report. The report is available at http://www.adfg.alaska.gov/FedAidPDFs/FDS15-40.pdf

- Provide an explanation and legend for figures comparing input sample sizes with effective sample.

  Done

- Provide the documentation on the survey CPUE standardization as an Appendix

  Included in the Appendix B.

- Fix trawl survey selectivity parameter to 1.0 (i.e., do not estimate)

  Not conducted because selectivity was not always 1.0.

- Provide stock-specific maturity information for possible move to Tier 3.

  Author's reply:
  Assumed male size at (functional) maturity of the NSRKC (CL 94 mm) was determined by adjusting that of Tier 3 BBRKC (CL 120mm) reflecting their slower growth and smaller size. However, male size at (functional) maturity of Tier 3 BBRKC is also assumed (Zheng et al. 2014). For BBRKC male size at maturity is 103 mm CL by chelae allometry (Somerton 1980), 50-59 mm CL by spermatophore presence (Paul et al. 1991). Functional size-at-functional maturity is likely greater than physiological or morphological maturity based on *in situ* grasping pair morphometry was estimated at 120 to 130mm CL for Kodiak Island red king crab (Powell et al. 2002, Webb 2014).

- Include a discussion of the relative uncertainty in model parameters and data employed in the model as well as relative weightings in model configuration for use in best approximating the uncertainty in the OFL.

  Author's reply:
  Tagging data weighting issue has been discussed in SAFE 2015 and effects of input sample size for length composition have been discussed at modeling workshop in 2013

and 2014. We would gladly examine if there is a request for examining effects of specific data set.

SSC Feb 2-4 2015

- The SSC identified the fate of large males as the major uncertainty and hopes that this can be resolved through further research. The competing hypotheses of localized depletion, high natural mortality, or migration to a refuge from fishing have very different implications for OFL and ABC. Until this is resolved, the SSC felt that moving this stock to Tier 3 status would be problematic.

  Author's reply:

  The CPT (Sept 17 2015) commented that the fate of large males is not really a tier 3 question, although does need more investigation.

  Regarding the SSC's hypotheses of localized depletion, high natural mortality, or migration to a refuge from fishing; we examined the available data and suggest the following:

  Trawl survey did not show any pattern that higher number of larger crab being caught at edge of survey boundaries. Spring survey 2012-2015 also did not see higher proportion of large crabs along the coastal area. On the other hand, fall surveys in 2013-2014 consistently showed higher proportion (17% in 2013, 23% in 2014) of the largest size class (> 123mm CL) crab. Those larger crabs were absent in spring survey conducted 8 months later (5% in 2014, 3.5% in 2015). Winter commercial catch length composition did not show high large crab proportion (11 % in Jan-May 2015). These results do not seem to support the hypotheses of localized depletion or migration to a refuge from fishing.

  Regarding the high natural mortality, see section 3.c: Model selection and evaluation – search for balance.

- The SSC prefers that OFL and ABC be consistently presented in units of tons.

  Author's reply:

  We agree to SSC about using of tons as standard metric, international standard. Unfortunately, however, pounds is the customary unit of the US public. We prefer our report to be easily readable to the US public, including crab fishermen, by using the US customary units.

CPT Sept 17 2015

- Explore iterative data reweighting after guidance from the data weighting workshop.

  Author's reply:
  As of preparation of this report (Nov. 2015), no specific recommendations of exploring iterative re-weighting procedures have been provided by the time of NSRKC assessment. We look forward implementing the recommendations for January 2017 assessment.

- Maturity data on males is needed before moving NSRKC to tier 3.

  Author's reply:
  Assumed male size at (functional) maturity of the NSRKC (CL 94 mm) was determined by adjusting that of Tire 3 BBRKC (CL 120mm) reflecting their slower growth and smaller size. However, male size at (functional) maturity of Tire 3 BBRKC is also assumed (Zheng et al. 2014). For BBRKC male size at maturity is CL 103 mm by chelae allometry (Somerton 1980), 50-59 mm CL by spermatophore presence (Paul et al. 1991). Estimated size at functional maturity is only available for one red king crab stock in Alaska (Webb 2014) in which the 5th percentile of the size frequency distribution of males observed in grasping pairs near Kodiak Island was ~ 120 mm CL (Powell et al. 2002).

SSC Oct 5-7 2015

- The SSC supports the plan team's recommendations of exploring iterative re-weighting procedures after the Center for the Advancement of Population Assessment Methodology (CAPAM) data-weighting workshop in late October 2015.

  Author's reply:
  As of preparation of this report (Nov. 2015), no specific recommendations of exploring iterative re-weighting procedures have been provided by the time of NSRKC assessment. We look forward implementing the recommendations for January 2017 assessment.

- The SSC also recommends that the author follow the terms of reference and provide retrospective estimates of spawning stock biomass and the appropriate statistics (e.g., Mohns' rho).

  Author's reply:
  Mohns' rho (Mohn 1999) was calculated, as $\rho = \sum (B_{(1976,y),y+1} - B_{(1976,2015),y+1}) / B_{(1976,y),y+1}$,

  only for the author preferred model. Mohns' rho has NO statistical range criteria of whether an assessment model is deemed acceptable/ unacceptable. We appreciate SSC providing a list of appropriate statistics to be reported for assessment model evaluations, and guidance how each statistics are weighed for selecting the best assessment model.

Draft - Norton Sound Red King Crab Stock Assessment January 15, 2016

C. Introduction

1. Species: red king crab (*Paralithodes camtschaticus*) in Norton Sound, Alaska.
2. General Distribution: Norton Sound red king crab is one of the northernmost red king crab populations that can support a commercial fishery (Powell et al. 1983). It is distributed throughout Norton Sound with a westward limit of 167-168^{o} W. longitude, depths less than 30 m, and summer bottom temperatures above 4^{o}C. The Norton Sound red king crab management area consists of two units: Norton Sound Section (Q3) and Kotzebue Section (Q4) (Menard et al. 2011). The Norton Sound Section (Q3) consists of all waters in Registration Area Q north of the latitude of Cape Romanzof, east of the International Dateline, and south of 66°N latitude (Figure 1). The Kotzebue Section (Q4) lies immediately north of the Norton Sound Section and includes Kotzebue Sound. Commercial fisheries have not occurred regularly in the Kotzebue Section. This report deals with the Norton Sound Section of the Norton Sound red king crab management area.
3. Evidence of stock structure: Thus far, no studies have been made on possible stock separation within the putative stock known as Norton Sound red king crab.
4. Life history characteristics relevant to management: One of the unique life-history traits of Norton Sound red king crab is that they spend their entire lives in shallow water since Norton Sound is generally less than 40 m in depth. Distribution and migration patterns of Norton Sound red king crab have not been well studied. Based on the 1976-2006 trawl surveys, red king crab in Norton Sound are found in areas with a mean depth range of 19 ± 6 (SD) m and bottom temperatures of 7.4 ± 2.5 (SD) ^{o}C during summer. Norton Sound red king crab are consistently abundant offshore of Nome.

   Norton Sound red king crab migrate between deeper offshore and inshore shallow waters. . Timing of the inshore mating migration is unknown, but is assumed to be during late fall to winter (Powell et al. 1983). Offshore migration occurs in late May - July (Jennifer Bell, ADF&G, personal communication). The results from a study funded by North Pacific Research Board (NPRB) during 2012-2014 suggest that older/large crab (> 104mm CL) stay offshore in winter, based on findings that large crab are not found nearshore during spring offshore migration periods (Jennifer Bell, ADF&G, personal communication). Timing of molting is unknown but is considered to occur in late August – September, based on increase catches of fresh-molted crab later in the fishing season (August- September) (Joyce Soong, ADF&G personal communication); however, blood hormonal studies suggested an April-May molting season (Jennifer Bell, ADF&G, personal communication), which is consistent with Powell et al. (1983). Recent observations indicate biennial mating (Robert Foy, NOAA, personal communication). Trawl surveys show that crab distribution is dynamic. Recent surveys show high abundance on the southeast side of the sound, offshore of Stebbins and Saint Michael.
5. Brief management history: Norton Sound red king crab fisheries consist of commercial and subsistence fisheries. The commercial red king crab fishery started in 1977 and occurs in summer (June – August) and winter (December – May). The majority of red king crab is harvested offshore during the summer commercial fishery, whereas most of the winter subsistence fishery harvest occurs nearshore.

Summer Commercial Fishery

A large-vessel summer commercial crab fishery started in 1977 in the Norton Sound Section (Table 1) and continued from 1977 through 1990. No summer commercial fishery occurred in 1991 because there was no staff to manage the fishery. In March 1993, the Alaska Board of Fisheries (BOF) limited participation in the fishery to small boats. Then on June 27, 1994, a super-exclusive designation went into effect for the fishery. This designation stated that a vessel registered for the Norton Sound crab fishery may not be used to take king crabs in any other registration areas during that registration year. A vessel moratorium was put into place before the 1996 season. This was intended to precede a license limitation program. In 1998, Community Development Quota (CDQ) groups were allocated a portion of the summer harvest; however, no CDQ harvest occurred until the 2000 season. On January 1, 2000 the North Pacific License Limitation Program (LLP) went into effect for the Norton Sound crab fishery. The program dictates that a vessel which exceeds 32 feet in length overall must hold a valid crab license issued under the LLP by the National Marine Fisheries Service. Regulation changes and location of buyers resulted in harvest distribution moving eastward in Norton Sound in the mid-1990s.In Norton Sound, a legal crab is defined as ≥ 4-3/4 inch carapace width (CW, Menard et al. 2011), which is approximately equivalent to ≥ 104 mm carapace length mm CL. Since 2005, commercial buyers started accepting only legal crab of ≥ 5 inch CW.

Not all Norton Sound area is open for commercial fisheries. Since the beginning of the commercial fisheries in 1977, approximately 5-10 miles off the shore of southern Seward Peninsula from Port Clarence to St. Michael have been closed to protect crab nursery grounds during the summer commercial crab fishery (Figure 2). The spatial extent of closed waters has varied historically.

CDQ Fishery

The Norton Sound and Lower Yukon CDQ groups divide the CDQ allocation. Only fishers designated by the Norton Sound and Lower Yukon CDQ groups are allowed to participate in this portion of the king crab fishery. Fishers are required to have a CDQ fishing permit from the Commercial Fisheries Entry Commission (CFEC) and register their vessel with the Alaska Department of Fish and Game (ADF&G) before begin fishing. Fishers operate under the authority of each CDQ group who decides how their crab quota is to be harvested. During the March 2002 BOF meeting, new regulations for the CDQ crab fishery were adopted that affected; closed-water boundaries were relaxed in eastern Norton Sound and waters west of Sledge Island. In March 2008, the BOF changed the start date of the Norton Sound open-access portion of the fishery to be opened by emergency order as early as June 15. The CDQ fishery may open at any time (as soon as ice is out), by emergency order.

Winter Commercial Fishery

The winter commercial crab fishery is a small fishery using hand lines and pots through the nearshore ice. On average 10 permit holders harvested 2,500 crabs during 1978-2009. From 2007 to 2015 the winter commercial catch increased from 3,000 crabs to over 40,000 (Table 2). In 2015 winter commercial catch reached 20% of total crab catch. The BOF responded in May 2015 by amending regulations to allocate 8% of the total commercial guideline harvest level (GHL) to the winter commercial fishery. The winter red king crab commercial fishing season was also set from January 15 to April 30, unless changed by emergency order. The new regulation will be in effect for the 2016 season.

Subsistence Fishery

While the subsistence fishery has a long history, harvest information is available only since the 1977/78 season. The majority of the subsistence crab fishery harvest occurs during winter using hand lines and pots through nearshore ice. Average annual winter subsistence harvest was 5,400 crab (1977-2010). Subsistence harvesters need to obtain a permit before fishing and record daily effort and catch. Subsistence fishery has no size or sex limit; however, the majority of retained catches are males of near legal crab size. The subsistence fishery catch is influenced not only by crab abundance, but also by changes in distribution, changes in gear (e.g., more use of pots instead of hand lines since 1980s), and ice conditions (e.g., reduced catch due to unstable ice conditions: 1987-88, 1988-89, 1992-93, 2000-01, 2003-04, 2004-05, and 2006-07).

The summer subsistence crab fishery harvest has been monitored since 2004 with an average harvest of 712 crab per year. Since this harvest is very small, the summer subsistence fishery was not included in the assessment model.

6. Brief description of the annual ADF&G harvest strategy

Since 1997 Norton Sound red king crab have been managed based on a guideline harvest level (GHL). From 1999 to 2011 the GHL for the summer commercial fishery was determined by a prediction model and the model estimated predicted biomass: (1) 0% harvest rate of legal crab when estimated legal biomass < 1.5 million lb; (2) ≤ 5% of legal male abundance when the estimated legal biomass falls within the range 1.5-2.5 million lb; and (3) ≤ 10% of legal male when estimated legal biomass >2.5 million lb.

In 2012 a revised GHL for the summer commercial fishery was implemented: (1) 0% harvest rate of legal crab when estimated legal biomass < 1.25 million lb; (2) ≤ 7% of legal male abundance when the estimated legal biomass falls within the range 1.25-2.0 million lb; (3) ≤ 13% of legal male abundance when the estimated legal biomass falls within the range 2.0-3.0 million lb; and (3) ≤ 15% of legal male biomass when estimated legal biomass >3.0 million lb.

In 2015 the Alaska Board of Fisheries passed the following regulations regarding winter commercial fisheries:

1. Revised GHL to include all fisheries (winter, summer, commercial, and subsistence).
2. Set guideline harvest level for winter commercial fishery (GHL_w) at 8% of the total GHL (i.e., GHL_w = 0.08 x GHL), and summer commercial guideline harvest level (GHL_s) be remainder of total GHL (i.e., GHL_s = GHL - winter comm. harvest - winter subsistence harvest).
3. Date of the winter red king crab commercial fishing season is from January 15 to April 30.

Year	Notable historical management changes
1976	The abundance survey started
1977	Large vessel commercial fisheries began

1991	Fishery closed due to staff constraints
1994	Super exclusive designation went into effect. The end of large vessel commercial fishery operation. The majority of commercial fishery subsequently shifted to east of 164°W longitude.
1998	Community Development Quota (CDQ) allocation went into effect
1999	Guideline Harvest Level (GHL) went into effect
2000	North Pacific License Limitation Program (LLP) went into effect.
2002	Change in closed water boundaries (Figure 2)
2005	Commercially accepted legal crab size changed from ≥ 4-3/4 inch CW to ≥ 5 inch CW
2006	The Statistical area Q3 section expanded (Figure 1)
2008	Start date of the open access fishery changed from July1 to after June 15 by emergency order. Pot configuration requirement: at least 4 escape rings (>4½ inch diameter) per pot located within one mesh of the bottom of the pot, or at least ½ of the vertical surface of a square pot or sloping side-wall surface of a conical or pyramid pot with mesh size > 6½ inches.
2012	The Board of Fisheries adopted a revised GHL for summer fishery.
2016	Winter GHL for commercial fisheries was established and modified winter fishing season dates were implemented.

7. Summary of the history of the $B_{MSY.}$

NSRKC is a Tier4 crab stock. Direct estimation of the B_{MSY} is not possible. The B_{MSY} proxy is calculated as mean model estimated mature male biomass (MMB) from 1980 to present. Choice of this period was based on a hypothesized shift in stock productivity a due to a climatic regime shift indexed by the Pacific Decadal Oscillation (PDO) in 1976-77. Stock status of the NSRKC was Tier 4a until 2013. In 2014 the stock fell to Tier 4b, but came back to Tire 4a in 2015.

D. Data

1. Summary of new information:

Trawl survey:

Trawl survey report is published as ADFG report. The report is available at http://www.adfg.alaska.gov/FedAidPDFs/FDS15-40.pdf

Winter commercial and subsistence fishery:

Winter commercial fishery catch in 2015 was 41,046 crabs (98,750 lb.), which was the highest harvest record since development of its fishery. Subsistence crab catch was 7,651 (15,302 lb., Table 2).

Summer commercial fishery:

The summer commercial fishery opened on June 29 and closed on July 24 due to meeting the GHL. This was the shortest fishery in the history. A total of 144,255 crabs (401,115 lb.) were harvested (Table 1).

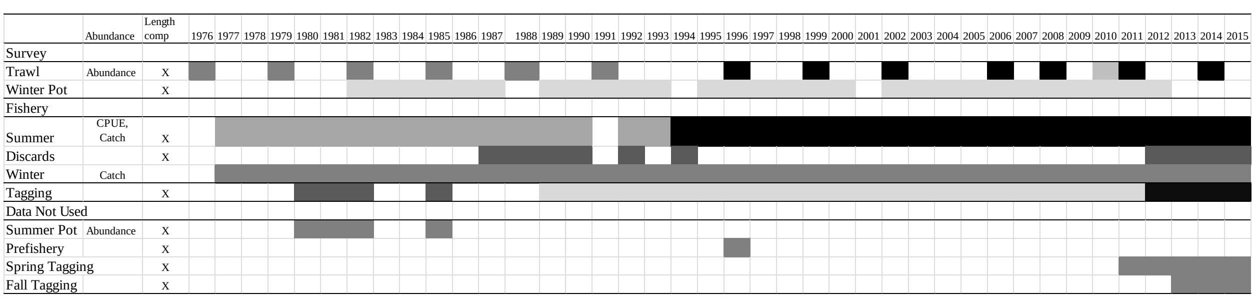
Total harvest for 2015 season was 192,952 crabs (515,167 lb.) and did not exceed the 2015 ABC of 0.58 million lb.

2. Available survey, catch, and tagging data

	Years	Data Types	Tables
Summer trawl survey	76,79,82,85,88,91,96, 99, 02,06,08,10,11, 14	Abundance Length proportion	3 5, Figure 3
Winter pot survey	81-87, 89-91,93,95-00,02-12	Length proportion	6, Figure 3
Summer commercial fishery	76-90,92-15	Retained catch Standardized CPUE, Length proportion	1 1 4, Figure 3
Summer commercial Discards	87-90,92,94, 2012-2014	Length proportion (sublegal only)	7, Figure 3
Winter subsistence fishery	76-15	Total catch Retained catch	2 2
Winter commercial fishery	78-15	Retained catch	2
Tag recovery	80-15	Recovered tagged crab	8

Data available but not used for assessment

Data	Years	Data Types	Reason for not used
Summer pot survey	80-82,85	Abundance Length proportion	Uncertainties on how estimates were made.
Summer preseason survey	95	Length proportion	Just one year of data
Summer subsistence fishery	2005-2013	retained catch	Too few catches compared to commercial
Winter Pot survey	-87, 89-91,93,95-00,02-12	CPUE, Length	Not reliable due to ice conditions
Winter Commercial	2015	Length proportion	Years of data too short
Preseason Spring pot survey	2011-15	CPUE, Length proportion	Years of data too short
Postseason Fall pot survey	2013-15	CPUE, Length proportion	Years of data too short



Catches in other fisheries

In Norton Sound, no other crab, groundfish, or shellfish fisheries exist.

	Fishery	Data availability
Bycatch in other crab fisheries	Does not exist	NA
Bycatch in groundfish pot	Does not exist	NA
Bycatch in groundfish trawl	Does not exist	NA
Bycatch in the scallop fishery	Does not exist	NA

3. Other miscellaneous data:

   Spring offshore migration distance and direction (2013-2015)

   Monthly blood hormone level (indication of molting timing) (2014-2015)

Data aggregated:

   Proportion of legal size crab, estimated from trawl survey and observer data. (Table 11)

Data estimated outside the model:

   Summer commercial catch standardized CPUE (Table 1)

E. Analytic Approach

1. **History of the modeling approach.**

   The Norton Sound red king crab stock was assessed using a length-based synthesis model (Zheng et al. 1998). Since adoption of the model, the major challenge is a conflict between model projection and data, specifically the model projects higher abundance-proportion of the largest size class of crab than in seen in data. This problem was further exasperated when natural mortality M was set as 0.18 from previous M = 0.3 in 2011 (SAFE 2011). This problem was examined and resolved by increasing M of the largest length crabs to 3.6×M or M = 0.648 (SAFE 2012). Profile likelihood analyses have been conducted several times, which resulted in **the lowest likelihood at M = 0.34** (SAFE 2012, 2013). However, even at this higher M, the model was not able to resolve poor fits to the commercial catch. Profile likelihood of commercial catch was lowest around M = 0.5 or greater.

   From 2013 to 2014, the NSRKC model was thoroughly examined by the CPT during the modeling workshop. The workshop improved the model fit thorough excluding some data (summer pot survey), revising the trawl survey abundance estimates, standardizing commercial catch CPUE, including tag recovery data to estimate the growth transition matrix within the model, and changing weights in the likelihood. However, the issue of M

was not addressed in this workshop. For the 2016 assessment we again examined the influence of *M* on model performance.

Historical Model configuration progression:

2011 (SAFE 2011)
1. *M* =0.18
2. *M* of the last length class = 0.288
3. Include summer commercial discards mortality = 0.2
4. Weight of fishing effort = 20,
5. The maximum effective sample size for commercial catch and winter surveys = 100,

2012 (SAFE 2012)
1. *M* of the last length class = 3.6×*M*
2. The maximum effective sample size for commercial catch and winter surveys = 50,
3. Weight of fishing effort = 50.

2013 (SAFE 2013)
1. Standardize commercial catch cpue and replace likelihood of commercial catch efforts to standardized commercial catch cpue with weight = 1.0
2. Eliminate summer pot survey data from likelihood
3. Estimate survey *q* of 1976-1991 NMFS survey with maximum of 1.0
4. The maximum effective sample size for commercial catch and winter surveys = 20.

2014 (SAFE 2014)
1. Modify functional form of selectivity and molting probability to improve parameter estimates (2 parameter logistic to 1 parameter logistic)
2. Include additional variance for the standardized cpue.
3. Include winter pot survey cpue (But was removed from the final model due to lack of fit)
4. Estimate growth transition matrix from tagged recovery data.

2015 (SAFE 2015)
1. Winter pot survey selectivity is an inverse logistic, estimating selectivity of the smallest length group independently
2. Reduce Weight of tag-recovery: W = 0.5
3. Model parsimony: one trawl survey selectivity and one commercial pot selectivity

2. Model Description

a. Description of overall modeling approach:

   The model is a male-only size structured model that combines multiple sources of survey, catch, and mark-recovery data using a maximum likelihood approach to estimate abundance, recruitment, catchability of the commercial pot gear, and parameters for selectivity and molting probabilities (See Appendix A for full model description).

b-f. See Appendix A.

g. Critical assumptions of the model:

i. Male crab mature at CL length 94mm.

Size at maturity of the NSRKC (CL 94 mm) was determined by adjusting that of BBRKC (CL 120mm) reflecting their slower growth and smaller size.

ii. Molting events in fall after the fishery

iii. Instantaneous natural mortality *M* is 0.18 for all length classes, except for the last length group (> 123mm) where *M* is 3.6 times higher (0.648). *M* is constant over time.

iv. Trawl survey selectivity is a logistic function with 1.0 for length classes 5-6. . Selectivity is constant over time.

v. Winter pot survey selectivity is a dome shaped function: Reverse logistic function of 1.0 for length class CL 84mm, and model estimate for CL < 84mm length classes. Selectivity is constant over time.

This assumption is based on the fact that low proportion of large crabs caught in nearshore area where the winter surveys occur. Causes of this have been argued: (1) large crab do not migrate into nearshore in winter, or (2) large crab are fished out by winter fisheries where the survey occurs (i.e., local depletion). Recent studies suggest that the former was more likely the cause (Jennifer Bell, ADFG, personal communication).

vi. Summer commercial fisheries selectivity is an asymptotic logistic function of 1.0 at the length class CL 124mm. While fishery changed greatly between the periods of 1977-1992 and 1993-present in terms of fishing vessel composition and pot configuration, the selectivity of each period was assumed to be identical. Model fits of separating and combining two periods were examined in 2015, which showed no difference between the two models (SAFE 2015). For model parsimony, the two were combined.

vii. Summer trawl survey selectivity is an asymptotic logistic function of 1.0 at the length of CL 124mm. While the survey changed greatly between NOAA (1976-1991) and ADF&G (1996-present) in terms of survey vessel and trawl net structure, selectivity of both periods was assumed to be identical. Model fits separating and combining the two surveys were examined in 2015. No differences between the two model were observed (SAFE 2015) and for model parsimony the two were combined.

viii. Winter commercial and subsistence fishery selectivity and length-shell conditions are the same as those of the winter pot survey. All winter commercial and subsistence harvests occur February 1st.

Winter commercial king crab pots can be any dimension (5AAC 34.925(d)). No length composition data exists for crab harvested in the winter commercial or subsistence fisheries. However, because commercial fishers are also subsistence fishers, it is reasonable to assume that the commercial fishers used crab pots that they use for subsistence harvest, and hence both fisheries have the same selectivity.

ix. Growth increments are a function of length, are constant over time, estimated from tag recovery data.

x. Molting probability is an inverse logistic function of length for males.

xi. A summer fishing season for the directed fishery is short. All summer commercial harvests occur July 1st.

xii. Discards handling mortality for all fisheries is 20%.
No empirical estimate is available.

xiii. Annual retained catch is measured without error.

xiv. All legal size crab (≥ 4-3/4 inch CW) are retained.

Since 2005, buyers announced that only legal crab with ≥ 5 inch CW are acceptable for purchase. Since samples are taken at a commercial dock, it was anticipated that this change would lower the proportion of legal crab for length class 4. However, the model was not sensitive to this change (SAFE 2013).

xv. All sublegal size crab or commercially unacceptable size crab (< 5 inch CW, since 2005) are discarded.

xvi. Length compositions have a multinomial error structure and abundance has a log-normal error structure.

h. Changes of assumptions since last assessment:

None.

i. Code validation
The model code was reviewed at the CPT modeling workshop in 2013 and 2014. It is available from the authors.

3. Model Selection and Evaluation

a. Description of alternative model configurations.

CPT did not recommend any future model modifications in Jan 2015, except for fixing the trawl survey selectivity parameter. Here, we examined 3 major model scenarios: (1) estimate multiplier of the last length class natural mortality multiplier (*ms*) from the model, (2) estimate *M* equal for all length classes from the model, and (3) estimate *M* and *ms* from the model. For data input, we examined 3 scenarios: (1) expand length classes (2) change growth increment interval from 10 mm to 5 mm, and (3) both (1) and (2). Increasing length ranges or reducing growth increment interval increases use of data. This may increase the number of parameters to be estimated, but may also improve model fit.

List of model scenarios considered.

Scenario	Length Range	Length Interval	M	ms (> 123mm)
0 (Default)	74-124	10	0.18	3.6
1			0.18	Est
2			Est	1.0
3			Est	Est
4	64-134	10	0.18	3.6
5			0.18	Est
6			Est	1.0
7			Est	Est
8	74-124	5	0.18	3.6
9			0.18	Est
10			Est	1.0
11			Est	Est
12	64-134	5	0.18	3.6
13			0.18	Est
14			Est	1.0
15			Est	Est

Est: model estimated.

b. Evaluation of alternative models results:

For model 1 to 15

Model	Number of Parameters	Total	TSA	St. CPUE	TLP	WLP	CLP	OBS	REC	TAG
0	59	310.9	9.7	-21.7	124.5	44.6	59.7	33.5	12.0	48.6
1	60	310.8	9.6	-21.7	124.2	44.6	60.1	33.5	12.1	48.4
2	60	324.2	9.3	-21.2	120.1	44.8	72.1	34.4	11.2	53.4
3	61	310.7	9.6	-21.6	123.6	44.3	60.5	33.5	11.9	48.8
4	61	292.9	10.0	-21.1	102.0	42.3	58.0	29.8	12.3	59.5
5	62	293.0	10.0	-21.0	102.0	42.3	58.2	29.8	12.3	59.5
6	62	314.0	9.9	-20.9	103.3	45.1	69.7	31.4	11.4	64.1
7	63	292.6	9.9	-21.1	102.6	42.2	57.9	29.5	12.4	59.2
8	60	353.2	9.8	-22.1	119.4	43.7	63.4	30.5	11.6	96.8
9	61	353.1	9.8	-22.1	119.1	43.6	63.8	30.4	11.6	96.8
10	61	366.3	9.5	-21.7	116.7	46.3	71.2	32.1	11.0	101.2
11	62	352.8	9.8	-22.1	118.3	43.8	63.7	30.7	11.5	97.0
12	64	354.8	10.3	-21.3	101.9	44.7	62.5	28.0	12.3	116.3
13	65	354.8	10.3	-21.3	101.9	44.7	62.5	28.0	12.3	116.3
14	65	378.4	10.2	-21.2	104.6	49.0	73.3	29.8	11.6	121.0
15	66	354.3	10.2	-21.3	102.1	44.3	62.9	27.6	12.4	116.1

TSA: Trawl survey abundance
St. CPUE: Summer commercial catch standardized cpue
TLP: Trawl survey length composition:
WLP: Winter pot survey length composition
CLP: Summer commercial catch length composition
REC: Recruitment deviation

OBS: Summer Commercial catch Observer discards length composition
TAG: Tagging recovery data composition

Estimated *M*, *ms*, MMB (2016) and OFL. Bold fonts are model estimate.

Model	*M*	*ms*	MMB(2016)	OFL
0	0.18	3.6	5.99	0.85
1	0.18	**3.42**	5.78	0.82
2	**0.42**	1	6.15	1.74
3	**0.21**	**2.96**	6.03	0.78
4	0.18	3.6	5.88	0.77
5	0.18	**3.56**	5.87	0.77
6	**0.4**	1	5.81	1.42
7	**0.14**	**4.61**	6.54	0.81
8	0.18	3.6	6.50	0.86
9	0.18	**3.45**	6.46	0.85
10	**0.41**	1	6.63	1.64
11	**0.22**	**2.78**	6.54	1.02
12	0.18	3.6	6.17	0.76
13	0.18	**3.60**	6.17	0.76
14	**0.39**	1	6.16	1.33
15	**0.14**	**4.82**	6.05	0.59

c. Search for balance:

Diagnostics and output from alternative models are detailed in Appendices C1 (model 0) to C16 (model 15) Among all alternative models, major differences are: estimate *M* of the largest length class, estimate M for all lengths equal, estimate *M* and the largest length class, increase range of length classes, and decrease increments length class. Estimating *M* multiplier of the largest length class (*ms*) did not change model fit (Model 0 vs. Model 1), indicating that *ms* = 3.6 is still a valid assumption. Estimating *M* (Model 0 vs. Model 2) improved fits of trawl survey length composition, but worsened fit of commercial fishery length composition and tag recovery. The model tends to overestimate commercial catch proportion of largest length class or underestimate that of middle length crabs. We also attempted to estimate selectivity of the largest length class as separate parameter, which allows model to choose dome shaped selectivity. However, the estimate was 1.0. Estimate of *M* was 0.42 that was more than twice higher than the default assumption of *M* = 0.18. Profile analyses showed that each likelihood components had different information about *M* (Appendix B1); however, except for winter pot and observer length comp, all other likelihood components were minimized at *M* ranging 0.3 to 0.6. This suggests that under the assumption of constant natural mortality across length classes and current model configurations, the data do not support the assumption of *M* = 0.18. Estimating both *M* and that of the largest length class (Model 0 vs. Model 3) did not change model fit. Estimated *M* was 0.21 for all and 0.617 (*ms* = 2.96) for the largest length class, similar to model assumption. This suggests that given available data and model configuration, assuming higher mortality for the largest length classes is the best option. This also suggests that if M = 0.18 across all length classes is true then model structure may need to be re-examined. Increasing the length classes (Model 0 vs. Model 4) or decreasing length category interval from 10 mm to 5 mm (Model 0 vs. Model 8) can increase use of more data and thus may yield better estimates for selectivities and molting probability. Regardless, all models had similar fit to trawl survey abundance and standardized CPUE.

Projected MMB for 2016 was similar across models ranging from 5.8 to 6.6 million lb. On the other hand, estimates of OFL differed greatly across the models because of differences in M. Considering all factors, we initially considered alternative models 0, 1, 5, and 13 for the 2016 assessment. Among the 4 models, Model 5 had the lowest Mohn's rho (Model 0: -0.482, Model 1: -0.556, Model 5: 0.115, Model 13: 0.924). While Mohn's rho has no cut-off criteria to which a model is deemed unacceptable, a model with Mohn's roh closer to 0 is generally considered a better model. Thus, we recommend the Model 5 for the 2016 assessment model.

4. Results

1. List of effective sample sizes and weighting factors (Figure 4)

   "Implied" effective sample sizes were calculated as

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

Where $P_{y,l}$ and $\hat{P}_{y,l}$ are observed and estimated length compositions in year y and length group l, respectively. Estimated effective sample sizes vary greatly over time.

Maximum sample size for length proportion:

Survey data	Sample size
Summer commercial, winter pot, and summer observer	minimum of 0.1× actual sample size or 10
Summer trawl and pot survey	minimum of 0.5× actual sample size or 20

2. Tables of estimates.

   a. Model parameter estimates (Tables 10, 11, 12, 13).

   b. Abundance and biomass time series (Table 14)

c. Recruitment time series (Table 14).

d. Time series of catch/biomass (Tables 14 and 15)

3. Graphs of estimates.

a. Molting probability and trawl/pot selectivity (Figure 5)

b. Trawl survey and model estimated trawl survey abundance (Figure 6)

c. Estimated male abundances (recruits, legal, and total) (Figure 7)

d. Estimated mature male biomass (Figure 8)

e. Time series of standardized cpue for the summer commercial fishery (Figure 9).

f. Time series of catch and estimated harvest rate (Figure 10).

4. Evaluation of the fit to the data.

a. Fits to observed and model predicted catches.
Not applicable. Catch is assumed to be measured without error; however fits of cpue are available (Figures 9, 11).

b. Model fits to survey numbers (Figures 6, 11).

All model estimated abundances of total crab were within the 95% confidence interval of the survey observed abundance, except for 1976 and 1979, where model estimates were higher than the observed abundances.

c. Fits of catch proportions by lengths (Figures 12, 13).

d. Model fits to catch and survey proportions by length (Figures 12, 14, 15, 16).

e. Marginal distribution for the fits to the composition data

f. Plots of implied versus input effective sample sizes and time-series of implied effective sample size (Figure 4).

g. Tables of RMSEs for the indices:

Trawl survey: 0.36
Summer commercial standardized CPUE: 0.5.

h. QQ plots and histograms of residuals (Figure 11).

5. Retrospective and prospective analyses (Figure 17,18).
6. Uncertainty and sensitivity analyses.

   See Sections 2 and 5.

F. Calculation of the OFL

1. Specification of the Tier level and stock status.

The Norton Sound red king crab stock is placed in Tier 4. It is not possible to estimate the spawner-recruit relationship, but some abundance and harvest estimates are available to build a computer simulation model that captures the essential population dynamics. Tier 4 stocks are assumed to have reliable estimates of current survey biomass and instantaneous *M*; however, the estimates for the Norton Sound red king crab stock are uncertain. Survey biomass is based on triennial trawl surveys with CVs ranging from 15-42% (Table 4).

Tire 4 level and the OFL are determined by the F_{MSY} proxy, B_{MSY} proxy, and estimated legal male abundance and biomass:

level	Criteria	F_{OFL}
a	$B/B_{MSY^{prox}} > 1$	$F_{OFL} = \gamma\, M$
b	$\beta < B/B_{MSY^{prox}} \le 1$	$F_{OFL} = \gamma\, M\, (B/B_{MSY^{prox}} - \alpha)/(1-\alpha)$
c	$B/B_{MSY^{prox}} \le \beta$	$F_{OFL} = bycatch\ mortality\ \&\ directed\ \ fishery\ F = 0$

where *B* is a mature male biomass (MMB), B_{MSY} proxy is average mature male biomass over a specified time period, $M = 0.18$, $\gamma = 1$, $\alpha = 0.1$, and $\beta = 0.25$

For Norton Sound red king crab, MMB is defined as the biomass of males > 94 mm CL on February 01 (Appendix A). B_{MSY} proxy is

B_{MSY} proxy = average model estimated MMB from 1980-2016

Predicted mature male biomass in 2016 in February 01 is:

Mature male biomass : 5.87 (SD 1.12) million lb.

Estimated B_{MSY} proxy is:

4.53 million lb.

Since projected MMB is greater than B_{MSY} proxy, **Norton Sound red king crab stock status is Tire 4 a.**

2. Calculation of OFL.

The OFL was calculated for retained, unretained, and total male catch, in which OFL is calculated by applying F_{OFL} control rule to crab abundance estimates.

$$OFL = (1 - \exp(-F_{OFL}))Legal\_B$$

Legal_B, biomass of legal crab subject to fisheries is calculated as : Projected abundance by length crab × fishing selectivity by length crab × Proportion of legal crab per length class × Average lb per length class (Appendix A)

The Norton Sound red king crab fishery consists of a small (1-17% of total catch biomass) winter subsistence and commercial fishery from January to May and summer commercial fishery (83-99% of total catch biomass) from mid-June to September. The two fisheries use different fishing gears and thus have different catch selectivities (Figure 5, Table 11).

In determination of OFL, *Legal_B* should be biomass right before the majority of fisheries occur that is July 01, which is calculated as: (Feb 1st abundance – winter fishery harvests – winter fishery discards × handling mortality) × natural mortality from Feb 1st to June 30th. However, because model assessment is based on February 01 population, and winter fishery is yet to occur, predicted July 01 population cannot be calculated directly.

Hence, under the direction of the CPT (Jan 12, 2016), the crab abundance (*Legal_B*) used for calculation of the OFL the July 01 *Legal_B* was calculated as: Projected legal abundance (Feb 1st) × Commercial pot selectivity × Proportion of legal crab per length class × average lb per length class × natural mortality from February 1st to July 1st.

$$Legal\_B = (\sum_l (N_{w,l,} + O_{w,l,})S_{s,l} L_l wm_l)e^{-0.42M}$$

$$OFL_r = (1 - \exp(-F_{OFL}))Legal\_B$$

For next year (2017) calculation of (*Legal_B*) will be updated to incorporate projected winter fishery removal.

The unretained OFL is a sub-legal crab biomass catchable to summer commercial pot fisheries calculated as: Projected legal abundance (Feb 1st) × Commercial pot selectivity × Proportion of sub-legal crab per length class × Average lb per length class × handling mortality.

$$OFL_{nr} = (1-\exp(-F_{OFL}))\sum_{l}(N_{s,l,} + O_{s,l,})S_{s,l}(1-L_l)wm_l\ hm$$

where $N_{s,l}$ and $O_{s,l}$ are summer abundances of newshell and oldshell crab in length class l in the terminal year, L_l is the proportion of legal males in length class l, $S_{s,l}$ is summer commercial catch selectivity, wm_l is average weight in length class l and hm is handling mortality rate. .

The total male OFL is

$$OFL_T = OFL_r + OFL_{nr}$$

For calculation of the OFL 2016

Legal male biomass (July 01): 4.31 (SD 0.89) million lb
OFL_r = 0.710 million lb.
OFL_{nr} = 0.180 million lb.
OFL_T = 0.890 million lb.

G. Calculation of the ABC

1. Specification of the probability distribution of the OFL.

Probability distribution of the OFL was determined based on the CPT recommendation in January 2015 of 20% buffer:

Retained ABC for legal male crab is 80% of OFL

ABC = 0.710× 0.8 = 0.568 million lb.

H. Rebuilding Analyses

Not applicable

I. Data Gaps and Research Priorities

The major data gap is the fate of crab greater than 123 mm.

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Table 1. Historical summer commercial red king crab fishery economic performance, Norton Sound Section, eastern Bering Sea, 1977-2014. Bold type shows data that are used for the assessment model.

	Guideline Harvest	Commercial Harvest (lb) [a, b]			Total Number (Open Access)			Total Pots		**ST CPUE**		Season Length		**Mid-day from**
Year	Level (lb) [b]	Open Access	CDQ	**Harvest**	Vessels	Permits	Landings	Registered	Pulls	**CPUE**	**SD**	Days	Dates	**July 1**
1977	[c]	0.52		**195,877**	7	7	13		5,457	**4.18**	**0.34**	60	[c]	**0.03**
1978	3.00	2.09		**660,829**	8	8	54		10,817	**2.21**	**0.23**	60	6/07-8/15	**0.03**
1979	3.00	2.93		**970,962**	34	34	76		34,773	**3.09**	**0.18**	16	7/15-7/31	**0.063**
1980	1.00	1.19		**329,778**	9	9	50		11,199	**3.03**	**0.26**	16	7/15-7/31	**0.063**
1981	2.50	1.38		**376,313**	36	36	108		33,745	**0.89**	**0.19**	38	7/15-8/22	**0.093**
1982	0.50	0.23		**63,949**	11	11	33		11,230	**0.11**	**0.25**	23	8/09-9/01	**0.14**
1983	0.30	0.37		**132,205**	23	23	26	3,583	11,195	**1.00**	**0.22**	3.8	8/01-8/05	**0.093**
1984	0.40	0.39		**139,759**	8	8	21	1,245	9,706	**0.94**	**0.23**	13.6	8/01-8/15	**0.107**
1985	0.45	0.43		**146,669**	6	6	72	1,116	13,209	**0.34**	**0.20**	21.7	8/01-8/23	**0.132**
1986	0.42	0.48		**162,438**	3	3		578	4,284	**0.76**	**0.41**	13	8/01-8/25	**0.153**
1987	0.40	0.33		**103,338**	9	9		1,430	10,258	**0.57**	**0.32**	11	8/01-8/12	**0.118**
1988	0.20	0.24		**76,148**	2	2		360	2,350	**1.44**	**0.67**	9.9	8/01-8/11	**0.115**
1989	0.20	0.25		**79,116**	10	10		2,555	5,149	**1.80**	**0.32**	3	8/01-8/04	**0.096**
1990	0.20	0.19		**59,132**	4	4		1,388	3,172	**1.13**	**0.40**	4	8/01-8/05	**0.099**
1991	0.34			**0**	No Summer Fishery									
1992	0.34	0.07		**24,902**	27	27		2,635	5,746	**0.30**	**0.31**	2	8/01-8/03	**0.093**
1993	0.34	0.33		**115,913**	14	20	208	560	7,063	**0.91**	**0.10**	52	7/01-8/28	**0.09**
1994	0.34	0.32		**108,824**	34	52	407	1,360	11,729	**0.81**	**0.06**	31	7/01-7/31	**0.044**
1995	0.34	0.32		**105,967**	48	81	665	1,900	18,782	**0.43**	**0.05**	67	7/01-9/05	**0.066**
1996	0.34	0.22		**74,752**	41	50	264	1,640	10,453	**0.51**	**0.08**	57	7/01-9/03	**0.096**
1997	0.08	0.09		**32,606**	13	15	100	520	2,982	**0.85**	**0.10**	44	7/01-8/13	**0.101**
1998	0.08	0.03	0.00	**10,661**	8	11	50	360	1,639	**0.80**	**0.13**	65	7/01-9/03	**0.088**
1999	0.08	0.02	0.00	**8,734**	10	9	53	360	1,630	**0.93**	**0.13**	66	7/01-9/04	**0.101**
2000	0.33	0.29	0.01	**111,728**	15	22	201	560	6,345	**1.26**	**0.06**	91	7/01- 9/29	**0.11**
2001	0.30	0.28	0.00	**98,321**	30	37	319	1,200	11,918	**0.66**	**0.05**	97	7/01- 9/09	**0.085**
2002	0.24	0.24	0.01	**86,666**	32	49	201	1,120	6,491	**1.25**	**0.06**	77	6/15-9/03	**0.074**
2003	0.25	0.25	0.01	**93,638**	25	43	236	960	8,494	**0.88**	**0.05**	68	6/15-8/24	**0.079**
2004	0.35	0.31	0.03	**120,289**	26	39	227	1,120	8,066	**1.37**	**0.05**	51	6/15-8/08	**0.063**
2005	0.37	0.37	0.03	**138,926**	31	42	255	1,320	8,867	**1.26**	**0.05**	73	6/15-8/27	**0.071**
2006	0.45	0.42	0.03	**150,358**	28	40	249	1,120	8,867	**1.38**	**0.05**	68	6/15-8/22	**0.09**
2007	0.32	0.29	0.02	**110,344**	38	30	251	1,200	9,118	**1.07**	**0.05**	52	6/15-8/17	**0.063**
2008	0.41	0.36	0.03	**143,337**	23	30	248	920	8,721	**1.42**	**0.05**	73	6/23-9/03	**0.063**
2009	0.38	0.37	0.03	**143,485**	22	27	359	920	11,934	**0.89**	**0.04**	98	6/15-9/20	**0.1**
2010	0.40	0.39	0.03	**149,822**	23	32	286	1,040	9,698	**1.27**	**0.04**	58	6/28-8/24	**0.096**
2011	0.36	0.37	0.03	**141,626**	24	25	173	1,040	6,808	**1.62**	**0.05**	33	6/28-7/30	**0.038**
2012	0.47	0.44	0.03	**161,113**	40	29	312	1,200	10,041	**1.34**	**0.04**	72	6/29-9/08	**0.077**
2013	0.50	0.37	0.02	**130,603**	37	33	460	1,420	15,058	**0.69**	**0.04**	74	7/3-9/14	**0.107**
2014	0.38	0.36	0.03	**129,657**	52	33	309	1,560	10,127	**1.16**	**0.05**	52	6/25-8/15	**0.052**
2015	0.39	0.37	0.03	**144,255**	42	36	251	1,480	8,356	**1.53**	**0.05**	26	6/29-7/24	**0.030**

[a] Deadloss included in total. [b] Millions of pounds. [c] Information not available.

Table 2. Historical winter commercial and subsistence red king crab fisheries, Norton Sound Section, eastern Bering Sea, 1977-2015. Bold typed data are used for the assessment model.

	Commercial			Subsistence					
					Permits			Total Crab	
Model Year	Year[a]	# of Fishers	# of Crab Harvested	Winter[b]	Issued	Returned	Fished	Caught[c]	Retained[d]
1978	1978	37	**9,625**	1977/78	290	206	149	**NA**	**12,506**
1979	1979	1[f]	**221[f]**	1978/79	48	43	38	**NA**	**224**
1980	1980	1[f]	**22[f]**	1979/80	22	14	9	**NA**	**213**
1981	1981	0	**0**	1980/81	51	39	23	**NA**	**360**
1982	1982	1[f]	**17[f]**	1981/82	101	76	54	**NA**	**1,288**
1983	1983	5	**549**	1982/83	172	106	85	**NA**	**10,432**
1984	1984	8	**856**	1983/84	222	183	143	**15,923**	**11,220**
1985	1985	9	**1,168**	1984/85	203	166	132	**10,757**	**8,377**
1986	1985/86	5	**2,168**	1985/86	136	133	107	**10,751**	**7,052**
1987	1986/87	7	**1,040**	1986/87	138	134	98	**7,406**	**5,772**
1988	1987/88	10	**425**	1987/88	71	58	40	**3,573**	**2,724**
1989	1988/89	5	**403**	1988/89	139	115	94	**7,945**	**6,126**
1990	1989/90	13	**3,626**	1989/90	136	118	107	**16,635**	**12,152**
1991	1990/91	11	**3,800**	1990/91	119	104	79	**9,295**	**7,366**
1992	1991/92	13	**7,478**	1991/92	158	105	105	**15,051**	**11,736**
1993	1992/93	8	**1,788**	1992/93	88	79	37	**1,193**	**1,097**
1994	1993/94	25	**5,753**	1993/94	118	95	71	**4,894**	**4,113**
1995	1994/95	42	**7,538**	1994/95	166	131	97	**7,777**	**5,426**
1996	1995/96	9	**1,778**	1995/96	84	44	35	**2,936**	**1,679**
1997	1996/97	2[f]	**83[f]**	1996/97	38	22	13	**1,617**	**745**
1998	1997/98	5	**984**	1997/98	94	73	64	**20,327**	**8,622**
1999	1998/99	5	**2,714**	1998/99	95	80	71	**10,651**	**7,533**
2000	1999/00	10	**3,045**	1999/00	98	64	52	**9,816**	**5,723**
2001	2000/01	3	**1,098**	2000/01	50	27	12	**366**	**256**
2002	2001/02	11	**2,591**	2001/02	114	61	45	**5,119**	**2,177**
2003	2002/03	13	**6,853**	2002/03	107	70	61	**9,052**	**4,140**
2004	2003/04	2[f]	**522** [f]	2003/04[g]	96	77	41	**1,775**	**1,181**
2005	2004/05	4	**2,091**	2004/05	170	98	58	**6,484**	**3,973**
2006	2005/06	1[f]	**75[f]**	2005/06	98	97	67	**2,083**	**1,239**
2007	2006/07	8	**3,313**	2006/07	129	127	116	**21,444**	**10,690**
2008	2007/08	9	**5,796**	2007/08	139	137	108	**18,621**	**9,485**
2009	2008/09	7	**4,951**	2008/09	105	105	70	**6,971**	**4,752**
2010	2009/10	10	**4,834**	2009/10	125	123	85	**9,004**	**7,044**
2011	2010/11	5	**3,365**	2010/11	148	148	95	**9,183**	**6,640**
2012	2011/12	35	**9,157**	2011/12	204	204	138	**11,341**	**7,311**
2013	2012/13	26	**22,639**	2012/13	149	148	104	**21,524**	**7,622**
2014	2013/14	21	**14,986**	2013/14	103	103	75	**5,421**	**3,252**
2015	2014/15	44	**41,046**	2014/15	155	153	107	**9,840**	**7,651**

a Prior to 1985 the winter commercial fishery occurred from January 1 - April 30. As of March 1985, fishing may occur from November 15 - May 15.
b The winter subsistence fishery occurs during months of two calendar years (as early as December, through May).
c The number of crab actually caught; some may have been returned.
d The number of crab Retained is the number of crab caught and kept.
f Confidentiality was waived by the fishers.
h Prior to 2005, permits were only given out of the Nome ADF&G office. Starting with the 2004-5 season, permits were given out in Elim, Golovin, Shaktoolik, and White Mountain.

Table 3. Summary of triennial trawl survey Norton Sound male red king crab abundance estimates. Trawl survey abundance estimate is based on 10×10 nmil^2 grid, except for 2010 (20×20 nmil^2).

				Survey coverage			Abundance ≥74 mm	
Year	Dates	Survey Agency	Survey method	surveyed stations	Stations w/ NSRKC	n mile^2 covered		CV
1976	9/02 - 9/05	NMFS	Trawl	103	62	10260	**4247.5**	**0.31**
1979	7/26 - 8/05	NMFS	Trawl	85	22	8421	**1417.2**	**0.20**
1980	7/04 - 7/14	ADFG	Pots				2092.3	N/A
1981	6/28 - 7/14	ADFG	Pots				2153.4	N/A
1982	7/06 - 7/20	ADFG	Pots				1140.5	N/A
1982	9/05 - 9/11	NMFS	Trawl	58	37	5721	**2791.7**	**0.29**
1985	7/01 - 7/14	ADFG	Pots				2320.4	0.083
1985	9/16 -10/01	NMFS	Trawl	78	49	7688	**2306.3**	**0.25**
1988	8/16 - 8/30	NMFS	Trawl	78	41	7721	**2263.4**	**0.29**
1991	8/22 - 8/30	NMFS	Trawl	52	38	5183	**3132.5**	**0.43**
1996	8/07 - 8/18	ADFG	Trawl	50	30	4938	**1264.7**	**0.317**
1999	7/28 - 8/07	ADFG	Trawl	53	31	5221	**2276.1**	**0.194**
2002	7/27 - 8/06	ADFG	Trawl	57	37	5621	**1747.6**	**0.125**
2006	7/25 - 8/08	ADFG	Trawl	101	45	10008	**2549.7**	**0.288**
2008	7/24 - 8/11	ADFG	Trawl	74	44	7330	**2707.1**	**0.164**
2010[a]	7/27 - 8/09	NMFS	Trawl	35	15	13749	**2041.0**	**0.455**
2011	7/18 - 8/15	ADFG	Trawl	65	34	6447	**2701.7**	**0.133**
2014	7/18 - 7/30	ADFG	Trawl	47	34	4700	**5481.5**	**0.486**

Table 4. Summer commercial catch size/shell compositions. Sizes in this and Tables 5-10 and 12 are mm carapace length. Legal size (4.75 inch carapace width is approximately equal to 124 mm carapace length.

Model 5 data

		New Shell								Old Shell							
Year	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
1977	1549	0	0	0	0.00	0.42	0.34	0.08	0.05	0	0	0	0.00	0.06	0.04	0.01	0.00
1978	389	0	0	0	0.01	0.19	0.47	0.26	0.04	0	0	0	0.00	0.01	0.01	0.01	0.00
1979	1660	0	0	0	0.03	0.23	0.38	0.26	0.07	0	0	0	0.00	0.03	0.00	0.00	0.01
1980	1068	0	0	0	0.00	0.10	0.31	0.37	0.18	0	0	0	0.00	0.00	0.01	0.02	0.01
1981	1784	0	0	0	0.00	0.07	0.15	0.28	0.23	0	0	0	0.00	0.00	0.05	0.12	0.09
1982	1093	0	0	0	0.04	0.19	0.16	0.22	0.29	0	0	0	0.00	0.01	0.02	0.03	0.03
1983	802	0	0	0	0.04	0.41	0.36	0.06	0.03	0	0	0	0.00	0.04	0.01	0.02	0.02
1984	963	0	0	0	0.10	0.42	0.28	0.06	0.01	0	0	0	0.01	0.07	0.05	0.01	0.00
1985	2691	0	0	0.00	0.06	0.31	0.37	0.15	0.02	0	0	0	0.00	0.03	0.03	0.01	0.00
1986	1138	0	0	0	0.03	0.36	0.39	0.12	0.02	0	0	0	0.00	0.02	0.04	0.02	0.00
1987	1985	0	0	0	0.02	0.18	0.29	0.27	0.11	0	0	0	0.00	0.03	0.06	0.03	0.01
1988	1522	0	0.00	0	0.02	0.20	0.30	0.18	0.04	0	0	0	0.01	0.06	0.10	0.07	0.02
1989	2595	0	0	0	0.01	0.16	0.32	0.17	0.05	0	0	0	0.00	0.06	0.12	0.09	0.02
1990	1289	0	0	0	0.01	0.14	0.35	0.26	0.07	0	0	0	0.00	0.04	0.07	0.05	0.01
1991																	
1992	2566	0	0	0	0.02	0.20	0.27	0.14	0.09	0	0	0	0.00	0.08	0.13	0.06	0.02
1993	17804	0	0	0	0.01	0.23	0.39	0.23	0.03	0	0	0	0.00	0.02	0.04	0.03	0.01
1994	404	0	0	0	0.02	0.09	0.08	0.07	0.02	0	0	0	0.02	0.19	0.25	0.20	0.05
1995	1167	0	0	0	0.04	0.26	0.29	0.15	0.05	0	0	0	0.01	0.05	0.07	0.06	0.01
1996	787	0	0	0	0.03	0.22	0.24	0.09	0.05	0	0	0	0.01	0.12	0.14	0.08	0.02
1997	1198	0	0	0	0.03	0.37	0.34	0.10	0.03	0	0	0	0.00	0.06	0.04	0.03	0.01
1998	1055	0	0	0	0.03	0.23	0.24	0.08	0.03	0	0	0	0.02	0.11	0.14	0.08	0.03
1999	562	0	0	0	0.06	0.29	0.24	0.18	0.09	0	0	0	0.00	0.02	0.05	0.04	0.00
2000	17213	0	0	0	0.02	0.30	0.39	0.11	0.02	0	0	0	0.00	0.05	0.07	0.04	0.01
2001	20030	0	0	0	0.02	0.22	0.37	0.21	0.07	0	0	0	0.00	0.02	0.05	0.02	0.01
2002	5219	0	0	0	0.04	0.23	0.28	0.25	0.07	0	0	0	0.00	0.03	0.04	0.03	0.01
2003	5226	0	0	0	0.02	0.37	0.32	0.12	0.03	0	0	0	0.00	0.02	0.05	0.05	0.01
2004	9606	0	0	0	0.01	0.38	0.39	0.11	0.03	0	0	0	0.00	0.03	0.03	0.01	0.01
2005	5360	0	0	0	0.00	0.25	0.47	0.16	0.02	0	0	0	0.00	0.02	0.05	0.02	0.01
2006	6707	0	0	0	0.00	0.18	0.35	0.17	0.02	0	0	0	0.00	0.05	0.14	0.07	0.01
2007	6125	0	0	0	0.01	0.36	0.34	0.14	0.03	0	0	0	0.00	0.02	0.06	0.03	0.01
2008	5766	0	0	0	0.00	0.35	0.35	0.06	0.01	0	0	0	0.00	0.09	0.09	0.04	0.01
2009	6026	0	0	0	0.01	0.34	0.33	0.11	0.02	0	0	0	0.00	0.08	0.08	0.02	0.01
2010	5902	0	0	0	0.01	0.39	0.36	0.10	0.01	0	0	0	0.00	0.05	0.05	0.02	0.00
2011	2552	0	0	0	0.00	0.32	0.40	0.12	0.02	0	0	0	0.00	0.06	0.06	0.02	0.00
2012	5056	0	0	0	0.00	0.24	0.46	0.18	0.02	0	0	0	0.00	0.03	0.04	0.02	0.00
2013	6072	0	0	0	0.00	0.24	0.37	0.24	0.06	0	0	0	0.00	0.01	0.04	0.02	0.00
2014	4682	0	0	0	0.01	0.28	0.24	0.18	0.07	0	0	0	0.00	0.04	0.09	0.07	0.02
2015	4173	0	0	0	0.01	0.48	0.28	0.10	0.03	0	0	0	0.00	0.02	0.03	0.03	0.01

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Model 13 data

		New Shell														
Year	Sample	64-68	79-73	74-78	79-83	84-88	89-93	94-98	99-103	104-108	109-113	114-118	119-123	124-128	129-133	134+
1977	1549	0	0	0	0	0.00	0.00	0.00	0.00	0.15	0.27	0.22	0.12	0.05	0.02	0.05
1978	389	0	0	0	0	0.00	0.00	0.00	0.01	0.04	0.14	0.23	0.24	0.17	0.10	0.04
1979	1660	0	0	0	0	0.00	0.00	0.00	0.03	0.09	0.14	0.20	0.19	0.16	0.10	0.07
1980	1068	0	0	0	0	0.00	0.00	0.00	0.00	0.04	0.05	0.12	0.18	0.19	0.18	0.18
1981	1784	0	0	0	0	0.00	0.00	0.00	0.00	0.03	0.05	0.06	0.09	0.13	0.15	0.23
1982	1093	0	0	0	0	0.00	0.00	0.00	0.04	0.09	0.10	0.07	0.09	0.10	0.12	0.29
1983	802	0	0	0	0	0.00	0.00	0.00	0.04	0.16	0.25	0.23	0.13	0.04	0.02	0.03
1984	963	0	0	0	0	0.00	0.00	0.01	0.09	0.21	0.21	0.16	0.12	0.04	0.02	0.01
1985	2691	0	0	0	0	0.00	0.00	0.00	0.06	0.14	0.17	0.19	0.19	0.11	0.05	0.02
1986	1138	0	0	0	0	0.00	0.00	0.00	0.03	0.14	0.22	0.23	0.16	0.08	0.04	0.02
1987	1985	0	0	0	0	0.00	0.00	0.00	0.02	0.05	0.13	0.14	0.15	0.14	0.13	0.11
1988	1522	0	0	0	0	0.00	0.00	0.00	0.02	0.06	0.14	0.16	0.15	0.10	0.08	0.04
1989	2595	0	0	0	0	0.00	0.00	0.00	0.01	0.07	0.10	0.15	0.16	0.11	0.06	0.05
1990	1289	0	0	0	0	0.00	0.00	0.00	0.01	0.05	0.09	0.17	0.18	0.16	0.10	0.07
1991																
1992	2566	0	0	0	0	0.00	0.00	0.00	0.02	0.08	0.12	0.14	0.12	0.08	0.05	0.09
1993	17804	0	0	0	0	0.00	0.00	0.00	0.01	0.09	0.14	0.19	0.20	0.15	0.08	0.03
1994	404	0	0	0	0	0.00	0.00	0.00	0.02	0.04	0.05	0.03	0.05	0.04	0.03	0.02
1995	1167	0	0	0	0	0.00	0.00	0.00	0.04	0.10	0.17	0.15	0.14	0.09	0.06	0.05
1996	787	0	0	0	0	0.00	0.00	0.00	0.03	0.10	0.12	0.13	0.11	0.05	0.04	0.05
1997	1198	0	0	0	0	0.00	0.00	0.00	0.03	0.13	0.24	0.22	0.13	0.07	0.03	0.03
1998	1055	0	0	0	0	0.00	0.00	0.00	0.02	0.08	0.16	0.14	0.11	0.05	0.03	0.03
1999	562	0	0	0	0	0.00	0.00	0.00	0.06	0.13	0.17	0.12	0.12	0.11	0.08	0.09
2000	17213	0	0	0	0	0.00	0.00	0.00	0.02	0.10	0.19	0.23	0.16	0.08	0.03	0.02
2001	20030	0	0	0	0	0.00	0.00	0.00	0.02	0.09	0.14	0.21	0.16	0.13	0.07	0.07
2002	5219	0	0	0	0	0.00	0.00	0.00	0.04	0.10	0.13	0.13	0.15	0.15	0.10	0.07
2003	5226	0	0	0	0	0.00	0.00	0.00	0.02	0.14	0.23	0.20	0.12	0.07	0.05	0.03
2004	9606	0	0	0	0	0.00	0.00	0.00	0.01	0.11	0.28	0.24	0.15	0.07	0.04	0.03
2005	5360	0	0	0	0	0.00	0.00	0.00	0.00	0.05	0.20	0.26	0.21	0.12	0.04	0.02
2006	6707	0	0	0	0	0.00	0.00	0.00	0.00	0.04	0.14	0.18	0.17	0.12	0.06	0.02
2007	6125	0	0	0	0	0.00	0.00	0.00	0.01	0.13	0.23	0.19	0.15	0.09	0.05	0.03
2008	5766	0	0	0	0	0.00	0.00	0.00	0.00	0.10	0.25	0.23	0.12	0.04	0.01	0.01
2009	6026	0	0	0	0	0.00	0.00	0.00	0.01	0.12	0.22	0.19	0.14	0.08	0.04	0.02
2010	5902	0	0	0	0	0.00	0.00	0.00	0.01	0.11	0.28	0.23	0.13	0.07	0.03	0.01
2011	2552	0	0	0	0	0.00	0.00	0.00	0.00	0.09	0.23	0.25	0.15	0.08	0.04	0.02
2012	5056	0	0	0	0	0.00	0.00	0.00	0.00	0.06	0.18	0.25	0.21	0.13	0.05	0.02
2013	6072	0	0	0	0	0.00	0.00	0.00	0.00	0.07	0.16	0.19	0.18	0.15	0.10	0.06
2014	4682	0	0	0	0	0.00	0.00	0.00	0.01	0.11	0.17	0.13	0.11	0.09	0.09	0.07
2015	4173	0	0	0	0	0.00	0.00	0.00	0.01	0.19	0.28	0.19	0.10	0.06	0.04	0.03

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Model 13 data

		Old Shell														
Year	Sample	64-68	79-73	74-78	79-83	84-88	89-93	94-98	99-103	104-108	109-113	114-118	119-123	124-128	129-133	134+
1977	1549	0	0	0	0	0.00	0.00	0.00	0.00	0.02	0.04	0.03	0.01	0.01	0.00	0.00
1978	389	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00
1979	1660	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.01
1980	1068	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
1981	1784	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.07	0.09
1982	1093	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.03
1983	802	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.01	0.01	0.02
1984	963	0	0	0	0	0.00	0.00	0.00	0.01	0.04	0.03	0.03	0.02	0.00	0.00	0.00
1985	2691	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.01	0.00	0.00
1986	1138	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.01	0.00
1987	1985	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03	0.02	0.01	0.01
1988	1522	0	0	0	0	0.00	0.00	0.00	0.01	0.03	0.04	0.05	0.05	0.05	0.02	0.02
1989	2595	0	0	0	0	0.00	0.00	0.00	0.00	0.02	0.03	0.06	0.06	0.06	0.03	0.02
1990	1289	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.03	0.03	0.02	0.01
1991																
1992	2566	0	0	0	0	0.00	0.00	0.00	0.00	0.03	0.05	0.07	0.06	0.03	0.03	0.02
1993	17804	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.01	0.01
1994	404	0	0	0	0	0.00	0.00	0.00	0.02	0.09	0.10	0.10	0.15	0.11	0.09	0.05
1995	1167	0	0	0	0	0.00	0.00	0.00	0.01	0.02	0.03	0.03	0.04	0.04	0.03	0.01
1996	787	0	0	0	0	0.00	0.00	0.00	0.01	0.05	0.07	0.08	0.06	0.04	0.03	0.02
1997	1198	0	0	0	0	0.00	0.00	0.00	0.00	0.03	0.03	0.02	0.02	0.02	0.01	0.01
1998	1055	0	0	0	0	0.00	0.00	0.00	0.02	0.05	0.06	0.08	0.06	0.05	0.04	0.03
1999	562	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.02	0.04	0.01	0.00
2000	17213	0	0	0	0	0.00	0.00	0.00	0.00	0.02	0.03	0.03	0.03	0.02	0.01	0.01
2001	20030	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.02	0.02	0.01	0.01
2002	5219	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.02	0.02	0.01	0.01
2003	5226	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.02	0.01
2004	9606	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.01	0.01	0.01
2005	5360	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.02	0.01	0.01	0.01
2006	6707	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.04	0.07	0.07	0.05	0.02	0.01
2007	6125	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.03	0.02	0.01	0.01
2008	5766	0	0	0	0	0.00	0.00	0.00	0.00	0.03	0.06	0.05	0.04	0.02	0.01	0.01
2009	6026	0	0	0	0	0.00	0.00	0.00	0.00	0.02	0.05	0.05	0.03	0.01	0.01	0.01
2010	5902	0	0	0	0	0.00	0.00	0.00	0.00	0.02	0.04	0.03	0.02	0.02	0.01	0.00
2011	2552	0	0	0	0	0.00	0.00	0.00	0.00	0.02	0.04	0.03	0.02	0.01	0.00	0.00
2012	5056	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.02	0.01	0.01	0.00
2013	6072	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.01	0.00
2014	4682	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.05	0.04	0.03	0.02
2015	4173	0	0	0	0	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.01	0.01

Table 5. Summer Trawl Survey size/shell compositions.

Model 5 data

		New Shell								Old Shell							
Year	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
1976	1326	0.01	0.02	0.10	0.19	0.34	0.18	0.02	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.01	0.01
1979	220	0.01	0.01	0.00	0.02	0.05	0.05	0.03	0.01	0.01	0.00	0.01	0.04	0.14	0.40	0.19	0.03
1982	327	0.22	0.07	0.16	0.23	0.17	0.03	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.02	0.02	0.03
1985	350	0.11	0.11	0.19	0.17	0.16	0.06	0.01	0.00	0.00	0.00	0.00	0.02	0.05	0.08	0.05	0.01
1988	366	0.16	0.19	0.12	0.13	0.11	0.06	0.03	0.00	0.00	0.00	0.01	0.01	0.03	0.07	0.05	0.03
1991	340	0.18	0.08	0.02	0.03	0.06	0.03	0.01	0.01	0.03	0.06	0.02	0.08	0.16	0.14	0.09	0.02
1996	269	0.29	0.21	0.13	0.09	0.05	0.00	0.00	0.01	0.00	0.00	0.03	0.03	0.04	0.04	0.04	0.03
1999	283	0.03	0.01	0.10	0.29	0.26	0.13	0.03	0.01	0.00	0.00	0.00	0.03	0.05	0.04	0.02	0.00
2002	244	0.09	0.12	0.14	0.11	0.02	0.03	0.02	0.01	0.01	0.03	0.07	0.10	0.09	0.09	0.05	0.02
2006	373	0.18	0.26	0.21	0.11	0.06	0.04	0.02	0.00	0.00	0.00	0.00	0.02	0.04	0.04	0.01	0.00
2008	275	0.12	0.15	0.21	0.11	0.10	0.03	0.02	0.01	0.00	0.01	0.04	0.06	0.08	0.01	0.04	0.00
2010	69	0.01	0.04	0.06	0.17	0.06	0.03	0.00	0.00	0.00	0.03	0.09	0.20	0.19	0.07	0.03	0.01
2011	315	0.13	0.11	0.09	0.11	0.18	0.14	0.03	0.01	0.00	0.00	0.01	0.02	0.09	0.04	0.03	0.00
2014	391	0.08	0.15	0.24	0.18	0.09	0.02	0.01	0.01	0.00	0.00	0.03	0.10	0.05	0.04	0.01	0.00

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Model 13 data

		New Shell														
Year	Sample	64-68	79-73	74-78	79-83	84-88	89-93	94-98	99-103	104-108	109-113	114-118	119-123	124-128	129-133	134+
1976	1326	0.00	0.01	0.01	0.02	0.04	0.06	0.08	0.10	0.16	0.18	0.13	0.05	0.02	0.01	0.00
1979	220	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.03	0.02	0.03	0.02	0.01	0.01
1982	327	0.14	0.08	0.04	0.03	0.06	0.10	0.09	0.14	0.10	0.06	0.02	0.01	0.00	0.00	0.00
1985	350	0.05	0.06	0.05	0.05	0.08	0.11	0.09	0.08	0.08	0.08	0.03	0.03	0.01	0.00	0.00
1988	366	0.09	0.08	0.10	0.09	0.06	0.06	0.07	0.06	0.06	0.04	0.03	0.02	0.02	0.01	0.00
1991	340	0.09	0.09	0.06	0.01	0.01	0.01	0.01	0.02	0.02	0.04	0.03	0.00	0.01	0.01	0.01
1996	269	0.09	0.20	0.10	0.11	0.07	0.06	0.06	0.03	0.03	0.01	0.00	0.00	0.00	0.00	0.01
1999	283	0.02	0.01	0.00	0.01	0.03	0.07	0.10	0.19	0.14	0.12	0.09	0.04	0.03	0.00	0.01
2002	244	0.07	0.03	0.07	0.05	0.06	0.07	0.07	0.05	0.01	0.00	0.01	0.02	0.02	0.00	0.01
2006	373	0.08	0.11	0.12	0.14	0.11	0.10	0.06	0.06	0.04	0.02	0.01	0.03	0.01	0.01	0.00
2008	275	0.07	0.06	0.07	0.08	0.11	0.11	0.05	0.06	0.06	0.04	0.03	0.00	0.01	0.01	0.01
2010	69	0.00	0.01	0.01	0.03	0.04	0.01	0.09	0.09	0.03	0.03	0.00	0.03	0.00	0.00	0.00
2011	315	0.05	0.08	0.09	0.03	0.04	0.05	0.05	0.06	0.07	0.11	0.08	0.06	0.03	0.01	0.01
2014	391	0.04	0.04	0.06	0.09	0.10	0.14	0.11	0.07	0.06	0.03	0.01	0.01	0.01	0.01	0.01

Model 13 data

		Old Shell														
Year	Sample	64-68	79-73	74-78	79-83	84-88	89-93	94-98	99-103	104-108	109-113	114-118	119-123	124-128	129-133	134+
1976	1326	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.00	0.01	0.01
1979	220	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.01	0.04	0.10	0.16	0.24	0.12	0.07	0.03
1982	327	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.03
1985	350	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.04	0.03	0.02	0.01
1988	366	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.03	0.03	0.04	0.03	0.02	0.03
1991	340	0.01	0.02	0.04	0.02	0.01	0.01	0.04	0.04	0.08	0.08	0.07	0.07	0.05	0.04	0.02
1996	269	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
1999	283	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.03	0.02	0.02	0.01	0.02	0.00	0.00
2002	244	0.00	0.01	0.01	0.02	0.02	0.05	0.06	0.05	0.05	0.04	0.05	0.04	0.03	0.02	0.02
2006	373	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.02	0.02	0.01	0.00	0.00
2008	275	0.00	0.00	0.00	0.01	0.02	0.03	0.02	0.04	0.03	0.05	0.00	0.01	0.01	0.02	0.00
2010	69	0.00	0.00	0.03	0.00	0.04	0.04	0.07	0.13	0.06	0.13	0.07	0.00	0.01	0.01	0.01
2011	315	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.05	0.04	0.02	0.03	0.01	0.02	0.00
2014	391	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.05	0.02	0.03	0.03	0.01	0.01	0.00	0.00

Table 6. Winter pot survey size/shell compositions.

Model 5 data

			New Shell								Old Shell							
Year	CPUE	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
1981/82	NA	719	0.00	0.10	0.23	0.21	0.07	0.02	0.02	0.00	0.00	0.05	0.11	0.11	0.04	0.02	0.02	0.00
1982/83	24.2	2583	0.03	0.08	0.28	0.28	0.21	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.01
1983/84	24.0	1677	0.01	0.16	0.26	0.23	0.15	0.06	0.01	0.00	0.00	0.00	0.00	0.02	0.06	0.03	0.01	0.01
1984/85	24.5	789	0.02	0.09	0.25	0.35	0.16	0.06	0.01	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.00	0.00
1985/86	19.2	594	0.04	0.12	0.17	0.24	0.19	0.08	0.01	0.00	0.00	0.00	0.00	0.01	0.06	0.04	0.01	0.00
1986/87	5.8	144	0.00	0.06	0.15	0.19	0.07	0.04	0.00	0.00	0.00	0.00	0.01	0.04	0.30	0.11	0.03	0.00
1987/88																		
1988/89	13.0	500	0.02	0.13	0.15	0.13	0.19	0.17	0.03	0.00	0.00	0.00	0.00	0.00	0.05	0.08	0.03	0.00
1989/90	21.0	2076	0.00	0.05	0.21	0.26	0.18	0.12	0.06	0.01	0.00	0.00	0.00	0.00	0.03	0.06	0.02	0.00
1990/91	22.9	1283	0.00	0.01	0.09	0.29	0.27	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.12	0.07	0.02
1992/93	5.5	181	0.00	0.01	0.03	0.06	0.13	0.12	0.03	0.00	0.00	0.00	0.00	0.02	0.19	0.27	0.10	0.05
1993/94																		
1994/95	6.2	858	0.01	0.06	0.08	0.10	0.26	0.23	0.07	0.01	0.00	0.00	0.00	0.00	0.03	0.07	0.06	0.02
1995/96	9.9	1580	0.06	0.14	0.20	0.19	0.11	0.07	0.03	0.00	0.00	0.00	0.00	0.01	0.06	0.07	0.03	0.01
1996/97	2.9	398	0.07	0.21	0.22	0.11	0.15	0.11	0.05	0.01	0.00	0.00	0.00	0.00	0.02	0.03	0.01	0.01
1997/98	10.9	881	0.00	0.14	0.41	0.27	0.05	0.02	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.02	0.02	0.01
1998/99	10.7	1307	0.00	0.02	0.12	0.36	0.36	0.08	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.01	0.00
1999/00	6.2	575	0.02	0.09	0.10	0.16	0.33	0.18	0.03	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.01	0.00
2000/01	3.1	44																
2001/02	13.0	828	0.05	0.29	0.26	0.17	0.06	0.06	0.04	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00
2002/03	9.6	824	0.02	0.10	0.22	0.28	0.18	0.06	0.02	0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.02	0.01
2003/04	3.7	296	0.00	0.02	0.16	0.26	0.32	0.14	0.01	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.02	0.01
2004/05	4.4	405	0.00	0.07	0.14	0.18	0.22	0.19	0.07	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.01	0.00
2005/06	6.0	512	0.00	0.14	0.23	0.21	0.16	0.05	0.02	0.00	0.00	0.01	0.01	0.02	0.04	0.07	0.03	0.01
2006/07	7.3	159	0.07	0.14	0.19	0.35	0.13	0.04	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.00	0.00
2007/08	25.0	3552	0.01	0.14	0.25	0.17	0.14	0.07	0.01	0.00	0.01	0.04	0.07	0.03	0.03	0.01	0.01	0.00
2008/09	21.9	525	0.00	0.07	0.13	0.35	0.20	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.04	0.10	0.00	0.00
2009/10	25.3	578	0.01	0.05	0.13	0.21	0.24	0.11	0.02	0.00	0.00	0.00	0.01	0.06	0.10	0.05	0.01	0.00
2010/11	22.1	596	0.02	0.08	0.13	0.20	0.17	0.13	0.05	0.00	0.00	0.00	0.01	0.03	0.11	0.05	0.01	0.00
2011/12	29.4	675	0.03	0.11	0.23	0.19	0.12	0.13	0.04	0.00	0.00	0.00	0.00	0.01	0.05	0.05	0.03	0.00

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Model 13 data

			New Shell														
Year	CPUE	Sample	64-68	79-73	74-78	79-83	84-88	89-93	94-98	99-103	104-108	109-113	114-118	119-123	124-128	129-133	134+
1981/82	NA	719	0.00	0.00	0.03	0.07	0.09	0.13	0.12	0.09	0.04	0.03	0.01	0.01	0.01	0.01	0.00
1982/83	24.2	2583	0.01	0.02	0.03	0.06	0.12	0.16	0.14	0.14	0.11	0.10	0.05	0.02	0.01	0.00	0.00
1983/84	24.0	1677	0.00	0.01	0.05	0.11	0.14	0.11	0.12	0.11	0.09	0.06	0.04	0.02	0.00	0.00	0.00
1984/85	24.5	789	0.01	0.01	0.03	0.06	0.09	0.16	0.21	0.14	0.10	0.05	0.04	0.02	0.00	0.00	0.00
1985/86	19.2	594	0.01	0.03	0.06	0.07	0.07	0.10	0.13	0.12	0.09	0.10	0.06	0.02	0.01	0.00	0.00
1986/87	5.8	144	0.00	0.00	0.02	0.03	0.06	0.10	0.09	0.10	0.03	0.04	0.03	0.01	0.00	0.00	0.00
1987/88																	
1988/89	13.0	500	0.00	0.01	0.05	0.08	0.10	0.05	0.06	0.08	0.10	0.09	0.11	0.06	0.02	0.01	0.00
1989/90	21.0	2076	0.00	0.00	0.01	0.04	0.08	0.13	0.14	0.12	0.09	0.09	0.06	0.06	0.04	0.02	0.01
1990/91	22.9	1283	0.00	0.00	0.01	0.00	0.03	0.06	0.12	0.17	0.15	0.11	0.07	0.03	0.01	0.00	0.00
1992/93	5.5	181	0.00	0.00	0.00	0.01	0.01	0.03	0.03	0.02	0.06	0.07	0.09	0.03	0.02	0.01	0.00
1993/94																	
1994/95	6.2	858	0.00	0.01	0.02	0.04	0.04	0.04	0.05	0.05	0.11	0.15	0.14	0.10	0.05	0.03	0.01
1995/96	9.9	1580	0.02	0.05	0.06	0.07	0.08	0.12	0.11	0.09	0.07	0.05	0.03	0.03	0.02	0.01	0.00
1996/97	2.9	398	0.01	0.06	0.11	0.11	0.12	0.10	0.06	0.05	0.06	0.09	0.06	0.05	0.02	0.03	0.01
1997/98	10.9	881	0.00	0.00	0.03	0.11	0.19	0.22	0.16	0.10	0.04	0.02	0.02	0.01	0.00	0.00	0.00
1998/99	10.7	1307	0.00	0.00	0.01	0.01	0.04	0.08	0.14	0.22	0.22	0.14	0.06	0.02	0.01	0.00	0.00
1999/00	6.2	575	0.01	0.01	0.04	0.05	0.04	0.06	0.07	0.09	0.15	0.18	0.12	0.06	0.03	0.00	0.00
2000/01	3.1	44															
2001/02	13.0	828	0.01	0.04	0.13	0.17	0.14	0.12	0.10	0.07	0.04	0.03	0.03	0.03	0.03	0.01	0.01
2002/03	9.6	824	0.01	0.01	0.04	0.06	0.09	0.13	0.16	0.12	0.10	0.08	0.04	0.02	0.01	0.01	0.00
2003/04	3.7	296	0.00	0.00	0.00	0.01	0.04	0.12	0.12	0.14	0.14	0.18	0.10	0.04	0.01	0.01	0.00
2004/05	4.4	405	0.00	0.00	0.03	0.04	0.06	0.08	0.08	0.10	0.11	0.10	0.11	0.08	0.04	0.03	0.00
2005/06	6.0	512	0.00	0.00	0.04	0.10	0.12	0.11	0.12	0.09	0.09	0.07	0.03	0.03	0.02	0.00	0.00
2006/07	7.3	159	0.03	0.04	0.04	0.09	0.03	0.16	0.19	0.16	0.09	0.04	0.02	0.03	0.00	0.00	0.00
2007/08	25.0	3552	0.00	0.01	0.04	0.11	0.12	0.13	0.09	0.08	0.07	0.07	0.04	0.02	0.00	0.00	0.00
2008/09	21.9	525	0.00	0.00	0.02	0.05	0.04	0.09	0.15	0.20	0.13	0.07	0.05	0.03	0.01	0.00	0.00
2009/10	25.3	578	0.00	0.01	0.01	0.03	0.04	0.09	0.09	0.12	0.12	0.12	0.08	0.03	0.01	0.01	0.00
2010/11	22.1	596	0.00	0.02	0.02	0.05	0.07	0.07	0.09	0.12	0.08	0.09	0.07	0.06	0.03	0.02	0.00
2011/12	29.4	675	0.00	0.02	0.05	0.06	0.11	0.12	0.10	0.09	0.07	0.05	0.06	0.07	0.03	0.01	0.00

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Model 13 data

			Old Shell														
Year	CPUE	Sample	64-68	79-73	74-78	79-83	84-88	89-93	94-98	99-103	104-108	109-113	114-118	119-123	124-128	129-133	134+
1981/82	NA	719	0.00	0.00	0.02	0.03	0.05	0.07	0.06	0.05	0.03	0.01	0.01	0.01	0.01	0.01	0.00
1982/83	24.2	2583	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.01
1983/84	24.0	1677	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.03	0.02	0.01	0.00	0.00	0.01
1984/85	24.5	789	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.02	0.01	0.00	0.00	0.00
1985/86	19.2	594	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.03	0.02	0.02	0.01	0.00	0.00
1986/87	5.8	144	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.02	0.15	0.15	0.08	0.03	0.02	0.01	0.00
1987/88																	
1988/89	13.0	500	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.05	0.04	0.02	0.01	0.00
1989/90	21.0	2076	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03	0.01	0.01	0.00
1990/91	22.9	1283	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.07	0.04	0.03	0.02
1992/93	5.5	181	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.06	0.14	0.10	0.17	0.06	0.05	0.05
1993/94																	
1994/95	6.2	858	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.03	0.03	0.02
1995/96	9.9	1580	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.04	0.03	0.02	0.01	0.01
1996/97	2.9	398	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.02	0.01	0.00	0.01
1997/98	10.9	881	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.01	0.01	0.01	0.01	0.01
1998/99	10.7	1307	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.00	0.00	0.00	0.00	0.00
1999/00	6.2	575	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.02	0.01	0.00	0.01	0.00
2000/01	3.1	44															
2001/02	13.0	828	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
2002/03	9.6	824	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
2003/04	3.7	296	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.02	0.01	0.00	0.01	0.01	0.01
2004/05	4.4	405	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.04	0.02	0.01	0.00	0.00
2005/06	6.0	512	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.03	0.05	0.03	0.02	0.01	0.01
2006/07	7.3	159	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.02	0.03	0.01	0.00	0.00	0.00
2007/08	25.0	3552	0.00	0.01	0.01	0.03	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00
2008/09	21.9	525	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.04	0.00	0.00	0.00
2009/10	25.3	578	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.05	0.05	0.03	0.03	0.01	0.00	0.00
2010/11	22.1	596	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.05	0.06	0.03	0.02	0.01	0.00	0.00
2011/12	29.4	675	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.03	0.03	0.02	0.01	0.00

Table 7. Summer commercial1987-1994, 2012-2015 observer discards size/shell compositions
Model 5 data

		New Shell								Old Shell							
Year	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
1987	1146	0.06	0.19	0.32	0.33	0.03	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.00	0.00	0.00	0.00
1988	722	0.01	0.04	0.15	0.48	0.14	0.00	0.00	0.00	0.00	0.01	0.03	0.10	0.04	0.00	0.00	0.00
1989	1000	0.07	0.19	0.24	0.22	0.03	0.00	0.00	0.00	0.02	0.03	0.07	0.11	0.03	0.00	0.00	0.00
1990	507	0.08	0.23	0.27	0.27	0.04	0.00	0.00	0.00	0.02	0.02	0.02	0.05	0.01	0.00	0.00	0.00
1992	580	0.11	0.17	0.30	0.29	0.03	0.00	0.00	0.00	0.01	0.02	0.02	0.04	0.01	0.00	0.00	0.00
1994	850	0.07	0.06	0.11	0.15	0.02	0.00	0.00	0.00	0.07	0.07	0.15	0.24	0.05	0.00	0.00	0.00
2012	939	0.21	0.11	0.19	0.32	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00
2013	2617	0.34	0.29	0.16	0.16	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	1755	0.05	0.10	0.26	0.41	0.12	0.01	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.00	0.00	0.00
2015	824	0.01	0.08	0.18	0.44	0.23	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00

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Model 13 data

		New Shell														
Year	Sample	64-68	79-73	74-78	79-83	84-88	89-93	94-98	99-103	104-108	109-113	114-118	119-123	124-128	129-133	134+
1987	1146	0.02	0.04	0.08	0.11	0.13	0.19	0.18	0.15	0.03	0.00	0.00	0.00	0.00	0.00	0.00
1988	722	0.00	0.01	0.01	0.03	0.06	0.09	0.21	0.26	0.12	0.02	0.00	0.00	0.00	0.00	0.00
1989	1000	0.02	0.05	0.10	0.09	0.10	0.14	0.13	0.09	0.02	0.00	0.00	0.00	0.00	0.00	0.00
1990	507	0.03	0.05	0.09	0.13	0.14	0.13	0.16	0.11	0.02	0.01	0.00	0.00	0.00	0.00	0.00
1992	580	0.04	0.07	0.07	0.10	0.14	0.15	0.15	0.14	0.03	0.00	0.00	0.00	0.00	0.00	0.00
1994	850	0.03	0.05	0.02	0.04	0.04	0.06	0.08	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.00
2012	939	0.11	0.10	0.06	0.05	0.09	0.10	0.15	0.17	0.09	0.01	0.01	0.00	0.00	0.00	0.00
2013	2617	0.14	0.20	0.17	0.12	0.08	0.08	0.08	0.08	0.04	0.01	0.00	0.00	0.00	0.00	0.00
2014	1755	0.01	0.03	0.04	0.06	0.10	0.16	0.19	0.22	0.10	0.02	0.01	0.00	0.00	0.00	0.00
2015	824	0.00	0.01	0.02	0.06	0.07	0.11	0.15	0.29	0.19	0.04	0.01	0.01	0.00	0.00	0.00

Model 13 data

		Old Shell														
Year	Sample	64-68	79-73	74-78	79-83	84-88	89-93	94-98	99-103	104-108	109-113	114-118	119-123	124-128	129-133	134+
1987	1146	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	722	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.05	0.04	0.01	0.00	0.00	0.00	0.00	0.00
1989	1000	0.01	0.01	0.01	0.02	0.03	0.04	0.06	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00
1990	507	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1992	580	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1994	850	0.03	0.04	0.03	0.04	0.07	0.08	0.12	0.12	0.04	0.01	0.00	0.00	0.00	0.00	0.00
2012	939	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00
2013	2617	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	1755	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
2015	824	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00

Table 8 The number of tagged data released and recovered after 1 year (Y1) – 3 year (Y3) during 1980-1992 and 1993-2015 periods.

Model 5 data

Release Length Class	Recap Length Class	1980-1992			1993-2014		
		Y1	Y2	Y3	Y1	Y2	Y3
64 – 73	64 – 73						
64 – 73	74 - 83	1					
64 – 73	84 - 93	1			3	1	
64 – 73	94 - 103		1			4	
64 – 73	104 – 113					4	1
64 – 73	114 – 123						2
64 – 73	124 – 133						
64 – 73	134+						
74 - 83	74 - 83						
74 - 83	84 - 93				21		
74 - 83	94 - 103				22	10	
74 - 83	104 – 113		2		4	68	3
74 - 83	114 – 123			2		3	2
74 - 83	124 – 133						
74 - 83	134+						
84 - 93	84 - 93						
84 - 93	94 - 103	5			42	4	
84 - 93	104 – 113	10	2		80	20	6
84 - 93	114 – 123		1	1	7	37	2
84 - 93	124 – 133				1	1	2
84 - 93	134+						
94 - 103	94 - 103	3			6	1	
94 - 103	104 – 113	31	1	1	144	19	
94 - 103	114 – 123	26	1	3	71	7	10
94 - 103	124 – 133	2		1		8	6
94 - 103	134+				1		
104 – 113	104 – 113	16			44	2	
104 – 113	114 – 123	34	13		73	22	4
104 – 113	124 – 133	7	6	3	12	4	7
104 – 113	134+						
114 – 123	114 – 123	16	2		62	4	
114 – 123	124 – 133	26	9	1	59	28	3
114 – 123	134+	5	1		19	4	2
124 – 133	124 – 133	15			36	6	
124 – 133	134+	10	4	2	10	8	4
134+	134+	15	6	1	8		

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Model 13 data

Release Length Class	Recap Length Class	1980-1992			1993-2014		
		Y1	Y2	Y3	Y1	Y2	Y3
64-68	64-68						
64-68	69-73						
64-68	74-78	1					
64-68	79-83						
64-68	84-88						
64-68	89-93						
64-68	94-98						
64-68	99-103						
64-68	104-108					1	
64-68	109-113						
64-68	114-118						
64-68	119-123						
64-68	123-128						
64-68	129-133						
64-68	134+						
69-73	69-73						
69-73	74-78						
69-73	79-83						
69-73	84-88	1			3		
69-73	89-93					1	
69-73	94-98					2	
69-73	99-103		1			2	
69-73	104-108					2	
69-73	109-113					1	1
69-73	114-118						1
69-73	119-123						
69-73	123-128						
69-73	129-133						
69-73	134+						
74-78	74-78						
74-78	79-83						
74-78	84-88				5		
74-78	89-93				10		
74-78	94-98				1	1	
74-78	99-103					7	
74-78	104-108		1			10	
74-78	109-113					3	
74-78	114-118						2
74-78	119-123			2			

74-78	123-128						
74-78	129-133						
74-78	134+						
79-83	79-83						
79-83	84-88				1		
79-83	89-93				5		
79-83	94-98				17	1	
79-83	99-103				4	1	
79-83	104-108		1		3	20	1
79-83	109-113				1	35	2
79-83	114-118					3	
79-83	119-123						
79-83	123-128						
79-83	129-133						
79-83	134+						
84-88	84-88						
84-88	89-93						
84-88	94-98				5		
84-88	99-103				25	3	
84-88	104-108	2			8	1	
84-88	109-113		2		2	15	4
84-88	114-118					22	1
84-88	119-123						
84-88	123-128						
84-88	129-133					1	
84-88	134+						
89-93	89-93						
89-93	94-98						
89-93	99-103	5			12	1	
89-93	104-108	5			58		1
89-93	109-113	3			12	4	1
89-93	114-118		1	1		7	1
89-93	119-123				5	6	
89-93	123-128				1		1
89-93	129-133						1
89-93	134+						
94-98	94-98						
94-98	99-103				1		
94-98	104-108	5			32	6	
94-98	109-113	14			84	7	
94-98	114-118	4			10		3
94-98	119-123		1	3		4	5
94-98	123-128	1		1		6	1

94-98	129-133	1					
94-98	134+				1		
99-103	99-103	3			5	1	
99-103	104-108				4		
99-103	109-113	12	1	1	24	6	
99-103	114-118	19			59	2	1
99-103	119-123	3			2	1	1
99-103	123-128					2	2
99-103	129-133						3
99-103	134+						
104-108	104-108	10			7		
104-108	109-113	1			4	1	
104-108	114-118	10	2		21	6	1
104-108	119-123	15	3		20	4	
104-108	123-128	3	1	2	2	2	1
104-108	129-133			1		1	3
104-108	134+						
109-113	109-113				29		
109-113	114-118	5			1		1
109-113	119-123		2		31	12	2
109-113	123-128	9	6		10	1	1
109-113	129-133	4	5				2
109-113	134+						
114-118	114-118				24		
114-118	119-123	3			18	2	
114-118	123-128		2		22	7	2
114-118	129-133	10	4		8	2	1
114-118	134+	2			1	1	
119-123	119-123	1			20		
119-123	123-128	12			5	4	
119-123	129-133	1			24	15	
119-123	134+	13	5	1	18	3	2
123-128	123-128	4	1		19	1	
123-128	129-133	3			6	1	
123-128	134+	4	2	1	8	5	3
129-133	129-133	12			11	4	
129-133	134+	6	2	1	2	3	1
134+	134+	15	6	1	8		

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Table 9. Summary of initial input parameter values and bounds for a length-based population model of Norton Sound red king crab. Parameters with "log_" indicate log scaled parameters.

Parameter	Parameter description	Equation Number in Appendix A	Lower	Upper
log_q_1	Commercial fishery catchability (1977-92)	(20)	-32.5	8.5
log_q_2	Commercial fishery catchability (1993-2014)	(20)	-32.5	10.0
log_N_{76}	Initial abundance	(1)	2.0	15.0
R_0	Mean Recruit	(13)	2.0	12.0
log_σ_R^2	Recruit standard deviation	(13)	-20.0	20.0
a_1	Parameter for intimal length proportion	(2)	-5.0	5.0
a_2	Parameter for intimal length proportion	(2)	-5.0	5.0
a_3	Parameter for intimal length proportion	(2)	-5.0	5.0
a_4	Parameter for intimal length proportion	(2)	-5.0	5.0
a_5	Parameter for intimal length proportion	(2)	-5.0	5.0
r	Proportion of length class 1 for recruit	(14)	0.5	0.9
log_α	Inverse logistic molting parameter	(15)	-5.5	-2.0
log_ϕ_{st1}	Logistic trawl selectivity parameter (NMFS)	(16)	-15.0	-1.0
log_ϕ_{st2}	Logistic trawl selectivity parameter (ADF&G)	(16)	-15.0	-1.0
log_ϕ_w	Logistic winter pot selectivity parameter Or Inverse logistic winter pot selectivity parameter	(15,16)	-10.0	10.0
Sw_6 / Sw_1	Winter pot selectivity of length class 6 (logistic), length class 1 (inverse logistic)	(15,16)	0.1	1.0
log_ϕ_1	Logistic commercial catch selectivity parameter (1977-92)	(16)	-5.0	-1.0
log_ϕ_2	Logistic commercial catch selectivity parameter (1993-2014)	(16)	-5.0	-1.0
w^2_t	Additional varince for standard CPUE	(31)	0.0	6.0
q	Survey q for NMFS trawl 1976-91	(31)	0.1	1.0
σ	Growth transition sigma	(17)	0.0	30.0
β_1	Growth transition mean	(17)	0.0	20.0
β_2	Growth transition increment	(17)	0.0	20.0

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Table 10 . Summary of parameter estimates and standard deviations of Norton Sound red king crab. Model 5

	Estimate	std.dev
log_q_1	-6.9259	0.1906
log_q_2	-6.7761	0.11195
log_N_{76}	9.1231	0.15299
R_0	6.4911	0.090086
log_σ_R^2	0.027945	0.44393
log_R_{77}	-0.56982	0.37063
log_R_{78}	-0.71447	0.35474
log_R_{79}	0.24017	0.32398
log_R_{80}	0.34399	0.29828
log_R_{81}	0.31351	0.27449
log_R_{82}	0.40028	0.31875
log_R_{83}	0.58749	0.28078
log_R_{84}	0.061908	0.31094
log_R_{85}	0.45028	0.28276
log_R_{86}	-0.008591	0.30533
log_R_{87}	-0.008095	0.26231
log_R_{88}	0.010236	0.2729
log_R_{89}	-0.39646	0.29694
log_R_{90}	-0.28167	0.26238
log_R_{91}	-0.54566	0.2904
log_R_{92}	-0.74061	0.31228
log_R_{93}	-0.61466	0.29318
log_R_{94}	-0.37182	0.26754
log_R_{95}	-0.086911	0.24029
log_R_{96}	0.53258	0.21708
log_R_{97}	-0.20834	0.31568
log_R_{98}	-0.66352	0.31794
log_R_{99}	-0.17289	0.31294
log_R_{00}	0.14649	0.26868
log_R_{01}	0.16903	0.25699
log_R_{02}	0.006718	0.30956
log_R_{03}	-0.31276	0.33503
log_R_{04}	0.28697	0.24744
log_R_{05}	0.3216	0.24164
log_R_{06}	0.48335	0.24985
log_R_{07}	0.485	0.24724
log_R_{08}	0.11161	0.29966
log_R_{09}	-0.31992	0.30542
log_R_{10}	0.050226	0.25402
log_R_{11}	0.2479	0.2958
log_R_{12}	0.95366	0.26511

name	Estimate	std.dev
log_R_{13}	-0.064742	0.36781
log_R_{14}	-0.14998	0.44671
a_1	2.5859	4.3418
a_2	2.6678	4.2709
a_3	4.003	4.0705
a_4	4.2557	4.0567
a_5	4.4771	4.0493
a_6	3.6832	4.0742
a_7	2.0469	4.2894
r1	14.988	63.407
r2	14.626	63.407
log_α	-2.0122	0.016911
log_ϕ_{st1}	-2.6268	0.35705
log_ϕ_w	-2.0465	0.050315
Sw_1	0.070758	0.034013
Sw_2	0.44402	0.10674
log_ϕ_l	-2.0887	0.057957
w^2_t	0.075056	0.023717
q	0.74645	0.13422
σ	4.3015	0.26533
β_1	10.292	0.80362
β_2	8.1997	0.20266
M		
ms	3.5552	0.31672

Model 13

	Estimate	std.dev
log_q_1	-6.915	0.1882
log_q_2	-6.7478	0.10959
log_N_{76}	9.1446	0.15016
R_0	6.4965	0.087764
log_σ_R^2	-0.017897	0.4288
log_R_{77}	-0.6057	0.35732
log_R_{78}	-0.70196	0.34304
log_R_{79}	0.34168	0.27485
log_R_{80}	0.26841	0.27664
log_R_{81}	0.33319	0.25218
log_R_{82}	0.48945	0.27443
log_R_{83}	0.48783	0.26815
log_R_{84}	0.11651	0.28101
log_R_{85}	0.46689	0.25099
log_R_{86}	-0.051417	0.27787
log_R_{87}	-0.007842	0.24367
log_R_{88}	0.024252	0.2508
log_R_{89}	-0.44084	0.27779
log_R_{90}	-0.29302	0.24642
log_R_{91}	-0.5423	0.27091
log_R_{92}	-0.74135	0.29141
log_R_{93}	-0.53768	0.2666
log_R_{94}	-0.4061	0.25618
log_R_{95}	-0.087755	0.22817
log_R_{96}	0.54883	0.19138
log_R_{97}	-0.31011	0.2923
log_R_{98}	-0.62355	0.29992
log_R_{99}	-0.16896	0.28657
log_R_{00}	0.18266	0.24043
log_R_{01}	0.18352	0.23424
log_R_{02}	-0.068791	0.29021
log_R_{03}	-0.2684	0.30106
log_R_{04}	0.32018	0.22461
log_R_{05}	0.26825	0.23038
log_R_{06}	0.53006	0.21792
log_R_{07}	0.44263	0.22501
log_R_{08}	0.10561	0.26684
log_R_{09}	-0.27795	0.27491
log_R_{10}	0.027615	0.24224
log_R_{11}	0.34476	0.27238
log_R_{12}	0.91115	0.26265

name	Estimate	std.dev
log_R_{13}	-0.080906	0.35931
log_R_{14}	-0.16095	0.44919
a_1	2.5616	4.089
a_2	1.8895	4.5519
a_3	1.3861	4.7425
a_4	2.2245	4.1301
a_5	2.9176	3.9276
a_6	3.1745	3.8839
a_7	3.4127	3.8627
a_8	3.3869	3.8586
a_9	3.4946	3.8463
a_{10}	3.4981	3.8466
a_{11}	3.1417	3.8613
a_{12}	2.1496	3.9518
a_{13}	1.7873	4.1704
a_{14}	0.30529	5.1112
r1	14.967	135.17
r2	14.943	135.17
r3	14.885	135.17
r4	14.347	135.17
r5	-6.8084	17901
log_α	-2.0597	0.012815
log_ϕ_{st1}	-2.5495	0.27329
log_ϕ_w	-2.0929	0.049215
Sw_1	0.032224	0.034442
Sw_2	0.10802	0.061776
Sw_3	0.2926	0.11008
Sw_4	0.52251	0.15919
log_ϕ_l	-2.0581	0.060299
w_t^2	7.38E-02	0.023578
q	0.743	0.13223
σ	3.5999	0.31154
β_1	2.7995	0.12141
β_2	13.289	0.4609
M		
ms	3.5999	0.31154

Table 11. Estimated selectivities, molting probabilities, and proportions of legal crab by length (mm CL) class for Norton Sound male red king crab.

Model 5

Length Class	Legal Proportion	Mean weight (lb)	Selectivity ADFG/ NOAA	Selectivity Winter Pot	Selectivity Summer Fishery	Molting Probability
64 - 73	0.00	0.434	0.86	0.07	0.15	1.00
74 - 83	0.00	0.855	0.93	0.44	0.37	1.00
84 - 93	0.00	1.313	0.96	0.99	0.67	0.99
94 - 103	0.13	1.823	0.98	0.95	0.88	0.95
104 - 113	0.87	2.387	0.99	0.85	0.96	0.83
114 - 123	1.00	3.064	1.00	0.61	0.99	0.56
124 - 133	1.00	3.840	1.00	0.30	1.00	0.25
134+	1.00	4.649	1.00	0.11	1.00	0.08

Model 13

Length Class	Legal Proportion	Mean weight (lb)	Selectivity ADFG/ NOAA	Selectivity Winter Pot	Selectivity Summer Fishery	Molting Probability
64-68	0.00	0.332	0.81	0.03	0.12	1.00
69-73	0.00	0.537	0.86	0.11	0.20	1.00
74-78	0.00	0.747	0.90	0.29	0.32	1.00
79-83	0.00	0.965	0.93	0.52	0.47	0.99
84-88	0.00	1.194	0.95	0.99	0.63	0.99
89-93	0.00	1.435	0.97	0.98	0.76	0.98
94-98	0.02	1.691	0.98	0.96	0.86	0.96
99-103	0.23	1.958	0.98	0.93	0.92	0.92
104-108	0.77	2.239	0.99	0.88	0.96	0.86
109-113	0.97	2.543	0.99	0.80	0.98	0.76
114-118	1.00	2.882	1.00	0.68	0.99	0.63
119-123	1.00	3.252	1.00	0.53	0.99	0.47
123-128	1.00	3.641	1.00	0.38	1.00	0.32
129-133	1.00	4.041	1.00	0.25	1.00	0.20
134+	1.00	4.446	1.00	0.15	1.00	0.12

Table 12: Estimated molting probability incorporated transition matrix.

Model 5: without molting probability

Pre-molt Length Class	Post-molt Length Class							
	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
64 – 73	0.001	0.208	0.726	0.065	0.000	0.000	0.000	0.000
74 - 83		0.003	0.344	0.626	0.027	0.000	0.000	0.000
84 - 93			0.011	0.499	0.480	0.009	0.000	0.000
94 - 103				0.030	0.641	0.326	0.003	0.000
104 – 113					0.072	0.734	0.194	0.001
114 – 123						0.148	0.752	0.100
124 – 133							0.277	0.723
134+								1.000

Model 5: with molting probability

Pre-molt Length Class	Post-molt Length Class							
	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
64 - 73	0.002	0.207	0.726	0.065	0.000	0.000	0.000	0.00
74 - 83		0.007	0.343	0.624	0.027	0.000	0.000	0.00
84 - 93			0.025	0.492	0.474	0.009	0.000	0.00
94 - 103				0.081	0.608	0.309	0.003	0.00
104 - 113					0.233	0.606	0.160	0.00
114 - 123						0.527	0.418	0.06
124 - 133							0.821	0.18
134+								1.00

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Model 13: without molting probability

Pre-molt Length Class	Post-molt Length Class													
	64-68	79-73	74-78	79-83	84-88	89-93	94-98	99-103	104-108	109-113	114-118	119-123	124-128	129-133	134+
64-68	0.000	0.000	0.034	0.451	0.474	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
69-73		0.000	0.000	0.057	0.525	0.394	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
74-78			0.000	0.001	0.091	0.584	0.312	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000
79-83				0.000	0.002	0.137	0.619	0.235	0.006	0.000	0.000	0.000	0.000	0.000	0.000
84-88					0.000	0.004	0.196	0.627	0.169	0.003	0.000	0.000	0.000	0.000	0.000
89-93						0.000	0.009	0.268	0.607	0.115	0.001	0.000	0.000	0.000	0.000
94-98							0.000	0.016	0.347	0.561	0.075	0.001	0.000	0.000	0.000
99-103								0.000	0.029	0.429	0.495	0.046	0.000	0.000	0.000
104-108									0.000	0.050	0.506	0.416	0.027	0.000	0.000
109-113										0.001	0.080	0.570	0.334	0.015	0.000
114-118											0.002	0.123	0.612	0.255	0.008
119-123												0.004	0.179	0.631	0.187
123-128													0.008	0.284	0.708
129-133														0.041	0.959
134+															1.000

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Model 13: with molting probability

Pre-molt Length Class	Post-molt Length Class														
	64-68	79-73	74-78	79-83	84-88	89-93	94-98	99-103	104-108	109-113	114-118	119-123	124-128	129-133	134+
64-68	0.001	0.000	0.034	0.451	0.474	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
69-73		0.002	0.000	0.057	0.525	0.393	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
74-78			0.004	0.001	0.090	0.582	0.311	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000
79-83				0.007	0.002	0.136	0.615	0.234	0.006	0.000	0.000	0.000	0.000	0.000	0.000
84-88					0.013	0.004	0.194	0.620	0.167	0.003	0.000	0.000	0.000	0.000	0.000
89-93						0.024	0.008	0.261	0.593	0.113	0.001	0.000	0.000	0.000	0.000
94-98							0.044	0.016	0.332	0.536	0.071	0.001	0.000	0.000	0.000
99-103								0.080	0.027	0.395	0.455	0.042	0.000	0.000	0.000
104-108									0.141	0.043	0.435	0.358	0.023	0.000	0.000
109-113										0.237	0.061	0.435	0.255	0.011	0.000
114-118											0.371	0.077	0.386	0.161	0.005
119-123												0.528	0.085	0.299	0.088
123-128													0.680	0.092	0.228
129-133														0.807	0.193
134+															1.000

Table 13. Annual abundance estimates (million crab) and mature male biomass (MMB, million lb) for Norton Sound red king crab estimated by a length-based analysis from 1976 to 2014

Model 5.

	Abundance			Legal (≥ 104 mm)				MMB	
Year	Recruits	Total (≥ 74 mm)	Mature (≥ 94 mm)	Abundance	S.D	Biomass	S.D	Biomass	S.D.
1976	2.610	9.165	6.554	4.250	1.036	11.262	2.929	15.667	3.424
1977	1.175	8.041	6.866	5.580	0.960	16.221	2.908	18.739	3.087
1978	0.797	6.368	5.571	5.024	0.738	15.872	2.402	16.957	2.437
1979	0.566	4.383	3.817	3.485	0.505	11.589	1.723	12.235	1.751
1980	1.039	3.126	2.087	1.878	0.339	6.373	1.186	6.776	1.218
1981	1.426	2.929	1.504	1.216	0.236	4.109	0.824	4.650	0.887
1982	1.467	2.787	1.319	0.890	0.211	2.746	0.679	3.553	0.802
1983	1.544	3.129	1.585	1.097	0.225	3.249	0.688	4.173	0.825
1984	1.791	3.537	1.746	1.239	0.246	3.659	0.745	4.620	0.887
1985	1.427	3.375	1.948	1.376	0.270	4.078	0.813	5.161	0.975
1986	1.488	3.554	2.065	1.537	0.296	4.576	0.894	5.584	1.052
1987	1.280	3.294	2.013	1.531	0.299	4.666	0.924	5.583	1.050
1988	1.075	3.121	2.046	1.577	0.291	4.837	0.905	5.731	1.031
1989	1.072	3.006	1.934	1.551	0.272	4.840	0.856	5.573	0.951
1990	0.856	2.674	1.817	1.450	0.244	4.582	0.776	5.281	0.861
1991	0.782	2.464	1.682	1.363	0.217	4.324	0.692	4.935	0.762
1992	0.690	2.232	1.542	1.269	0.184	4.073	0.592	4.596	0.641
1993	0.557	1.956	1.400	1.150	0.155	3.712	0.501	4.189	0.544
1994	0.554	1.714	1.160	0.958	0.131	3.091	0.425	3.479	0.458
1995	0.673	1.638	0.965	0.779	0.110	2.510	0.357	2.863	0.388
1996	0.881	1.750	0.869	0.657	0.098	2.077	0.313	2.477	0.350
1997	1.491	2.418	0.927	0.655	0.096	2.004	0.299	2.517	0.355
1998	1.211	2.439	1.228	0.796	0.111	2.361	0.332	3.171	0.409
1999	0.696	2.268	1.571	1.113	0.141	3.241	0.407	4.113	0.497
2000	0.775	2.320	1.545	1.256	0.148	3.812	0.447	4.372	0.492
2001	1.098	2.448	1.350	1.100	0.131	3.471	0.417	3.949	0.449
2002	1.245	2.584	1.339	1.002	0.119	3.150	0.375	3.786	0.422
2003	1.146	2.595	1.449	1.043	0.120	3.184	0.367	3.951	0.424
2004	0.898	2.419	1.521	1.123	0.126	3.388	0.381	4.144	0.445
2005	1.185	2.651	1.466	1.136	0.136	3.457	0.407	4.089	0.474
2006	1.436	2.851	1.415	1.056	0.137	3.251	0.420	3.930	0.473
2007	1.629	3.170	1.541	1.082	0.140	3.253	0.425	4.120	0.499
2008	1.726	3.467	1.741	1.219	0.151	3.618	0.453	4.605	0.528
2009	1.399	3.339	1.940	1.371	0.162	4.049	0.485	5.128	0.565
2010	0.949	2.972	2.023	1.514	0.170	4.512	0.513	5.485	0.585
2011	1.001	2.859	1.858	1.490	0.165	4.562	0.509	5.270	0.568
2012	1.265	2.911	1.646	1.318	0.151	4.142	0.478	4.766	0.520
2013	2.227	3.801	1.574	1.177	0.139	3.670	0.437	4.422	0.505
2014	1.639	3.477	1.838	1.208	0.163	3.642	0.480	4.821	0.633
2015	0.994	3.174	2.179	1.541	0.253	4.477	0.702	5.694	0.933

Model 13.

	Abundance			Legal (≥ 104 mm)				MMB	
Year	Recruits	Total (≥ 64 mm)	Mature (≥ 94 mm)	Abundance	S.D	Biomass	S.D	Biomass	S.D.
1976	2.921	9.364	6.443	4.072	0.994	10.830	2.831	15.270	3.283
1977	1.440	8.167	6.727	5.487	0.950	15.861	2.855	18.277	3.015
1978	0.824	6.449	5.624	4.975	0.737	15.708	2.391	16.945	2.410
1979	0.580	4.432	3.852	3.509	0.500	11.646	1.709	12.305	1.736
1980	1.153	3.243	2.090	1.886	0.334	6.420	1.171	6.806	1.201
1981	1.474	2.952	1.479	1.192	0.228	4.072	0.803	4.593	0.861
1982	1.502	2.818	1.316	0.860	0.200	2.647	0.647	3.494	0.779
1983	1.702	3.254	1.552	1.068	0.218	3.151	0.664	4.054	0.792
1984	1.801	3.535	1.735	1.204	0.237	3.546	0.716	4.534	0.860
1985	1.470	3.415	1.945	1.362	0.264	4.015	0.791	5.104	0.957
1986	1.567	3.609	2.042	1.510	0.290	4.489	0.874	5.492	1.025
1987	1.331	3.314	1.983	1.503	0.292	4.584	0.903	5.477	1.024
1988	1.094	3.137	2.043	1.548	0.283	4.739	0.880	5.671	1.011
1989	1.122	3.030	1.909	1.535	0.268	4.786	0.842	5.490	0.931
1990	0.883	2.673	1.790	1.420	0.238	4.500	0.759	5.191	0.842
1991	0.789	2.457	1.668	1.337	0.211	4.238	0.675	4.864	0.746
1992	0.717	2.227	1.510	1.246	0.180	4.006	0.580	4.500	0.623
1993	0.579	1.952	1.373	1.118	0.149	3.619	0.486	4.097	0.527
1994	0.602	1.739	1.138	0.932	0.126	3.007	0.410	3.394	0.442
1995	0.699	1.645	0.946	0.756	0.106	2.437	0.345	2.790	0.374
1996	0.901	1.758	0.856	0.639	0.094	2.015	0.301	2.419	0.340
1997	1.550	2.449	0.899	0.631	0.093	1.932	0.288	2.427	0.339
1998	1.243	2.416	1.173	0.750	0.105	2.233	0.312	3.009	0.386
1999	0.703	2.266	1.563	1.070	0.131	3.085	0.378	4.018	0.475
2000	0.804	2.329	1.525	1.246	0.146	3.758	0.437	4.289	0.477
2001	1.166	2.488	1.322	1.080	0.128	3.420	0.409	3.871	0.437
2002	1.324	2.628	1.304	0.962	0.113	3.042	0.359	3.673	0.407
2003	1.154	2.584	1.430	1.005	0.115	3.058	0.351	3.851	0.411
2004	0.928	2.435	1.507	1.103	0.123	3.305	0.369	4.065	0.431
2005	1.257	2.701	1.444	1.115	0.130	3.388	0.391	4.007	0.453
2006	1.468	2.848	1.381	1.026	0.131	3.169	0.402	3.824	0.452
2007	1.708	3.221	1.513	1.041	0.133	3.127	0.404	4.005	0.479
2008	1.780	3.470	1.690	1.170	0.144	3.469	0.431	4.434	0.503
2009	1.432	3.342	1.910	1.324	0.154	3.891	0.460	4.986	0.543
2010	1.006	2.999	1.993	1.477	0.163	4.381	0.492	5.355	0.562
2011	1.026	2.870	1.844	1.467	0.159	4.476	0.492	5.191	0.547
2012	1.388	3.009	1.621	1.300	0.147	4.088	0.463	4.686	0.502
2013	2.269	3.816	1.547	1.137	0.132	3.562	0.419	4.321	0.482
2014	1.696	3.479	1.783	1.161	0.154	3.504	0.451	4.646	0.601
2015	1.005	3.172	2.167	1.484	0.238	4.274	0.654	5.568	0.901

Table 14. Summary of catch and estimated discards (million lb) for Norton Sound red king crab. Assumed average crab weight is 2.5 lb for the winter commercial catch, 2.0 lb for the subsistence catch, and 1.0 lb for Winter subsistence discards. Summer and winter commercial discards were estimated from the model.

Model 5.

Year	Summer Com	Winter Com	Winter Sub	Discards Summer	Discards Winter Sub	Discards Winter com	Total	Catch/ MMB
1977	0.52	0.000	0.000	0.020	0.000	0.000	0.54	0.029
1978	2.09	0.024	0.025	0.038	0.008	0.000	2.185	0.129
1979	2.93	0.001	0.000	0.049	0.000	0.000	2.98	0.244
1980	1.19	0.000	0.000	0.025	0.000	0.000	1.215	0.179
1981	1.38	0.000	0.001	0.069	0.000	0.000	1.45	0.312
1982	0.23	0.000	0.003	0.020	0.001	0.000	0.254	0.071
1983	0.37	0.001	0.021	0.036	0.006	0.000	0.434	0.104
1984	0.39	0.002	0.022	0.036	0.005	0.000	0.455	0.098
1985	0.43	0.003	0.017	0.037	0.002	0.000	0.489	0.095
1986	0.48	0.005	0.014	0.031	0.004	0.000	0.534	0.096
1987	0.33	0.003	0.012	0.020	0.002	0.000	0.367	0.066
1988	0.24	0.001	0.005	0.013	0.001	0.000	0.26	0.045
1989	0.25	0.001	0.012	0.012	0.002	0.000	0.277	0.050
1990	0.19	0.009	0.024	0.009	0.004	0.000	0.236	0.045
1991	0	0.010	0.015	0.000	0.002	0.000	0.027	0.005
1992	0.07	0.019	0.023	0.003	0.003	0.001	0.119	0.026
1993	0.33	0.004	0.002	0.014	0.000	0.000	0.35	0.084
1994	0.32	0.014	0.008	0.014	0.001	0.001	0.358	0.103
1995	0.32	0.019	0.011	0.016	0.002	0.001	0.369	0.129
1996	0.22	0.004	0.003	0.016	0.001	0.000	0.244	0.099
1997	0.09	0.000	0.001	0.010	0.001	0.000	0.102	0.041
1998	0.03	0.002	0.017	0.004	0.012	0.000	0.065	0.020
1999	0.02	0.007	0.015	0.002	0.003	0.000	0.047	0.011
2000	0.3	0.008	0.011	0.014	0.004	0.000	0.337	0.077
2001	0.28	0.003	0.001	0.015	0.000	0.000	0.299	0.076
2002	0.25	0.006	0.004	0.019	0.003	0.000	0.282	0.074
2003	0.26	0.017	0.008	0.022	0.005	0.001	0.313	0.079
2004	0.34	0.001	0.002	0.024	0.001	0.000	0.368	0.089
2005	0.4	0.005	0.008	0.024	0.003	0.000	0.44	0.108
2006	0.45	0.000	0.002	0.035	0.001	0.000	0.488	0.124
2007	0.31	0.008	0.021	0.030	0.011	0.001	0.381	0.092
2008	0.39	0.014	0.019	0.039	0.009	0.001	0.472	0.102
2009	0.4	0.012	0.010	0.035	0.002	0.001	0.46	0.090
2010	0.42	0.012	0.014	0.027	0.002	0.001	0.476	0.087
2011	0.4	0.008	0.013	0.020	0.003	0.000	0.444	0.084
2012	0.47	0.023	0.015	0.027	0.004	0.001	0.54	0.113
2013	0.35	0.057	0.015	0.032	0.014	0.005	0.473	0.107
2014	0.39	0.037	0.007	0.044	0.002	0.004	0.484	0.100
2015	0.40	0.103	0.019	0.030	0.005	0.006	0.563	0.099

Model 13

Year	Summer Com	Winter Com	Winter Sub	Discards Summer	Discards Winter Sub	Discards Winter com	Total	Catch/ MMB
1977	0.52	0.000	0.000	0.021	0.000	0.000	0.541	0.030
1978	2.09	0.024	0.025	0.044	0.008	0.000	2.191	0.129
1979	2.93	0.001	0.000	0.052	0.000	0.000	2.983	0.242
1980	1.19	0.000	0.000	0.026	0.000	0.000	1.216	0.179
1981	1.38	0.000	0.001	0.077	0.000	0.000	1.458	0.317
1982	0.23	0.000	0.003	0.022	0.001	0.000	0.256	0.073
1983	0.37	0.001	0.021	0.039	0.006	0.000	0.437	0.108
1984	0.39	0.002	0.022	0.040	0.005	0.000	0.459	0.101
1985	0.43	0.003	0.017	0.038	0.002	0.000	0.49	0.096
1986	0.48	0.005	0.014	0.034	0.004	0.000	0.537	0.098
1987	0.33	0.003	0.012	0.021	0.002	0.000	0.368	0.067
1988	0.24	0.001	0.005	0.014	0.001	0.000	0.261	0.046
1989	0.25	0.001	0.012	0.012	0.002	0.000	0.277	0.050
1990	0.19	0.009	0.024	0.010	0.004	0.000	0.237	0.046
1991	0	0.010	0.015	0.000	0.002	0.000	0.027	0.006
1992	0.07	0.019	0.023	0.003	0.003	0.001	0.119	0.026
1993	0.33	0.004	0.002	0.016	0.000	0.000	0.352	0.086
1994	0.32	0.014	0.008	0.015	0.001	0.001	0.359	0.106
1995	0.32	0.019	0.011	0.018	0.002	0.001	0.371	0.133
1996	0.22	0.004	0.003	0.018	0.001	0.000	0.246	0.102
1997	0.09	0.000	0.001	0.011	0.001	0.000	0.103	0.042
1998	0.03	0.002	0.017	0.004	0.012	0.000	0.065	0.022
1999	0.02	0.007	0.015	0.002	0.003	0.000	0.047	0.012
2000	0.3	0.008	0.011	0.015	0.004	0.000	0.338	0.079
2001	0.28	0.003	0.001	0.016	0.000	0.000	0.3	0.078
2002	0.25	0.006	0.004	0.022	0.003	0.001	0.286	0.078
2003	0.26	0.017	0.008	0.025	0.005	0.001	0.316	0.082
2004	0.34	0.001	0.002	0.026	0.001	0.000	0.37	0.091
2005	0.4	0.005	0.008	0.026	0.003	0.000	0.442	0.110
2006	0.45	0.000	0.002	0.038	0.001	0.000	0.491	0.128
2007	0.31	0.008	0.021	0.033	0.011	0.001	0.384	0.096
2008	0.39	0.014	0.019	0.043	0.009	0.001	0.476	0.107
2009	0.4	0.012	0.010	0.038	0.002	0.001	0.463	0.093
2010	0.42	0.012	0.014	0.029	0.002	0.001	0.478	0.089
2011	0.4	0.008	0.013	0.021	0.003	0.000	0.445	0.086
2012	0.47	0.023	0.015	0.028	0.004	0.001	0.541	0.115
2013	0.35	0.057	0.015	0.037	0.014	0.005	0.478	0.111
2014	0.39	0.037	0.007	0.048	0.002	0.004	0.488	0.105
2015	0.40	0.103	0.019	0.033	0.005	0.006	0.566	0.102

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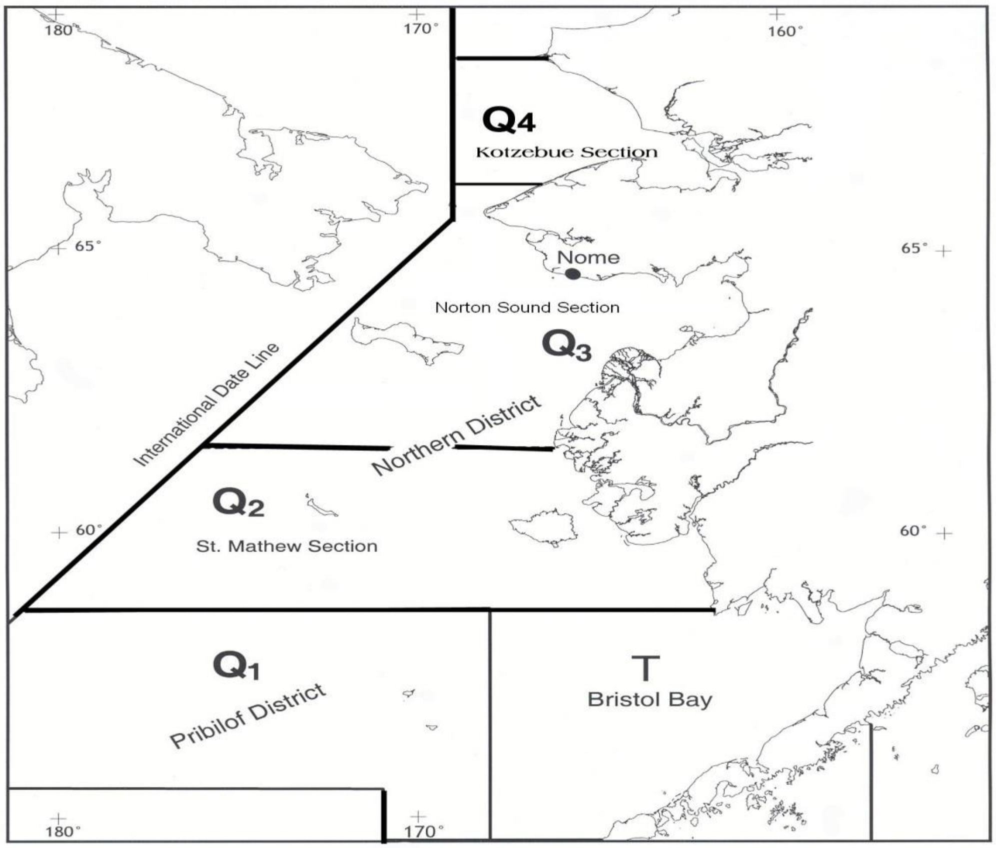

Figure 1. King crab fishing districts and sections of Statistical Area Q.

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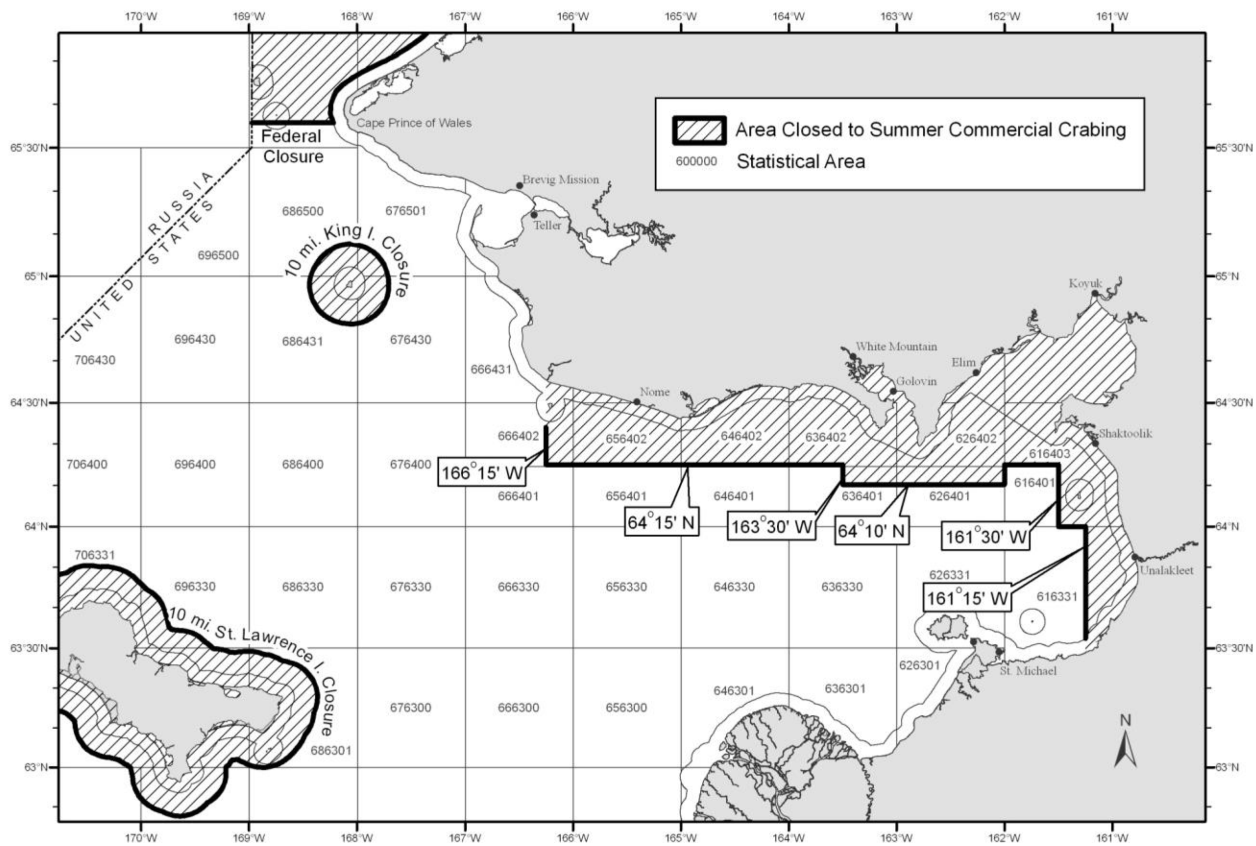

Figure 2. Closed water regulations in effect for the Norton Sound commercial crab fishery.

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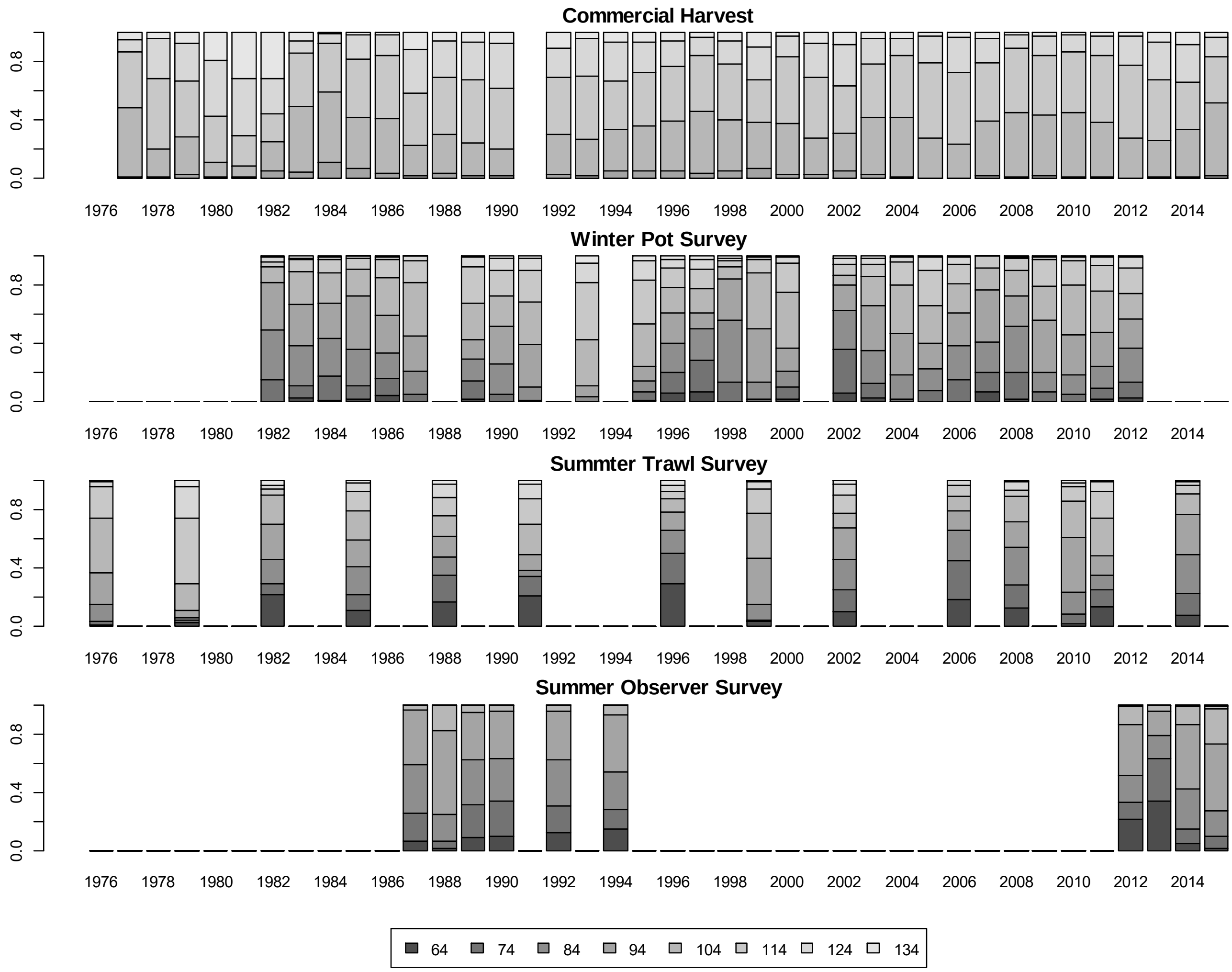

Figure 3. Observed length compositions 1976-2015.

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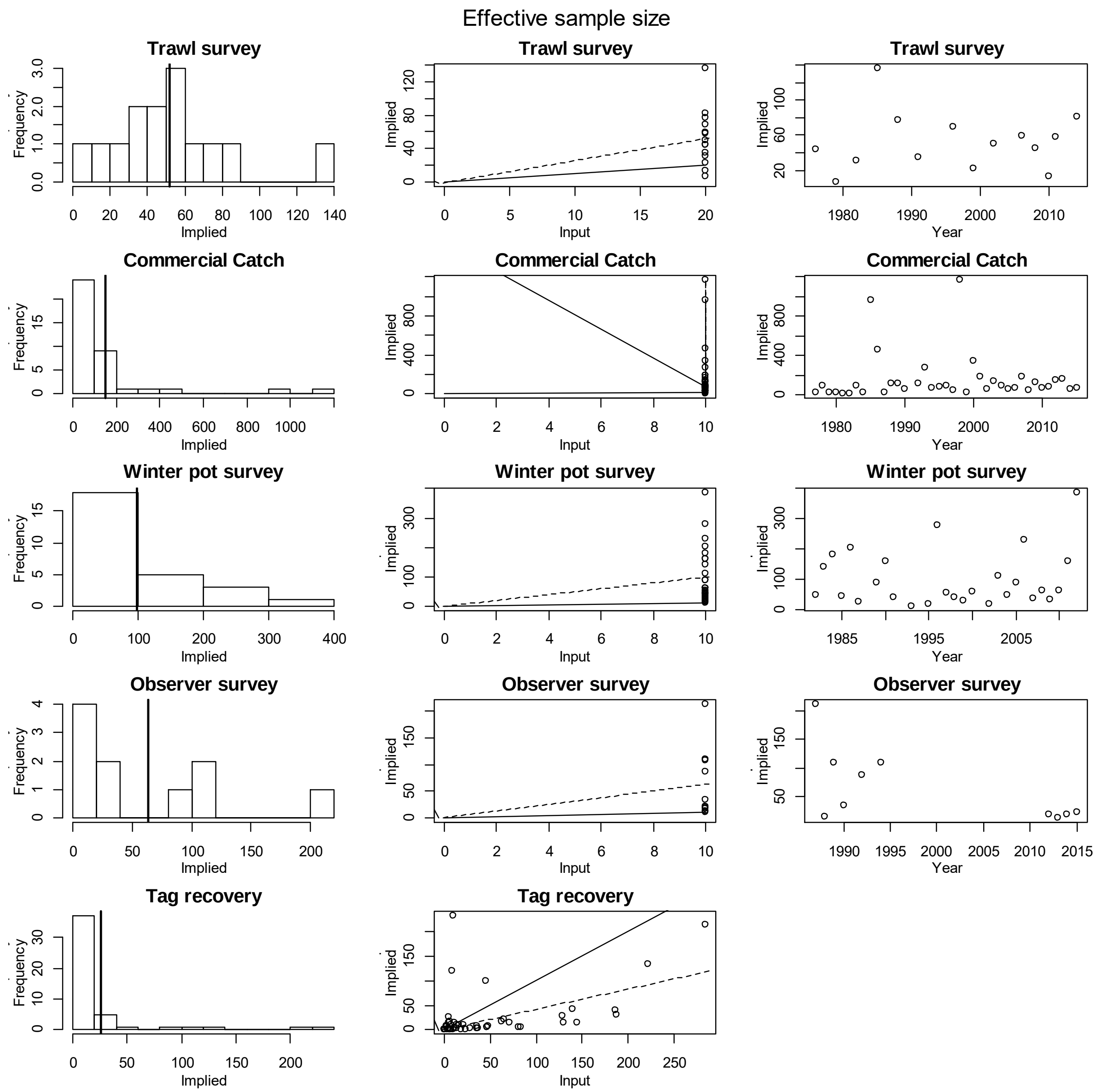

Figure 4. Effective sample size vs. implied sample size. Figures in the first column show effective sample size (x-axis) vs. frequency (y-axis). Vertical solid line is the implied sample size. Figures in the second column show implied sample size (x-axis) vs. effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. Figures in the third column show year (x-axis) vs. effective sample size (y-axis).

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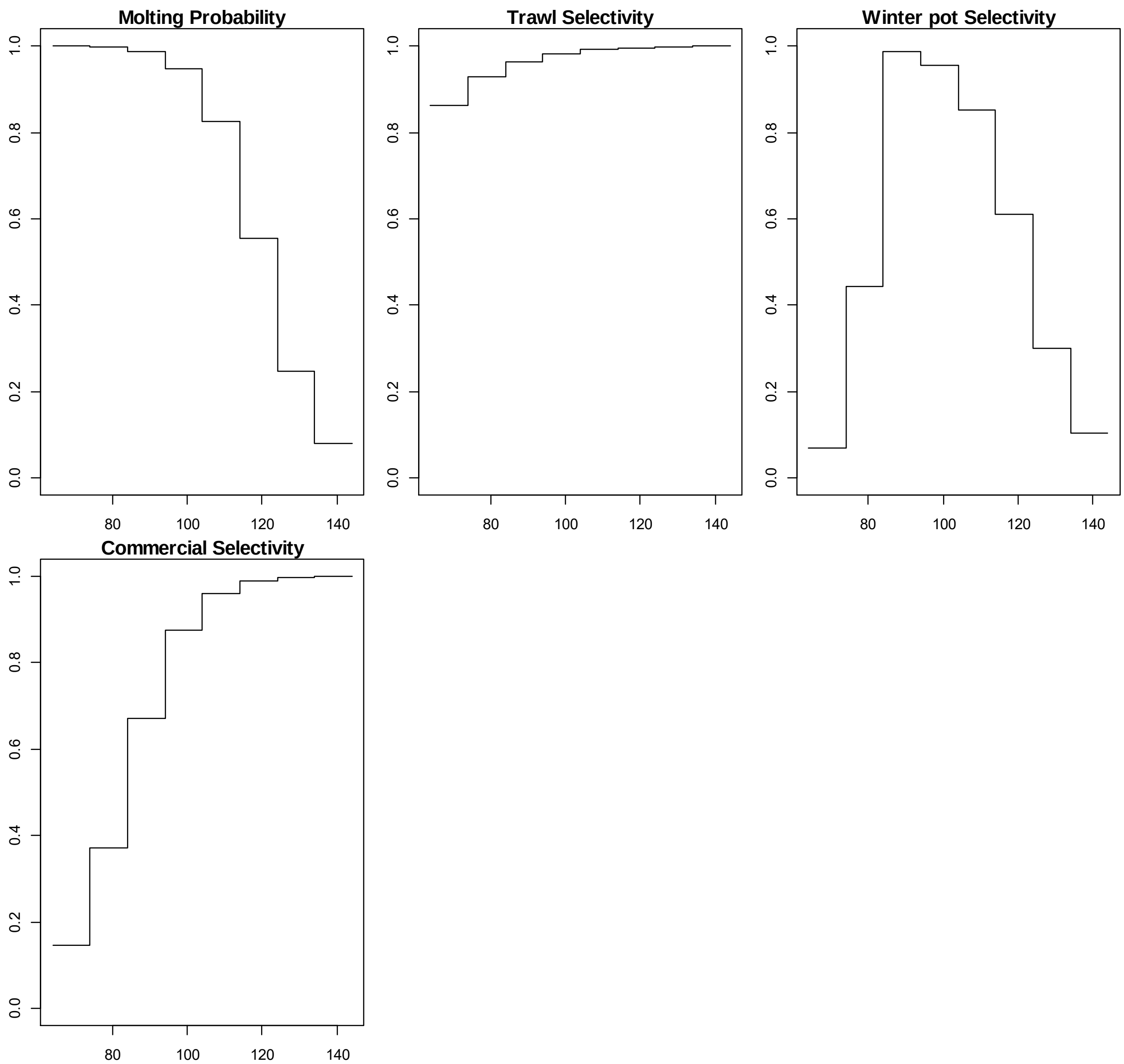

Figure 5. Molting probability and trawl/pot selectivities.

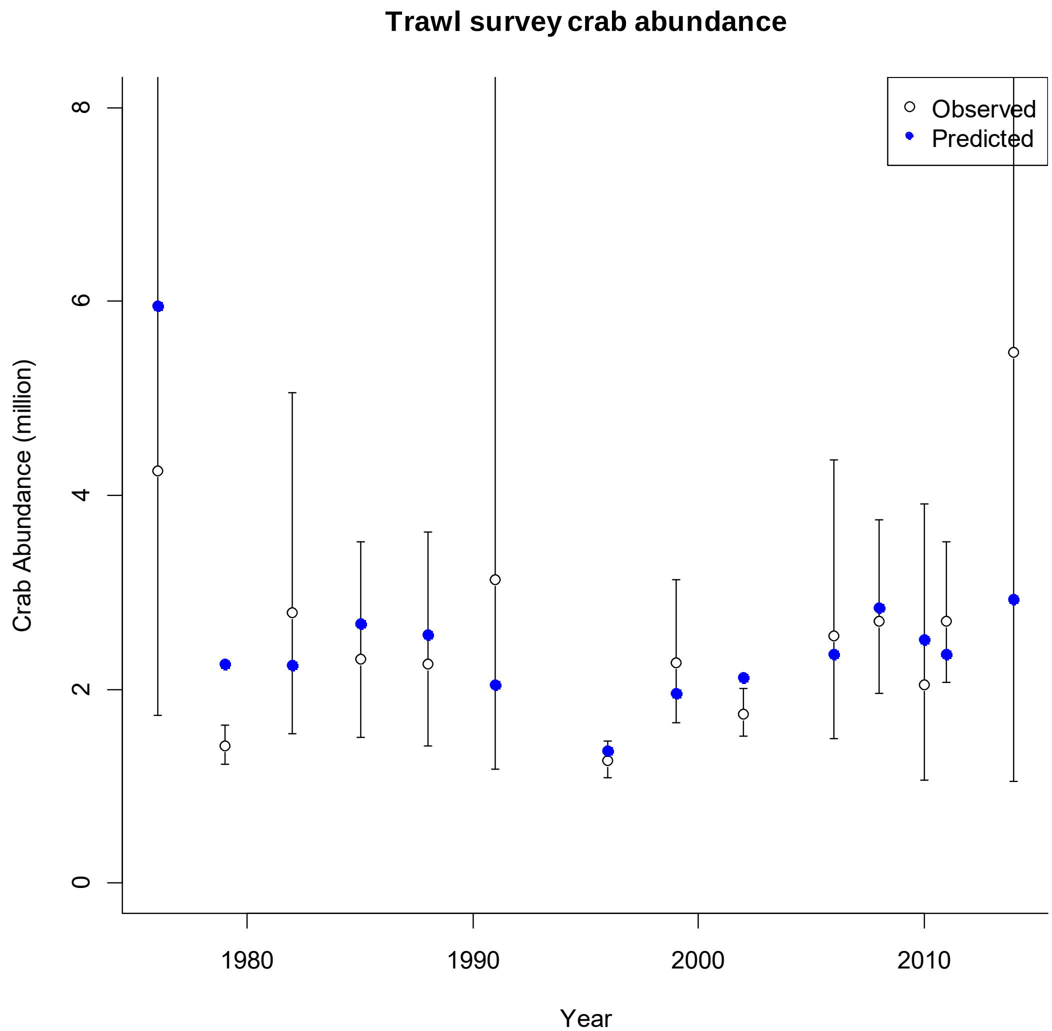

Figure 6. Estimated trawl survey male abundance with 95% lognormal Confidence Interval (crab ≥ 74 mm CL).

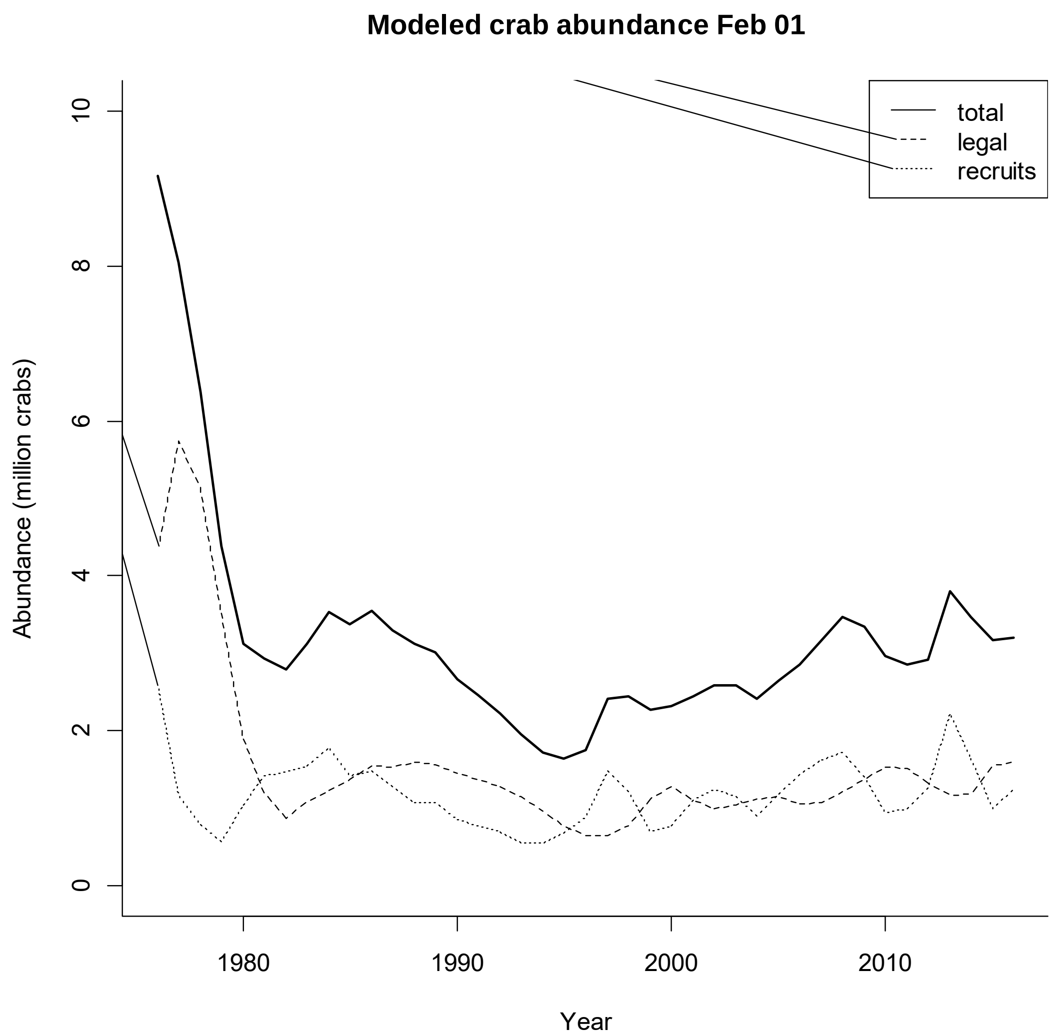

Figure 7. Estimated abundances of legal and recruits males from 1976-2015.

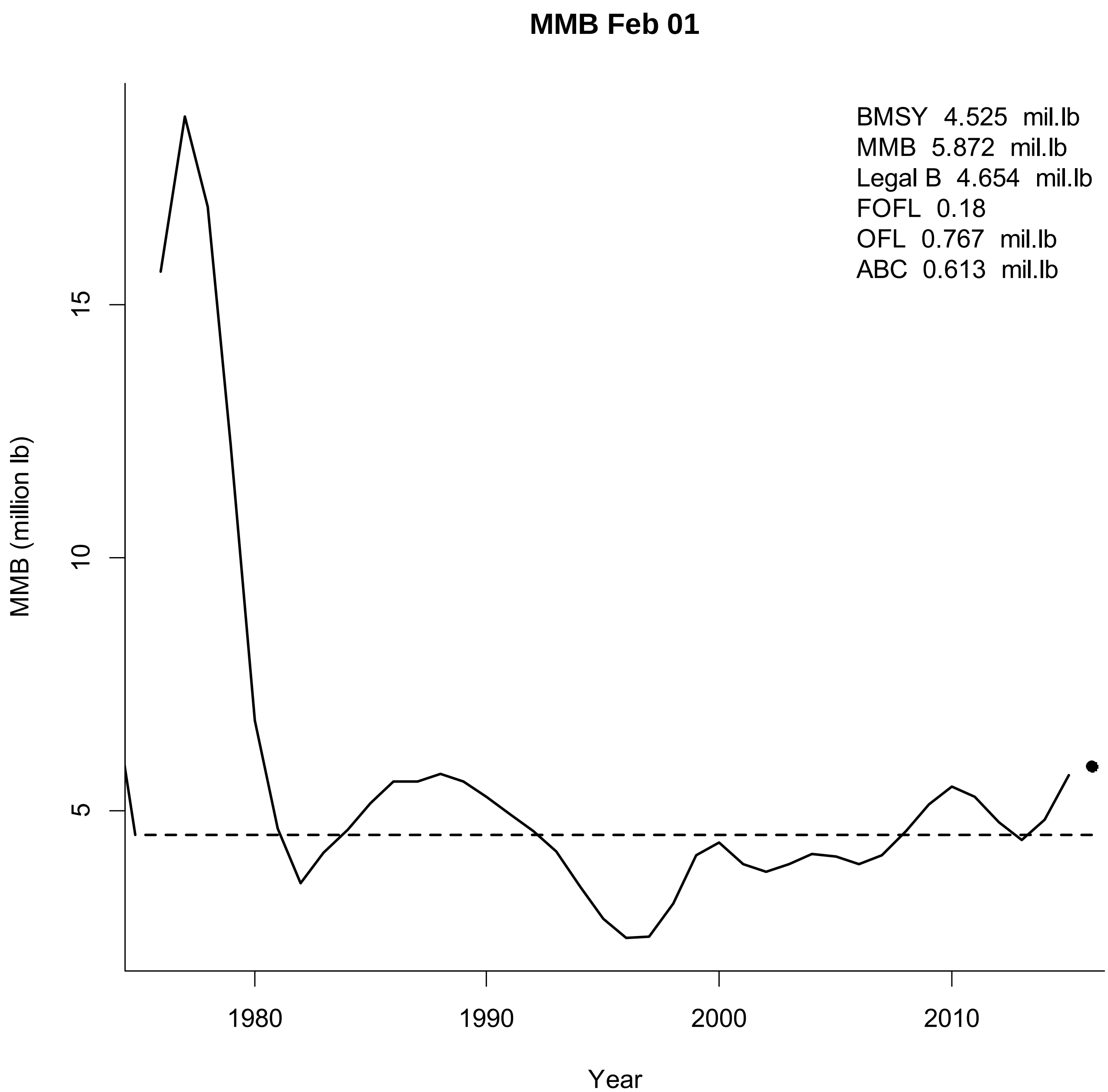

Figure 8. Estimated MMB from 1976-2015. Dash line shows Bmsy (Average MMB of 1980-2016). Black points indicate projected MMB of 2016.

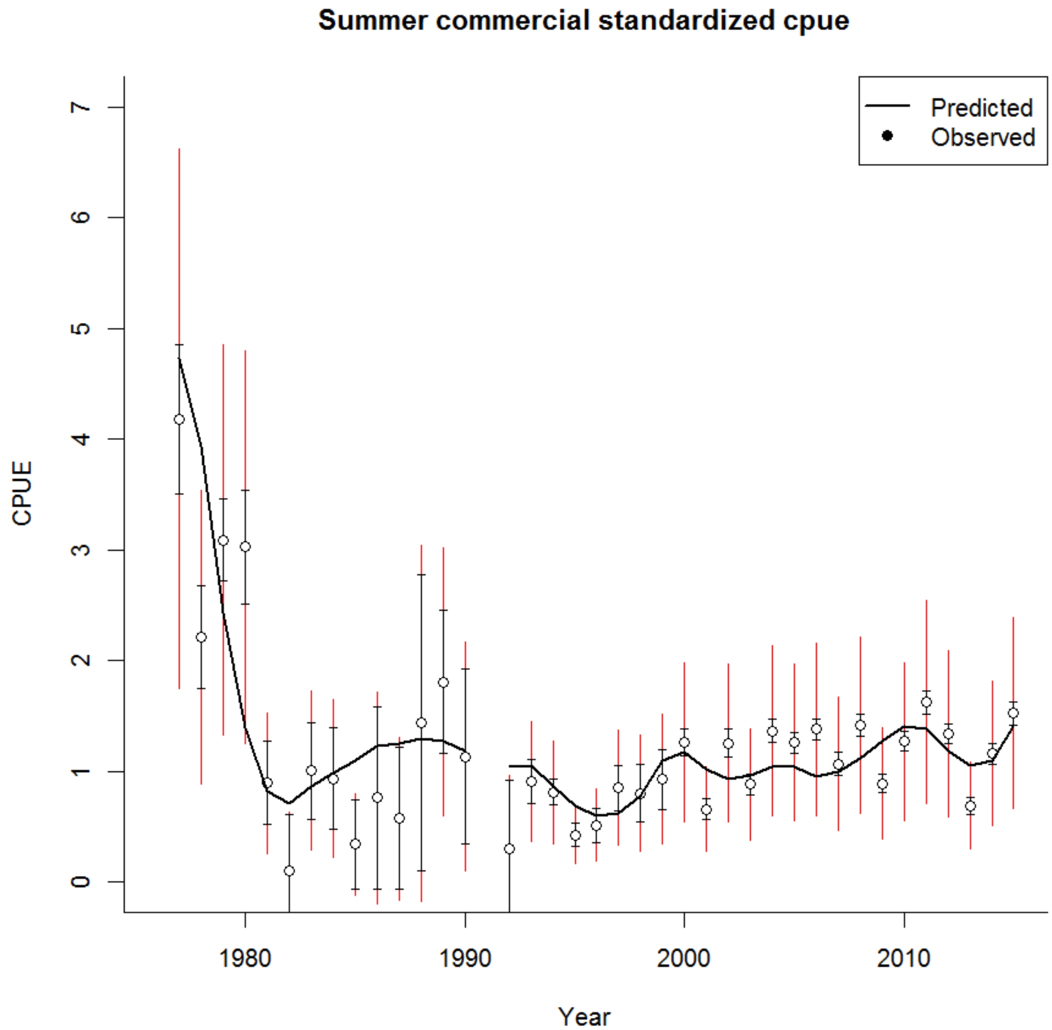

Figure 9. Summer commercial standardized cpue. Black line is input SD and red line is input and estimated additional SD.

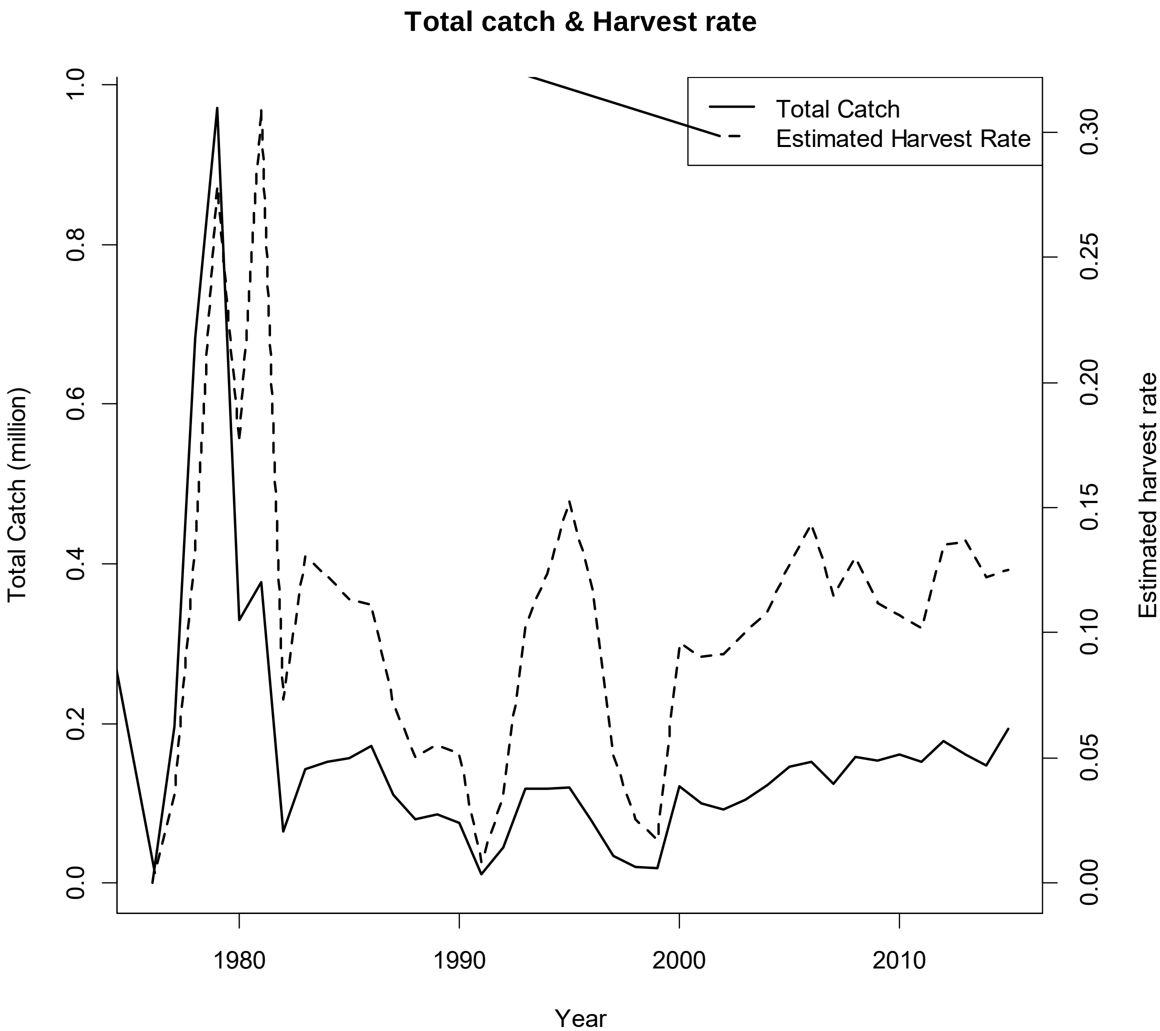

Figure 10. Commercial Catch and estimated harvest rate of legal male.

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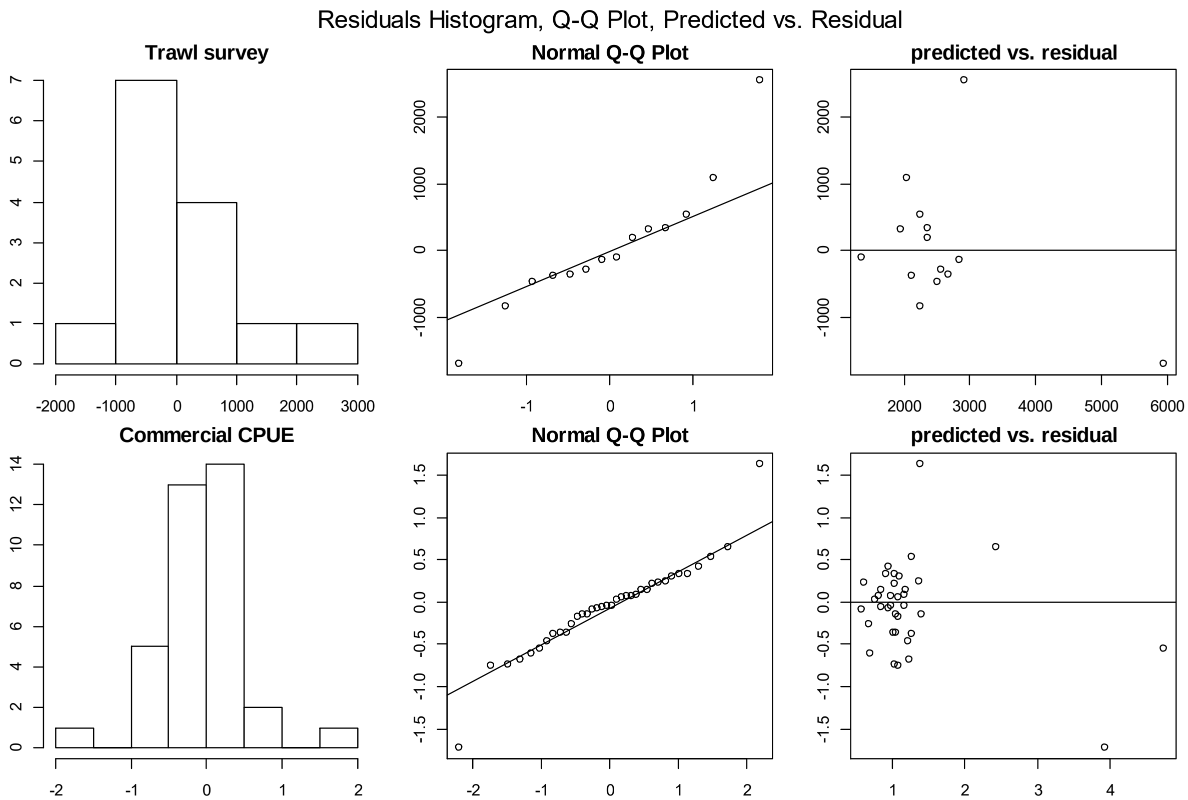

Figure 11. Residual and QQ plot.

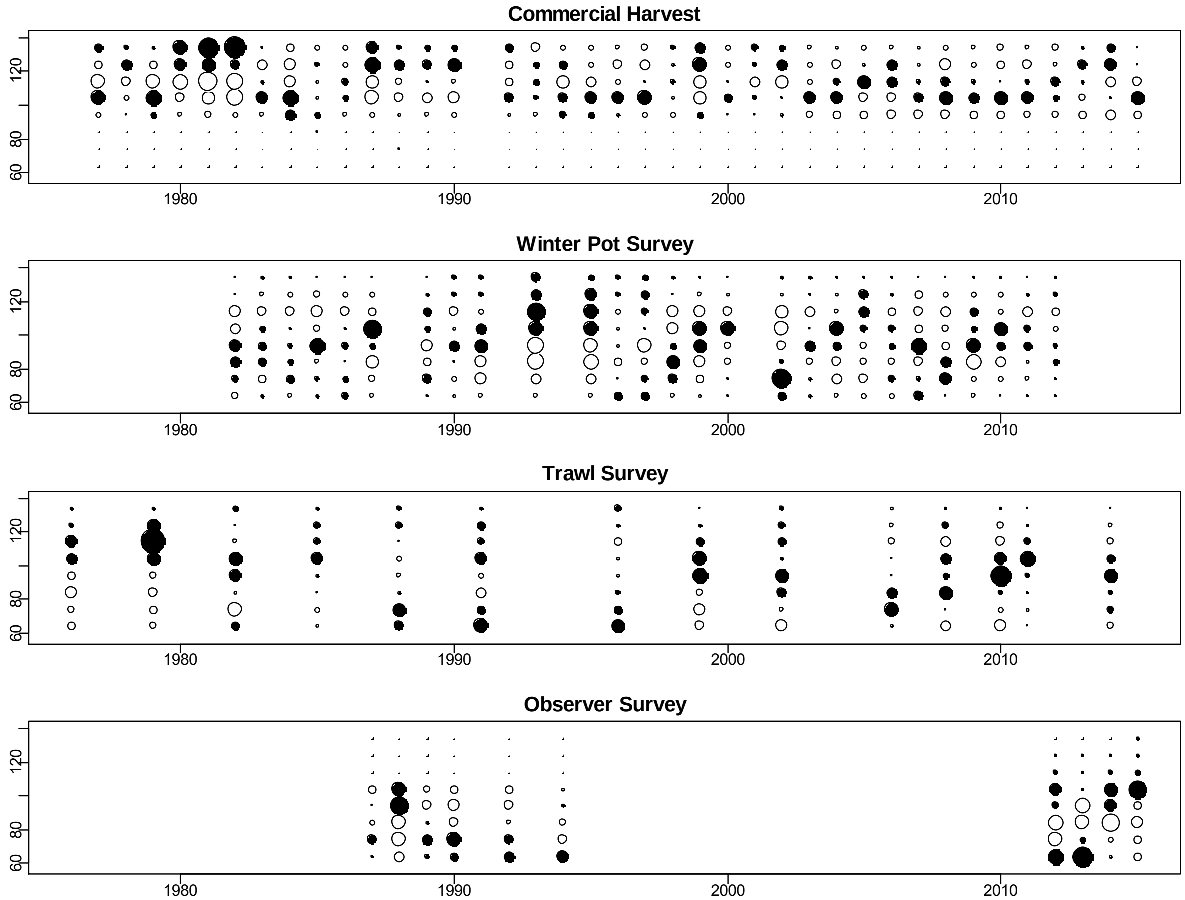

Figure 12. Bubble plot of predicted and observed length proportion (Alternative model 0). Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicate degree of deviance (larger circle = larger deviance).

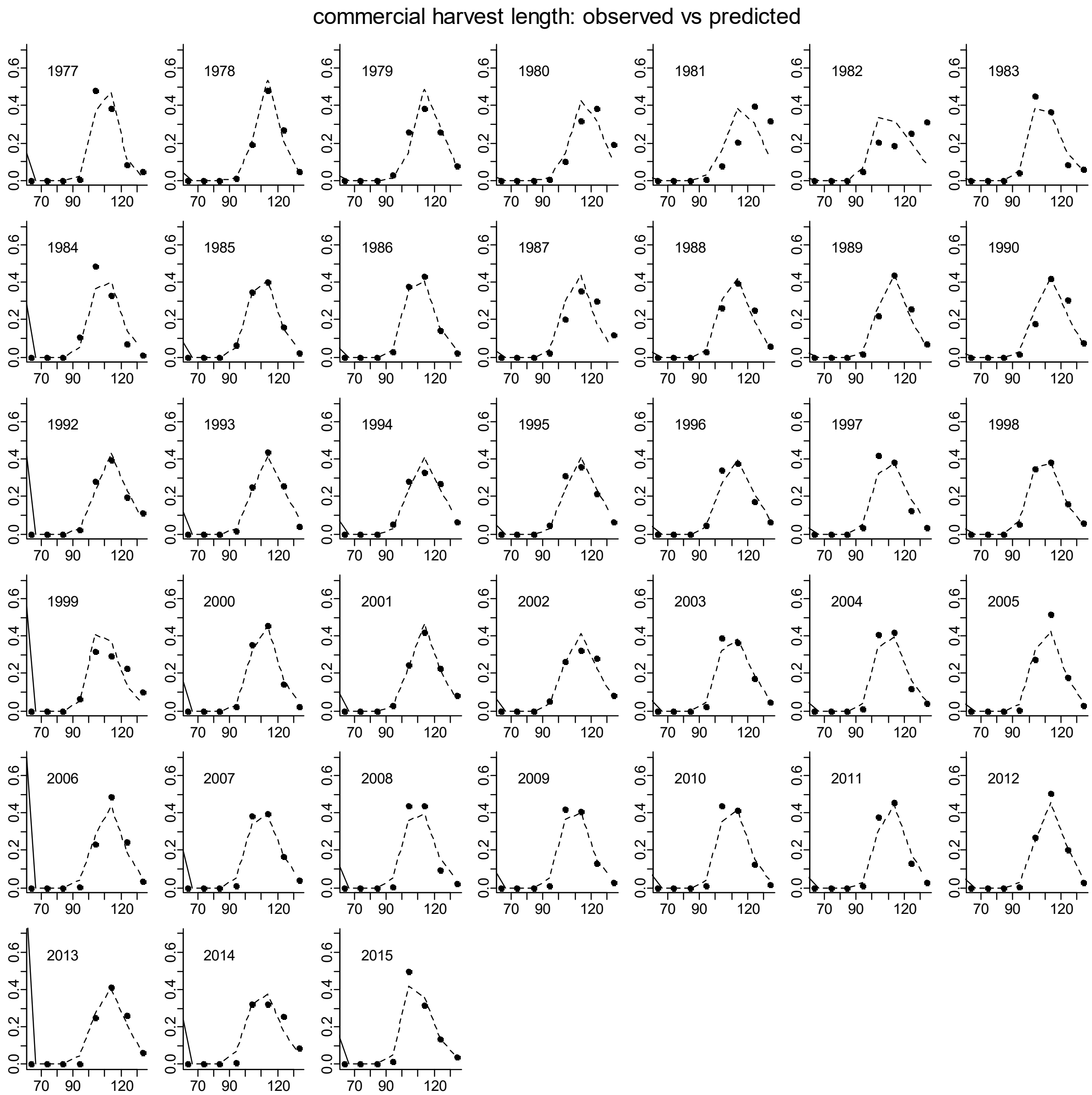

Figure 13. Predicted (dashed line) vs. observed (black dots) length class proportion for the summer commercial catch.

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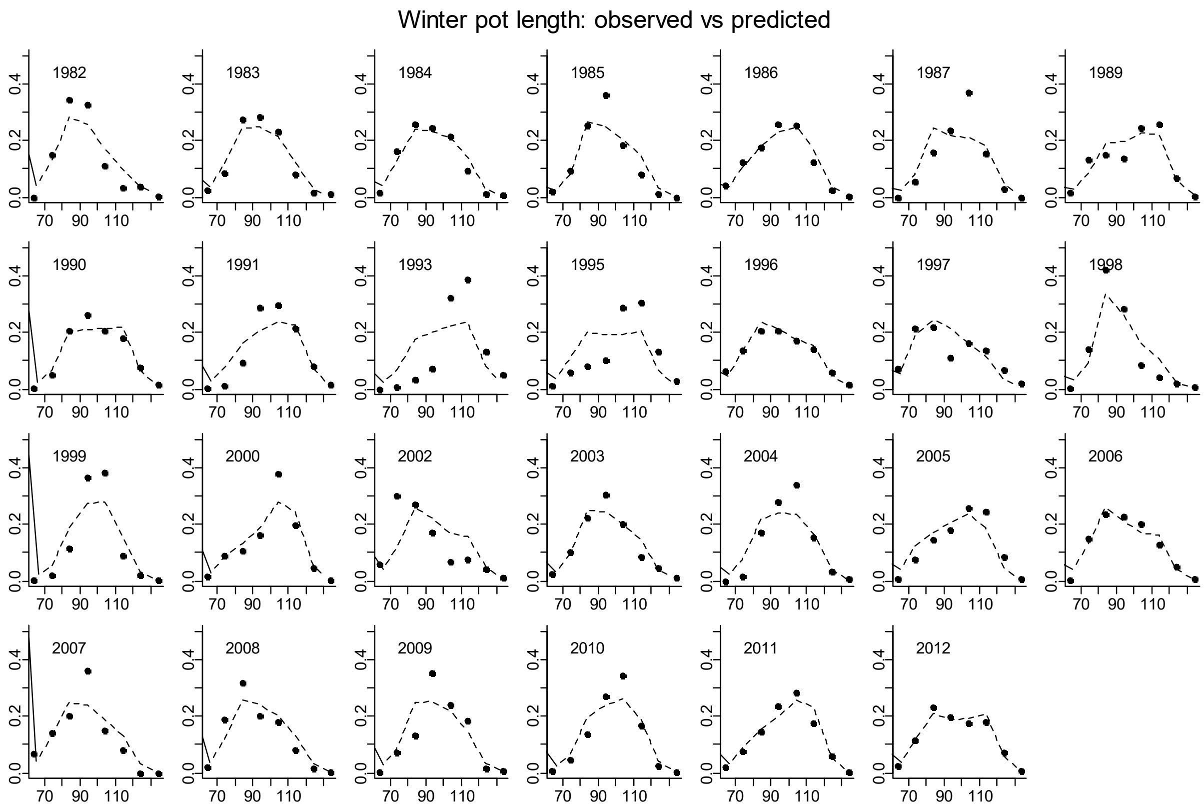

Figure 14. Predicted vs. observed length class proportion for winter pot survey.

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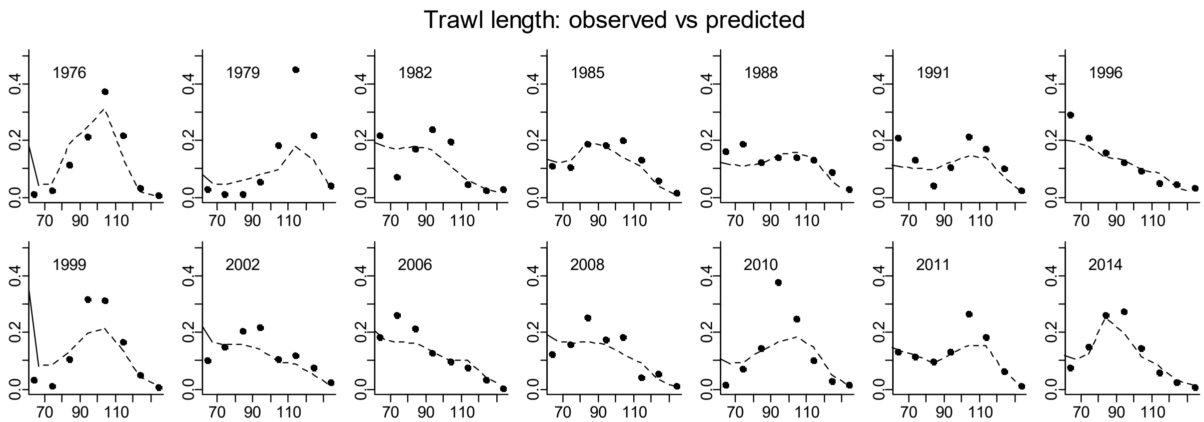

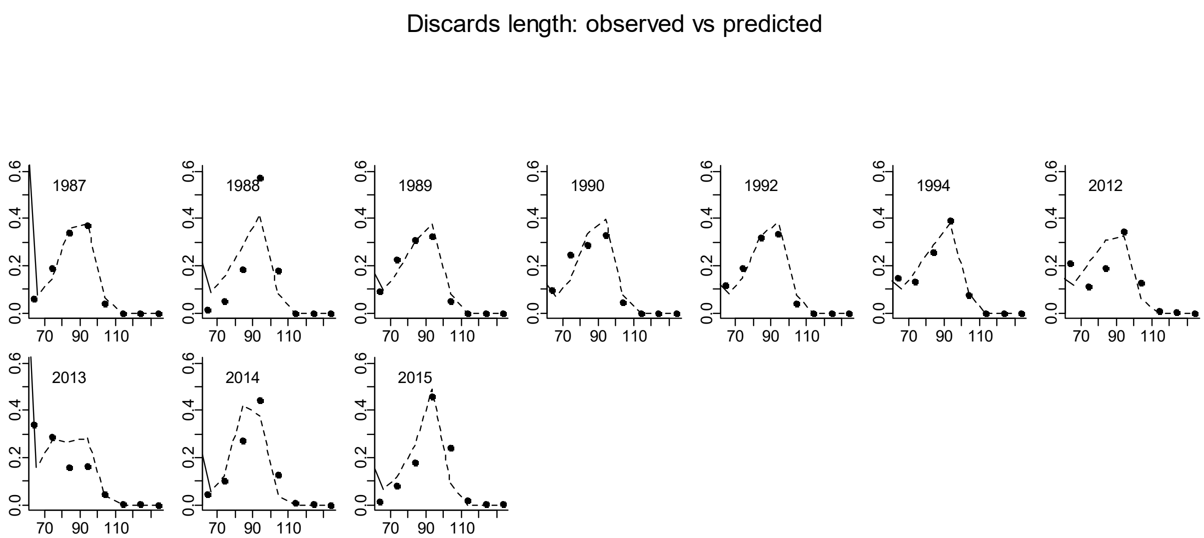

Figure 15. Predicted vs. observed length class proportion for trawl survey and commercial observer.

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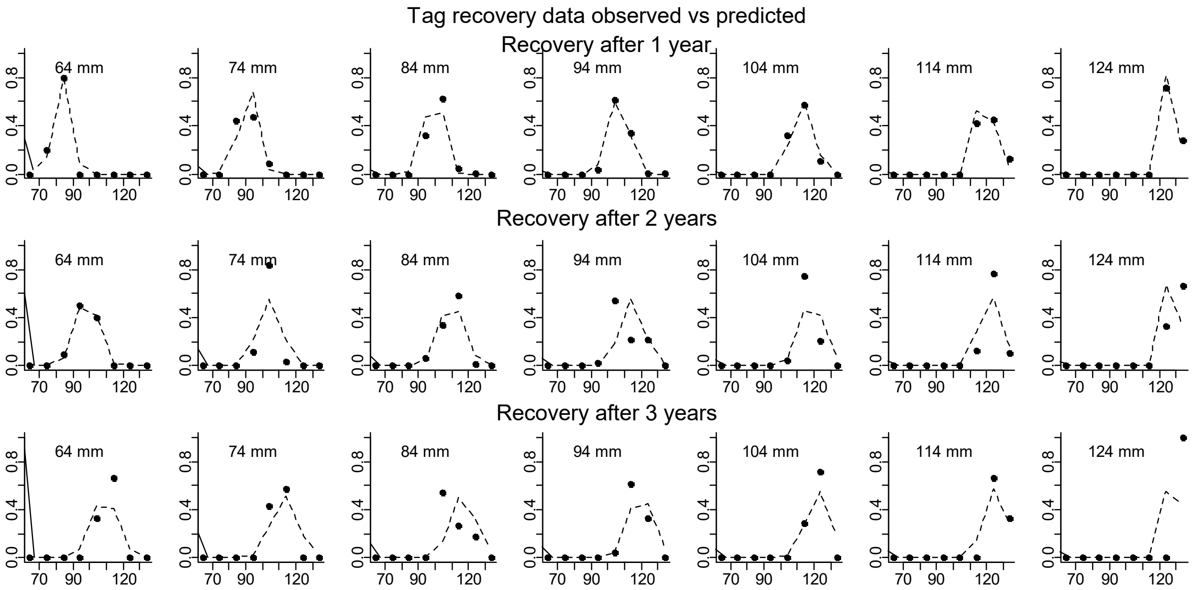

Figure 16. Predicted vs. observed length class proportion for tag recovery data 1980-1992, and 1993-2014.

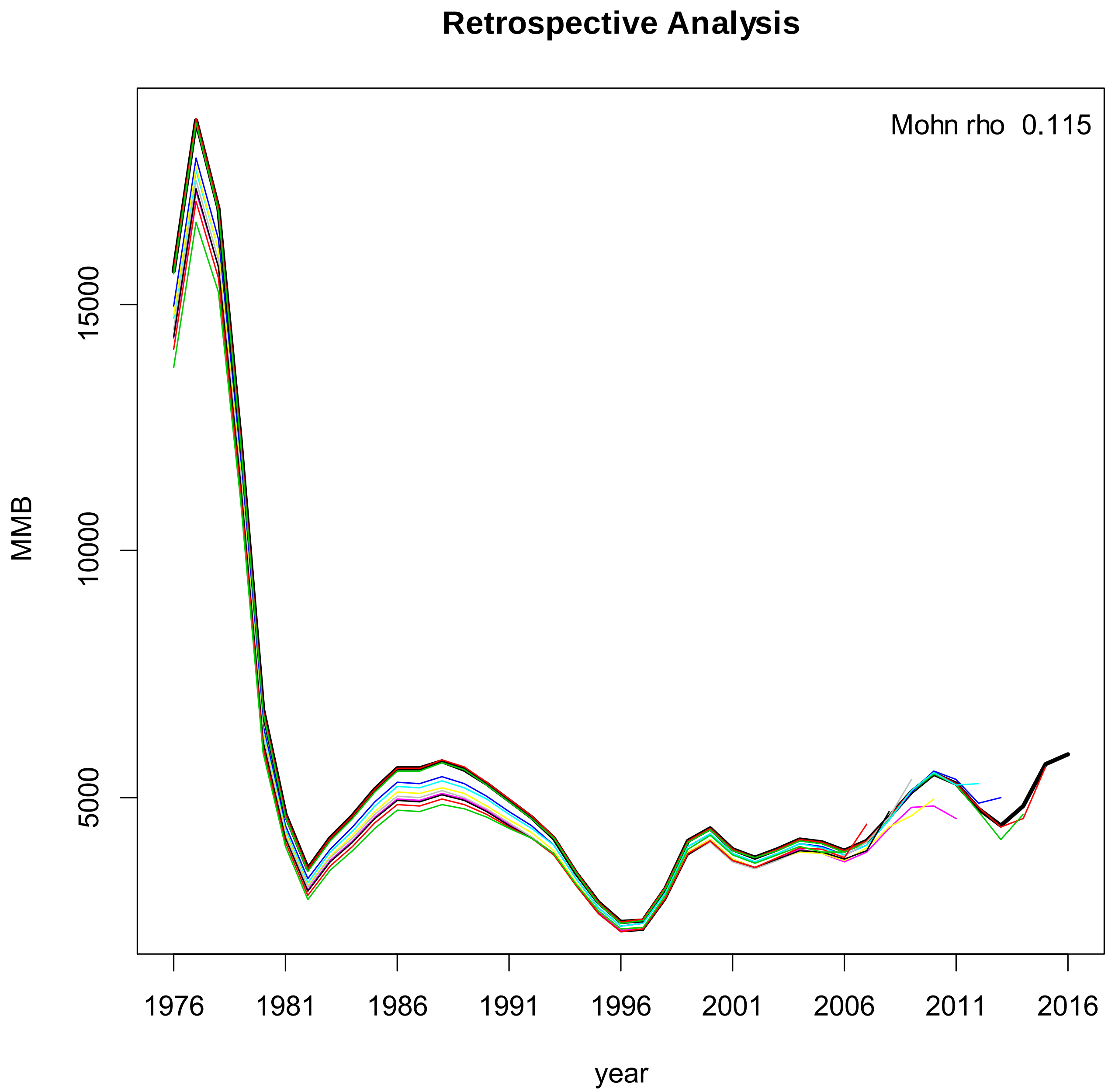

Figure 17. Retrospective analyses. Each line shows retrospective MMB. Model 5

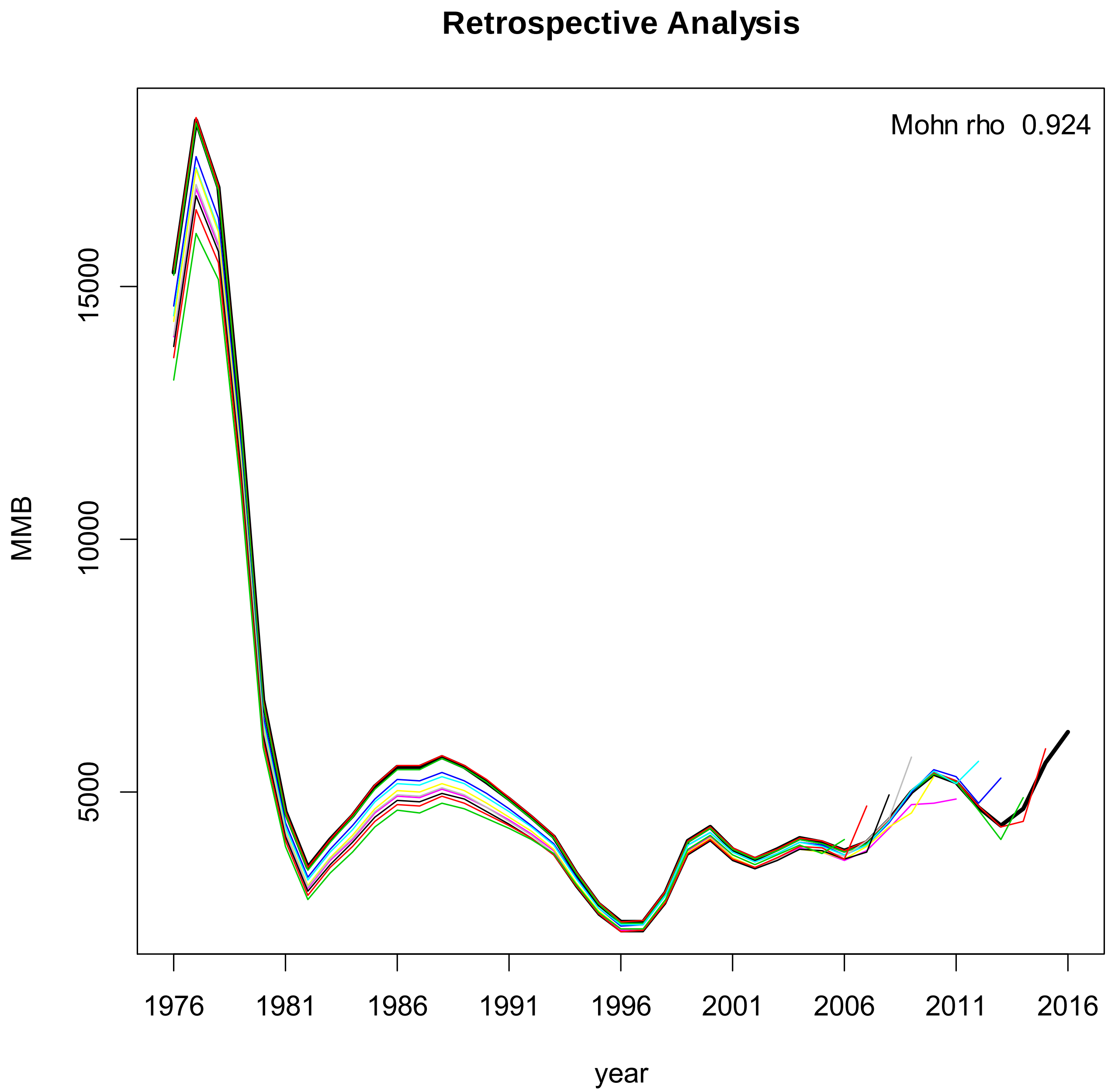

Figure 18. Retrospective analyses. Each line shows retrospective MMB. Model 13

Aleutian Islands Golden King Crab – 2016 Tier 5 Assessment

2016 Crab SAFE Report Chapter (September 2016)

Douglas Pengilly, ADF&G, Kodiak
Alaska Department of Fish and Game
Division of Commercial Fisheries
351 Research Ct.
Kodiak, AK 99615, USA
Phone: (907) 486-1865
Email: doug.pengilly@alaska.gov

Executive Summary

1. **Stock:** Aleutian Islands golden king crab *Lithodes aequispinus*

2. Catches:

The fishery has been prosecuted as a directed fishery since 1981/82 and has been opened every year since then. Retained catch peaked in 1986/87 at 6,696 t (14,762,494 lb), but the retained catch dropped sharply after 1989/90 to an average of 3,145 t (6,933,822 lb) for the period 1990/91–1995/96. A guideline harvest level (GHL) was introduced into management for the first time in 1996/97. A GHL of 2,676 t (5,900,000 lb) was established in 1996/97 and subsequently reduced to 2,585 t (5,700,000 lb) beginning in 1998/99. The GHL (or, since 2005/06, the total allowable catch, or TAC) remained at 2,585 t (5,700,000 lb) through 2007/08, but was increased to 2,715 t (5,985,000 lb) for 2008/09–2011/12 and increased to 2,853 t (6,290,000 lb) for 2012/13–2015/16. The TAC for 2016/17 was reduced to 2,515 t (5,545,000 lb), which reflects a 25% reduction on the TAC for the area west of 174° W longitude. In addition to the retained catch that is allotted as TAC, there was retained catch in a cost-recovery fishery towards a $300,000 goal in 2013/14 and 2014/15 and towards a $500,000 goal in 2015/16 and 2016/17. Catch per pot lift (CPUE) of retained legal males decreased from the 1980s into the mid-1990s, but increased steadily after 1994/95 and increased markedly at the initiation of the Crab Rationalization program in 2005/06. The fishery has been managed separately east and west of 174° W longitude since 1996/97 and, although CPUE for the two areas showed similar trends through 2010/11, during 2011/12–2014/15 CPUE trends have diverged (increasing east of 174° W longitude and decreasing west of 174° W longitude). Total retained catch in 2015/16 is confidential because only 2 vessels participated in the western Aleutian Islands fishery. However, portions of the catch that can be reported include 1,498 t (3,302,480 lb) from the eastern Aleutian Islands fishery and 92 t (202,169 lb) from the cost recovery fishery. Discarded (non-retained) catch occurs mainly during the directed fishery. Although low levels of discarded catch can occur during other crab fisheries, there have been no such fisheries prosecuted since 2004/05. Additionally, discarded catch could occur during surveys for red king crab conducted under a Commissioner's permit (no golden king crab were caught during the cooperative red king crab survey performed by industry and ADF&G in the Adak area in September 2015 (Hilsinger et al. 2016)). Estimates of the bycatch mortality during crab fisheries decreased during 1995/96–2005/06, both in absolute value and relative to the retained catch weight, and stabilized during 2005/06–2014/15. Estimated bycatch mortality during crab fisheries in 2015/16 is confidential because only 2 vessels participated in the western Aleutian Islands fishery. However, bycatch mortality that can be reported includes 166 t from both the eastern Aleutian Islands and cost recovery fisheries. Discarded catch also occurs during fixed-gear and trawl groundfish fisheries, but is small relative to discards during the directed fishery and the groundfish fisheries are a minor contributor to total fishery mortality; estimated bycatch mortality during groundfish fisheries in 2015/16 was 30 t. Estimated total fishery mortality during 1995/96–2015/16 has ranged from 2,242 t in 1998/99 to 3,157 t in 1995/96.). A cooperative golden king crab survey was performed by the Aleutian Islands King Crab Foundation (an industry group) and ADF&G during the eastern Aleutian Islands fishery in August 2015, by vessels that were simultaneously fishing. The author doesn't know if gear was configured differently during the survey period. However, for the purpose of catch accounting for 2015/16, it was assumed bycatch mortality that occurred during the survey was accounted for by observed discards during the eastern Aleutian Islands fishery.

3. Stock biomass:
Estimates of stock biomass are not available for this Tier 5 assessment.

4. Recruitment:
Estimates of recruitment trends and current levels relative to virgin or historic levels are not available for this Tier 5 assessment.

5. Management performance:
Overfishing did not occur in 2015/16 because the 2015/16 estimated total catch (confidential) did not exceed the Tier 5 OFL established for 2015/16 (5.69-thousand t; 12.54-million lb). The 2015/16 estimated total catch did not exceed the ABC established for 2015/16 (4.26-thousand t; 9.40-million lb). The TACs for 2013/14–2016/17 do not include landings towards a cost-recovery fishing goal (which was $300,000 for 2013/14–2014/15 and $500,000 for 2015/16–2016/17); the catch reported for 2013/14–2015/16 includes the catch towards the cost-recovery fishery. The OFL and ABC values for 2016/17 are the author's status quo, Alternative 1 recommended values.

Management Performance Table (values in t)

Fishing Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch	Total Catch	OFL	ABC
2012/13	N/A	N/A	2,853	2,843	3,115	5.69[c]	5.12[c]
2013/14	N/A	N/A	2,853	2,894[b]	3,192	5.69[c]	5.12[c]
2014/15	N/A	N/A	2,853	2,771[b]	3,079	5.69[c]	4.26[c]
2015/16	N/A	N/A	2,853	Conf. [d]	Conf. [d]	5.69[c]	4.26[c]
2016/17	N/A	N/A	2,515			5,689	4,267

a. Total allowable catch, established in lb and converted to t.
b. Includes retained catch towards cost-recovery fisheries.
c. Established in thousands of t.
d. Confidential under Sec. 16.05.815 (SOA statute). TAC not attained.

Management Performance Table (values in lb)

Fishing Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch	Total Catch	OFL	ABC
2012/13	N/A	N/A	6,290,000	6,267,759	6,867,391	12.54[c]	11.28[c]
2013/14	N/A	N/A	6,290,000	6,379,553[b]	7,037,147	12.54[c]	11.28[c]
2014/15	N/A	N/A	6,290,000	6,108,674[b]	6,788,025	12.53[c]	9.40[c]
2015/16	N/A	N/A	6,290,000	Conf. [d]	Conf. [d]	12.53[c]	9.40[c]
2016/17	N/A	N/A	5,545,000			12,542,830	9,407,122

a. Total allowable catch.
b. Includes retained catch towards cost-recovery fisheries.
c. Established in millions of lb.
d. Confidential under Sec. 16.05.815 (SOA statute). TAC not attained.

Basis for the OFL and ABC: See table below; 2016/17 values are the author's recommended values.

Year	Tier	Years to define Average catch (OFL)	Natural Mortality[a]	Buffer
2012/13	5	1985/86–1995/96[b]	0.18	10%
2013/14	5	1985/86–1995/96[b]	0.18	10%
2014/15	5	1985/86–1995/96[b]	0.18	25%
2015/16	5	1985/86–1995/96[b]	0.18	25%
2016/17	5	1985/86–1995/96[b]	0.18	25%

a. Assumed value for FMP king crab in NPFMC (2007b); does not enter into OFL estimation for Tier 5 stock.
b. OFL was for total catch as was computed as the average of the retained catch for these years times an estimated average annual value of (bycatch mortality in crab fisheries)/(retained catch) plus an estimated average annual bycatch mortality in groundfish fisheries.

6. **PDF of the OFL:** Sampling distribution of the recommended (status quo Alternative 1) Tier 5 OFL was estimated by bootstrapping (see section G.1). The standard deviation of the estimated sampling distribution of the recommended OFL is 537 t (CV = 0.09). Note that generated sampling distribution and computed standard deviation are meaningful as measures in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Sections E.2 and E.4.f).

7. **Basis for the ABC recommendation:** A 25% buffer on the OFL; i.e., ABC = (1.0-0.25)·OFL.

8. **A summary of the results of any rebuilding analyses:** Not applicable; stock is not under a rebuilding plan.

A. Summary of Major Changes

1. **Changes to the management of the fishery:**
   - In March 2014, the BOF changed the 9-month season opening date from 15 August to 1 August; that change became effective in 2015/16.

- In 2014, the State of Alaska (SOA) legislature increased the allocation that ADF&G may receive annually from the harvest and sale of Aleutian Islands golden king crab from $300,000 for funding of observer coverage in the fishery to $500,000, with the additional $200,000 for funding red king crab surveys and research in the Aleutian Islands. Harvest towards the increased cost-recovery goal was initiated in 2015/16. Retained catch from that cost-recovery fishing is not counted towards attainment of the annually-established TAC.

2. **<u>Changes to the input data</u>:**
   - Commercial fishery data (weight of retained catch, number of retained crab, and number of pot lifts) that have been used in previous assessments were updated with values from the most recent ADF&G Area Management Report (Baechler and Cook 2014) and more recent fish ticket data. Fishery data has been updated with the catches during 2015/16: retained catch for the directed fishery and discarded catch estimates for the directed fishery, non-directed crab fisheries, and groundfish fisheries. Data from 2015/16 does not enter as input into computation of the recommended 2016/17 OFL.

3. **<u>Changes to the assessment methodology</u>:** None: the computation of OFL in this assessment follows the methodology recommended by the CPT in May 2012 and the SSC in June 2012.

4. **<u>Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL</u>:** None: the computation of OFL in this assessment follows the methodology recommended by the CPT in May 2012 and the SSC in June 2012 applied to the same data and estimates with the same assumptions that were used for estimating the 2012/13–2016/17 OFLs.

B. Responses to SSC and CPT Comments

1. **<u>Responses to the most recent two sets of SSC and CPT comments on assessments in general (and relevant to this assessment)</u>:**
   - <u>CPT, May 2015</u>: *None pertaining to a Tier 5 assessment*.
   - <u>SSC, June 2015</u>: "*The SSC appreciates the author's inclusion of standard and metric units in the text but requests consistency in which units are used (e.g., lbs., thousand lbs., or million lbs. and t, mt, or kg). The SSC also requests consistency in the units chosen for tables and figures, requests that the units cited in the table legends match the values in the tables, and suggests authors refer to the terms of reference for chapters.*"
     - <u>Response</u>: The CPT terms of reference (as updated during the January 2016 meeting) were referred to:
     - "*To maintain consistency among SAFEs, the documents should report everything in the document in metric tons. The executive summary and the data used in the harvest strategy should be presented in both metric tons (abbreviated t) and pounds (lb).*" Weight-related numbers were reported in metric tons. Weights are given in both t and lb for the following: weights in the text of the <u>Management performance</u> section of the Executive

Summary; weights in the Management Performance table; retained catch weights in the Executive Summary; GHLs/TACs throughout the document; retained catch weights when presented relative to GHLs/TACs throughout the document; retained catch weights in section C.4 ("Brief summary of management history); and the results of computation of the recommended 2016/17 OFL and ABC. Otherwise weights are presented only in t. For consistency in units, weights in the text and in reporting of recommended OFL and ABC are given in whole t for metric units and whole lb for U.S. customary units; in tables of data and estimates, however, some metric weights in are given to several decimal places because some non-zero values round to 0 t. Reporting OFL and ABC for 2016/17 in t and lb may result in inconsistencies in the Management Performance tables and in the text when presenting previous OFLs and ABCs established using different conventions for units.

- *"Provide single plot of all model data sources and years applicable – **Comment [4]: The Stockhausen tables**."* Done. See Table 5.

- CPT, September 2015 (via September 2015 SAFE Introduction chapter): *None pertaining to a Tier 5 assessment*.
- SSC, October 2015: *None pertaining to a Tier 5 assessment*.

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

- CPT, May 2015 (May 2015 CPT minutes):
  - *"The CPT recommended that the author plot CPUE over time by area rather than by both areas combined so that these trends can be tracked in the Tier 5 assessment."*
    - Response: Done. See Table 1c and Figure 6.
- SSC, June 2015 (June 2015 SSC minutes):
  - *"The SSC also endorses this recommendation" (i.e, of the CPT recommendation of, "splitting the CPUE trend data into areas east and west of 174 degrees west, so that trends in CPUE can be tracked in the Tier 5 assessment.")*
    - Response: Done. See Table 1c and Figure 6.
- CPT, September 2015 (via Sept 2014 SAFE): *None.*
- SSC, October 2015: *None*.

C. Introduction

1. **Scientific name:** *Lithodes aequispinus* J. E. Benedict, 1895

2. **Description of general distribution:**

General distribution of golden king crab is summarized by NMFS (2004):

> Golden king crab, also called brown king crab, range from Japan to British Columbia. In the BSAI [Bering Sea and Aleutian Islands], golden king crab are found at depths from 200 m to 1,000 m, generally in high-relief habitat such as inter-island passes.

> Golden, or brown, king crab occur from the Japan Sea to the northern Bering Sea (ca. 61° N latitude), around the Aleutian Islands, on various sea mounts, and as far south as northern British Columbia (Alice Arm) (Jewett et al. 1985). They are typically found on the continental slope at depths of 300–1,000 m on extremely rough bottom. They are frequently found on coral bottom.

The Aleutian Islands king crab stock boundary is defined by the boundaries of the Aleutian Islands king crab Registration Area O (Figure 1). In this chapter, “Aleutian Islands Area” means the area described by the current definition of Aleutian Islands king crab Registration Area O. Baechler and Cook (2014, page 7) define the boundaries of Aleutian Islands king crab Registration Area O:

> The Aleutian Islands king crab Registration Area O has as its eastern boundary the longitude of Scotch Cap Light (164° 44' W long.), its northern boundary a line from Cape Sarichef (54° 36' N latitude) to 171° W long., north to 55° 30' N lat., and as its western boundary the Maritime Boundary Agreement Line as that line is described in the text of and depicted in the annex to the Maritime Boundary Agreement between the United States and the Union of Soviet Socialist Republics signed in Washington, June 1, 1990. Area O encompasses both the waters of the Territorial Sea (0–3 nautical miles) and waters of the Exclusive Economic Zone (3–200 nautical miles).

During 1984/85–1995/96, the Aleutian Islands king crab populations had been managed using the Adak and Dutch Harbor Registration Areas, which were divided at 171° W longitude (Figure 2), but from the 1996/97 season to present the fishery has been managed using a division at 174° W longitude (Figure 1; Baechler and Cook 2014). In March 1996 the Alaska Board of Fisheries (BOF) replaced the Adak and Dutch Harbor areas with the newly created Aleutian Islands Registration Area O and directed the Alaska Department of Fish and Game (ADF&G) to manage the golden king crab fishery in the areas east and west of 174° W longitude as two distinct stocks. That re-designation of management areas was intended to more accurately reflect golden king crab stock distribution, coherent with the longitudinal pattern in fishery production prior to 1996/97 (Figure 3). The longitudinal pattern in fishery production relative to 174° W longitude since 1996/97 is similar to that observed prior to the change in management area definition, although there have been some changes in the longitudinal pattern in fishery production within the areas east and west of 174° W longitude (Figure 4).

Commercial fishing for golden king crab in the Aleutian Islands Area typically occurs at depths of 100–275 fathoms (183–503 m). Pots sampled by at-sea fishery observers in 2013/14 were fished at an average depth of 176 fathoms (322 m; N=499) in the area east of 174° W longitude and 158 fathoms (289 m; N=1,223) for the area west of 174° W longitude (Gaeuman 2014).

3. **<u>Evidence of stock structure</u>:**

Given the expansiveness of the Aleutian Islands Area and the existence of deep (>1,000 m) canyons between some islands, at least some weak structuring of the stock within the area would be expected. Data for making inferences on stock structure of golden king crab within the

Aleutian Islands are largely limited to the geographic distribution of commercial fishery catch and effort. Catch data by statistical area from fish tickets and catch data by location from pots sampled by observers suggest that habitat for legal-sized males may be continuous throughout the waters adjacent to the islands in the Aleutian chain. However, regions of low fishery catch suggest that availability of suitable habitat, in which golden king crab are present at only low densities, may vary longitudinally. Catch has been low in the fishery in the area between 174° W longitude and 176° W longitude (the Adak Island area, Figures 3 and 4) in comparison to adjacent areas, a pattern that is consistent with low CPUE for golden king crab between 174° W longitude and 176° W longitude (Figure 5) during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys (von Szalay et al. 2011). In addition to longitudinal variation in density, there is also a gap in fishery catch and effort between the Petrel Bank-Petrel Spur area and the Bowers Bank area; both of those areas, which are separated by Bowers Canyon, have reported effort and catch. Recoveries during commercial fisheries of golden king crab tagged during ADF&G surveys (Blau and Pengilly 1994; Blau et al. 1998; Watson and Gish 2002; Watson 2004, 2007) provided no evidence of substantial movements by crab in the size classes that were tagged (males and females ≥90-mm carapace length [CL]). Maximum straight-line distance between release and recovery location of 90 golden king crab released prior to the 1991/92 fishery and recovered through the 1992/93 fishery was 61.2 km (Blau and Pengilly 1994). Of the 4,567 recoveries reported through 12 April 2016 for the male and female golden king crab tagged and released between 170.5° W longitude and 171.5° W longitude during the 1991, 1997, 2000, 2003, and 2006 ADF&G Aleutian Island golden king pot surveys, none of the 3,807 with recovery locations specified by latitude and longitude were recovered west of 173° W longitude and only fifteen were recovered west of 172° W longitude (V. Vanek, ADF&G, Kodiak, pers. comm.). Similarly, of 139 recoveries in which only the statistical area of recovery was reported, none were recovered in statistical areas west of 173° W longitude and only one was in a statistical area west of 172° W longitude.

4. <u>Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology)</u>:

The following review of molt timing and reproductive cycle of golden king crab is adapted from Watson et al. (2002):

> Unlike red king crab, golden king crab may have an asynchronous molting cycle (McBride et al. 1982; Otto and Cummiskey 1985; Sloan 1985; Blau and Pengilly 1994). In a sample of male golden king crab 95–155-mm CL and female golden king crab 104–157-mm CL collected from Prince William Sound and held in seawater tanks, Paul and Paul (2000) observed molting in every month of the year, although the highest frequency of molting occurred during May–October. Watson et al. (2002) estimated that only 50% of 139-mm CL male golden king crab in the eastern Aleutian Islands molt annually and that the intermolt period for males ≥150-mm CL averages >1 year.
>
> Female lithodids molt before copulation and egg extrusion (Nyblade 1987). From their observations on embryo development in golden king crab, Otto and Cummiskey (1985) suggested that time between successive ovipositions was roughly twice that of embryo development and that spawning and molting of

mature females occurs approximately every two years. Sloan (1985) also suggested a reproductive cycle >1 year with a protracted barren phase for female golden king crab. Data from tagging studies on female golden king crab in the Aleutian Islands are generally consistent with a molt period for mature females of 2 years or less and that females carry embryos for less than two years with a prolonged period in which they remain in barren condition (Watson et al 2002). From laboratory studies of golden king crab collected from Prince William Sound, Paul and Paul (2001) estimated a 20-month reproductive cycle with a 12-month clutch brooding period.

Numerous observations on clutch and embryo condition of mature female golden king crab captured during surveys have been consistent with asynchronous, aseasonal reproduction (Otto and Cummiskey 1985; Hiramoto 1985; Sloan 1985; Somerton and Otto 1986; Blau and Pengilly 1994; Blau et al. 1998; Watson et al. 2002). Based on data from Japan (Hiramoto and Sato 1970), McBride et al. (1982) suggested that spawning of golden king crab in the Bering Sea and Aleutian Islands occurs predominately during the summer and fall.

The success of asynchronous and aseasonal spawning of golden king crab may be facilitated by fully lecithotrophic larval development (i.e., the larvae can develop successfully to juvenile crab without eating; Shirley and Zhou 1997). Current knowledge of reproductive biology and maturity of male and female golden king crab is also reviewed by Webb (2014).

Note that asynchronous, aseasonal molting and the prolonged intermolt period (>1 year) of mature female and the larger male golden king crab likely makes precise scoring of shell condition very difficult. That difficulty obscures potential relationships between shell condition and time-elapsed since molting and pose problems for inclusion of shell condition data into assessment models.

5. <u>Brief summary of management history</u>:
A complete summary of the management history through 2011/12 is provided in Baechler and Cook (2014, pages 13–19). The first commercial landing of golden king crab in the Aleutian Islands was in 1975/76, but directed fishing did not occur until 1981/82. Peak retained catch occurred in 1986/87 at 6,696 t (14,762,494 lb; Tables 1a and 1b). From 1981/82 to 1995/96 the fishery was managed as two separate fisheries in two separate registration areas, the Adak and Dutch Harbor areas, with the two areas divided at 172° W longitude through 1983/84 and divided at 171° W longitude after 1983/84. Prior to the 1996/97 season no formal preseason harvest target or limit was established for the fishery and average annual retained catch during 1981/82 – 1995/96 was 3,816 t (8,412,587 lb).

The Aleutian Islands golden king crab fishery was restructured beginning in 1996/97 to replace the Adak and Dutch Harbor areas with the newly created Aleutian Islands Registration Area O and golden king crab in the areas east and west of 174° W longitude were managed separately as two stocks. Table 1c and Figure 6 summarize trends in retained catch and CPUE (retained crab per pot lift) for the areas east and west of 174° W longitude. The fisheries in 1996/97–1997/98 were managed under a 2,676 t (5,900,000 lb) guideline harvest level (GHL; Tables 1a and 1b), with 1,452 t (3,200,000 lb) apportioned to the area east of 174° W longitude and 1,225 t (2,700,000 lb) apportioned to the area west of 174° W longitude. During 1998/99–2004/05 the fisheries were managed under a 2,585 t (5,700,000 lb) GHL, with 1,361 t (3,000,000 lb) apportioned to the area east of 174° W longitude and 1,225 t (2,700,000 lb) apportioned to the area west of 174° W longitude. During 2005/06–2007/08 the fisheries were managed under a 2,585 t (5,700,000 lb) total allowable catch (TAC), with a TAC of 1,361 t (3,000,000 lb) for the area east of 174° W longitude and a TAC of 1,225 t (2,700,000 lb) for the area west of 174° W longitude. By state regulation (**5 AAC 34.612**), TAC for the Aleutian Islands golden king crab fishery during 2008/09–2011/12 was 2,715 t (5,985,000 lb), with a TAC of 1,429 t (3,150,000 lb) for the area east of 174° W longitude and a TAC of 1,286 t (2,835,000 lb) for the area west of 174° W longitude. In March 2012 the BOF changed **5 AAC 34.612** so that the TAC beginning in 2012/13 would be 2,853 t (6,290,000 lb), with a TAC of 1,501 t (3,310,000 lb) for the area east of 174° W longitude and a TAC of 1,352 t (2,980,000 lb) for the area west of 174° W longitude. Additionally, the BOF added a provision to **5 AAC 34.612** that allows ADF&G to lower the TAC below the specified level if conservation concerns arise. The TAC for 2016/17 was reduced to 2,515 t (5,545,000 lb), with the TAC of 1,501 t (3,310,000 lb) remaining the same for the area east of 174° W longitude but a 25% reduction on the TAC for the area west of 174° W longitude to 1,014 t (2,235,000 lb). During 1996/97–2015/16 the annual retained catch during commercial fishing (including cost-recovery fishing that occurred during 2013/14–2015/16) has averaged 2% below the annual GHL/TACs. During 1996/97–2015/16, the retained catch has been as much as 13% below (1998/99) and as much as 6% above (2000/01) the GHL/TAC. Fishery CPUE (retained crab per pot lift) declined from 12 in 1985/86 to 5 in 1994/95, increased from 5 to 14 during 1995/96–2004/05, and increased to 23 in 2005/06 (Tables 1a and 1b, Figure 6). During 2006/07–2015/16 fishery CPUE has ranged from 22 to 29. Trends in fishery CPUE within the areas east of 174° W longitude and west of 174° longitude generally paralleled each other during 1985/86–2010/11, but diverged during 2011/12–2014/15 (an increasing trend in the area east of 174° W longitude and a decreasing trend in the area west of 174° W longitude; Table 1c, Figure 6).

A summary of other relevant SOA fishery regulations and management actions pertaining to the Aleutian Islands golden king crab fishery is provided below.

Beginning in 2005/06 the Aleutian Islands golden king crab fishery has been prosecuted under the Crab Rationalization Program. Accompanying the implementation of the Crab Rationalization program was implementation of a community development quota (CDQ) fishery for golden king crab in the eastern Aleutians (i.e., east of 174° W longitude) and the Adak Community Allocation (ACA) fishery for golden king crab in the western Aleutians (i.e., west of 174° W longitude; Hartill 2012). The CDQ fishery in the eastern Aleutians is allocated 10% of the golden king crab TAC for the area east of 174° W longitude and the ACA fishery in the western Aleutians is allocated 10% of the golden king crab TAC for the area west of 174° W longitude. The CDQ fishery and the ACA fishery are managed by ADF&G and prosecuted concurrently with the IFQ fishery.

Only males of a minimum size may be retained by the commercial golden king crab fishery in the Aleutian Islands Area. By SOA regulation (**5 AAC 34.620 (b)**), the minimum legal size limit is 6.0-inches (152 mm) carapace width (CW), including spines. A carapace length (CL) ≥136 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007b). Note that size limit for golden king crab has been 6-inches (165 mm) CW for the entire Aleutian Islands Area since the 1985/86 season. Prior to the 1985/86 season, the legal size limit was 6.5-inches for at least one of the now-defunct Adak or Dutch Harbor Registration Areas.

Golden king crab may be commercially fished only with king crab pots (defined in **5 AAC 34.050**). Pots used to fish for golden king crab in the Aleutian Islands Area must be operated from a shellfish longline and, since 1996, must have at least four escape rings of five and one-half inches minimum inside diameter installed on the vertical plane or at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized golden king crab (**5 AAC 34.625 (b)**). Prior to the regulation requiring an escape mechanism on pots, some participants in the Aleutian Islands golden king crab fishery voluntarily sewed escape rings (typically 139 mm or 5.5 inches) into their gear or, more rarely, included panels with escape mesh (Beers 1992). With regard to the gear used since the establishment of **5 AAC 34.625 (b)** in 1996, Linda Kozak, a representative of the industry, reported in a 19 September 2008 email to the Crab Plan Team that, "… the golden king crab fleet has modified their gear to allow for small crab sorting," and provided a written statement from Lance Nylander, of Dungeness Gear Works in Seattle, who "believes he makes all the gear for the golden king crab harvesting fleet," saying that, "Since 1999, DGW has installed 9[-inch] escape web on the door of over 95% of Golden Crab pot orders we manufactured." A study to estimate the contact-selection curve for male golden king crab that was conducted aboard one vessel commercial fishing for golden king crab during the 2012/13 season showed that gear and fishing practices used by that vessel was highly effective in reducing bycatch of sublegal-sized males and females (Vanek et al. 2013). In March 2011 (effective for 2011/12), the BOF amended **5 AAC 34.625 (b)** to relax the "biotwine" specification for pots used in the Aleutian Islands golden king crab fishery relative to the requirement in **5 AAC 39.145** that "(1) a sidewall ...of all shellfish and bottomfish pots must contain an opening equal to or exceeding 18 inches in length... The opening must be laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 30 thread." Regulation **5 AAC 34.625 (b)(1)** allows the opening described in **5 AAC 39.145 (1)** to be "laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 60 [rather than 30] thread."

Regulation (**5 AAC 34.610 (b)**) sets the commercial fishing season for golden king crab in the Aleutian Islands Area as 1 August through 30 April. That regulatory fishing season became effective in 2015/16 (the commercial fishing season was set in regulation as 15 August through 15 May during 2005/06–2014/15).

Current regulations (**5 AAC 39.645 (d)(4)(A)**) stipulate that onboard observers are required on catcher vessels during the time that at least 50% of the retained catch is captured in each of the three trimesters of the 9-month fishing season. Onboard observers are required on catcher-processors at all times during the fishing season.

6. <u>Brief description of the annual ADF&G harvest strategy</u>:

The annual TAC is set by state regulation, **5 AAC 34.612 (Harvest Levels for Golden King Crab in Registration Area O),** as approved by the BOF in March 2012:

(a) Until the Aleutian Islands golden king crab stock assessment model and a state regulatory harvest strategy are established, the harvest levels for the Registration Area O golden king crab fishery are as follows:

(1) east of 174° W long.: 3.31 million pounds; and
(2) west of 174° W long.: 2.98 million pounds;

(b) The department may reduce the harvest levels based on the best scientific information available and considering the reliability of estimates and performance measures, sources of uncertainty as necessary to avoid overfishing, and any other factors necessary to be consistent with sustained yield principles.

In addition to the retained catch that is limited by the TAC established by ADF&G under **5 AAC 34.612**, ADF&G also has authority to annually receive receipts of $500,000 through cost-recovery fishing on Aleutian Islands golden king crab. The retained catch from that cost-recovery fishing is not counted against attainment of the annually-established TAC.

7. **Summary of the history of B_{MSY}:** Not applicable for this Tier 5 stock.

D. Data

1. **Summary of new information:**
   - Commercial fishery data (weight of retained catch, number of harvested crab, and number of pot lifts) that have been used in previous assessments were updated with values from the most recent ADF&G Area Management Report (Baechler and Cook 2014) and more recent fish ticket data.
   - Fishery data on retained catch and discarded catch during crab fisheries in 2015/16 have been added.
   - Data on discarded catch during groundfish fisheries in reporting areas 541, 542, and 543 (Figure 7) have been updated with data grouped by “fixed” (hook-and-line and pot) and “trawl” (non-pelagic trawl) in 2015/16 have been added.
   - Estimates of total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) in 2015/16 have been added.

2. **Data presented as time series:**

a. ***Total catch*** ***and b.*** ***Information on bycatch and discards:***
   - Fish ticket data on retained catch weight, catch numbers, pot lifts, CPUE, and average weight of retained catch for 1981/82–2015/16 (Tables 1a–1c).
   - Statistics from all available data on discarded catch of Aleutian Islands golden king crab obtained from pot lifts sampled by at-sea observers during the directed and non-directed crab fisheries are presented for 1990/91–1992/93 and 1995/96–2015/16 (Table 2). Some observer data exists for the 1988/89–1989/90 seasons, but those data are not considered reliable. Although discarded catch can occur in the red king crab, scarlet king crab, grooved Tanner crab, and triangle Tanner crab fisheries of the Aleutian Islands, those

discards account for ≤2% of the estimated total discarded catch weight in the crab fisheries when those fisheries were prosecuted. Only one vessel was observed during the directed fishery throughout the 1993/94 season and only two vessels were observed throughout the 1994/95 season (an additional catcher vessel carried an observer for one trip during the 1993/94 season and an additional three catcher vessels carried an observer for one trip during the 1994/95 season, but observed effort was small relative to the total season effort for those vessels and the author does not consider the data from those vessels reliable). Hence data on discarded catch during the 1993/94 and 1994/95 directed fishery seasons are confidential. Observer data on size distributions and estimated catch numbers of discarded catch were used to estimate the weight of discarded catch of red king crab by applying a weight-at-length estimator (see below); data on the size distribution of discarded legal males was not recorded prior to 1998/99 and weights of retained legal males are used to estimate the weights of discarded legal males during the unobserved years.

- Data on discarded catch of golden king crab obtained by at-sea observers during groundfish fisheries in reporting areas 541, 542, and 543 (Figure 7) for 1993/94–2015/16 are presented (estimates for 1991/92–1992/93 are also presented, but they seem suspect; Table 3).
- Estimates of bycatch mortality in 1990/91–1992/93 and 1995/96–2015/16 directed and non-directed crab fisheries and 1993/94–2015/16 groundfish fisheries are presented in Table 4. Estimates of total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) in 1995/96–2015/16 are presented (Table 4). Following Siddeek et al. (2014), the bycatch mortality rate of king crab captured and discarded during Aleutian Islands king crab fisheries was assumed to be 0.2; that value was also applied as the bycatch mortality during other crab fisheries. Following Foy (2012a, 2012b), the bycatch mortality of king crab captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crab captured by trawls during groundfish fisheries was assumed to be 0.8.
- Table 5 summarizes the available data on retained catch weight and the available estimates of discarded catch weight.

c. ***Catch-at-length:*** Not used in a Tier 5 assessment; none are presented.

d. ***Survey biomass estimates:*** Not used in a Tier 5 assessment; none are presented.

e. ***Survey catch at length:*** Not used in a Tier 5 assessment; none are presented (see section D.4).

f. ***Other data time series:*** See section D.4 on other time-series data that are available, but not presented here.

3. Data which may be aggregated over time:

a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):

Not used in a Tier 5 assessment. Growth per molt and probability of molt estimates are not used in a Tier 5 assessment. However, growth per molt and probability of molt have been estimated for Aleutian Islands golden king crab by Watson et al. (2002) using data from male and female golden king crab that were tagged and released during July–August 1997 in the area east of 174° W longitude and recovered during the 1997/98–2000/01 commercial fisheries (see Tables 24–28 *in* Pengilly 2009).

Watson et al. (2002) used logistic regression to estimate the probability as a function of carapace length (CL, mm) at release that a male tagged and released in new-shell condition would molt within 12–15 months after release:

$$P(\text{molt}) = \exp(17.930 - 0.129 * CL)/[1 + \exp(17.930 - 0.129 * CL)].$$

Based on the above logistic regression, Watson et al. (2002) estimated that the size at which 50% of new-shell males would be expected to molt within 12–15 months is 139-mm CL (S.E. = 0.81-mm CL).

Watson et al. (2002) used logistic regression to estimate the probability as a function of carapace length (CL, mm) at release that a male tagged and released as a sublegal ≥ 90-mm CL in new-shell condition would molt to legal size within 12–15 months after release:

$$P(\text{molt to legal size}) = 1 - \exp(15.541 - 0.127 * CL)/[1 + \exp(15.541 - 0.127 * CL)].$$

Based on the above logistic regression, Watson et al. (2002) estimated that the size at which 50% of sublegal ≥90-mm CL, new-shell males would be expected to molt to legal size within 12–15 months is 123-mm CL (S.E. = 1.54-mm CL).

See section C.4 for discussion of evidence that mature female and the larger male golden king crab exhibit asynchronous, aseasonal molting and a prolonged intermolt period (>1 year).

b. Weight-at length or weight-at-age (by sex):

Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female golden king crab according to the equation, Weight = $A*CL^B$ (from Table 3-5 in NPFMC 2007b) are: A = 0.0002988 and B = 3.135 for males and A = 0.001424 and B = 2.781 for females.

c. Natural mortality rate:

Not used in a Tier 5 assessment. The default natural mortality rate assumed for king crab species by NPFMC (2007b) is M=0.18.

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

Data from triennial ADF&G pot surveys for Aleutian Islands golden king crab in a limited area east of 174° W longitude (between 170° 21’ and 171° 33’ W longitude) that were performed during 1997 (Blau et al. 1998), 2000 (Watson and Gish 2002), 2003 (Watson 2004), and 2006 (Watson 2007) are available, but were not used in this Tier 5 assessment.

E. Analytic Approach

1. History of modeling approaches for this stock: This is a Tier 5 assessment.

2. Model Description: *Subsections a–i are not applicable to a Tier 5 assessment.*
It was recommended by NPFMC (2007b) that the Aleutian Islands golden king crab stock be managed as a Tier 5 stock until an assessment model is accepted for use in management. In 2015 the SSC recommended that this stock continue to be managed under Tier 5 in 2015/16 (June 2015 SSC minutes). Separate from this Tier 5 assessment, an Aleutian Islands golden king crab assessment model will be reviewed for use in Tier 4 management of this stock by the Crab Plan Team in May 2016.

For Tier 5 stocks only an OFL is estimated, because it is not possible to estimate MSST without an estimate of biomass, and "the OFL represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock" (NPFMC 2007b). Additionally, NPFMC (2007b) states that for estimating the OFL of Tier 5 stocks, "The time period selected for computing the average catch, hence the OFL, should be based on the best scientific information available and provide the required risk aversion for stock conservation and utilization goals." Although NPFMC (2007b) defined the OFL in terms of the retained catch, total-catch OFLs may be considered for Tier 5 stocks for which nontarget fishery removal data are available (Federal Register/Vol. 73, No. 116, 33926). The CPT (in May 2010) and the SSC (in June 2010) endorsed the use of a total-catch OFL to establish the 2010/11 and subsequent OFLs for this stock. This assessment recommends – and only considers – use of a total-catch Tier 5 OFL for 2016/17.

For estimating the OFL of Tier 5 stocks, NPFMC (2007b) states, "The time period selected for computing the average catch, hence the OFL, should be based on the best scientific information available and provide the required risk aversion for stock conservation and utilization goals." Prior to 2008, two time periods were considered for computing the average retained catch for Aleutian Islands golden king crab: 1985–2005 (NPFMC 2007a) and 1985–1999 (NPFMC 2007b). The average retained catch over the years 1985 to 1999 was recommended by NPFMC (2007b) for the estimated OFL for Aleutian Islands golden king crab. Years post-1984 were chosen based on an assumed 8-year lag between hatching during the 1976/77 "regime shift" and growth to legal size. With regard to excluding data from years after 1999, NPFMC (2007b) states, "Years from 2000 to 2005 were excluded for Aleutian Islands golden king crab when the TAC was set below the previous average catch." Note, however, that there was no TAC or GHL established for the entire Aleutian Islands Area prior to the 1996/97 season (see above). Pengilly (2008) discussed nine periods, with durations as long as 26 years (1981/82–2006/07) to as short as six years (1990/91–1995/96), for computing average annual retained catch and estimating the OFL for the 2008/09 season. Only periods beginning no earlier than 1985/86 were recommended for consideration, however, due to the size limit change that occurred prior to the 1985/86 season (Tables 1a and 1b, footnotes d–f). The Crab Plan Team in May 2008 recommended using the period 1990/91–1995/96 for computing the 2008/09 OFL. The CPT recommended the period 1990/91–1995/96 due to concerns raised by a decline in retained catch and CPUE that occurred from 1985/86 into the mid-1990s, the seasons of unconstrained catch under the current size limit. The SSC recommended using the period 1985/86–1995/96 for computing the 2008/09 OFL, however, because the period 1985/86–1995/96 is the longest possible period of unconstrained catch under the current size limit ("Earlier years were not recommended for inclusion because of a difference in the size limit regulations prior to 1985/86." Minutes of the NPFMC SSC meeting, 2–4 June 2008)**.** Pengilly (2009) discussed only three time periods to consider for setting the 2009/10 OFL: 1985/86–1995/96, the period recommended by the SSC for the 2008/09 OFL; 1990/91–1995/96, the period recommended by the CPT for the 2008/09 OFL; and 1987/88–1995/96. The period 1987/88–1995/96 was offered as a compromise between the desire for the longest period possible under the current size limit for averaging catch and the desire for a period reflecting long-term production potential of the stock (the years excluded from the period, 1985/86–1986/87, were the years with the highest retained catch in the history of the fishery and there were trends of declining catch, declining CPUE, and declining average weight of landed crab that occurred from 1985/86 into the mid-1990s). Of those, the CPT at the May 2009 again recommended using the period 1990/91–1995/96 for computing the 2009/10 OFL, whereas the SSC again recommended 1985/86–1995/96, noting that "the management system was relatively constant from 1985 onward" and that a "longer time period likely provides a more robust estimate than a shorter time period." (Minutes of the NPFMC SSC meeting, 1–3 June 2009).

Three alternatives were considered for setting a total-catch OFL for 2010/11 (see the Executive Summary of the May Draft of the 2010 Crab SAFE), none of which could be chosen with consensus by the CPT in May 2010 and all of which were rejected by the SSC in June 2010. In June 2010 the SSC recommended an approach to computing a total-catch OFL for this stock for 2010/11 as follows (Minutes of the NPFMC SSC meeting, 7–9 June 2010):

$$OFL_{2010/11} = (1+R_{96/97\text{-}08/09})\bullet RET_{85/86\text{-}95/96} + BM_{GF,96/97\text{-}08/09},$$

where

- $R_{96/97\text{-}08/09}$ is the average of the estimated annual ratios of bycatch mortality due to crab fisheries to retained catch in the directed fishery during 1996/97–2008/09,
- $RET_{85/86\text{-}95/96}$ is the average annual retained catch in the directed crab fishery during 1985/86-1995/96, and
- $BM_{GF,\ 96/97\text{-}08/09}$ is the average of the annual estimates of bycatch mortality due to groundfish fisheries during 1996/97–2008/09.

Additionally, the SSC in June 2010 recommended that "...this time period be frozen to stabilize the control rule."

Data on discarded catch during crab fisheries prior to 1996/97 were presented to the CPT in May 2011 and the CPT recommended the following OFL for the 2011/12 season, which was also recommended by the SSC in June 2011:

$$OFL_{2011/12} = (1+R_{90/91\text{-}08/09})\bullet RET_{85/86\text{-}95/96} + BM_{GF,93/94\text{-}08/09},$$

where,

- $R_{90/91\text{-}08/09}$ is the average of the estimated annual ratios of bycatch mortality due to crab fisheries to retained catch in the directed fishery during 1990/91–2008/09 (excluding 1993/94–1994/95, due to data confidentialities and insufficiencies)
- $RET_{85/86\text{-}95/96}$ is the same as defined for $OFL_{2010/11}$, above (i.e., the average annual retained catch in the directed crab fishery during 1985/86–1995/96), and
- $BM_{GF,93/94\text{-}08/09}$ is the same as defined for $OFL_{2010/11}$, above (i.e., the average of the annual estimates of bycatch mortality due to groundfish fisheries during 1993/94–2008/09).

Trends in the estimated annual ratios of bycatch mortality due to crab fisheries to retained catch in the directed fishery during 1990/91–2008/09 were presented to the CPT in May 2012 and SSC in June 2012. The SSC found that the estimated annual ratios of bycatch mortality due to crab fisheries to retained catch in the directed fishery prior to 1996/97 were a better reflection of bycatch mortality during 1985/86–1995/96 than the estimates from 1996/97–2008/09. Accordingly, the SSC (June 2012 SSC minutes) recommended that the OFL for the 2012/13 season be computed according to the "Alternative 1" approach as:

$$OFL_{2012/13} = (1+R_{90/91\text{-}95/96})\bullet RET_{85/86\text{-}95/96} + BM_{GF,93/94\text{-}08/09},$$

where,

- $R_{90/91\text{-}95/96}$ is the average of the estimated annual ratios of bycatch mortality due to crab fisheries to retained catch in the directed fishery during 1990/91–1995/96 (excluding 1993/94–1994/95, due to data confidentialities and insufficiencies),
- $RET_{85/86\text{-}95/96}$ is the same as defined for $OFL_{2010/11}$ and $OFL_{2011/12}$, above (i.e., the average annual retained catch in the directed crab fishery during 1985/86–1995/96), and
- $BM_{GF,93/94\text{-}08/09}$ is the same as defined for $OFL_{2010/11}$ and $OFL_{2011/12}$, above (i.e., the average of the annual estimates of bycatch mortality due to groundfish fisheries over the period 1993/94–2008/09).

The OFLs for 2013/14–2015/16 and the recommended OFL for 2016/17 were computed following the status quo, Alternative 1 approach as for $OFL_{2012/13}$, above.

3. Model Selection and Evaluation:

a. *Description of alternative model configurations*

The SSC has recommended that the "time period be frozen to stabilize the control rule" in determination of a Tier 5 OFL (see section 2, above). With regard to the Tier 5 OFL for the Aleutian Islands golden king crab stock, the SSC has recommended that computation of the OFL computation should use: 1) the period 1985/86–1995/96 to compute the average retained catch (June 2008, and 2009 SSC minutes); 2) the "time period [to compute the Tier 5 OFL] be frozen to stabilize the control rule" at 1985/86–2008/09 (June 2010 SSC minutes); and 3) that discarded catch data from crab fisheries from the period prior to 1996/97 be used to compute the Tier 5 OFL (June 2012 SSC minutes). Given those recommendations from the SSC and the lack of any additional fishery data from the period 1985/86–2008/09 that were not already available and presented during 2012–2015, only one alternative is presented, the author's recommended Alternative 1, which is the status quo (i.e., the same as the Tier 5 OFL for 2012/13–2015/16 that was established in 2012):

$$OFL_{2016/17} = (1+R_{90/91\text{-}95/96}) \bullet RET_{85/86\text{-}95/96} + BM_{GF,93/94\text{-}08/09},$$

where,

- $R_{90/91\text{-}95/96}$ is the average of the estimated annual ratios of bycatch mortality due to crab fisheries to retained catch in the directed fishery during the period 1990/91–1995/96 (excluding 1993/94–1994/95, due to data confidentialities and insufficiencies),
- $RET_{85/86\text{-}95/96}$ is the average annual retained catch in the directed crab fishery during the period 1985/86–1995/96, and
- $BM_{GF,93/94\text{-}08/09}$ is the average of the annual estimates of bycatch mortality due to groundfish fisheries over the period 1993/94–2008/09.

b. ***Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed:*** None; see section A.4.

c. ***Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models:*** None; see section A.4.

d. ***Convergence status and convergence criteria for the base-case model (or proposed base-case model):*** Not applicable.

e. ***Table (or plot) of the sample sizes assumed for the compositional data:*** Not applicable.

f. ***Do parameter estimates for all models make sense, are they credible?:***
The 1985/86–2008/09 time period and the time periods for fishery mortality subcomponents within 1985/86–2008/09 used for determining the OFL were established by the SSC during 2008–2012. The values for retained catch and estimated bycatch mortality used in the OFL computation are in Table 6. Temporal trends during 1985/86–2014/15 in retained catch and in the available estimates of bycatch mortality due to crab fisheries and groundfish fisheries are shown in Figure 8. Trends in the ratio of the estimated bycatch mortality due to crab fisheries to the retained catch are shown in Figures 9 and 10 for the years that data and estimates are available during 1985/86–2014/15. Retained catch data come from fish tickets and annual retained catch is considered a known (not estimated) value. Estimates of discarded catch from crab fishery observer data are generally considered credible (e.g., Byrne and Pengilly 1998; Gaeuman 2014). Estimates of bycatch mortality were derived as estimates of discarded catch weight times an assumed bycatch mortality rate. The assumed bycatch mortality rates (i.e., 0.2 for crab fisheries, 0.5 for fixed-gear groundfish fisheries, and 0.8 for trawl groundfish fisheries) have not been estimated from data.

g. ***Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty:*** See section E.3.c, above.

h. ***Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach):*** Not applicable.

i. ***Evaluation of the model, if only one model is presented; or evaluation of alternative models and selection of final model, if more than one model is presented:*** The model for computing the single, status quo Alternative 1 recommended OFL follows the SSC recommendations to freeze the time period to stabilize the control role by using only 1985/86–1995/96 to estimate the average annual retained catch component of the OFL (June 2008 and June 2009 SSC minutes), to not include discarded catch data after 2008/09 (June 2010 SSC minutes), and to use only the bycatch mortality estimates from the crab fisheries that are available from 1990/91–1995/96 (June 2012 SSC minutes). The author and the SSC (June 2012 SSC minutes) agree that the discarded catch data from crab fisheries during 1990/91–1995/96 are the most representative data available of the conditions that existed during 1985/86–1995/96: those years fall within the period 1985/86–1995/96; regulations stipulating escape mechanisms in pots became effective after 1995/96 (see section **C.5-Brief summary of management history**); and there is a clear decreasing trend in the estimated ratio of bycatch mortality due to crab fisheries to retained catch weight in the directed fishery since 1996/97 (Figures 9 and 10).

4. Results (best model(s)):

a. List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties: Not applicable to a Tier 5 assessment.

b. Tables of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible; include estimates from previous SAFEs for retrospective comparisons): See Tables 6–7.

c. Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible): Not applicable to a Tier 5 assessment.

d. Evaluation of the fit to the data: Not applicable to a Tier 5 assessment.

e. Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments): Not applicable to a Tier 5 assessment.

f. Uncertainty and sensitivity analyses (this section should highlight unresolved problems and major uncertainties, along with any special issues that complicate scientific assessment, including questions about the best model, etc.): For a Tier 5 assessment, the major uncertainties are:

- Whether the chosen time period is "representative of the production potential of the stock" and if it serves to "provide the required risk aversion for stock conservation and utilization goals" or whether any such time period exists.

- The Tier 5 OFL for this stock is highly sensitive to the choice of years used to compute the average annual catch. The table on page 19 of Pengilly (2008) addressed the justifications for alternative choices of time periods that could be used to compute the retained-catch OFL. Interested readers are directed to that document. Briefly, however, the average retained-catch for the nine alternative time periods presented by Pengilly (2008) range from 2,555 t for 1996/97–2006/07 to 4,166 t for 1985/86–1995/96. The CPT in 2008 and 2009 recommended that the average retained catch during 1990/91–1995/96 (3,145 t) be used to compute the retained-catch OFL. In both 2008 and 2009, the SSC overrode the CPT's recommendation and selected the years 1985/86–1995/96 to compute the retained-catch OFL. The SSC recommended in 2009 that the time period for computing the retained-catch portion of the OFL "be frozen" at 1985/86–1995/96 "to stabilize the control rule."
- The Tier 5 OFL is also sensitive to the choice of years used to estimate the average annual ratio of bycatch mortality in the crab fisheries to retained catch. The SSC has recommended that the time period for computing the bycatch-mortality portion of the OFL be restricted to pre-2008/09. Within the pre-2008/09 period, estimates of annual bycatch mortality in crab fisheries to retained catch are generally highest during 1990/91–1995/96 and show a decreasing trend during 1996/97–2008/09: the ratios are 0.3–0.4 during 1990/91–1995/96, 0.2–0.3 during 1996/97–2004/05, and 0.1 during 2005/06–2014/15 (Figures 9 and 10). Hence including the later years to compute the average annual ratio decreases the OFL estimate, whereas restricting the period to 1990/91–1995/96 increases the OFL estimate.
- The Tier 5 OFL has only a slight sensitivity to the choice of years used to compute the bycatch mortality due to groundfish fisheries. This assessment only considers the period 1993/94–2008/09 for discarded catch in the groundfish fisheries. Estimates of annual bycatch mortality due to groundfish fisheries during 1993/94–2008/09 range from <1 t to 59 t. Because the estimate of weight of discarded catch due to groundfish fisheries is small relative to the weight of retained catch (≥2,242 t annually since 1985/86), the effect of choice of years here is negligibly small.

- The bycatch mortality rates used in estimation of total fishery mortality are assumed values. Bycatch mortality is unknown and no data that could be used to estimate the bycatch mortality of this stock is known to the author. After discussion on information presented on the apparent "hardiness" of golden king relative to red king crab at the May 2013 meeting, the CPT concluded that the handling mortality rate used in golden king crab assessments should remain at the status quo, 0.2, until data for estimating handling mortality are presented (May 2013 CPT minutes). Hence only the values that are assumed for other BSAI king crab stock assessments are considered in this assessment. Due to the difference in scale between the estimated discarded catch in crab fisheries and the groundfish fisheries (see bullet above), the estimated OFL is most sensitive to the assumed bycatch mortality rate in crab fisheries and less sensitive to the assumed bycatch mortality rate in groundfish fisheries. Given a fixed period of years to compute the average of annual discarded catch estimates for the crab fisheries, the estimated OFL is inversely related to the bycatch mortality rate assumed for the crab fisheries. If the assumed bycatch mortality rate is doubled from 0.2 to 0.4, the OFL estimate increases by a factor of 1.17 (1.4/1.2); if halved from 0.2 to 0.1, the assumed bycatch mortality rate, and the OFL estimate decreases by a factor of 0.92 (1.1/1.2).

- There has been no program to survey this stock in its entirety, and a program to survey a portion of this stock on a triennial basis ended after 2006 due to the costs of survey implementation. The CPT in September 2013 strongly recommended that, *"A survey is needed to provide a better index of abundance and information on recruitment for stock assessment"* and encouraged ADF&G, NMFS, and industry to discuss how to make such a survey happen. Such discussions occurred at meetings amongst ADF&G, NMFS, and the Aleutian King Crab Research Foundation (AKCRF) in January and March 2014. Follow-up meetings occurred between ADF&G and AKCRF where plans for a survey utilizing cooperating commercial fishing vessels was developed (see May 2014 CPT minutes for more details on the survey design that was developed). A cooperative golden king crab survey was performed by AKCRF and ADF&G during the eastern Aleutian Islands fishery in August 2015, by vessels that were simultaneously fishing. See the May 2015, September 2015, and May 2016 CPT minutes for updates from AKCRF and ADF&G on survey development, activities, and plans for the future.

F. Calculation of the OFL

1. <u>Specification of the Tier level and stock status level for computing the OFL:</u>

- Recommended as Tier 5, total-catch OFL computed as the estimated average annual total catch over a specified period.
- Recommended time period for computing retained-catch portion of the OFL: 1985/86–1995/96.
- Recommended time period for computing bycatch mortality due to crab fisheries: 1990/91–1995/96.
- Recommended time period for computing bycatch mortality due to groundfish fisheries: 1993/94–2008/09.
- Recommended bycatch mortality rates: 0.2 for crab fisheries; 0.5 for fixed-gear groundfish fisheries; 0.8 for trawl groundfish fisheries.
- Recommended OFL for 2016/17 is estimated by,

$$OFL_{2016/17} = (1+R_{90/91\text{-}95/96})\bullet RET_{85/86\text{-}95/96} + BM_{GF,93/94\text{-}08/09},$$

where,

- $R_{90/91\text{-}95/96}$ is the average of the estimated annual ratios of bycatch mortality due to crab fisheries to retained catch in the directed fishery during the period 1990/91–1995/96 (excluding 1993/94–1994/95, due to data confidentialities and insufficiencies),
- $RET_{85/86\text{-}95/96}$ is the average annual retained catch in the directed crab fishery during the period 1985/86–1995/96, and
- $BM_{GF,93/94\text{-}08/09}$ is the average of the annual estimates of bycatch mortality due to groundfish fisheries over the period 1993/94–2008/09.

Statistics on the data and estimates used to calculate, $RET_{(85/86\text{-}95/96}$, $R_{90/91\text{-}95/96}$, and $BM_{GF,93/94\text{-}08/09}$ are provided in Table 6; the column averages in Table 6 are the calculated values of

$RET_{(85/86\text{-}95/96}$, $R_{90/91\text{-}95/96}$, and $BM_{GF,93/94\text{-}08/09}$. Using those calculated values of $RET_{(85/86\text{-}95/96}$, $R_{90/91\text{-}95/96}$, and $BM_{GF,93/94\text{-}08/09}$, $OFL_{2015/16}$ is computed as,

$$OFL_{2016/17} = (1+0.363)\bullet(4{,}166 \text{ t}) + 10.6 \text{ t} = 5{,}689 \text{ t } (12{,}542{,}830 \text{ lb}).$$

2. **List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan:** Not applicable to Tier 5 assessment.

3. **Specification of the OFL:**

a. ***Provide the equations (from Amendment 24) on which the OFL is to be based:***

From **Federal Register** / Vol. 73, No. 116, page 33926, "For stocks in Tier 5, the overfishing level is specified in terms of an average catch value over an historical time period, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information." Additionally, "For stocks where nontarget fishery removal data are available, catch includes all fishery removals, including retained catch and discard losses. Discard losses will be determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the overfishing level is set for and compared to the retained catch" (FR/Vol. 73, No. 116, 33926). That compares with the specification of NPFMC (2007b) that the OFL "represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock."

b. ***Basis for projecting MMB to the time of mating:*** Not applicable to Tier 5 assessment.

c. ***Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring:*** See Management Performance tables, below. The OFL and ABC values for 2016/17 in the table below are the recommended values. The 2016/17 TAC has not yet been established. Complete catch data for 2015/16 are not presently available. The TACs for 2013/14–2015/16 in the table below do not include landings towards a cost-recovery fishery goal, but the catches towards cost-recovery fishing in 2013/14–2014/15 are included in the retained and total catch.

Management Performance Table (values in t)

Fishing Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch	Total Catch	OFL	ABC
2012/13	N/A	N/A	2,853	2,843	3,115	5.69[c]	5.12[c]
2013/14	N/A	N/A	2,853	2,894[b]	3,192	5.69[c]	5.12[c]
2014/15	N/A	N/A	2,853	2,771[b]	3,079	5.69[c]	4.26[c]
2015/16	N/A	N/A	2,853	Conf.[d]	Conf.[d]	5.69[c]	4.26[c]
2016/17	N/A	N/A	2,515			5,689	4,267

a. Total allowable catch, established in lb and converted to t.
b. Includes retained catch towards cost-recovery fisheries.
c. Established in thousands of t.
d. Confidential under Sec. 16.05.815 (SOA statute). TAC not attained.

Management Performance Table (values in lb)

Fishing Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch	Total Catch	OFL	ABC
2012/13	N/A	N/A	6,290,000	6,267,759	6,867,391	12.54[c]	11.28[c]
2013/14	N/A	N/A	6,290,000	6,379,553[b]	7,037,147	12.54[c]	11.28[c]
2014/15	N/A	N/A	6,290,000	6,108,674[b]	6,788,025	12.53[c]	9.40[c]
2015/16	N/A	N/A	6,290,000	Conf.[d]	Conf.[d]	12.53[c]	9.40[c]
2016/17	N/A	N/A	5,545,000			12,542,830	9,407,122

a. Total allowable catch.
b. Includes retained catch towards cost-recovery fisheries.
c. Established in millions of lb.
d. Confidential under Sec. 16.05.815 (SOA statute). TAC not attained.

4. **Specification of the retained-catch portion of the total-catch OFL:**
   a. Equation for recommended retained-portion of total-catch OFL:
   Retained-catch portion = average retained catch during 1985/86–1995/96
   = 4,166 t (9,185,232 lb).

5. **Recommended F_{OFL}, OFL total catch and the retained portion for the coming year:**
   See sections ***F.3*** and ***F.4***, above; no F_{OFL} is recommended for a Tier 5 assessment.

G. Calculation of ABC

1. PDF of OFL. Bootstrap estimate of the sampling distribution (assuming no error in estimation of discarded catch) of the recommended OFL is shown in Figure 11 (1,000 samples drawn with replacement independently from each of the three columns of values in Table 6 to calculate $R_{90/91-95/96}$, $RET_{85/86-95/96}$, $BM_{GF,93/94-08/09}$ and $OFL_{Alt-2,2010/11}$). The mean and CV computed from the 1,000 replicates are 5,675 t and 0.09, respectively. Note that generated sampling distribution and computed standard deviation are meaningful as measures in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Sections E.2 and E.4.f).

2. List of variables related to scientific uncertainty.

- The time period to compute the average catch relative to the assumption that this represents “a time period determined to be representative of the production potential of the stock.”
- Bycatch mortality rate in each fishery that discarded catch occurs. Note that for Tier 5 stocks, an increase in an assumed bycatch mortality rate will increase the total-catch OFL (and hence the ABC), but has no effect on the retained-catch portion of the OFL or the retained-catch portion of the ABC.
- Estimated discarded catch and bycatch mortality for each fishery that bycatch occurred in during 1985/86–1995/96.
- See **E.4.*f*** for details.

3. List of additional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.

5. Author recommended ABC.

$$(1.0\text{-}0.25)\cdot 5{,}689 \text{ t} = 4{,}267 \text{ t } (9{,}407{,}122 \text{ lb}).$$

The recommended ABC for 2016/17 was computed according to the status quo buffer of 0.25 recommended by the Crab Plan Team and SSC for 2014/15 – 2015/16. The 2014 SAFE, May 2014 CPT minutes, and June 2014 SSC minutes provide the reasoning for use of a buffer of 0.25, rather than a buffer of 0.1 as was used to compute the ABCs for 2011/12 – 2013/14.

H. Rebuilding Analyses

Not applicable; this stock has not been declared overfished.

I. Data Gaps and Research Priorities

Currently, there are no biomass estimates for this stock. A Tier 4 assessment based on fishery data has been in development to provide such estimates and will be reviewed again at the September 2016 CPT meeting. The CPT in September 2013 identified the need for development of a survey to provide fishery-independent data for estimation of stock abundance and recruitment. A cooperative golden king crab survey was performed by the Aleutian Islands King Crab Foundation (an industry group) and ADF&G during the eastern Aleutian Islands fishery in August 2015, by vessels that were simultaneously fishing. See the May 2015, September 2015, and May 2016 CPT minutes for further information on this survey and future planned cooperative surveys.

Bycatch mortality rate in directed fishery is unknown.

J. Literature Cited

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List of Tables.

Table 1a: page 28. Commercial fishery history for the Aleutian Islands golden king crab fishery 1981/82–2015/16: number of vessels, guideline harvest level (GHL; established in lb, **converted to t**) for 1981/82–2004/05, total allowable catch (TAC; established in lb, **converted to t**) for 2005/06–2015/16, weight of retained catch (Harvest; **t**), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (**kg**) of landed crab.

Table 1b: page 29. Commercial fishery history for the Aleutian Islands golden king crab fishery 1981/82–2015/16: number of vessels, guideline harvest level (GHL; **lb**) for 1981/82–2004/05, total allowable catch (TAC; **lb**) for 2005/06–2015/16, weight of retained catch (Harvest; **lb**), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (**lb**) of landed crab.

Table 1c: page 30. Commercial fishery history for the Aleutian Islands golden king crab fishery, 1985/86–2015/16, separately for the areas east and west of 174° W longitude: weight of retained catch (Harvest; **t**), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (**kg**) of landed crab.

Table 2: page 31. Retained catch (**t**) of Aleutian Islands golden king crab, with the estimated discarded catch (**t**; <u>not</u> discounted for an assumed bycatch mortality rate) and components of discarded catch during commercial crab fisheries, 1990/91–2015/16; observer data on discarded catch for 1993/94 and 1994/95 are confidential and considered to have poor reliability.

Table 3: page 32. Estimated annual weight (**t**) of discarded catch of golden king crab (all sizes, males and females) and bycatch mortality (**t**) during federal groundfish fisheries in federal reporting areas 541, 542, and 543 (see Figure 7) by gear type (fixed or trawl), 1991/92–2015/16; assumes bycatch mortality rate of 0.5 for fixed-gear fisheries and 0.8 for trawl fisheries.

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Table 6: page 35. Data for calculation of $RET_{85/86\text{-}95/96}$ (**t**) and estimates used in calculation of $R_{90/91\text{-}95/96}$ (ratio, t:t) and $BM_{GF,93/94\text{-}08/09}$ (**t**) for calculation of the recommended (status quo Alternative 1) Aleutian Islands golden king crab Tier 5 2016/17 OFL (**t**); values under $RET_{85/86\text{-}95/96}$ are from Table 1, values under $R_{90/91\text{-}95/96}$ were computed from the retained catch data and the crab bycatch mortality estimates in Table 4, and values under $BM_{GF,93/94\text{-}08/09}$ are from Table 4.

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Figure 3: page 37. Percent of total 1981/82–1995/96 golden king crab retained catch weight (harvest) from one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude used during the 1984/85–1995/96 seasons to divide fishery management between the Dutch Harbor Area (east of 171° W longitude) and the Adak Area (west of 171° W longitude) and solid line denoting the border at 174° W longitude used since the 1996/97 season to manage crab east and west of 174° W longitude (adapted from Figure 4-2 *in* Morrison et al. 1998).

Figure 4: page 37. Retained catch (**t**) of golden king crab within one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2014/15 commercial fishery seasons; solid line denotes the border at 174° W longitude that has been used since the 1996/97 season to manage Aleutian Island golden king crab as separate stocks east and west of 174° W longitude and dashed line denotes the border at 171° W longitude used during the 1984/85–1995/96 seasons to divide fishery management between the Dutch Harbor Area (east of 171° W longitude) and the Adak Area (west of 171° W longitude).

Figure 5: page 38. Average golden king crab CPUE (**kg**/nm^2) for tows, number of tows, and average depth of tows from one-degree longitude intervals during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys; preliminary summary of data obtained on 1 April 2013 from http://www.afsc.noaa.gov/RACE/groundfish/survey_data/default.htm.

Figure 6: page 39. Retained catch (**t**; top) and catch per unit effort (CPUE; bottom) in the Aleutian Islands golden king crab fishery, 1985/86–2015/16: in the total area (east and west of 174° W longitude), in the area east of 174° W longitude, and in the area west of 174° W longitude. Note: CF = confidential.

Figure 7: page 40. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands showing reporting areas 541, 542, and 543 that are used to summarize groundfish fisheries discarded catch data for Aleutian Islands golden king crab (from http://www.alaskafisheries.noaa.gov/rr/figures/fig1.pdf).

Figure 8: page 41. Retained catch (**t**) during the directed fishery, estimated bycatch mortality (**t**) during all crab fisheries, and estimated bycatch mortality (**t**) during all groundfish fisheries of Aleutian Islands golden king crab, 1985/86–2015/16 (from Table 4). Note: CF = confidential.

Figure 9: page 42. Ratio of estimated weight of bycatch mortality in directed and non-directed crab fisheries to weight of retained catch in the directed fishery for Aleutian Islands golden king crab, 1990/91–2015/16 (ratios for 1993/94–1994/95 and 2015/16 are not available due to data confidentialities and insufficiencies). Note: CF = confidential.

Figure 10: page 43. Ratio of estimated weight of bycatch mortality in directed and non-directed crab fisheries to weight of retained catch in the directed fishery for Aleutian Islands golden king crab plotted against weight (**t**) of retained catch, 1990/91–2015/16 (ratios for 1993/94–1994/95 and 2015/16 are not available due to data confidentialities and insufficiencies).

Figure 11: page 44. Bootstrapped estimates of the sampling distribution of the status quo, Alternative 1 recommended 2016/2017 Tier 5 OFL (total-catch, **t**) for the Aleutian Islands golden king crab stock; histograms in left column, cumulative distribution in right column.

Table 1a. Commercial fishery history for the Aleutian Islands golden king crab fishery 1981/82–2015/16: number of vessels, guideline harvest level (GHL; established in lb, **converted to t**) for 1981/82–2004/05, total allowable catch (TAC; established in lb, **converted to t**) for 2005/06–2015/16, weight of retained catch (Harvest; **t**), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (**kg**) of landed crab.

Crab fishing year	Vessels	GHL/TAC	Harvest[a]	Crab[a]	Pot lifts		Average weight[c]
1981/82	14–20	-	599	240,458	27,533	9	2.5[d]
1982/83	99–148	-	4,169	1,737,109	179,472	10	2.4[d]
1983/84	157–204	-	4,508	1,773,262	256,393	7	2.5[d]
1984/85	38–51	-	2,132	971,274	88,821	11	2.2[e]
1985/86	53	-	5,787	2,816,313	236,601	12	2.1[f]
1986/87	64	-	6,696	3,345,680	433,870	8	2.0[f]
1987/88	66	-	4,202	2,177,229	307,130	7	1.9[f]
1988/89	76	-	4,820	2,488,433	321,927	8	1.9[f]
1989/90	68	-	5,453	2,902,913	357,803	8	1.9[f]
1990/91	24	-	3,161	1,707,618	215,840	8	1.9[f]
1991/92	20	-	3,494	1,847,398	234,857	8	1.9[f]
1992/93	22	-	2,854	1,528,328	203,221	8	1.9[f]
1993/94	21	-	2,518	1,397,530	234,654	6	1.8[f]
1994/95	35	-	3,687	1,924,271	386,593	5	1.9[f]
1995/96	28	-	3,157	1,582,333	293,021	5	2.0[f]
1996/97	18	2,676	2,638	1,334,877	212,727	6	2.0[f]
1997/98	15	2,676	2,697	1,350,160	193,214	7	2.0[f]
1998/99	16	2,585	2,242	1,150,029	119,353	10	1.9[f]
1999/00	17	2,585	2,648	1,385,890	186,169	7	1.9[f]
2000/01	17	2,585	2,730	1,410,315	172,790	8	1.9[f]
2001/02	21	2,585	2,685	1,416,768	168,151	8	1.9[f]
2002/03	22	2,585	2,478	1,308,709	131,021	10	1.9[f]
2003/04	21	2,585	2,570	1,319,707	125,119	11	1.9[f]
2004/05	22	2,585	2,529	1,323,001	91,694	14	1.9[f]
2005/06	8	2,585	2,504	1,263,339	54,685	23	2.0[f]
2006/07	7	2,585	2,380	1,174,288	52,885	22	2.0[f]
2007/08	5	2,585	2,498	1,233,848	52,609	23	2.0[f]
2008/09	5	2,715	2,576	1,254,608	50,666	25	2.1[f]
2009/10	5	2,715	2,682	1,308,218	52,787	25	2.0[f]
2010/11	5	2,715	2,707	1,297,229	55,795	23	2.1[f]
2011/12	5	2,715	2,705	1,284,946	44,241	29	2.1[f]
2012/13	6	2,853	2,843	1,360,582	53,543	25	2.1[f]
2013/14[g]	5	2,853	2,894	1,407,103	63,223	22	2.1[f]
2014/15[g]	5	2,853	2,771	1,354,376	58,550	23	2.0[f]
2015/16	5	2,853	CF	CF	CF	CF	CF

Note: CF = confidential.

a. Includes deadloss.

b. Catch (number of crab) per pot lift.

c. Average weight of landed crab, including deadloss.

[d.] Managed with 6.5" CW minimum size limit.
[e.] Managed with 6.5" CW minimum size limit west of 171° W longitude and 6.0" minimum size limit east of 171° W longitude.
[f.] Managed with 6.0" minimum size limit.
[g.] Catch and effort data includes cost-recovery fishery.

Table 1b. Commercial fishery history for the Aleutian Islands golden king crab fishery 1981/82–2015/16: number of vessels, guideline harvest level (GHL; **lb**) for 1981/82–2004/05, total allowable catch (TAC; **lb**) for 2005/06–2015/16, weight of retained catch (Harvest; **lb**), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (**lb**) of landed crab.

Crab fishing year	Vessels	GHL/TAC	Harvest[a]	Crab[a]	Pot lifts	CPUE[b]	Average weight[c]
1981/82	14–20	-	1,319,761	240,458	27,533	9	5.5[d]
1982/83	99–148	-	9,191,245	1,737,109	179,472	10	5.3[d]
1983/84	157–204	-	9,939,002	1,773,262	256,393	7	5.6[d]
1984/85	38–51	-	4,701,237	971,274	88,821	11	4.8[e]
1985/86	53	-	12,758,637	2,816,313	236,601	12	4.5[f]
1986/87	64	-	14,762,494	3,345,680	433,870	8	4.4[f]
1987/88	66	-	9,264,395	2,177,229	307,130	7	4.3[f]
1988/89	76	-	10,627,042	2,488,433	321,927	8	4.3[f]
1989/90	68	-	12,022,052	2,902,913	357,803	8	4.1[f]
1990/91	24	-	6,969,535	1,707,618	215,840	8	4.1[f]
1991/92	20	-	7,702,141	1,847,398	234,857	8	4.2[f]
1992/93	22	-	6,291,197	1,528,328	203,221	8	4.1[f]
1993/94	21	-	5,551,143	1,397,530	234,654	6	4.0[f]
1994/95	35	-	8,128,511	1,924,271	386,593	5	4.2[f]
1995/96	28	-	6,960,406	1,582,333	293,021	5	4.4[f]
1996/97	18	5,900,000	5,815,772	1,334,877	212,727	6	4.4[f]
1997/98	15	5,900,000	5,945,683	1,350,160	193,214	7	4.4[f]
1998/99	16	5,700,000	4,941,893	1,150,029	119,353	10	4.3[f]
1999/00	17	5,700,000	5,838,788	1,385,890	186,169	7	4.2[f]
2000/01	17	5,700,000	6,018,761	1,410,315	172,790	8	4.3[f]
2001/02	21	5,700,000	5,918,706	1,416,768	168,151	8	4.2[f]
2002/03	22	5,700,000	5,462,455	1,308,709	131,021	10	4.2[f]
2003/04	21	5,700,000	5,665,828	1,319,707	125,119	11	4.3[f]
2004/05	22	5,700,000	5,575,051	1,323,001	91,694	14	4.2[f]
2005/06	8	5,700,000	5,520,318	1,263,339	54,685	23	4.4[f]
2006/07	7	5,700,000	5,245,926	1,174,288	52,885	22	4.5[f]
2007/08	5	5,700,000	5,508,100	1,233,848	52,609	23	4.5[f]
2008/09	5	5,985,000	5,680,084	1,254,608	50,666	25	4.5[f]
2009/10	5	5,985,000	5,912,287	1,308,218	52,787	25	4.5[f]
2010/11	5	5,985,000	5,968,849	1,297,229	55,795	23	4.6[f]
2011/12	5	5,985,000	5,964,416	1,284,946	44,241	29	4.6[f]
2012/13	6	6,290,000	6,267,759	1,360,582	53,543	25	4.6[f]
2013/14[g]	5	6,290,000	6,379,553	1,407,103	63,223	22	4.5[f]
2014/15[g]	5	6,290,000	6,108,674	1,354,376	58,550	23	4.5[f]
2015/16	5	6,290,000	CF	CF	CF	CF	CF

Note: CF = confidential.

a. Includes deadloss.

b. Catch (number of crab) per pot lift.

c. Average weight of landed crab, including deadloss.

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[d.] Managed with 6.5" CW minimum size limit.
[e.] Managed with 6.5" CW minimum size limit west of 171° W longitude and 6.0" minimum size limit east of 171° W longitude.
[f.] Managed with 6.0" minimum size limit.
[g.] Catch and effort data includes cost-recovery fishery.

Table 1c. Commercial fishery history for the Aleutian Islands golden king crab fishery, 1985/86–2015/16, separately for the areas east and west of 174° W longitude: weight of retained catch (Harvest; **t**), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (**kg**) of landed crab.

	East of 174° W longitude					West of 174° W longitude				
Crab fishing year	Harvest	Crab	Pot lifts	CPUE	Avg weight	Harvest	Crab	Pot lifts	CPUE	Avg weight
1985/86	2,966	1,405,602	118,038	12	2.1	2,821	1,410,711	118,563	12	2.0
1986/87	2,697	1,312,085	156,090	8	2.1	3,999	2,033,595	277,780	7	2.0
1987/88	2,014	1,032,077	146,901	7	2.0	2,189	1,145,152	160,229	7	1.9
1988/89	2,335	1,169,427	155,518	8	2.0	2,485	1,319,006	166,409	8	1.9
1989/90	2,483	1,317,833	155,262	8	1.9	2,971	1,585,080	202,541	8	1.9
1990/91	1,795	950,008	107,307	9	1.9	1,366	757,610	108,533	7	1.8
1991/92	2,065	1,093,983	133,428	8	1.9	1,428	753,415	101,429	7	1.9
1992/93	2,089	1,118,955	133,778	8	1.9	764	409,373	69,443	6	1.9
1993/94	1,510	832,194	106,890	8	1.8	1,008	565,336	127,764	4	1.8
1994/95	2,155	1,128,013	191,455	6	1.9	1,532	796,258	195,138	4	1.9
1995/96	2,099	1,046,780	177,773	6	2.0	1,058	535,553	115,248	5	2.0
1996/97	1,493	731,909	113,460	6	2.0	1,145	602,968	99,267	6	1.9
1997/98	1,588	780,610	106,403	7	2.0	1,109	569,550	86,811	7	1.9
1998/99	1,473	740,011	83,378	9	2.0	768	410,018	35,975	11	1.9
1999/00	1,392	709,332	79,129	9	2.0	1,256	676,558	107,040	6	1.9
2000/01	1,422	704,702	71,551	10	2.0	1,308	705,613	101,239	7	1.9
2001/02	1,442	730,030	62,639	12	2.0	1,243	686,738	105,512	7	1.8
2002/03	1,280	643,886	52,042	12	2.0	1,198	664,823	78,979	8	1.8
2003/04	1,350	643,074	58,883	11	2.1	1,220	676,633	66,236	10	1.8
2004/05	1,309	637,536	34,848	18	2.1	1,219	685,465	56,846	12	1.8
2005/06	1,300	623,971	24,569	25	2.1	1,204	639,368	30,116	21	1.9
2006/07	1,357	650,587	26,195	25	2.1	1,022	523,701	26,690	20	2.0
2007/08	1,356	633,253	22,653	28	2.1	1,142	600,595	29,956	20	1.9
2008/09	1,426	666,947	24,466	27	2.1	1,150	587,661	26,200	22	2.0
2009/10	1,429	679,886	26,298	26	2.1	1,253	628,332	26,489	24	2.0
2010/11	1,428	670,983	25,851	26	2.1	1,279	626,246	29,944	21	2.0
2011/12	1,429	668,828	17,915	37	2.1	1,276	616,118	26,326	23	2.1
2012/13	1,504	687,666	20,827	33	2.2	1,339	672,916	32,716	21	2.0
2013/14	1,546	720,220	21,388	34	2.1	1,347	686,883	41,835	16	2.0
2014/15	1,554	719,064	17,002	42	2.2	1,217	635,312	41,548	15	1.9
2015/16	1,498	717,864	18,481	39	2.1	CF	CF	CF	CF	CF

Note: CF = confidential.

Table 2. Retained catch (**t**) of Aleutian Islands golden king crab, with the estimated discarded catch (**t**; not discounted for an assumed bycatch mortality rate) and components of discarded catch during commercial crab fisheries, 1990/91–2015/16; observer data on discarded catch for 1993/94 and 1994/95 are confidential and considered to have poor reliability.

	Retained	Non-retained	Components of non-retained catch:		
Crab fishing year	Catch	Catch	Legal males	Sublegal males	Females
1990/91	3,161	6,270	5	2,906	3,359
1991/92	3,494	5,106	97	2,510	2,499
1992/93	2,854	5,934	28	2,665	3,241
1993/94	2,518	CF	CF	CF	CF
1994/95	3,687	CF	CF	CF	CF
1995/96	3,157	5,466	29	2,746	2,691
1996/97	2,638	4,128	11	1,915	2,202
1997/98	2,697	3,961	18	1,905	2,038
1998/99	2,242	3,351	19	1,952	1,381
1999/00	2,648	3,426	29	1,783	1,613
2000/01	2,730	4,038	16	2,169	1,852
2001/02	2,685	3,124	12	1,718	1,395
2002/03	2,478	2,572	19	1,412	1,141
2003/04	2,570	2,256	18	1,208	1,030
2004/05	2,529	1,960	34	1,139	786
2005/06	2,504	1,145	64	671	411
2006/07	2,380	1,167	54	573	540
2007/08	2,498	1,377	58	683	636
2008/09	2,576	1,254	79	619	555
2009/10	2,682	1,264	74	619	572
2010/11	2,707	1,236	101	567	569
2011/12	2,705	1,152	122	536	494
2012/13	2,843	1,315	155	560	600
2013/14	2,894	1,436	167	675	593
2014/15	2,771	1,514	218	623	673
2015/16	CF	CF	CF	CF	CF

Note: CF = confidential.

Table 3. Estimated annual weight (**t**) of discarded catch of golden king crab (all sizes, males and females) and bycatch mortality (**t**) during federal groundfish fisheries in federal reporting areas 541, 542, and 543 (see Figure 7) by gear type (fixed or trawl), 1991/92–2015/16; assumes bycatch mortality rate of 0.5 for fixed-gear fisheries and 0.8 for trawl fisheries.

	Bycatch		Bycatch Mortality		
Crab fishing year	Fixed Gear	Trawl Gear	Fixed Gear	Trawl Gear	Total
1991/92	0.000	0.000	0.000	0.000	0.000
1992/93	0.002	0.001	0.001	0.001	0.002
1993/94	1.796	3.703	0.898	2.962	3.861
1994/95	0.611	1.213	0.305	0.970	1.276
1995/96	0.166	2.343	0.083	1.874	1.958
1996/97	0.012	6.288	0.006	5.030	5.036
1997/98	0.244	0.486	0.122	0.389	0.511
1998/99	1.769	0.626	0.885	0.501	1.386
1999/00	4.795	0.645	2.398	0.516	2.914
2000/01	3.250	0.303	1.625	0.243	1.868
2001/02	0.629	0.189	0.315	0.152	0.466
2002/03	34.451	0.395	17.226	0.316	17.542
2003/04	39.093	0.679	19.547	0.543	20.090
2004/05	1.111	1.112	0.556	0.890	1.446
2005/06	0.565	1.883	0.283	1.506	1.789
2006/07	32.797	1.396	16.399	1.117	17.515
2007/08	115.315	1.652	57.658	1.321	58.978
2008/09	49.298	10.302	24.649	8.242	32.890
2009/10	20.061	8.192	10.030	6.554	16.584
2010/11	14.268	15.785	7.134	12.628	19.763
2011/12	16.436	9.089	8.218	7.271	15.489
2012/13	0.540	11.155	0.270	8.924	9.194
2013/14	1.579	12.420	0.789	9.936	10.725
2014/15	0.137	6.055	0.069	4.844	4.913
2015/16	56.391	4.788	28.195	3.830	32.026

Table 4. Estimated annual weight (**t**) of total fishery mortality to Aleutian Islands golden king crab, 1990/91–2015/16, partitioned by source of mortality: retained catch, estimated bycatch mortality during crab fisheries, and estimated bycatch mortality during groundfish fisheries; from Tables 2 and 3 with assumed bycatch mortality rate of 0.2 applied to the discarded catch estimates in Table 2.

		Bycatch Mortality by Fishery Type		Total
Crab fishing year	Retained Catch	Crab	Groundfish	Fishery Mortality
1990/91	3,161	1,254	—	—
1991/92	3,494	1,021	—	—
1992/93	2,854	1,187	—	—
1993/94	2,518	—	3.9	—
1994/95	3,687	—	1.3	—
1995/96	3,157	1,093	2.0	4,252
1996/97	2,638	823	5.0	3,466
1997/98	2,697	789	0.5	3,486
1998/99	2,242	670	1.4	2,913
1999/00	2,648	685	2.9	3,337
2000/01	2,730	807	1.9	3,539
2001/02	2,685	625	0.5	3,310
2002/03	2,478	514	17.5	3,010
2003/04	2,570	451	20.1	3,041
2004/05	2,529	392	1.4	2,922
2005/06	2,504	229	1.8	2,735
2006/07	2,380	234	17.5	2,638
2007/08	2,498	275	59.0	2,833
2008/09	2,576	251	32.9	2,860
2009/10	2,682	253	16.6	2,951
2010/11	2,707	247	19.8	2,975
2011/12	2,705	230	15.5	2,951
2012/13	2,843	263	9.2	3,115
2013/14	2,894	287	10.7	3,192
2014/15	2,771	303	4.9	3,079
2015/16	CF	CF	32.0	CF

Note: CF = confidential.

Table 5. Annual retained-catch weight (**t**) and estimates of annual discarded catch weight (**t**) of Aleutian Islands golden king crab available for a Tier 5 assessment; shaded, bold values are used in computation of the recommended (status quo Alternative 1) Tier 5 OFL.

	Retained catch weight	Discarded catch weight (estimated)		
	Fish tickets	Observer data: lengths, catch per sampled pot	Blend method; Catch Accounting System	
Crab Fishing Year	Directed fishery	Crab fisheries	Fixed gear, groundfish	Trawl gear, groundfish
1981/82	599	–	–	–
1982/83	4,169	–	–	–
1983/84	4,508	–	–	–
1984/85	2,132	–	–	–
1985/86	**5,787**	–	–	–
1986/87	**6,696**	–	–	–
1987/88	**4,202**	–	–	–
1988/89	**4,820**	–	–	–
1989/90	**5,453**	–	–	–
1990/91	**3,161**	**6,270**	–	–
1991/92	**3,494**	**5,106**	0.000	0.000
1992/93	**2,854**	**5,934**	0.002	0.001
1993/94	**2,518**	Confidential	**1.796**	**3.703**
1994/95	**3,687**	Confidential	**0.611**	**1.213**
1995/96	**3,157**	**5,466**	**0.166**	**2.343**
1996/97	2,638	4,128	**0.012**	**6.288**
1997/98	2,697	3,961	**0.244**	**0.486**
1998/99	2,242	3,351	**1.769**	**0.626**
1999/00	2,648	3,426	**4.795**	**0.645**
2000/01	2,730	4,038	**3.250**	**0.303**
2001/02	2,685	3,124	**0.629**	**0.189**
2002/03	2,478	2,572	**34.451**	**0.395**
2003/04	2,570	2,256	**39.093**	**0.679**
2004/05	2,529	1,960	**1.111**	**1.112**
2005/06	2,504	1,145	**0.565**	**1.883**
2006/07	2,380	1,167	**32.797**	**1.396**
2007/08	2,498	1,377	**115.315**	**1.652**
2008/09	2,576	1,254	**49.298**	**10.302**
2009/10	2,682	1,264	20.061	8.192
2010/11	2,707	1,236	14.268	15.785
2011/12	2,705	1,152	16.436	9.089
2012/13	2,843	1,315	0.540	11.155
2013/14	2,894	1,436	1.579	12.420
2014/15	2,771	1,514	0.137	6.055
2015/16	Confidential	Confidential	56.391	4.788

Table 6. Data for calculation of $RET_{85/86\text{-}95/96}$ (**t**) and estimates used in calculation of $R_{90/91\text{-}95/96}$ (ratio, t:t) and $BM_{GF,93/94\text{-}08/09}$ (**t**) for calculation of the recommended (status quo Alternative 1) Aleutian Islands golden king crab Tier 5 2016/17 OFL (**t**); values under $RET_{85/86\text{-}95/96}$ are from Table 1, values under $R_{90/91\text{-}95/96}$ were computed from the retained catch data and the crab bycatch mortality estimates in Table 4, and values under $BM_{GF,93/94\text{-}08/09}$ are from Table 4.

Crab fishing year	$RET_{85/86\text{-}95/96}$	$R_{90/91\text{-}95/96}$	$BM_{GF,93/94\text{-}08/09}$
1985/86	5,787		
1986/87	6,696		
1987/88	4,202		
1988/89	4,820		
1989/90	5,453		
1990/91	3,161	0.398	
1991/92	3,494	0.292	
1992/93	2,854	0.416	
1993/94	2,518	—	3.9
1994/95	3,687	—	1.3
1995/96	3,157	0.346	2.0
1996/97			5.0
1997/98			0.5
1998/99			1.4
1999/00			2.9
2000/01			1.9
2001/02			0.5
2002/03			17.5
2003/04			20.1
2004/05			1.4
2005/06			1.8
2006/07			17.5
2007/08			59.0
2008/09			32.9
N	11	4	16.0
Average	4,166	0.363	10.6
S.E.M.	407	0.028	4.0
CV	0.10	0.08	0.38

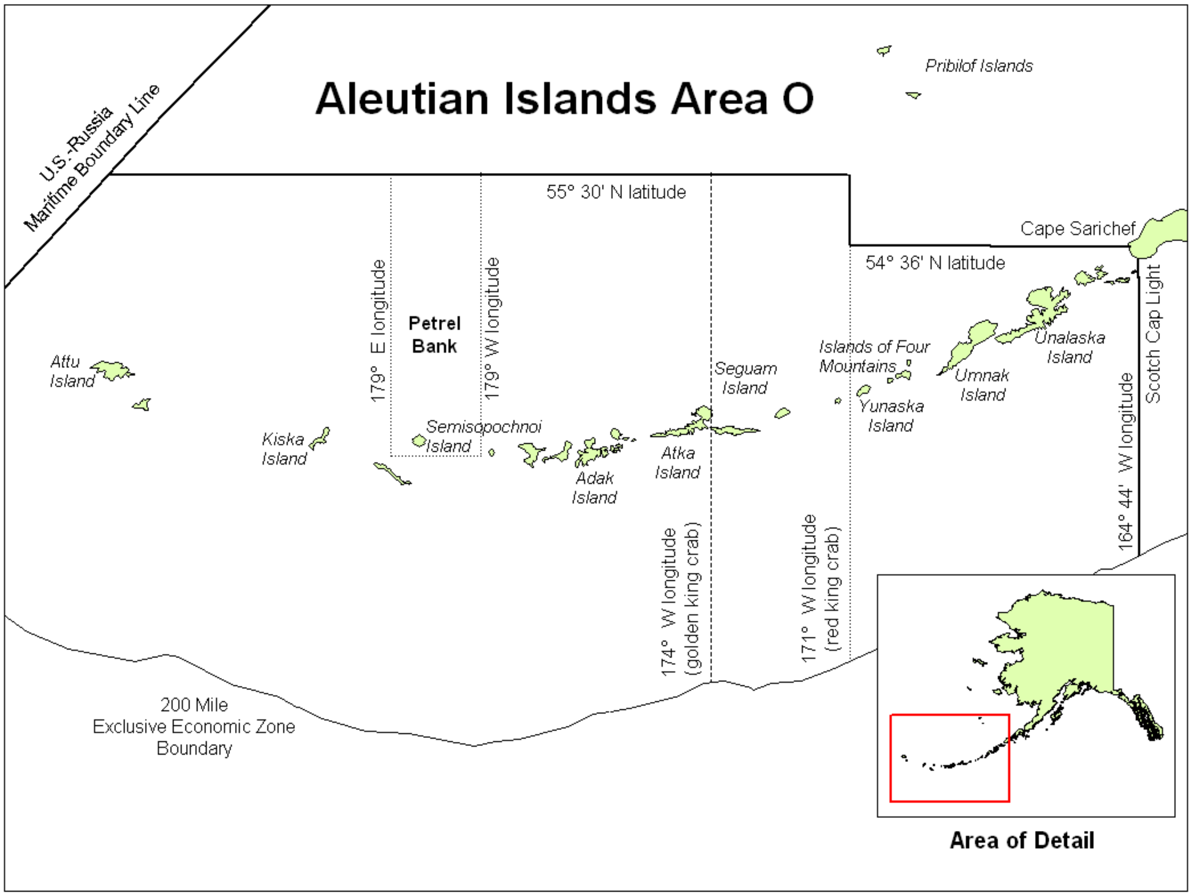


Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Baechler and Cook 2014).

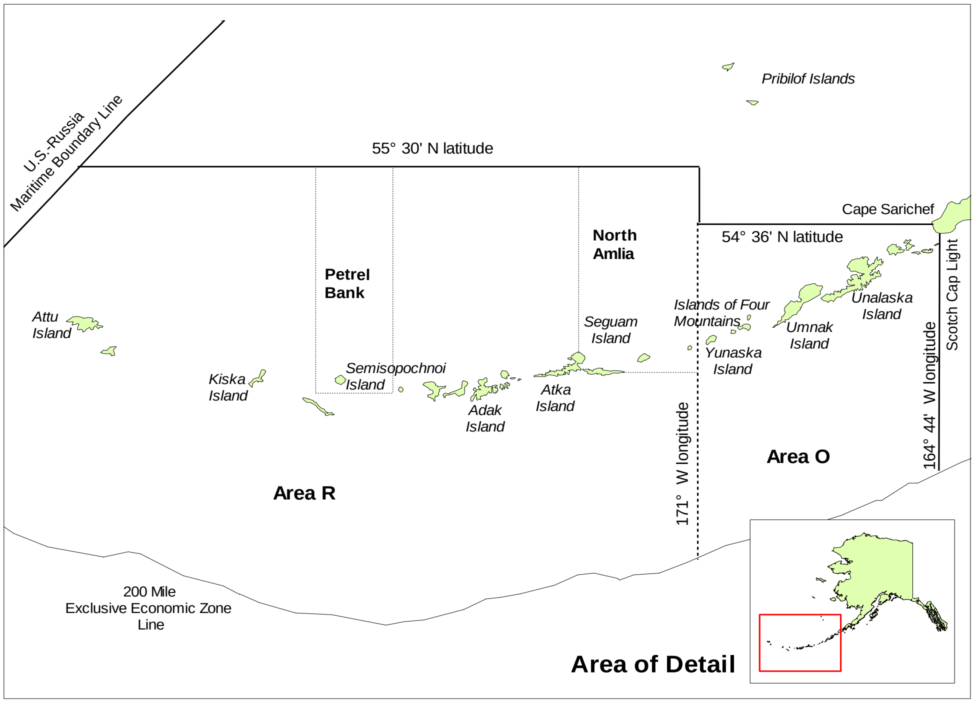


Figure 2. Adak (Area R) and Dutch Harbor (Area O) king crab Registration Areas and Districts, 1984/85–1995/96 seasons (from Baechler 2012).

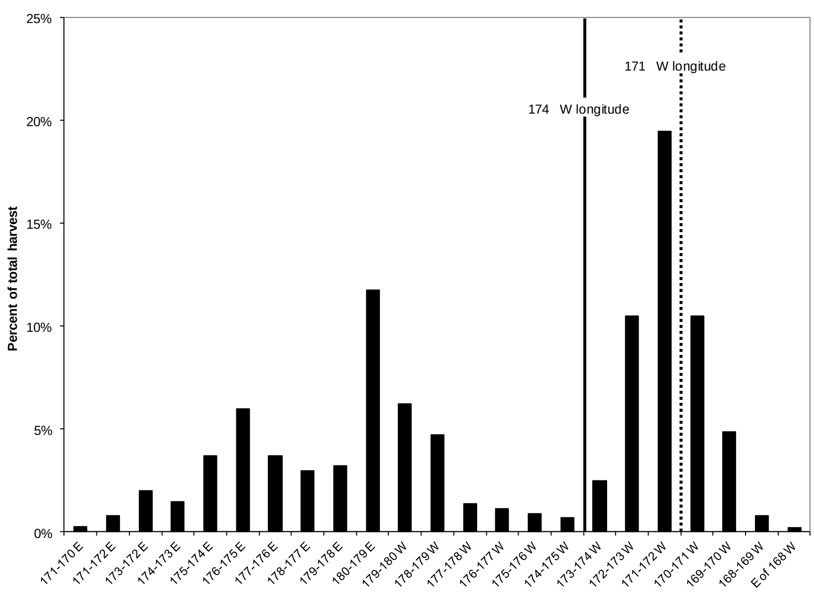


Figure 3. Percent of total 1981/82–1995/96 golden king crab retained catch weight (harvest) from one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude used during the 1984/85–1995/96 seasons to divide fishery management between the Dutch Harbor Area (east of 171° W longitude) and the Adak Area (west of 171° W longitude) and solid line denoting the border at 174° W longitude used since the 1996/97 season to manage crab east and west of 174° W longitude (adapted from Figure 4-2 *in* Morrison et al. 1998).

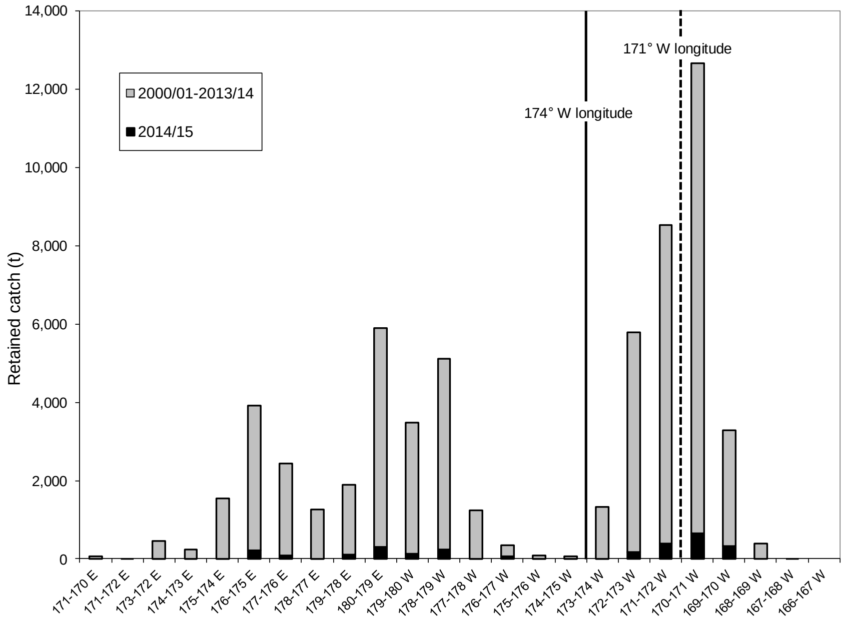


Figure 4. Retained catch (**t**) of golden king crab within one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2014/15 commercial fishery seasons; solid line denotes the border at 174° W longitude that has been used since the 1996/97 season to manage Aleutian Island golden king crab as separate stocks east and west of 174° W longitude and dashed line denotes the border at 171° W longitude used during the 1984/85–1995/96 seasons to divide fishery management between the Dutch Harbor Area (east of 171° W longitude) and the Adak Area (west of 171° W longitude).

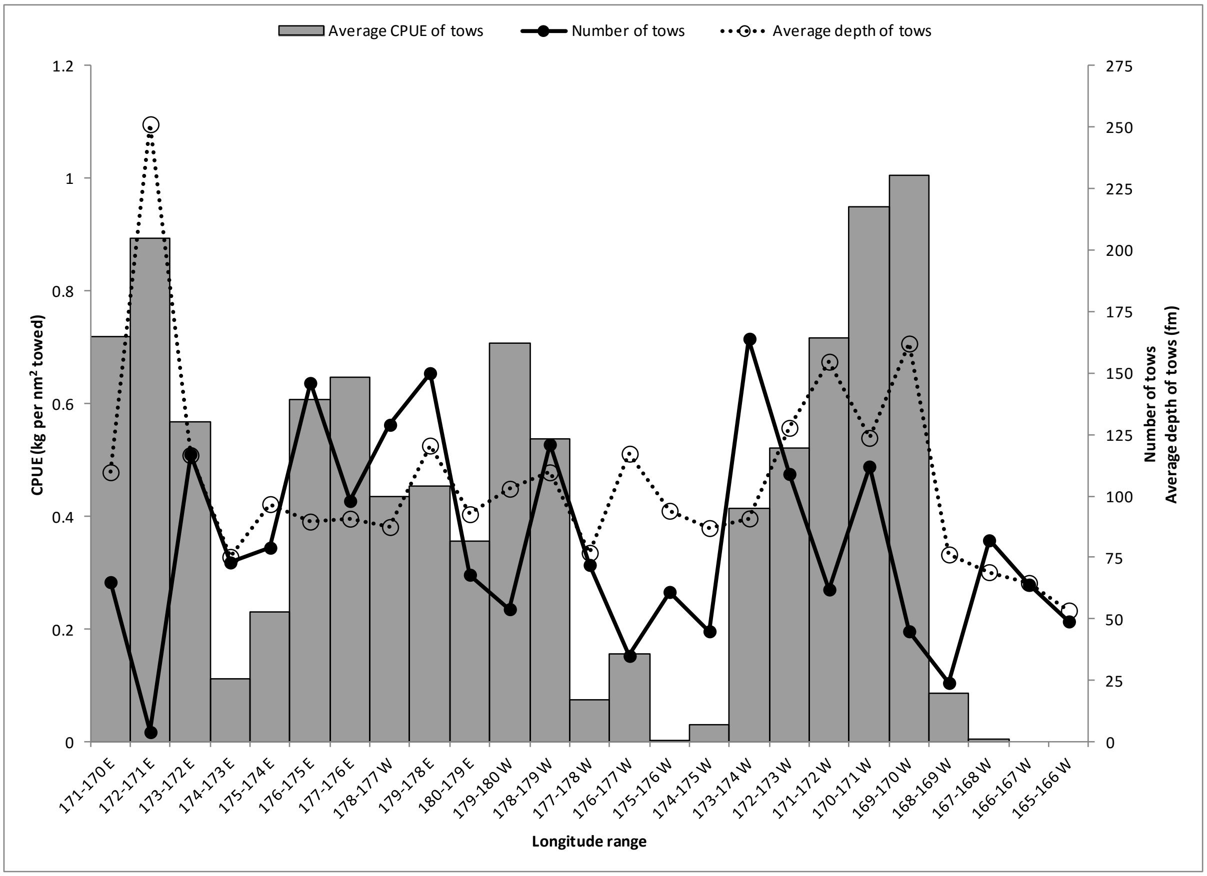
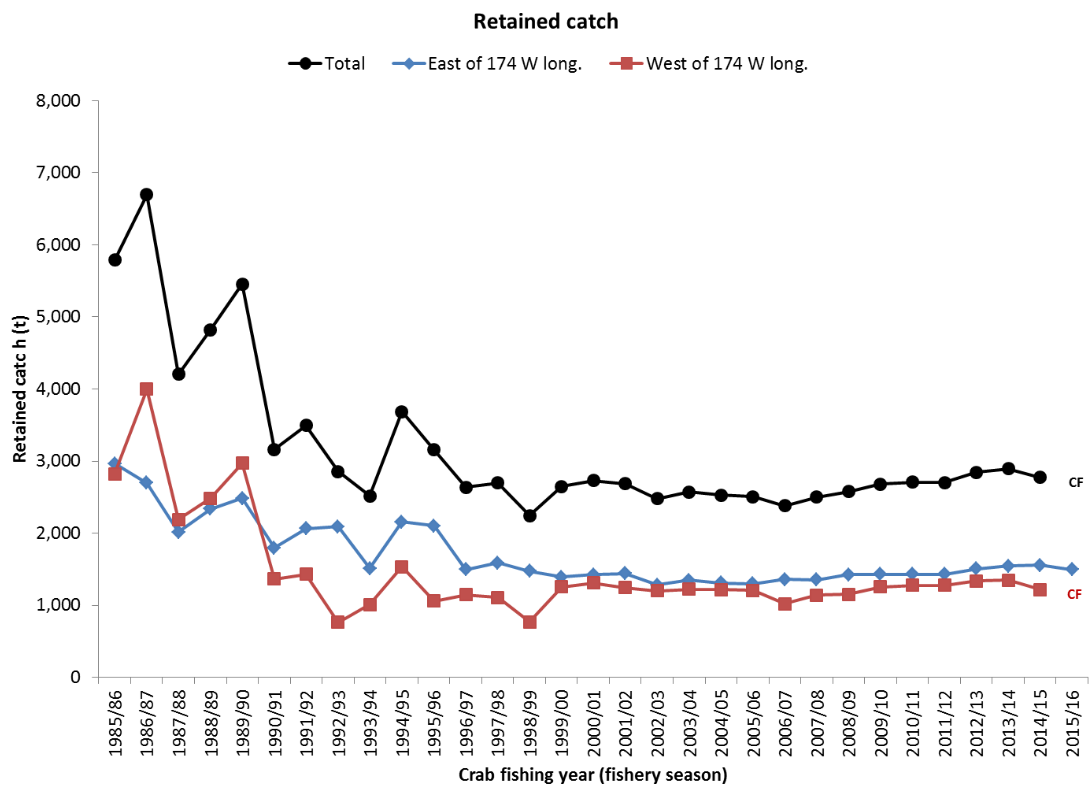
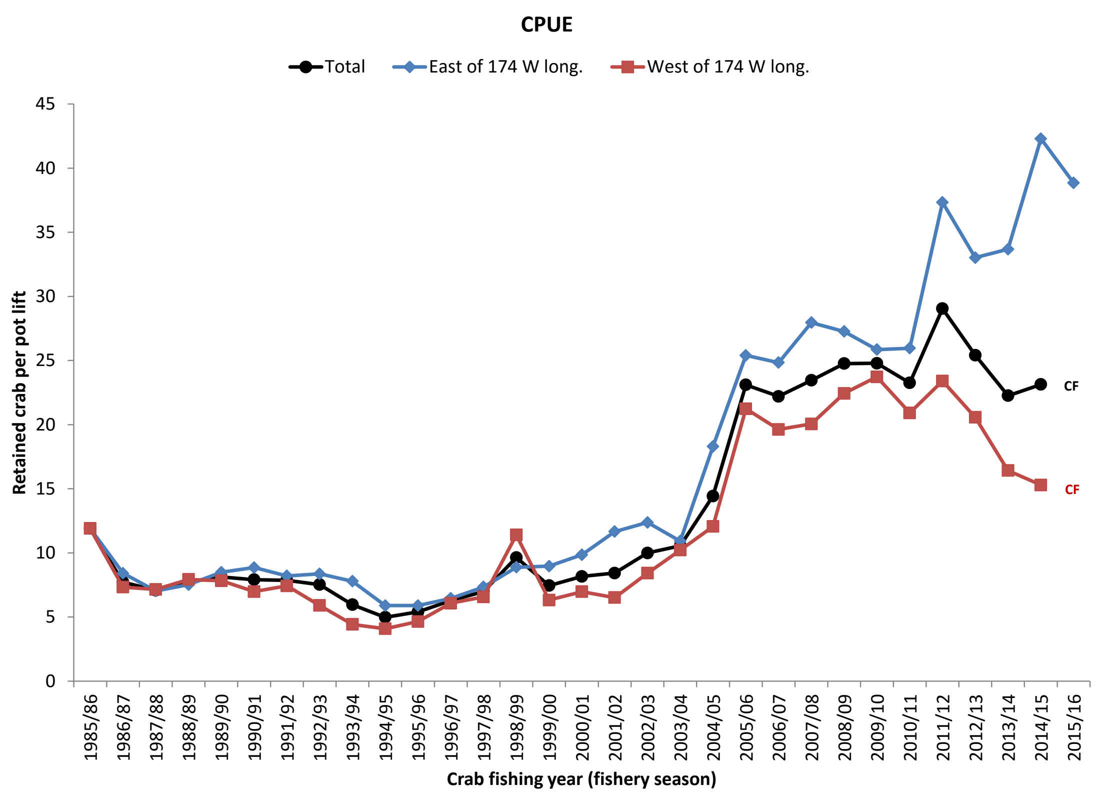


Figure 5. Average golden king crab CPUE (**kg**/nm^2) for tows, number of tows, and average depth of tows from one-degree longitude intervals during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys; preliminary summary of data obtained on 1 April 2013 from http://www.afsc.noaa.gov/RACE/groundfish/survey_data/default.htm.


Retained catch
Total
East of 174 W long.
West of 174 W long.
Retained catc h (t)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
CF
CF
1985/86
1986/87
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93
1993/94
1994/95
1995/96
1996/97
1997/98
1998/99
1999/00
2000/01
2001/02
2002/03
2003/04
2004/05
2005/06
2006/07
2007/08
2008/09
2009/10
2010/11
2011/12
2012/13
2013/14
2014/15
2015/16
Crab fishing year (fishery season)


CPUE
Total
East of 174 W long.
West of 174 W long.
Retained crab per pot lift
45
40
35
30
25
20
15
10
5
0
CF
CF
1985/86
1986/87
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93
1993/94
1994/95
1995/96
1996/97
1997/98
1998/99
1999/00
2000/01
2001/02
2002/03
2003/04
2004/05
2005/06
2006/07
2007/08
2008/09
2009/10
2010/11
2011/12
2012/13
2013/14
2014/15
2015/16
Crab fishing year (fishery season)

44

Figure 6. Retained catch (**t**; top) and catch per unit effort (CPUE; bottom) in the Aleutian Islands golden king crab fishery, 1985/86–2015/16: in the total area (east and west of 174° W longitude), in the area east of 174° W longitude, and in the area west of 174° W longitude. Note: CF = confidential.

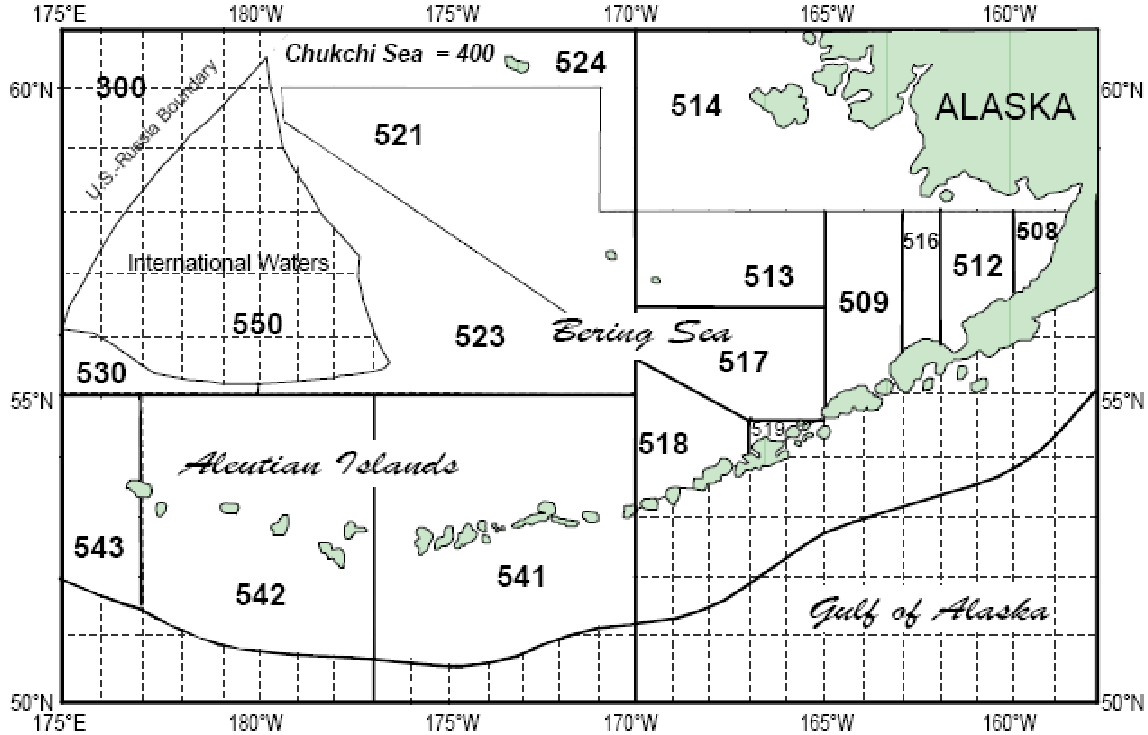


Figure 7. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands showing reporting areas 541, 542, and 543 that are used to summarize groundfish fisheries discarded catch data for Aleutian Islands golden king crab (from http://www.alaskafisheries.noaa.gov/rr/figures/fig1.pdf).

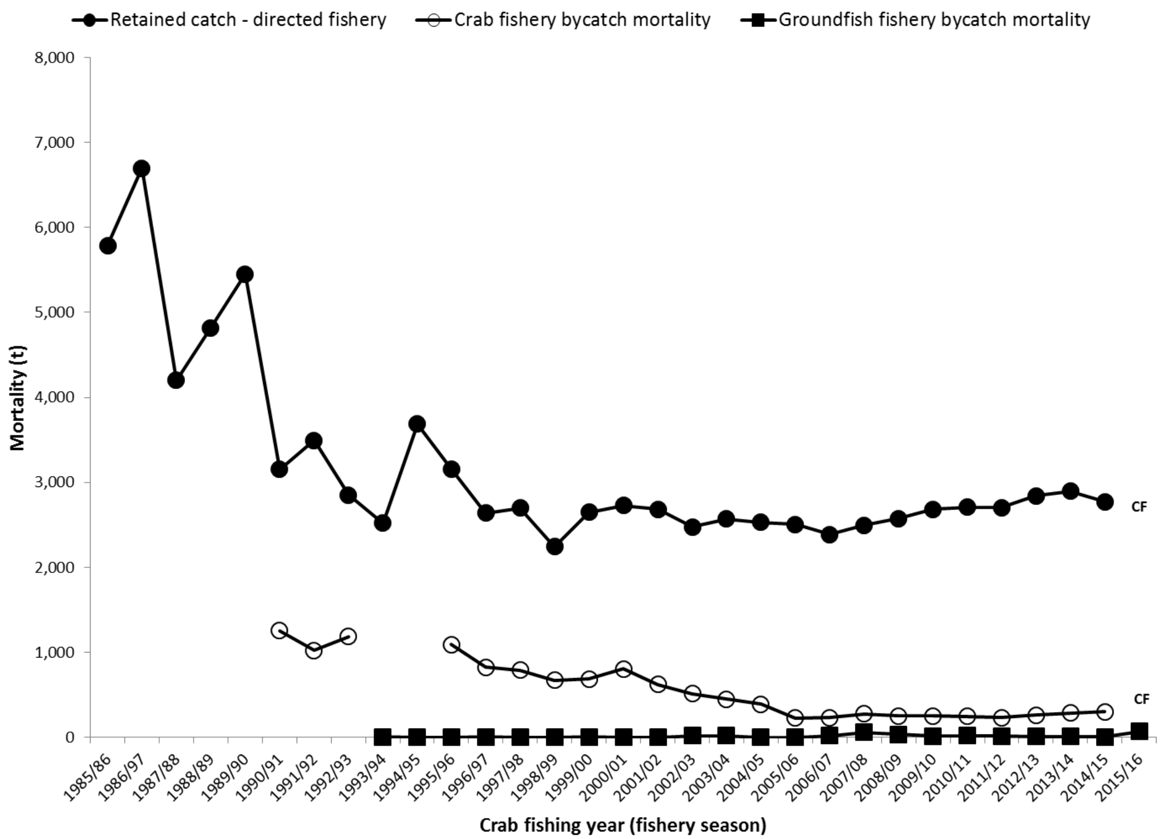


Figure 8. Retained catch (**t**) during the directed fishery, estimated bycatch mortality (**t**) during all crab fisheries, and estimated bycatch mortality (**t**) during all groundfish fisheries of Aleutian Islands golden king crab, 1985/86–2015/16 (from Table 4). Note: CF = confidential.

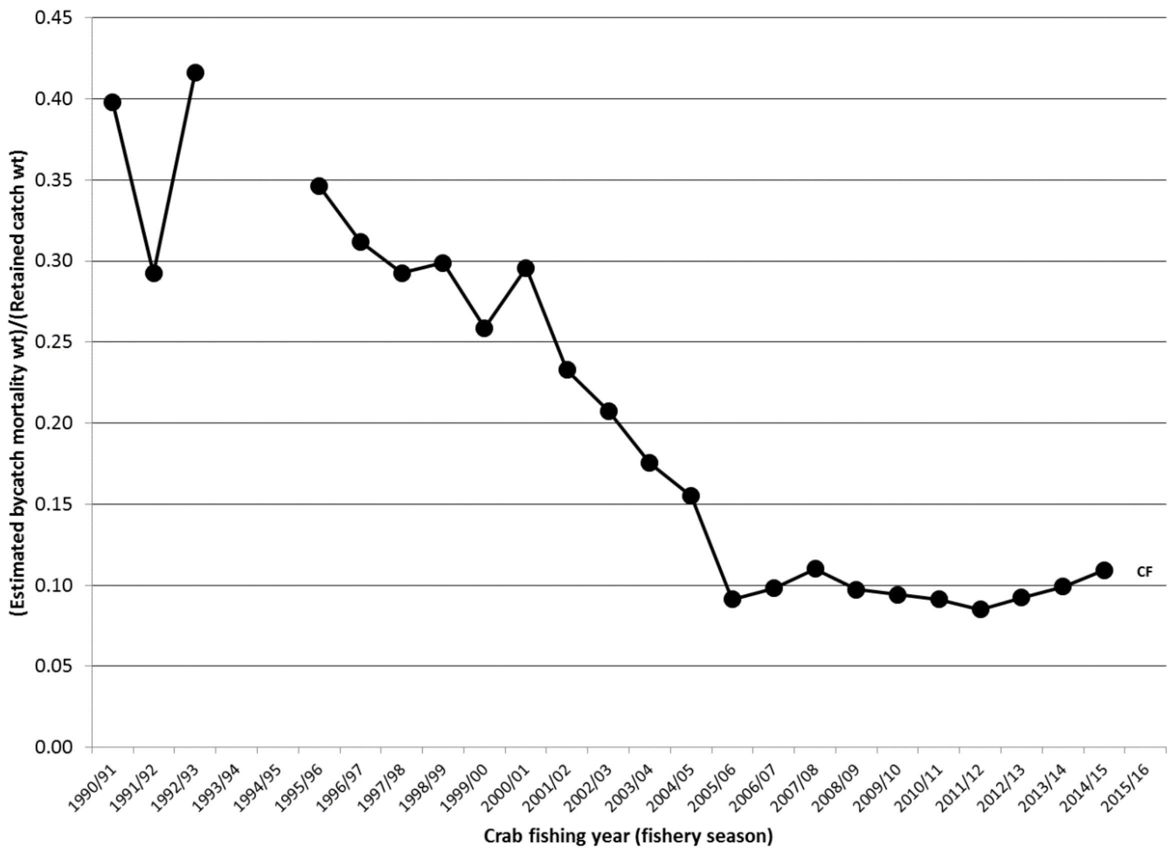


Figure 9. Ratio of estimated weight of bycatch mortality in directed and non-directed crab fisheries to weight of retained catch in the directed fishery for Aleutian Islands golden king crab, 1990/91–2015/16 (ratios for 1993/94–1994/95 and 2015/16 are not available due to data confidentialities and insufficiencies). Note: CF = confidential.

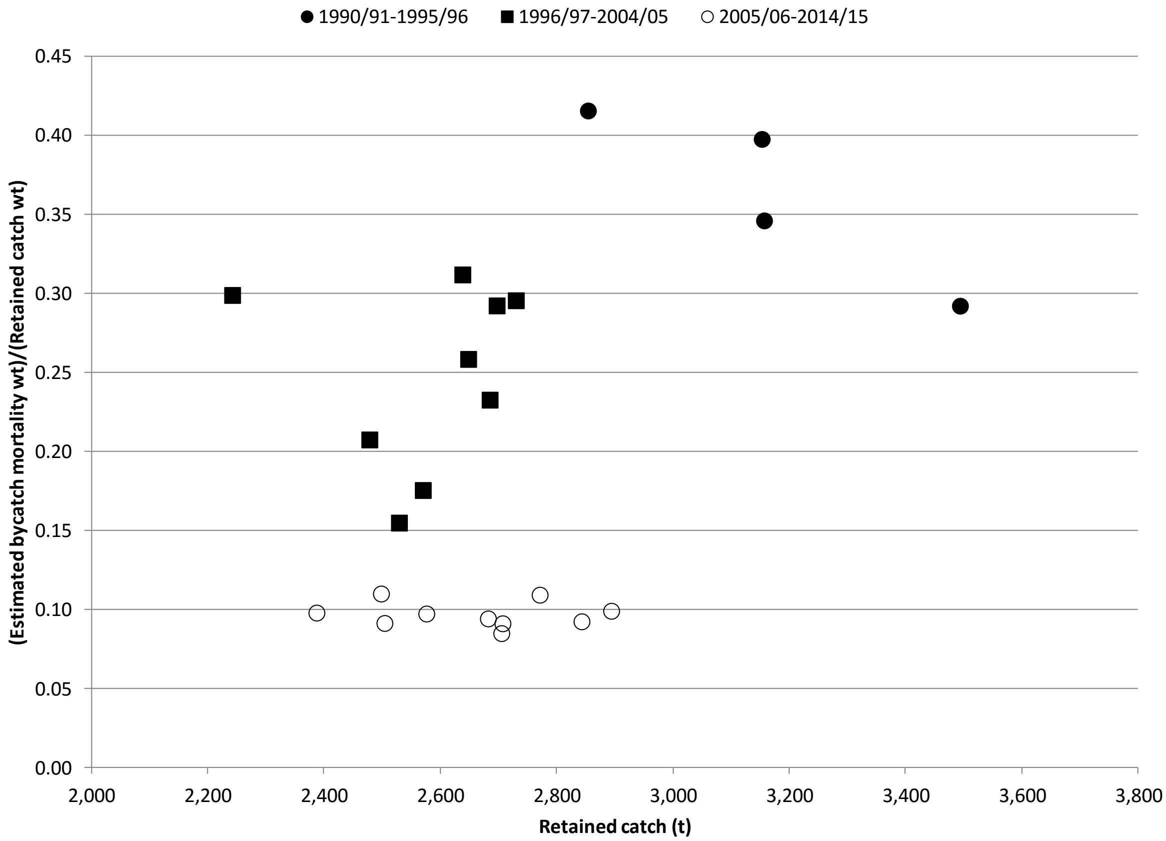


Figure 10. Ratio of estimated weight of bycatch mortality in directed and non-directed crab fisheries to weight of retained catch in the directed fishery for Aleutian Islands golden king crab plotted against weight (**t**) of retained catch, 1990/91–2015/16 (ratios for 1993/94–1994/95 and 2015/16 are not available due to data confidentialities and insufficiencies).

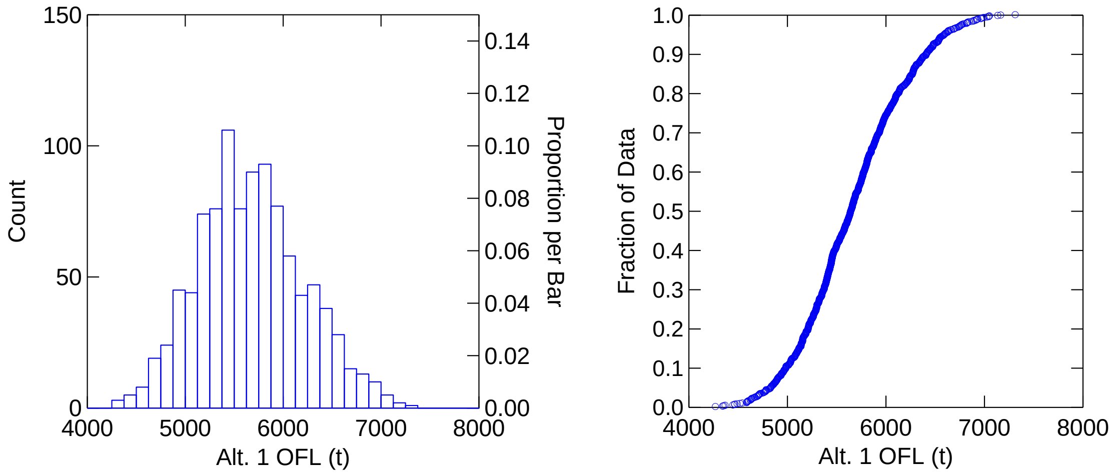


Figure 11. Bootstrapped estimates of the sampling distribution of the status quo, Alternative 1 recommended 2016/2017 Tier 5 OFL (total-catch, **t**) for the Aleutian Islands golden king crab stock; histograms in left column, cumulative distribution in right column.

Pribilof Islands Golden King Crab

– 2016 Tier 5 Assessment

2016 Crab SAFE Report Chapter (September 2016)

Douglas Pengilly, ADF&G, Kodiak
Alaska Department of Fish and Game
Division of Commercial Fisheries
351 Research Ct.
Kodiak, AK 99615, USA
Phone: (907) 486-1865
Email: doug.pengilly@alaska.gov

Executive Summary

1. **<u>Stock</u>:** Pribilof Islands (Pribilof District) golden king crab *Lithodes aequispinus*.

2. **<u>Catches</u>:**

Commercial fishing for golden king crab in the Pribilof District has been concentrated in the Pribilof Canyon. The domestic fishery developed in 1982/83, although some limited fishing occurred at least as early as 1981/82. Peak retained catch occurred in 1983/84 at 388 t (856,475 lb). The fishing season for this stock has been defined as a calendar year (as opposed to 1-July-to-30-June crab fishing year) after 1983/84. Since then, participation in the fishery has been sporadic and annually retained catch has been variable: from 0 t (0 lb) in the ten years that no vessels participated (1984, 1986, 1990–1992, 2006–2009, and 2015) to 155 t (341,908 lb) in 1995, when seven vessels made landings. The fishery is not rationalized. There is no state harvest strategy in regulation. A guideline harvest level (GHL) was first established for the fishery in 1999 at 91 t (200,000 lb). The GHL was reduced to 68 t (150,000 lb) for 2000–2014 and reduced to 59 t (130,000 lb) in 2015. No vessels participated in the directed fishery and no landings were made during 2006–2009. Catch data from 2003–2005 and 2010–2014 cannot be reported here under the confidentiality requirements of State of Alaska (SOA) statute Sec. 16.05.815. The 2003 and 2004 fisheries were closed by emergency order to manage the fishery retained catch towards the GHL; the 2005 and 2010–2014 fisheries were not closed by emergency order. No vessels participated in the directed fishery during 2015. Discarded (non-retained) catch has occurred in the directed golden king crab fishery and in the eastern Bering Sea snow crab fishery and in the Bering Sea grooved Tanner crab fishery. Estimates of annual total fishery mortality during 2001–2015 due to crab fisheries range from 0 t to 73 t, with an average of 29 t. There was no discarded catch during crab fisheries in 2015. Discarded catch also occurs in Bering Sea groundfish fisheries. Estimates of annual fishery mortality during 1991/92–2015/16 due to groundfish fisheries range from <1 t to 12 t, with an average of 3 t (estimates of annually discarded catch during Bering Sea groundfish fisheries are reported for crab fishing years, rather than for calendar years). Total fishery mortality in groundfish fisheries during the 2015/16 crab fishing year was 1.15 t.

3. <u>Stock biomass</u>:

Stock biomass (all sizes, both sexes) of golden king crab have been estimated for the Pribilof Canyon area using the area-swept technique applied to data obtained from the erstwhile biennial eastern Bering Sea upper continental slope trawl survey performed by NMFS-AFSC in 2002 (Hoff and Britt 2003), 2004 (Hoff and Britt 2005), 2008 (Hoff and Britt 2009), 2010 (Hoff and Britt 2011), and 2012 (Hoff 2013). See Appendices A1–A3 for summaries of the slope survey as they pertain to data on and estimates of Pribilof Island golden king crab stock biomass. Complete data on size-sex composition of survey catch are available only from the 2008–2012 biennial surveys (C. Armistead, NMFS-AFSC, Kodiak). Biomass estimates by sex and size class from the 2008, 2010, and 2012 surveys were presented in a May 2013 (Gaeuman 2013b; Appendix 2) report to the Crab Plan Team and biomass estimates of mature males from the 2008–2012 biennial surveys were presented in a September 2013 (Gaeuman 2013a) report to the Crab Plan Team. Using the size-sex composition data from the 2012 NMFS-AFSC eastern Bering Sea upper continental slope survey, Gaeuman (2013b) estimated total biomass for 2012 to be 1,925 t for the entire survey area and 711 t in the Pribilof Canyon area; Gaeuman (2013a) estimated mature male biomass for 2012 to be 812 t for the entire survey area and 256 t in the Pribilof Canyon area. Pengilly (2015; Appendix A3) estimated total and mature male biomass in the Pribilof District to be 1,444 t and 429 t, respectively, from the 2012 slope survey data.

4. <u>Recruitment</u>:

Using the size-sex composition data from the eastern Bering Sea upper continental slope trawl survey (see above), Gaeuman (2013a) estimated mature male biomass in the entire survey area to have increased slightly from 767 t in 2010 to 812 t in 2012, but have decreased in the Pribilof canyon area between those two years 440 t to 256 t. Pengilly (2015; Appendix A3) estimated mature male biomass from the slope survey data to have declined in the Pribilof District from 638 t in 2008 to 565 t in 2010 and to 429 t in 2012.

5. <u>Management performance</u>:

No overfished determination (i.e., MSST) has been made for this stock, although approaches to using data from the biennial NMFS-AFSC eastern Bering Sea upper continental slope surveys has been presented to and considered by the Crab Plan Team (Gaeuman 2013a, 2013b, Pengilly 2015; see Appendices A2 and A3). No vessels participated in the 2015 directed fishery (i.e., retained catch= 0 t; 0 lb) and no bycatch was observed in crab fisheries in 2015; therefore total catch in 2015 was zero. Although 1.15 t of fishery mortality occurred during groundfish fisheries in 2015/16, bycatch due to groundfish fisheries are not included in the total catch here because available data are summarized by "crab fishery year" rather than calendar year. Overfishing did not occur in 2015. The GHL for the 2017 has yet to be established (W. Donaldson, ADF&G, Kodiak, *pers. comm.*, 5 April 2016). The 2017 OFL and ABC in the table below are the author's recommendations.

Management Performance Table (values in t)

Calendar Year	MSST	Biomass (MMB)	GHL[a]	Retained Catch	Total Catch[b]	OFL	ABC
2013	N/A	N/A	68	Conf. [c]	Conf. [c]	90.7	81.6
2014	N/A	N/A	68	Conf. [c]	Conf. [c]	90.7	81.6
2015	N/A	N/A	59	0	1.15	91	68
2016	N/A	N/A	59			91	68
2017	N/A	N/A				93	70

a. Guideline harvest level, established in lb and converted to t.
b. Includes total retained catch and estimated bycatch mortality during crab fisheries by calendar year and bycatch mortality due to groundfish fisheries by "crab fishery year" (as this is how data are currently available).
c. Confidential under Sec. 16.05.815 (SOA statute). GHL not attained.

Management Performance Table (values in lb)

Calendar Year	MSST	Biomass (MMB)	GHL[a]	Retained Catch	Total Catch[b]	OFL	ABC
2013	N/A	N/A	150,000	Conf.[c]	Conf.[c]	0.20[d]	0.18[d]
2014	N/A	N/A	150,000	Conf.[c]	Conf.[c]	0.20[d]	0.18[d]
2015	N/A	N/A	130,000	0	2,535	0.20[d]	0.15[d]
2016	N/A	N/A	130,000			0.20[d]	0.15[d]
2017	N/A	N/A				204,527	153,395

a. Guideline harvest level.
b. Includes total retained catch and estimated bycatch mortality during crab fisheries by calendar year and bycatch mortality due to groundfish fisheries by "crab fishery year" (as this is how data are currently available).
c. Guideline harvest level.
d. Total retained catch plus estimated bycatch mortality of discarded catch during crab fisheries only. Bycatch mortality due to groundfish fisheries is not included here because available data are summarized by "crab fishery year" rather than calendar year; estimates of annual bycatch mortality during 1991/92–2014/15 groundfish fisheries are ≤19,480 lb, with an average of 5,101 lb.
e. Confidential under Sec. 16.05.815 (SOA statute). GHL not attained.
f. Established in millions of lb to the nearest 0.01-million lb.

6. **<u>Basis for the OFL and ABC</u>:** The values for 2017 are the author's recommendation.

Calendar Year	**Tier**	**Years to define Average catch (OFL)**	**Natural Mortality[b]**	**Buffer**
2013	5	1993–1998[a]	0.18 yr^{-1}	10%
2014	5	1993–1998[a]	0.18 yr^{-1}	10%
2015	5	1993–1998[a]	0.18 yr^{-1}	25%
2016	5	1993–1998[a]	0.18 yr^{-1}	25%
2017	5	1993–1998[a]	0.18 yr^{-1}	25%

a. OFL was for total catch and was determined by the average of the annual retained catch for these years multiplied by a factor of 1.052 to account for the estimated bycatch mortality occurring in the directed fishery plus an estimate of the average annual bycatch mortality due to non-directed crab fisheries and groundfish fisheries for the period.
b. Assumed value for FMP king crab in NPFMC (2007); does not enter into OFL estimation for Tier 5 stock.

7. **<u>PDF of the OFL:</u>** Sampling distribution of the recommended Tier 5 OFL was estimated by bootstrapping. The standard deviation of the estimated sampling distribution of the recommended OFL (Alternative 1) is 23 t (CV = 0.25). See section G.1.

8. **<u>Basis for the ABC recommendation:</u>** A 25% buffer on the OFL, the default; i.e., ABC = (1-0.25)·OFL. This is a data-poor stock.

9. **<u>A summary of the results of any rebuilding analyses</u>:** Not applicable; stock is not under a rebuilding plan.

A. Summary of Major Changes

1. **<u>Changes to the management of the fishery</u>:** Fishery continues to be managed under authority of an ADF&G commissioner's permit; guideline harvest level (GHL) was reduced from 68 t (150,000 lb) to 59 t (130,000 lb) in 2015 and remained at that level in 2016. The GHL for the 2017 has yet to be established.

2. **<u>Changes to the input data</u>:**
- Retained catch and discarded catch data have been updated with the results for the 2015 directed fishery, during which no vessels participated, and bycatch in other crab fisheries in 2015, which was zero.
- Discarded catch estimates from groundfish fisheries have been updated with estimates for the 2015/16 crab fishery season, which resulted in 1.15 t of bycatch mortality.

3. **<u>Changes to the assessment methodology</u>:** This assessment follows the methodology recommended by the CPT since May 2012 and the SSC since June 2012.

4. **<u>Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL</u>:** The computation of OFL in this assessment follows the methodology recommended by the CPT in May 2012 and the SSC in June 2012 applied to the same data and estimates with the same assumptions that were used for estimating the 2013–2017 Tier 5 OFLs; computations applied directly to data and estimates expressed in metric units resulted in minor changes in results due to rounding used in previous assessments.

B. Responses to SSC and CPT Comments

- **<u>Responses to the most recent two sets of SSC and CPT comments on assessments in general (and relevant to this assessment)</u>:**
  - <u>CPT, May 2015</u>: *None pertaining to a Tier 5 assessment*.
  - <u>SSC, June 2015</u>: "*The SSC appreciates the author's inclusion of standard and metric units in the text but requests consistency in which units are used (e.g., lbs., thousand lbs., or million lbs. and t, mt, or kg). The SSC also requests consistency in the units chosen for tables and figures, requests that the units cited in the table legends match the values in the tables, and suggests authors refer to the terms of reference for chapters.*"
    - <u>Response</u>: The CPT terms of reference (as updated during the January 2016 meeting) were referred to: "*To maintain consistency among SAFEs, the documents should report everything in the document in metric tons. The executive summary and the data used in the harvest strategy should be presented in both metric tons (abbreviated t) and pounds (lb).*" Weight-related numbers were reported in metric tons. Weights are given in both t

and lb for the following: weights in the text of the <u>Management performance</u> section of the Executive Summary; weights in the Management Performance table; retained catch weights in the Executive Summary; GHLs/TACs throughout the document; retained catch weights when presented relative to GHLs/TACs throughout the document; retained catch weights in section C.4 ("Brief summary of management history); and the results of computation of the recommended 2017 OFL and ABC. Otherwise weights are presented only in t. For consistency in units, weights in the text and in reporting of recommended OFL and ABC are given in whole t for metric units and whole lb for U.S. customary units; in tables of data and estimates, however, some metric weights are given to several decimal places because some non-zero values round to 0 t. Reporting OFL and ABC for 2017 in t and lb may result in inconsistencies in the Management Performance tables and in the text when presenting previous OFLs and ABCs established using different conventions for units.

- *"Provide single plot of all model data sources and years applicable – **Comment [4]: The Stockhausen tables**."* Done. See Table 4.

- <u>CPT, September 2015</u> (via September 2014 SAFE Introduction chapter): *None pertaining to a Tier 5 assessment*.
- <u>SSC, October 2015</u>: *None.*

- **<u>Responses to the most recent two sets of SSC and CPT comments specific to the assessment</u>:**
  - <u>CPT, May 2015</u>:
    - "*The CPT recommends the author add a notation to tables specifying whether or not the GHL was reached."*
      - <u>Response</u>: Done.
    - "*...the document should include a summary of available slope survey data.*"
      - <u>Response</u>: Done (see Appendices A1–A3).
  - <u>SSC, June 2015:</u>
    - "*...supports the CPT recommendation that the author add notation to tables specifying whether or not the GHL was reached.*"
      - <u>Response</u>: Done.
    - "*The SSC also requests that the author approach the harvester(s) regarding whether they would voluntarily allow confidential data to be presented in assessments.*"
      - In progress (M. Westphal, ADF&G, Dutch Harbor, *pers. comm.*, 29 August 2016)
    - "*The SSC supports the CPT recommendation that a preliminary Tier 4 assessment be brought to the September 2015 meeting, using existing slope data and applying a Kalman filter approach.*"
      - Done in September 2015 (see Appendix A3).
    - "*The SSC also asks that a Stock Structure Template be completed for PI GKC.*"
      - Done in September 2015 (see Appendix A3:C of Appendix A3).

    - "*...future versions of the document include a summary of available slope survey data with appropriate graphs and plots...*"
        - Done (see Appendices A1–A3).
- CPT, September 2015:
    - "*The CPT recommends the random effects model be re-evaluated after results from the 2016 slope survey are available.*"
        - Response: Okay.
- SSC, October 2015:
    - *"The SSC concurs with the CPT recommendation"* ["*that the random effects model be re-evaluated after results from the 2016 slope survey are available*"]
        - Response: Okay.

C. Introduction

1. **Scientific name:** *Lithodes aequispinus* J. E. Benedict, 1895

2. **Description of general distribution:**

General distribution of golden king crab is summarized by NMFS (2004):

> Golden king crab, also called brown king crab, range from Japan to British Columbia. In the BSAI, golden king crab are found at depths from 200 m to 1,000 m, generally in high-relief habitat such as inter-island passes (pages 3–34).
>
> Golden, or brown, king crab occur from the Japan Sea to the northern Bering Sea (ca. 61° N latitude), around the Aleutian Islands, on various sea mounts, and as far south as northern British Columbia (Alice Arm) (Jewett et al. 1985). They are typically found on the continental slope at depths of 300–1,000 m on extremely rough bottom. They are frequently found on coral bottom (pages 3–43).

The Pribilof District is part of king crab Registration Area Q (Figure 1). Fitch et al. (2014, page 8) define those boundaries:

> The Bering Sea king crab Registration Area Q has as its southern boundary a line from 54° 36' N lat., 168° W long., to 54° 36' N lat., 171° W long., to 55° 30' N lat., 171° W. long., to 55° 30' N lat., 173° 30' E long., as its northern boundary the latitude of Point Hope (68° 21' N lat.), as its eastern boundary a line from 54° 36' N lat., 168° W long., to 58° 39' N lat., 168° W long., to Cape Newenham (58° 39' N lat.), and as its western boundary the United States-Russia Maritime Boundary Line of 1991. Area Q is divided into the Pribilof District, which includes waters south of Cape Newenham, and the Northern District, which incorporates all waters north of Cape Newenham.

NMFS-AFSC conducted an eastern Bering Sea continental slope trawl survey on a biennial schedule during 2002–2012, the survey scheduled for 2014 was cancelled, and the survey schedule resumed in 2016. Results of the 2002–2012 biennial eastern Bering Sea continental slope trawl surveys show that the biomass, number, and density (in number per area and in weight per area) of golden king crab on the eastern Bering Sea continental slope are higher in the southern areas than in the northern areas (Gaeuman 2013a, 2013b; Haaga et al. 2009; Hoff 2013; Hoff and Britt 2003, 2005, 2009, 2011; Pengilly 2015). Of the six survey subareas (see Figure 1 in Hoff 2013), biomass and abundance of golden king crab were estimated through 2010 to be highest in the Pribilof Canyon area (survey subarea 2). Most of the commercial fishery catch for golden king crab is reported to occur in the Pribilof Canyon area (Fitch et al. 2014; Neufeld and Barnard 2003; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006). However, biomass was estimated to have decreased between 2010 and 2012 in the Pribilof Canyon area and to have increased between 2010 and 2012 in the survey subarea 1 (the southernmost of the survey subareas), so that biomass in 2012 was estimated to be highest in survey subarea 1. Results from the 2016 survey have yet to be reviewed.

Results of the 2002–2012 biennial NMFS-AFSC eastern Bering Sea continental slope trawl surveys showed that a majority of golden king crab on the eastern Bering Sea continental slope occurred in the 200–400 m and 400–600 m depth ranges (Haaga et al. 2009; Hoff 2013; Hoff and Britt 2003, 2005, 2009, 2011). Commercial fishing for golden king crab in the Bering Sea typically occurs at depths of 100–300 fathoms (183–549 m; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006; Gaeuman 2011, 2013c, 2014; Neufeld and Barnard 2003); average depth of pots fished in the 2002 Pribilof District golden king crab fishery (the most recently prosecuted fishery for which fishery observer data are not confidential) was 214 fathoms (391 m).

3. **<u>Evidence of stock structure</u>:**

Although highest densities of golden king crab are found in the deep canyons of the eastern Bering Sea continental slope, golden king crab occur sporadically on the surveyed slope at locations between those canyons in the eastern Bering Sea (Hoff 2013; Hoff and Britt 2003, 2005, 2009, 2011; Gaeuman 2013b, 2014). Stock structure within the Pribilof District has not been evaluated. Fishery and slope survey data suggest that areas at the northern and southern border of the Pribilof District are largely devoid of golden king crab (Pengilly 2015; Appendix A3), but the stock relationship of the golden king crab within the Pribilof District with the golden king crab outside of the Pribilof District has not been evaluated.

4. **<u>Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology)</u>:**

The following review of molt timing and reproductive cycle of golden king crab is adapted from Watson et al. (2002):

> Unlike red king crab, golden king crab may have an asynchronous molting cycle (McBride et al. 1982, Otto and Cummiskey 1985, Sloan 1985, Blau and Pengilly 1994). In a sample of male golden king crab 95–155-mm CL and female golden king crab 104–157-mm CL collected from Prince William Sound and held in seawater tanks, Paul and Paul (2000) observed molting in every month of the year, although the highest frequency of molting occurred during May–October. Watson et al. (2002) estimated that only 50% of 139-mm CL male golden king crab in the eastern Aleutian Islands molt annually and that the intermolt period for males ≥150-mm CL averages >1 year.

Female lithodids molt before copulation and egg extrusion (Nyblade 1987). From their observations on embryo development in golden king crab, Otto and Cummiskey's (1985) suggested that time between successive ovipositions was roughly twice that of embryo development and that spawning and molting of mature females occurs approximately every two years. Sloan (1985) also suggested a reproductive cycle >1 year with a protracted barren phase for female golden king crab. Data from tagging studies on female golden king crab in the Aleutian Islands are generally consistent with a molt period for mature females of 2 years or less and that females carry embryos for less than two years with a prolonged period in which they remain in barren condition (Watson et al 2002). From laboratory studies of golden king crab collected from Prince William Sound, Paul and Paul (2001b) estimated a 20-month reproductive cycle with a 12-month clutch brooding period.

Numerous observations on clutch and embryo condition of mature female golden king crab captured during surveys have been consistent with asynchronous, aseasonal reproduction (Otto and Cummiskey 1985, Hiramoto 1985, Sloan 1985, Somerton and Otto 1986, Blau and Pengilly 1994, Blau et al. 1998, Watson et al. 2002). Based on data from Japan (Hiramoto and Sato 1970), McBride et al. (1982) suggested that spawning of golden king crab in the Bering Sea and Aleutian Islands occurs predominately during the summer and fall.

The success of asynchronous and aseasonal spawning of golden king crab may be facilitated by fully lecithotrophic larval development (i.e., the larvae can develop successfully to juvenile crab without eating; Shirley and Zhou 1997).

Current knowledge of reproductive biology and maturity of male and female golden king crab is also reviewed by Webb (2014).

Note that asynchronous, aseasonal molting and the prolonged intermolt period (>1 year) of mature female and the larger male golden king crab likely makes scoring shell conditions very difficult and especially difficult to relate to "time post-molt," posing problems for inclusion of shell condition data into assessment models.

5. <u>Brief summary of management history</u>:

A complete summary of the management history through 2011 is provided in Fitch et al. (2014, pages 86–87).

The first domestic harvest of golden king crab in the Pribilof District was in 1981/82 when two vessels fished. Peak retained catch and participation occurred in 1983/84 at a retained catch of 388 t (856,475 lb) landed by 50 vessels (Tables 1a and 1b). Since 1984 the fishery has been managed with a calendar-year fishing season under authority of a commissioner's permit and landings and participation has been low and sporadic. Retained catch since 1984 has ranged from 0 t (0 lb) to 155 t (341,908 lb) and the number of vessels participating annually has ranged from 0 to 8. No vessels fished in 2006–2009 and 2015, 1 vessel fished in each of 2010 and 2012–2014, and 2 vessels fished in 2011.

The fishery is not rationalized and has been managed inseason to a guideline harvest level (GHL) since 1999. The GHL for 1999 was 91 t (200,000 lb), whereas the GHL for 2000–2014 was 68 t (150,000 lb). Following the reduction of ABC from 82 t for 2014 to 68 t for 2015, the GHL was reduced in 2015 to 59 t (130,000 lb).

Catch statistics for 2003–2005 and 2010–2014 are confidential under Sec. 16.05.815 of SOA statutes. It can be noted, however, that the 2003 and 2004 fisheries were closed by emergency order to manage the fishery retained catch towards the GHL, whereas the 2005 and 2010–2014 fisheries were not closed by emergency order. With regard to 2004, "Catch rates during the 2004 fishery were among the highest on record, and the fishery was the shortest ever at approximately three weeks in duration" (Bowers et al. 2005, pages 84–85).

A summary of relevant fishery regulations and management actions pertaining to the Pribilof District golden king crab fishery is provided below.

Only males of a minimum legal size may be retained. By State of Alaska regulation (**5 AAC 34.920 (a)**), the minimum legal size limit for Pribilof District golden king crab is 5.5-inches (140 mm) carapace width (CW), including spines. A carapace length (CL) ≥124 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007). Golden king crab may be commercially fished only with king crab pots (as defined in 5 AAC 34.050); pots used to take golden king crab in Registration Area Q (Bering Sea) may be longlined (5 AAC 34.925(f)). Pots used to fish for golden king crab in the Pribilof District must have at least four escape rings of no less than five and one-half inches inside diameter installed on the vertical plane or at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized golden king crab (5 AAC 34.925 (c)) and the sidewall "…must contain an opening equal to or exceeding 18 inches in length... The opening must be laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 30 thread." (5 AAC 39.145(1)). There is a pot limit of 40 pots for vessels ≤125-feet LOA and of 50 pots for vessels >125-feet LOA (5 AAC 34.925 (e)(1)(B)). Golden king crab can be harvested from 1 January through 31 December only under conditions of a permit issued by the commissioner of ADF&G (**5 AAC 34.910 (b)(3)**). Since 2001, those conditions have included the carrying of a fisheries observer.

D. Data

1. **Summary of new information**:
    1. Retained catch and estimated discarded catch during the 2015 directed fishery (no effort and no catch), estimated discarded catch during other crab fisheries in 2015 (no catch), and the estimated discarded catch in groundfish fisheries during the 2015/16 crab fishery year have been added.

2. **Data presented as time series**:

a. Total catch and b. Information on bycatch and discards:

- The 1981/82–1983/84, 1984–2015 time series of retained catch (number and weight of crab, including deadloss), effort (vessels and pot lifts), average weight of landed crab, average carapace length of landed crab, and CPUE (number of landed crab captured per pot lift) are presented in Tables 1a and 1b.

- The 1993–2015 time series of weight of retained catch and estimated weight of discarded catch and estimated weight of fishery mortality of Pribilof golden king crab during the directed fishery and all other crab fisheries are given in Table 2. Discarded catch of Pribilof golden king crab occurs mainly in the directed golden king crab fishery, when prosecuted, and to a lesser extent in the Bering Sea snow crab fishery and the Bering Sea grooved Tanner crab fishery when prosecuted. Because the Bering Sea snow crab fishery is largely prosecuted between January and May and the Bering Sea grooved Tanner crab fishery is prosecuted with a calendar year season, discarded catch in the crab fisheries can be estimated on a calendar year basis to align with the calendar-year season for Pribilof District golden king crab. Observer data on size distributions and estimated catch numbers of discarded catch were used to estimate the weight of discarded catch of golden king crab by applying a weight-at-length estimator (see below). Observers were first deployed to collect discarded catch data during the Pribilof District golden king crab fishery in 2001 and during the Bering Sea grooved Tanner crab fishery in 1994. Retained catch or observer data are confidential for at least one of the crab fisheries in 1999–2001, 2003–2005, and 2010−2014. Following Siddeek et al. (2014), the bycatch mortality rate of golden king crab captured and discarded during Aleutian Islands golden king crab fishery was assumed to be 0.2. Following Foy (2013), bycatch mortality rate of king crab during the snow crab fishery was assumed to be 0.5. The bycatch mortality rate during the grooved Tanner crab fishery was also assumed to be 0.5.
- The groundfish fishery discarded catch data are grouped into crab fishery years, rather than into calendar years. The 1991/92–2015/16 time series of estimated annual weight of discarded catch and total fishery mortality of golden king crab during federal groundfish fisheries by gear type (combining pot and hook-and-line gear as a single “fixed gear” category and combining non-pelagic and pelagic trawl gear as a single “trawl” category) is provided in Table 3. Following Foy (2013), the bycatch mortality of king crab captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crab captured by trawls during groundfish fisheries was assumed to be 0.8. Data from 1991/92–2008/09 are from federal reporting areas 513, 517, and 521, whereas the data from 2009/10–2015/16 are from the State statistical areas falling within the Pribilof District (see various attachments to 13 August 2015 email from R. Foy, NMFS-AFSC-Kodiak).
- Table 4 summarizes the available data on retained catch weight and the available estimates of discarded catch weight.

c. ***Catch-at-length:*** Not used in a Tier 5 assessment; none are presented.

d. Survey biomass estimates: Survey biomass estimates are not used in a Tier 5 assessment. However, see Appendices A2-A3 for biomass estimates of mature male golden king crab using data from the 2002–2012 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey.

e. ***Survey catch at length:*** Survey catch at length data are not used in a Tier 5 assessment. However, see Appendices A1–A3 for size data composition by sex of golden king crab during the 2002–2012 Bering Sea upper continental slope trawl surveys.

f. ***Other data time series:*** None.

3. Data which may be aggregated over time:

a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):

The author is not aware of data on growth per molt collected from golden king crab in the Pribilof District. Growth per molt of juvenile golden king crab, 2–35 mm CL, collected from Prince William Sound have been observed in a laboratory setting and equations describing the increase in CL and intermolt period were estimated from those observations (Paul and Paul 2001a); those results are not provided here. Growth per molt has also been estimated from golden king crab with CL ≥90 mm that were tagged in the Aleutian Islands and recovered during subsequent commercial fisheries (Watson et al. 2002); those results are not presented here because growth-per-molt information does not enter into a Tier 5 assessment.

See section **C.4** for discussion of evidence that mature female and the larger male golden king crab exhibit asynchronous, aseasonal molting and a prolonged intermolt period (>1 year).

b. Weight-at length or weight-at-age (by sex):

Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female golden king crab according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007) are: A = 0.0002988 and B = 3.135 for males and A = 0.001424 and B = 2.781 for females.

c. Natural mortality rate:

The default natural mortality rate assumed for king crab species by NPFMC (2007) is M=0.18. Note, however, natural mortality was not used for OFL estimation because this stock belongs to Tier 5.

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

- Standardized bottom trawl surveys to assess the groundfish and invertebrate resources of the eastern Bering Sea upper continental slope were performed in 2002, 2004, 2008, 2010, 2012, and 2016 (Hoff and Britt 2003, 2005, 2009, 2011; Haaga et al. 2009, Gaeuman 2013a, b). Data and analysed results pertaining to golden king crab from the 2008–2012 EBS upper continental slope surveys are provided in Appendices A1–A3, but are not used in this Tier 5 assessment. Data from the 2016 survey has yet to be reviewed.
- Data on the size and sex composition of retained catch and discarded catch of Pribilof District golden king crab during the directed fishery and other crab fisheries are available but are not presented in this Tier 5 assessment.

E. Analytic Approach

1. History of modeling approaches for this stock:

Gaeuman (2013a, b) and Pengilly (2015) presented assessment-modelling approaches for this stock to the Crab Plan Team using data from the biennial NMFS EBS continental slope survey Appendices A2 and A3). However, following the cancellation of the 2014 slope survey, this stock continued to be managed as a Tier 5 stock for 2016, as had been recommended by NPFMC (2007) and by the CPT and SSC in 2008−2015.

2. <u>Model Description</u>: *Subsections a–i are not applicable to a Tier 5 sock.*
Only an OFL and ABC is estimated For Tier 5 stocks, where "the OFL represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock" (NPFMC 2007). Although NPFMC (2007) defined the OFL in terms of the retained catch, total-catch OFLs may be considered for Tier 5 stocks for which non-target fishery removal data are available (Federal Register/Vol. 73, No. 116, 33926). The CPT (in May 2010) and the SSC (in June 2010) endorsed the use of a total-catch OFL to establish the OFL for this stock. This assessment recommends – and only considers – use of a total-catch OFL for 2017.

Additionally, NPFMC (2007) states that for estimating the OFL of Tier 5 stocks, "The time period selected for computing the average catch, hence the OFL, should be based on the best scientific information available and provide the required risk aversion for stock conservation and utilization goals." Given that a total-catch OFL is to be used, alternative configurations for the Tier 5 model are limited to: 1) alternative time periods for computing the average total-catch mortality; and 2) alternative approaches for estimating the discarded catch component of the total catch mortality during that period.

With regard to choosing from alternative time periods for computing average annual catch to compute the OFL, NPFMC (2007) suggested using the average retained catch over the years 1993 to 1999 as the estimated OFL for Pribilof District golden king crab. Years post-1984 were chosen based on an assumed 8-year lag between hatching and growth to legal size after the 1976/77 "regime shift". With regard to excluding data from years 1985 to 1992 and years after 1999, NPFMC (2007) states, "The excluded years are from 1985 to 1992 and from 2000 to 2005 for Pribilof Islands golden king crab when the fishing effort was less than 10% of the average or the GHL was set below the previous average catch." In 2008 the CPT and SSC endorsed the approach of estimating OFL as the average retained catch during 1993–1999 for setting a retained-catch OFL for 2009. However, in May 2009 the CPT set a retained-catch OFL for 2010, but using the average retained catch during 1993–1998; 1999 was excluded because it was the first year that a preseason GHL was established for the fishery. In May 2010, the CPT established a total-catch OFL computed as a function of the average retained catch during 1993–1998, a ratio-based estimate of the bycatch mortality during the directed fishery of that period, and an estimate of the "background" bycatch mortality due to other fisheries. Other time periods, extending into years post-1999, had been considered for computing the average retained catch in the establishment of the 2009, 2010, 2011 OFLs, but those time periods were rejected by the CPT and the SSC. Hence the period for calculating the retained-catch portion of the Tier 5 total-catch OFL for this stock has been firmly established by the CPT and SSC at 1993–1998 (the CPT said "this freezes the time frame..."). For the 2012 and the 2013 OFLs, the CPT and SSC recommended the period 2001–2010 for calculating the ratio-based estimate of the bycatch mortality during the 1993–1998 directed fishery, the period 1994–1998 for calculating the estimated bycatch mortality due to non-directed crab fisheries during 1993–1998, and the period 1992/93–1998/99 for calculating the estimated bycatch mortality due to groundfish fisheries during 1993–1998.

Two alternative approaches for determination of the 2013 OFL were presented to the CPT and SSC in May–June 2013. Alternative 1 was the status quo approach (i.e., the approach used to establish the 2012 total-catch OFL). Alternative 2 was the same as Alternative 1 except that it used updated discarded catch data from crab fisheries in 2011. Alternative 2 was presented specifically to allow the CPT and the SSC to clarify whether the 2013 and subsequent OFLs should be computed using data collected after 2010, or if the time periods for data used to calculate the 2013 and subsequent OFLs should be "frozen" at the years used to calculate the 2012 OFL. The CPT and the SSC both recommended Alternative 1, clarifying that Tier 5 OFLs for future years should be computed using only data collected through 2010. Following that recommendation from CPT and the SSC, only one alternative was presented for computing the 2014–2016 Tier 5 OFLs (i.e., the Alternative 1 that was presented in 2013). The 2017 Tier 5 OFL recommended here uses the same approach as used for the 2013–2016 Tier 5 OFLs.

3. Model Selection and Evaluation:

a. ***Description of alternative model configurations***

The recommended OFL is set as a total-catch OFL using 1993–1998 to compute average annual retained catch, an estimate of the ratio of bycatch mortality to retained catch during the directed fishery, an estimate of the average annual bycatch mortality due to the non-directed crab fisheries during 1994–1998, and an estimate of average annual bycatch mortality due to the groundfish fisheries during 1992/93–1998/99; i.e.,

$$OFL_{2017} = (1+R_{2001\text{–}2010})*RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,92/93\text{–}98/99},$$

where,

- $R_{2001\text{–}2010}$ is the average of the estimated annual ratio of bycatch mortality to retained catch in the directed fishery during 2001–2010
- $RET_{1993\text{-}1998}$ is the average annual retained catch in the directed crab fishery during 1993–1998
- $BM_{NC,1994\text{-}1998}$ is the estimated average annual bycatch mortality in non-directed crab fisheries during 1994–1998
- $BM_{GF,92/93\text{–}98/99}$ is the estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99.

The average of the estimated annual ratio of bycatch mortality to retained catch in the directed fishery during 2001–2010 is used as a factor to estimate bycatch mortality in the directed fishery during 1993–1998 because, whereas there are no data on discarded catch for the directed fishery during 1993–1998, there are such data from the directed fishery during 2001–2010 (excluding 2006–2009, when there was no fishery effort).

The estimated average annual bycatch mortality in non-directed fisheries during 1994–1998 is used to estimate the average annual bycatch mortality in non-directed fisheries during 1993–1998 because there are no discarded catch data available for the non-directed fisheries during 1993.

The estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99 is used to estimate the average annual bycatch mortality in groundfish fisheries during 1993–1998 because 1992/93–1998/99 is the shortest time period of crab fishery years that encompasses calendar years 1993–1998.

Statistics on the data and estimates used to calculate $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$ are provided in Table 5; the column means in Table 5 are the calculated values of $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$. Using the calculated values of $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$, the calculated value of OFL_{2017} is,

$$OFL_{2017} = (1+0.052)*78.80 \text{ t} + 6.09 \text{ t} + 3.79 \text{ t} = 93 \text{ t } (204{,}527 \text{ lbs}).$$

b. ***Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed:*** See the table, below.

Model	**Retained-vs. Total-catch**	**Time Period**	**Resulting OFL (t)**
Recommended/status quo	Total-catch	1993–1998	93

This is recommended as being the best approach with the limited data available and follows the advice of the CPT and SSC to “freeze” the period for calculation of the OFL at the time period that was established for the 2012 OFL and uses the computations recommended by the CPT and SSC in 2013.

c. ***Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models:*** See Section E, above.

d. ***Convergence status and convergence criteria for the base-case model (or proposed base-case model):*** Not applicable.

e. ***Table (or plot) of the sample sizes assumed for the compositional data:*** Not applicable.

f. ***Do parameter estimates for all models make sense, are they credible?:***
The time period used for determining the OFL was established by the SSC in June 2012. Retained catch data come from fish tickets and annual retained catch is considered a known (not estimated) value. Estimates of discarded catch from crab fisheries data are generally considered credible (e.g., Byrne and Pengilly 1998, Gaeuman 2011, 2013c, 2014), but may have greater uncertainty in a small, low effort fishery such as the Pribilof golden king crab fishery. Estimates of bycatch mortality are estimates of discarded catch times an assumed bycatch mortality rate. The assumed bycatch mortality rates (i.e., 0.2 for crab fisheries, 0.5 for fixed-gear groundfish fisheries, and 0.8 for trawl groundfish fisheries) have not been estimated from data.

g. ***Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty:*** See section E.3.c, above.

h. ***Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach):*** Not applicable.

i. ***Evaluation of the model, if only one model is presented; or evaluation of alternative models and selection of final model, if more than one model is presented:*** See section E.3.c, above.

4. Results (best model(s)):

a. List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties: Not applicable.

b. Tables of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible; include estimates from previous SAFEs for retrospective comparisons): See Tables 2–5.

c. Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible): Information requested for this subsection is not applicable to a Tier 5 stock.

d. Evaluation of the fit to the data: Not applicable for Tier 5 stock.

e. Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments): Not applicable for Tier 5 stock.

f. Uncertainty and sensitivity analyses (this section should highlight unresolved problems and major uncertainties, along with any special issues that complicate scientific assessment, including questions about the best model, etc.): For this assessment, the major uncertainties are:

- Whether the time period is "representative of the production potential of the stock" and if it serves to "provide the required risk aversion for stock conservation and utilization goals." Or whether any such time period exists.
    - Only a period of 6 years is used to compute the OFL, 1993–1998. The SSC has noted its uneasiness with that situation ("6 years of data are very few years upon which to base these catch specifications." June 2011 SSC minutes).
- No data on discarded catch due to the directed fishery are available from the period used to compute the OFL. Estimation of the OFL rests on the assumption that data on the ratio of discarded catch to retained catch from post-2000 can be used to accurately estimate that ratio in 1993–1998.
- The bycatch mortality rates used in estimation of total catch. Bycatch mortality is unknown and no data that could be used to estimate the bycatch mortality of this stock are known to the author. Hence, only the values that are assumed for other BSAI king crab stock assessments are considered in this assessment. The estimated OFL increases (or decreases) relative to the bycatch mortality rates assumed: doubling the assumed

bycatch mortality rates increases the OFL estimate by a factor of 1.15; halving the assumed bycatch mortality rates decreases the OFL estimate by a factor of 0.92.

F. Calculation of the OFL

1. **Specification of the Tier level and stock status level for computing the OFL:**
   - Recommended as Tier 5, total-catch OFL estimated by estimated average total catch over a specified period.
   - Recommended time period for computing retained-catch OFL: 1993–1998.
     - This is the same time period that was used to establish OFL for 2010–2016. The time period 1993–1998 provides the longest continuous time period through 2015 during which vessels participated in the fishery, retained-catch data can be retrieved that are not confidential, and the retained catch was not constrained by a GHL. Data on discarded catch contemporaneous with 1993-1998 to the extent possible are used to calculate the total-catch OFL.

2. **List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan:** Not applicable for Tier 5 stock.

3. **Specification of the total-catch OFL:**

a. Provide the equations (from Amendment 24) on which the OFL is to be based:

From **Federal Register** / Vol. 73, No. 116, page 33926, "For stocks in Tier 5, the overfishing level is specified in terms of an average catch value over an historical time period, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information." Additionally, "For stocks where nontarget fishery removal data are available, catch includes all fishery removals, including retained catch and discard losses. Discard losses will be determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the overfishing level is set for and compared to the retained catch" (FR/Vol. 73, No. 116, 33926). That compares with the specification of NPFMC (2007) that the OFL "represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock."

b. Basis for projecting MMB to the time of mating: Not applicable for Tier 5 stock.

c. Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring: See table below. No vessels participated in the 2015 directed fishery and no bycatch was observed in crab fisheries in 2015; therefore total catch in 2015 was zero. Although 1.15 t of fishery mortality occurred during groundfish fisheries in 2015/16, bycatch due to groundfish fisheries is not included in the total catch here because available data are summarized by "crab fishery year" rather than calendar year. Overfishing did not occur in 2015. Values for the 2017 OFL and ABC are the author's recommendations.

Management Performance Table (values in t)

Calendar Year	MSST	Biomass (MMB)	GHL[a]	Retained Catch	Total Catch[b]	OFL	ABC
2013	N/A	N/A	68	Conf. [c]	Conf. [c]	90.7	81.6
2014	N/A	N/A	68	Conf. [c]	Conf. [c]	90.7	81.6
2015	N/A	N/A	59	0	0	91	68
2016	N/A	N/A	59			91	68
2017	N/A	N/A				93	70

a. Guideline harvest level, established in lb and converted to t.
b. Total retained catch plus estimated bycatch mortality of discarded catch during crab fisheries only. Bycatch mortality due to groundfish fisheries is not included here because available data are summarized by "crab fishery year" rather than calendar year; estimates of annual bycatch mortality during 1991/92–2014/15 groundfish fisheries are ≤9 t, with an average of 2 t.
c. Confidential under Sec. 16.05.815 (SOA statute). GHL not attained.

Management Performance Table (values in lb)

Calendar Year	MSST	Biomass (MMB)	GHL[a]	Retained Catch	Total Catch[b]	OFL	ABC
2013	N/A	N/A	150,000	Conf.[c]	Conf.[c]	0.20[d]	0.18[d]
2014	N/A	N/A	150,000	Conf.[c]	Conf.[c]	0.20[d]	0.18[d]
2015	N/A	N/A	130,000	0	0	0.20[d]	0.15[d]

a. Confidential under Sec. 16.05.815 (SOA statute). GHL not attained.
b. Established in millions of lb to the nearest 0.01-million lb.

4. **Specification of the retained-catch portion of the total-catch OFL:**
   a. **Equation for recommended retained-portion of total-catch OFL.**
   Retained-catch portion = average retained catch during 1993–1998 (Table 5).
   = 79 t.

   Note that a retained catch of 79 t would exceed the author's recommended ABC for 2017 (70 t); see G.4, below.

5. **<u>Recommended F_{OFL}, OFL total catch and the retained portion for the coming year</u>:**
   See sections ***F.3*** and ***F.4****,* above; no F_{OFL} is recommended for a Tier 5 stock.

G. Calculation of ABC

1. PDF of OFL. A bootstrap estimates of the sampling distribution (assuming no error in estimation of discarded catch) of the status quo Alternative 1 OFL is shown in Figure 2 (1,000 samples drawn with replacement independently from each of the four columns of values in Table 5 to calculate $R_{2001\text{-}2010}$, $RET_{1993\text{-}1998}$, $BM_{NC,1994\text{-}1998}$, $BM_{GF,92/93\text{-}98/99}$, and OFL_{2016}). The mean and CV computed from the 1,000 replicates are 92 t and 0.25, respectively. Note that generated sampling distribution and computed standard deviation are meaningful as measures in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Sections E.2 and E.4.f).

2. List of variables related to scientific uncertainty.

- Bycatch mortality rate in each fishery that discarded catch occurs. Note that for Tier 5 stocks, an increase in an assumed bycatch mortality rate will increase the OFL (and hence the ABC), but has no effect on the retained-catch portion of the OFL or the retained-catch portion of the ABC.

- Estimated discarded catch and bycatch mortality for each fishery that discarded catch occurred in during 1993–1998.
- The time period to compute the average catch under the assumption of representing "a time period determined to be representative of the production potential of the stock."
- Stock size in 2017 is unknown.

3. List of additional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.

5. Author recommended ABC. 25% buffer on OFL; i.e., ABC = (1-0.25)·(93 t) = 70 t (153,395 lb).

H. Rebuilding Analyses

Not applicable; this stock has not been declared overfished.

I. Data Gaps and Research Priorities

Data from the 2008–2012 biennial NMFS-AFSC eastern Bering Sea upper continental slope trawl surveys have been examined for their utility in determining overfishing levels and stock status by Gaeuman (2103a, b) and Pengilly (2015). Cancellation of the survey that was scheduled for 2014 raised uncertainties on the prospects for obtaining fishery-independent survey data on this stock in the future; however, the slope survey was conducted in summer 2016.

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Table 1a. Commercial fishery history for the Pribilof District golden king crab fishery, 1981/82 through 2015: number of vessels, guideline harvest level (GHL; established in lb, **converted to t**), weight of retained catch (Harvest; **t**), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (**kg**) of landed crab.

Fishing/Calendar Year	Vessels	GHL	Harvest[a]	Crab[a]	Pot lifts	CPUE	Average weight
1981/82	2	–	CF	CF	CF	CF	CF
1982/83	10	–	32	15,330	5,252	3	2.1
1983/84	50	–	388	253,162	26,035	10	1.5
1984	0	–	0	0	0	–	–
1985	1	–	CF	CF	CF	CF	CF
1986	0	–	0	0	0	–	–
1987	1	–	CF	CF	CF	CF	CF
1988 - 1989	2	–	CF	CF	CF	CF	CF
1990 - 1992	0	–	0	0	0	–	–
1993	5	–	31	17,643	15,395	1	1.7
1994	3	–	40	21,477	1,845	12	1.9
1995	7	–	155	82,489	9,551	9	1.9
1996	6	–	149	91,947	9,952	9	1.6
1997	7	–	81	43,305	4,673	9	1.9
1998	3	–	16	9,205	1,530	6	1.8
1999	3	91	80	44,098	2,995	15	1.8
2000	7	68	58	29,145	5,450	5	2.0
2001	6	68	66	33,723	4,262	8	2.0
2002	8	68	68	34,860	5,279	6	2.0
2003	3	68	**CF**	**CF**	**CF**	**CF**	**CF**
2004	5	68	**CF**	**CF**	**CF**	**CF**	**CF**
2005	4	68	CF	CF	CF	CF	CF
2006 - 2009	0	68	0	0	0	–	–
2010	1	68	CF	CF	CF	CF	CF
2011	2	68	CF	CF	CF	CF	CF
2012	1	68	CF	CF	CF	CF	CF
2013	1	68	CF	CF	CF	CF	CF
2014	1	68	CF	CF	CF	CF	CF
2015	0	59	0	0	0	–	–

Note: CF: confidential information due to less than three vessels or processors having participated in fishery;
CF: confidential information and fishery was closed by emergency order to manage the harvest to the preseason GHL.

[a] Deadloss included.

Table 1b. Commercial fishery history for the Pribilof District golden king crab fishery, 1981/82 through 2015: number of vessels, guideline harvest level (GHL; **lb**), weight of retained catch (Harvest; **lb**), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (**lb**) of landed crab.

Fishing/Calendar Year	Vessels	GHL	Harvest[a]	Crab[a]	Pot lifts	CPUE	Average weight
1981/82	2	–	CF	CF	CF	CF	CF
1982/83	10	–	69,970	15,330	5,252	3	4.6
1983/84	50	–	856,475	253,162	26,035	10	3.4
1984	0	–	0	0	0	–	–
1985	1	–	CF	CF	CF	CF	CF
1986	0	–	0	0	0	–	–
1987	1	–	CF	CF	CF	CF	CF
1988 - 1989	2	–	CF	CF	CF	CF	CF
1990 - 1992	0	–	0	0	0	–	–
1993	5	–	67,458	17,643	15,395	1	3.8
1994	3	–	88,985	21,477	1,845	12	4.1
1995	7	–	341,908	82,489	9,551	9	4.1
1996	6	–	329,009	91,947	9,952	9	3.6
1997	7	–	179,249	43,305	4,673	9	4.1
1998	3	–	35,722	9,205	1,530	6	3.9
1999	3	200,000	177,108	44,098	2,995	15	4.0
2000	7	150,000	127,217	29,145	5,450	5	4.4
2001	6	150,000	145,876	33,723	4,262	8	4.3
2002	8	150,000	150,434	34,860	5,279	6	4.3
2003	3	150,000	**CF**	**CF**	**CF**	**CF**	**CF**
2004	5	150,000	**CF**	**CF**	**CF**	**CF**	**CF**
2005	4	150,000	CF	CF	CF	CF	CF
2006 - 2009	0	150,000	0	0	0	–	–
2010	1	150,000	CF	CF	CF	CF	CF
2011	2	150,000	CF	CF	CF	CF	CF
2012	1	150,000	CF	CF	CF	CF	CF
2013	1	150,000	CF	CF	CF	CF	CF
2014	1	150,000	CF	CF	CF	CF	CF
2015	0	130,000	0	0	0	–	–

Note: CF: confidential information due to less than three vessels or processors having participated in fishery.

CF: confidential information and fishery was closed by emergency order to manage the harvest to the preseason GHL.

[a] Deadloss included.

Table 2. Weight (**t**) of retained catch and estimated discarded catch of Pribilof golden king crab during crab fisheries, 1993–2015, with total fishery mortality (**t**) estimated by applying a bycatch mortality rate of 0.2 to the discarded catch in the directed fishery and a bycatch mortality rate of 0.5 to the discarded catch in the non-directed fisheries.

		Discarded (no mortality rate applied)			
Calendar Year	Retained	Pribilof Islands golden king crab	Bering Sea snow crab	Bering Sea grooved Tanner crab	Total Mortality
1993	30.60	no data	0.00	no data	—
1994	40.36	no data	3.80	1.15	—
1995	155.09	no data	0.63	15.65	—
1996	149.24	no data	0.24	2.34	—
1997	81.31	no data	4.05	no fishing	—
1998	16.20	no data	33.00	no fishing	—
1999	80.33	no data	0.00	confidential	—
2000	57.70	no data	0.00	confidential	—
2001	66.17	17.82	0.00	confidential	confidential
2002	68.24	19.00	1.06	no fishing	72.57
2003	confidential	confidential	0.15	confidential	72.20
2004	confidential	confidential	0.00	confidential	66.93
2005	confidential	confidential	0.00	confidential	29.85
2006	no fishing	no fishing	0.00	0.00	0.00
2007	no fishing	no fishing	0.00	0.00	0.00
2008	no fishing	no fishing	0.00	no fishing	0.00
2009	no fishing	no fishing	0.96	no fishing	0.48
2010	confidential	confidential	0.00	no fishing	confidential
2011	confidential	confidential	0.27	no fishing	confidential
2012	confidential	confidential	0.27	no fishing	confidential
2013	confidential	confidential	0.58	no fishing	confidential
2014	confidential	confidential	0.12	no fishing	confidential
2015	no fishing	no fishing	0.00	no fishing	0.00

Table 3. Estimated annual weight (**t**) of discarded catch of Pribilof golden king crab (all sizes, males and females) during federal groundfish fisheries by gear type (fixed or trawl), 1991/92–2015/16, with total bycatch mortality (**t**) estimated by assuming bycatch mortality rate = 0.5 for fixed-gear fisheries and bycatch mortality rate = 0.8 for trawl fisheries.

	Discarded catch (no mortality rate applied)			Total
Crab fishing year	Fixed	Trawl	Total	Mortality
1991/92	0.05	6.11	6.16	4.91
1992/93	3.49	8.87	12.35	8.84
1993/94	0.51	9.64	10.14	7.96
1994/95	0.25	3.22	3.47	2.70
1995/96	0.41	1.90	2.31	1.72
1996/97	0.02	0.87	0.89	0.71
1997/98	1.34	0.49	1.83	1.06
1998/99	6.77	0.18	6.95	3.53
1999/00	4.79	0.65	5.43	2.91
2000/01	1.63	1.88	3.50	2.31
2001/02	1.50	0.36	1.85	1.03
2002/03	0.55	0.21	0.77	0.45
2003/04	0.23	0.18	0.41	0.26
2004/05	0.16	0.39	0.55	0.39
2005/06	0.09	0.06	0.15	0.09
2006/07	1.32	0.12	1.44	0.75
2007/08	8.47	0.16	8.63	4.36
2008/09	3.99	1.56	5.55	3.24
2009/10	2.40	1.17	3.57	2.14
2010/11	0.65	0.94	1.59	1.08
2011/12	0.73	1.13	1.87	1.27
2012/13	0.70	0.87	1.58	1.05
2013/14	0.46	2.73	3.19	2.42
2014/15	0.31	0.23	0.54	0.34
2015/16	0.66	1.02	1.68	1.15
Average	1.66	1.80	3.46	2.27

Table 4. Retained-catch weights (**t**) and estimates of discarded catch weights (**t**) of Pribilof Islands golden king crab available for a Tier 5 assessment; shaded, bold values are used in computation of the recommended (status quo Alternative 1) Tier 5 OFL.

		Retained catch weight	Discarded catch weight (estimated)			
		Fish tickets	Observer data: lengths, catch per sampled pot		Blend method; Catch Accounting System	
Calendar Year[a]	Crab Fishing Year[b]	Directed fishery	Directed fishery	Non-directed crab fisheries	Fixed gear, groundfish	Trawl gear, groundfish
	1981/82	Confidential				
	1982/83	31.74				
	1983/84	388.49				
1984	1984/85	0.00				
1985	1985/86	Confidential				
1986	1986/87	0.00				
1987	1987/88	Confidential				
1988	1988/89	Confidential				
1989	1989/90	Confidential				
1990	1990/91	0.00				
1991	1991/92	0.00			0.05	6.11
1992	1992/93	0.00			**3.49**	**8.87**
1993	1993/94	**30.60**			**0.51**	**9.64**
1994	1994/95	**40.36**		**4.95**	**0.25**	**3.22**
1995	1995/96	**155.09**		**16.28**	**0.41**	**1.90**
1996	1996/97	**149.24**		**2.58**	**0.02**	**0.87**
1997	1997/98	**81.31**		**4.05**	**1.34**	**0.49**
1998	1998/99	**16.20**		**33.00**	**6.77**	**0.18**
1999	1999/00	80.33		Confidential	4.79	0.65
2000	2000/01	57.70		Confidential	1.63	1.88
2001	2001/02	**66.17**	**17.20**	Confidential	1.50	0.36
2002	2002/03	**68.24**	**19.00**	1.06	0.55	0.21
2003	2003/04	**Confidential**	**Confidential**	Confidential	0.23	0.18
2004	2004/05	**Confidential**	**Confidential**	Confidential	0.16	0.39
2005	2005/06	**Confidential**	**Confidential**	Confidential	0.09	0.06
2006	2006/07	0.00	0.00	0.00	1.32	0.12
2007	2007/08	0.00	0.00	0.00	8.47	0.16
2008	2008/09	0.00	0.00	0.00	3.99	1.56
2009	2009/10	0.00	0.96	0.96	2.40	1.17
2010	2010/11	**Confidential**	**Confidential**	0.00	0.65	0.94
2011	2011/12	Confidential	Confidential	0.27	0.73	1.13
2012	2012/13	Confidential	Confidential	0.27	0.70	0.87
2013	2013/14	Confidential	Confidential	0.58	0.46	2.73
2014	2014/15	Confidential	Confidential	0.12	0.31	0.23
2015	2015/16	0.00	0.00	0.00	0.66	1.02

a. Year convention for retained weights in directed fishery, 1984-2015, and estimates of discarded bycatch weights in directed, non-directed crab fisheries.

b. Year convention for retained weights in directed fishery, 1981/82-1983/84, and estimates of discarded bycatch rates in groundfish fisheries.

Table 5. Data for calculation of $RET_{1993\text{-}1998}$ (**t**) and estimates used in calculation of $R_{2001\text{-}2010}$ (ratio, t:t), $BM_{NC,1994\text{-}1998}$ (**t**), and $BM_{GF,92/93\text{-}98/99}$ (**t**) for calculation of the recommended (status quo Alternative 1) Pribilof Islands golden king crab Tier 5 2017 OFL (**t**); values under $RET_{1993\text{-}1998}$ are from Table 1, values under $R_{2001\text{-}2010}$ were computed from the retained catch data and the directed fishery discarded catch estimates in Table 2 (assumed bycatch mortality rate = 0.2), values under $BM_{NC,1994\text{-}1998}$ were computed from the non-directed crab fishery discarded catch estimates in Table 2 (assumed bycatch mortality rate = 0.5) and values under $BM_{GF,92/93\text{-}98/99}$ are from Table 3.

Calendar Year[a]	Crab Fishing Year[b]	$RET_{1993\text{-}1998}$	$R_{2001\text{-}2010}$	$BM_{NC,1994\text{-}1998}$	$BM_{GF,92/93\text{-}98/99}$
1993	1992/93	30.60			8.84
1994	1993/94	40.36		2.48	7.96
1995	1994/95	155.09		8.14	2.70
1996	1995/96	149.24		1.29	1.72
1997	1996/97	81.31		2.03	0.71
1998	1997/98	16.20		16.50	1.06
1999	1998/99				3.53
2000	1999/00				
2001	2000/01		0.054		
2002	2001/02		0.056		
2003	2002/03		conf.		
2004	2003/04		conf.		
2005	2004/05		conf.		
2006	2005/06				
2007	2006/07				
2008	2007/08				
2009	2008/09				
2010	2009/10		conf.		
	N	6	6	5	7
	Mean	78.80	0.052	6.09	3.79
	S.E.M	24.84	0.004	2.87	1.25
	CV	0.32	0.07	0.47	0.33

a. Year convention corresponding with values under $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, and $BM_{NC,1994\text{-}1998}$.

b. Year convention corresponding with values under $BM_{GF,92/93\text{-}98/99}$.

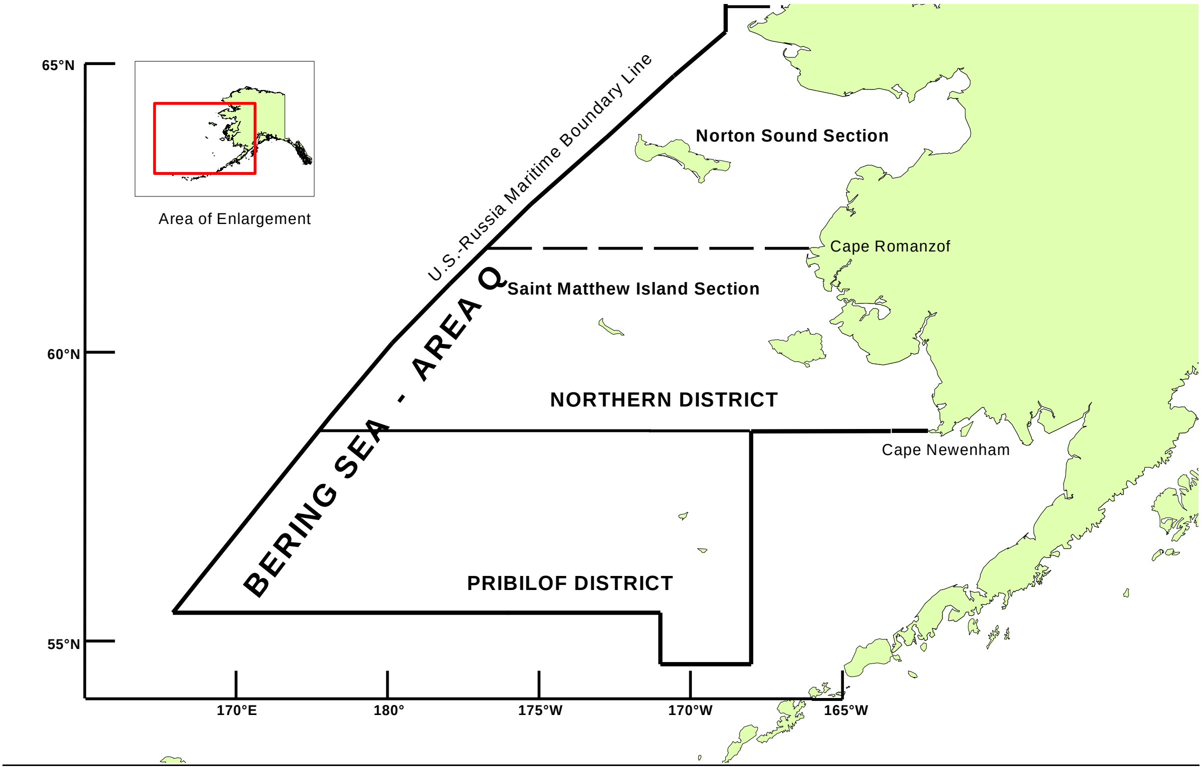

Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District (from Figure 2-4 *in* Fitch et al. 2014).

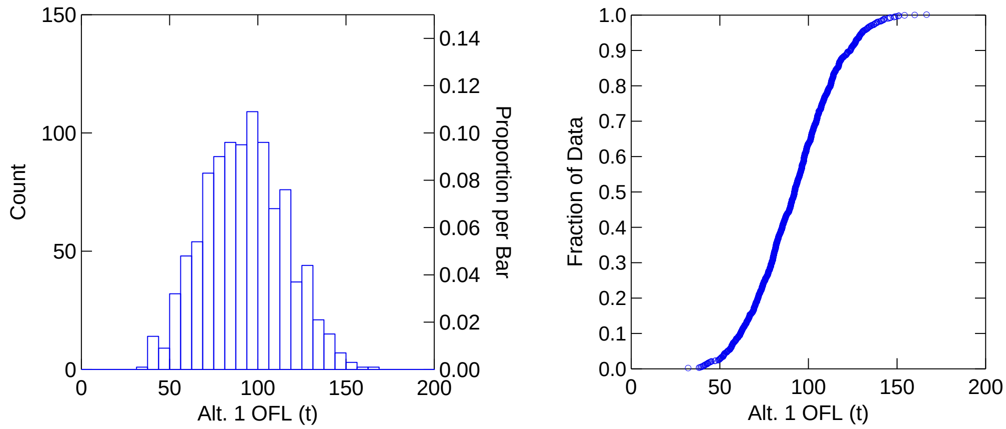

Figure 2. Bootstrapped estimates of the sampling distribution of the 2017 Alternative 1 Tier 5 OFL (total catch, t) for the Pribilof Islands golden king crab stock; histogram on left, quantile plot on right.

Appendix A1. EBS slope survey data on Pribilof Islands golden king crab (from Pengilly 2012, 2012 SAFE chapter).

Survey biomass estimates are not used in a Tier 5 assessment. However, biomass estimates of golden king crab (all sizes and sexes) by area and depth zone from the 2002, 2004, 2008, and 2010 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey are presented in Table 4. The survey area is depicted in Figure 2 and catch distribution and density of golden king crab during the 2010 survey is shown in Figure 3. Trends in survey biomass, with the Pribilof Canyon area shown separately, are presented graphically in Figure 4.

Survey catch at length data are not used in a Tier 5 assessment. However, size composition by sex of the estimated golden king crab population from the 2004, 2008, and 2010 eastern Bering Sea upper continental slope trawl survey is presented in Figure 5.

Standardized bottom trawl surveys to assess the groundfish and invertebrate resources of the eastern Bering Sea (EBS) upper continental slope have been performed in 2002, 2004, 2008, 2010 (Hoff and Britt 2003, 2005, 2009, 2011; Haaga et al. 2009). The raw data from those surveys have not been accessed for this assessment; only summary of results and stock biomass estimates that have been reported by Hoff and Britt (2003, 2005, 2009, 2011) and reported by Haaga et al. (2009) are presented in this assessment. Access to the raw data from those standardized surveys could allow for "area-swept" estimation of abundance and biomass of golden king crab in the Pribilof District by relevant size, sex, and reproductive-status classes (e.g., mature male biomass, mature female biomass, legal-sized male biomass, etc.). Additionally, a pilot slope survey was also performed in 2000 and triennial surveys using a variety of nets, methods, vessels, and sampling locations were performed during 1979–1991 (Hoff and Britt 2011); no data from those surveys were accessed for, and no results from those surveys were reported on, in this assessment because, according to Hoff and Britt (2011), "Comparisons between the post-2000 surveys and those conducted from 1979–1991 remains confounded due to differences in sampling gear, survey design, sampling methodology, and species identification."

The CPT encouraged that data from the EBS slope survey be included to the extent possible to consider whether that information may be sufficient to move this assessment up to Tier 4 in future years (2009 Crab SAFE, Executive Summary). Although published and unpublished summaries of the EBS slope survey data have been included in recent SAFEs, the author has not acquired the raw survey data, as would be necessary for considering if that data is sufficient for a Tier 4 assessment. With regard to the 2011 SSC's encouragement to explore the eastern Bering Sea upper continental slope survey data "for their utility to provide estimates of biomass for the Pribilof District" and to give consideration to "the distribution of the survey with respect to stock distribution, as well as estimation of survey catchability by size and sex," the author reports the following, generalizing from the 2010 survey report (Hoff and Britt 2011).

The survey samples approximately 200 randomly-chosen locations (stratified by 200 m depth zones) from the areas of 200–1,200 m depth. In 2010, the mean sampling density over the total surveyed area of 32,723 km^2 was one haul per 204.48 km^2; survey tow sampling is denser at depths < 800 m. That sampling density compares to one haul per 400 nmi^2 (1,372 km^2) for the standard stations in the eastern Bering Sea continental shelf survey. Hence the survey design provides a high sampling density within the depth range that golden king crab typically occur and at which the commercial fishery is typically prosecuted. Moreover, the survey area contains all areas at depths of 200–1,200 m within the borders of the Pribilof District and the survey area, extending beyond the north and south borders of the district.

With regard to the survey catchability by size and sex, the survey uses a Poly Nor'eastern high-opening bottom trawl equipped with mud-sweeper roller gear (see Hoff and Britt 2011 for details). The author has no idea how such gear affects survey catchability by size or sex, or how such would compare with that realized by the continental shelf survey, which does not use mud-sweeper roller gear. The author is not aware of any studies that provide data to estimate catchability by size and sex for this survey. Under the survey protocols, sites are considered towable when depth change less than 50 m over a 2-nmi transect and there are no detectable obstacles in the trawl path; that restriction on trawl locations may or may not affect catchability for all sizes and both sexes, depending on habitat preferences. The author notes that a cursory examination of the size/sex frequency distribution of golden king crab captured during the last three biennial surveys (Figure 5), shows that golden king crab <20 mm CL are captured by the survey gear, but that highest frequencies tend to occur at sizes >100 mm CL, consistent with reduced catchability at smaller sizes. Size and sex frequencies of captured golden king crab appear to track poorly across the last three biennial surveys (Figure 4). For example, the catch in 2008 was dominated by males of roughly 90–120 mm CL and the size frequency distribution of females in 2008 was relatively flat, whereas the catch in 2010 was dominated by females of roughly 110–140 mm CL and the size frequency distribution of males in 2010 was relatively flat.

Table 4. Biomass estimates (metric tons) of golden king crab (all sizes, both sexes) from results of the 2002, 2004, 2008, 2010 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey, by survey subarea and depth zone (from Haaga et al. 2009, Hoff and Britt 2003, 2005, 2009, 2011, and J. Haaga, NMFS-AFSC, Kodiak, 26 August 2009).

Year	Depth (m)	Subarea 1 Bering Canyon[a]	**Subarea 2 Pribilof Canyon[b]**	**Subarea 3[b]**	**Subarea 4 Zhemchug Canyon[b]**	Subarea 5[a]	Subarea 6 Pervenets/Navarin Canyons[c]
2002	200-400	53	**289**	**49**	**52**	16	29
	400-600	78	**253**	**32**	**1**	3	14
	600-800	0	**121**	**1**	**0**	0	0
	800-1000	1	**0**	**0**	**0**	0	0
	1000-1200	0	**19**	**-**	**0**	0	0
	Total	131	**682**	**81**	**53**	19	44
2004	200-400	4	**526**	**25**	**121**	13	2
	400-600	45	**220**	**13**	**0**	13	22
	600-800	14	**67**	**10**	**0**	0	0
	800-1000	1	**4**	**3**	**0**	0	0
	1000-1200	0	**0**	**0**	**0**	0	0
	Total	65	**817**	**51**	**121**	25	24
2008	200-400	67	**258**	**65**	**173**	0	38
	400-600	78	**584**	**19**	**0**	2	29
	600-800	2	**76**	**8**	**32**	0	0
	800-1000	0	**0**	**0**	**0**	0	0
	1000-1200	0	**2**	**0**	**0**	0	0
	Total	146	**919**	**91**	**206**	2	66
2010	200-400	116	**1050**	**85**	**72**	34	53
	400-600	246	**432**	**4**	**0**	3	64
	600-800	0.4	**104**	**0.1**	**0**	0	6
	800-1000	1	**12**	**0**	**0**	0	0
	1000-1200	0	**17**	**0**	**0**	0	0
	Total	363	**1615**	**89**	**72**	37	123

a. Partially in Pribilof District.
b. Entirely in Pribilof District.
c. Not in Pribilof District.

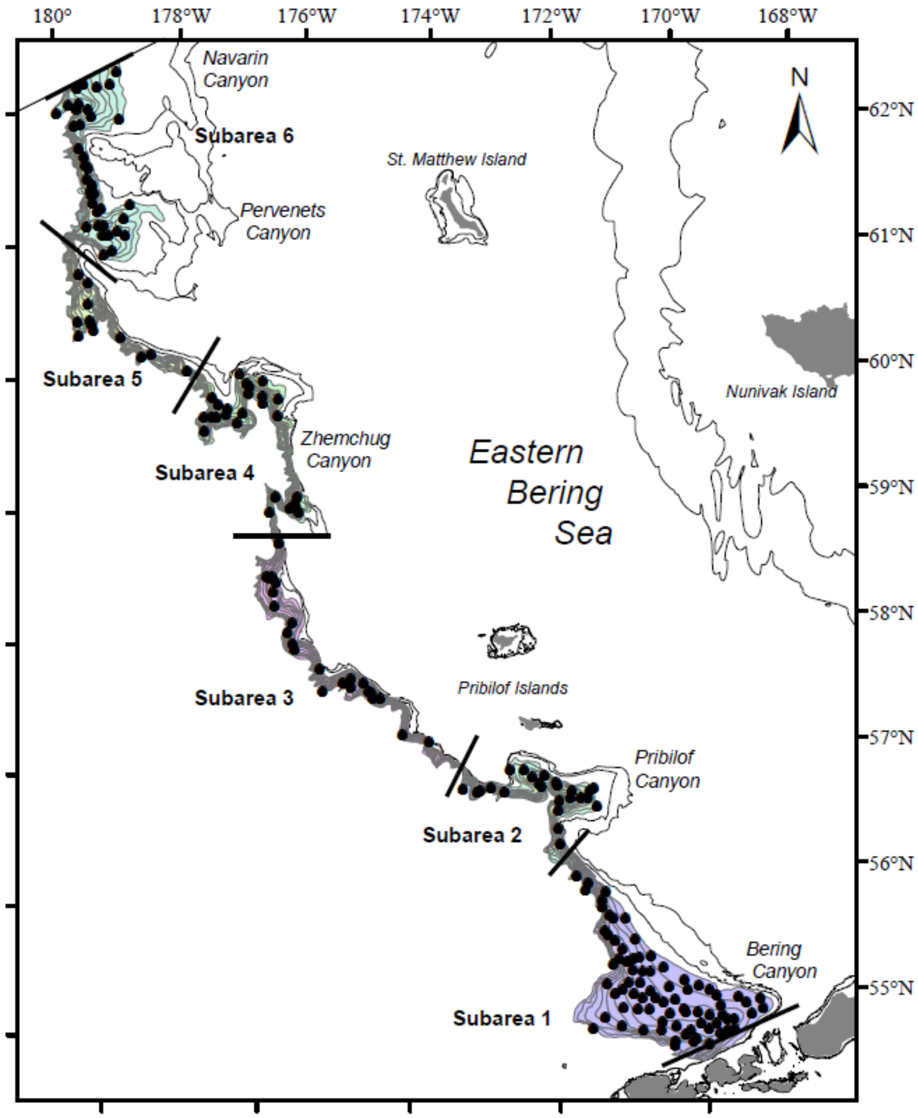

Figure 2. Map of standard survey area for NMFS-AFSC eastern Bering Sea upper continental slope trawl survey with survey subareas identified; black dots show locations of successful tows during the 2010 survey (from Figure 1 *in* Hoff and Britt 2011).

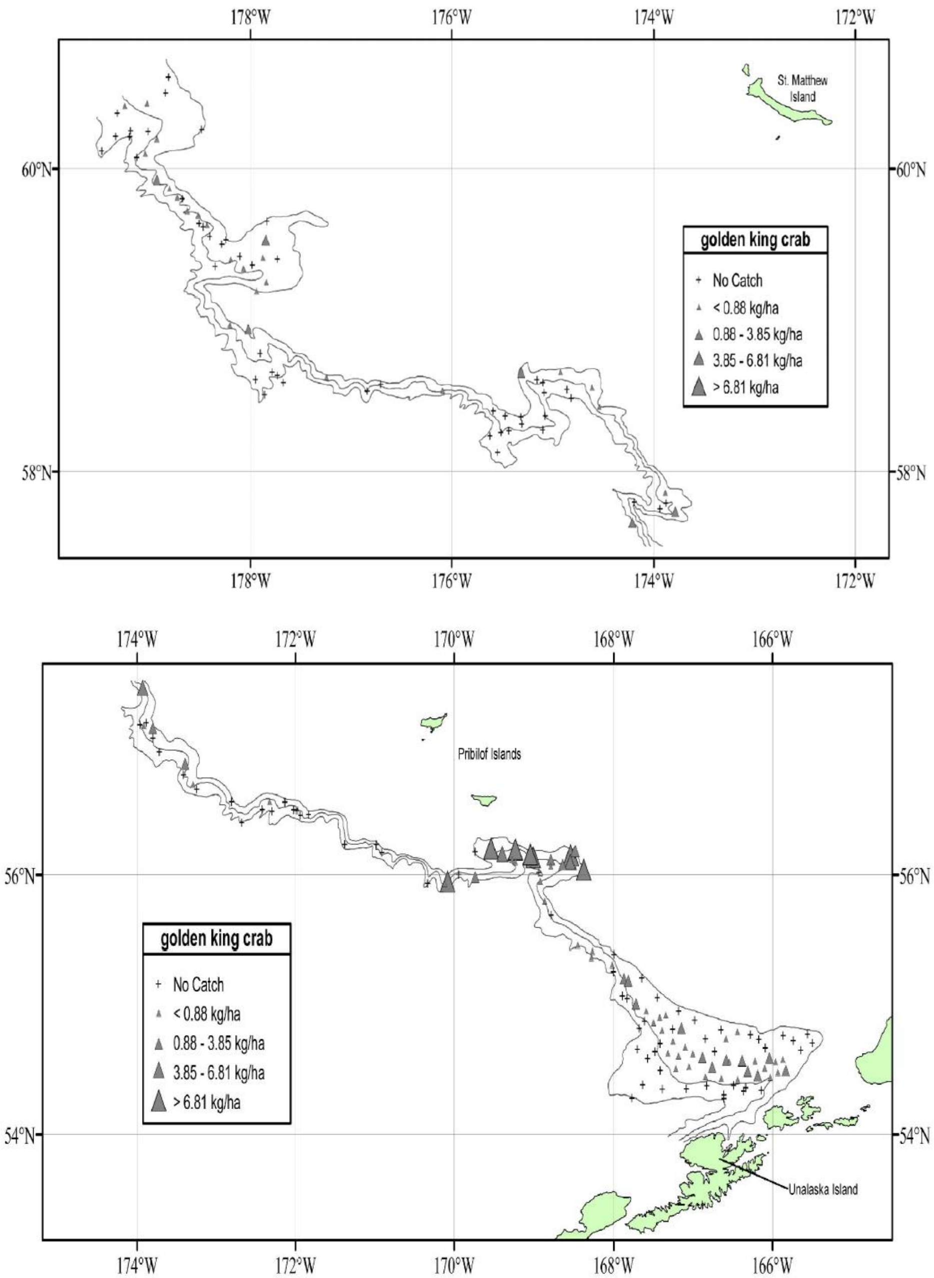

Figure 3. Distribution and relative abundance of golden king crab from the 2010 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey. Relative abundance is categorized by no catch, sample CPUE less than the mean CPUE, between the mean CPUE and two standard deviations above the mean CPUE, between two and four standard deviations above the mean CPUE, and greater than four standard deviations above the mean CPUE (from Figure 82 *in* Hoff and Britt 2011).

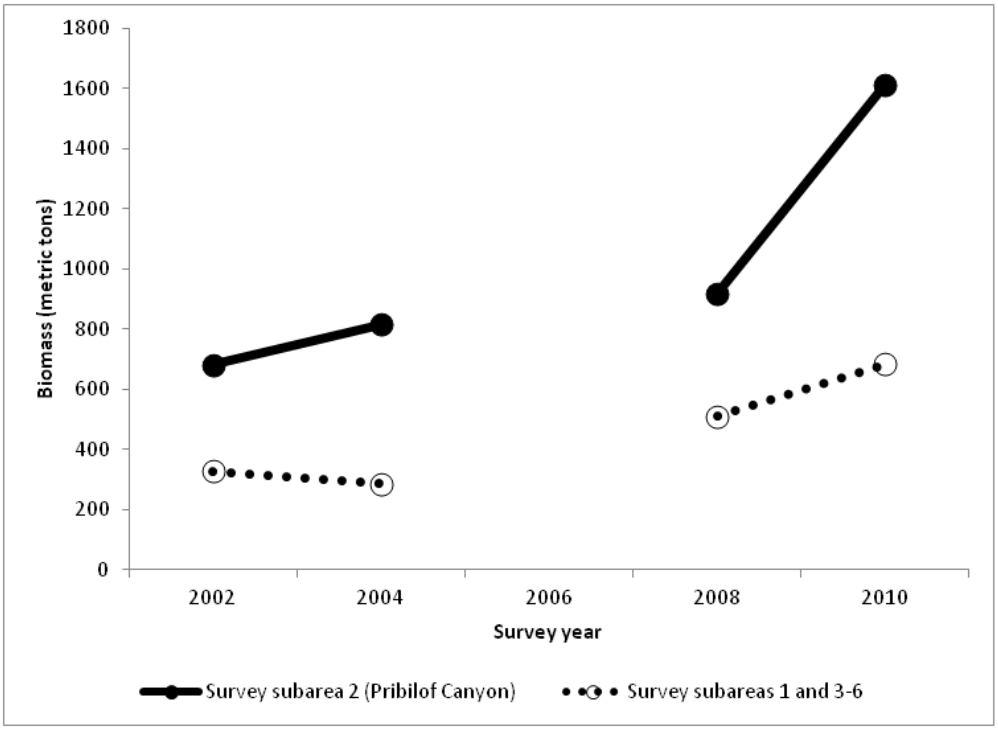

Figure 4. Biomass estimates (all sexes and sizes) for the Pribilof Canyon survey subarea and the aggregated remaining survey subareas (see Figure 2) from the biennial eastern Bering Sea upper continental slope surveys that were performed during 2002–2010.

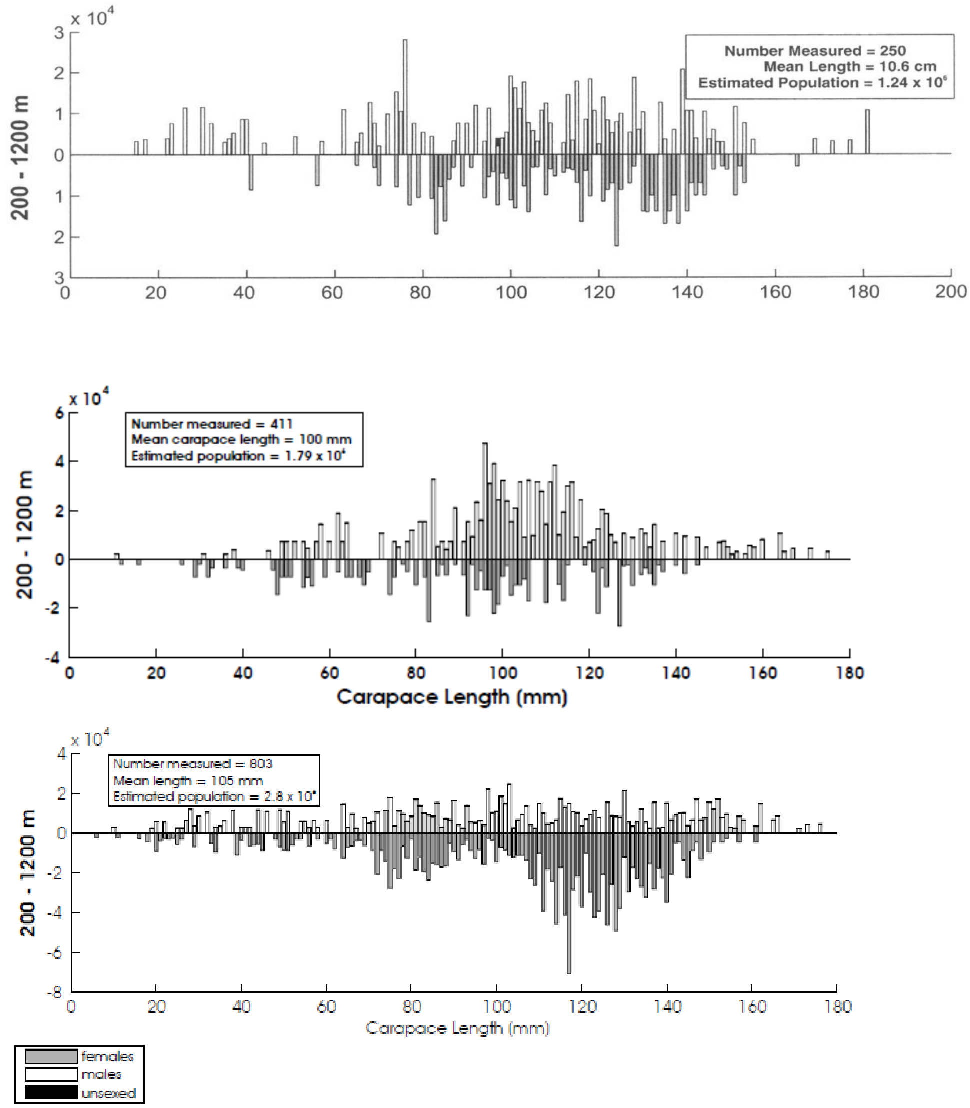

Figure 5. Size distribution of male and female golden king crab captured in all survey subareas and depths fished during the 2004, 2008, and 2010 (bottom panel; from Figure 83 *in* Hoff and Britt 2011) NMFS-ASFC eastern Bering Sea upper continental shelf trawl surveys (not available for the 2002 survey).

Appendix A2. EBS slope survey data on Pribilof Islands golden king crab (from Gaeuman May 2013 report to Crab Plan Team: Pribilof Islands golden king crab Tier 4 Stock assessment considerations, April 2013).

The EBS upper continental slope survey

Details on the EBS continental slope survey methods are provided in Hoff and Britt (2011). Standardized surveys have been conducted in 2002, 2004, 2008, 2010, and 2012; although intended to be biennial, no survey was performed in 2006. The survey occurs during June–July and the surveyed region consists of a swath of (trawlable[1]) ocean bottom at depths of 200–1,200 m extending northwest from near Dutch Harbor some 600 mi along the EBS continental slope (Figure 1). The survey area is divided into 6 geographic subareas running north-to-south in the survey area: Bering Canyon area, Pribilof Canyon area, the inter-canyon area between Pribilof Canyon and Zhemchug Canyon, the Zhemchug Canyon area, the inter-canyon area between Zhemchug and Pervenets Canyon, and the Pervenets and Navarin Canyons area. The subareas are partitioned into five 200-m depth zones, from 200 to 1,200 m. The survey samples approximately 200 locations by stratified simple random sampling from the 30 area-by-depth-zone strata. In 2010 sampling densities within strata ranged from one haul per 112.39 km^2 to one haul per 368.96 km^2 (survey tow sampling is denser at depths < 800 m), and the mean sampling density over the total surveyed area of 32,723 km^2 was one haul per 204.48 km^2. That sampling density compares to one haul per 400 nmi^2 (1,372 km^2) for the standard stations in the eastern Bering Sea continental shelf survey. The survey uses a Poly Nor'eastern high-opening bottom trawl equipped with mud-sweep roller gear; the mudsweep roller gear was constructed of 203 mm solid rubber disks strung over 16 mm high-tensile chain. The standard tow is 30 minutes at 2.5 knots.

Limited biennial data series. The set of available EBS slope-survey results useful for such an assessment consists only of those for 2008, 2010, and 2012, resulting in an extremely limited time series of abundance and biomass estimates by which to understand stock history and dynamics and to use in formulating credible management quantities. Length measurements on individual crab were not recorded during the first survey in 2002 (Claire Armistead, NMFS-AFSC Kodiak Laboratory, 18 March 2013 email) and incompletely so in 2004 (250 of 321 captured GKC in successful tows; Hoff and Britt 2005), precluding necessary Tier-4 sex-by-size-class estimates for those surveys, and no EBS slope survey was conducted in 2006. Moreover, how the mud-sweep roller gear used in the survey affects survey selectivity by size or sex is unknown, as is how such selectivity compares with that realized by the continental shelf survey gear, which does not use mud-sweep roller gear.

[1] A site was considered trawlable "when the depth changed less than 50 m over the 2-nmi transect and there were no detectable obstacles in the trawl path." (Hoff and Britt 2011, p.4)

Determination of stock boundaries for assessment. The boundaries of the PIGKC fishery are defined by the boundaries of the Pribilof District of Registration Area Q and, within that area, the fishery has occurred mostly in the Pribilof Canyon area to the south of the Pribilof Islands (Figure 1). By contrast, the surveyed area extends north into the Northern District of Registration Area Q (north of 58° 39' N) and south into the Aleutian Islands Registration Area O (south of 54° 36' N). Though a large proportion of the GKC encountered in the slope survey are caught in the Pribilof Canyon area, some GKC crab are captured sporadically throughout the surveyed area (Hoff and Britt 2003, 2005, 2009, 2011), and a Northern District GKC fishery has been successfully prosecuted historically, mostly to the west of St. Matthew Island in the area of the northern-most extent of the slope survey, with a peak harvest of 414,000 lb in 1987 (Fitch et al. 2012). All of this serves to underscore the fact that the PIGKC "stock" is, like some other fisheries stocks, an artificial construct, depending for its existence on the reification of administrative boundaries rather than on biological reality. It is thus inherently unclear how slope-survey results should be used for its assessment.

Biomass estimates and other results from the 2012, 2010, and 2008 surveys

Estimates of mature male biomass necessary for the sketched Tier-4 assessment, along with estimates of mature male abundance and legal male, total male and total female biomass and abundance, were calculated by the author from 2012, 2010 and 2008 NMFS-AFSC EBS slope-survey data supplied by the NMFS-AFSC Kodiak Laboratory. All estimates were calculated for both the full survey area (Table 3) and for the Pribilof Canyon subarea of the survey region (Table 4) assuming the survey's stratified simple-random-sample design (Hoff and Britt 2011). Survey-recorded CL measurements of individual crab (Figure 4) were used to delineate sex-by-size classes and to model individual crab weights in class biomass estimation. In a few instances (5 of 416 captured crab in 2008 and 1 of 427 in 2012) missing CL measurements were imputed by averaging over recorded CL measurements within the same haul and sex; sex had also to be imputed for the 1 unsized animal in the 2012 dataset. By contrast, Hoff and Britt (2011, 2009, 2005, 2003) report only total (all sizes and both sexes combined) GKC abundance and biomass estimates based on haul total-catch numbers and weights (G.R. Hoff, NMFS-AFSC Seattle, 13 Mar 2013 email) from the 2002, 2004, 2008 and 2010 slope surveys (Table 5). Some discrepancies between the comparable sets of estimates are evident. So far as the author is aware, 2012 slope-survey results have yet to be reported.

Table 3: EBS slope-survey estimates of golden king crab abundance and biomass for the full survey region.

year	female		male		mature male		legal male	
	Abundance (1000s) and CV							
2012	1,282	0.33	1,061	0.21	540	0.24	378	0.28
2010	1,743	0.26	1,083	0.14	508	0.16	348	0.17
2008	748	0.25	1,187	0.26	593	0.30	257	0.22
	Biomass (1000 lb) and CV							
	female		male		mature male		legal male	
2012	2,120	0.43	2,124	0.24	1,791	0.26	1,478	0.28
2010	2,812	0.33	2,042	0.15	1,692	0.17	1,384	0.18
2008	943	0.25	2,173	0.26	1,624	0.25	997	0.22

Table 4: EBS slope-survey estimates of golden king crab abundance and biomass for the Pribilof Canyon subarea.

year	female		male		mature male		legal male	
	Abundance (1000s) and CV							
2012	592	0.53	360	0.42	174	0.32	113	0.36
2010	1,295	0.34	633	0.20	288	0.24	185	0.25
2008	395	0.43	908	0.34	403	0.43	167	0.29
	Biomass (1000 lb) and CV							
	female		male		mature male		legal male	
2012	866	0.54	701	0.34	565	0.32	456	0.34
2010	2,219	0.41	1,200	0.22	970	0.24	770	0.25
2008	340	0.54	1,546	0.36	1,080	0.36	648	0.29

Table 5: Hoff and Britt (2011, 2009, 2005, 2003) reported EBS slope-survey estimates of total (all sizes and both sexes combined) golden king crab abundance and biomass.

	Full survey region		Pribilof Canyon subarea	
year	Abundance (1000s)	Biomass (1000 lb)	Abundance (1000s)	Biomass (1000 lb)
2012	NA[a]	NA[a]	NA[a]	NA[a]
2010	2,830	5,070	1,930	3,560
2008	1,860	3,150	1,300	2,030
2004	1,240	2,430	862	1,800
2002	1,800	2,230	1,300	1,500

[a] Not yet available.

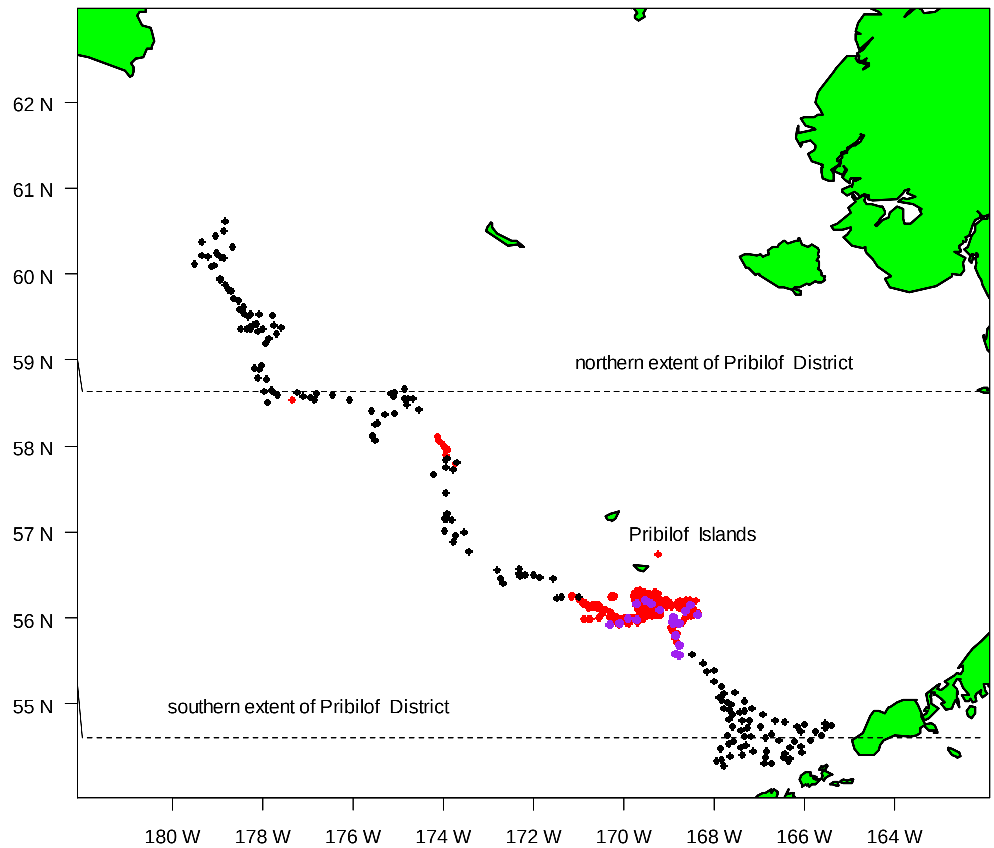

Figure 1. Locations of observer-sampled pots (red) from the 2001–2005 and 2010–2012 PIGKC fisheries and of the 189 tows of the 2012 EBS slope-survey (black/purple) used to construct abundance and biomass estimates. Locations of the 19 tows in the Pribilof Canyon subarea are colored purple.

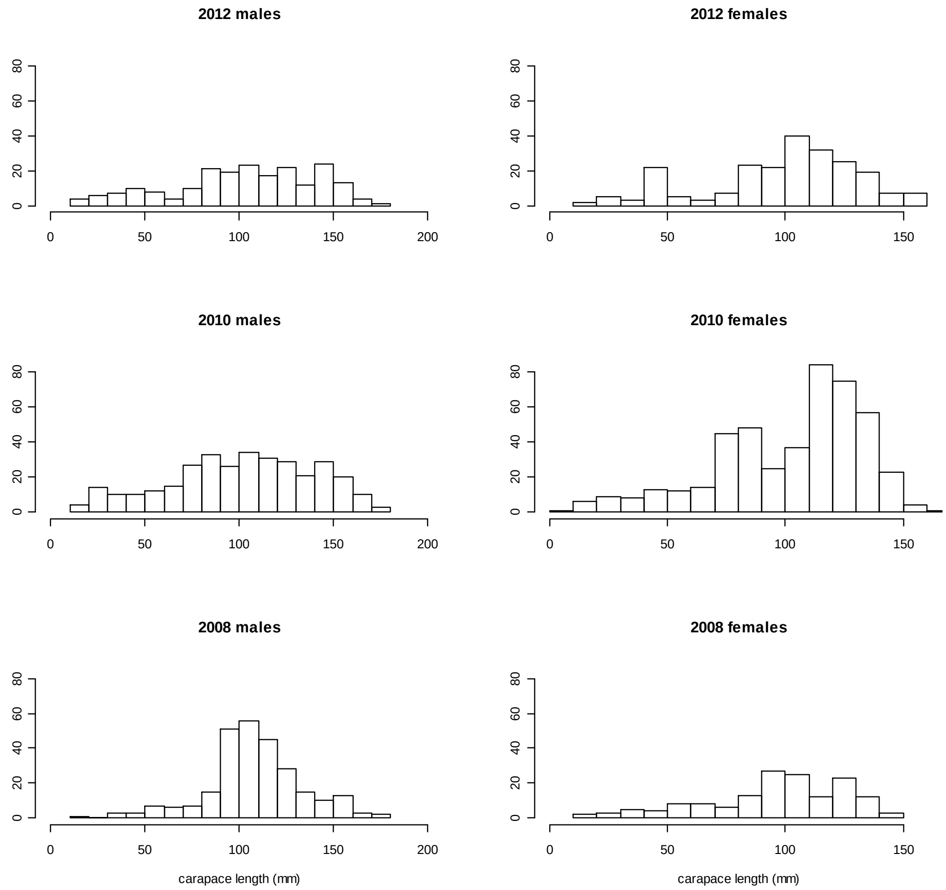

Figure 4: Size-frequency distributions of male (left panels) and female (right panels) GKC captured in the 2012 (189 tows; 427 crab), 2010 (200 tows; 790 crab) and 2008 (200 tows; 416 crab) EBS slope surveys.

Appendix A3. EBS slope survey data on Pribilof Islands golden king crab and draft Pribilof Island golden king crab stock structure template (from Pengilly September 2015 report to Crab Plan Team).

Discussion paper for September 2015 Crab Plan Team meeting:
Random effects approach to modeling NMFS EBS slope survey area-swept biomass estimates for Pribilof Islands golden king crab.

Douglas Pengilly
Alaska Department of Fish and Game, Kodiak, AK
Division of Commercial Fisheries
301 Research Ct.
Kodiak, AK 99615, USA
Phone: (907) 486-1865
Email: doug.pengilly@alaska.gov

Introduction.

The Pribilof Islands golden king crab stock has been defined by the geographic borders of the Pribilof District (Figure 1) and has been managed as a Tier 5 stock (i.e., no reliable estimates of biomass and only historical catch data available) for determination of federal overfishing limits and annual catch limits (Pengilly 2014). Since 2011, the Council's Crab Plan Team (CPT) and the Scientific and Statistical Committee (SSC) have expressed interest in utilizing data collected during NMFS eastern Bering Sea (EBS) upper continental slope surveys (Hoff 2013) to establish an annual overfishing limit (OFL) and acceptable biological catch (ABC) on the basis of biomass estimates as an alternative to the standard Tier 5 historical-catch approach (see: reports of the June 2011, June 2012, June 2013, and October 2013 SSC meetings; reports of the May 2013 and September 2013 CPT meetings). Reviews of the EBS slope survey relative to the data collected on golden king crab, summaries of those data, and area-swept biomass estimates (Pengilly 2012, Gaeuman 2013a, 2013b), a Tier 4 approach to establishing OFL and ABC (Gaeuman 2013b), and "modified Tier 5" approach to establishing OFL and ABC (Gaeuman 2013a) have been presented to the CPT and SSC. Cancellation of the EBS biennial slope survey scheduled for 2014 precluded application of Gaeuman's (2013a) approach to establishment of OFL and ABC (see: report of the May 2015 CPT meeting; report of the June 2015 SSC meeting).

In May 2105 the CPT recommended that, "*a preliminary Tier 4 assessment be brought to the September 2015 meeting using available slope survey data and applying a Kalman filter approach (e.g., the program developed by Jim Ianelli for groundfish stock assessments)*" (report of May 2015 CPT meeting). In June 2015, the SSC supported "*the CPT recommendation that a preliminary Tier 4 assessment be brought to the September 2015 meeting, using existing slope data and applying a Kalman filter approach*" (report of the June 2015 SSC meeting). The SSC also requested that the assessment include "*a discussion … of what stock delineation was chosen (what slope data were used) and the reason for that delineation*," and that "*a Stock Structure Template be completed for PI GKC*" (report of the June 2015 SSC meeting).

This report provides: results of applying the program developed for groundfish stock assessments to the slope survey area-swept biomass estimates of golden king crab; a discussion of the stock delineation chosen (what slope data were used and why); and a Stock Structure Template for Pribilof Islands golden king crab (Appendix C) that was prepared with the guidance of Spencer et al. (2010).

This report does not provide a Tier 4 assessment, however (i.e., no OFLs or ABCs are computed from the results of this exercise). Prior to computation of an OFL or ABC, the author would like to review the biomass estimates with the CPT so that the CPT can evaluate the results relative to the Tier 4 and Tier 5 criteria (i.e., Do the biomass estimates meet the "reliability" criterion for removing the stock from Tier 5? Do the results meet the Tier 4 criterion of having sufficient information for simulation modeling that captures the essential population dynamics of the stock?). Additionally, the term "Tier 4 assessment" in application to this stock since 2013 has lost its clarity, making it unclear if the requested assessment was to be made according to Tier 4 as defined in the FMP, according to the "modified Tier 5" approach of Gaeuman (2014a), or according to some modification to a Tier 4 assessment. Dependent on the evaluation of results and after clarification of the assessment approach, the computations of OFL and ABC can be performed with the results presented here.

The NMFS EBS slope survey.
Only data from NMFS EBS slope trawl surveys performed in 2002 and later are used here. Although a pilot slope survey was also performed in 2000 and triennial surveys using a variety of nets, methods, vessels, and sampling locations were performed during 1979–1991 (Hoff and Britt 2011), Hoff and Britt (2011) noted that, "Comparisons between the post-2000 surveys and those conducted from 1979–1991 remain confounded due to differences in sampling gear, survey design, sampling methodology, and species identification." Starting in 2002, the slope survey was nominally a biennial survey, but no survey was performed in 2006 and no survey has been performed since 2012. Details on the methods and survey gear used in the 2002, 2004, 2008, 2010, and 2012 NMFS EBS slope surveys are provided in Hoff and Britt (2003, 2005, 2009, 2011) and Hoff (2013), respectively. Those methods and the applicability of the slope survey data to golden king crab abundance and biomass estimation have also been summarized by Pengilly (2012) and Gaeuman (2013a,b).

Briefly, the survey samples from an area of 32,723 km^2 in the 200–1,200 m depth zone. The surveyed area is divided into six subareas (Figure 1). Each subarea is divided into strata defined by 200 m depth zones and tows are performed at randomly-selected locations within each stratum, with target sampling density within strata proportional to the area in each subarea and stratum. Number of stations towed per survey ranged from 156 in 2002 to 231 in 2004; mean sampling density within strata ranged from approximately one tow per 162 km^2 in 2004 to approximately one tow per 255 km^2 in 2002. With regard to survey catchability of golden king crab by size and sex, the survey uses a Poly Nor'eastern high-opening bottom trawl equipped with mud-sweeper roller gear and the opinion of ASFC scientists was conveyed to the CPT during the May meeting that, with respect to golden king crab, "… the catchability of the slope net is less than 1.0 and probably considerably lower than the shelf net due to the differences in the foot rope and surveyed habitat" (report of the May 2013 CPT meeting).

Methods.
Data available by survey. Data on golden king crab that are available from the 2002, 2004, 2006, 2008, 20010, and 2012 NMFS EBS slope surveys are summarized in Table 1.

Although the CPT and SSC both suggested that NMFS would "*provide the author with slope survey CPUE data based on State statistical areas or other stratification instead of the entire slope survey area because the entire survey extends beyond the Pribilof management area*" (reports of the May 2015 CPT meeting and June 2015 SSC meeting), the author did not find it necessary or useful for this exercise to receive the data stratified by State statistical area or by any other stratification besides that defined by the survey design.

Data summarization: area-swept biomass estimates. Area-swept estimates of total (male and female, all sizes) biomass and variances of estimates within strata within survey subarea for 2002, 2004, 2008, 2010, and 2012 were obtained directly from the tables presented in Hoff and Britt (2003, 2005, 2009, 2011) and Hoff (2013). For area-swept biomass estimation of mature males and legal males from the 2008, 2010, and 2012 survey data, 107 mm CL was used as a proxy for size at maturity (Somerton and Otto 1986) and 124 mm CL was used as a proxy for the 5.5 in carapace width (including spines) legal size (NPFMC 2007); weight of males was estimated from the CL measured during the survey by weight (g) = $(0.0002988)x(CL)^{3.135}$ (NPFMC 2007). An area-swept estimate of biomass and of the variance of the biomass estimate was computed for each stratum within a survey subarea and summed over strata within the subarea to obtain area-swept estimates of biomass within a subarea and of the variance of that biomass estimate; estimates of the biomass and of variances of estimates within subareas were summed over subareas to obtain estimates of biomass in aggregates of subareas and of the variances of those estimates.

Model estimates of biomass and projections to 2016.[2] The program "re.exe" was used to estimate biomass from the area-swept estimates in surveyed years and to project biomass estimates for unsurveyed years into 2016 via a state-space random walk plus noise model. The state-space random walk plus noise is formulated as a random effect model. The random effects model considers the process errors as "random effects" (i.e., drawn from an underlying distribution) and integrated out of the likelihood. The method was developed by the NPFMC groundfish plan team's survey averaging working group as a smoothing technique similar to the Kalman Filter, but which provides more flexibility with non-linear processes and non-normal error structures.

Stock delineation chosen (what slope data were used). The author followed the guidance provided by the SSC in June 2013 (report of the June 2013 SSC meeting):

> "*Because the stock structure is unknown, the SSC recommends that the authors examine maps of catch-per-unit-effort by survey year to identify natural breaks in the spatial distribution of golden king crab along the slope. If no obvious breaks exist, the SSC recommends that the authors bring forward biomass estimates for the Pribilof canyon region and for the slope as a whole. However, we note that the Pribilof Canyon stations do not encompass the historical catches, which occurred inside and to the north of Pribilof Canyon. Therefore, the authors*

[2] The author acknowledges help from Martin Dorn, Jim Ianelli, and Paul Spencer, AFSC, in getting this paragraph completed.

should consider a biomass estimate for an area that encompasses the majority of historical catches."

Figures 2–6 show CPUE (kg/km^2) of golden king crab (males and females, all sizes) by tow and survey subarea during the 2002, 2004, 2008, 2010, and 2012 NMFS EBS slope surveys relative to the boundaries of the Pribilof District. Highest survey CPUE occurs at tows within survey subareas 2–4 (particularly in subarea 2; i.e., Pribilof Canyon). Tows performed in the portion of subarea 5 that lie within the Pribilof District have produced little or no catch of golden king crab, indicating a gap in golden king crab distribution between subarea 4 and the portion of the surveyed area north of the Pribilof District boundary (i.e., the portion of subarea 5 that is north of the Pribilof District boundary and all of subarea 6). Tows performed in subarea 1 that are within the Pribilof District have produced little or no catch of golden king crab, indicating a gap in distribution between Pribilof Canyon and the area east of the Pribilof District within subarea 1. It appears that the areas of subareas 1 and 5 that lie within the Pribilof District support limited densities of golden king crab. Subarea 3 appears to support only low-to-moderate densities of golden king crab relative to subarea 4 and – especially – subarea 2; tows with catch of golden king crab occurred sporadically within subarea 3, with highest densities occurring near the border of subarea 4 in 2010 and 2012 and near the border of subarea 2 in 2002.

Figure 7 shows the distribution of all 6,104 pot lifts sampled by observers with locations recorded during 1992–2014 Bering Sea golden king crab fisheries (including the Saint Matthew section of the Northern District, which is north of the Pribilof District) relative to the borders of the Pribilof District and of the survey subareas. Only one of those locations is within the portion of subarea 5 that is within the Pribilof District, none are within the portion of subarea 1 that is within the Pribilof District, and none are within subarea 3.

Figure 8 shows the 26 statistical areas with reported catch during the 1985–2014 Pribilof District golden king crab fisheries relative to the borders of the Pribilof District and of the survey subareas: one (accounting for 0.7% of the 1985–2014 total catch) lies largely in subarea 4, but extends into subarea 5; four (2.9% of the total catch) include portions of subarea 4; six (1.5% of total catch) include portions of subarea 3; one (8.9% of total catch) includes portions of subareas 3 and 2; four (83.9% of total catch) are in or extend into subarea 2; one (0.7% of total catch) includes portions of subareas 2 and 1; one (<0.1% of total catch) is largely within subarea 1; and eight (1.4% of total catch) are outside of the survey area (some of those may be errors in recording of statistical area).

This review of survey distribution and fishery catch and effort distribution shows that golden king crab in the Bering Sea and the fishery for golden king crab in the Bering Sea are concentrated in the Pribilof Canyon area (survey subarea 2). Nonetheless, golden king crab do occur more sporadically and at lower densities in survey subareas 3 and 4 and there has been some limited catch and effort during Pribilof District fisheries within survey subareas 3 and 4. Portions of survey subareas 1 and 5 that lie within the Pribilof District appear to be largely devoid of golden king crab, have produced little or no catch during the Pribilof District fishery, and have received little or no fishery effort. The golden king crab that occur in survey subarea 6 are exploited by the Saint Matthew section fishery when it is prosecuted. Accordingly, the following analyses to estimate trends in the Pribilof District stock were performed using survey data from only survey subareas 2, 3, and 4. Because of the high concentration of fishery effort and fishery catch in Pribilof Canyon and the high CPUE of golden king crab within Pribilof Canyon during the slope surveys, data summaries and analyses were also performed using data only from survey Subarea 2.

Results.
Size frequency distributions of golden king crab captured within subareas 2, 3, and 4 during the 2008, 2010, and 2012 NMFS EBS slope surveys are shown in Figures 9–12.

Area-swept biomass estimates by survey subarea, for the total surveyed area (pooled subareas 1–6), and for pooled subareas 2–4 for 2002, 2004, 2008, 2010, and 2012 are in Table 2.

Estimates and projections through 2016 of total, mature male, and legal male biomass in survey subareas 2-4 and survey subarea 2 from the state-space random walk plus noise model are plotted in Figures 13 and 14, respectively. More detailed results produced by re.exe are provided in Appendices A and B.

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Table 1. Data on golden king crab recorded during the 2002, 2004, 2008, 2010, and 2012 NMFS EBS slope surveys.

Survey	Weight in tow	Count in tow	Sex/CL/shell con/fem repro	Individual weights
2002	YES	YES	NO	NO
2004	YES	YES	NO	NO
2008	YES	YES	YES	285 of 416 meas'd
2010	YES	YES	YES	NO
2012	YES	YES	YES[a]	495 of 899 meas'd

a. Golden king crab <100 mm CL were subsampled for data recording at one tow in subarea 4 during the 2012 survey.

Table 2. Area-swept biomass (t) estimates of total (sexes combined), mature-sized males, and legal male golden king crab computed from 2002, 2004, 2008, 2010, and 2012 NMFS eastern Bering Sea slope survey data, by survey subarea, and with coefficients of variation (CV = standard error of estimate divided by the estimate).

		Total (males and females)		Mature males (males ≥ 107 mm CL)		Legal males (males ≥ 124 mm CL)	
Survey Year	Subarea	Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV
2002	1	131	0.39	–	–	–	–
2002	2	682	0.22	–	–	–	–
2002	3	81	0.40	–	–	–	–
2002	4	53	0.40	–	–	–	–
2002	5	19	0.86	–	–	–	–
2002	6	44	0.69	–	–	–	–
2002	1–6	1,010	0.16	–	–	–	–
2002	2–4	816	0.19	–	–	–	–
2004	1	65	0.22	–	–	–	–
2004	2	817	0.38	–	–	–	–
2004	3	51	0.41	–	–	–	–
2004	4	121	0.36	–	–	–	–
2004	5	20	0.73	–	–	–	–
2004	6	24	0.73	–	–	–	–
2004	1–6	1,098	0.29	–	–	–	–
2004	2–4	989	0.32	–	–	–	–
2008	1	146	0.40	47	0.35	11	0.70
2008	2	920	0.32	490	0.36	294	0.29
2008	3	91	0.44	64	0.44	28	0.54
2008	4	205	0.46	85	0.53	78	0.52
2008	5	2	1.00	22	1.00	22	1.00
2008	6	66	0.50	30	0.63	19	0.61
2008	1–6	1,431	0.22	737	0.25	452	0.22
2008	2–4	1,216	0.26	638	0.29	401	0.24
2010	1	363	0.20	168	0.20	145	0.23
2010	2	1,614	0.31	440	0.24	349	0.25
2010	3	89	0.63	79	0.72	71	0.75
2010	4	72	0.41	46	0.47	44	0.50
2010	5	37	0.45	10	0.76	7	1.00
2010	6	122	0.43	25	0.51	12	1.00
2010	1–6	2,298	0.22	768	0.17	628	0.18
2010	2–4	1,776	0.29	565	0.22	464	0.23
2012	1	421	0.37	328	0.45	280	0.50
2012	2	778	0.45	256	0.32	207	0.34
2012	3	172	0.75	146	0.83	131	0.81
2012	4	494	0.69	26	0.48	8	1.00
2012	5	12	0.43	6	0.74	4	1.00
2012	6	149	0.40	49	0.33	40	0.38
2012	1–6	2,025	0.26	812	0.26	670	0.28
2012	2–4	1,444	0.35	429	0.34	346	0.37

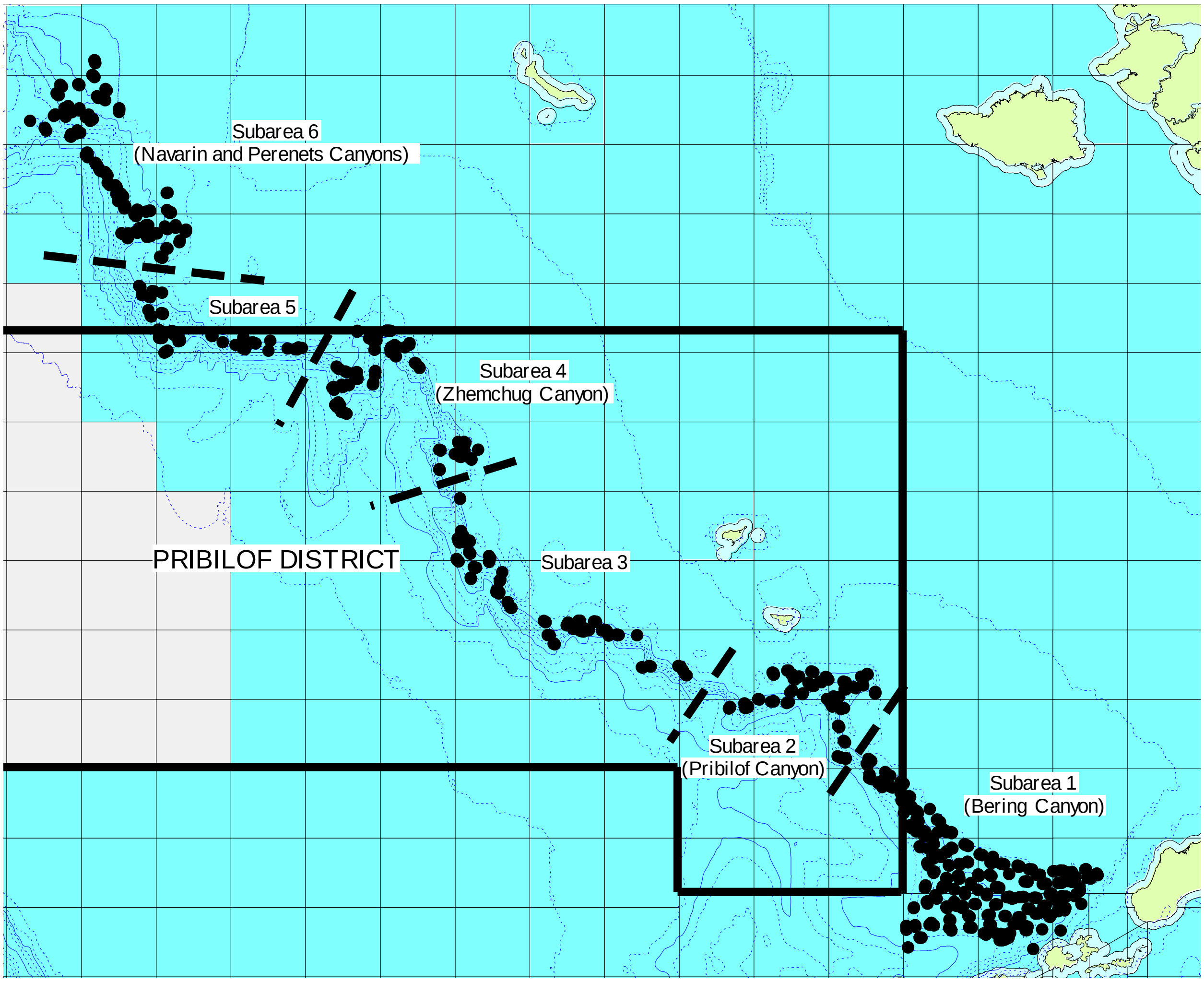

Figure 1. Pribilof District boundaries, slope survey subareas, and 2002–2012 slope survey tow locations; squares are 1° longitude x 30' latitude State statistical areas.

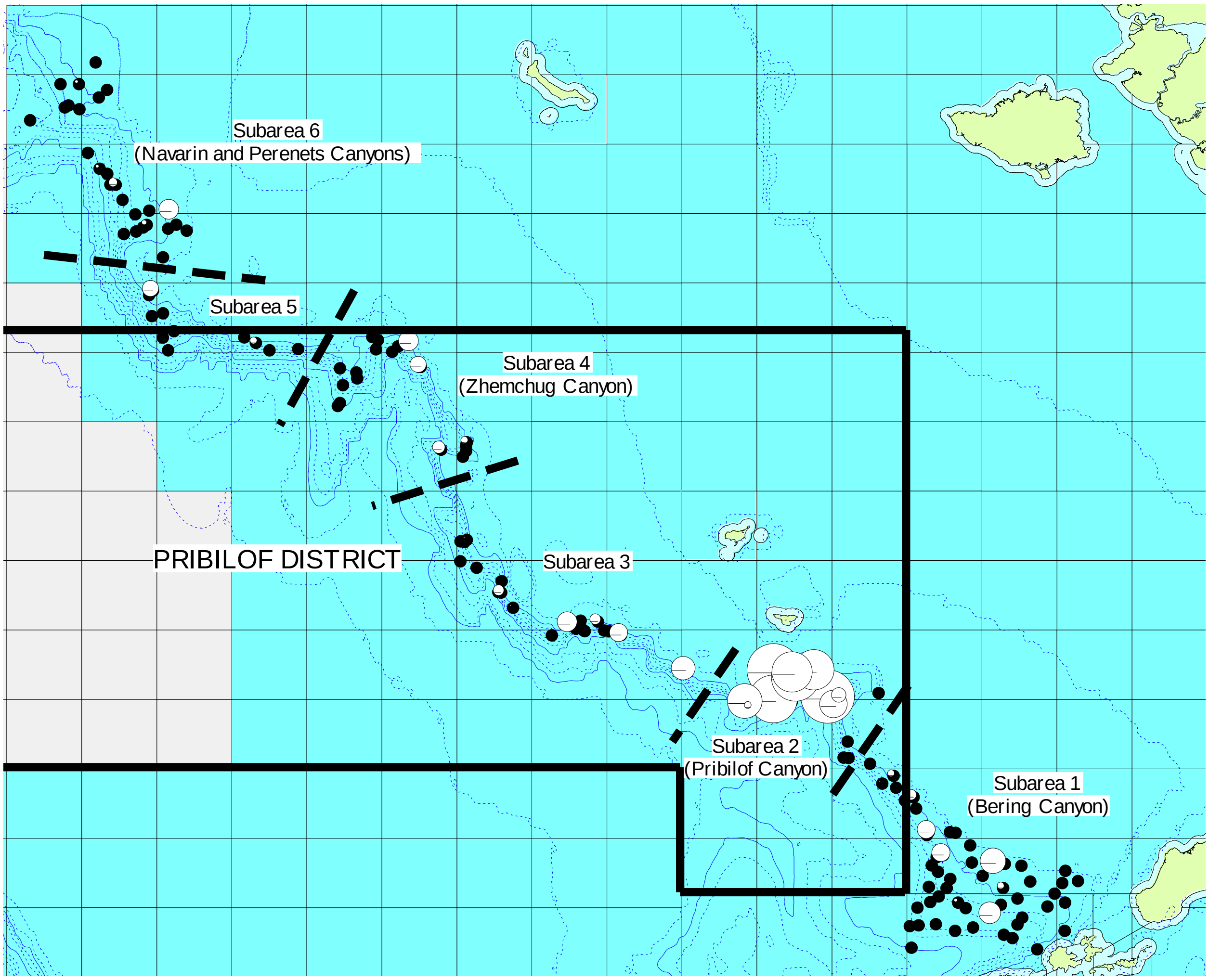

Figure 2. 2002 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 510 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

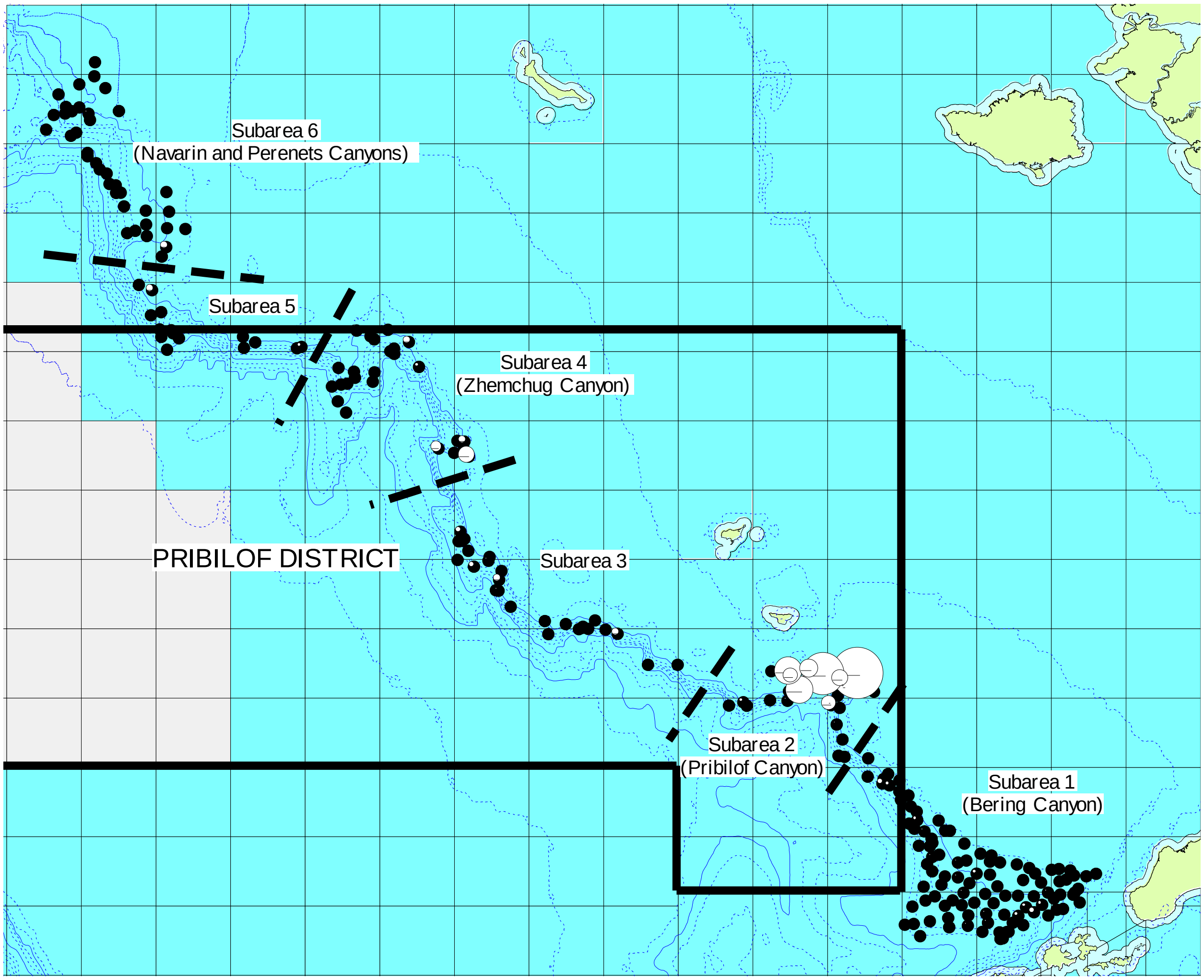

Figure 3. 2004 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 2,300 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

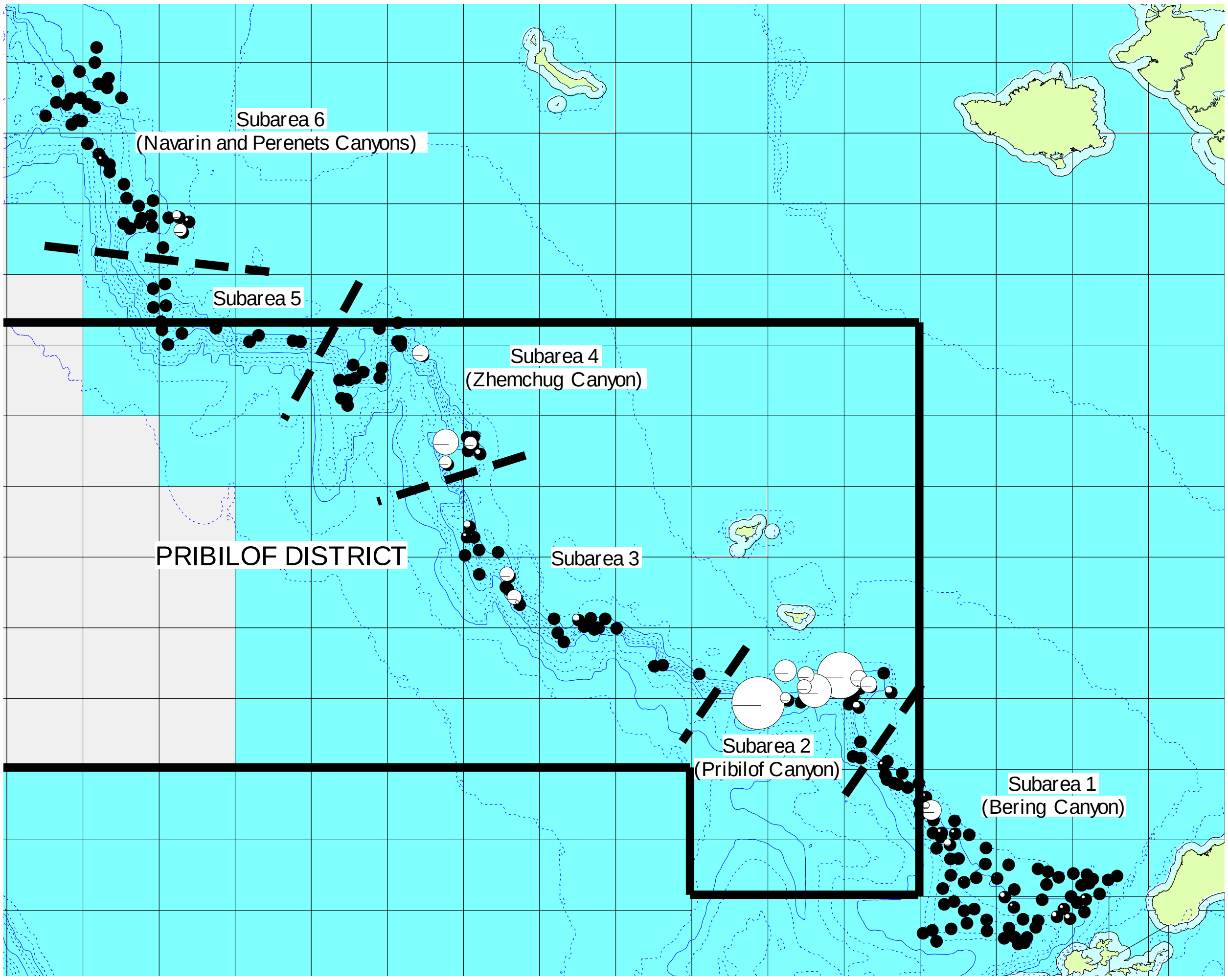

Figure 4. 2008 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 1,700 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

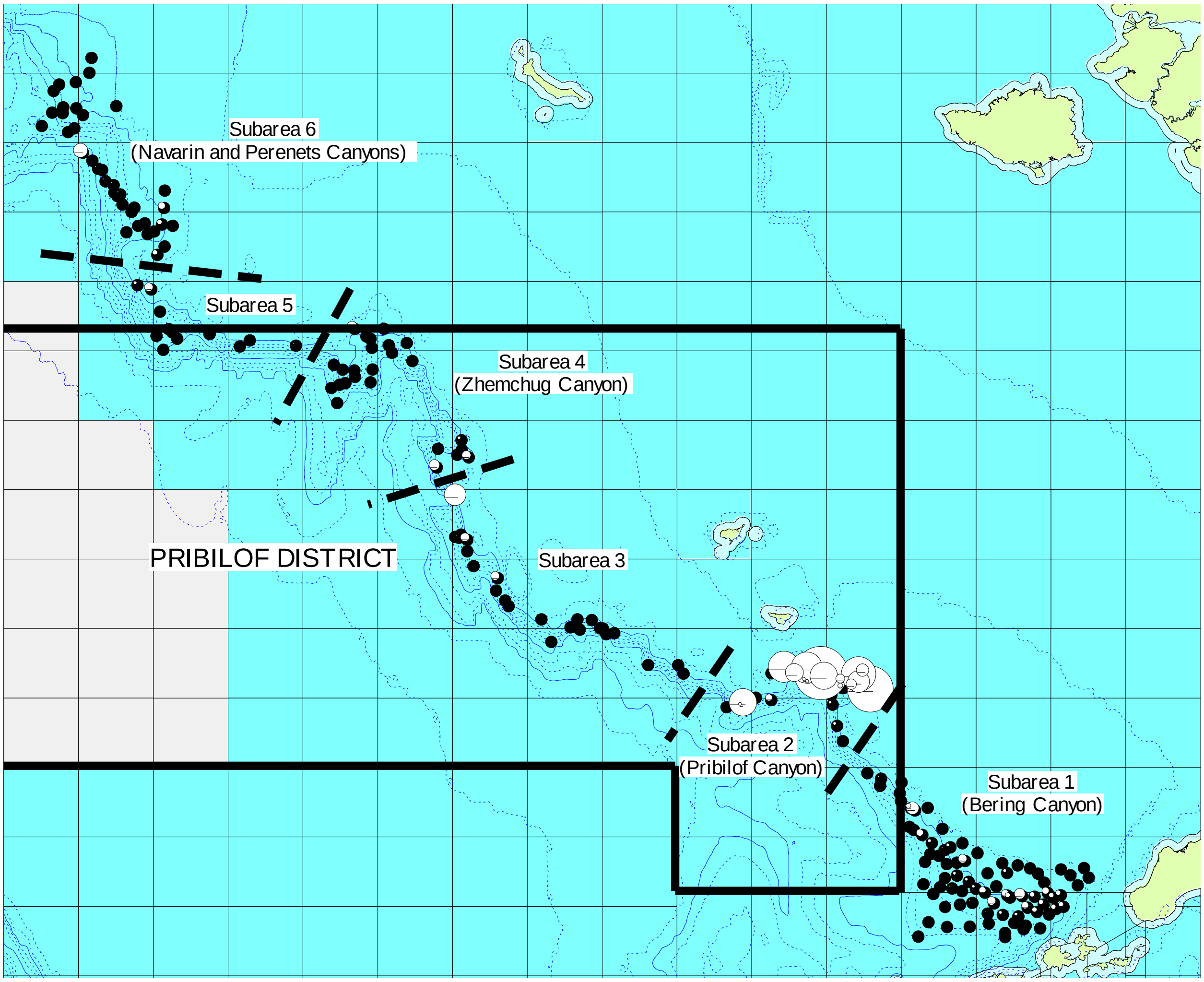

Figure 5. 2010 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 2,700 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

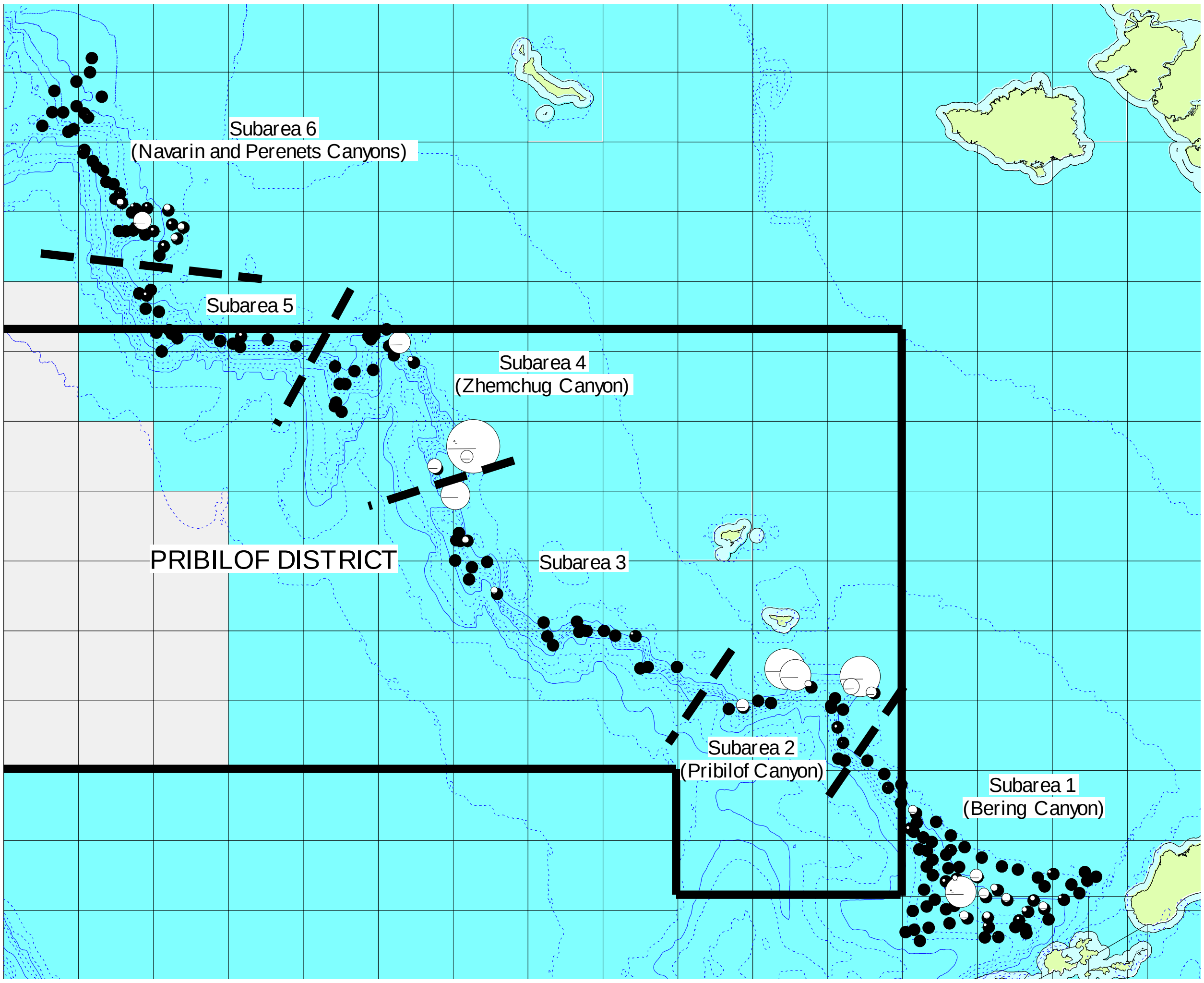

Figure 6. 2012 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 2,000 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

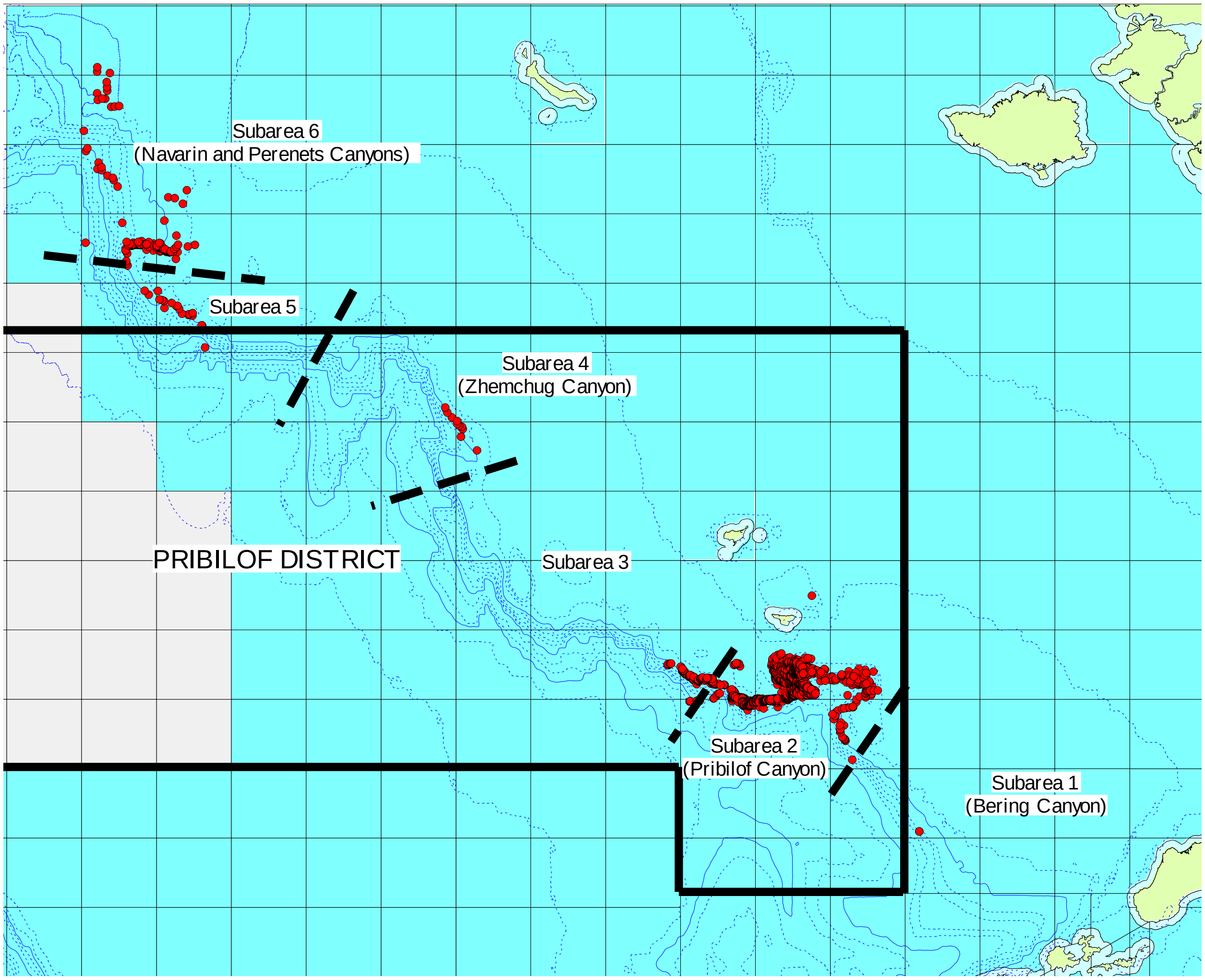

Figure 7. Locations of all pots sampled by observers during Bering Sea golden king crab fisheries (n = 6,104), 1992–2014; pots north of the Pribilof District northern boundary were fished during the Northern District – Saint Matthew Island Section fishery; squares are 1° longitude x 30' latitude State statistical areas.

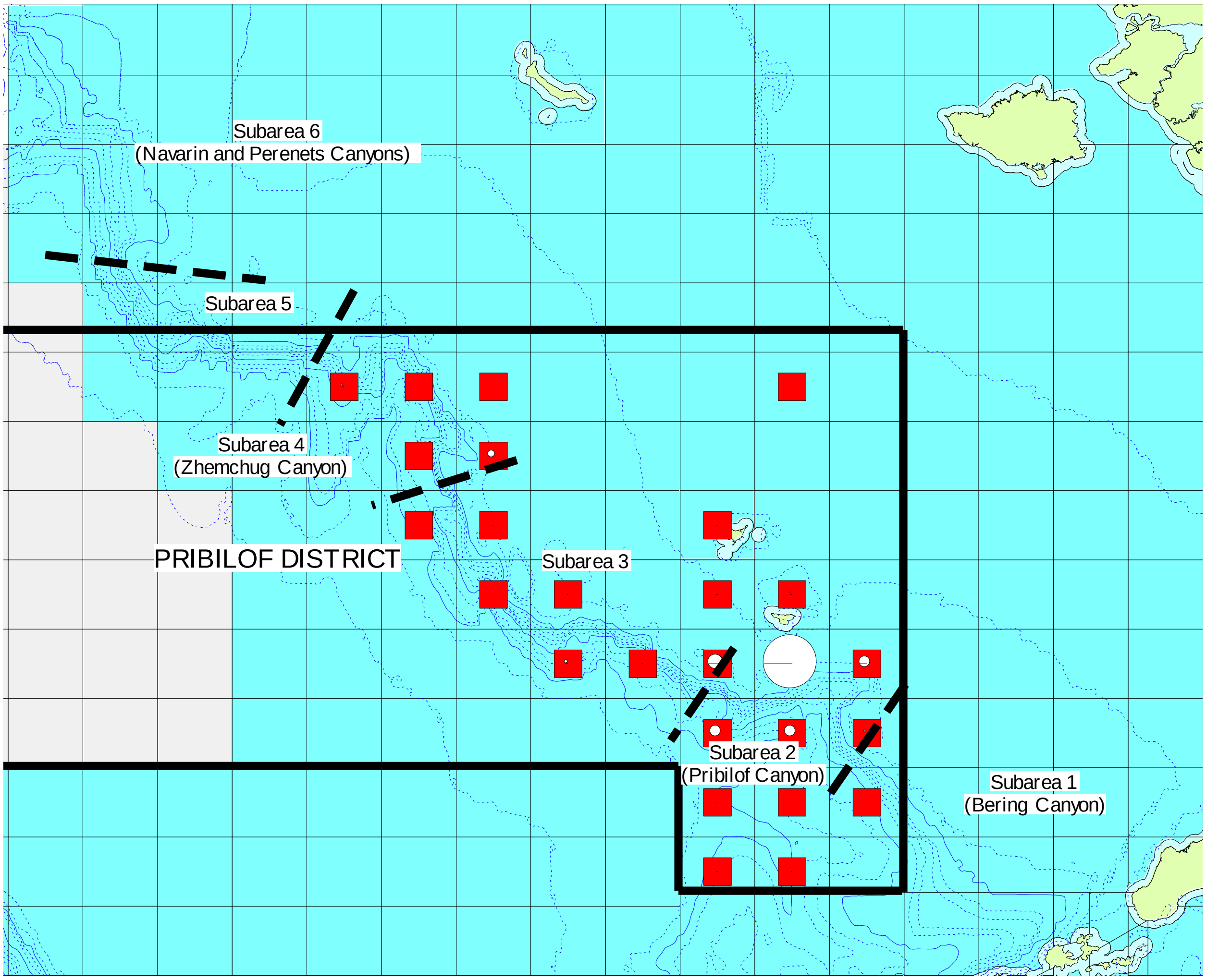

Figure 8. Statistical areas with reported catch during the 1985–2014 Pribilof District golden king crab fisheries: filled red squares denote statistical areas with reported catch; size of overlain white circles are proportional to the percentage of the total 1985–2014 catch reported from statistical area (biggest circle = 68% of total); squares are 1° longitude x 30' latitude State statistical areas.

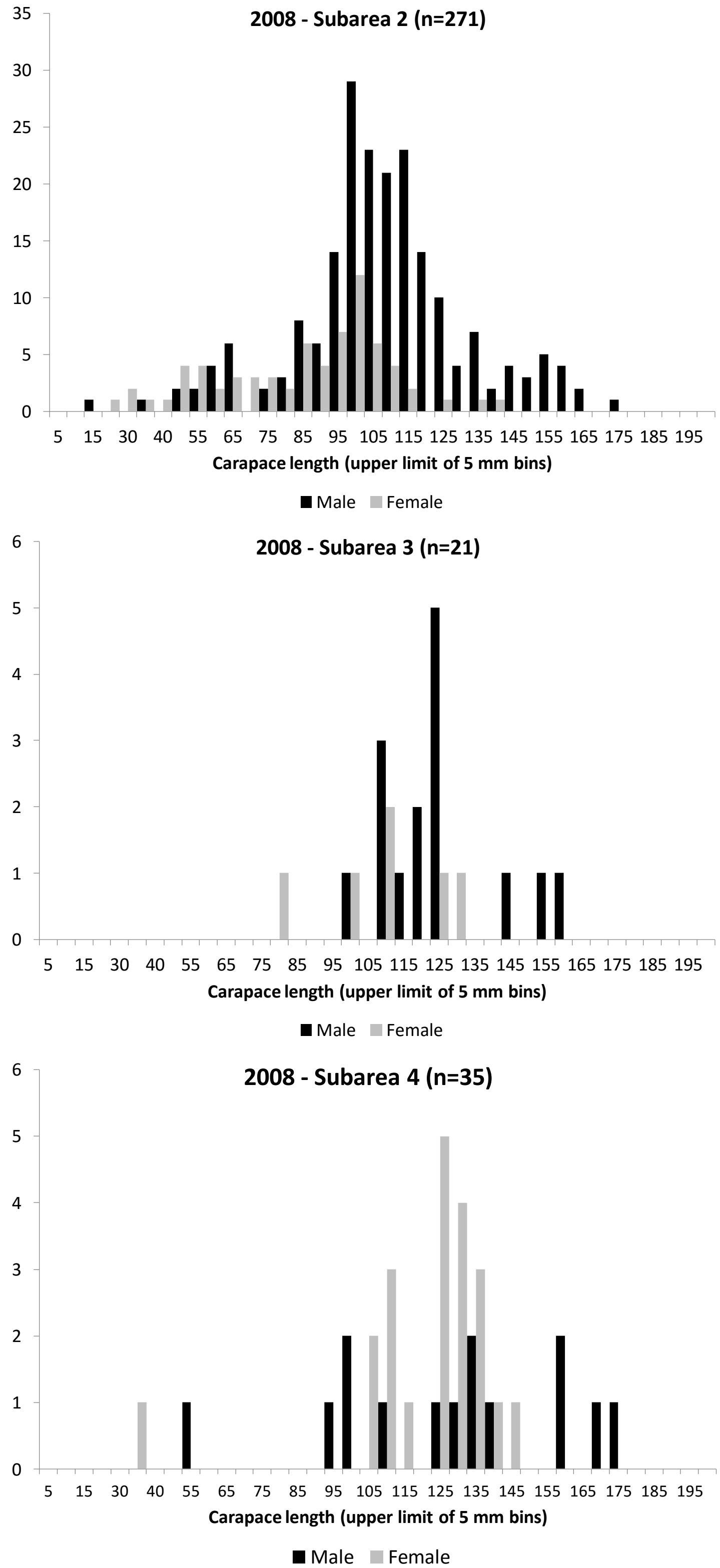

Figure 9. Size distribution of measured golden king crab during the 2008 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

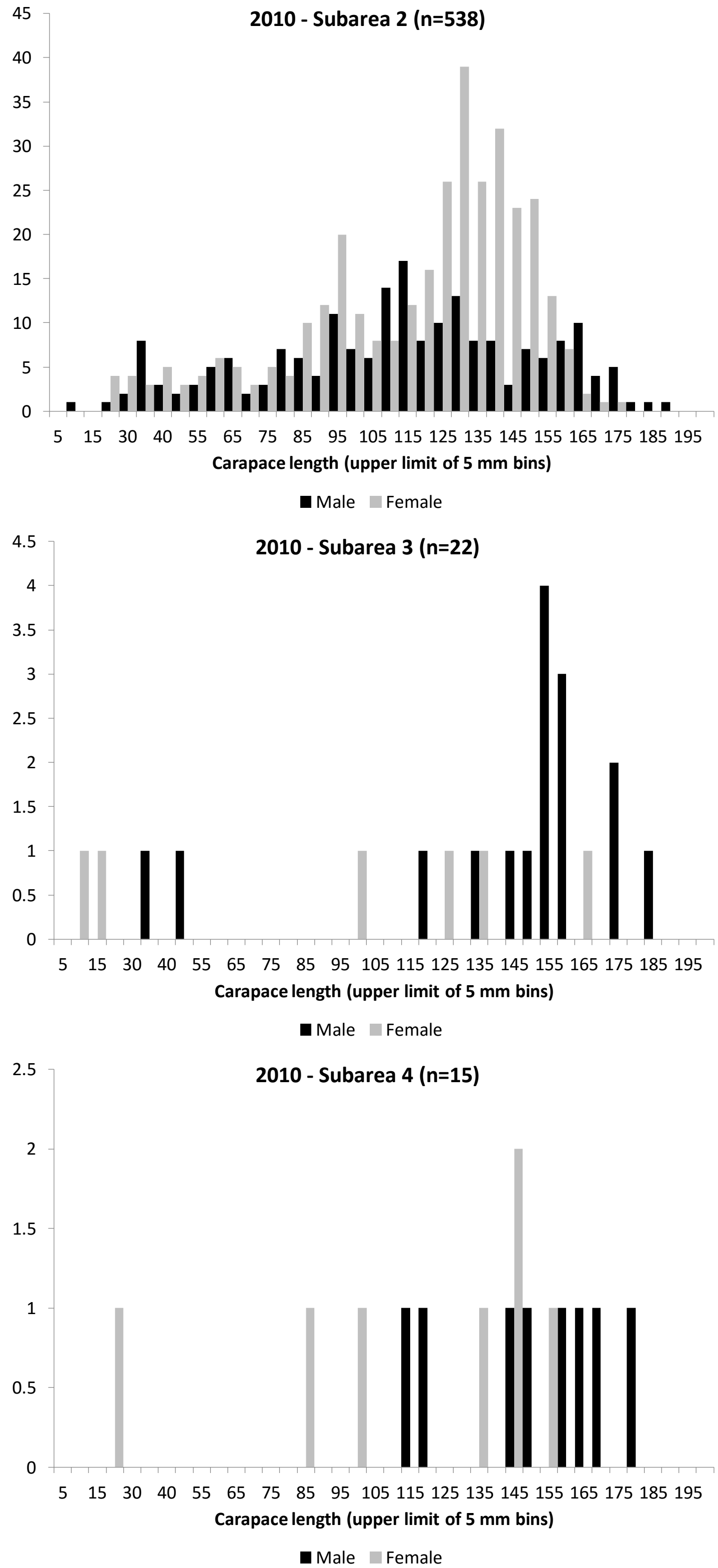

Figure 10. Size distribution of measured golden king crab during the 2010 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

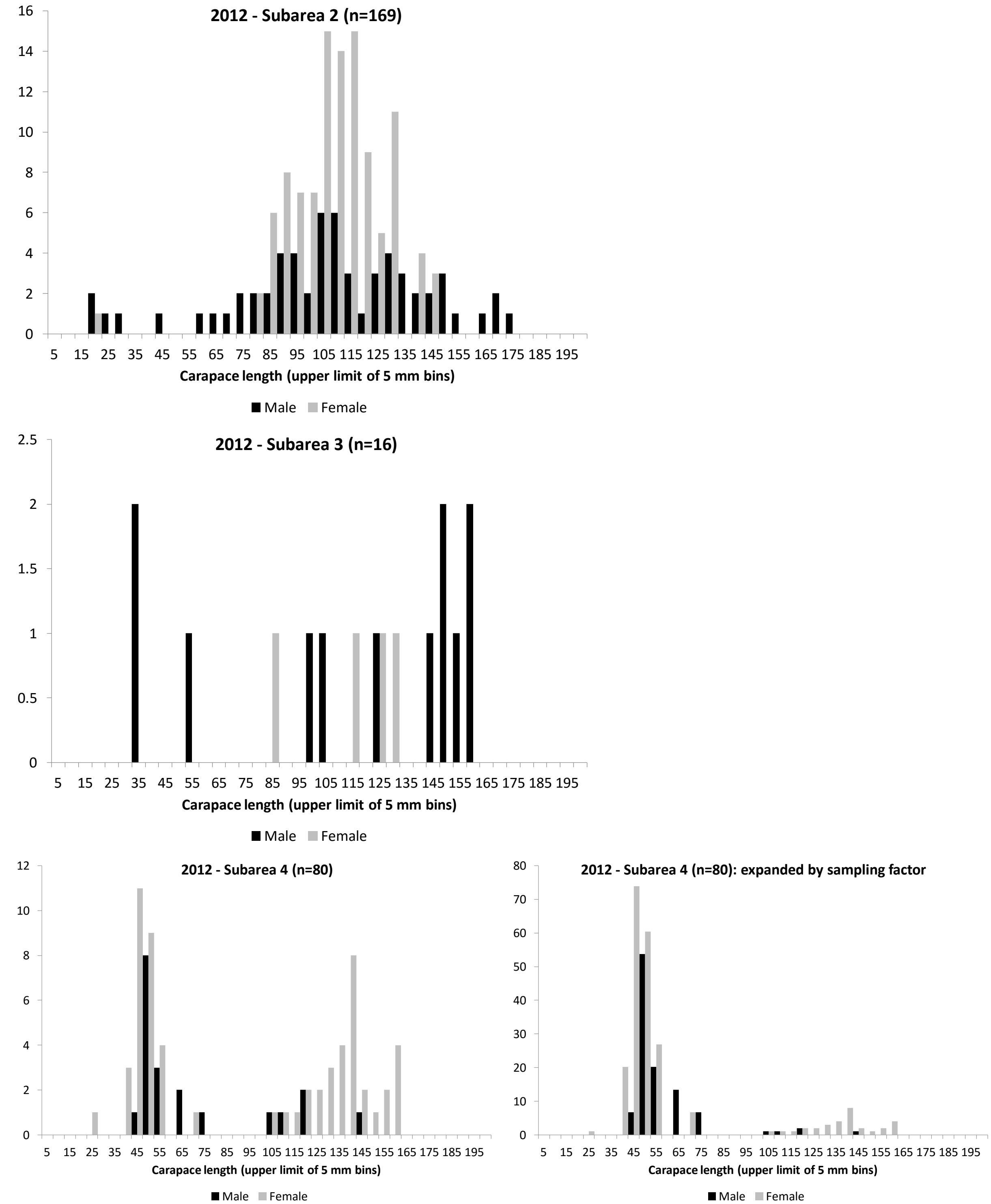

Figure 12. Size distribution of measured golden king crab during the 2012 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

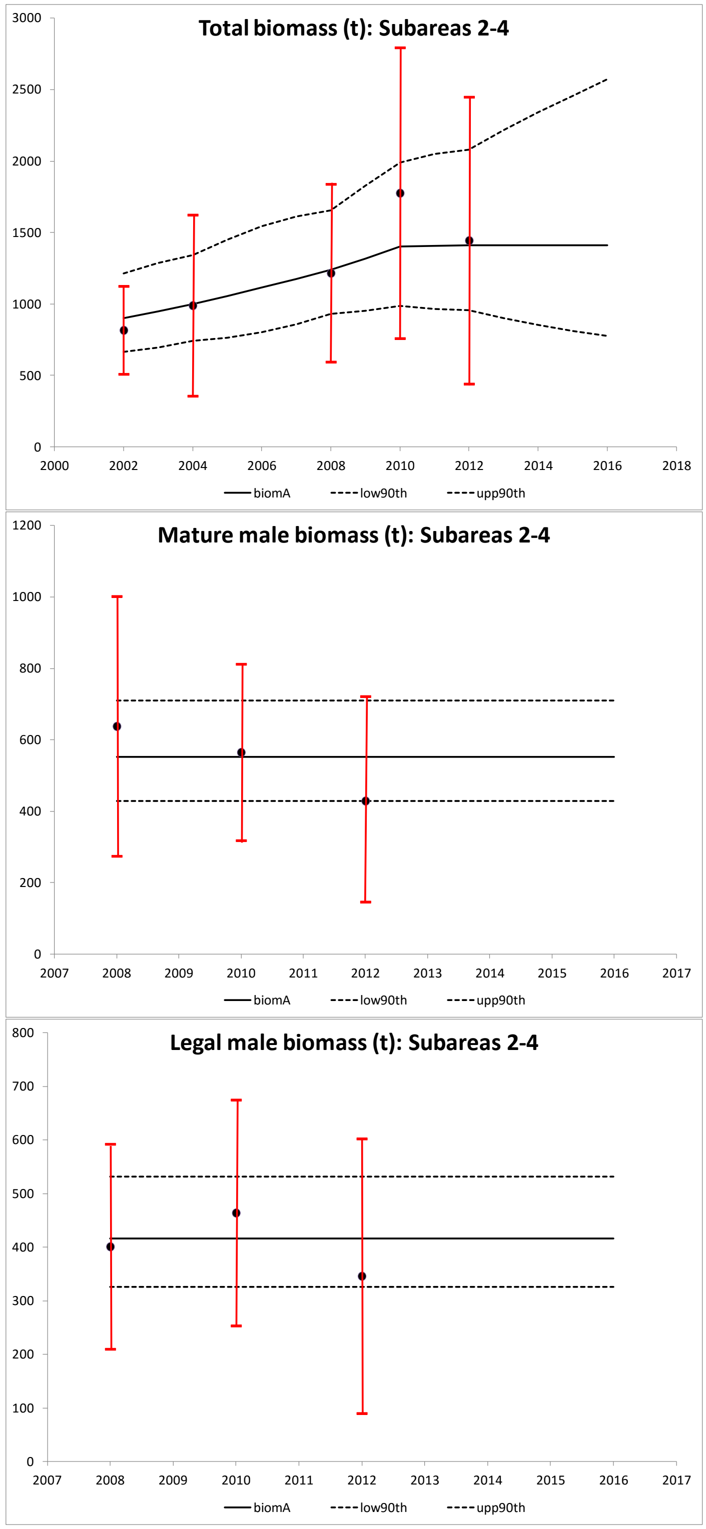

Figure 13. Plots of estimated and projected-into-2016 biomass of total, mature male, and legal male golden king crab in NMFS slope survey Subareas 2–4 with 90% confidence intervals and survey area-swept estimates; red bars are survey estimate plus/minus 2 standard errors.

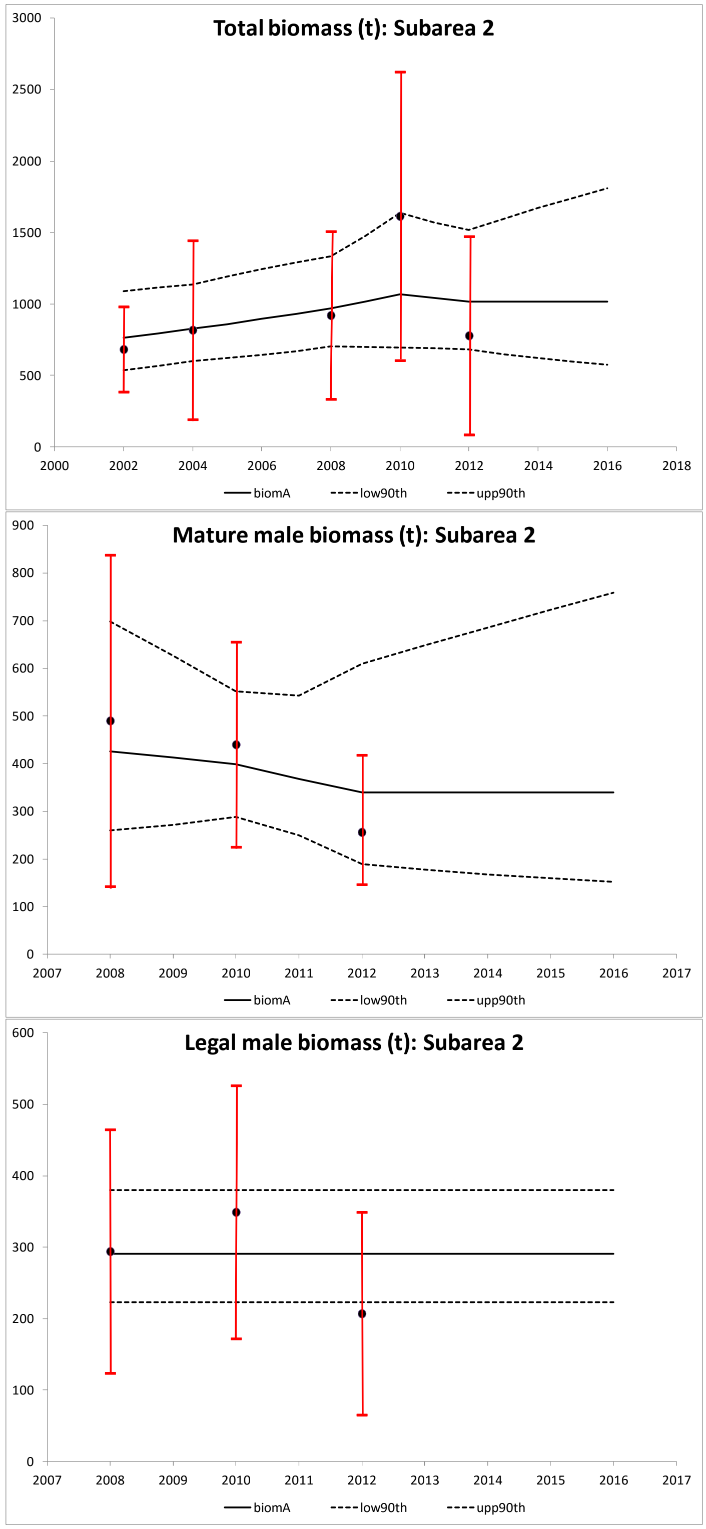

Figure 14. Plots of estimated and projected-into-2016 biomass of total, mature male, and legal male golden king crab in NMFS slope survey Subarea 2 with 90% confidence intervals and survey area-swept estimates; red bars are survey estimate plus/minus 2 standard errors.

Appendix A3:A1. Input file (re.dat) for total golden king crab biomass in NMFS EBS slope survey Subareas 2-4 and results file (rwout.rep) produced by re.exe.

Total biomass (t) estimates for subareas 2-4, 2002-2012 slope surveys

re.dat file				
2002	#Start year of model			
2016	#End year of model			
5	#number of survey estimates			
#Years of survey				
2002	2004	2008	2010	2012
#Biomass estimates				
816	989	1216	1776	1444
#Coefficients of variation for biomass estimates				
0.19	0.32	0.26	0.29	0.35

rwout.rep file															
yrs_srv															
	2002	2004	2008	2010	2012										
srv_est															
	816	989	1216	1776	1444										
srv_sd															
	0.188318	0.312233	0.25576	0.284166	0.339939										
yrs															
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
LCI															
	629.437	656.433	701.98	720.12	754.662	806.877	882.1	894.822	923.012	898.032	888.492	825.005	773.028	728.958	690.711
biomA															
	898.729	947.241	998.371	1054.23	1113.21	1175.49	1241.26	1318.69	1400.94	1406.26	1411.6	1411.6	1411.6	1411.6	1411.6
UCI															
	1283.23	1366.88	1419.91	1543.35	1642.11	1712.51	1746.66	1943.33	2126.34	2202.12	2242.7	2415.29	2577.69	2733.52	2884.89
low90th															
	666.517	696.286	742.863	765.61	803.314	857.176	931.878	952.361	987.031	965.15	957.12	899.382	851.578	810.642	774.792
upp90th															
	1211.84	1288.65	1341.76	1451.65	1542.66	1612.02	1653.36	1825.92	1988.42	2048.98	2081.89	2215.55	2339.92	2458.08	2571.82
biomsd															
	6.80098	6.85355	6.90613	6.96056	7.015	7.06944	7.12388	7.18439	7.2449	7.24869	7.25248	7.25248	7.25248	7.25248	7.25248
biomsd.sd															
	0.181712	0.187108	0.179704	0.194463	0.198334	0.191976	0.174274	0.19784	0.212886	0.228819	0.236202	0.274026	0.307228	0.337176	0.364673

Appendix A3:A2. Input file (re.dat) for mature male golden king crab biomass in NMFS EBS slope survey Subareas 2-4 and results file (rwout.rep) produced by re.exe.

Mature (>=107 mm CL) male biomass (t) estimates for subareas 2-4, 2008-2012 slope surveys

re.dat file			
2008	#Start year of model		
2016	#End year of model		
3	#number of survey estimates		
#Years of survey			
2008	2010	2012	
#Biomass estimates			
638	565	429	
#Coefficients of variation for biomass estimates			
0.29	0.22	0.34	

rwout.rep file									
yrs_srv									
	2008	2010	2012						
srv_est									
	638	565	429						
srv_sd									
	0.284166	0.217406	0.330745						
yrs									
	2008	2009	2010	2011	2012	2013	2014	2015	2016
LCI									
	408.72	408.738	408.744	408.724	408.686	408.673	408.661	408.649	408.636
biomA									
	551.765	551.76	551.755	551.749	551.743	551.743	551.743	551.743	551.743
UCI									
	744.872	744.828	744.803	744.824	744.878	744.9	744.923	744.945	744.967
low90th									
	428.915	428.93	428.936	428.917	428.882	428.871	428.861	428.85	428.839
upp90th									
	709.8	709.764	709.743	709.759	709.8	709.818	709.836	709.854	709.872
biomsd									
	6.31312	6.31311	6.3131	6.31309	6.31308	6.31308	6.31308	6.31308	6.31308
biomsd.sd									
	0.153107	0.153081	0.153069	0.153089	0.153131	0.153146	0.153162	0.153177	0.153193

Appendix A3:A3. Input file (re.dat) for legal male golden king crab biomass in NMFS EBS slope survey Subareas 2-4 and results file (rwout.rep) produced by re.exe.

Legal (>=124 mm CL) male biomass (t) estimates for subareas 2-4, 2008-2012 slope surveys

re.dat file		
2008	#Start year of model	
2016	#End year of model	
3	#number of survey estimates	
#Years of survey		
2008	2010	2012
#Biomass estimates		
401	464	346
#Coefficients of variation for biomass estimates		
0.24	0.23	0.37

rwout.rep file									
yrs_srv									
	2008	2010	2012						
srv_est									
	401	464	346						
srv_sd									
	0.236648	0.227042	0.358197						
yrs									
	2008	2009	2010	2011	2012	2013	2014	2015	2016
LCI									
	310.83	310.831	310.832	310.829	310.823	310.819	310.814	310.809	310.805
biomA									
	416.246	416.246	416.247	416.246	416.244	416.244	416.244	416.244	416.244
UCI									
	557.413	557.412	557.412	557.415	557.42	557.429	557.437	557.445	557.454
low90th									
	325.766	325.767	325.768	325.765	325.76	325.756	325.752	325.748	325.744
upp90th									
	531.856	531.855	531.855	531.857	531.862	531.868	531.875	531.882	531.888
biomsd									
	6.03128	6.03128	6.03128	6.03128	6.03127	6.03127	6.03127	6.03127	6.03127
biomsd.sd									
	0.148995	0.148994	0.148992	0.148997	0.149004	0.149011	0.149019	0.149027	0.149034

Appendix A3:B1. Input file (re.dat) for total golden king crab biomass in NMFS EBS slope survey Subarea 2 and results file (rwout.rep) produced by re.exe.

Total biomass (t) estimates for subarea 2, 2002-2012 slope surveys

re.dat file				
2002	#Start year of model			
2016	#End year of model			
5	#number of survey estimates			
#Years of survey				
2002	2004	2008	2010	2012
#Biomass estimates				
682	817	920	1614	778
#Coefficients of variation for biomass estimates				
0.22	0.38	0.32	0.31	0.45

rwout.rep file															
yrs_srv															
	2002	2004	2008	2010	2012										
srv_est															
	682	817	920	1614	778										
srv_sd															
	0.217406	0.367261	0.312233	0.302917	0.429421										
yrs															
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
LCI															
	501.727	530.855	565.671	582.598	603.885	629.85	661.103	651.433	639.392	639.842	632.362	595.772	564.672	537.6	513.629
biomA															
	765.392	795.334	826.446	859.928	894.766	931.015	968.733	1016.4	1066.42	1042.21	1018.54	1018.54	1018.54	1018.54	1018.54
UCI															
	1167.62	1191.58	1207.44	1269.27	1325.76	1376.18	1419.51	1585.86	1778.65	1697.6	1640.55	1741.31	1837.22	1929.73	2019.79
low90th															
	536.964	566.491	601.209	620.218	643.275	670.677	702.97	699.711	694.179	692.03	682.709	649.397	620.824	595.745	573.37
upp90th															
	1091	1116.62	1136.07	1192.28	1244.58	1292.41	1334.97	1476.44	1638.28	1569.58	1519.57	1597.52	1671.04	1741.39	1809.35
biomsd															
	6.64039	6.67876	6.71714	6.75685	6.79656	6.83628	6.87599	6.92403	6.97206	6.9491	6.92613	6.92613	6.92613	6.92613	6.92613
biomsd.sd															
	0.215476	0.206262	0.19343	0.198649	0.200602	0.199385	0.194939	0.226966	0.260994	0.248915	0.243196	0.273606	0.300959	0.326026	0.349298

Appendix A3:B2. Input file (re.dat) for mature male golden king crab biomass in NMFS EBS slope survey Subarea 2 and results file (rwout.rep) produced by re.exe.

Mature (>=107 mm CL) male biomass (t) estimates for subarea 2, 2008-2012 slope surveys

re.dat file			
2008	#Start year of model		
2016	#End year of model		
3	#number of survey estimates		
#Years of survey			
2008	2010	2012	
#Biomass estimates			
490	440	256	
#Coefficients of variation for biomass estimates			
0.36	0.24	0.32	

rwout.rep file									
yrs_srv									
	2008	2010	2012						
srv_est									
	490	440	256						
srv_sd									
	0.34909	0.236648	0.312233						
yrs									
	2008	2009	2010	2011	2012	2013	2014	2015	2016
LCI									
	236.563	250.548	271.48	231.49	168.758	156.739	146.522	137.661	129.86
biomA									
	426.017	412.406	399.23	367.956	339.133	339.133	339.133	339.133	339.133
UCI									
	767.196	678.825	587.094	584.872	681.513	733.775	784.941	835.466	885.654
low90th									
	260.02	271.441	288.838	249.389	188.79	177.438	167.678	159.125	151.522
upp90th									
	697.987	626.577	551.811	542.894	609.201	648.175	685.902	722.769	759.037
biomsd									
	6.05448	6.02201	5.98954	5.90796	5.82639	5.82639	5.82639	5.82639	5.82639
biomsd.sd									
	0.300135	0.254263	0.196759	0.236443	0.356084	0.393781	0.428172	0.459999	0.489763

Appendix A3:B3. Input file (re.dat) for legal male golden king crab biomass in NMFS EBS slope survey Subareas 2 and results file (rwout.rep) produced by re.exe.

Legal (>=124 mm CL) male biomass (t) estimates for subarea 2, 2008-2012 slope surveys

re.dat file		
2008	#Start year of model	
2016	#End year of model	
3	#number of survey estimates	
#Years of survey		
2008	2010	2012
#Biomass estimates		
294	349	207
#Coefficients of variation for biomass estimates		
0.29	0.25	0.34

rwout.rep file									
yrs_srv									
	2008	2010	2012						
srv_est									
	294	349	207						
srv_sd									
	0.284166	0.246221	0.330745						
yrs									
	2008	2009	2010	2011	2012	2013	2014	2015	2016
LCI									
	211.81	211.814	211.818	211.805	211.755	211.744	211.733	211.723	211.712
biomA									
	291.091	291.091	291.09	291.083	291.075	291.075	291.075	291.075	291.075
UCI									
	400.047	400.038	400.029	400.033	400.107	400.128	400.148	400.168	400.189
low90th									
	222.914	222.918	222.922	222.909	222.864	222.854	222.845	222.835	222.826
upp90th									
	380.119	380.112	380.105	380.106	380.163	380.18	380.196	380.212	380.228
biomsd									
	5.67364	5.67363	5.67363	5.67361	5.67358	5.67358	5.67358	5.67358	5.67358
biomsd.sd									
	0.162218	0.162207	0.162196	0.162214	0.162322	0.162348	0.162374	0.1624	0.162426

Appendix A3:C. Draft Pribilof Islands (Pribilof District) golden king crab stock structure template (adapted from Spencer et al. 2010). Page 1 of 2.

Factor and criterion	**Justification**
	Harvest and trends
Fishing mortality (5-year average percent of F_{abc} or F_{ofl})	F, F_{ABC}, and F_{OFL} are not estimated for Tier 5 stock. Total catch annual catch is confidential, but has been below the OFLs and ABCs established for season.
Spatial concentration of fishery relative to abundance (Fishing is focused in areas << management areas)	Fishery effort and catch is concentrated in Pribilof Canyon, a very small area of the Pribilof District, but also an area of concentrated golden king crab density (see EBS slope survey data).
Population trends (Different areas show different trend directions)	Uncertain. Standardized trawl surveys in the Pribilof District have only been performed in 2002, 2004, 2008, 2010, and 2012. Total biomass estimates generally increased from 2002 through 2012; mature-sized male biomass estimates decreased from 2008 through 2012, principally due to decrease between 2010 and 2012 within the Pribilof Canyon area.
	Barriers and phenotypic characters
Generation time (e.g., >10 years)	Unknown, but likely >10 years.
Physical limitations (Clear physical inhibitors to movement)	Species occurs primarily in the 200-1000 m depth zone. No known physical barriers exist in the Pribilof District, although survey and fishery data suggest low densities in the 200-1000 m depth zone of the EBS slope between Pribilof Canyon and Zhemchug Canyon.
Growth differences (Significantly different LAA, WAA, or LW parameters)	No data for estimating size at age. Spatial differences in length-weight relationship within Pribilof District have not been investigated. Within the Bering Sea males at higher latitudes have been estimated to be heavier than equal-sized males at lower latitudes.
Age/size-structure (Significantly different size/age compositions)	Age structure data is lacking. Spatial trends within Pribilof District in size structure have not been investigated, but trend of latitudinal decrease in mean size may exist over the Bering Sea due to latitudinal decrease in size at maturity.
Spawning time differences (Significantly different mean time of spawning)	Species is known to exhibit an asynchronous reproductive cycle lacking distinct seasonal variation; mean spawning time within Pribilof District has not been estimated.

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Factor and criterion	**Justification**
Maturity-at-age/length differences (Significantly different mean maturity-at-age/ length)	No data for estimating maturity at age. Spatial differences in size at maturity within Pribilof District have not been investigated. Within Bering Sea, estimates of size at maturity decrease south-to-north.
Morphometrics (Field identifiable characters)	Spatial trends within Pribilof District in morphometrics have not been investigated. Latitudinal trends in male morphometrics (chela size at length) may exist over the Bering Sea that are related to latitudinal trends in size at maturity.
Meristics (Minimally overlapping differences in counts)	N/A.
Behavior & movement	
Spawning site fidelity (Spawning individuals occur in same location consistently)	Not likely: ovigerous females tend to occur in the shallower depth zones at sites throughout the Pribilof District within the species depth distribution.
Mark-recapture data (Tagging data may show limited movement)	Mark-recapture data not available.
Natural tags (Acquired tags may show movement smaller than management areas)	Unknown.
Genetics	
Isolation by distance (Significant regression)	Unknown.
Dispersal distance (<<Management areas)	Unknown.
Pairwise genetic differences (Significant differences between geographically distinct collections)	Unknown.

Western Aleutian Islands Red King Crab

– 2016 Tier 5 Assessment

2016 Crab SAFE Report Chapter (September 2016)

Douglas Pengilly, ADF&G, Kodiak
Alaska Department of Fish and Game
Division of Commercial Fisheries
301 Research Ct.
Kodiak, AK 99615, USA
Phone: (907) 486-1865
Email: doug.pengilly@alaska.gov

Executive Summary

1. **Stock:**

Western Aleutian Islands (Aleutian Islands, west of 171° W longitude) red king crab, *Paralithodes camtschaticus*

There are two districts for State management of commercial red king crab fisheries in waters of the Aleutian Islands west of 171º W longitude: the Adak District for waters east of 179º W longitude and the Petrel District for waters west of 179º W longitude. Although this stock has been referred to colloquially as the "Adak" stock, this report will refer to the stock as the "Western Aleutian Islands (WAI) red king crab" stock to avoid confusion with the Adak District.

2. **Catches:**

The domestic fishery has been prosecuted since 1960/61 and was opened every year through the 1995/96 crab fishing year. Peak retained catch occurred in 1964/65 at 9,613 t (21,193,000 lb). During the early years of the fishery through the late 1970s, most or all of the retained catch was harvested in the area between 172° W longitude and 179°15' W longitude. As the annual retained catch decreased into the mid-1970s and the early-1980s, the area west of 179°15' W longitude began to account for a larger portion of the retained catch. Retained catch during the 10-year period 1985/86–1994/95 averaged 428 t (942,940 lb), but the retained catch in 1995/96 was only 18 t (38,941 lb). The fishery has been opened only occasionally during 1996/97 to present. There was an exploratory fishery with a low guideline harvest level (GHL) in 1998/99, three commissioner's permit fisheries in limited areas during 2000/01–2002/03 to allow for ADF&G-Industry surveys, and two commercial fisheries with a GHL of 227 t (500,000 lb) in 2002/03 and 2003/04. Most of the retained catch since 1990/91 was harvested in the Petrel Bank area (between 179° W longitude and 179° E longitude); in 2002/03 and 2003/04 the commercial fishery was opened only in the Petrel Bank area. Retained catch in the last two years with commercial fishing was 229 t (505,642 lb) in 2002/03 and 217 t (479,113 lb) in 2003/04. The fishery has been closed during 2004/05–2015/16. Discarded (non-retained) catch of red king crab occurs in the directed red king crab fishery (when prosecuted), in the Aleutian Islands golden king crab fishery, and in groundfish fisheries. Estimated annual weight of bycatch mortality due to crab fisheries during 1995/96–2015/16 averaged 1 t. Estimated annual weight of bycatch mortality due to groundfish fisheries during 1993/94–2015/16 averaged 9 t. Estimated weight of annual total fishery mortality during 1995/96–2015/16 averaged 36 t; the average annual retained catch during that period was 27 t (60,006 lb). A cooperative red king crab survey (with no retention of catch) was performed by the Aleutian Islands King Crab Foundation (an industry group) and ADF&G in the Adak area in September 2015 (Hilsinger et al. 2016), which resulted in an estimated bycatch mortality of 0.16 t (346 lb). Estimated total fishery mortality in 2015/16 resulted from groundfish fisheries (1.19 t) and the cooperative survey (0.16 t).

3. <u>Stock biomass</u>:
Estimates of past or present stock biomass are not available for this Tier 5 assessment.

4. <u>Recruitment</u>:
Estimates of recruitment trends and current levels relative to virgin or historic levels are not available for this Tier 5 assessment.

5. <u>Management performance</u>:
Overfishing did not occur during 2015/16 because the 2015/16 estimated total catch (1.2 t; 2,648 lb) did not exceed the Tier 5 OFL established for 2015/16 (56 t; 0.12-million lb). The 2015/16 estimated total catch did not exceed the ABC established for 2015/16 (34 t; 0.07-million lb). No determination has yet been made for a fishery opening or harvest level, if opened, for 2016/17. The OFL and ABC values for 2016/17 in the tables below are the author's status quo, Alternative 1 recommended values.

Management Performance Table (values in t)

Fishing Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch	Total Catch	OFL	ABC
2012/13	N/A	N/A	Closed	0	<1	56	34
2013/14	N/A	N/A	Closed	0	<1	56	34
2014/15	N/A	N/A	Closed	0	<1	56	34
2015/16	N/A	N/A	Closed	0	2.3	56	34
2016/17	N/A	N/A				56	34

a. Pre-season harvest levels are established as total allowable catch for the rationalized fishery west of 179° W longitude and as a guideline harvest level for the non-rationalized fishery east of 179° W longitude.

Management Performance Table (values in lb)

Fishing Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch	Total Catch	OFL	ABC
2012/13	N/A	N/A	Closed	0	624	0.12[b]	0.07[b]
2013/14	N/A	N/A	Closed	0	732	0.12[b]	0.07[b]
2014/15	N/A	N/A	Closed	0	474	0.12[b]	0.07[b]
2015/16	N/A	N/A	Closed	0	5,071	0.12[b]	0.07[b]
2016/17	N/A	N/A				123,867	74,320

a. Pre-season harvest levels are established as total allowable catch for the rationalized fishery west of 179° W longitude and as a guideline harvest level for the non-rationalized fishery east of 179° W longitude.
b. Established in millions of lb.

6. **Basis for the OFL and ABC:** See table, below; values for 2016/17 are the author's recommended values.

Year	Tier	Years to define Average catch (OFL)	Natural Mortality	Buffer
2012/13	5	1995/96-2007/08[a]	0.18[b]	40%
2013/14	5	1995/96-2007/08[a]	0.18[b]	40%
2014/15	5	1995/96-2007/08[a]	0.18[b]	40%
2015/16	5	1995/96-2007/08[a]	0.18[b]	40%
2016/17	5	1995/96-2007/08[a]	0.18[b]	40%

a. OFL is for total catch and was determined by the average of the total catch for these years.
b. Assumed value for FMP king crab in NPFMC (2007); does not enter into OFL estimation for Tier 5 stock.

7. **PDF of the OFL:** Sampling distribution of the recommended (status quo Alternative 1) Tier 5 OFL was estimated by bootstrapping (see section G.1). The standard deviation of the estimated sampling distribution of the recommended OFL is 56 t (CV = 0.42). Note that generated sampling distribution and computed standard deviation are meaningful as measures in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Section E.4.f).

8. **Basis for the ABC recommendation:** The recommended ABC of 34 t is the status quo; i.e., it is the ABC that was recommended by the SSC for 2012/13 – 2015/16. The ABC for 2012/13 was established at 34 t to accommodate an Industry request for a small test fishery during 2012/13 or in future years to obtain additional data on the stock (CPT minutes for May 2012 meeting and SSC minutes for June 2012 meeting) and has been maintained at that level since then.

   At 34 t the ABC provides a 40% buffer on the OFL of 56 t; i.e., (1.0-0.4)·56 t = 34 t.

9. **A summary of the results of any rebuilding analyses:** Not applicable; stock is not under a rebuilding plan.

A. Summary of Major Changes

1. **<u>Changes to the management of the fishery</u>:** No changes have been made to management of the fishery (the fishery has remained closed) and no changes have been made to regulations pertaining to the fishery since those adopted by the Alaska Board of Fisheries in March 2014.

2. **<u>Changes to the input data</u>:**
   - Data on retained catch, discarded catch, and estimates of bycatch mortality in crab and groundfish fisheries during 2015/16 have been added, but were not entered into the calculation of the recommended 2016/17 total-catch OFL.

3. **<u>Changes to the assessment methodology</u>:** None: the computation of OFL in this assessment follows the methodology recommended by the SSC in June 2010.

4. **<u>Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL</u>:** None: the computation of OFL in this assessment follows the methodology recommended by the SSC in June 2010 applied to the same data and estimates with the same assumptions that were used for estimating the 2010/11–2015/16 OFLs.

B. Responses to SSC and CPT Comments

1. **<u>Responses to the most recent two sets of SSC and CPT comments on assessments in general</u>:**
   - <u>CPT, May 2015</u>: *None pertaining to a Tier 5 assessment*.
   - <u>SSC, June 2015</u>: "*The SSC appreciates the author's inclusion of standard and metric units in the text but requests consistency in which units are used (e.g., lbs., thousand lbs., or million lbs. and t, mt, or kg). The SSC also requests consistency in the units chosen for tables and figures, requests that the units cited in the table legends match the values in the tables, and suggests authors refer to the terms of reference for chapters.*"
     - <u>Response</u>: The CPT terms of reference (as updated during the January 2016 meeting) were referred to:
     - "*To maintain consistency among SAFEs, the documents should report everything in the document in metric tons. The executive summary and the data used in the harvest strategy should be presented in both metric tons (abbreviated t) and pounds (lb).*" Weight-related numbers were reported in metric tons. Weights are given in both t and lb for the following: weights in the text of the <u>Management performance</u> section of the Executive Summary; weights in the Management Performance table; retained catch weights in the Executive Summary; GHLs/TACs throughout the document; retained catch weights when presented relative to GHLs/TACs throughout the document; retained catch weights in section C.4 ("Brief summary of management history); and the results of computation of the recommended 2016/17 OFL and ABC. Otherwise weights are presented only in t. For consistency in units, weights in the text and in reporting of recommended OFL and ABC are given in whole t for metric units and whole lb for U.S. customary units; in tables of data and estimates,

however, some metric weights in are given to several decimal places because some non-zero values round to 0 t. Reporting OFL and ABC for 2016/17 in t and lb may result in inconsistencies in the Management Performance tables and in the text when presenting previous OFLs and ABCs established using different conventions for units.

i. *"Provide single plot of all model data sources and years applicable – **Comment [4]: The Stockhausen tables**."* Done. See Table 7.

- CPT, September 2015 (via September 2015 SAFE Introduction chapter): *None pertaining to a Tier 5 assessment*.
- SSC, October 2015: *None pertaining to a Tier 5 assessment*.

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

- CPT, May 2015: *"If information could be recovered, the CPT requested the author provide a plot of CPUE through time in the 2016/17 assessment."*
  - Response: Plots of the CPUE data presented in Table 1a and 1b have not been presented in the Tier 5 assessment since 2010. Figure 6 provides a plot of those data for this assessment. CPUE data from historic fisheries not already presented in the 2015 assessment have not been recovered.
- SSC, June 2015: *"The SSC concurs with the CPT recommendation that the author try to recover length and effort information in historical data to inform an assessment and to provide a plot of CPUE through time in the 2016/17 assessment, if possible."*
  - Response: Data from retained-catch sampling have not been presented since 2009.The available size frequency data on the retained catch from the directed commercial fishery are summarized in Appendices A1–A4.
- CPT, September 2015 (via Sept 2014 SAFE): *None*.
- SSC, October 2014: *None*.

C. Introduction

1. **Scientific name:** *Paralithodes camtschaticus*, Tilesius, 1815

2. Description of general distribution:

The general distribution of red king crab is summarized by NMFS (2004):

> Red king crab are widely distributed throughout the BSAI, GOA, Sea of Okhotsk, and along the Kamchatka shelf up to depths of 250 m. Red king crab are found from eastern Korea around the Pacific rim to northern British Columbia and as far north as Point Barrow (page 3-27).
>
> Most red and blue king crab fisheries occur at depths from 50-200 m, but red king crab fisheries in the Aleutian Islands sometimes extend to 300 m.
>
> Red king crab is native to waters of 300 m or less extending from eastern Korea, the northern coast of the Japan Sea, Hokkaido, the Sea of Okhotsk, through the

> eastern Kamchatkan Peninsula, the Aleutian Islands, the Bering Sea, the GOA, and the Pacific Coast of North America as far south as Alice Arm in British Columbia. They are not found north of the Kamchatkan Peninsula on the Asian Pacific Coast. In North America red king crab range includes commercial fisheries in Norton Sound and sparse populations extending through the Bering Straits as far east as Barrow on the northern coast of Alaska. Red king crab have been acclimated to Atlantic Ocean waters in Russia and northern Norway. In the Bering Sea, red king crab are found near the Pribilof Islands and east through Bristol Bay; but north of Bristol Bay (58 degrees 39 minutes) they are associated with the mainland of Alaska and do not extend to offshore islands such as St. Matthew or St. Laurence Islands.

Commercial fishing for WAI red king crab during the last two years that the fishery was prosecuted (2002/03 and 2003/04) was opened only in the Petrel Bank area (i.e., between 179° W longitude and 179° E longitude; Baechler and Cook 2014). Fishery effort during those two years typically occurred at depths of 60–90 fathoms (110–165 m); average depth of pots fished in the Aleutian Islands area during 2002/03 was 68 fathoms (124 m; Barnard and Burt 2004) and during 2003/04 was 82 fathoms (151 m; Burt and Barnard 2005). In the 580 pot lifts sampled by observers in the Aleutian Islands golden king crab fishery during 1996/97–2006/07 that contained 1 or more red king crab, depth was recorded for 578 pots (ADF&G observer database, Dutch Harbor, April 2008). Of those, the deepest recorded depth was 266 fathoms (486 m) and 90% of pot lifts had recorded depths of 100–200 fathoms (183–366 m); no red king crab were present in any of the 6,465 pot lifts sampled during the 1996/97–2006/07 Aleutian Islands golden king crab fishery with depths >266 fathoms (486 m).

In this chapter we will refer to the area west of 171° W longitude within the Aleutian Islands king crab Registration Area O as the "Western Aleutian Islands" (WAI). The Aleutian Islands king crab Registration Area O is described by Baechler and Cook (2014, page 7) as follows (see also Figure 1):

> "The Aleutian Islands king crab Registration Area O has as its eastern boundary the longitude of Scotch Cap Light (164° 44' W longitude), its northern boundary a line from Cape Sarichef (54° 36' N latitude) to 171° W longitude, north to 55° 30' N latitude, and as its western boundary the Maritime Boundary Agreement Line as that line is described in the text of and depicted in the annex to the Maritime Boundary Agreement between the United States and the Union of Soviet Socialist Republics signed in Washington, June 1, 1990. Area O encompasses both the waters of the Territorial Sea (0-3 nautical miles) and waters of the Exclusive Economic Zone (3-200 nautical miles)."

From 1984/85 until the March 1996 Alaska Board of Fisheries meeting, the Aleutian Islands king crab Registration Area O as currently defined had been subdivided at 171° W longitude into the historic Adak Registration Area R and the Dutch Harbor Registration Area O. The geographic boundaries of the WAI red king crab stock are defined here by the boundaries of the historic Adak Registration Area R; i.e., the current Aleutian Islands king crab Registration Area O, west of 171° W longitude. Note that in March 2014 the Alaska Board of Fisheries established two districts for management of commercial fisheries for red king crab in the waters of the Aleutian Islands west of 171° W longitude: 1) the Adak District, 171º to 179º W longitude; and the Petrel District, west of 179º W longitude.

3. <u>Evidence of stock structure</u>:

Seeb and Smith (2005) analyzed microsatellite DNA variability in nearly 1,800 individual red king crab originating from the Sea of Okhotsk to Southeast Alaska, including a sample 75 specimens collected during 2002 from the vicinity of Adak Island in the Aleutian Islands (51° 51' N latitude, 176° 39' W longitude), to evaluate the degree to which the established geographic boundaries between stocks in the BSAI reflect genetic stock divisions. Seeb and Smith (2005) concluded that, "There is significant divergence of the Aleutian Islands population (Adak sample) and the Norton Sound population from the southeastern Bering Sea population (Bristol Bay, Port Moller, and Pribilof Islands samples)." Recent analysis of patterns of genetic diversity among red king crab stocks in the western north Pacific (Asia), eastern North Pacific, and Bering Sea by multiple techniques (SNPs, allozymes, and mtDNA) also showed that red king crab sampled near Adak Island had greater genetic similarity to stocks in Asia rather than other stocks in Alaskan waters including Bristol Bay and the Gulf of Alaska (Grant et al. 2014).

We know of no analyses of genetic relationships among red king crab from different locations within the WAI. However, given the expansiveness of the WAI and the canyons between some islands that are deep (>1,000 m) relative to the depth zone restrictions of red king crab (see above), at least some weak structuring within the WAI red king crab stock would be expected. A summary of total retained catch by 1-degree longitude groupings during 1985/86–1995/96 (years for which state statistical area definitions allow for grouping by 1-degree longitude and for which catch distribution was not affected by area closures and openings; see Section C.5) shows that catch and, presumably, distribution of legal-sized male red king crab is not evenly distributed across the Aleutian Islands, with most catch during that period having come from Petrel Bank, followed by the vicinity of Adak, Atka, and Amlia Islands (Figure 2). Note that the 1-degree longitude grouping of catch does not portray the spatial gaps in catch that are apparent in a closer inspection of the 1985/86–1995/96 catch data by state statistical areas. For example, no catch was reported during 1985/86–1995/96 from the two statistical areas (795102 and 795132) that include Amchitka Pass (Amchitka Pass lies between Petrel Bank and the Delarof Is; see Figure 2).

McMullen and Yoshihara (1971) reported the following on male red king crab that were tagged in February 1970 on the Bering Sea and Pacific Ocean sides of Atka Island and recovered in the subsequent fishery:

> "Fishermen landing tagged crabs were questioned carefully concerning the location of recapture. In no instance did crabs migrate through ocean passes between the Pacific Ocean and Bering Sea."

4. <u>Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology)</u>:

Red king crab eggs are fertilized externally and the clutch of fertilized eggs (embryos) are carried under the female's abdominal flap until hatching. Male king crab fertilize eggs by passing spermatophores from the fifth periopods to the gonopores and coxae of the female's third periopods; the eggs are fertilized during ovulation and attach to the female's pleopodal setae (Nyblade 1987, McMullen 1967). Females are generally mated within hours after molting (Powell and Nickerson 1965), but may mate up to 13 days after molting (McMullen 1969). Males must wait at least 10 days after completing a molt before mating (Powell et al. 1973), but, unlike females, do not need to molt prior to mating (Powell and Nickerson 1965).

Wallace et al. (1949, page 23) described the "egg laying frequency" of red king crab:

> "Egg laying normally takes place once a year and only rarely are mature females found to have missed an egg laying cycle. The eggs are laid in the spring immediately following shedding [i.e., molting] and mating and are incubated for a period of nearly a year. Hatching of the eggs does not occur until the following spring just prior to moulting [i.e., molting] season."

McMullen and Yoshihara (1971) reported that from 804 female red king crab (79–109-mm CL) collected during the 1969/70 commercial fishery in the western Aleutians, "Female king crab in the western Aleutians appeared to begin mating at 83 millimeters carapace length and virtually all females appeared to be mature at 102 millimeters length." Blau (1990) estimated size at maturity for WAI red king crab females as the estimated CL at which 50% of females are mature (SM50; as evidenced by presence of clutches of eggs or empty) according to a logistic regression: 89-mm CL (SD = 2.6 mm). Size at maturity has not been estimated for WAI male red king crab. However, because the estimated SM50 for WAI red king crab females is the same as that estimated for Bristol Bay red king crab females (Otto et al. 1990), the estimated maturity schedule used for Bristol Bay red king crab males (see SAFE chapter on Bristol Bay red king crab) could be applied to males in the WAI stock as a proxy.

Few data are available on the molting and mating period for red king crab specifically in the WAI. Among the red king crab captured by ADF&G staff for tagging on the south side of Amlia Island (173° W longitude to 174° W longitude) in the first half of April 1971, males and females were molting, females were hatching embryos, and mating was occurring (McMullen and Yoshihara 1971). The spring mating period for red king crab is known to last for several months, however. For example, although mating activity in the Kodiak area apparently peaks in April, mating pairs in the Kodiak area have been documented from January through May (Powell et al. 2002). Due to the timing of the commercial fishery within a year, little data on reproductive condition of WAI red king crab females have been collected by at-sea fishery observers that can be used for evaluating the mating period. For example, of the 3,211 mature females that were examined during the 2002/03 and 2003/04 red king crab fisheries in the Petrel Bank area, which were prosecuted in late October, only 10 were scored as "hatching" (ADF&G observer database, Dutch Harbor, April 2008).

Data on mating pairs of red king crab collected from the Kodiak area during March–May of 1968 and 1969 showed that size of the females in the pairs increased from March to May, indicating that females tend to release their larvae and mate later in the mating season with increasing body size (Powell et al. 2002). Size of the males in those mating pairs did not increase with later sampling periods, but did show a decreasing trend in estimated time since last molt. In all the data on mating pairs collected from the Kodiak area during 1960–1984, the proportion of males that were estimated to have not recently molted prior to mating decreased monthly over the mating period (Powell et al. 2002). Those data suggest that males that do not molt early in the mating period have an advantage in mating early in the mating period, when primiparous females and smaller, multiparous females tend to ovulate, and that males that do molt early in the mating period likely participate later in the mating period, likely mating with the larger females.

Current knowledge of red king crab reproductive biology, including male and female maturation, migration, mating dynamics, and potential effects of exploitation on reproductive potential, is summarized by Webb (2014).

5. Brief summary of management history:

A complete summary of the management history through 2011/12 is provided by Baechler and Cook (2014, pages 7–13). The domestic fishery for red king crab in the WAI began in 1960/61. Retained catch of red king crab in the Aleutians west of 172° W longitude averaged 5,259 t (11,595,068 lb) during 1960/61–1975/76, with a peak retained catch of 9,613 t (21,193,000 lb) in 1964/65 (Tables 1a and 1b, Figure 3). Guideline harvest levels (GHL; sometimes expressed as ranges, with an upper and lower GHL) for the fishery were established in most years since 1973/74. The fishery was closed in 1976/77 in the area west of 172º W longitude, but was reopened for each year during 1977/78–1995/96. Average retained catch during 1977/78–1995/96 (for the area west of 172º W longitude prior to 1984/85 and for the area west of 171º W longitude since 1984/85) was 470 t (1,036,659 lb); the peak retained catch during that period occurred in 1983/84 at 899 t (1,981,579 lb). During the mid-to-late 1980s, significant portions of the catch during the WAI red king crab fishery occurred west of 179º E longitude or east of 179º W longitude, whereas most of the retained catch was harvested from the Petrel Bank area (179° W longitude to 179° W longitude) during 1990/91–1994/95 (Figure 4). Retained catch and fishery CPUE (retained crab per pot lift) declined from 1993/94 to 1994/95 and 1995/96; retained catch in 1994/95 and, especially, 1995/96 was far below the lower GHL established. Due to concerns about the low stock level and poor recruitment indicated by results of the fishery in 1994/95–1995/96, the fishery was closed in 1996/97–1997/98. During 1998/99–2003/04 the fishery was opened only in restricted areas, either as an open fishery managed under a GHL or as an ADF&G-Industry survey conducted as a commissioner's permit fishery (Table 2); peak retained catch during that period was 229 t (505,642 lb) harvested from the Petrel Bank area in 2002/03. The fishery has been closed during 2004/05–2015/16.

Only males of a minimum legal size may be retained by the commercial red king crab fishery in the WAI. By State of Alaska regulation (**5 AAC 34.620 (a)**), the minimum legal size limit is 6.5-inches (165 mm) carapace width (CW), including spines. A carapace length (CL) ≥138 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007). Except for the years 1968–1970, the minimum size has been 6.5-inches CW since 1950; in 1968 there was a "first-season" minimum size of 6.5-inches CW and a "second-season" minimum size of 7.0-inches and in 1969–1970 the minimum size was 7.0-inches CW (Donaldson and Donaldson 1992).

Red king crab may be commercially fished only with king crab pots (as defined in **5 AAC 34.050**). Pots used to fish for red king crab in the WAI must, since 1996, have at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized red king crab and may not be longlined (**5 AAC 34.625 (e)**). The sidewall of the pot "…must contain an opening equal to or exceeding 18 inches in length...

The opening must be laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 30 thread." (**5 AAC 39.145(1)**).

The WAI red king crab fishery west of 179° W longitude has been managed since 2005/06 under the Crab Rationalization program (50 CFR Parts 679 and 680). The WAI red king crab fishery in the area east of 179° W longitude was not included in the Crab Rationalization program (Baechler and Cook 2014). In March 2014 the Alaska Board of Fisheries established two red king crab management districts in state regulations for the Aleutian Islands west of 171° W longitude (the Adak District, 171º to 179º W longitude; and the Petrel District, west of 179º W longitude) and some notable differences in regulations exist between the two districts. The red king crab commercial fishing season in the Adak District is August 1 to February 15, unless closed by emergency order (**5 AAC 34.610 (a) (1)**); the red king crab commercial fishing season in the Petrel is October 15 to February 15, unless closed by emergency order (**5 AAC 34.610 (a) (2)**). Only vessels 60 feet or less in overall length may participate in the commercial red king crab fishery within the state waters of the Adak District (**5 AAC 34.610 (d)**); no vessel size limit is established for federal waters in the Adak District or for state or federal waters in the Petrel District. Federal waters in the Adak District are opened to commercial red king crab fishing only if the season harvest level established by ADF&G for the Adak District is 250,000 lb or more (**5 AAC 34.616 (a) (2)**); there is no comparable regulation for the Petrel District. In the Adak District, pots commercially fished for red king crab may only be deployed and retrieved between 8:00 AM and 5:59 PM each day (**5 AAC 34.625 (g) (2)**) and the following pot limits pertain: 10 pots per vessel for vessels fishing within state waters (**5 AAC 34.625 (g) (1) (A)**); and 15 pots per vessel for vessels fishing in federal waters (**5 AAC 34.625 (g) (1) (B)**). In the Petrel District there is no regulation pertaining to periods for operation of gear and a pot limit of 250 pots per vessel (**5 AAC 34.625 (d)**). See also "6. Brief description of the annual ADF&G harvest strategy," below.

6. <u>Brief description of the annual ADF&G harvest strategy</u>:

Prior to the March 2014 Alaska Board of Fisheries meeting, when the board adopted a harvest strategy for the Adak District only, there was no harvest strategy in state regulation for WAI red king crab. Following results of the January/February and November 2001 ADF&G-Industry pot surveys for red king crab in the Petrel Bank area, which produced high catch rates of legal males (CPUE = 28), but low catches of females and sublegal males, ADF&G opened the fishery in 2002/03 and 2003/04 with a GHL of 227 t (500,000 lb); that GHL was established as the minimum GHL that could be managed inseason, given expected participation and effort (Baechler and Cook 2014). The fishery was closed in 2004/05 due to continued uncertainty on the status of pre-recruit legal males, a reduction in legal male CPUE from 18 in 2002/03 to 10 in 2003/04, and a strategy adopted by ADF&G to close the fishery before the CPUE of legal crab dropped below 10.

The harvest strategy for red king crab in the Adak District adopted by the Alaska Board of Fisheries in March 2014 is as follows:

> **5 AAC 34.616. Adak District red king crab harvest strategy.** (a) In the Adak District, based on the best scientific information available, if the department determines that there is a harvestable surplus of

(1) red king crab available in the waters of Alaska in the Adak District, the commissioner may open, by emergency order, a commercial red king crab fishery only in the waters of Alaska in the Adak District under 5 AAC 34.610(a)(1);

(2) at least 250,000 pounds of red king crab in the Adak District, the commissioner may open, by emergency order, a commercial red king crab fishery in the entire Adak District under 5 AAC 34.610(a)(1).

(b) In the Adak District, during a season opened under 5 AAC 34.610(a)(1), the operator of a validly registered king crab fishing vessel shall

(1) report each day to the department

(A) the number of pot lifts;

(B) the number of crab retained for the 24-hour fishing period preceding the report; and

(C) any other information the commissioner determines is necessary for the management and conservation of the fishery, as specified in the vessel registration certificate issued under 5 AAC 34.020; and

(2) complete and submit a logbook as prescribed and provided by the department.

7. **Summary of the history of B_{MSY}:** Not applicable for this Tier 5 stock.

D. Data

1. **Summary of new information:**
    - Retained catch data from the 2015/16 directed fishery has been added; the fishery was closed and the retained catch was 0 t (0 lb).
    - Data on discarded catch in crab and groundfish fisheries has been updated with data from the 2015/16 Aleutian Islands golden king crab fishery (no bycatch of WAI RKC) and the 2015/16 groundfish fisheries in reporting areas 541, 542, and 543 (Figure 5).
    - Discarded catch during the cooperative industry-ADF&G survey in 2015. Data was available as number of crab caught per size/sex group (males: legal, pre recruit, or juvenile and females). Assumptions were made on the representative size (width) of each group, which were converted to length then weight. A bycatch mortality rate of 0.2 (as applied to crab fisheries) was applied to the estimated total weight caught.

2. **Data presented as time series:**

a. Total catch and b. Information on bycatch and discards:

- Annual retained catch weight for 1960/61–2015/16 (Tables 1a and 1b, Figure 3).
- Annual retained catch weight and estimated weights of discarded legal males, discarded sublegal males, and discarded females captured by commercial crab fisheries during 1995/96–2015/16 (Table 3). Observer data on size distributions and estimated catch numbers of discarded catch were used to estimate the weight of discarded catch of red king crab by applying a weight-at-length estimator (see below). Estimates of discarded catch prior to 1995/96 are not given due to non-existence of data or to limitations on sampling for discarded catch during the crab fisheries: prior to 1988/89 there was no fishery observer program for Aleutian Islands crab fisheries and observers were required only on vessels processing king crab at sea (including catcher-processor vessels) during

1988/89–1994/95; observer data from the Aleutian Islands prior to 1990/91 is considered unreliable; and the observer data from the directed WAI red king crab fishery in 1990/91 and 1992/93–1994/95 and golden king crab fishery in the 1993/94–1994/95 are confidential due to the limited number of observed vessels. During 1995/96–2004/05, observers were required on all vessels fishing for king crab in the Aleutian Islands area at all times that a vessel was fishing. With the advent of the Crab Rationalization program in 2005/06, all vessels fishing for golden king crab in the Aleutian Islands area are now required to carry an observer for a period during which 50% of the vessel's retained catch was obtained during each trimester of the fishery; observers continue to be required at all times on a vessel fishing in the red king crab fishery west of 179° W longitude. All red king crab that were captured and discarded during the Aleutian Islands golden king crab fishery west of 174° W longitude by a vessel while an observer was on board during 2001/02–2002/03 and 2004/05–2015/16 were counted and recorded for capture location and biological data.

- Annual estimated weight of discarded catch and estimated bycatch mortality in the WAI (reporting areas 541, 542, and 543; i.e., Aleutian Islands west of 170° W longitude; Figure 5) during federal groundfish fisheries by gear type (fixed or trawl) for 1993/94–2015/16 (Table 4). Following Foy (2012a, 2012b), the bycatch mortality rate of king crab captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crab captured by trawls during groundfish fisheries was assumed to be 0.8. Estimates of discarded catch by gear type for 1992/93 are available, but appear to be suspect because they are extremely low. Annual estimated weight of discarded catch during federal groundfish fisheries by reporting area (541, 542, and 543) for 1993/94–2015/16 is also presented in Table 5.
- Annual estimated weight of total fishery mortality for 1995/96–2015/16, partitioned into retained catch, estimated bycatch mortality during crab fisheries, and estimated bycatch mortality during federal groundfish fisheries (Table 6). Following Siddeek et al. (2011), the bycatch mortality rate of king crab captured and discarded during Aleutian Islands king crab fisheries was assumed to be 0.2; bycatch mortality in crab fisheries was estimated for Table 6 by applying that assumed bycatch mortality rate to the estimates of discarded catch given in Table 3. The estimates of bycatch mortality in groundfish fisheries given in Table 6 are from Table 4.
- Table 7 summarizes the available data on retained catch weight and estimates of discarded catch weight.

c. ***Catch-at-length:*** Although not used in a Tier 5 assessment, available retained-catch size frequency sample data from 1960/61–2015/16 are summarized and presented (Appendices A1–A4).

d. ***Survey biomass estimates:*** Not available; there is no program for regular performance of standardized surveys sampling from the entirety of the stock range.

e. ***Survey catch at length:*** Not used in a Tier 5 assessment; none are presented.

f. ***Other data time series:*** Although not used in a Tier 5 assessment, available data on CPUE (retained crab per pot lift) from 1972/73–2015/16 directed fisheries are presented (Table 1, Figure 6).

3. Data which may be aggregated over time:

a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):

Not used in a Tier 5 assessment. Growth per molt was estimated for WAI male red king crab by Vining et al. (2002) based on information received from recoveries during commercial fisheries of tagged red king crab released in the Adak Island to Amlia Island area during the 1970s (see Table 5 in Pengilly 2009). Vining et al. (2002) used a logit estimator to estimate the probability as a function of carapace length (CL, mm) at release that a male WAI red king tagged and released in new-shell condition would molt within 8–14 months after release (see Tables 6 and 7 in Pengilly 2009).

b. Weight-at length or weight-at-age (by sex):

Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female red king crab according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007) are: A = 0.000361 and B = 3.16 for males and A = 0.022863 and B = 2.23382 for females; note that although the estimated parameters, A and B, are those estimated for ovigerous females, those parameters were used to estimate the weight of all females without regard to reproductive status. Estimated weights in grams were converted to lb by dividing by 453.6.

c. ***Natural mortality rate:***

Not used in a Tier 5 assessment. NPFMC (2007) assumed a natural mortality rate of M = 0.18 for king crab species, but natural mortality rate has not been estimated specifically for red king crab in the WAI.

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

- Distribution of effort and catch during the 2006 ADF&G Petrel Bank red king crab pot survey (Gish 2007) and the 2009 ADF&G Petrel Bank red king crab pot survey (Gish 2010).
- Sex-size distribution of catch and distribution of effort and catch during the January/February 2001 and November 2001 ADF&G-Industry red king crab survey of the Petrel Bank area (Bowers et al. 2002) and ADF&G-Industry red king crab pot survey conducted as a commissioner's permit fishery in November 2002 in the Adak Island and Atka-Amlia Islands areas (Granath 2003).
- Observer data on size distribution and geographic distribution of discarded catch of red king crab in the WAI red king crab fishery and the Aleutian Islands golden king crab fishery, 1988/89–2015/16 (ADF&G observer database).
- Summary of data collected by ADF&G WAI red king crab fishery observers or surveys during 1969–1987 (Blau 1993).

E. Analytic Approach

1. History of modeling approaches for this stock: This is a Tier 5 assessment.

2. <u>Model Description</u>: *Subsections a–i are not applicable to a Tier 5 assessment.*
There is no regular survey of this stock. No assessment model for the WAI red king crab stock exists and none is in development. The SSC in June 2010 recommended that: the WAI red king crab stock be managed as a Tier 5 stock; the OFL be specified as a total-catch OFL; the total-catch OFL be established as the estimated average annual weight of the retained catch and bycatch mortality in crab and groundfish fisheries over the period 1995/96–2007/08; and the period used for computing the Tier 5 total-catch OFL be fixed at 1995/96–2007/08.

Given the strong recommendations from the SSC in June 2010, Tier 5 total-catch OFLs would change only if retained catch data and estimates of discarded catch for the period 1995/96–2007/08 or assumed values of bycatch mortality rates used in the 2010 SAFE were revised. Given that no need has been shown to revise either the retained catch data or the discarded catch estimates for the period 1995/96–2007/08 or assumed values of bycatch mortality rates used in the 2010 SAFE, the recommended approach for establishing the 2016/17 OFL is the approach identified by the SSC in June 2010 and no alternative approaches are suggested by the author. Hence the recommended total-catch OFL for 2016/17 is computed according to the status quo “Alternative 1” approach as:

$$OFL_{2016/17} = RET_{95/96\text{-}07/08} + BM_{CF,\ 95/96\text{-}07/08} + BM_{GF,\ 95/96\text{-}07/08},$$

where,

- $RET_{95/96\text{-}07/08}$ is the average annual retained catch in the directed crab fishery during 1995/96–2007/08
- $BM_{CF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the directed and non-directed crab fisheries during 1995/96–2007/08, and
- $BM_{GF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the groundfish fisheries during 1995/96–2007/08.

Given the June 2010 SSC recommendations, items ***E.2 a–i*** are not applicable.

3. <u>Model Selection and Evaluation</u>:

a. *<u>Description of alternative model configurations</u>*
Not applicable; see section E.2.

b. *<u>Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed</u>:* None; see section A.4.

c. *<u>Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models</u>:* None; see the section A.4.

d. *<u>Convergence status and convergence criteria for the base-case model (or proposed base-case model)</u>:* Not applicable.

e. *<u>Table (or plot) of the sample sizes assumed for the compositional data</u>:* Not applicable.

f. ***Do parameter estimates for all models make sense, are they credible?:*** Use of the 1995/96–2007/08 time period for estimating annual total fishery mortality and computing a Tier 5 OFL was established by the SSC in 2010.

g. ***Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty:*** Use of the 1995/96–2007/08 time period for estimating annual total fishery mortality and computing a Tier 5 OFL was established by the SSC in 2010.

h. ***Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach):*** Not applicable.

i. ***Evaluation of the model, if only one model is presented; or evaluation of alternative models and selection of final model, if more than one model is presented:*** The model follows the June 2010 SSC recommendations to freeze the time period for estimation of the Tier 5 OFL.

4. **Results (best model(s)):**

a. ***List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties:*** Not applicable to a Tier 5 assessment.

b. ***Tables of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible; include estimates from previous SAFEs for retrospective comparisons):*** See Table 6.

c. ***Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible):*** Not applicable to a Tier 5 assessment.

d. ***Evaluation of the fit to the data:*** Not applicable to a Tier 5 assessment.

e. ***Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments):*** Not applicable to a Tier 5 assessment.

f. ***Uncertainty and sensitivity analyses (this section should highlight unresolved problems and major uncertainties, along with any special issues that complicate scientific assessment, including questions about the best model, etc.):*** For a Tier 5 assessment, the major uncertainties are:

- Whether the time period is "representative of the production potential of the stock" and if it serves to "provide the required risk aversion for stock conservation and utilization goals." Or whether any such time period exists.

    - In this regard, the CPT (May 2011 minutes) noted that the OFL (56 t; 0.12-million lb) that was established for this stock by the SSC in June 2010 "could be considered biased high because of years of high exploitation" and questioned "whether the time frame used to compute the OFL is meaningful as an estimate of the productivity potential of this stock."
- The bycatch mortality rates used in estimation of total catch. Being as most (78%) of the estimated total mortality during 1995/96–2007/08 is due to the retained catch component, the total catch estimate is not severely sensitive to the assumed bycatch mortality rates. Doubling the assumed bycatch mortality during crab fisheries from 0.2 to 0.4 would increase the OFL by a factor of 1.02; halving that assumed rate from 0.2 to 0.1 would decrease the OFL by a factor of 0.99. Increasing the assumed bycatch mortality rate for all groundfish fisheries (regardless of gear type) to 1.0, would increase the OFL by a factor of 1.07.

F. Calculation of the OFL

1. <u>Specification of the Tier level and stock status level for computing the OFL:</u>

- Recommended as Tier 5, total-catch OFL computed as the estimated average annual total catch over a specified period.
- Recommended time period for computing retained-catch portion of the OFL: 1995/96–2007/08.
- Recommended time period for computing bycatch mortality due to crab fisheries: 1995/96–2007/08.
- Recommended time period for computing bycatch mortality due to groundfish fisheries: 1995/96–2007/08.
- Recommended bycatch mortality rates: 0.2 for crab fisheries; 0.5 for fixed-gear groundfish fisheries; 0.8 for trawl groundfish fisheries.
- Recommended OFL for 2016/17 is estimated by,

$$OFL_{2016/17} = RET_{95/96\text{-}07/08} + BM_{CF,\ 95/96\text{-}07/08} + BM_{GF,\ 95/96\text{-}07/08},$$

where,

- $RET_{95/96\text{-}07/08}$ is the average annual retained catch in the directed crab fishery during 1995/96–2007/08
- $BM_{CF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the directed and non-directed crab fisheries during 1995/96–2007/08, and
- $BM_{GF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the groundfish fisheries during 1995/96–2007/08.

Statistics on the data and estimates used to calculate $RET_{95/96\text{-}07/08}$, $BM_{CF,\ 95/96\text{-}07/08}$, and $BM_{GF,95/96\text{-}07/08}$ are provided in the "Mean, 1995/96–2007/08" row of Table 6. Using the calculated values of $RET_{95/96\text{-}07/08}$, $BM_{CF,\ 95/96\text{-}07/08}$, and $BM_{GF,95/96\text{-}07/08}$, $OFL_{2016/17}$ is,

$$OFL_{2016/17} = 43.97\ t + 1.36\ t + 10.86\ t = 56\ t\ (123{,}867\ lb).$$

2. **<u>List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan</u>:** Not applicable to Tier 5 assessment.

3. **<u>Specification of the OFL</u>:**

a. ***<u>Provide the equations (from Amendment 24) on which the OFL is to be based</u>:***

From **Federal Register** / Vol. 73, No. 116, page 33926, "For stocks in Tier 5, the overfishing level is specified in terms of an average catch value over an historical time period, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information." Additionally, "For stocks where nontarget fishery removal data are available, catch includes all fishery removals, including retained catch and discard losses. Discard losses will be determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the overfishing level is set for and compared to the retained catch" (FR/Vol. 73, No. 116, 33926). That compares with the specification of NPFMC (2007) that the OFL "represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock."

b. ***<u>Basis for projecting MMB to the time of mating</u>:*** Not applicable to Tier 5 assessment.

c. ***<u>Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring</u>:*** See Management Performance tables, below. No vessels participated in the 2015/16 directed fishery and no bycatch was observed in crab fisheries in 2015/16. Total catch mortality in 2015/16 consists of what occurred during groundfish fisheries (1.19 t) and the cooperative industry-ADF&G survey (0.16 t). Overfishing did not occur in 2015/16. The OFL and ABC values for 2016/17 in the table below are the author's recommended values. The 2016/17 TAC has not yet been established.

Management Performance Table (values in t)

Fishing Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch	Total Catch	OFL	ABC
2012/13	N/A	N/A	Closed	0	<1	56	34
2013/14	N/A	N/A	Closed	0	<1	56	34
2014/15	N/A	N/A	Closed	0	<1	56	34
2015/16	N/A	N/A	Closed	0	2.3	56	34
2016/17	N/A	N/A				56	34

a. Pre-season harvest levels are established as total allowable catch for the rationalized fishery west of 179° W longitude and as a guideline harvest level for the non-rationalized fishery east of 179° W longitude.

Management Performance Table (values in lb)

Fishing Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch	Total Catch	OFL	ABC
2012/13	N/A	N/A	Closed	0	624	0.12[b]	0.07[b]
2013/14	N/A	N/A	Closed	0	732	0.12[b]	0.07[b]
2014/15	N/A	N/A	Closed	0	474	0.12[b]	0.07[b]
2015/16	N/A	N/A	Closed	0	2,964	0.12[b]	0.07[b]
2016/17	N/A	N/A				123,867	74,320

a. Pre-season harvest levels are established as total allowable catch for the rationalized fishery west of 179° W longitude and as a guideline harvest level for the non-rationalized fishery east of 179° W longitude.
b. Established in millions of lb.

4. <u>Specification of the recommended retained-catch portion of the total-catch OFL</u>:

a. Equation for recommended retained portion of the total-catch OFL,
Retained-catch portion = average retained catch during 1995/96–2007/08
= 44 t (96,932 lb).

5. <u>Recommended F_{OFL}, OFL total catch and the retained portion for the coming year</u>:
See sections ***F.3*** and ***F.4***, above; no F_{OFL} is recommended for a Tier 5 assessment.

G. Calculation of ABC

1. PDF of OFL. A bootstrap estimate of the sampling distribution (assuming no error in estimation of the discarded catch) of the OFL is shown in Figure 7 (the sample means of 1,000 samples drawn with replacement from the 1995/96–2007/08 estimates of total fishery mortality in Table 6). The mean (56 t) and CV (0.42) computed from the 1,000 replicates are essentially the same as for the mean and CV of the 1995/96–2007/08 total catch estimates given in Table 6. Note that generated sampling distribution is meaningful as a measure in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Section E.4.f).

2. List of variables related to scientific uncertainty.

- The time period to compute the average catch relative to the assumption that it represents “a time period determined to be representative of the production potential of the stock.”
- Bycatch mortality rate in each fishery that bycatch occurs. Note that for a Tier 5 assessment, an increase in an assumed bycatch mortality rate will increase the OFL (and hence the ABC), but has no effect on the retained catch portion of the OFL or the retained catch portion of the ABC.
- Estimated discarded catch and bycatch mortality during each fishery that bycatch occurred in during 1995/96–2007/08.

3. List of additional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.

4. Author recommended ABC: 34 t. This is the status quo ABC that has been recommended by the author since the SSC recommended a 34 t ABC for 2012/13. The SSC’s recommended ABC of 34 t for 2012/13 was determined as a value “sufficient to cover bycatch and the proposed test fishery catch" (June 2012 SSC meeting minutes, page 10). It provides a 40% buffer on the OFL of 56 t. Note that the ABC recommended by the SSC for 2011/12 was lower (12 t) and was based on the estimated average bycatch mortality due to groundfish and the non-directed crab fisheries during 1995/96–2007/08.

H. Rebuilding Analyses

Entire section is not applicable; this stock has not been declared overfished.

I. Data Gaps and Research Priorities

This fishery has a long history, with the domestic fishery dating back to 1960/61. However, much of the data on this stock prior to the early-mid 1980s is difficult to retrieve for analysis. Fishery data summarized to the level of statistical area are presently not available prior to 1980/81. Changes in definitions of fishery statistical areas between 1984/85 and 1985/86 also make it difficult to assess geographic trends in effort and catch over much of the fishery's history. An effort to compile all fishery data and other written documentation on the stock and fishery and to enter all existing fishery, observer, survey, and tagging data into a database that allows for analysis of all data from the fishery and stock through the history of the fishery would be time-consuming, challenging, and perhaps disappointing, but could provide valuable information if successful.

The SSC in October 2008, June 2011, and June 2013 noted the need for systematic surveys to obtain the data to estimate the biomass of this stock. Surveys on this stock have, however, been few and the geographic scope of the surveyed area is limited. Aside from the pot surveys performed in the Adak-Atka area during the mid-1970s (ADF&G 1978, Blau 1993), the only standardized surveys for red king crab performed by ADF&G were performed in November 2006 and November 2009 and those were limited to the Petrel Bank area (Gish 2007, 2010). ADF&G-Industry surveys, conducted as limited fisheries that allowed retention of captured legal males under provisions of a commissioner's permit, have been performed in limited areas of the WAI: during January–February 2001 and November 2001 in the Petrel Bank area (Bowers et al. 2002) and during November 2002 in the Adak-Atka-Amlia area (Granath 2003). A very limited (18 pot lifts) Industry exploratory survey without any retention of crab was performed during mid-October to mid-December 2009 between 178°00' E longitude and 175°30' E longitude produced a catch of one red king crab, a legal-sized male (Baechler and Cook 2014). Based on requests from Industry in 2012, ADF&G designed a state-waters red king crab pot survey for the Adak Island group. Twenty-five stations were designated with 20 pot lifts in each station. To defray cost of the survey, participants would be allowed to sell up to 14 t (31,417 lb) of red king crab. In addition, bycatch mortality during the proposed survey was assumed not to exceed 9 t based on assumed maximum discarded catch weight and an assumed bycatch mortality rate of 0.2. In 2012 the CPT and SSC recommended an ABC of 34 t (0.74-million lb) for 2012/13 to accommodate total fishery mortality due the proposed red king crab survey in addition to estimated bycatch mortality due to non-directed fisheries (12 t). In late summer 2012, Industry advocates decided to forgo the fall 2012 survey.

Trawl surveys are preferable relative to pot surveys for providing density estimates, but crab pots may be the only practical gear for sampling king crab in the Aleutians. Standardized pot surveys are a prohibitively expensive approach to surveying the entire WAI. Surveys or exploratory fishing performed by Industry in cooperation with ADF&G, with or without allowing retention of captured legal males, reduce the costs to agencies. Agency-Industry cooperation can provide a means to obtain some information on distribution and density during periods of fishery closures. However, there can be difficulties in assuring standardization of procedures during ADF&G-Industry surveys (Bowers et al. 2002). Moreover, costs of performing a survey have resulted in incompletion of ADF&G-Industry surveys (Granath 2003). Hence surveys performed by Industry in cooperation with ADF&G cannot be expected to provide sampling over the entire WAI during periods of limited stock distribution and overall low density, as apparently currently exists.

A cooperative survey between industry and ADF&G was performed in the Adak area in September 2015 (Hilsinger et al. 2016). A total of 442 red king crab (23 legal males, 74 pre recruit males, 140 juvenile males, and 204 females) were captured in Sitkin Sound and Expedition Harbor from 730 pots. Since RKC were highly aggregated (most were in inner Sitkin Sound) and few crab were legal males, further surveys of RKC in this area are a low priority.

J. Literature Cited

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Table 1a. Commercial fishery history for the western Aleutian Islands red king crab commercial fishery, 1960/61–2015/16: number of vessels, guideline harvest level (GHL; established in lb, **converted to t**) for 1973/74–2004/05, total allowable catch (TAC; established in lb, **converted to t**) in the area west of 179° W longitude combined with GHL (established in lb, **converted to t**) in the area east of 179° W longitude for 2005/06–2015/16, weight of retained catch (Harvest; **t**), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (**kg**) of retained crab.

Crab fishing year	Area	Vessels	GHL/TAC	Harvest[a]	Crab[a]	Pots lifted	CPUE	Weight
1960/61	West of 172° W	4	-	941	NA	NA	NA	NA
1961/62	West of 172° W	8	-	2,773	NA	NA	NA	NA
1962/63	West of 172° W	9	-	3,631	NA	NA	NA	NA
1963/64	West of 172° W	11	-	8,121	NA	NA	NA	NA
1964/65	West of 172° W	18	-	9,613	NA	NA	NA	NA
1965/66	West of 172° W	10	-	5,858	NA	NA	NA	NA
1966/67	West of 172° W	10	-	2,668	NA	NA	NA	NA
1967/68	West of 172° W	22	-	6,410	NA	NA	NA	NA
1968/69	West of 172° W	30	-	7,303	NA	NA	NA	NA
1969/70	West of 172° W	33	-	8,172	NA	115,929	NA	2.5
1970/71	West of 172° W	35	-	7,283	NA	124,235	NA	NA
1971/72	West of 172° W	40	-	7,020	NA	46,011	NA	NA
1972/73	West of 172° W	43	-	8,493	3,461,025	81,133	43	2.5
1973/74	West of 172° W	41	9,072[b]	4,419	1,844,974	70,059	26	2.4
1974/75	West of 172° W	36	9,072[b]	1,259	532,298	32,620	16	2.4
1975/76	West of 172° W	20	6,804[b]	187	79,977	8,331	10	2.3
1976/77	West of 172° W	FC	FC	FC	FC	FC	FC	FC
1977/78	West of 172° W	12	113–1,134	411	160,343	7,269	22	2.6
1978/79	West of 172° W	13	227–1,361	366	149,491	13,948	11	2.4
1979/80	West of 172° W	18	227–1,361	212	82,250	9,757	8	2.6
1980/81	West of 172° W	17	227–1,361	644	254,390	20,914	12	2.5
1981/82	West of 172° W	46	227–1,361	748	291,311	40,697	7	2.6
1982/83	West of 172° W	72	227–1,361	772	284,787	66,893	4	2.7
1983/84	West of 172° W	106	227–1,361	899	298,958	60,840	5	3.0
1984/85	West of 171° W	64	680–1,361	588	196,276	48,642	4	3.0
1985/86	West of 171° W	35	227–907	394	156,097	29,095	5	2.5
1986/87	West of 171° W	33	227–680	323	126,204	29,189	4	2.6
1987/88	West of 171° W	71	227–680	551	211,692	43,433	5	2.6
1988/89	West of 171° W	73	454	711	266,053	64,334	4	2.7
1989/90	West of 171° W	56	771	502	193,177	54,213	4	2.6
1990/91	West of 171° W	7	NA	376	146,903	10,674	14	2.6
1991/92	West of 171° W	10	NA	431	165,356	16,636	10	2.6
1992/93	West of 171° W	12	NA	584	218,049	16,129	14	2.7
1993/94	West of 171° W	12	NA	317	119,330	13,575	9	2.7
1994/95	West of 171° W	20	454–680	89	30,337	18,146	2	2.9
1995/96	West of 171° W	4	454–680	18	6,880	1,986	3	2.6
1996/97–1997/98	West of 171° W	FC	FC	FC	FC	FC	FC	FC
1998/99	174°–179° W; west of 179° E	1	7	CF	CF	CF	CF	CF
1999/00	West of 171° W	FC	FC	FC	FC	FC	FC	FC
2000/01[c]	179° W–179° E	1	(Permit/Survey)	35	11,299	496	23	3.1
2001/02[d]	179° W–179° E	4	(Permit/Survey)	70	22,080	564	39	3.2
2002/03	179° W–179° E	33	227	229	68,300	3,786	18	3.4
2003/04	179° W–179° E	30	227	217	59,828	5,774	10	3.6
2004/05–2015/16	West of 171° W	FC	FC	FC	FC	FC	FC	FC

Note: NA = Not available, FC = fishery closed, CF = confidential.

[a] Deadloss included.
[b] GHL includes all king crab species. Golden king crab incidental to red king crab.
[c] January/February 2001 Petrel Bank survey.
[d] November 2001 Petrel Bank survey.

Table 1b. Commercial fishery history for the western Aleutian Islands red king crab commercial fishery, 1960/61–2015/16 number of vessels, guideline harvest level (GHL; **lb**) for 1973/74–2004/05, total allowable catch (TAC; **lb**) in the area west of 179° W longitude combined with GHL (**lb**) in the area east of 179° W longitude for 2005/06–2015/16, weight of retained catch (Harvest; **lb**), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (**lb**) of retained crab.

Crab fishing year	Area	Vessels	GHL/TAC	Harvest[a]	Crab[a]	Pots lifted	CPUE	Weight
1960/61	West of 172° W	4	-	2,074,000	NA	NA	NA	NA
1961/62	West of 172° W	8	-	6,114,000	NA	NA	NA	NA
1962/63	West of 172° W	9	-	8,006,000	NA	NA	NA	NA
1963/64	West of 172° W	11	-	17,904,000	NA	NA	NA	NA
1964/65	West of 172° W	18	-	21,193,000	NA	NA	NA	NA
1965/66	West of 172° W	10	-	12,915,000	NA	NA	NA	NA
1966/67	West of 172° W	10	-	5,883,000	NA	NA	NA	NA
1967/68	West of 172° W	22	-	14,131,000	NA	NA	NA	NA
1968/69	West of 172° W	30	-	16,100,000	NA	NA	NA	NA
1969/70	West of 172° W	33	-	18,016,000	NA	115,929	NA	6.5
1970/71	West of 172° W	35	-	16,057,000	NA	124,235	NA	NA
1971/72	West of 172° W	40	-	15,475,940	NA	46,011	NA	NA
1972/73	West of 172° W	43	-	18,724,140	3,461,025	81,133	43	5.4
1973/74	West of 172° W	41	20,000,000[b]	9,741,464	1,844,974	70,059	26	5.3
1974/75	West of 172° W	36	20,000,000[b]	2,774,963	532,298	32,620	16	5.2
1975/76	West of 172° W	20	15,000,000[b]	411,583	79,977	8,331	10	5.2
1976/77	West of 172° W	FC	FC	FC	FC	FC	FC	FC
1977/78	West of 172° W	12	0.25 - 2.5 million	905,527	160,343	7,269	22	5.7
1978/79	West of 172° W	13	0.5 - 3.0 million	807,195	149,491	13,948	11	5.4
1979/80	West of 172° W	18	0.5 - 3.0 million	467,229	82,250	9,757	8	5.7
1980/81	West of 172° W	17	0.5 - 3.0 million	1,419,513	254,390	20,914	12	5.6
1981/82	West of 172° W	46	0.5 - 3.0 million	1,648,926	291,311	40,697	7	5.7
1982/83	West of 172° W	72	0.5 - 3.0 million	1,701,818	284,787	66,893	4	6.0
1983/84	West of 172° W	106	0.5 - 3.0 million	1,981,579	298,958	60,840	5	6.6
1984/85	West of 171° W	64	1.5 - 3.0 million	1,296,385	196,276	48,642	4	6.6
1985/86	West of 171° W	35	0.5 - 2.0 million	868,828	156,097	29,095	5	5.6
1986/87	West of 171° W	33	0.5 - 1.5 million	712,543	126,204	29,189	4	5.7
1987/88	West of 171° W	71	0.5 - 1.5 million	1,213,892	211,692	43,433	5	5.7
1988/89	West of 171° W	73	1.0 million	1,567,314	266,053	64,334	4	5.9
1989/90	West of 171° W	56	1.7 million	1,105,971	193,177	54,213	4	5.7
1990/91	West of 171° W	7	NA	828,105	146,903	10,674	14	5.6
1991/92	West of 171° W	10	NA	951,278	165,356	16,636	10	5.8
1992/93	West of 171° W	12	NA	1,286,424	218,049	16,129	14	6.0
1993/94	West of 171° W	12	NA	698,077	119,330	13,575	9	5.9
1994/95	West of 171° W	20	1.0 - 1.5 million	196,967	30,337	18,146	2	6.5
1995/96	West of 171° W	4	1.0 - 1.5 million	38,941	6,880	1,986	3	5.7
1996/97–1997/98	West of 171° W	FC	FC	FC	FC	FC	FC	FC
1998/99	174°–179° W; west of 179° E	1	15,000	CF	CF	CF	CF	CF
1999/00	West of 171° W	FC	FC	FC	FC	FC	FC	FC
2000/01[c]	179° W–179° E	1	(Permit/Survey)	76,562	11,299	496	23	6.8
2001/02[d]	179° W–179° E	4	(Permit/Survey)	153,961	22,080	564	39	7.0
2002/03	179° W–179° E	33	500,000	505,642	68,300	3,786	18	7.4
2003/04	179° W–179° E	30	500,000	479,113	59,828	5,774	10	8.0
2004/05–2015/16	West of 171° W	FC	FC	FC	FC	FC	FC	FC

Note: NA = Not available, FC = fishery closed, CF = confidential.

[a] Deadloss included.

[b] GHL includes all king crab species. Golden king crab incidental to red king crab.

[c] January/February 2001 Petrel Bank survey.

[d] November 2001 Petrel Bank survey.

Table 2. A summary of relevant fishery activities and management measures pertaining to the Western Aleutian Islands red king crab fishery since 1996/97.

Crab fishing year	Fishery Activities and Management Measures
1996/97–1997/98	• Fishery closed.
1998/99	• GHL of 7 t (15,000 lb) for exploratory fishing with fishery closed in the Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) o 1 vessel
1999/00	• Fishery closed
2000/01	• Fishery closed • Catch retained during ADF&G-Industry survey of Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) conducted as commissioner's permit fishery, Jan–Feb 2001 o 1 vessel o Retained catch weight = 35 t (76,562 lb) o CPUE = 23 retained crab per pot lift
2001/02	• Fishery closed • Catch retained ADF&G-Industry survey of Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) conducted as commissioner's permit fishery, November 2001 o 4 vessels o Retained catch weight = 70 t (153,961 lb) o CPUE = 39 retained crab per pot lift
2002/03	• Fishery opened with GHL of 227 t (500,000 lb) restricted to Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) o 33 vessels o Retained catch weight = 229 t (505,642 lb) o CPUE = 18 retained crab per pot lift • ADF&G-Industry survey of the Adak, Atka, and Amlia Islands area conducted as a commissioner's permit fishery o 4 legal males captured in 1,085 pot lifts
2003/04	• Fishery opened with GHL of 227 t (500,000 lb) restricted to Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) o 30 vessels o Retained catch weight = 217 t (479,113) lb o 10 retained crab per pot lift
2004/05–2015/16	• Fishery closed o 2006 and 2009 ADF&G pot surveys on Petrel Bank o 2015 exploratory/reconnaissance survey in Adak Island area.

Table 3. Annual retained catch (**t**) of Western Aleutian Islands red king crab, with the estimated annual discarded catch (**t**; not discounted for an assumed bycatch mortality rate) and components of discarded catch (legal males, sublegal males, and females) during commercial crab fisheries, 1995/96–2015/16.

	WAI red king crab fishery				AI golden king crab fishery			
Crab fishing		Discarded						Total
year	Retained	Legal male	Sublegal male	Female	Legal male	Sublegal male	Female	Discarded
1995/96	17.66	0.00	9.38	12.53	0.00	0.93	0.14	22.98
1996/97	0.00	0.00	0.00	0.00	1.49	0.92	0.30	2.71
1997/98	0.00	0.00	0.00	0.00	0.08	0.26	0.08	0.42
1998/99[a]	2.68	–[a]	–[a]	–[a]	0.34	0.06	0.08	–[a]
1999/00	0.00	0.00	0.00	0.00	0.07	0.34	0.04	0.46
2000/01	34.73	0.00	0.35	0.17	0.17	0.12	0.02	0.83
2001/02	69.84	0.08	2.98	3.80	9.07	0.00	0.17	16.09
2002/03	229.36	0.75	2.73	7.91	9.86	0.16	0.23	21.65
2003/04	217.32	0.29	2.99	3.61	4.28	2.88	3.03	17.08
2004/05	0.00	0.00	0.00	0.00	0.97	0.10	0.00	1.07
2005/06	0.00	0.00	0.00	0.00	0.09	0.00	0.02	0.11
2006/07	0.00	0.00	0.00	0.00	0.15	0.05	0.02	0.22
2007/08	0.00	0.00	0.00	0.00	0.28	0.83	0.25	1.36
2008/09	0.00	0.00	0.00	0.00	0.10	0.01	0.04	0.15
2009/10	0.00	0.00	0.00	0.00	0.26	0.11	0.02	0.39
2010/11	0.00	0.00	0.00	0.00	1.96	0.08	0.04	2.07
2011/12	0.00	0.00	0.00	0.00	0.43	0.01	0.04	0.49
2012/13	0.00	0.00	0.00	0.00	0.40	0.03	0.02	0.44
2013/14	0.00	0.00	0.00	0.00	1.34	0.05	0.08	1.46
2014/15	0.00	0.00	0.00	0.00	0.24	0.01	0.03	0.28
2015/16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	27.22	0.06	0.92	1.40	1.56	0.34	0.23	4.51

a. Data on discarded catch of red king crab during the red king crab fishery not available (see Moore et al. 2000).

Table 4. Estimated annual weight (**t**) of discarded catch of red king crab (all sizes, males and females) and estimated annual bycatch mortality (**t**) during federal groundfish fisheries by gear type (fixed or trawl) in reporting areas 541, 542, and 543 (Aleutian Islands west of 170° W longitude), 1993/94–2015/16 (assumes bycatch mortality rate of 0.5 for fixed-gear fisheries and 0.8 for trawl fisheries).

Crab fishing	Discarded catch		Bycatch Mortality		
year	Fixed Gear	Trawl Gear	Fixed Gear	Trawl Gear	Total
1993/94	0.60	40.09	0.30	32.07	32.37
1994/95	1.36	10.34	0.68	8.27	8.95
1995/96	2.63	6.93	1.32	5.55	6.86
1996/97	1.30	20.26	0.65	16.21	16.86
1997/98	1.73	5.31	0.87	4.25	5.12
1998/99	4.60	20.65	2.30	16.52	18.82
1999/00	17.13	12.69	8.57	10.15	18.72
2000/01	1.22	6.30	0.61	5.04	5.65
2001/02	2.42	27.01	1.21	21.61	22.82
2002/03	5.12	33.12	2.56	26.50	29.06
2003/04	1.62	4.15	0.81	3.32	4.13
2004/05	0.36	5.86	0.18	4.69	4.87
2005/06	1.61	1.07	0.80	0.86	1.66
2006/07	3.08	0.28	1.54	0.22	1.76
2007/08	7.70	1.19	3.85	0.95	4.80
2008/09	4.89	4.67	2.44	3.73	6.18
2009/10	0.14	6.40	0.07	5.12	5.19
2010/11	0.04	1.99	0.02	1.59	1.61
2011/12	1.19	0.82	0.60	0.41	1.01
2012/13	0.01	0.24	0.00	0.19	0.19
2013/14	0.01	0.04	0.01	0.03	0.04
2014/15	0.00	0.11	0.00	0.09	0.09
2015/16	0.03	1.46	0.02	1.17	1.19
Average	2.56	9.17	1.28	7.33	8.61

Table 5. Estimated annual weight of discarded catch (**t**; not discounted by an assumed bycatch mortality rate) of red king crab in reporting areas 541, 542, and 543 (Aleutian Islands west of 170° W longitude) during federal groundfish fisheries (all gear types combined) by reporting area, 1993/94–2015/16.

Crab fishing	Reporting Area			
year	541	542	543	Total
1993/94	37.9893	2.6590	0.0372	40.6855
1994/95	10.7216	0.8718	0.1025	11.6959
1995/96	5.9520	1.8398	1.7763	9.5681
1996/97	1.9477	3.0890	16.5258	21.5624
1997/98	1.0061	3.9639	2.0770	7.0470
1998/99	6.7549	7.1659	11.3335	25.2542
1999/00	16.3416	8.0535	5.4227	29.8183
2000/01	1.7686	3.6541	2.0961	7.5192
2001/02	3.4750	24.0341	1.9250	29.4341
2002/03	10.9996	21.3098	5.9384	38.2483
2003/04	2.2294	3.5280	0.0163	5.7733
2004/05	0.5280	5.6803	0.0154	6.2237
2005/06	1.6057	0.0395	1.0333	2.6785
2006/07	2.9688	0.3869	0.0000	3.3557
2007/08	5.1233	3.0427	0.7248	8.8909
2008/09	1.1440	7.5455	0.8668	9.5563
2009/10	1.6719	3.7548	1.1136	6.5404
2010/11	0.2123	1.8162	0.0005	2.0289
2011/12	0.8768	1.1335	0.0000	2.0108
2012/13	0.1560	0.0903	0.0000	0.2463
2013/14	0.0000	0.0435	0.0118	0.0553
2014/15	0.0000	0.1148	0.0005	0.1152
2015/16	0.0000	0.8864	0.6102	1.4966
Average	4.9336	4.5523	2.2447	11.7307

Table 6. Estimated annual weight (**t**) of total fishery mortality to Western Aleutian Islands red king crab, 1995/96–2015/16, partitioned by source of mortality: retained catch, estimated bycatch mortality during crab fisheries, and estimated bycatch mortality during groundfish fisheries.

		Bycatch Mortality by Fishery Type		Total Estimated
Crab fishing year	Retained Catch	Crab	Groundfish	Fishery mortality
1995/96	17.66	4.60	6.86	29.12
1996/97	0.00	0.54	16.86	17.40
1997/98	0.00	0.08	5.12	5.20
1998/99[a]	2.68	0.70	18.82	22.19
1999/00	0.00	0.09	18.72	18.81
2000/01	34.73	0.17	5.65	40.54
2001/02	69.84	3.22	22.82	95.88
2002/03	229.36	4.33	29.06	262.75
2003/04	217.32	3.42	4.13	224.87
2004/05	0.00	0.21	4.87	5.08
2005/06	0.00	0.02	1.66	1.68
2006/07	0.00	0.04	1.76	1.81
2007/08	0.00	0.27	4.80	5.08
2008/09	0.00	0.03	6.18	6.21
2009/10	0.00	0.08	5.19	5.27
2010/11	0.00	0.41	1.61	2.02
2011/12	0.00	0.10	1.01	1.10
2012/13	0.00	0.09	0.19	0.28
2013/14	0.00	0.29	0.04	0.33
2014/15	0.00	0.12	0.09	0.22
2015/16	0.00	0.00	1.19	1.19
Mean, 1995/96–2007/08	43.97	1.36	10.86	56.19
CV of mean	0.52	0.37	0.23	0.43
Mean, 1995/96–2015/16	27.22	0.90	7.46	35.57
CV of mean	0.54	0.37	0.25	0.45

a. No discarded catch data was available from the 1998/99 directed fishery for red king crab (see Table 2); bycatch mortality due to the 1998/99 crab fisheries was estimated by multiplying the retained catch for the 1998/99 directed red king crab fishery by the ratio of the 1995/96 bycatch mortality in crab fisheries to the 1995/96 retained catch.

Table 7. Annual retained catch weight (**t**) and estimates of annual discarded catch weight (**t**; not discounted for an assumed bycatch mortality rate) of Western Aleutian Islands red king crab available for a Tier 5 assessment; shaded, bold values are used in computation of the recommended (status quo) 2016/17 Tier 5 OFL.

	Retained catch weight	Discarded catch weight (estimated)		
	Fish tickets	Observer data: lengths, catch per sampled pot	Blend method; Catch Accounting System	
Crab Fishing Year	Directed fishery	Crab fisheries	Fixed gear, groundfish	Trawl gear, groundfish
1960/61	940.75	—	—	—
1961/62	2773.27	—	—	—
1962/63	3631.46	—	—	—
1963/64	8121.13	—	—	—
1964/65	9612.99	—	—	—
1965/66	5858.15	—	—	—
1966/67	2668.49	—	—	—
1967/68	6409.72	—	—	—
1968/69	7302.85	—	—	—
1969/70	8171.93	—	—	—
1970/71	7283.34	—	—	—
1971/72	7019.78	—	—	—
1972/73	8493.14	—	—	—
1973/74	4418.66	—	—	—
1974/75	1258.70	—	—	—
1975/76	186.69	—	—	—
1976/77	0.00	—	—	—
1977/78	410.74	—	—	—
1978/79	366.14	—	—	—
1979/80	211.93	—	—	—
1980/81	643.88	—	—	—
1981/82	747.94	—	—	—
1982/83	771.93	—	—	—
1983/84	898.83	—	—	—
1984/85	588.03	—	—	—
1985/86	394.09	—	—	—
1986/87	323.20	—	—	—
1987/88	550.61	—	—	—
1988/89	710.92	—	—	—
1989/90	501.66	—	—	—
1990/91	375.62	Confidential	—	—
1991/92	431.49	Confidential	—	—
1992/93	583.51	Confidential	—	—
1993/94	316.64	Confidential	0.60	40.09
1994/95	89.34	Confidential	1.36	10.34
1995/96	**17.66**	**22.98**	**2.63**	**6.93**
1996/97	**0.00**	**2.71**	**1.30**	**20.26**
1997/98	**0.00**	**0.42**	**1.73**	**5.31**
1998/99	**2.68**	**3.48**	**4.60**	**20.65**
1999/00	**0.00**	**0.46**	**17.13**	**12.69**
2000/01	**34.73**	**0.83**	**1.22**	**6.30**
2001/02	**69.84**	**16.09**	**2.42**	**27.01**
2002/03	**229.36**	**21.65**	**5.12**	**33.12**
2003/04	**217.32**	**17.08**	**1.62**	**4.15**
2004/05	**0.00**	**1.07**	**0.36**	**5.86**
2005/06	**0.00**	**0.11**	**1.61**	**1.07**
2006/07	**0.00**	**0.22**	**3.08**	**0.28**
2007/08	**0.00**	**1.36**	**7.70**	**1.19**
2008/09	0.00	0.15	4.89	4.67
2009/10	0.00	0.39	0.14	6.40
2010/11	0.00	2.07	0.04	1.99
2011/12	0.00	0.49	1.19	0.82
2012/13	0.00	0.44	0.01	0.24
2013/14	0.00	1.46	0.01	0.04
2014/15	0.00	0.28	0.00	0.11
2015/16	0.00	0.00	0.03	1.46

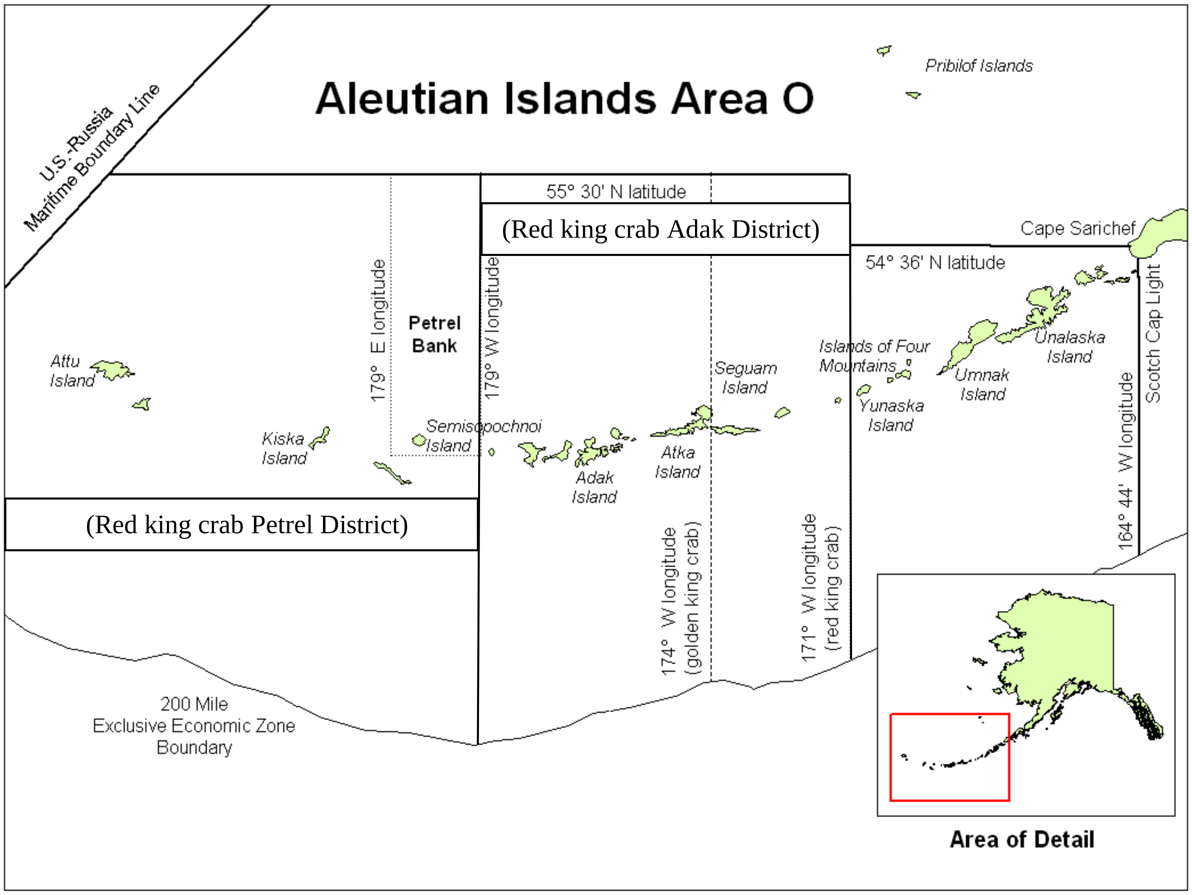

Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Baechler and Cook 2014, updated to show boundaries of the Adak and Petrel Districts for red king crab as established by the Alaska Board of Fisheries in March 2014).

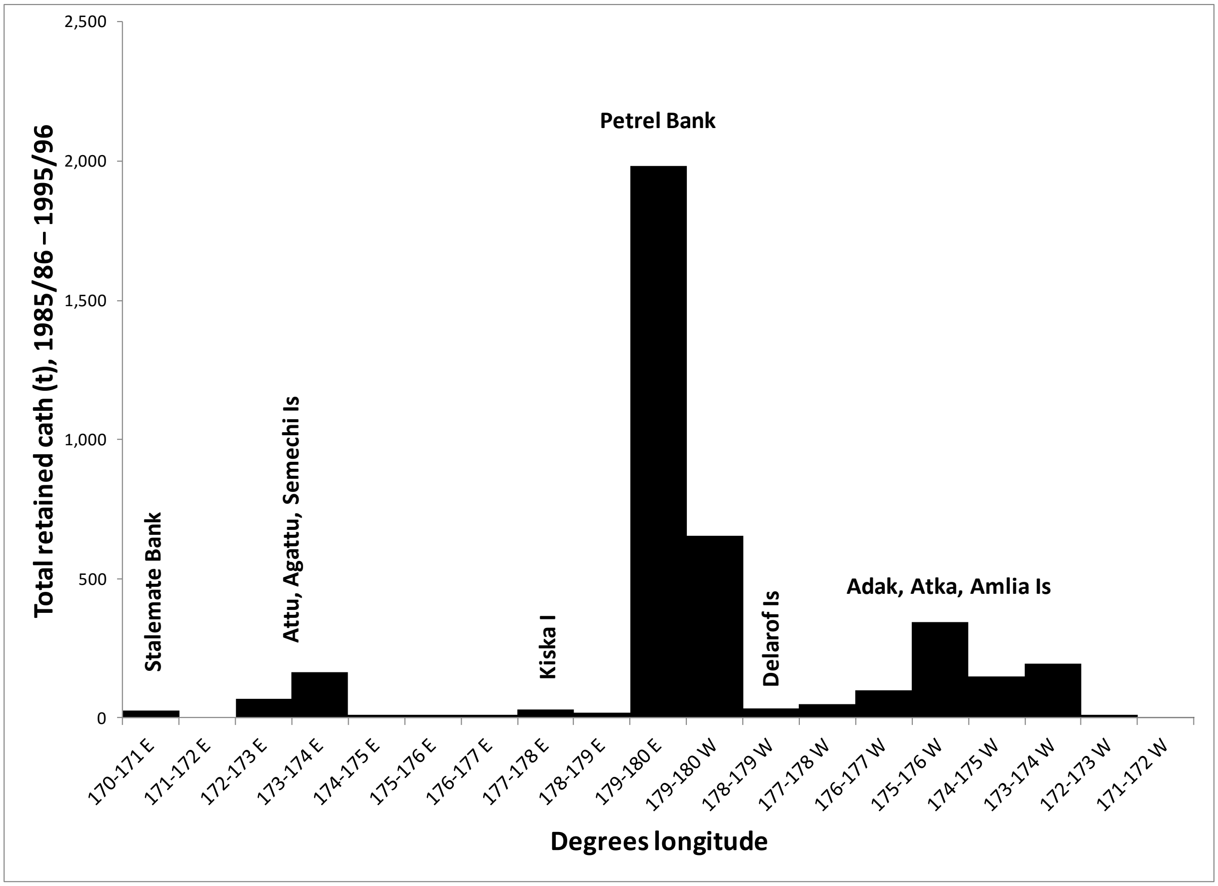

Figure 2. Retained catch (**t**) in the Western Aleutian Islands red king crab fishery, 1985/86–1995/96 by 1-degree longitude grouping, summarized from fish ticket catch by state statistical area landing data.

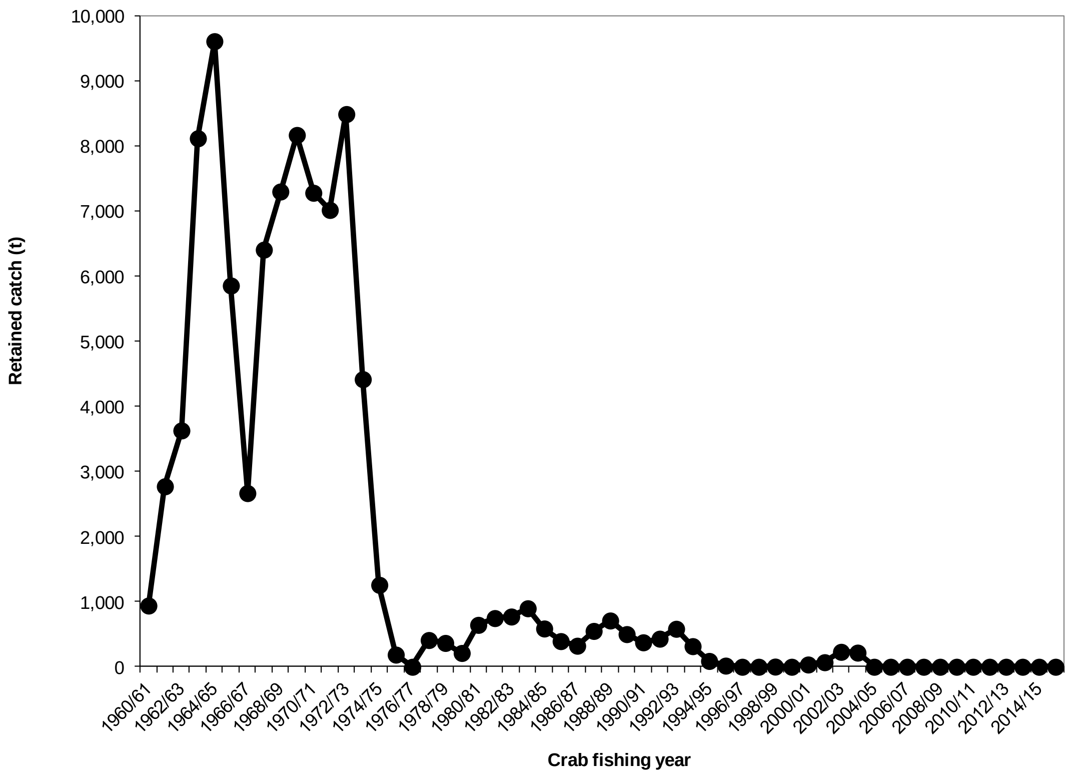

Figure 3. Retained catch (**t**) in the Western Aleutian Islands red king crab fishery, 1960/61–2015/16 (catch is for the area west of 172° W longitude during 1960/61–1983/84 and for the area west of 171° W longitude during 1984/85–2015/16; see Table 1a).

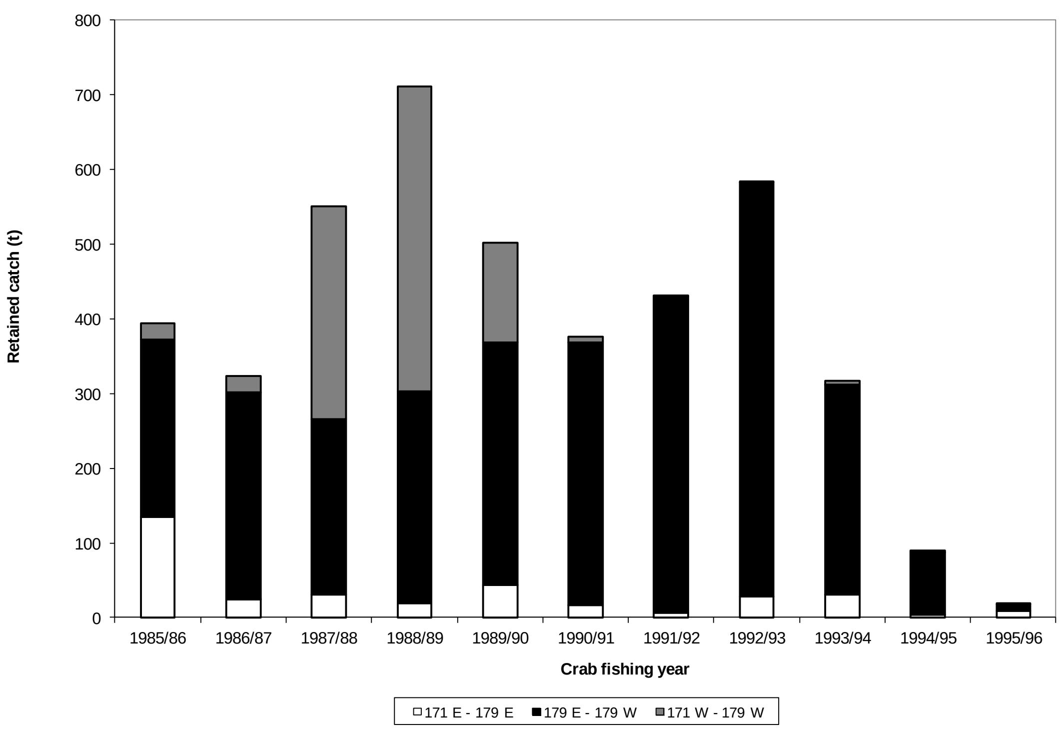

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Figure 4. Annual retained catch (**t**) in the Western Aleutian Islands red king crab fishery during 1985/86–1995/96, partitioned into three longitudinal zones: 171º W longitude to 179º W longitude (white bars); 179º W longitude to 179º E longitude (black bars); and 179º E longitude to 171º E longitude.

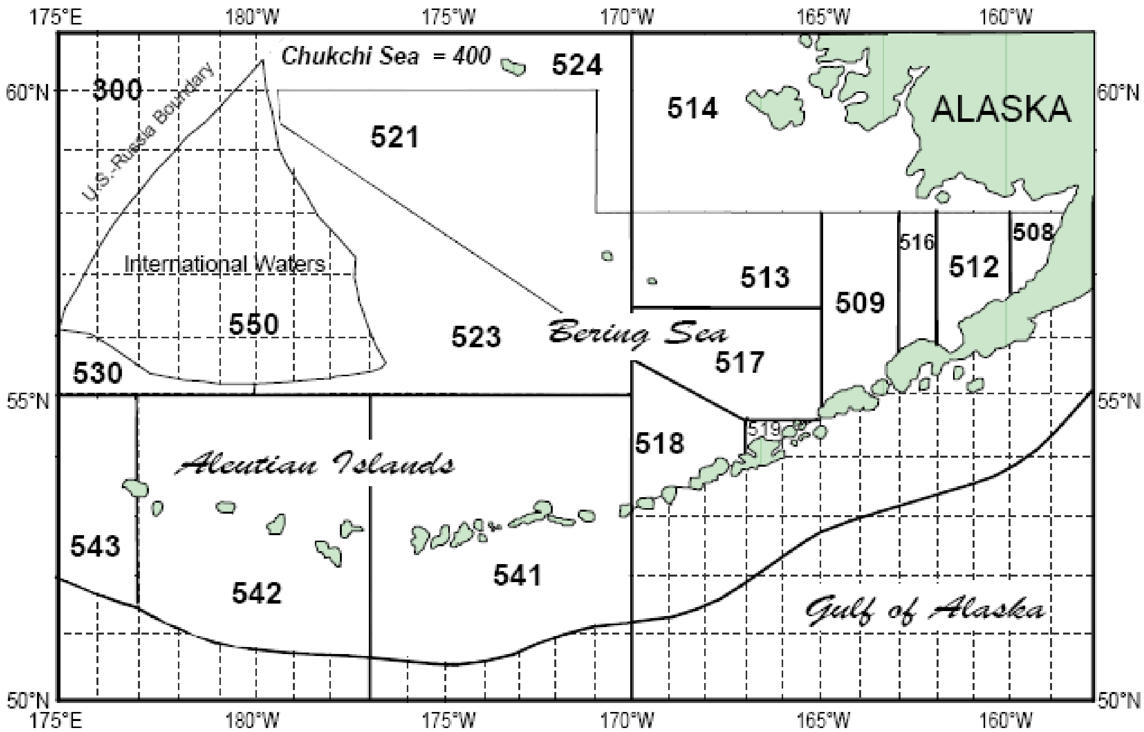

Figure 5. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands showing reporting areas 541, 542, and 543 that are used to obtain data on discarded catch of Western Aleutian Islands red king crab during groundfish fisheries (from http://www.alaskafisheries.noaa.gov/rr/figures/fig1.pdf).

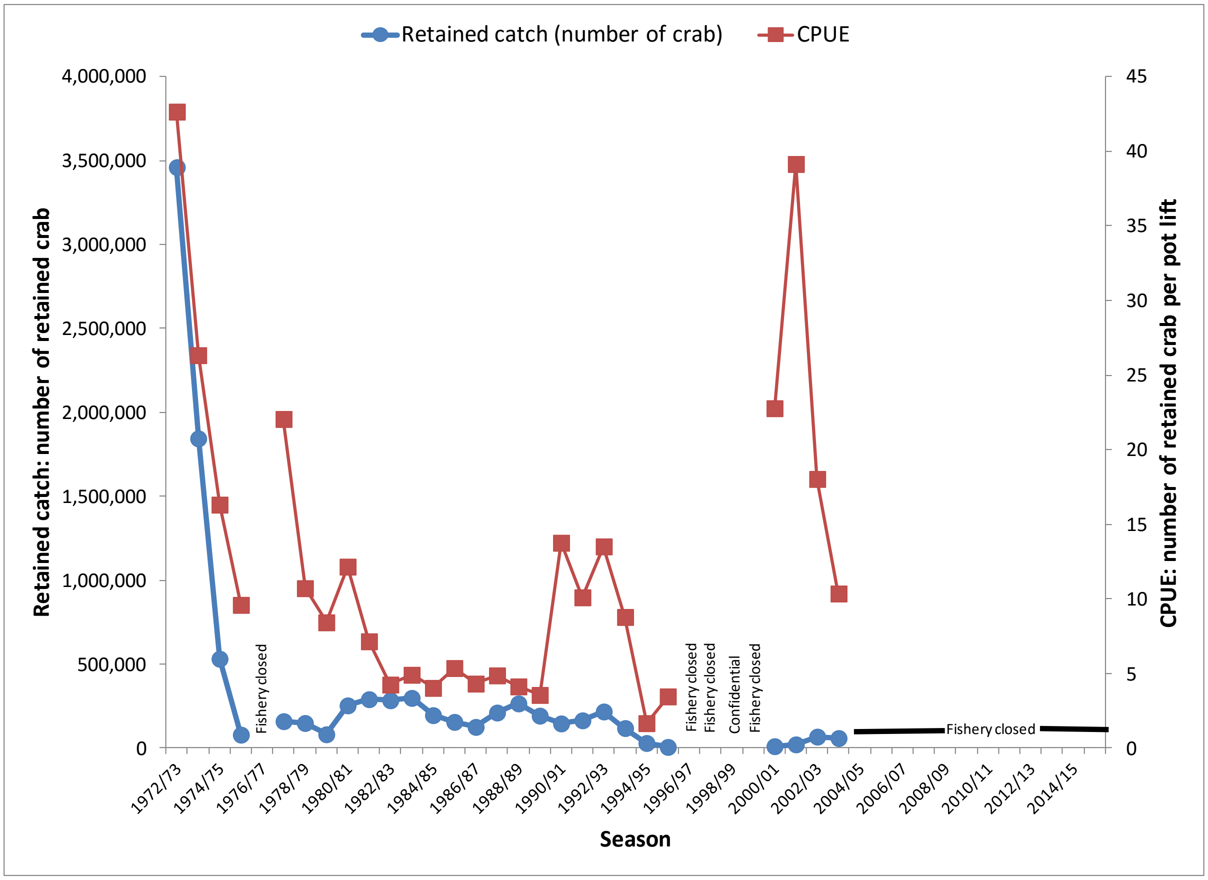

Figure 6. Retained catch (number of crab) and CPUE (number of retained crab per pot lift) in the western Aleutian Islands red king crab fishery, 1972/73–2015/16 (from Table 1a). Data for 1972/73–1983/84 are for the area west of 172° W longitude; data for 1984/85–1997/98, 1999/00, and 2004/05–2015/16 are for the area west of 171° W longitude; data for 1998/99 are for the area west of 174° W longitude; and data for 2000/01–2003/04 are for the area between 179° W longitude and 179° E longitude.

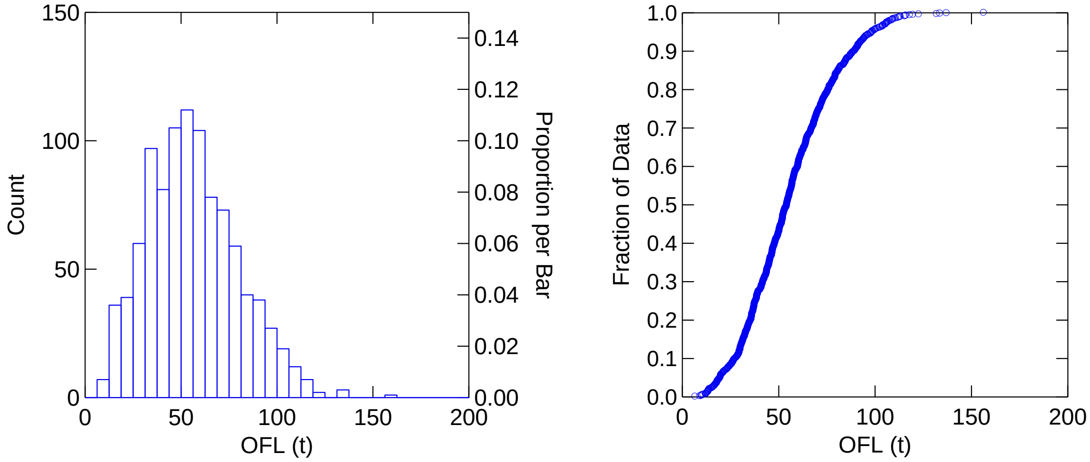

Figure 7. Bootstrapped estimate of the sampling distribution of the recommended 2016/2017 Tier 5 OFL (total-catch, t) for the Western Aleutian Islands red king crab stock; histogram in left column, cumulative distribution in right column.

Appendix A1. Summary of retained catch size frequency data available from Western Aleutian Islands directed red king crab fishery, 1960/61–2015/16.

Crab fishing year	N
1960/61	0
1961/62	386
1962/63	661
1963/64	0
1964/65	1,285
1965/66	423
1966/67	0
1967/68	0
1968/69	0
1969/70	0
1970/71	0
1971/72	0
1972/73	10,043
1973/74	9,789
1974/75	2,609
1975/76	680
1976/77	0
1977/78	666
1978/79	1,485
1979/80	963
1980/81	2,537
1981/82	2,175
1982/83	6,287
1983/84	3,806
1984/85	1,805
1985/86	1,217
1986/87	422
1987/88	441
1988/89	4,860
1989/90	12,405
1990/91	9,406
1991/92	8,306
1992/93	5,195
1993/94	4,426
1994/95	1,037
1995/96	978
1996/97−1997/98	Closed
1998/99	0
1999/00	Closed
2000/01	460
2001/02	589
2002/03	2,056
2003/04	2,381
2004/05−2015/16	Closed

Appendix A2. Available retained catch size frequency sample data 1961/62–1979/80 western Aleutian Islands directed red king crab fishery. Page 1 of 3.

CL (mm)	1961/62	1962/63	1964/65	1965/66	1972/73	1973/74	1974/75	1975/76	1977/78	1978/79	1979/80
98	0	0	0	0	0	0	0	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0
101	0	0	0	0	0	0	0	0	0	0	0
102	0	0	0	0	0	0	0	0	0	0	0
103	0	0	0	0	0	0	0	0	0	0	0
104	0	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0
106	0	0	0	0	0	0	0	0	0	0	0
107	0	0	0	0	0	0	0	0	0	0	0
108	0	0	0	0	0	0	0	0	0	0	0
109	0	0	0	0	0	0	0	0	0	0	0
110	0	0	0	0	0	0	0	0	0	0	0
111	0	0	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0	0	0	0
113	0	0	0	0	0	0	0	0	0	0	0
114	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0
116	0	0	0	0	0	0	0	0	0	0	0
117	0	0	0	0	0	0	0	0	0	0	0
118	0	0	0	0	0	0	0	0	0	0	0
119	0	0	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0	0	0
121	0	0	0	0	0	0	0	0	0	0	0
122	0	0	0	0	0	0	0	0	0	0	0
123	0	0	0	0	0	0	0	0	0	0	0
124	0	2	0	0	0	0	0	0	0	0	0
125	0	1	0	0	0	0	0	0	0	0	0
126	0	2	0	0	0	0	0	0	0	0	0
127	0	3	0	0	0	0	0	0	0	0	0
128	0	2	0	0	0	0	0	0	0	0	0
129	0	1	0	0	0	0	0	0	0	1	0
130	0	7	0	0	3	1	0	0	0	3	0
131	0	2	0	0	1	0	0	0	0	1	0
132	0	1	0	0	1	7	6	1	0	1	1
133	0	3	0	0	13	15	9	1	0	7	4
134	0	3	2	0	22	24	15	0	1	4	1
135	0	5	0	0	52	58	31	7	0	12	9
136	0	4	0	1	91	107	30	7	5	13	3
137	0	3	2	0	179	174	52	17	11	37	8

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CL (mm)	1961/62	1962/63	1964/65	1965/66	1972/73	1973/74	1974/75	1975/76	1977/78	1978/79	1979/80
138	0	3	4	0	313	281	114	20	16	40	9
139	0	6	3	1	267	295	103	22	15	38	15
140	0	9	1	2	434	362	119	37	19	45	28
141	0	11	2	1	384	403	102	31	17	53	15
142	0	9	3	0	476	445	150	46	29	65	33
143	0	8	3	2	532	462	136	44	35	71	32
144	0	6	7	1	473	497	112	49	35	52	32
145	2	7	14	1	547	549	109	37	30	82	49
146	2	15	10	4	508	514	119	31	16	63	39
147	0	5	9	7	552	488	114	25	35	80	43
148	2	3	11	4	589	478	101	46	41	101	36
149	2	10	17	4	477	488	79	29	15	64	50
150	8	9	23	5	524	490	84	28	24	59	38
151	4	12	10	1	393	432	65	21	17	58	46
152	10	16	20	7	436	409	93	21	21	69	40
153	0	13	29	9	439	367	69	13	12	45	32
154	10	11	33	6	324	318	76	17	17	53	37
155	2	13	42	8	330	337	67	14	27	56	49
156	2	19	32	9	272	285	60	10	24	37	35
157	4	22	28	6	203	229	63	11	12	43	36
158	12	10	39	16	226	234	62	17	17	31	36
159	10	17	34	14	147	174	51	6	11	24	22
160	18	13	38	15	180	146	53	5	20	25	30
161	18	12	30	10	127	129	40	7	6	23	21
162	8	16	32	17	120	145	45	8	17	14	21
163	8	7	44	15	99	93	39	10	15	17	12
164	4	13	34	9	74	70	33	5	11	13	15
165	6	16	54	17	46	56	31	5	6	15	16
166	16	18	39	13	51	43	25	6	6	12	14
167	10	13	55	24	40	37	21	4	7	16	5
168	24	13	47	19	24	30	19	5	15	7	8
169	10	20	36	12	14	29	10	3	12	9	13
170	22	20	28	23	16	18	16	2	7	2	10
171	18	14	43	16	9	15	6	2	8	6	3
172	16	15	36	18	10	9	13	2	5	5	4
173	8	9	42	12	6	7	7	0	8	4	1
174	8	12	25	8	5	7	5	2	3	0	1
175	22	27	30	14	4	6	7	3	7	1	3
176	14	19	30	11	1	3	3	0	1	3	3
177	12	10	22	9	4	5	1	0	1	0	1
178	14	17	23	12	2	6	4	1	4	1	0

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CL (mm)	1961/62	1962/63	1964/65	1965/66	1972/73	1973/74	1974/75	1975/76	1977/78	1978/79	1979/80
179	0	11	21	10	2	2	4	1	2	0	0
180	10	13	20	9	0	3	4	1	0	2	1
181	2	14	13	3	0	1	1	0	0	0	2
182	4	11	23	6	0	2	2	0	1	0	0
183	8	8	13	3	0	1	2	0	1	1	0
184	4	7	16	1	1	0	3	0	0	1	1
185	6	2	10	3	0	1	1	0	1	0	0
186	2	4	15	1	0	0	5	0	0	0	0
187	8	8	11	1	0	0	4	0	0	0	0
188	6	4	10	2	0	0	2	0	0	0	0
189	0	5	11	1	0	0	0	0	0	0	0
190	2	4	12	0	0	0	2	0	0	0	0
191	0	3	8	0	0	0	1	0	0	0	0
192	0	2	8	0	0	1	3	0	0	0	0
193	0	1	5	0	0	0	1	0	0	0	0
194	0	1	5	0	0	1	1	0	0	0	0
195	0	0	2	0	0	0	0	0	0	0	0
196	0	1	3	0	0	0	0	0	0	0	0
197	0	1	5	0	0	0	0	0	0	0	0
198	0	0	3	0	0	0	2	0	0	0	0
199	2	1	3	0	0	0	2	0	0	0	0
200	2	3	0	0	0	0	0	0	0	0	0
201	0	0	0	0	0	0	0	0	0	0	0
202	0	0	1	0	0	0	0	0	0	0	0
203	4	0	0	0	0	0	0	0	0	0	0
204	0	0	1	0	0	0	0	0	0	0	0
205	0	0	0	0	0	0	0	0	0	0	0
206	0	0	0	0	0	0	0	0	0	0	0
207	0	0	0	0	0	0	0	0	0	0	0
208	0	0	0	0	0	0	0	0	0	0	0
209	0	0	0	0	0	0	0	0	0	0	0
210	0	0	0	0	0	0	0	0	0	0	0
Total	386	661	1,285	423	10,043	9,789	2,609	680	666	1,485	963

Appendix A3. Available retained catch size frequency sample data 1980/81–1989/90 Western Aleutian Islands directed red king crab fishery. Page 1 of 3.

CL (mm)	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90
98	0	0	0	0	0	0	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0
101	0	0	0	0	0	0	0	0	0	0
102	0	0	0	0	0	0	0	0	0	0
103	0	0	0	0	0	0	0	0	0	0
104	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0
106	0	0	0	0	0	0	0	0	0	0
107	0	0	0	0	0	0	0	0	0	0
108	0	0	0	0	0	0	0	0	0	0
109	0	0	0	0	0	0	0	0	0	1
110	0	0	0	0	0	0	0	0	0	0
111	0	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0	0	0
113	0	0	0	0	0	0	0	0	0	0
114	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0
116	0	0	0	0	0	0	0	0	0	0
117	0	0	0	0	0	0	0	0	0	0
118	0	0	0	0	0	0	0	0	0	0
119	0	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0	0
121	0	0	0	0	0	0	0	0	0	0
122	0	0	0	1	0	0	1	0	0	1
123	0	0	0	0	0	0	0	0	0	0
124	0	0	0	0	1	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	1
126	0	0	0	0	0	1	0	0	0	0
127	1	1	1	0	0	3	0	0	0	2
128	0	0	1	0	1	0	0	0	1	0
129	2	1	0	0	0	1	0	0	3	1
130	3	4	2	3	1	2	1	1	5	8
131	4	3	8	2	3	7	0	3	7	29
132	6	6	23	8	6	9	2	2	5	51
133	15	11	34	10	6	19	2	5	18	88
134	25	11	55	17	9	10	5	8	19	161
135	34	25	70	25	19	27	3	10	38	280
136	53	51	92	27	21	18	8	8	55	276
137	72	45	145	32	33	23	12	11	92	370

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CL (mm)	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90
138	89	76	187	49	39	29	10	10	108	497
139	106	55	184	49	30	39	10	11	121	532
140	119	76	221	74	30	48	16	17	134	631
141	99	78	224	58	46	48	16	13	118	529
142	128	104	256	97	41	59	16	20	157	562
143	127	110	323	94	57	38	13	18	161	514
144	96	100	226	73	39	33	14	21	139	494
145	115	105	224	94	56	28	25	21	179	559
146	95	112	208	107	49	21	14	25	164	460
147	103	97	250	99	47	36	14	17	186	460
148	98	93	269	128	55	36	11	10	158	483
149	94	79	186	94	36	28	14	17	170	399
150	85	100	249	122	61	42	16	21	177	451
151	76	82	172	87	47	27	13	18	146	283
152	59	98	215	121	48	24	13	5	191	371
153	66	75	234	134	58	27	8	17	170	361
154	59	72	184	104	40	30	14	16	152	292
155	45	73	176	104	58	39	12	13	147	370
156	53	63	152	99	44	24	15	12	129	265
157	59	59	164	111	41	31	6	7	132	244
158	32	54	162	117	42	35	10	17	132	256
159	41	27	131	70	30	36	14	6	105	232
160	40	34	126	100	62	31	7	5	128	233
161	30	33	99	93	30	17	6	9	105	190
162	42	37	89	83	53	34	6	7	98	178
163	31	21	106	94	52	23	6	4	97	185
164	40	24	87	77	26	34	7	9	108	134
165	43	18	86	88	50	24	5	8	92	153
166	27	7	69	161	38	18	5	5	72	92
167	32	11	90	80	41	17	3	2	71	92
168	29	5	86	73	45	19	2	3	70	76
169	21	1	46	51	32	18	5	2	57	85
170	20	11	45	69	39	12	5	2	65	85
171	18	3	37	47	22	3	3	1	45	65
172	19	9	42	59	30	12	1	1	50	51
173	15	1	45	57	24	7	2	1	32	48
174	13	3	41	44	30	10	3	0	48	32
175	12	3	28	36	24	5	1	0	48	35
176	7	1	20	40	17	7	3	0	28	23
177	9	2	20	39	17	2	0	0	19	26
178	6	0	19	34	18	7	1	0	21	18

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CL (mm)	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90
179	8	1	13	33	12	1	6	0	14	19
180	2	2	14	28	8	4	2	0	13	16
181	3	0	10	15	7	1	0	0	15	9
182	2	0	12	23	4	5	1	1	5	4
183	2	0	4	22	6	2	2	0	7	12
184	1	0	8	27	3	5	3	0	6	4
185	1	0	6	21	5	1	2	0	5	5
186	2	1	2	14	3	0	0	0	5	2
187	0	0	1	14	1	2	2	1	4	2
188	0	1	4	10	2	2	1	0	7	3
189	1	0	2	11	2	3	0	0	2	4
190	1	0	0	13	4	1	0	0	1	4
191	0	0	1	10	1	1	0	0	1	2
192	0	0	0	2	0	3	0	0	1	0
193	1	0	0	10	0	2	1	0	0	2
194	0	0	1	4	0	2	1	0	1	0
195	0	0	0	6	2	0	1	0	0	1
196	0	0	0	4	0	0	0	0	0	0
197	0	0	0	1	0	0	0	0	0	0
198	0	0	0	1	1	2	0	0	0	1
199	0	0	0	0	0	0	0	0	0	0
200	0	0	0	1	0	0	0	0	0	0
201	0	0	0	0	0	0	0	0	0	0
202	0	0	0	0	0	0	1	0	0	0
203	0	0	0	0	0	1	0	0	0	0
204	0	0	0	0	0	1	0	0	0	0
205	0	0	0	0	0	0	0	0	0	0
206	0	0	0	0	0	0	0	0	0	0
207	0	0	0	0	0	0	0	0	0	0
208	0	0	0	0	0	0	0	0	0	0
209	0	0	0	0	0	0	0	0	0	0
210	0	0	0	1	0	0	0	0	0	0
Total	2,537	2,175	6,287	3,806	1,805	1,217	422	441	4,860	12,405

Appendix A4. Available retained catch size frequency sample data 1990/91–2003/04 Western Aleutian Islands directed red king crab fishery. Page 1 of 3.

CL (mm)	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	2000/01	2001/02	2002/03	2003/04
98	1	0	0	0	0	0	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0
101	0	0	0	0	0	0	0	0	0	0
102	0	0	0	0	0	0	0	0	0	0
103	1	0	0	0	0	0	0	0	0	0
104	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0
106	0	0	0	0	0	0	0	0	0	0
107	0	0	0	0	0	0	0	0	0	0
108	0	0	0	0	0	0	0	0	0	0
109	0	0	0	0	0	0	0	0	0	0
110	0	0	0	0	0	0	0	0	0	0
111	0	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0	0	0
113	0	0	0	0	0	0	0	0	0	0
114	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0
116	0	0	0	0	0	0	0	0	0	0
117	1	0	0	0	0	0	0	0	0	0
118	0	0	0	0	0	0	0	0	0	0
119	0	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0	0
121	0	0	0	0	0	0	0	0	0	0
122	0	0	0	1	0	0	0	0	0	0
123	0	0	0	0	0	0	0	0	0	0
124	0	0	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	0
126	0	0	0	0	0	0	0	0	0	0
127	2	0	0	0	0	0	0	0	0	0
128	0	0	0	0	0	0	0	0	0	0
129	2	0	0	0	0	0	0	0	0	1
130	4	0	1	1	0	1	0	0	0	0
131	9	0	1	2	0	0	0	0	0	0
132	12	3	6	1	2	4	0	0	0	0
133	22	13	6	4	1	3	0	0	0	0
134	46	47	19	9	5	8	0	0	0	0
135	108	65	47	15	8	9	0	0	1	0
136	152	115	59	15	10	11	0	3	1	1
137	223	173	76	32	15	17	0	2	5	1

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CL (mm)	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	2000/01	2001/02	2002/03	2003/04
138	310	211	118	35	11	27	0	3	6	1
139	381	255	101	41	18	24	1	2	2	0
140	391	289	186	63	12	24	0	4	7	3
141	455	315	156	89	16	31	1	5	14	4
142	467	341	184	92	24	32	1	9	10	3
143	449	392	216	102	20	23	2	8	13	6
144	521	342	206	114	23	32	2	11	15	5
145	483	359	220	148	16	32	3	7	18	11
146	456	356	229	162	27	38	4	7	30	8
147	469	390	244	155	29	24	3	7	18	12
148	408	304	221	183	31	27	6	16	18	9
149	428	319	160	136	20	30	7	10	30	8
150	386	364	251	177	39	24	12	13	26	19
151	315	288	145	186	29	25	15	16	35	22
152	333	344	233	169	31	29	19	25	43	17
153	292	369	170	180	38	18	20	22	41	27
154	288	320	145	180	19	33	12	28	63	36
155	311	295	164	174	28	34	14	18	58	39
156	223	280	165	182	30	18	22	14	74	46
157	203	294	148	154	25	30	17	24	74	33
158	169	211	158	167	30	37	12	23	81	52
159	167	199	86	154	25	23	20	20	97	56
160	136	149	142	154	43	23	26	19	81	78
161	106	121	88	149	28	21	16	15	69	64
162	103	115	92	114	33	27	22	25	84	72
163	77	118	96	115	34	16	15	30	78	57
164	78	80	76	117	30	23	26	25	100	98
165	78	66	79	95	21	22	20	13	75	115
166	48	51	52	85	33	17	22	17	91	95
167	59	56	74	77	24	29	21	24	82	105
168	34	47	69	68	24	33	13	18	80	99
169	33	43	29	70	16	13	20	13	53	99
170	25	33	52	39	22	15	9	13	71	126
171	29	33	33	47	13	10	16	6	58	87
172	24	20	37	30	14	16	12	13	60	119
173	14	19	23	19	17	10	4	18	41	99
174	17	15	20	27	13	6	7	5	44	86
175	18	12	19	23	8	11	6	9	49	92
176	11	11	19	12	13	4	3	4	35	62
177	4	5	12	19	13	2	5	4	27	68
178	6	3	12	7	4	5	0	2	20	50

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CL (mm)	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	2000/01	2001/02	2002/03	2003/04
179	7	7	11	9	3	1	1	6	20	53
180	1	8	9	5	6	1	2	2	20	45
181	1	13	6	5	7	1	0	2	9	44
182	2	5	5	6	3	1	0	3	12	37
183	0	8	3	2	3	1	0	2	3	22
184	2	2	2	4	4	0	1	1	2	26
185	1	1	3	0	6	0	0	0	0	11
186	2	0	3	2	2	0	0	0	7	14
187	1	2	0	1	4	1	0	1	1	13
188	0	3	1	0	0	1	0	1	1	1
189	1	1	1	1	5	0	0	0	0	6
190	0	1	1	1	3	0	0	0	3	6
191	0	1	1	0	1	0	0	1	0	2
192	0	1	1	0	2	0	0	0	0	4
193	0	0	1	0	0	0	0	0	0	3
194	0	1	1	0	2	0	0	0	0	3
195	0	0	1	0	1	0	0	0	0	0
196	0	2	0	0	0	0	0	0	0	0
197	0	0	0	0	0	0	0	0	0	0
198	0	0	0	0	0	0	0	0	0	0
199	0	0	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	0	0	0
201	0	0	0	0	0	0	0	0	0	0
202	0	0	0	0	0	0	0	0	0	0
203	0	0	0	0	0	0	0	0	0	0
204	0	0	0	0	0	0	0	0	0	0
205	0	0	0	0	0	0	0	0	0	0
206	0	0	0	0	0	0	0	0	0	0
207	0	0	0	0	0	0	0	0	0	0
208	0	0	0	0	0	0	0	0	0	0
209	0	0	0	0	0	0	0	0	0	0
210	0	0	0	0	0	0	0	0	0	0
Total	9,406	8,306	5,195	4,426	1,037	978	460	589	2,056	2,381